AR TARGET SHEET

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Hanford Immobilized Low-Activity Waste Performance Assessment: 2001 Version

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

Office of River Protection

P.O. Box 450
Richland, Washington 99352

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Revision 0
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Hanford Immobilized Low-Activity Waste Performance Assessment: 2001 Version

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EXECUTIVE SUMMARY

The *Hanford Immobilized Low-Activity Waste Performance Assessment* examines the long-term environmental and human health effects associated with the planned disposal of the vitrified low-activity fraction of waste presently contained in Hanford Site tanks. The tank waste is the byproduct of separating special nuclear materials from irradiated nuclear fuels over the past 50 years. This waste is stored in underground single- and double-shell tanks. The tank waste is to be retrieved, separated into low-activity and high-level fractions, and then immobilized by vitrification. The U.S. Department of Energy (DOE) plans to dispose of the low-activity fraction in the Hanford Site 200 East Area. The high-level fraction will be stored at the Hanford Site until a national repository is approved.

This report provides the site-specific long-term environmental information needed by the DOE to modify the current Disposal Authorization Statement for the Hanford Site[1] that would allow the following:

- Construction of disposal trenches
- Filling of these trenches with ILAW containers and filler material with the intent to dispose of the containers.

The original Disposition Authorization Statement was based on the 1998 version[2] of this performance assessment, which was conditionally accepted by DOE.[3] There were two conditions for DAS approval. The first condition required the submittal of results of glass testing that occurred after the submittal of the performance assessment and the second condition was addressing of minor concerns in the next (i.e., this) performance assessment. A report on glass testing has been submitted[4] to DOE; and this document (the 2001 ILAW PA) addresses the concerns raised in the second condition.

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[1] "Disposal Authorization Statement for the Hanford Site Low-Level Waste Disposal Facilities," Memorandum from J.J. Fiore, DOE/HQ and M.W. Frei, DOE/HQ, to R.T. French, DOE/ORP, and K.A. Kline, DOE/RL, Washington, D.C., October 25, 1999.

[2] F. M. Mann, R. J. Puigh II, P. D. Rittmann, N. W. Kline, J. A. Voogd, Y. Chen, C. R. Eiholzer, C. T. Kincaid, B. P. McGrail, A. H. Lu, G. F. Williamson, N. R. Brown, and P. E. LaMont, *Hanford Immobilized Low-Activity Tank Waste Performance Assessment*, DOE/RL-97-69, Rev. 0, U.S. Department of Energy, Richland, Washington, March 1998.

[3] Conditional Acceptance of the Immobilized Low-Activity Tank Waste Disposal Facility Performance Assessment and the Hanford Site 200 Plateau Composite Analysis, Memorandum from James J. Fiore and Mark W. Frei to Richard French and Keith A. Klein, U.S. Department of Energy, Washington, D.C., October 20, 1999.

[4] "Initial Data Package from the Tank Focus Area on 55 Test Glasses for Hanford Immobilized Low-Activity Waste (ILAW) Studies," memorandum to Mark W. Frei, 00-DPD-018, Office of River Protection, U.S. Department of Energy, Richland, Washington, March 10, 2000.

Four major changes have occurred since the issuance of the 1998 performance assessment: the design of the disposal facility has been changed from underground concrete vaults to trenches, all of the low-level fraction will be disposed in a new facility rather than just 90 percent, a class of glasses (termed low-temperature glasses) has been chosen (although a final composition is still not available), and site-specific and waste-form-specific data have been collected. This performance assessment addresses each of these changes individually.

This report also analyzes the long-term performance of the planned disposal system as a basis to perform the following:

- Set requirements for the waste form and the facility design that will protect the long-term public health and safety and protect the environment
- Demonstrate that the requirements can be met.

The calculations in this performance assessment show that a "reasonable expectation" exists that the disposal of the immobilized low-level fraction of tank waste from the Hanford Site can meet environmental and health performance objectives. As shown by the sensitivity studies, this conclusion remains valid despite the conceptual designs of the disposal facility and the ILAW packaging having undergone changes.

The performance assessment activity will continue beyond this assessment. The activity will collect additional data on the geotechnical features of the disposal sites, the disposal facility design and construction, and the long-term performance of the waste form. This activity also will perform analyses to determine the impact of these new data or information collected from other programs. Better estimates of long-term performance will be produced and reviewed regularly. Performance assessments supporting closure of filled facilities will be issued seeking DOE approval of those actions necessary to conclude active disposal facility operations.

ES1 BACKGROUND

DOE and its predecessor agencies have used the Hanford Site in south-central Washington State extensively for producing defense materials. Over the last 50 years, radioactive and mixed waste from materials production and related activities have been stored and disposed on the Hanford Site. The largest fraction (in terms of activity) is stored in underground single- and double-shell tanks in 18 tank farms.

As part of the Hanford Site's environmental restoration and waste management mission, DOE is proceeding with plans to retrieve to the maximum extent possible, the waste from the tanks, some of which have already leaked part of their contents. The mission is to accomplish the following:

- Separate the waste into a small quantity of high-level waste and a much larger quantity of low-activity waste
- Immobilize both waste streams

- Store the immobilized high-level waste until it can be sent to a federal geologic repository
- Dispose of the immobilized low-activity waste on Site in near-surface low-activity waste disposal facilities.

This plan is based on Revision 6 of the *Hanford Federal Facility Agreement and Consent Order* (Tri-Party Agreement)[5] and on the *Record of Decision for the Tank Waste Remediation Systems, Hanford Site, Richland, Washington*[6]. More than 200,000 m^3 (7,000,000 ft^3) of immobilized low-activity waste will be disposed under this plan. This large volume will contain one of the largest inventories of long-lived radionuclides in the DOE complex to be disposed in a near-surface, low-activity waste facility.

By source definition, most of the waste in the Hanford Site tanks is considered high-level radioactive waste. However, the staff of the U.S. Nuclear Regulatory Commission (NRC) has indicated that the low-level fraction would be considered "incidental waste" if DOE follows its program plan for separating and immobilizing the waste to the maximum extent that is technically and economically practical, if the waste meets the Class C standards of Title 10 *Code of Federal Regulations* (CFR) Part 61[7], and if the performance assessments continue to indicate that public health and safety would be protected to standards comparable to those established by the NRC for the disposal of low-level waste.[8] Therefore, disposal of the ILAW as incidental waste does not fall under the licensing authority of the NRC.

The current program plan is to construct new trench facilities for ILAW disposal. An earlier program to dispose of the tank waste built four large concrete subsurface vaults with a total usable volume of about 15,000 m^3. These vaults will be kept in reserve and may be used for storage or disposal of various Hanford Site waste types. ILAW production is scheduled to continue until 2024, with closure of the ILAW disposal facilities later in the decade.

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[5]Ecology, DOE, and EPA, 1996, *Hanford Facility Agreement and Consent Order*, Sixth Amendment, Washington State Department of Ecology, United States Environmental Protection Agency, United States Department of Energy. The document is available from any of the parties.

[6]62 FR 8693, "Record of Decision for the Tank Waste Remediation System, Hanford Site, Richland Washington," *Federal Register*, Volume 62, page 8693, February 26, 1997.

[7]10 CFR 61, Section 55, "Licensing Requirements for the Land Disposal of Radioactive Waste," *Code of Federal Regulations*, as amended.

[8]C.J. Paperiello, *Classification of Hanford Low-Activity Tank Waste Fraction*, letter to Jackson Kinzer, Assistant Manager, Office of Tank Waste Remediation System, dated June 9, 1997. Director, Office of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission, Washington, D.C.

DOE and its contractors are currently obligated to meet the DOE order on radioactive waste management, currently DOE O 435.1.[9] Before a new low-level radioactive waste disposal facility can be constructed or the waste can be disposed, DOE-Headquarters must issue a Disposal Authorization Statement. The issuance of a Disposal Authorization Statement is predicated on many analyses, including the performance assessment, which investigates the disposal system's ability to provide long-term environmental, public health, and safety protection. DOE and its contractors also will meet the requirements of the Washington State regulations for dangerous waste. As noted, DOE has issued a Disposal Authorization Statement to the Hanford Site for the disposal of ILAW packages in underground concrete vaults.

ES2 APPROACH

This performance assessment has been written for a waste form (vitrified low-level fraction) that doesn't exist yet and for a disposal facility that has not been fully designed yet. Therefore, due to the possible variability of waste composition and the likelihood of different disposal facility designs, this performance assessment takes the following three-step approach:

1. Understand the important principles, data, and requirements
2. Set requirements based on long-term environmental and human health impacts
3. Demonstrate that the requirements can be reasonably expected to be met.

The first step is to understand the important principles, data, and requirements of this disposal action that impact the public and the environment. Running a base analysis case and numerous sensitivity cases develops such an understanding on how the system will perform as various conditions or parameters are changed. Based on applicable regulations and earlier performance assessments, performance objectives were established[10] to protect the following:

The general public

The inadvertent intruder

Groundwater resources

Surface water resources

Air resources.

The quantitative values for the performance objectives are provided later in this executive summary where the results are compared to the performance objectives.

The protection level for Hanford Site workers is assumed to be the same as that for the general public.

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[9] DOE O 435.1, "Radioactive Waste Management," U.S. Department of Energy, Washington, D.C., July 9, 1999.

[10] F. M. Mann, *Performance Objectives for the Hanford Immobilized Low-Activity Waste (ILAW) Performance Assessment*, HNF-EP-0826, Revision 3, Fluor Daniel Northwest, Inc., Richland, Washington August 1999.

The performance objectives included not only the peak impact that would be acceptable, but also the time period ("time of compliance") over which the impacts would be determined. Following DOE standards, the time of compliance for protecting the general public as well as groundwater, surface water, and air resources is 1,000 years, in contrast with the 10,000 years used in the 1998 analyses. However, this analysis also compares estimated impacts at 10,000 years to the impact limits. Data and models were selected based on earlier Hanford Site studies.

The second step involved using this understanding to set requirements on the disposal facility design and on the ILAW product quality. Finally, to show, with reasonable expectation, that public health and the environment will be protected, this document shows that the requirements are likely to be met.

As more data are collected through performance assessment activity data collection, tank retrieval sampling, ILAW production experience, disposal facility operating history, and other research, this performance assessment will be modified. Because of the requirements of DOE O 435.1 and to follow good business practices, this performance assessment will be revised to reflect our growing knowledge and understanding.

This commitment to iterative analysis is demonstrated by noting that this performance assessment is actually the fourth set of environmental analyses performed for the program. The first set[11] provided the background for disposal facility conceptual design and waste form quality. The second set, the *Hanford Low-Level Tank Waste Interim Performance Assessment*[12], provided a set of analyses based on the previous DOE order on radioactive waste management and showed that the disposal of ILAW would likely meet its performance objectives based on DOE's current plans and on current knowledge. The third set, the 1998 performance assessment, built on the analyses presented in the interim performance assessment. The fourth set is this document report, which relies on much new data and many improved methods developed since the last performance assessment.

The data are summarized and the assumptions are listed in Table ES-1. The data used in this performance assessment are documented in *Data Packages for the Hanford Immobilized Low-Activity Tank Waste Performance Assessment: 2001 Version.*[13] Analyses of likely conditions, along with sensitivity scenarios, provide the range of impacts to be expected.

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[11]F. M. Mann, C. R. Eiholzer, N. W. Kline, B. P. McGrail, and M. G. Piepho, *Impacts of Disposal System Design Options on Low-Level Glass Waste Disposal System Performance*, WHC-EP-0810, Revision 1, Westinghouse Hanford Company, Richland, Washington, September 1995.

[12]F. M. Mann, C. R. Eiholzer, A. H. Lu, P. D. Rittmann, N. W. Kline, Y. Chen, B. P. McGrail, G. F. Williamson, J. A. Voogd, N. R. Brown, and P. E. LaMont, *Hanford Low-Level Tank Waste Interim Performance Assessment*, HNF-EP-0884, Revision 1, Lockheed Martin Hanford Company, Richland, Washington, September 1997.

[13] F. M. Mann and R. J. Puigh II, *Data Packages for the Hanford Immobilized Low-Activity Tank Waste Performance Assessment: 2001 Version*, HNF-5636, Revision 0A, Fluor Federal Services, Richland, Washington, February 2001.

Disposal will occur in the southern part of the 200 East Area of the Hanford Site in a previously unused area. This disposal facility is expected to consist of a series of large trenches based on similar trenches presently being used by the Hanford Site Waste Management Project. Current planning for the disposal facilities includes installing a RCRA-compliant surface cover to minimize the flow of water or other potential intrusions into the facility and a sand-gravel capillary barrier to divert water around the waste form.[14]

Table ES-1. Major Sources of Information for the Base Analysis Case

Data Type	Major Source	Reference
Location	The new facilities are just southwest of the PUREX Facility (in the 200 East Area).	[15]
Waste form	Waste package design based on early BNFL, Inc. documentation and River Protection Project planning.	[16], also App. I of [13]
Inventory	Based on Best Basis Inventory estimates (calculated from modeling Hanford Site production reactors corrected for off-site transfers, and discharges to the ground and biased to tank measurements). **ASSUMED** separations into high- and low-activity fractions, and off-gas generation.	[17], also App. H of [13]
Long-term waste form performance	Based on data collected on relevant glass formulations.	[18], also App. K of [13]

[14] *Preliminary Closure Plan for the Immobilized Low Activity Waste Disposal Facility*, RPP-6911, Revision 0, CH2M Hill Hanford Group, Inc., Richland, Washington, August 2000. This plan was approved by the DOE/ORP Field Manager in memorandum to Carolyn L. Huntoon (Assistant Secretary), "U.S. Department of Energy (DOE), Office of River Protection (ORP) Approval of the Hanford Site Transmittal of the Immobilized Low-Activity Waste (ILAW) Disposal Facility Preliminary Closure Plan," 00-PRD-63, Office of River Protection, U.S. Department of Energy, Richland, Washington, September 22, 2000.

[15] W.A. Rutherford (Director, Site Infrastructure Division), letter 97-SID-285 to H.J. Hatch (President of Fluor Daniel Hanford, Inc.), "Contract DE-AC06-96RL113200 - Approval of Tank Waste Remediation System Complex Site Evaluation Report," dated July 10, 1997, U.S. Department of Energy, Richland, Washington.

[16] R. J. Puigh II, *Disposal Facility Data for the Hanford Immobilized Low-Activity Tank Waste*, HNF-4950, Rev. 1, Fluor Federal Services, Richland, Washington, December 1999.

[17] D. W. Wootan, *Immobilized Low Activity Tank Waste Inventory Data Package*, HNF-4921, Revision 0, Fluor Daniel Northwest, Inc., September 1999.

[18] B. P. McGrail, J. P. Icenhower, W. L. Ebert, P. F. Martin, H. T. Schaef, M. J. O'Hara, J. L. Steele, and E. A. Rodriguez, *Waste Form Release Data Package for the 2001 Immobilized Low-Activity Waste Performance Assessment*, PNNL-13043, Revision 2, Pacific Northwest National Laboratory, Richland, Washington, January 2001.

Table ES-1. Major Sources of Information for the Base Analysis Case

Data Type	Major Source	Reference
Disposal facility design	**ASSUMED** from preconceptual ideas for the remote-handled trench and preliminary design for the concrete vault.	[14], also App. I of [13]
Recharge	Estimates were derived from lysimeter and tracer measurements collected by the ILAW PA activity and by other projects combined with a modeling analysis.	[19], also App. J of [13]
Geotechnical	Taken from geotechnical measurements studies of ILAW site borehole and other locations in the Hanford Site 200 East Area.	[20], [21], and [22]; also App. L, M, and N of [13]
Exposure	Taken from past Hanford Site documents and experience and DOE O 435.1 direction.	[23], also App. O of [13]

DOE = U.S. Department of Energy
ILAW = immobilized low-activity waste
PA = performance assessment
PUREX = Plutonium-Uranium Extraction (Facility)

Site-specific geologic, hydraulic, geochemical, and water infiltration data were obtained for this analysis.[18, 19, 20, 21] Additional disposal site-specific data are being collected and through integration with other projects like the Hanford Groundwater/Vadose Zone Integration Project additional related geotechnical data are being collected. The inventory[16] of contaminants in the waste form is based on estimates for the tank waste inventory and uses a conservative estimate to project the low-level fraction of radionuclides immobilized in the waste form after the separation

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[19] M. J. Fayer, *Recharge Data Package for the Immobilized Low-Activity Waste 2001 Performance Assessment*, PNNL-13033, Pacific Northwest National Laboratory, Richland, Washington, December 1999.

[20] R. Khaleel, *Far-Field Hydrology Data Package For The Immobilized Low-Activity Waste Performance Assessment*, HNF-4769, Revision 2, Fluor Federal Services, Richland, Washington, December 1999.

[21] P. D. Meyer and R. J. Serne, *Near Field Hydrology Data Package for the Immobilized Low-Activity Waste 2001 Performance Assessment*, PNNL-13035, Revision 1, Pacific Northwest National Laboratory, Richland, Washington, December 1999.

[22] D. L. Kaplan And R. J. Serne, *Geochemical Data Package For The Immobilized Low-Activity Waste Performance Assessment*, PNNL - 13037, Pacific Northwest National Laboratory, Richland, Washington, December 1999.

[23] P. D. Rittmann, *Exposure Scenarios And Unit Dose Factors For The Hanford Immobilized Low-Activity Tank Waste Performance Assessment*, HNF-SD-WM-TI-707, Revision 1, Fluor Federal Services, Richland, Washington, December 1999.

and immobilization processes. The tank waste inventory estimate is based on a synthesis of actual tank waste measurements and of computer simulations of the production reactor history and the known reprocessing histories. It is estimated that a wide range of tank waste compositions are presently contained within the Hanford site underground storage tanks.

The release rates of contaminants from the waste form are based on simulations. The low-activity glass LAWABP1 is used because it has an extensive experimental database and is in the expected composition envelope. The base case analysis assumed the dimensions as of early 2000. A sensitivity study shows that that the use of the current planning basis[24] for the dimensions and packing of the ILAW packages do not change the conclusions of the analyses.

A sand-gravel capillary barrier is included in the best-estimate case. However, because of the uncertainty of the final design parameters for a barrier, the more conservative case of not including a barrier was chosen for the base case. A wide variety of sensitivity cases (using different inventories, glass compositions, models, and parameter values) also were studied.

ES3 RESULTS OF COMPUTER SIMULATIONS

ES3.1 Introduction

A large number of simulations were run in this analysis. Details are provided in the following documents:

Waste Form Release Calculations for the 2001 Immobilized Low-Activity Waste Performance Assessment[25]

Near Field, Far –Field, and Estimated Impact Calculations for the Hanford Immobilized Low-Activity Tank Waste Performance Assessment: 2001 Version[26]

Groundwater Transport Calculations Supporting the Immobilized Low-Activity Waste Disposal Facility Performance Assessment[27]

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[24] D. A. Burbank, R. K. Biyani, and L. F. Janin, *Preliminary Closure Plan for the Immobilized Low Activity Waste Disposal Facility*, RPP-6911, Revision 0, CH2M Hill Hanford Group, Inc., Richland, Washington, August 2000.

[25] D. H. Bacon and B. P. McGrail, *Waste Form Release Calculations for the 2001 Immobilized Low-Activity Waste Performance Assessment*, PNNL-13369, Pacific Northwest National Laboratory, Richland, Washington, February 2001.

[26] S. H. Finfrock, E. J. Freeman, R. Khaleel, and R. J. Puigh, *Near Field, Far Field, and Estimated Impact Calculations for the Hanford Immobilized Low-Activity Tank Waste Performance Assessment: 2001 Version*, RPP-7463, Fluor Federal Services, Richland, Washington, December 2000.

[27] M. P. Bergeron and S. K. Wurstner, *Groundwater Transport Calculations Supporting the Immobilized Low-Activity Disposal Facility Performance Assessment*, PNNL-13400, Pacific Northwest National Laboratory, Richland, Washington, December 2000.

These reports are combined in *Simulations for the Hanford Immobilized Low-Activity Waste Performance Assessment: 2001 Version.*[28]

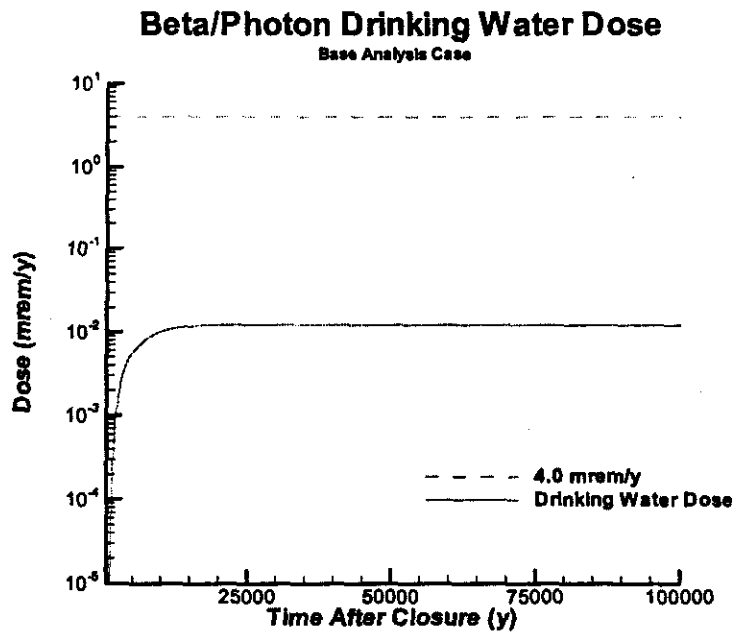
Because of the potential for variable recharge rates at the top of the disposal site, two-dimensional simulations of the moisture flow into the disposal facility were made. Using this moisture flow, one-dimensional simulations were run of the glass corrosion, contaminant release, and resulting contaminant transport in the disposal facility. Two-dimensional simulations then were made of the subsequent vadose zone moisture flow and contaminant transport, using the output of the preceding models. The Hanford Site groundwater model and a site-specific submodel derived from it were used to calculate groundwater flow and transport. The results from the codes were combined with inventory and dosimetry data to provide radionuclide concentrations in groundwater and dose rates.

Explicit calculations were conducted to 100,000 years after disposal. For inadvertent intruder analyses, a spreadsheet was used with calculations extending from 100 to 1,000 years.

Because of the very slow predicted release of contaminants from the waste form (hundreds of thousands of years), the estimated concentration of radionuclides in the groundwater shows a broad plateau rather than a peak (for an example, see the beta/photon drinking water dose rate shown in Figure ES-1). This result contrasts with most other environmental assessments, where the contaminant release time is short compared to the contaminant travel time, resulting in a peaked response.

Figure ES-1. Beta/photon drinking water dose rates for the base analysis case at a well 100 meters downgradient from the disposal facility.

The performance objective is less than 4.0 mrem in a year for the first 1,000 years.



[28] R. J. Puigh and F. M. Mann, *Simulations for the Hanford Immobilized Low-Activity Tank Waste Performance Assessment: 2001 Version,* RPP-7464, Fluor Federal Services, Richland, Washington, February 2001.

The base analysis case assumes a natural recharge rate. This case allows simpler, more flexible cases to be run while providing results very similar to, but slightly higher than, the case that explicitly considers the effect of a surface barrier whose properties change over time. A best estimate case, which includes the effect of a subsurface, sand–gravel capillary barrier, also was run.

ES3.2 Protection of the General Public

Table ES-2 compares the performance objectives for protecting the general public with the results from both the base analysis case and the best estimate case calculations. The estimated all-pathways doses are significantly lower than the performance objectives. The sensitivity cases show that these results are very robust. To invalidate the results, the inventory of key contaminants (^{99}Tc, ^{129}I, uranium isotopes, and ^{237}Np) would have to be orders of magnitude higher and/or the waste release must increase by a large amount.

During the first 1,000 years (the period of compliance), the estimated doses are insignificant. Even for a period of 10,000 years, the estimated all-pathways dose for the base analysis case is over 300 times smaller than the 25 mrem/year goal. The best estimate case is smaller still. The results for this analysis are significantly below that of the 1998 analysis because of newer data (better knowledge of waste form release, groundwater flow, inventory) and methods (explicit calculation of waste form release), as will be discussed in Section ES6. Technetium-99 is estimated to contribute 71 percent of this dose at 1,000 years, declining to 38 percent at 10,000 years as the uranium and neptunium isotopes become more important. The all-pathways dose is estimated to increase during the 100,000 years explicitly calculated, reaching 0.59 mrem in a year at 100,000 years. For these long times, ^{237}Np and uranium and its daughters are the main contributors.

The other two performance measures (all-pathways including other actions at the Hanford Site and a design that produces doses as low as reasonably achievable [ALARA]) are not expected to exceed the performance objectives of 100 mrem in a year or 500 person-rem per year at any time.

Impacts from chemicals also were investigated. The chemicals investigated were based on a data quality objectives process.[29] The impacts from these chemicals were found to be very small (see section 4.3.6). Using nominal estimates for the hazardous chemicals that may be in the waste form, the estimated impacts at 1,000 years were more than a factor of 100,000 less than the performance goals for groundwater concentrations at a well 100 meters downgradient from the disposal facility.

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[29] K. D. Wiemers, M. E. Lerchen, M. Miller, K. Meier, *Regulatory Data Quality Objectives Supporting Tank Waste Remediation System Privatization Project*, PNNL-12040, Rev. 0., Pacific Northwest National Laboratory, Richland, Washington, 1998.

Table ES-2. Comparison of Estimated Impacts with Performance Objectives for Protecting the Public.
The DOE time of compliance is 1,000 years. The point of compliance is a well 100 meters downgradient of the facility.

Performance Measure	Performance Objective[10]	Estimated Impact at 1,000 y	Estimated Impact at 10,000 y	
			1998 ILAW PA	Present Results
All-pathways [mrem in a y]	25.0			
Base Analysis Case		0.000078	6.4	0.070
Best Estimate Case		$1.7x10^{-10}$	nc*	$1.3x10^{-6}$

* nc = "not calculated" in the 1998 ILAW PA

ES3.3 Protection of Inadvertent Intruders

Table ES-3 compares the estimated impacts to the performance objectives for protecting the inadvertent intruder. A one-time dose (an acute exposure) scenario and a continuous exposure scenario (a chronic exposure) are defined. Both performance objectives are met.

The acute dose, estimated by assuming that a person drills a well through the disposal facility, is much less than the performance objective. The continuous dose, which includes the ingestion of contaminated food and water, the inhalation of air, and direct radiation exposure, is over a factor of 3 lower than the performance objective. At the time of compliance, 500 years, ^{126}Sn contributes more than 82 percent of the dose. Doses for later times to 1,000 years are smaller.

Table ES-3. Comparison of Estimated Impacts with Performance Objectives for Protecting the Inadvertent Intruder.
The time of compliance is 500 years.

Performance Measure	Performance Objective[10]	Estimated Impact at 500 y	
		1998 ILAW PA	Present Results
Acute exposure [mrem]	500.0	5.5	0.76
Continuous exposure [mrem in a year]	100.0	27.5	10.2

ES3.4 Protection of Groundwater Resources

Table ES-4 compares the estimated impacts to the performance objectives for protecting the groundwater resources. These performance objectives are based on the federal drinking water standards. The time of compliance is 1,000 years and the point of compliance is at a well 100 meters downgradient of the disposal facility. The estimated impact from beta emitters for the base analysis case at 1,000 years is a factor of over four orders of magnitude less than the performance objective and the estimated impact from alpha emitters (including radium) is insignificant. At 10,000 years, the estimated impact for the base analysis case from beta emitters remains small (still a factor of almost 400 below the 4 mrem in a year goal). The estimated impact from alpha emitters at 10,000 years is significantly larger than at 1,000 years, but still is a factor of over 400 below the goal of 15 pCi/L. The maximum impact is seen around 76,500 years, reaching a peak of 0.13 mrem in a year. Values for the best estimate case are many of orders of magnitude smaller in each case.

Impacts from chemicals also were investigated and again were found to be very small. The margins found for the protection of groundwater are similar to those found for protection of the general public. The most important drivers for determining peak groundwater concentrations are the inventory of technetium-99 for beta/photon emitters and neptunium for alpha emitters, the release rate from the waste form, and the amount of mixing in the aquifer.

For the most part, other geotechnical data (water infiltration rate, hydraulic parameters, and geochemical factors) are less important because they mainly affect the time at which the plateau is reached. The two exceptions are as follows.

For the base analysis case, the beta/gamma drinking water dose rate reaches a plateau of about 0.012 mrem in a year at about 15,000 years, which extends to the end of the explicit calculation at 100,000 years.

The concentration of alpha emitters slowly increases during the 100,000 years explicitly calculated, reaching a maximum of 0.54 pCi/L at 100,000 years.

Table ES-4. Comparison of Estimated Impacts with Performance Objectives for Protecting Groundwater Resources.

The DOE time of compliance is 1,000 years. The point of compliance is a well 100 m downgradient of the facility.

Performance Measure	Performance Objective[10]	Estimated Impact at 1,000 years	Estimated Impact at 10,000 years	
			1998 ILAW PA	Present Results
Beta/photon emitters [mrem in a y]	4.0	0.000021	2.0	0.0102
Alpha emitters [pCi/L]	15.0	1.0×10^{-16}	1.7	0.034
Radium [pCi/L]	5.0	0.0	<0.001	<0.001

ES3.5 Protection of Surface Water Resources

Table ES-5 compares the estimated impacts to the performance objectives for protecting the surface water resources. The time of compliance is 1,000 years and the point of compliance is at a well intersecting the groundwater just before the groundwater mixes with the Columbia River. The estimated impacts for the base analysis case are many orders of magnitudes lower than the performance objectives. The results for the best estimate case are far lower yet. The calculations indicate that the impacts never reach the values given as performance objectives. Because of the large flow of the Columbia River, mixing occurs in the river and the predicted impacts actually would be far lower than the performance objectives.

Table ES-5. Comparison of Estimated Impacts with Performance Objectives for Protecting Surface Water Resources.

The DOE time of compliance is 1,000 years. The point of compliance is a well located just before the groundwater mixes with the Columbia River.

Performance Measure	Performance Objective[10]	Estimated Impact at 1,000 y	Estimated Impact at 10,000 y	
			1998 ILAW PA	Present Results
Beta/photon emitters [mrem in a y]	1.0	2.0×10^{-6}	0.07	0.00095
Alpha emitters [pCi/L]	15.0	1.0×10^{-17}	0.058	0.0032
Radium [pCi/L]	0.3	0.0	<0.001	<0.001

ES3.6 Protection of Air Resources

Table ES-6 compares the estimated impacts to the performance objectives for protecting air resources. (The values of these performance objectives are given in federal clean air regulations.) The time of compliance is 1,000 years and the point of compliance is just above the disposal facility. The estimated impacts are significantly lower than the values prescribed in the performance objectives.

Table ES-6. Comparison of Estimated Impacts with Performance Objectives for Protecting Air Resources.

The DOE time of compliance is 1,000 years. The point of compliance is just above the disposal facility.

Performance Measure	Performance Objective[10]	Estimated Impact	
		1998 ILAW PA	Present Results
Radon [pCi m^{-2} s^{-1}]	20.0	<0.001	<0.96
Other radionuclides [mrem in a year]	10.0	$<10^{-8}$	$<6 \times 10^{-3}$

ES4 SETTING REQUIREMENTS

A major purpose of a performance assessment in the DOE system is a source of technical information for the setting of requirements on design, construction, and operation of the disposal facility. In past DOE PAs, the major requirements have been restrictions on the total amount of each significant radionuclide that could be disposed in the facility. Because this performance assessment deals with one type of waste, because the release rate from that waste form also drives the calculated impacts, and because the analyses are being done so early in the design cycle, this analysis can affect more functions and be more useful than previous PAs.

Based on the computer simulations, relatively simple requirements on disposal facility design and operation and on waste form characteristics can be set. The requirements are more complex than those normally set, but they are similar. To achieve more assurance during the design process that the final objectives will be met, the performance objectives used in the performance assessment were replaced with the more conservative values displayed in Table ES - 7. Because the impacts are increasing quickly at 1,000 years, the time of applicability was increased to 10,000 years for the all-pathways and drinking water doses. Protection of air and surface water are not considered because the estimated results from the base analysis case were shown to be so small.

Protection of the homesteader translates into limiting the contaminant inventory in the ILAW package multiplied by the stack height in the disposal facility. Besides these restrictions, the RPP Immobilized Waste Program also has decided to place additional restrictions on waste concentrations. To satisfy the NRC[7] in their determination that the immobilized low-activity waste is not high-level waste, the concentration of all radionuclides will be below the Class C limits set in 10 CFR 61.[7]

Table ES-7. Performance Goals for Requirement Cases.

Performance Measure	Requirement Point	Performance Objective	Performance Goal
Continuous inadvertent intruder dose	Disposal facility	100 mrem/year @ 500 years	100 mrem/year @ 500 years
All-pathways dose	Well 100 m downgradient	25 mrem/year @ 1,000 years	5 mrem/year @ 10,000 years
Beta/gamma drinking water dose	Well 100 m downgradient	4 mrem/year @ 1,000 years	1 mrem/year @10,000 years
Alpha emitter concentration	Well 100 m downgradient	15 pCi/L @ 1,000 years	5 pCi/L @ 10,000 years

The DOE also has mandated[30] concentration limits for strontium-90, technetium-99, and cesium-137 for the first phase of waste form production. To provide maximum flexibility in future decisions, these contract limitations are not placed on this analysis of waste disposed in the new disposal facilities.

The waste to be disposed must meet both the NRC Class C limits and the requirements set by this analysis. A few isotopes (mainly actinides) may be more restricted by this analysis than by the NRC restriction. Note that the radioisotope of greatest concern for intruder protection (^{126}Sn) is not addressed by the NRC regulation.

Protection of groundwater translates into limits on the release rate from all of the ILAW packages and on the amount of smearable contamination on the ILAW package surfaces. As expected from the results used in the comparison to performance objectives, the restrictions placed on inventory (I) and waste form release rate (R) are not great. Although it is the product (IR) that is important, using the current inventory, the contaminant release rate from the waste form less than should be less than 137 ppm/year. The present analysis estimates that the release rate will be less than 0.7 ppm/year for the base analysis case and 0.0003 ppm/year for the best estimate case at 10,000 years after facility closure.

The isotopes facing the greatest restrictions relative to the expected performance are technetium-99, iodine-129, and neptunium-237. This is not surprising because these are the most mobile, because most of the uranium and transuranic elements have been separated from the low-activity waste form, and because other fission products (e.g., carbon-14 and tritium) found to be important in other waste forms are volatile and are not captured in this waste form.

The limits for smearable contamination found from this analysis are quite high and are orders of magnitude less restrictive than those in the contract with the treatment vendor.[30]

Most of the requirements imposed by the performance assessment analysis are on the waste form. However, a few are imposed on the disposal facility. The major facility requirements deal with subsidence, recharge rate, layout, interactions with the waste form, and intruder protection.

The performance assessment assumes that subsidence is small based on the slow degradation of the waste form and the use of filler materials to minimize voids in the disposal facility. This means that the facility must be constructed without significant void space (i.e., empty space between packages). Similarly, the ILAW packages must have a minimum of empty space inside them to minimize subsidence. At present, such a requirement on the ILAW packages is part of the waste treatment plant contract.[30] In addition, after waste is placed inside the facility, the spaces between the waste containers must be filled with a dry material. The estimated impacts from a 1 m subsidence in the remote-handled trench facility located 10 m from

[30] Contract with Bechtel, National, Inc., *Design, Construction, and Commissioning of the Hanford Tank Waste Treatment and Immobilization Plant*, Contract number DE-AC27-01RV141376, U.S. Department of Energy, Office of River Protection, Richland, Washington, December 2000. Web reference: http://www.hanford.gov/orp/contracts/de-ac27-01rv14136/index.html.

the RCRA cap apex are factors of 500 and 1,000 times larger for the alpha concentration and beta/photon drinking water dose, respectively, than the estimated impacts for the best estimate case at 10,000 years after facility closure. Facility performance enhancements associated with the RCRA cap and the capillary break are effectively lost locally if subsidence occurs. For the subsidence case analyzed, the estimated impacts still are less than the estimated impacts for the base analysis case.

Because the waste form releases contaminants so slowly, the time-dependence curve for exposure shows more of a plateau structure than a peaked shaped. The major effects of the recharge rate are to slow the waste form release rate and delay the arrival of contaminants to the groundwater. If the recharge rate is large and the second group of contaminants (i.e., those having $K_d = 0.6$ mg/L, such as uranium) arrive before 10,000 years, the all-pathways dose performance objective could be violated and restrictions would have to be placed on the recharge rate. The base analysis case shows that achieving a moisture infiltration rate into the disposal facility equal to or less than the natural recharge rate (4.2 mm/year) is sufficient to meet the performance objectives. If a subsurface sand-gravel capillary barrier is used, the infiltration rate could be far lower.

The requirement for groundwater protection actually is on the disposal system. The designers of the disposal structures must ensure that materials are not used that would accelerate waste form degradation. Alternatively, the designers can add components (for example, hydraulic diverters, getters) to minimize the requirements on the waste form.

Designers of the engineered system may wish to add components to provide greater defense in depth. The major components would be an improved surface barrier to reduce the recharge rate, a hydraulic barrier to divert moisture from the waste, the addition of concrete material to trap uranium, and other getter materials to trap important radionuclides such as technetium. The recharge rate is the main driving function for the system. Having a surface barrier that could reduce this rate would lengthen the time the contaminants take to reach the groundwater. Diverting water away from the waste would likely reduce the contaminant release rate from the waste form and also would create a greater moisture shadow under the disposal system that also would delay contaminant travel. Concrete is known to highly retard uranium isotopes, thus reducing their impact during the time of compliance. If an inexpensive getter could be found for technetium, such a material also could have important impacts.

ES5 COMPLIANCE

The cases used to compare estimated performance of the disposal facility with the performance objectives are basically the same as the base analysis or best estimate cases. The major difference is that the dimensions of the ILAW package and the number of such packages would change. However, because of the large margin, such a change is not significant for the protection of the public, groundwater resources, and surface water resources. The consequence to the inadvertent intruder can be mitigated through operational controls based on projected waste container inventories. The operational controls will be better defined as the project matures.

ES6 SUMMARY OF THE IMPACT OF DIFFERENCES BETWEEN THE 1998 ILAW PA AND THIS DOCUMENT

Of the three types of scenarios (groundwater, air, and inadvertent intruder) studied in the 1998 ILAW PA[2] and in this document, only the results for the groundwater scenario are significantly different. Five major differences occur in inputs between the 1998 ILAW PA and this document that affect the peak values of estimated impacts for scenarios that contaminate groundwater:

Time of compliance

Inventory of mobile constituents

Disposal facility design

Waste form performance

Groundwater dilution.

Other new data (such as recharge rates, geochemistry, and hydrology) affect the time that the peak occurs or the estimated impacts through one of the last four inputs cited above.

The 1998 ILAW PA used 10,000 years as the time of compliance. Because of new DOE guidance, the present time of compliance is 1,000 years. However, because of the slow travel time in the vadose zone, even the mobile constituents do not reach the groundwater in any significant quantity in only 1,000 years.

To make comparisons with the 1998 ILAW PA easier, Table ES-8 summarizes the differences in estimated impacts at 10,000 years for the beta/gamma drinking water dose.

The facility design effect is associated with areal distribution of the waste. For the remote-handled trench disposal concept, the areal footprint for the facility is 124,800 m^2. For the 1998 ILAW PA, the Concept 1 disposal facility had an areal footprint of 51,000 m^2. The larger areal distribution of the waste leads to a dilution factor of 0.41 associated with the contaminant concentration entering the aquifer.

The impact at 10,000 years of changing the inventory of the mobile constituents is a factor of 0.34 (0.26 * 1.32). This results because of two changes, the change in the ^{99}Tc inventory (the most important radionuclide in either analysis) and the change of inventories of other mobile radionuclides. The 1998 ILAW PA assumed that 80 percent of the technetium in the tanks would end up in ILAW, while this document assumes, based on the contract between the treatment vendor and DOE, that only 20 percent of the technetium in tanks will go into ILAW. The remaining slight difference in technetium inventory results from a small change in tank inventory.

Table ES-8. Effect of Updated Model Inputs on the Estimated Beta/Gamma Drinking Water Dose at 10,000 Years.
(1998 ILAW PA estimated this dose as 2.0 mrem/y.)

Updated Model Input	Beta/gamma drinking water dose
	Ratio 2001 ILAW PA to 1998 ILAW PA
Facility design	0.41
Technetium inventory	0.26
Other mobile contaminants (1)	1.32
Technetium dose factor	0.83
Waste form release rate/ vadose zone transport	0.30
Groundwater dilution	0.14
All inputs	0.0049

(1) based on updated K_d values for selenium, iodine, and neptunium.

Based on disposal site-specific geochemical measurements, the determination of which contaminants are mobile has changed somewhat. Technetium-99 still is the most important mobile contaminant. In the 1998 ILAW PA, selenium-79 was assumed to be mobile because no Hanford Site-specific data were available that indicated otherwise. Since then, it has been learned that the half-life of selenium-79 is longer than believed and disposal-site specific information has shown that selenium transport in the vadose zone is chemically retarded. However, iodine and neptunium, which were treated as relatively immobile in the 1998 ILAW PA, are now known through disposal-site specific information to be more mobile. Thus, whereas technetium-99 was 75 percent of the drinking water dose in the 1998 ILAW PA, it is only 50 percent in this document. Therefore, the relative contribution from other mobile contaminants has increased to 1.32 (0.75/0.57). Finally, the new DOE Order 435.1 requires the use of the EPA dose factors; the dose factor for technetium-99 was a factor of 0.83 of the dose factor used in the 1998 ILAW PA. In the 1998 ILAW PA, the release from the vaults was assumed to be that given in the request for proposal for treatment services (4.0 x 10^{-6}/year).[31] At 10,000 years after facility closure the contaminant flux to the aquifer was 2.0 x 10^{-6}/year. In this document, the release from the remote-handled trench is calculated by simulating the waste form

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[31] *Request for Proposals (RFP) No. DE-RP06-96RL13308*, letter from J.D. Wagoner to Prospective Offerors, Department of Energy, Richland, Washington, February 20, 1996.

release (rate = 0.8×10^{-6}/year at 10,000 years after facility closure) from LAWABP1 glass and performing the transport of contaminants through the vadose zone resulting in a contaminant flux of 0.7×10^{-6}/year at 10,000 years after facility closure. This results in a 30 percent decrease in the contaminant flux to the aquifer when compared to the 1998 ILAW PA values.

The disposal site is now realized to be over the old channel of the Columbia River. Also, the base analysis case used a recharge rate of 3 mm/year in the 1998 ILAW PA and a rate of 4.2 mm/year in this analysis. The hydraulic conductivity of the unconfined aquifer is higher, resulting in greater dilution, by about a factor of 7.

Combining these factors (inventory of mobile constituents, disposal facility design, waste form performance, and groundwater dilution), the overall effect is a reduction by about a factor of 200 from the 1998 ILAW PA.

ES7 CONCLUSIONS

This performance assessment analyzed the long-term environmental and human health impact of disposing of immobilized low-activity waste from Hanford Site tanks. This analysis confirms the conclusions of the 1998 ILAW PA that an understanding of ILAW contaminant transport exists and that a base case can meet the performance objectives using a trench disposal concept. Based on this expectation, requirements for waste acceptance and disposal facility performance were established. The final analysis of this performance assessment shows a "reasonable expectation" that these requirements will be met.

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List of Acronyms

ADT	accelerated dissolution test
AEA	Atomic Energy Act
ALARA	as low as reasonably achievable
ALT	accelerated leach test
ANL	Argonne National Laboratory
ANS	American Nuclear Society
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
AREST-CT	Analyzer of Radionuclide Source Term with Chemical Transport
ASTM	American Society for Testing and Materials
BBI	best basis tank-by-tank inventory
BHI	Bechtel Hanford, Inc.
BNFL	British Nuclear Fuels, Ltd.
CEC	cation exchange capacity
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFEST	coupled fluid, energy, and solute transport (code)
CFR	code of Federal regulations
CHARIMA	commercial surface water hydrology and sediment transport model
CPU	central processing unit
DLT	dynamic leach test
DOE	U. S. Department of Energy
DNFSB	Defense Nuclear Facilities Safety Board
DQO	data quality objectives
Ecology	Washington State Department of Ecology
EDE	effective dose equivalent
EIS	environmental impact statement
EM-50	Environmental Management organization dealing with science and technology development
EMSP	Environmental Management Science Program
EP	the probability of exceedence over the performance life
EPA	U. S. Environmental Protection Agency
ERDF	Environmental Remediation Disposal Facility
FFTF	Fast Flux Test Facility
GIS	geographic information systems
GFLOPS	10^9 floating point operations per second
HDPE	high-density polyethylene
HFSUWG	Hanford Future Sites Uses Working Group
HLW	high level waste
HLP	product acceptance
HMS	Hanford Meteorology Station
HSRAM	Hanford Site risk assessment methodology
IHLW	immobilized high level waste
ILAW	immobilized low-activity waste
INVERTS	inverse reactive transport simulator

IR	inventory release rate
ISO	International Standards Organization
K	potassium
K_d	distribution coefficient
LAW	low-activity waste
LAWABP1	sample name of glass used in analysis
1LDL	lower detectability limit
LDR	land disposal restriction
LFRG	Low-Level Waste Disposal Facility Federal Review Group
LLW	low-level waste
MCC-1	Materials Characterization Center static leach test
MCC-3	Materials Characterization Center agitated powder leach test
MCC-5	Materials Characterization Center Soxhlet test
MIIT	materials interface interaction Test
NA	not available
NC	not calculated
NEPA	National Environmental Policy Act
NLLWMP	National Low-Level Waste Management Program
NRC	Nuclear Regulatory Commission
ORP	Office of River Protection
PA	performance assessment
PCT	product consistency test
PDE	partial differential equations
PNNL	Pacific Northwest National Laboratory
ppb	part per billion
PUF	pressurized unsaturated flow test
PUREX	Plutonium-Uranium Extraction (facility)
RCRA	Resource Conservation and Recovery Act
REDOX	Reduction-Oxidation (facility)
rem	roentgen equivalent man (unit used for measuring effective dose of radiation
RFP	request for proposals
RH	relative humidity
RH	remote-handled
RHO	Rockwell Hanford Operations
RI/FS	remedial investigation/feasibility study
RL	Richland Operations Office
RMW	radioactive mixed waste
RPP	River Protection Project
RWTSP	radioactive waste technical support program
SPFT	single pass flow-through (test)
STOMP	a nonisothermal, multiphase flow simulator
STORM	subsurface transport over reactive multiphases
S/V	surface area-to-solution volume ratio
TFA	tank focus area
TIG	tungsten-inert gas
TOX	total organic halides

TWRS	Tank Waste Remediation System
TWRSO&UP	Tank Waste Remediation System Operation and Utilization Plan
VAM3D	variably saturated analysis model code
VHT	vapor hydration test
VSL	Vitreous State Laboratory
WAC	Washington administrative code
WHC	Westinghouse Hanford Company
WIF	well intercept factor
WIPP	Waste Isolation Pilot Plan
WNP	Washington Nuclear Plant

1.0 INTRODUCTION

1.1 PURPOSE

This performance assessment examines the long-term environmental and human health effects of the planned Hanford Low-Level Tank Waste Disposal Facility to support the continuation of the Disposal Authorization Statement issued by the U.S. Department of Energy (DOE) (DOE 1999a) as required by DOE O 435.1, *Radioactive Waste Management* (DOE 1999b). This document also fulfills the requirement for a new performance assessment in fiscal year (FY) 2001 as stated in, DOE/ORP-2000-01, *Maintenance Plan for the ILAW Performance Assessment* (DOE/ORP 2000a).

This performance assessment updates DOE-97-69, *Hanford Immobilized Low-Activity Tank Waste Performance Assessment* (Mann 1998a), which is commonly known as the 1998 ILAW PA. The 1998 ILAW PA was submitted to the Low-Level Waste Disposal Facility Federal Review Group (LFRG) for review and action. The LFRG has completed their review (DOE 1999c). Based on this review, the DOE accepted the ILAW Performance Assessment (DOE 1999d) and issued the Disposal Authorization Statement. This acceptance is contingent on the following actions:

- Providing the LFRG with documentation of the near-term glass test results to assure DOE that the glass performance assumed in the performance assessment can actually be achieved

- Addressing the secondary issues identified by the review team in future revisions to the performance assessment.

The LFRG reviewed the documentation on relevant glass performance that was provided (French 1999 and French 2000a) and determined that the assumed glass performance can be achieved (DOE 2000). The secondary issues identified by the LFRG are addressed in this version of the ILAW PA (see Appendix A).

The major advances in understanding or programmatic changes since the 1998 ILAW PA have been the following:

- Waste form release data from vendor-relevant glass formulations
- ILAW site specific geologic, chemical, and hydraulic data from a new borehole
- New groundwater model
- Expanded understanding to extrapolate laboratory measurements to field conditions
- Selection of a different disposal facility conceptual design (Taylor 1999a).

The approach used to prepare this performance assessment document is to

- Limit its length (the supporting data summarized in this document are fully described in Mann/Puigh (2000a) while the analysis cases and simulations that are summarized in this document are fully described in Puigh 2001),
- Tier from other documents (see, for example, the discussion in Section 1.5.2 on earlier Hanford Site performance assessments and environmental impact statements), and
- Include detailed results and lengthy technical information in appendices.

1.2 BACKGROUND

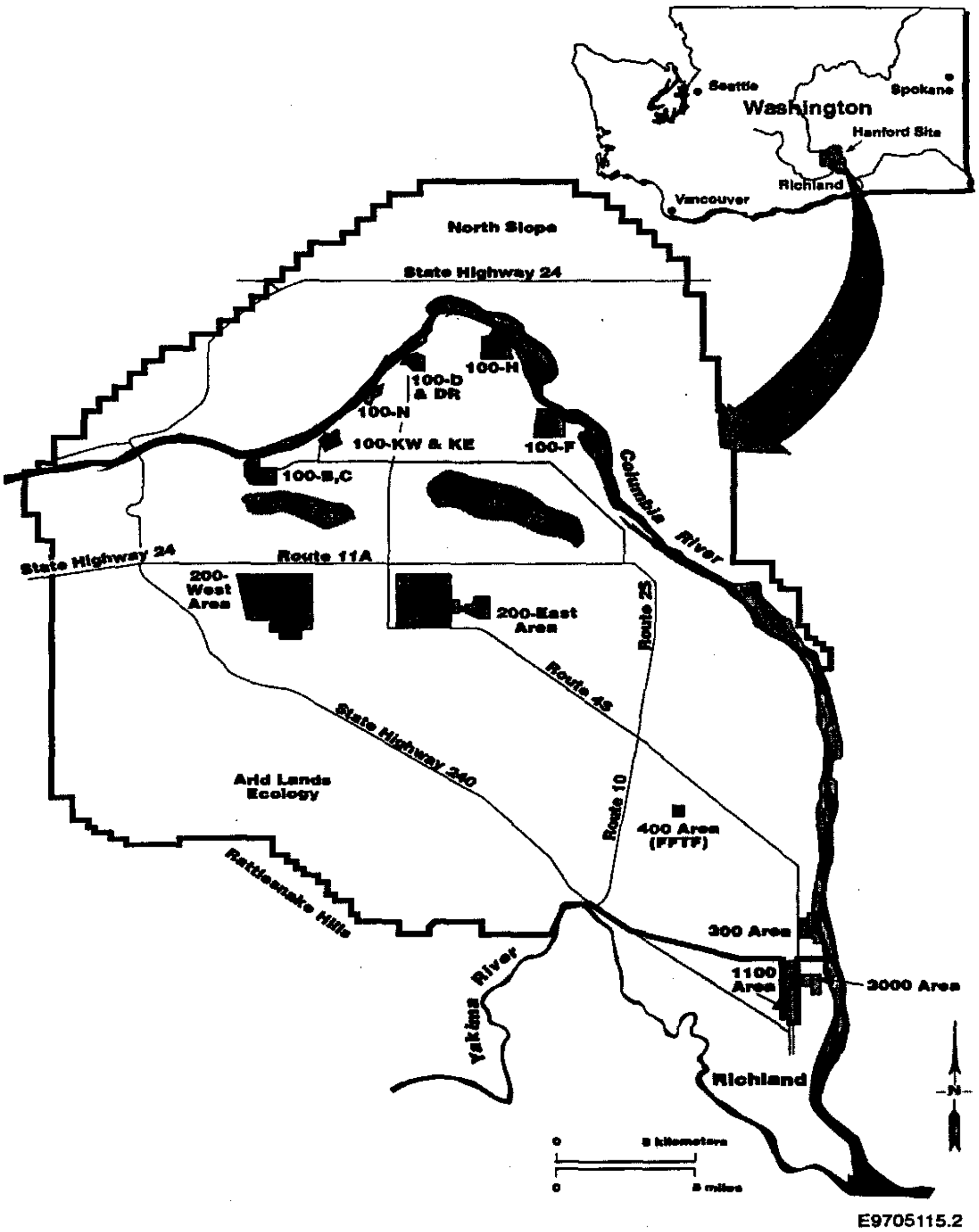
The Hanford Site, in south-central Washington State (Figure 1-1), has been used extensively for producing defense materials by DOE and its predecessors, the U.S. Atomic Energy Commission and the U.S. Energy Research and Development Administration. Starting in the 1940's, Hanford Site operations were dedicated primarily to producing nuclear weapons materials. In the 1960's, operations were expanded to producing electricity from a dual-purpose reactor, conducting diverse research projects, and managing waste. In the late 1980's, the Site's original mission ended. This mission left a large inventory of radioactive and mixed waste (~55 million gallons) stored in underground single- and double-shell tanks in the Hanford Site 200 Areas.

Today, the Site's missions are environmental restoration, energy-related research, and technology development. As part of its environmental restoration mission, DOE is proceeding with plans to permanently dispose of the waste stored on site. These plans are based on Revision 6 of the *Hanford Federal Facility Agreement and Consent Order* (Tri-Party Agreement) (Ecology 1998-1) and the *Record of Decision for the Tank Waste Remediation Systems Environmental Impact Statement* (DOE 1997b). These documents call for the waste to be retrieved from the tanks, then treated to separate the low-level fraction (now called the low-activity fraction) from the high-level/transuranic fraction. Both fractions will then be immobilized.

The two products (the small volume of high-level immobilized waste and the much larger volume of ILAW) will be disposed in different locations. The high-level waste will be stored on the Hanford Site until it is sent to a federal geologic repository. The ILAW will be buried in a near-surface disposal system on the Hanford Site. Over 200,000 m^3 (7,000,000 ft^3) of low-activity immobilized waste will be disposed under this plan. This is among the largest amounts of waste in the DOE Complex (DOE 1997) and has one of the largest inventories of long-lived radionuclides at a low-level waste disposal facility.

The DOE is procuring services to treat and immobilize the tank waste. The first immobilized waste should be delivered in 2008. The first phase of the effort would extend for about a decade. The contract for the second phase, in which most of the waste will be processed, will be awarded in the second half of this decade.

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



1.3 GENERAL DESCRIPTION OF THE FACILITY

This section provides a general description of the disposal facilities. Section 2.1 describes the geology, hydrology, and geochemistry of the Hanford Site and the 200 East Area where the disposal facility will reside. Section 2.3 provides much more information including figures showing the conceptual and preconceptual designs.

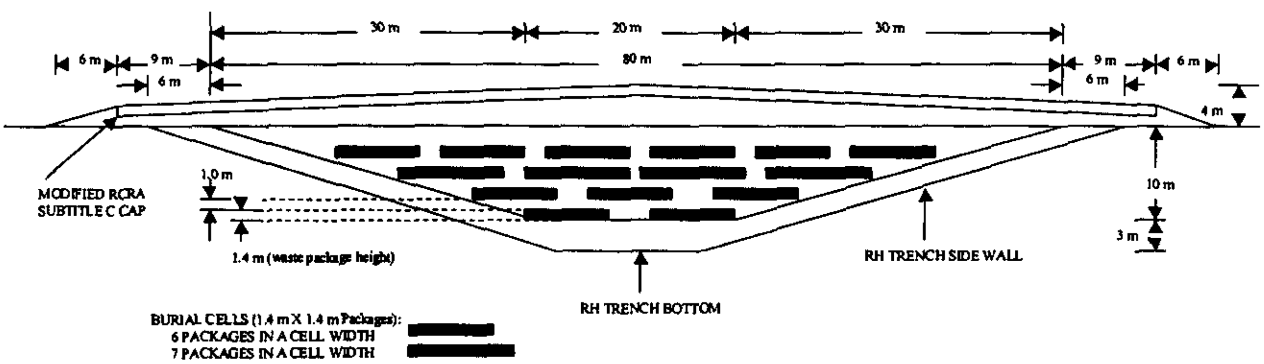
It was assumed in the 1998 ILAW PA that the waste would be disposed in underground concrete vaults. The current plan (Taylor 1999a) of DOE's Office of River Protection (ORP) is to dispose of the immobilized waste in trenches that are similar in design to those used to dispose of radioactive mixed waste at the Hanford Site. A major purpose of this version of the ILAW PA is to obtain DOE Headquarters' approval for this new disposal facility design.

Under the ILAW disposal planning described in the following paragraphs, the disposal facility is a *Resource Conservation and Recovery Act of 1976* (RCRA)-compliant landfill (i.e., a double-lined trench with leachate collection system). Many operational aspects and ancillary activities of the landfill (e.g., leachate collection and disposition, storm water control, installation of surface barrier at closure, etc.) would be similar to that incorporated into the radioactive mixed waste burial trench. However, operational activities related to ILAW package receipt and emplacement in the trench would be modified to accommodate the specific ILAW package size.

The design concept layout (Puigh 1999) of the trenches within the ILAW disposal site is shown schematically in Figure 1-2. The trench side slopes at a ratio of 3:1. This design concept will evolve as the design for the ILAW disposal trench is developed.

Figure 1-2. RH Trench Preconceptual Design (dimensions are in meters).

RH TRENCH CONCEPTUAL MODEL



A cell is defined as a contiguous group of waste packages in a given layer. In the base case analysis, the waste package is a cube with each side of the cube being 1.4 m (DOE/BNFL 1998 - contract modification 10) (see Section 3.4.3). Although this is not the current design, the results for a sensitivity case using the new design are similar. Using this packing density, approximately six trenches are needed to accommodate the entire total ILAW production.

The disposal system will include a set of barriers. The exact nature will be determined during the design effort before closure. The present conceptual design consists of both subsurface and surface barriers. Subsurface sand-gravel capillary barriers would be placed over the cells to divert water around the cells to minimize infiltration. A surface barrier (presently seen as a modified RCRA Subtitled C barrier) to minimize water, plant, animal, and human intrusion would cap each disposal facility.

1.4 IMMOBILIZED WASTE PROGRAM

The ORP is the DOE organization at the Hanford Site responsible for the safe underground storage of the liquid waste from previous Hanford Site operations presently stored in the Hanford Site tank farms, the retrieval of this waste, the treatment of this waste into immobilized waste forms, the storage and disposal of the immobilized tank waste, and the closure of the underground tanks. The contractors working for the ORP form the River Protection Project (RPP). As part of the RPP, the Immobilized Waste Program is responsible for the following:

- Designing the facilities for disposal of the immobilized low-activity tank waste
- Obtaining necessary permits and regulatory approvals
- Constructing the disposal facilities
- Operating the disposal facilities
- Closing the disposal facilities
- Designing, constructing, using, and decommissioning of the facilities for storing the immobilized high-level waste until it is shipped to a federal geologic repository.

[illegible]

Table 1-1 presents the schedule for the disposal facilities. Figure 1-3 illustrates the current baseline planning logic for the Immobilized Low-Activity Disposal Project within the Immobilized Waste Program. The performance assessment activity is closely connected with other parts of the Immobilized Waste Program.

Table 1-1. Schedule for ILAW Disposal Facilities.

Description	Date
Issue engineering studies (Done)	October 1997
Issue conceptual design	September 2001
Issue Part B RCRA Permit Application to state regulatory authority	August 2002
Issue detailed design for first set of facilities	September 2004
Start construction of first set of facilities	April 2005
Complete construction of first set of facilities	July 2006
Start use of first set of facilities	March 2008
Fill first set of facilities	September 2018
Construct and use additional disposal facilities	...
Receive last container of waste	September 2026
Close last disposal facility	September 2028

The Immobilized Waste Program has established a performance assessment team of leading Hanford Site geotechnical and waste-form experts. The team is supported by Site staff (including the Pacific Northwest National Laboratory), as well as scientists and engineers from around the DOE complex (particularly from the Argonne National Laboratory). The leader of the performance assessment team has been on the decision board for preconceptual design studies and interacts with the engineering and architect-engineering staff on the design. In addition, the team is cooperating closely with the ORP group waste treatment services. Current specifications for the waste form are based heavily on performance assessment results. Future modifications to the waste form specifications, if necessary, will be based on what is learned in the performance assessment activity. Finally, the performance assessment team is closely involved in characterizing the waste inventory.

The performance assessment activity supports design, use, and closure of the disposal facilities. Thus, the schedule for producing performance assessment documents is iterative (see Table 1-2). Maintenance of the ILAW performance assessment is based on DOE guidance (DOE 1999e) and is documented in the *Maintenance Plan for the ILAW Performance Assessment* (DOE/ORP 2000a). This document was approved by the ORP field manager and sent to the LFRG as required (French 2000b).

Figure 1-3. Activities Diagram for the Immobilized Low-Activity Waste Project.

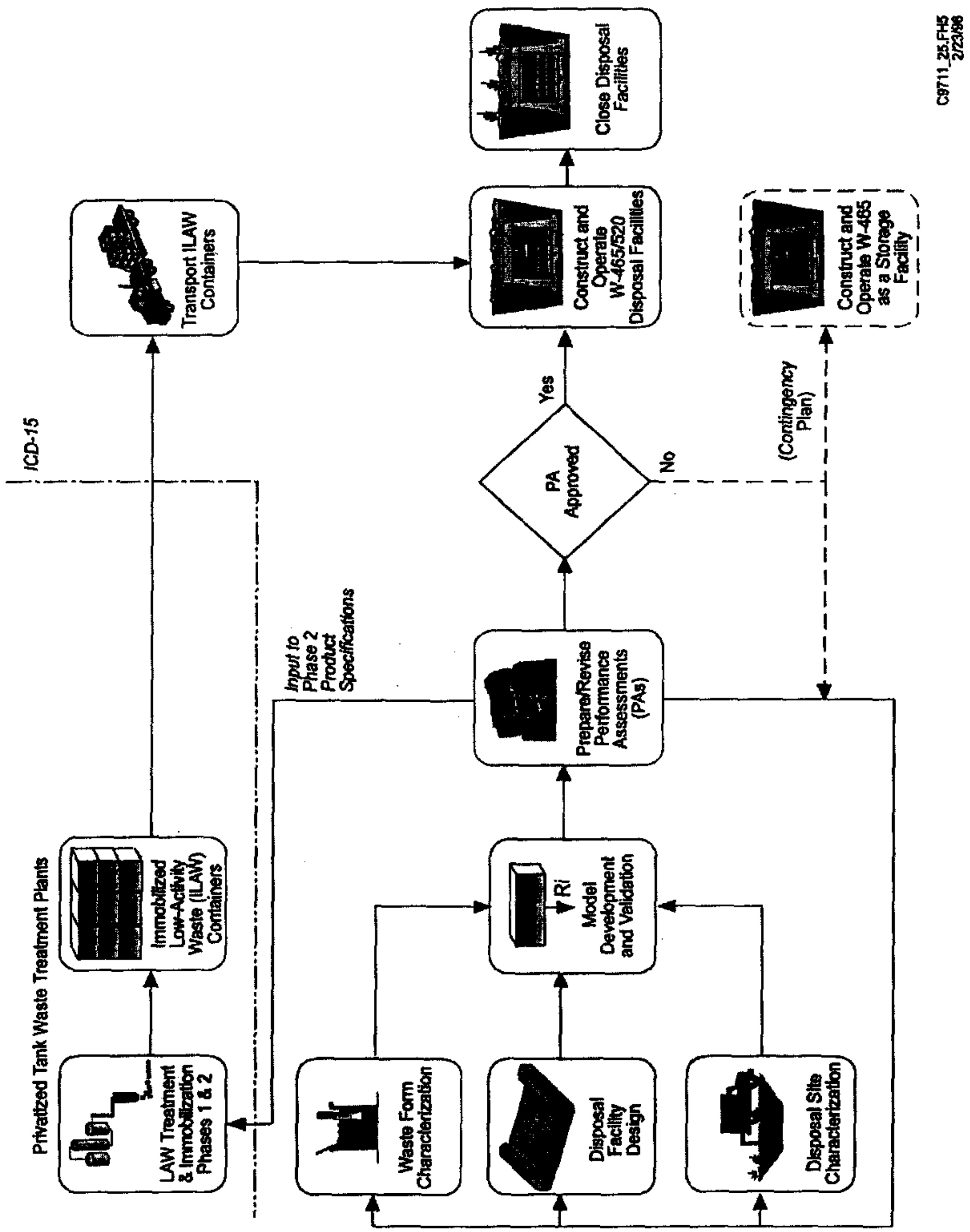


Table 1-2. Schedule for Performance Assessment Activities.

Revision	Purpose	Date of Issue
Interim Performance Assessment		
Rev. 0	Document potential impacts as early in project's life as possible.	September 1996
Rev. 1	Revise Rev. 0 based on comments, especially those of an external advisory board.	September 1997
Performance Assessment		
Rev. 0	Support application for Disposal Authorization Statement to modify existing disposal facilities, use existing disposal facilities, construct the first generation of new disposal facilities, and use the new disposal facilities.	March 1998
	Received conditional approval from the Low-Level Waste Disposal Facility Federal Review Group and a Disposal Authorization Statement from DOE.	October 1999
Rev. 1 (This document)	Update Rev. 0 based on results of waste form performance testing and simulations, geotechnical data collection and analysis, new facility design, and the RPP Standard Inventory effort.	March 2001
Rev. 2	Update Rev. 1 based on additional performance assessment activity data collection and analysis (just before start of operations).	September 2005
Rev. 3	Update Rev. 2 based on using actual inventories disposed in the existing facilities, additional data collection (especially waste performance of production samples), and engineering studies investigating the use of other Site facilities.	September 2010
Rev. 4	Update Rev. 3 using new data.	September 2015
Rev. 5	Update Rev. 4 using new data.	September 2020
Rev. 6	Update Rev. 5 using new data.	September 2025
Rev. 7	Update Rev. 6 to support closure of all immobilized low-activity waste disposal facilities.	September 2028

DOE = U.S. Department of Energy

As required by the maintenance plan, new site-specific, waste-form specific, and facility-specific data have been collected (Mann/Puigh 2000a). A *White Paper Updating the Conclusions of the 1998 ILAW Performance Assessment*, DOE/ORP-2000-07 (Mann 2000b) based on these new data was issued. The white paper determined that the conclusions of the 1998 ILAW PA were still valid, but that they were conservative. Based on the conclusions of the white paper, the ILAW PA annual summary (Mann 2000c) also was issued as required by the maintenance plan and by DOE guidance (DOE 1999f).

The goals of this performance assessment are to determine impacts from the following sources:

- Changes in disposal facility design
- Different waste form compositional space
- New geotechnical and other data.

The goals of the next ILAW PA version (scheduled for 2005) are to determine the impacts from new data so that these impacts can be considered before actual disposal operations begin. Even later performance assessments will focus on determining impacts before closure of individual trenches and before final closure.

1.5 RELATED DOCUMENTS

This section discusses the most important environmental assessments completed for the Hanford Site, as well as the documents used to provide guidance for preparing this document.

→→→ See Sections 3.2 and 3.4 for documents justifying data used in this document.

→→→ See Section 1.6 for documents supporting the setting of performance objectives.

1.5.1 Other Relevant Hanford Site Environmental Assessments

→→→ This document builds on earlier Hanford Site environmental assessments.

Many environmental assessments have been performed at the Hanford Site. They can be classified as documents pertaining to the disposal of immobilized low-activity tank waste, as documents fulfilling the requirements DOE O 435.1, or as more general documents.

1.5.1.1 Previous Work Related to the Proposed Disposal Action. A number of reports have been published on environmental aspects of ILAW disposal. As noted in Section 1.1, the 1998 ILAW PA was conditionally approved by the LFRG (DOE 1999d) and a Disposal Authorization Statement was issued (DOE 1999a). As required by the Disposal Authorization Statement, a maintenance plan for the ILAW PA was issued (DOE/ORP 2000a) and approved (French 2000b).

Monitoring (Horton 2000) and closure plans (Burbank 2000) were also issued and approved (Boston 2000a and Boston 2000b).

To support the 2001 version of the ILAW performance assessment, two auxiliary documents (*Data Packages for the Hanford Immobilized Low-Activity Tank Waste Performance Assessment: 20001 Version* [Mann/Puigh 2000a] and *Simulations for the 2001 ILAW PA* [Puigh 2001]) have been issued. Based on the data packages, a preliminary analysis of the ILAW disposal system performance was issued as *White Paper Updating the Conclusion of the 1998 ILAW Performance Assessment* (Mann/Puigh 2000b). This analysis was combined with other data required by the ILAW PA maintenance plan and issued as *Annual Summary of Immobilized Low-Activity Tank Waste (ILAW) Performance Assessment* (DOE/ORP 2000b) and sent to DOE/EM (French 2000c).

The 1998 ILAW PA (Mann 1998a) was described in Section 1.1. It used geotechnical data typical of the area in which the disposal facility will be located and waste form data based on procurement documents. The 1998 ILAW PA showed that a reasonable expectation exists that the public and the environment would be protected.

The first performance assessment on this disposal action was *Hanford Low-Level Tank Waste Interim Performance Assessment*, WHC-EP-0884, Rev. 0 (Mann 1996a) and WHC-EP-0884, Rev. 1 (Mann 1997a). These documents were designed to provide the best available analysis given limited project-specific data. The revision (Mann 1997a) was based on comments received on the initial interim performance assessment (Mann (1996a).

Data Packages for the Hanford Low-Level Tank Waste Interim Performance Assessment (Mann 1995a) and *Definition of the Base Analysis Case of the Interim Performance Assessment* (Mann 1995b) define the data used in the interim performance assessments. These document covering the data packages document (Mann 1995a) justify the values used in the analysis. The definition document (Mann 1995b) defines all data to be used in the interim performance assessment and the sensitivity cases studied.

Revisions 0 (Rawlins 1994) and 1 (Mann 1995d) of *Impacts of Disposal System Design Options on Low-Level Glass Waste Disposal System Performance* provided sensitivity analyses of the long-term environmental impact based on various design features for the low-level tank waste disposal facility. The first analysis was updated based on better data and on the comments received on Revision 0. Neither report is as comprehensive as a performance assessment.

1.5.1.2 Other Hanford Site Project-Specific Performance Assessments. This document also builds on the previous performance assessments prepared for the Hanford Site. These performance assessments were prepared under the requirements of the DOE Order 5820.2A, *Radioactive Waste Management* (DOE 1988a) for other Hanford Site disposal actions. All performance assessments prepared under DOE Order 5820.2A were reviewed for technical adequacy by the Peer Review Panel (established by the order). This panel performed a preliminary review, a completeness review, and a final review for each performance assessment. Then, DOE-Headquarters reviewed the documents and could approve the disposal action if the performance assessment satisfied the requirements of the DOE Orders.

The *Long-Term Performance Assessment of Grouted Phosphate/Sulfate Waste from N-Reactor Operations*, PNL-6512 (Stewart 1987), forms the basis of the environmental assessment (DOE 1986a) for the disposal of low-level radioactive waste generated by decontamination operations and other activities associated with N Reactor operations. The grouted phosphate-sulfate performance assessment predates the DOE approval process for performance assessments. The DOE review was conducted by reviewing the environmental assessment.

The *Performance Assessment of Grouted Double-Shell Tank Waste Disposal at Hanford* (Kincaid 1995) dealt with disposing of low-level liquid waste from the double-shell tanks. 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. The grout performance assessment was approved in principle by the Peer Review Panel (Wilhite 1994). DOE (Lytle 1995) found that the analysis performed in Kincaid (1995) was "technically adequate and provides reasonable assurance that the selected performance objectives would be met." However, noting that the grout project had been canceled, DOE also stated that a new or revised performance assessment would be needed for routine disposal of waste in the Grout Disposal Facility.

The *Performance Assessment for the Disposal of Low-Level Waste in the 200 West Area Burial Grounds* (Wood 1995a) dealt with the solid waste from operations at the Hanford Site and other DOE sites. This waste is placed into trenches in the western part of the 200 West Area then covered with a barrier. The Peer Review Panel found the performance assessment to be technically acceptable. The 200 West Area performance assessment has been "conditionally accepted" by DOE-Headquarters (Cowan 1996). The "conditions" referred to added documentation.

The *Performance Assessment for the Disposal of Low-Level Waste in the 200 East Area Waste Burial Grounds* (Wood 1996) addresses waste that is similar to that addressed in the 200 West Area performance assessment. However, the disposal trenches for this waste are in the northern part of the 200 East Area. The final performance assessment for this action also has been conditionally approved by DOE-Headquarters (Frei 1997).

A maintenance plan for these two performance assessments has been written. Annual summaries also have been submitted to LFRG. In addition, to satisfy a conditional requirement specified in the disposal authorization statement, a review of solid waste characterization practices has been completed and accepted by the LFRG. The review was conducted to determine if these practices were adequate to support the evaluation of disposal facility performance relative to compliance with performance objectives. Waste characterization practices were found to be adequate and a report was issued to DOE Headquarters in June 2000.

The *Environmental Remediation Disposal Facility Performance Assessment* (Wood 1995b) was written to support disposal of waste generated by the cleanup of the Hanford Site. Most of this waste is expected to be contaminated soil. Trenches are planned to be the main means of disposal at the facility. Because the Environmental Remediation Disposal Facility is regulated under the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA), this performance assessment was not submitted to the Peer Review Panel. However, *A Remedial Investigation and Feasibility Study Report for the Environmental Restoration Facility*, DOE-RL-93-99 (DOE/RL 1994a), was written. A cross walk between this report and the requirements of DOE O 435.1 has recently been submitted for LFRG approval.

1.5.1.3 More General Hanford Site Environmental Assessments. A series of general environmental assessments also has been written for Hanford Site activities. These assessments look at the Hanford Site as a whole or address environmental impacts in a more general manner.

The *Composite Analysis for Low-Level Waste Disposal in the 200-Area Plateau of the Hanford Site*, PNNL-11800 (Kincaid 1998), was prepared in response to Recommendation 94-2 of the Defense Nuclear Facilities Safety Board 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 a DOE site. The authors of the composite analysis are working with the authors of the previous performance assessments to maximize consistency in data and methods. The first version of this analysis was reviewed along with the 1998 ILAW PA. The LFRG also conditionally approved the Composite Analysis in "Disposal Authorization Statement for the Hanford Site Low-Level Waste Disposal Facilities" (DOE 1999a) with comments more fully documented in *Low-Level Waste Disposal Facility Federal Review Group Manual* (DOE 1999c).

The *Environmental Impact Statement for the Tank Waste Remediation System* (TWRS EIS) (DOE 1996b) analyzed various options to manage the Hanford Site's tank waste with the record of decision issued shortly thereafter (DOE 1997b). Because of the scope of the TWRS EIS, the analyses relied on data less complete and less project-specific than this performance assessment. The record of decision covers the disposal of ILAW in the Hanford Site 200 Areas. The TWRS EIS was preceded by the Hanford Defense Waste EIS, *Final Environmental Impact Statement: Disposal of Hanford Defense High-Level Transuranic and Tank Wastes*, DOE/EIS-0113 (DOE 1987).

The *Draft Hanford Remedial Action Environmental Impact Statement and Comprehensive Land Use Plan*, DOE/EIS-0222-D (DOE 1996c), 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 because they were part of the EIS and land-use plan. Based on comments, the draft EIS was rewritten and issued as a land use plan EIS (DOE 1999h) with an associated record of decision (DOE 1999i).

1.5.2 Regulatory Agreements and Documents

The Tri-Party Agreement (Ecology 1998) is an agreement between DOE, the U.S. Environmental Protection Agency (EPA), and the Washington State Department of Ecology (Ecology) concerning the cleanup of the Hanford Site. The Tri-Party Agreement has legally enforceable milestones, some of which (the M90 series) cover the Immobilized Waste Program. Milestone M-90-05T (due in March 2002) was met when DOE submitted a copy of the 1998 ILAW performance assessment to Ecology for comment at the same time that DOE submitted the document to DOE Headquarters for approval.

The DOE has written the *Hanford Site Ground Water Protection Management Plan*, DOE-RL-89-12, Rev. 2 (DOE/RL 1995c), with Ecology's approval. However, the current version of the management plan does not address long-term protection of the groundwater resource.

1.5.3 Guidance Documents

The main documents guiding this performance assessment are as follows:

- *Format and Content Guide for U.S. Department of Energy Low-Level Waste Disposal Facility Performance Assessments and Composite Analyses* (DOE 1999e)
- *Maintenance Plan for the Immobilized Low-Activity Waste Performance Assessment Activity* (DOE/ORP 2000b)
- Comments on the 1998 ILAW PA by the Low-Level Waste Disposal Facility Federal Review Group (DOE 1999c)

The following additional documents also were used as guidance in preparing this performance assessment:

- *Critical Assumptions for Department of Energy Low-Level Waste Disposal Facility Assessments* (Alm 1997)
- *Issuance of Low-Level Waste Performance Assessment Guidance* (Frei 1996)
- *Performance Assessment Review Guide for Low-Level Radioactive Waste Disposal Facility*, DOE/LLW-93 (Dodge 1991)
- *Proceedings of the Department of Energy Performance Assessment Briefing, Denver, Colorado, October 29, 1991*, DOE/LLW-138 (NLLWMP 1992)
- *Performance Assessment Task Team Progress Report*, Revision 1, DOE/LLW-157 (Wood 1994)

- *A Compilation of DOE Performance Assessment Peer Review Panel Review Comments and Recommendations*, DOE/LLW-216 (RWTSP 1994).

- "DOE Headquarters Review of the *Performance Assessment of Grouted Double-Shell Tank Waste at Hanford*" (Lytle 1995)

- *Implementation Plan, Defense Nuclear Facilities Safety Board Recommendation 94-2, Compliance with Safety Standards at Department of Energy Low-Level Nuclear Waste Sites* (DOE 1996a)

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

1.6 PERFORMANCE OBJECTIVES

1.6.1 Summary

The DOE's requirements for waste disposal (DOE 1999a) can be summarized as follows:

- Protect public health and safety
- Protect the environment.

The requirements for this performance assessment are the same as for the 1998 ILAW PA, except that comparisons at 1,000 years for the groundwater pathway and for non-radioactive hazardous compounds (hereafter referred to as chemicals in this Performance Assessment) have been added.

> The performance objectives are the same as for the 1998 ILAW PA. Time of compliance is 1,000 years for groundwater pathways, rather than 10,000 years. However, a comparison will be also be made at 10,000 years. In addition, this analysis includes chemicals.
>
> Most restrictive performance objectives are as follows:
> 1) Groundwater (βγ): 4 mrem in a year for 10,000 years
> 2) Intruder (continuous): 100 mrem in a year after 500 years

For this performance assessment, the following methods were used to establish the quantitative performance objectives as explained in *Performance Objectives of the Tank Waste Remediation Systems Low-Level Waste Disposal Program*, HNF-EP-0826 (Mann 1999a):

- Investigate all potentially applicable regulations, as well as interpretations made by the Peer Review Panel and the LFRG (Section 1.6.2)

- Work with Immobilized Waste Project management to establish their needs (Section 1.6.3)

- Work with the Hanford Site stakeholders to understand the values of residents in the Pacific Northwest (Section 1.6.4).

The manual (DOE 1999g –1) for DOE O 435.1 (DOE 1999b) provides performance objectives for a performance assessment as

(1)(a) "25 mrem in a year total effective dose equivalent from all exposure pathways"

(1)(b) "10 mrem in a year total effective dose equivalent " via the air pathway

(1)(c) "Release of radon shall not exceed 10 mrem in a year total effective dose equivalent"

(2)(g) "Include an assessment of impacts to water resources"

(2)(h) "The intruder analysis shall use performance measures for chronic and acute exposures, respectively, of 100 mrem in a year and 500 mrem in a year total effective dose equivalent."

(2)(b) "The point of compliance shall correspond to the point of highest projected dose or concentration beyond a 100 meter buffer zone surrounding the disposal waste."

(2) "Include calculations for a 1,000 year period after closure"

The proposed disposal action will also require concurrence from the U.S. Nuclear Regulatory Commission (NRC) on the waste classification of ILAW and a RCRA Part B permit. Therefore, additional constraints were considered in the establishment of the performance objectives used in the ILAW PAs.

The NRC has indicated that the ILAW would be considered "incidental waste" (Paperello 1997) if the following three conditions are met:

- DOE follows its program plan for separating and immobilizing the waste to the maximum extent possible that is technically and economically possible
- The wastes meet Class C standards of 10 *Code of Federal Regulations* (CFR) 61
- The performance assessments continue to indicate that public health and safety would be protected to standards comparable to those established by the NRC for the disposal of low-level waste.

The first two conditions are built into the current contract for the immobilization of LAW. Also, the 1998 ILAW performance assessment has shown that the public and safety are protected. As "incidental waste," the ILAW would not fall under the licensing authority of the NRC. This position does require the assessment of estimated impacts at 10,000 years after disposal site closure to make comparisons to standards established by the NRC.

Specifically, the RCRA concerns bring in the impacts of hazardous waste. The inorganic chemicals selected are based on a data quality objectives (DQO) process, while the organics are based on having the largest number of analytical detects from those organics identified in the DQO process (Wiemers 1998).

Therefore, as documented in Mann (1999a), these requirements have been merged into a unified set of performance objectives for the ILAW PA. Table 1-3 presents the performance objectives for radionuclides. Table 1-4 presents the performance objectives for chemicals identified as most important.

Table 1-3. Radiological Performance Objectives.

Protection of General Public and Workers [a, b]	
All-pathways dose from only this facility	25 mrem in a year [d, h]
All-pathways dose including other Hanford Site sources	100 mrem in a year [c, i]
Protection of an Inadvertent Intruder [c, f]	
Acute exposure	500 mrem
Continuous exposure	100 mrem in a year
Protection of Groundwater Resources [b, d, j]	
Alpha emitters	
^{226}Ra plus ^{228}Ra	5 pCi/L
All others (total)	15 pCi/L
Beta and photon emitters	4 mrem in a year
Protection of Surface Water Resources [b, g]	
Alpha emitters	
^{226}Ra plus ^{228}Ra	0.3 pCi/L
All others (total)	15 pCi/L
Beta and photon emitters	1 mrem in a year [k]
Protection of Air Resource [b, f, l]	
Radon (flux through surface)	20 pCi m^{-2} s^{-1}
All other radionuclides	10 mrem in a year

[a] All doses are calculated as effective dose equivalents; all concentrations are in water taken from a well. Values given are in addition to any existing amounts or background.

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

[c] Evaluated for 500 years, but calculated to 1,000 years.

[d] Evaluated at the point of maximum exposure, but no closer than 100 meters (328 feet) from the disposal facility.

[e] Evaluated at the 200 East Area fence (assumed future boundary of the DOE site).

[f] Evaluated at the disposal facility.

[g] Evaluated at the Columbia River, no mixing with the river is assumed.

[h] Main driver is DOE Orders on *Radioactive Waste Management* (DOE 1999b/g)

[i] Main driver is DOE Order 5400.5, *Radiation Protection of the Public and the Environment* (DOE 1993).

[j] Main driver is National Primary Drinking Water Regulations (40 CFR 141).

[k] Main driver is Washington State Surface Water Standards (WAC 173-201A)

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

Table 1-4. Performance Goals for Inorganic and Organic Materials. (See Mann 1999a for Source of Performance Goals.)

Inorganics		
Chemical	Groundwater	Surface Waters
Ammonia (NH_3)	(a)	4.0 mg/L
Antimony (Sb)	0.006 mg/L	0.006 mg/L
Arsenic (As)	0.00005 mg/L	0.05 mg/L
Barium (Ba)	1.0 mg/L	2.0 mg/L
Beryllium (Be)	0.004 mg/L	0.004 mg/L
Cadmium (Cd)	0.005 mg/L	0.00077 mg/L
Chlorine (Cl)	250 mg/L	230 mg/L
Chromium (Cr)	0.05 mg/L	0.011 mg/L
Copper (Cu)	1.0 mg/L	0.0078 mg/L
Cyanide (CN)	0.2 mg/L	0.0052 mg/L
Fluoride (F-)	4.0 mg/L	4.0 mg/L
Iron (Fe)	0.3 mg/L	(a)
Lead (Pb)	0.05 mg/L	0.0015 mg/L
Manganese (Mn)	0.05 mg/L	(a)
Mercury (Hg)	0.002 mg/L	0.000012 mg/L
Nickel (Ni)	(a)	0.115 mg/L
Nitrate as N (NO_2)	10 mg/L	10 mg/L
Nitrite as N (NO_3)	1.0 mg/L	1.0 mg/L
Nitrite plus Nitrate	10 mg/L	10 mg/L
Selenium (Se)	0.01 mg/L	0.005 mg/L
Silver (Ag)	0.05 mg/L	(a)
Sulfate (SO_4)	250 mg/L	(a)
Thallium (Tl)	0.002 mg/L	(a)
Zinc (Zn)	5.0 mg/L	0.072 mg/L

Table 1-4. Performance Goals for Inorganic and Organic Materials. (See Mann 1999a for Source of Performance Goals.)

Organics			
CAS #	Constituent (a)	Groundwater	Surface Waters
56-23-5	Carbon tetrachloride	0.0003 mg/L	0.005 mg/L
67-66-3	Chloroform	0.007 mg/L	(a)
71-43-2	Benzene	0.001 mg/L	0.005 mg/L
71-55-6	1,1,1-Trichloroethane	0.003 mg/L	0.2 mg/L
75-09-2	Dichloromethane (Methylene Chloride)	0.005 mg/L	0.005 mg/L
79-00-5	1,1,2-Trichloroethane	0.005 mg/L	0.005 mg/L
79-01-6	1,1,2-Trichloroethylene	0.005 mg/L	0.005 mg/L
95-47-6	o-Xylene	0.7 mg/L	0.7 mg/L
100-41-4	Ethyl benzene	0.1 mg/L	0.1 mg/L
106-46-7	1,4-Dichlorobenzene	0.004 mg/L	0.075 mg/L
108-88-3	Toluene	1.0 mg/L	1.0 mg/L
127-18-4	1,1,2,2-Tetrachloroethene	0.005 mg/L	0.005 mg/L

(a) No entry in a cell indicates that no limit was found

1.6.2 Regulations and Other Performance Assessments

1.6.2.1 Introduction. Several Federal and State regulations potentially apply to how well the public health and safety and the environment must be protected. The following categories of requirements were reviewed for relevance to this proposed disposal action:

- Protection of the general public
- Protection for workers
- Protection of the inadvertent intruder
- Protection of groundwater resources
- Protection of surface water resources
- Protection of air resources.

Appendix B of Mann (1999a) lists the regulations that were reviewed and judged to be potentially relevant to this proposed disposal action. Some regulations and general environmental acts were judged not relevant to the performance assessment activity for one or more of the following reasons:

- Requirements are the responsibility of other participants in the Immobilized Waste Program (for example, ensuring compliance with the *National Environmental Policy Act* [NEPA]).

- Requirements are for different environmental actions (for example, the CERCLA).

- Requirements deal with general environmental concerns such as the protection of endangered species that are thought to be adequately covered for the long-term by the regulations presented here.

- Requirements are only at a preliminary stage and are likely to change, {e.g., the "Radiation Site Cleanup Regulation" [proposed Title 40 CFR Part 196] and "Environmental Radiation Standards for Management and Disposal of Low-Level Waste" [proposed 40 CFR Part 193] from the EPA}. The development of these requirements will be closely followed and the requirements will be incorporated as appropriate.

Performance assessments of low-level waste disposal in the DOE complex were reviewed also to identify any regulations relevant to this proposed disposal action. These assessments provide "case law" interpretations. Appendix C of Mann (1999a) lists the other performance assessments in the DOE complex, as well as their performance objectives.

In their review of the Interim Performance Assessment (Mann 1997a), in "Classification of Hanford Low-Activity Tank Waste Fraction," the staff of the NRC (Paperiello 1997) indicated that meeting the performance objectives in that performance assessment (which are the same as the ones in this document) would meet the performance objectives of the NRC regulations (10 CFR 61-3).

1.6.2.2 Protection of the General Public. For this assessment, the performance objective for the protection of the general public is 25 mrem (effective dose equivalent [EDE]) in a year. This value is used consistently in the regulations (DOE 1999b and 10 CFR 61-3) and was used in the past performance assessments. Although other methods are available for determining body dose, the EDE method was selected because regulations normally use this method. The location for compliance is at the point of maximal exposure, but not less than 100 m (328 ft) from the disposal facility (DOE 1999g).

The Defense Nuclear Facilities Safety Board (DNFSB 1994) noted that a member of the public could receive exposures from several sources at a DOE site. Guidance from DOE Headquarters (DOE 1996a) is that protection of the general public from multiple sources should be based on *Radiation Protection of the Public and the Environment*, DOE Order 5400.5 (DOE 1993-1). This order sets a limit of 100 mrem in a year from all sources. The interpretation of DOE Order 5400.5 places the point of compliance at the fence line of the future site. For the Hanford Site, this is considered to be a fence surrounding the present Hanford Site 200 Areas. The *Composite Analysis for Low-Level Waste Disposal in the 200-Area Plateau of the Hanford Site* (Kincaid 1998) shows compliance with this requirement.

Little guidance is provided on interpreting the as low as reasonably achievable (ALARA) guidance. The Immobilized Waste Program is integrating design and safety, including environmental considerations, into a single program to optimize the design and operation of the ILAW disposal facility. The iterative approach uses environmental and safety analyses of preconceptual designs (see Mann 1996a), followed by preliminary and detailed designs using the results of those analyses, followed by more complete environmental and safety analysis, such as successors to this document. Disposal facility components will be incorporated into the design whenever their inclusion significantly adds protection to human health or the environment.

As directed by DOE guidance, the compliance time for this performance assessment is 1,000 years. (The compliance time is the time starting 100 years from the present over which the predicted dose must remain below the performance objectives.) However, explicit comparisons also are made at 10,000 years to show compliance with NRC guidance. In addition, the calculation was carried out to 100,000 years for the base analysis case and to 20,000 years for the other sensitivity cases.

1.6.2.3 Protection for Workers. For this performance assessment, as for others performed under the DOE orders on radioactive waste management, no distinction is made between performance objectives for workers and for the general public. Because the protection requirements for the general public are more restrictive than those for the workers, the workers will be adequately protected. Protection for workers during construction and operations will be addressed in the safety analysis report that will be written for the Immobilized Waste Program.

1.6.2.4 Protection of the Inadvertent Intruder. The exposure limits for protecting a hypothetical inadvertent intruder are consistent with the regulations (DOE 1999b and 10 CFR 61-3) and with earlier performance assessments. (Appendix Tables B-2 and C-2, respectively, in Mann [1999a] give details). These limits are 500 mrem (EDE) for a one-time (acute) exposure and 100 mrem (EDE)/year for a continuous exposure. These limits are used in this performance assessment.

The compliance time for protecting an inadvertent intruder is defined differently from the compliance time for protecting the general public or the environment. The inadvertent intrusion compliance time differs slightly between regulations. Current DOE guidance (Alm 1997) is that active institutional control shall occur for at least 100 years, but notes that longer times can be used if justified. DOE intends to control the Hanford Site 200 Areas as long as necessary to protect the public. U.S. Department of Energy, Richland Operations Office (RL) directive 5820.2A (DOE/RL 1993) allowed a compliance time of 500 years if passive barriers and markers are used. The Hanford Site grout performance assessment (Kincaid 1995-1) used the 500-year compliance time based on the assumption that passive barriers and markers would be present. The performance assessments for the disposal of solid radioactive waste on the Hanford Site (Wood 1995a and Wood 1996) also use a compliance time of 500 years. This is consistent with the NRC requirement for Class C waste that inadvertent intruders be protected for 500 years (10 CFR 61-1).

Following the precedent of the other Hanford Site performance assessments, the 500-year compliance time was used in this assessment because passive barriers and markers are planned for this proposed disposal action. Therefore, protection of an inadvertent intruder shall be considered met if the exposure limits are met at 500 years after closure. Calculations were run and results shown from 100 years to 1,000 years after the time of disposal to obtain the doses as a function of time.

1.6.2.5 Protection of Groundwater Resources. The protection level for groundwater is the most complicated requirement to determine. The level of protection for groundwater usually is based on its intended use. However, predicting future groundwater use is highly subjective given the long time frames involved in a performance assessment. The type of quantities being limited (decay rate and dose) differs in the various regulations. Moreover, different regulatory agencies approach protecting groundwater resources using different metrics. In addition, earlier DOE performance assessments have taken different approaches. The guidance under DOE O 435.1 is to use the Site groundwater protection management plan. However, the Hanford Site plan (DOE/RL 1995c) is silent on long-term protection of groundwater.

Previous performance assessments have generalized the requirements from the "National Primary Drinking Water Regulations," 40 CFR 141, for determining whether the disposal action met the groundwater protection requirement. The scenario used is based on a public drinking water system serving at least 25 people and located at least 100 m (328 ft) downstream from the disposal facility. The previous performance assessments set a limit for the total exposure at less than 4 mrem (EDE) in a year from all radionuclides for an individual drinking the water. The "National Primary Drinking Water Regulations," however, use the limit of 4 mrem in a year, not for all radionuclides, but for just beta and gamma emitters. The distance of 100 m from the disposal facility is given in *Manual for DOE O 435.1*, DOE M 435.1 (DOE 1999g), the DOE manual implementing DOE O 435.1. Four mrem (EDE) in a year was chosen for two reasons. First, the value corresponds to the risk-based limit found in the "National Primary Drinking Water Regulations." Also, for most of the radionuclides, the value is more restrictive (see Table B-3 of Mann 1999a) than the decay rate concentration limits specified in the Washington State regulations (WAC 173-200).

The requirements for alpha emitters are the same in both the Washington State (WAC 173-200) and Federal (10 CFR 141) regulations. Both regulations limit alpha emitters by decay rate concentration limits, not annual dose. In addition, both sets of requirements limit the same subsets of alpha emitters (^{226}Ra, total radium, and other) and set the same quantitative limits. These decay rate concentration limits (Table 1-3) are used for this performance assessment.

Washington State's requirements for beta emitters are based on screening levels previously used by the EPA. These screening levels were selected because the requirements are easily verified in the field. (The current EPA regulations are based on risk limitation.) The current state screening level ensures that, even for beta emitters emitting high-energy gamma radiation, the dose limit will be met. However, for low-energy beta emitters, the state screening level is overly conservative by a factor of about 100. This high degree of conservatism exists for radionuclides, such as ^{99}Tc, that are important in this performance assessment.

For this performance assessment, the Federal standards are used. This means that the current EPA regulation governing drinking water (40 CFR 141) is used to protect groundwater. The "National Secondary Drinking Water Standards" (40 CFR 143) were not used because they are stated only as goals. This follows the precedent set in the TWRS EIS (DOE 1996b), a joint publication of the Ecology and DOE. Thus, the performance objective is an EDE of 4 mrem in a year for beta and photon emitters and a concentration of 15 pCi/L for alpha emitters. Although uranium is not restricted by the regulations, for this analysis it is included under other alpha emitters. The values are displayed in Table 1-3. A dose of 4 mrem (EDE) in a year for 70 years corresponds to an incremental health risk of 0.0001 (EPA 1989b).

To ensure compliance with the intent of Federal and State groundwater regulations, the limits shown in Table 1-3 are applied to a well 100 m downgradient from the disposal facility for 10,000 years after closure, the same time of compliance as for protection of the general public. The hypothetical well from which the water is drawn is sized to be the minimum public drinking water system to serve 25 people. Further information is given in Section 3.4.7.2. The effects of placing the well at other locations (including the Hanford Site 200 Area fence line) also are determined.

1.6.2.6 Protection of Surface Water Resources. The thrust is the same of both the Federal (10 CFR 141) and State requirements (WAC 173-201A) for protecting surface water resources. The point of compliance is where the groundwater is predicted to reach the Columbia River. The concentration of radionuclides in the groundwater at the point where it enters the Columbia River should meet all the standards listed in Table 1-3.

The 1.0 mrem (EDE) dose in a year (one quarter of the EPA drinking water standard) value is selected because it meets the Washington State regulation while minimizing reporting requirements. The Washington State regulation (WAC 173-201A) mandates a dose limit that is the lesser of the EPA drinking water standard and the explicit limits for each radionuclide contained in the State regulation. For the major radionuclides of interest, the explicit limits (when converted to dose) are greater than 1.3 mrem in a year. Therefore, using 1.0 mrem in a year for the sum of all beta and photon emitters is restrictive in meeting this standard.

The compliance time for protecting surface water resources is selected as 1,000 years, the same compliance time as for protecting groundwater resources. However, the calculations are carried out to 10,000 years or to the time of maximum impact, if the peak occurs after 10,000 years.

1.6.2.7 Protection of Air Resources. Air emissions limits were taken from Parts H and Q of the "National Emissions Standards for Hazardous Air Pollutants" (40 CFR 61H and 40 CFR 61Q). These limits are more restrictive than the Washington State requirements (WAC 173-480 and WAC 246-247). Based on these standards, emissions (except radon) are limited to 10 mrem (EDE) in a year with radon emissions limited to 20 pCi/m^2s.

1.6.2.8 Chemical Objectives. The DOE O 435.1 (DOE 1999b) and its associated manual (DOE 1999g) cover only the management of radioactive waste. However, Chapter 1, Section 1, item 10 of the manual notes that mixed waste also is subject to the RCRA as amended. Because ILAW may contain some materials regulated under RCRA and because the RCRA Part B permit for the disposal facility will be based on this analysis, performance objectives for chemicals were established. The 1998 ILAW PA did not address chemicals.

The determination of chemical objectives followed the same process as for radiological objectives (see Mann 1999a). That is, all relevant regulations were reviewed and the most restrictive limits were used. The chemicals included are ones based on the those identified by a data quality objectives (DQO) process (Wiemers 1998). This DQO process included Ecology.

1.6.3 Programmatic Requirements

The Immobilized Waste Program also has established other requirements. The project mandated that all waste to be disposed or stored in the facility shall meet NRC Class C concentration limits (10 CFR 61-2). This restriction will satisfy the NRC determination that the immobilized low-activity waste is not high-level waste and can be disposed as "incidental" waste (Paperiello 1997).

1.6.4 Public Involvement

Giving Hanford Site stakeholders an opportunity to affect the performance objectives of this proposed disposal action is important. The performance objectives and scenarios (WHC 1994a) were summarized for the stakeholders. The summary was sent to each member and alternate of the Hanford Advisory Board, to selected Hanford Site contractor employees, and to selected members of the DOE's Peer Review Panel and Performance Assessment Task Team.

We received feedback from the stakeholders and have responded to their concerns. Copies of the performance objectives document (WHC 1994a) were sent to all who requested it. All comments received on either the summary or the performance objectives have been documented as an internal file. These comments and corresponding responses are available for review (Murkowski 1995).

A member of the Hanford Advisory Board, Todd Martin, also was a member of the external review board (see Appendix F.1 of Mann 19996a) that commented on the interim performance assessment and the performance assessment activity.

1.7 APPROACH AND MAJOR DATA SOURCES

This performance assessment is being performed early in the project life. Therefore a three-step approach is being taken:

- Perform forward calculations using a series of cases to understand the behavior of the disposal system
- Perform backward calculations using the best current data to establish requirements for the waste form and the disposal facility

- Perform forward calculations to show that such requirements can be "reasonably expected" to be met without heroic efforts.

The first set of calculations is built around a base analysis case that reasonably describes our understanding of the system components and how they will interact. This step starts with the known conditions and estimates the impacts from those conditions (i.e., a forward calculation). These calculations are supplemented by simulations built on a series of sensitivity cases to determine the robustness of the results from the base analysis case and to develop an understanding of the important features and parameters of the disposal system.

Based on this understanding, a set of relatively simple equations can be derived (See Section 7.6) that represents the important quantities of the system which drive the environmental and human impacts. The second set of calculations then back calculates these equations to set restrictions on the most important parameters involved in waste form performance and facility design.

Having such requirements then allows a final set of calculations to show whether engineered solutions exist that can meet these requirements. Because this performance assessment is being done early in the life of the program, the actual engineered solutions may differ, but the engineered solutions actually used should be better (e.g., more cost effective, perform better) than the ones used here to show compliance.

Because of the long time frames involved in this analysis, estimates of impacts require computer simulations, rather than direct observations. The models used in the analyses are very flexible and should be adequate to describe the evolving features of the disposal system. However, because this analysis is performed early in the project life, many of the data are taken from related Hanford Site projects.

The major sources of information for the base analysis case are present in Table 1-5. Sensitivity cases (See Section 3.5.5) were performed to determine the impact of uncertain data. Among the most important uncertain data were the following:

- Contaminant release from waste form,
- Facility layout and design
- Groundwater flows
- Infiltration.

→→→ See Section 3.3.5 for the definition of sensitivity cases.

Table 1-5. Major Sources of Information for the Base Analysis Case. (Significant differences with the 1998 ILAW PA are shown in italics.)

Data Type	Major Source	Data Base Reference
Location	The new facilities are just southwest of the PUREX Facility (in the 200 East Area).	Rutherford 1997
Waste Form	Waste package design based on early BNFL, Inc. documentation and River Protection Project planning.	Puigh 1999; also in Mann/Puigh 2000a Appendix I
Inventory	*Based on best basis inventory estimates (calculated from modeling Hanford Site production reactors corrected for offsite transfers, and discharges to the ground and biased to tank measurements).* ***ASSUMED*** *separations into high- and low-activity fractions, and off-gas generation.*	*Wootan 1999; also in Mann/Puigh 2000a Appendix H*
Long-term waste form performance	*Based on data collected on BNFL, Inc. relevant glass formulations.*	*McGrail 2001; McGrail 1999; also in Mann/Puigh 2000a and 2001 as Appendix K*
Disposal facility design	***ASSUMED*** *from preconceptual ideas for the remote handled trench and conceptualy design for the concrete vault.*	*Puigh 1999; also in Mann/Puigh 2000a Appendix I*
Recharge	Estimates were derived from lysimeter and tracer measurements collected by the ILAW PA activity and by other projects combined with a modeling analysis.	Fayer 1999; also in Mann/Puigh 2000a Appendix J
Geotechnical	*Taken from geotechnical measurements studies of ILAW site borehole and other locations in the Hanford Site 200 East Area.*	*Khaleel 1999, Meyer 1999, and Kaplan 1999; also in Mann/Puigh 2000a Appendices L, M, and N, respectively*
Exposure	Taken from past Hanford Site documents and experience and DOE O 435.1 direction.	Rittmann 1999; also in Mann/Puigh 2000a Appendix O

Table 1-5. Major Sources of Information for the Base Analysis Case. (Significant differences with the 1998 ILAW PA are shown in italics.)

Data Type	Major Source	Data Base Reference

DOE = U.S. Department of Energy
ILAW = immobilized low-activity waste
PA = performance assessment
PUREX = plutonium-uranium extraction (facility)

Future performance assessments will be issued as new information about the waste form, its inventory, the design of the disposal facility, and site characterization is collected and as these factors are better understood.

1.8 STRUCTURE OF THIS PERFORMANCE ASSESSMENT

This performance assessment is divided into nine chapters and eight appendices. The appendices provide additional detailed information about topics presented in the chapters. This section summarizes the contents of each of chapter and appendix.

- Chapter 2 describes the Hanford Site environment, the waste characteristics, and the waste disposal system.
- Chapter 3 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 presents and integrates results from the transport and exposure models used to estimate the potential consequences of long-term contaminant release from the disposal vaults.
- Chapter 5 presents the results from the inadvertent intruder analyses.
- Chapter 6 interprets disposal facility performance with respect to the performance objectives defined in Chapter 1, sets waste acceptance criteria and disposal facility requirements, shows that these requirements can be "reasonably expected" to be met, and discusses further work associated with the performance assessment activity.
- Chapter 7 outlines the quality assurance procedures used in the performance assessment activity.
- Chapter 8 contains brief resumes of contributors to the document.
- Chapter 9 lists the cited references.

- Appendix A contains the LFRG comments on the 1998 ILAW PA and their resolution.
- Appendix B contains dosimetry data factors used in the analysis.
- Appendix C contains the equations used in the major codes.
- Appendix D presents detailed results of the analysis.
- Appendix E contains the program plan to establish the expected long-term contaminant release rates from vendor-supplied waste forms.
- Appendix F contains quality assurance information.

2.0 DISPOSAL FACILITY DESCRIPTION

2.1 OVERVIEW

This chapter explains the expected environment within the region and around the immobilized low-activity tank waste disposal facilities, probable waste retrieval and immobilization methods, and likely design, operating, and closure concepts for the disposal facilities. It covers the following topics.

Hanford Site Characteristics (Section 2.2). Regional and local geography; demography, including future land use; climate, geology, hydrology, soils, ecological and biotic conditions; and natural background radiation.

Waste Characteristics (Section 2.3). Current waste storage in underground tanks and plans for retrieving the waste, separating it into high- and low-activity fractions, and immobilizing the low-activity fraction, including packaging and certification.

Disposal Technology (Section 2.4). The current concepts on disposal units, waste handling and interim storage operations, waste emplacement, disposal unit closure and stabilization, and site closure.

Disposal site-specific information has been collected since the last ILAW performance assessment (Mann 1998a). This information has been compiled into a database (Mann/Puigh 2000a) used for the analyses to be provided in this revision of the ILAW performance assessment. Some summary information has been included in this document. For a more complete description of this new information, the reader should review Mann/Puigh (2000a).

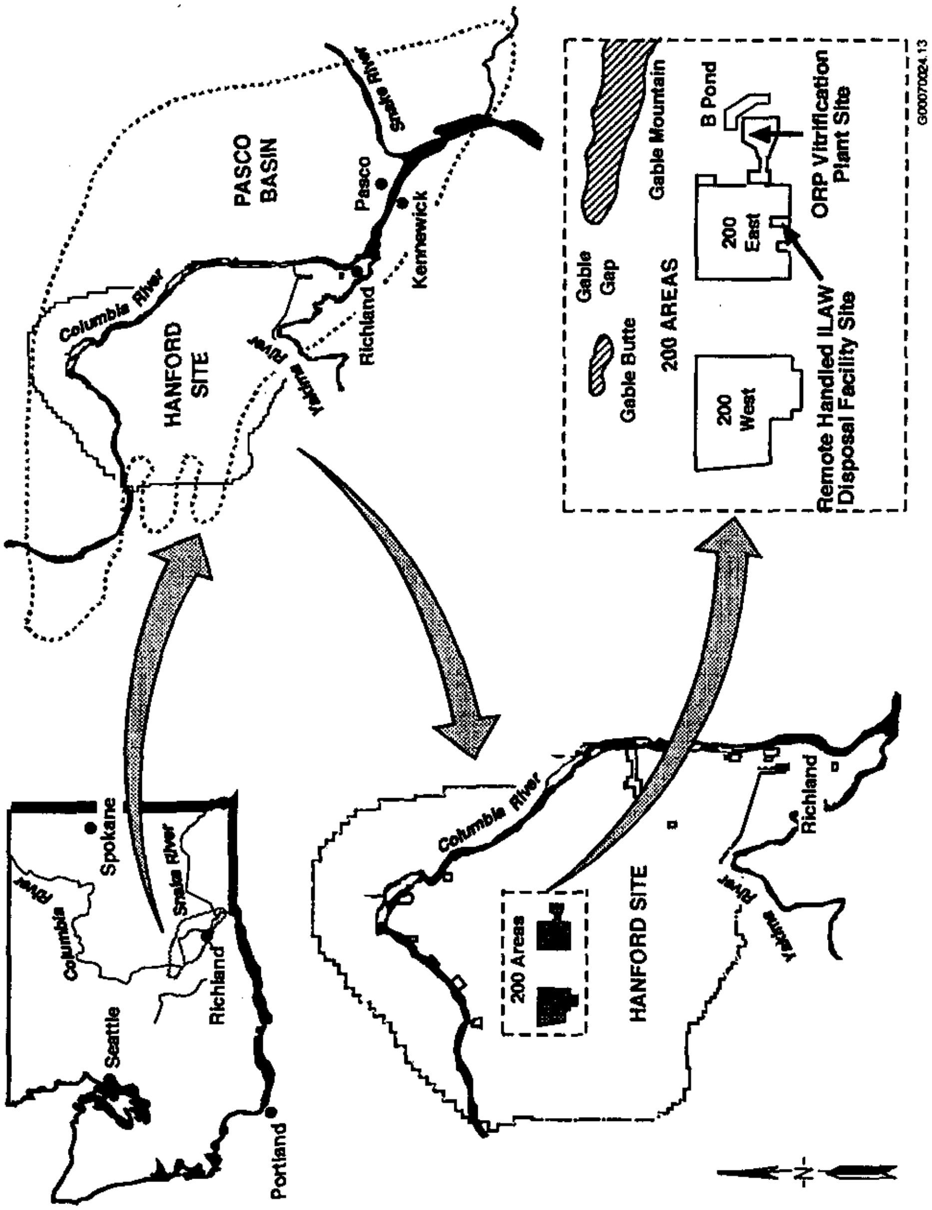
2.2 HANFORD SITE CHARACTERISTICS

This section describes the regional and local environment in which the immobilized low-activity tank waste disposal facilities will be located. Extensive research has been done on the physical characteristics of the Hanford Site. In addition, significant new data have been accumulated since the last ILAW PA (Mann 1998a) for the ILAW disposal sites (Mann/Puigh 2000a).

2.2.1 Geography of the Hanford Site

The Hanford Site is a 1450-km^2 (560-mi^2) area of semiarid land located in south-central Washington State. The Hanford Site is owned by the U.S. Government and restricted to uses approved by the DOE. Figure 2-1 shows the Hanford Site in relation to the rest of the state. It also identifies the major cities in the region, Seattle, Portland, and Spokane, all of which are over 160 km (100 mi) from the Hanford Site.

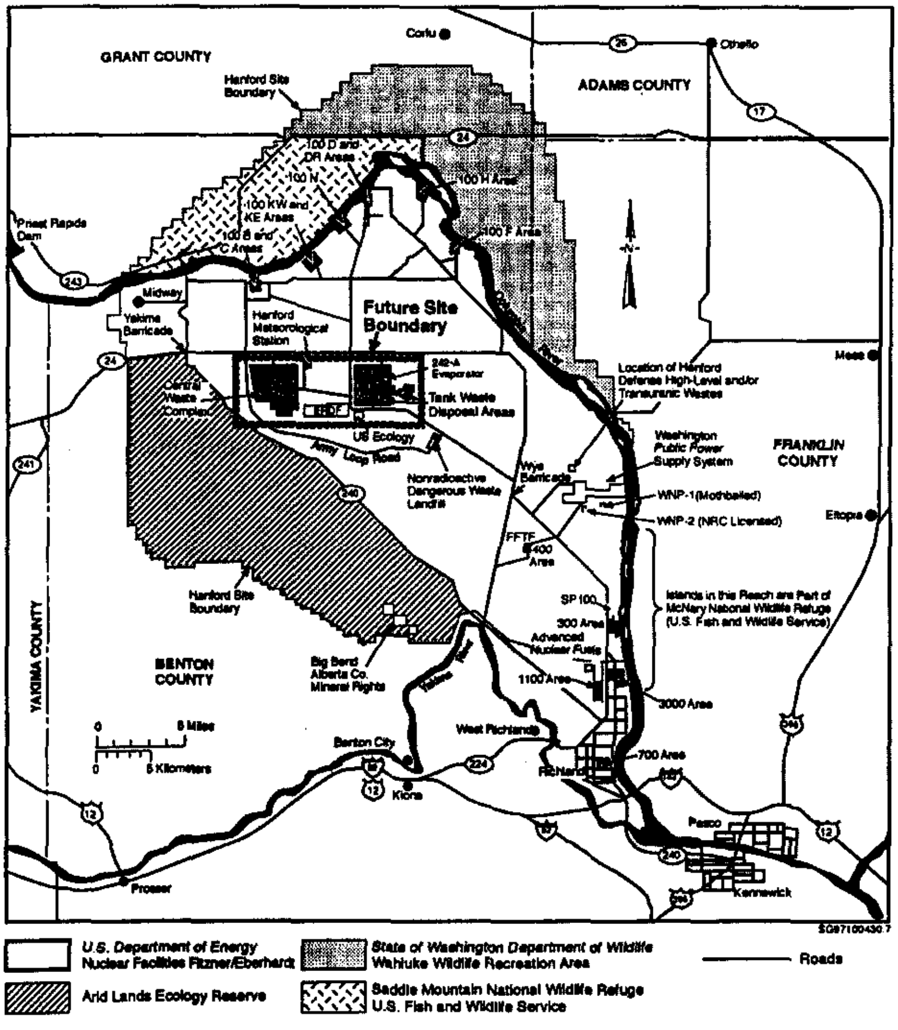
Figure 2-1. Hanford Site in Washington State.



The major features of regional geography are the nearby rivers and mountains. The Columbia River, which forms the eastern boundary of the Hanford Site, is an important source of water and hydroelectric power for the region. Other important rivers near the Hanford Site are the Yakima River to the 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, which is discussed in Section 2.2.5.

Figure 2-2 shows the Hanford Site. The DOE is planning to release some of the Hanford Site land for uses found in the *Final Hanford Comprehensive Land-Use Plan Environmental Impact Assessment* (DOE 1999h) and its associated record of decision (DOE 1999i). The areas planned for release are the area north of the Columbia River and the Fitzner/Eberhardt Arid Lands Ecology Reserve southwest of State Highway 240. This land now is part of the Hanford Reach National Monument (Clinton 2000).

Figure 2-2. Hanford Site Map Showing Public Highways and Future Site Boundary.



The 200 Areas, where the tank waste is located, are in the center of the Hanford Site. Just south of the 200 Areas is land used by U.S. Ecology, Inc., for commercial low-level radioactive waste disposal.

As discussed more fully in Section 2.2.4.3, the *Final Hanford Comprehensive Land Use Plan Environmental Impact Statement* (DOE 1999h) has defined the future site boundaries as just outside of the 200 Area boundaries, as shown in Figure 2-2.

2.2.2 Location of Disposal Sites

The ILAW Disposal Area is in the south central part of the 200 East Area of the Hanford Site.

Historically, two sites have been considered for disposal of immobilized low-activity tank waste (ILAW) (Shade 1997): the four existing TWRS disposal vaults, and the ILAW disposal site (Rutherford 1997). Figure 2-3 shows the two potential disposal areas. The four existing TWRS disposal vaults are located at the eastern edge of the Hanford Site 200 East Area (Burbank 1996, Burbank 1997). The vaults are just east of the AP Tank Farm and at the western edge of the Tank Waste Vitrification Area. These vaults originally were constructed for the disposal of double-shell tank waste in a grouted waste form. New facilities are located in the south-central part of the 200 East Area between existing office structures and the PUREX fuel reprocessing facility. The location of the new facilities was chosen (Rutherford 1997) for the following three reasons (Shord 1995):

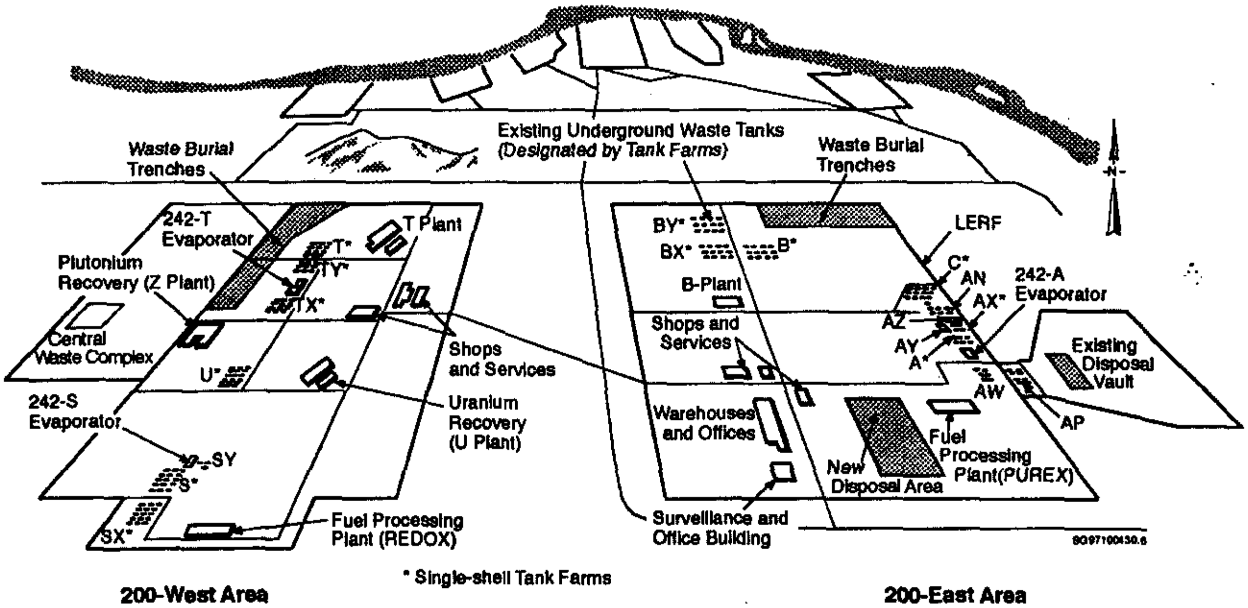
- The location is near existing tank farms
- Unused land is available
- The location is inside the fence line of the 200 Areas.

The current planning (Taylor 1999a) is to use the ILAW disposal site for the disposal of all ILAW waste. The ILAW Disposal program also may use the existing disposal vaults, if needed.

2.2.3 Demography

Demographic data are used in a performance assessment to help set the scenarios and select the dosimetry parameters. This section describes the current population database, area socioeconomics, past and planned DOE activities, and the results of an investigation of future uses conducted by the Hanford Future Site Uses Working Group.

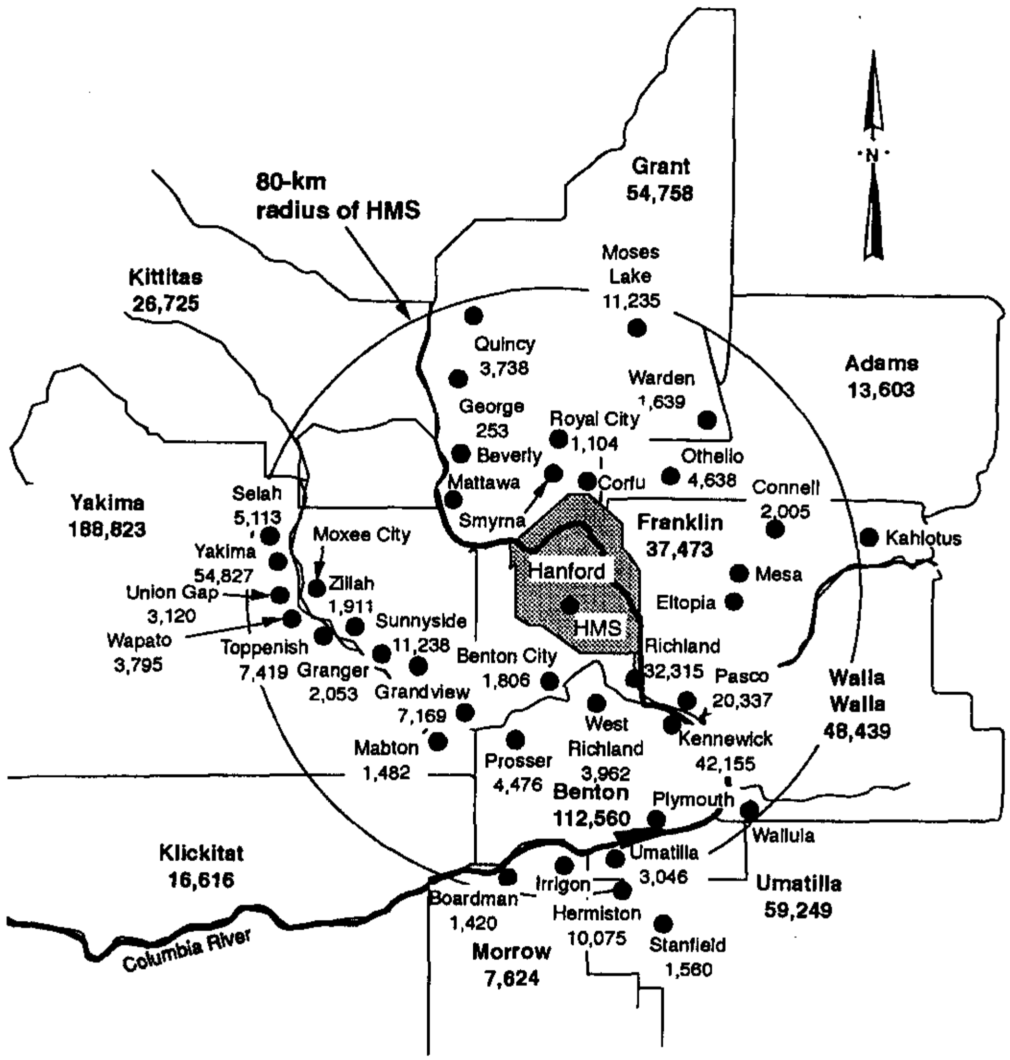
Figure 2-3. Activities in the 200 Areas. The plan area for ILAW disposal is located in the south central part of the 200 East Area and is labeled "New Disposal Area".



The major population centers within 80 km (50-mi) of the Hanford Site are identified in Figure 2-4, along with populations based on the 1990 U.S. Bureau of Census estimates (DOC 1991). This radius is centered on the Hanford Meteorology Station (HMS), located between the 200 East and 200 West Areas. The Tri-Cities (Richland, Kennewick, and Pasco), southeast of the Site, is the largest population center close to the Hanford Site. Other major population centers include Yakima and the 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.

The year 2000 population estimates for Washington State (OFM 2000), as summarized in *Hanford Site National Environmental Policy Act (NEPA) Characterization* (Neitzel 2000-1), are used. The population in Benton County was approximately 140,000 in 2000, compared to 112,560 in 1990. Approximately 37,190 people reside in Richland; 53,270 people reside in Kennewick; and 15,235 people reside in West Richland, Benton City, and Prosser. The approximate population in the unincorporated portions of the county is 35,005. The estimated population of Franklin County was 45,900 in 2000, compared to 37,473 in 1990, with 27,370 people living in Pasco, 15,110 people living in other incorporated areas, and 17,600 people living in unincorporated areas. Benton and Franklin Counties accounted for approximately 3 percent of Washington State's population (OFM 1999).

Figure 2-4. Population Centers Within an 80-km Radius of the Hanford Site. Populations shown are based on 1990 census (DOC 1991).



2.2.4 Land and Water Use

Land and water use information are used in a performance assessment to help set the scenarios and select the dosimetry parameters. This section describes area socioeconomics, past and planned DOE activities, and the results of an investigation of future uses conducted by the Hanford Future Site Uses Working Group.

2.2.4.1 Socioeconomics. The major employers in the Tri-Cities area since 1970 have been the DOE and the Hanford Site contractors; Energy Northwest (formerly the Washington Public Power Supply System), which operates a nuclear power plant; 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 (2000-2).

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's 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 area rivers are used as sources of irrigation and drinking water, as major sources of power production for the western United States, as primary salmon spawning grounds as well as for recreation. The Hanford Reach was designated as a national monument in 2000 (Clinton 2000).

2.2.4.2 Past and Future 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 fighting World War II. Since then, the major activities on the Hanford Site have been controlled by the DOE and its predecessors, the U.S. Atomic Energy Commission (1945-1975), and the Energy and Research Development Administration (1975-1976). Current major programs at the Hanford Site are dedicated to waste management, environmental restoration, long-term stewardship, and research and development.

The DOE nuclear facilities occupy about 6 percent of the Site's total available area. The major operating areas, as shown in Figure 2-2, 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 2-2), contain nine graphite-moderated plutonium production reactors, eight of which were shut down by the early 1970's. 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, were 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 2-2). The following major facilities are located in the 200 Areas (see Figure 2-3):

- Burial trenches
- Eighteen underground storage tank farms (the 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 waste water evaporator facilities (the 242-A, -S, and -T Evaporators)
- Office and warehouse buildings.

Many of these facilities are inactive. The Canister Storage Building was built recently just west of B Plant to store spent nuclear fuel from N Reactor. The Canister Storage Building will also be outfitted to store the immobilized high-level tank waste fraction.

Between and just south of the 200 East and West Areas is the Environmental Remediation Disposal Facility (ERDF) (see Figure 2-2). This trench system will hold most of the contaminated soil and materials from facility decontamination and decommissioning and Hanford Site remediation.

A 3.9 km^2 (1.5-mi^2) parcel located between the 200 West and East Areas is leased to Washington State. A portion of this land is subleased to U.S. Ecology, Inc., a private company, for the disposal of commercially generated low-level radioactive waste.

400 Area. The Fast Flux Test Facility (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. The FFTF operated until 1992 and now is in standby mode.

A 4.4 km^2 (1.7 mi^2) parcel northeast of the 400 Area is leased to Energy Northwest (formerly the Washington Public Power Supply System) for commercial nuclear power reactors. The Columbia Generating Station (CGS), a boiling-water reactor, currently is the only operating nuclear reactor on the Hanford Site. Construction of two pressurized-water reactors (WNP-1 and WNP-4) will not be completed.

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.

2.2.4.3 Future Hanford Use. In 1992, DOE, EPA, and Ecology gathered a group of stakeholders to study potential future uses for the Hanford Site land. This Hanford Future Site Uses Working Group 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 1998h) is heavily based on the work of the Hanford Future Site Uses Working Group. However, DOE's land use planning extends for only 50 years instead of the 100 years forecast by the working group.

HFSUWG (1992a-1) 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-2),

> *"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 working group, they could not agree on a definition of "general use." For the "foreseeable future" the working group 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 on the Hanford Site.

Finally (HFSUWG 1992a-3) says

> *"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 (DOE 1999i) for the *Final Hanford Comprehensive Land-Use Plan Environmental Impact Statement* (DOE 1999h) identifies near-term land uses for the Hanford Site. The record of decision proscribes 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. In the past year, the Hanford Reach National Monument (Clinton 2000) was established along the river corridor as well in lands at the northern and western edges of the site.

However, no formal land use planning is expected to be accurate over the hundreds to hundreds of thousands of years covered in this analysis.

2.2.5 Climate and Meteorology

The information in this section is taken from *Hanford Site National Environmental Policy Act (NEPA) Characterization,* PNNL-64415, Rev. 12, Section 4.1 (Neitzel 2000-3.)

2.2.5.1 Summary. Local and regional climate patterns and projections must be considered when estimating the effect of water on the disposal 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 climate of the Pasco Basin (where the Hanford Site is located) can be classified as midlatitude semiarid or midlatitude desert, depending on the climatological classification system 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 (104 °F). Winters are cool with occasional precipitation that makes up about 44 percent of the yearly total. During the winter, outbreaks of cold air associated with modified arctic air masses can reach the area and cause temperatures to drop below -18 °C (0 °F). 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. The mountains limit the Pacific Ocean's maritime influence, making the climate of Eastern Washington drier with greater temperature extremes than the coast. In addition to this rain shadow effect, the Cascades are a source of cold air drainage, which has a considerable effect on the Site's wind regime.

The rest of this section summarizes the modern climate patterns in the Hanford Site area, the regional climate patterns of the recent past, and the possible future changes.

2.2.5.2 Current Data. Climatological data are available from the Hanford Meteorological Station (HMS), located between the 200 East and 200 West Areas at about 215 m (705 ft) elevation (See 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. The most recent summary is *Hanford Site Climatological Data Summary 1999 With Historical Data*, PNNL-13117 (Hoitink 2000).

Daily maximum temperatures vary from a normal maxima of 2°C (35°F) in late December and early January to 35°C (95°F) in late July. On the average, 52 days during the summer months have maximum temperatures of 32°C (90°F) or higher and 12 days with maxima of 38°C (100°F) or higher. From mid-November through early March, minimum temperatures average ≤0°C (32°F), with the minima in late December and early January averaging -6°C (21°F). During the winter, on average, 3 days have minimum temperatures of -18°C (~0°F) or lower; however, only about 1 winter in 2 experiences such temperatures. The record maximum temperature is 45°C (113°F), and the record minimum temperature is -31°C (-23°F). The highest winter monthly average temperature at the HMS was 6.9°C (44°F) in February 1958, while the record lowest average temperature was -11.1°C (12°F) during January 1950. The record maximum summer monthly average temperature was 27.9°C (82°F) in July 1985, while the record lowest average temperature was 17.2°C (63°F) in June 1953.

Between 1946 and 1998, annual precipitation at the HMS averaged 16 cm (6.3 in.) and varied between 7.6 cm and 31.3 cm. The wettest season on record was the winter of 1996-1997 with 141 mm (5.4 in.) of precipitation; the driest season was the summer of 1973 when only 1 mm (0.03 in.) 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 (0.5 in.) precipitation occur on average less than once each year. Rainfall intensities of 13 mm/h (0.5 in./hr) persisting for 1 hour are expected once every 10 years. Rainfall intensities of 25 mm/h (1 in./hr) for 1 hour are expected only once every 500 years.

About 38 percent of the precipitation during December through February falls as snow. Winter monthly average snowfall ranges from 0.8 cm (0.3 in.) in March to 13.5 cm (5.3 in.) in January. Only one winter in four is expected to accumulate as much as 15 cm (5.9 in.) of snow on the ground. During these winters, four days, on average, have 15.2 cm (6.0 in.) 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 (12 in.) of snow occurring in December 1964. The record accumulation of snow is 62.2 cm (24.5 in.) in February 1916.

Prevailing wind directions on the 200 Area Plateau are 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 (6 to 7 mi/hr), and highest during the summer, averaging 13 to 15 km/hr (8 to 9 mi/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 (30 mi/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.

2.2.5.3 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 and Fritts (Cropper 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 3 centuries was slightly higher by 0.09 °C (0.16°F) and more variable (4 percent higher standard deviation) than in the twentieth century. The increase was primarily attributed to warmer winters. This reconstruction also suggests that the past 3 centuries were wetter on the average by 0.8 cm (0.3 in.), 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 (Chatters 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 percent 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 percent above current levels. Warmer, drier conditions returned between 2,400 and 2,000 years ago, reducing vegetation density and renewing flooding.

2.2.5.4 Long-Range Forecasts. Future long-range forecasts of climate are uncertain. 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 (1991) reviewed 7 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.

2.2.5.5 Severe Weather. Severe weather events are not significant to the Hanford Site. According to the records of the Hanford Meteorological Station and the National Severe Storms Forecast Center's 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 (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 x 10^{-6}/y. 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/h (81 mi/h), recorded at 15 m (50 ft) above ground level at the Hanford Meteorological Station. 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 (90 mi/hr) at 15 m above ground level.

2.2.5.6 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. Scientists generally accept that, at about 50,000 years from now or later, major glaciation will occur, followed by possible flooding similar to what occurred near the end of the last glacial stage. Although considerable uncertainty is associated with future glaciation, some simulations in this performance assessment examined human health impacts associated with a resident population following flooding and redeposition after 50,000 years.

2.2.6 Ecology and Biotic Conditions

The information in this section is taken from *Hanford Site National Environmental Policy Act (NEPA) Characterization,* PNNL-64415, Rev. 12, Section 4.4 (Neitzel 2000-4).

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 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 (2000-4) 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 the proposed immobilized low-activity tank waste disposal facility sites are not located near significant aquatic ecological systems.

The Hanford Site consists of mostly undeveloped land. Chemical processing facilities, shut down nuclear reactors, and supporting facilities occupy only about 6 percent of the site. Most of the Hanford Site has not experienced tillage or agricultural grazing since the early 1940's.

The Hanford Site is characterized as a shrub-steppe ecosystem that is adapted to the region's mid-latitude semiarid climate. Such ecosystems are typically dominated by a shrub overstory with a grass understory. In the early 1800's, 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 ricegrass, and prairie Junegrass.

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 Site was designated in 1943. 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 percent are non-native. 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.

The plant community at the two ILAW disposal sites is shrub-steppe dominated by big sagebrush, Sandberg's bluegrass, and cheatgrass. Most of the new ILAW Disposal Site has this cover, but the existing disposal site has a significant fraction of area where disturbance occurred during vault construction. Appendix F of Fayer (1999) describes some of the data collected recently to characterize the plant community at these two sites.

Approximately 300 species of terrestrial vertebrates have been observed on the Hanford Site, including approximately 40 species of mammals, 246 species of birds, 4 species of amphibians, and 9 species of reptiles. Terrestrial wildlife include Rocky Mountain elk, mule deer, coyote, bobcat, badger, deer mice, harvest mice, grasshopper mice, ground squirrels, voles, and black-tailed jackrabbits. The most abundant mammal on the Site is the Great Basin pocket mouse. Bird species commonly found in the shrub-steppe habitats at the Hanford Site include the western meadowlark, horned lark, long-billed curlew, vesper sparrow, sage sparrow, sage thrasher, loggerhead shrike, and burrowing owls.

Butterflies, grasshoppers, and darkling beetles are among the more conspicuous of the approximately 1,500 species of insects that have been identified from specimens collected on the Hanford Site. The actual number of insect species living on the Hanford Site may reach as high as 15,000.

The side-blotched lizard is the most abundant reptile species that occurs on the Hanford Site. Short-horned and sagebrush lizards are reported, but occur infrequently. The most common snake species includes gopher snake, yellow-bellied racer, and Pacific rattlesnake. The Great Basin Spadefoot Toad, Woodhouse's Toad, Pacific tree frog, and bullfrogs are the only amphibians found on the Site.

Wildlife species observed at the two ILAW disposal sites include mule deer, black-tailed jackrabbits, cottontail rabbits, coyotes, side-blotched lizards, gopher snakes, sage sparrows, shrikes, meadowlarks, and horned larks.

Wildfires are frequent on the Hanford Site. Three large wildfires in the past 2 decades have burned over 15 percent of the site. However, because of fire-control measures, no fire has been on the ILAW disposal sites for at least 50 years.

No farming has occurred on the Hanford Site since the government took control of the Site. However, the Hanford Site has all the components that favor successful irrigated farming Constraints to agricultural development are political and social, not economic or technical. A report prepared by Washington State University for this performance assessment, *Evaluation of the Potential for Agricultural Development at the Hanford Site* (Evans 2000), provides many details on potential agricultural activities on the Site.

2.2.7 Regional Geology

The information in this section is based on *Geologic Data Packages for 2001 Immobilized Low-Activity Tank Waste Performance Assessment*, HNF-SD-WM-TI-707 (Reidel 1999).

2.2.7.1 Overview. Knowledge of the thickness and lateral distribution of the sediments and other geologic characteristics is required for the following reasons:

To define a conceptual model for the flow of water and the transport of contaminants from a disposal facility through the vadose zone (the zone between the surface and the groundwater that is not saturated with water) and from the unconfined aquifer (the uppermost groundwater layer) to the human environment

To define hydraulic parameters

To interpret modeling results.

The geology of the Hanford Site includes thick sequences of water-derived sediments varying in texture from cobbles and coarse gravels to fine silts and clays. These sediments overlay thick basalt flows. The top sequence or surface soil has been modified by wind. An unconfined aquifer exists in the lower part of the sedimentary sequence overlaying the uppermost basalt flow. This relatively thin aquifer is considered the primary contaminant pathway for evaluating exposure scenarios. The aquifer intercepts infiltration from the vadose (unsaturated) zone above it, providing a pathway for water and contaminant transport to users or ultimately the Columbia River.

The geological and physical settings of the Hanford Site have been extensively characterized. This section summarizes the physical geology and environmental setting of the Hanford Site and of the proposed disposal site. Emphasis is on the sedimentary sequence, which is the pathway to the groundwater. More detailed discussions of the geology of the Northwest and the Hanford Site are found in *Final Environmental Impact Statement: Disposal of Hanford Defense High-Level Transuranic and Tank Wastes* DOE (1987-1), *Consultation Draft Site Characterization Plan* DOE (1988b), *Geologic Studies of the Columbia Plateau: A Status Report*, RHO-BWI-ST-4 (Myers 1979), *Subsurface Geology of the Cold Creek Syncline*, RHO-BWI-ST-14 (Myers 1981), "Volcanism and Tectonism in the Columbia River Flood-Basalt Province" (Reidel 1989), and *Geology and Hydrology of the Hanford Site: A Standardized Text for Use in WHC Documents and Reports*, WHC-SD-ER-TI-003 (Delaney 1991).

2.2.7.2 Topography and Physiography. The proposed disposal facilities are on the Hanford Central Plateau, a Pleistocene flood bar most commonly referred to as the 200 Areas Plateau, near the center of the Hanford Site. The Hanford Central Plateau is approximately 198 m (650 ft) to 229 m (750 ft) above mean sea level. The plateau decreases in elevation to the north, northwest, and east toward the Columbia River. The plateau escarpments have elevation changes of 15 m to 30 m (50 to 100 ft).

The Hanford Site is situated within the Pasco Basin of south-central Washington State (Figure 2-5). The Pasco Basin is one of many topographic depressions located within the Columbia Intermontane Province (Figure 2-6), a broad basin located between the Cascade Range and the Rocky Mountains. The Columbia Intermontane Province is the product of Miocene continental flood, basalt volcanism, and regional deformation. The Pasco Basin is bounded on the north by the Saddle Mountains; on the west by Umtanum Ridge, Yakima Ridge, and the Rattlesnake Hills; on the south by the Horse Heaven Hills; and on the east by the Palouse Slope (Figure 2-5).

The physical geography of the Hanford Site is dominated by the low-relief plains of the Pasco Basin and anticlinal ridges of the Yakima Folds physiographic region. The surface topography of the Hanford Site is the result of the following events:

- Uplift of anticlinal ridges
- Pleistocene cataclysmic flooding
- Holocene eolian activity.

Uplift of the ridges began in the Miocene epoch (starting about 17 million years ago) and continues to the present. This uplift is occurring on geologic time scales (i.e., over tens of millions of years). The uplift is not incorporated into our conceptual model of the immobilized low-activity tank waste disposal facilities, which addresses a time scale of tens of thousands of years.

Glacier-related flooding has had a major impact on the physical geography. Cataclysmic flooding occurred when ice dams in western Montana and northern Idaho were breached, allowing large volumes of water to spill across eastern and central Washington. The last major flood occurred about 13,000 years ago, during the late Pleistocene Epoch. Interconnected flood channels, giant current ripples, and giant flood bars are among the landforms created by the floods. These formations resulted in heterogeneous and discontinuous characteristics for sediments ranging in size from silts to coarse gravels. These sediments yield a wide range of vadose zone hydraulic properties.

Figure 2-5. Geologic Structures of the Pasco Basin and the Hanford Site.

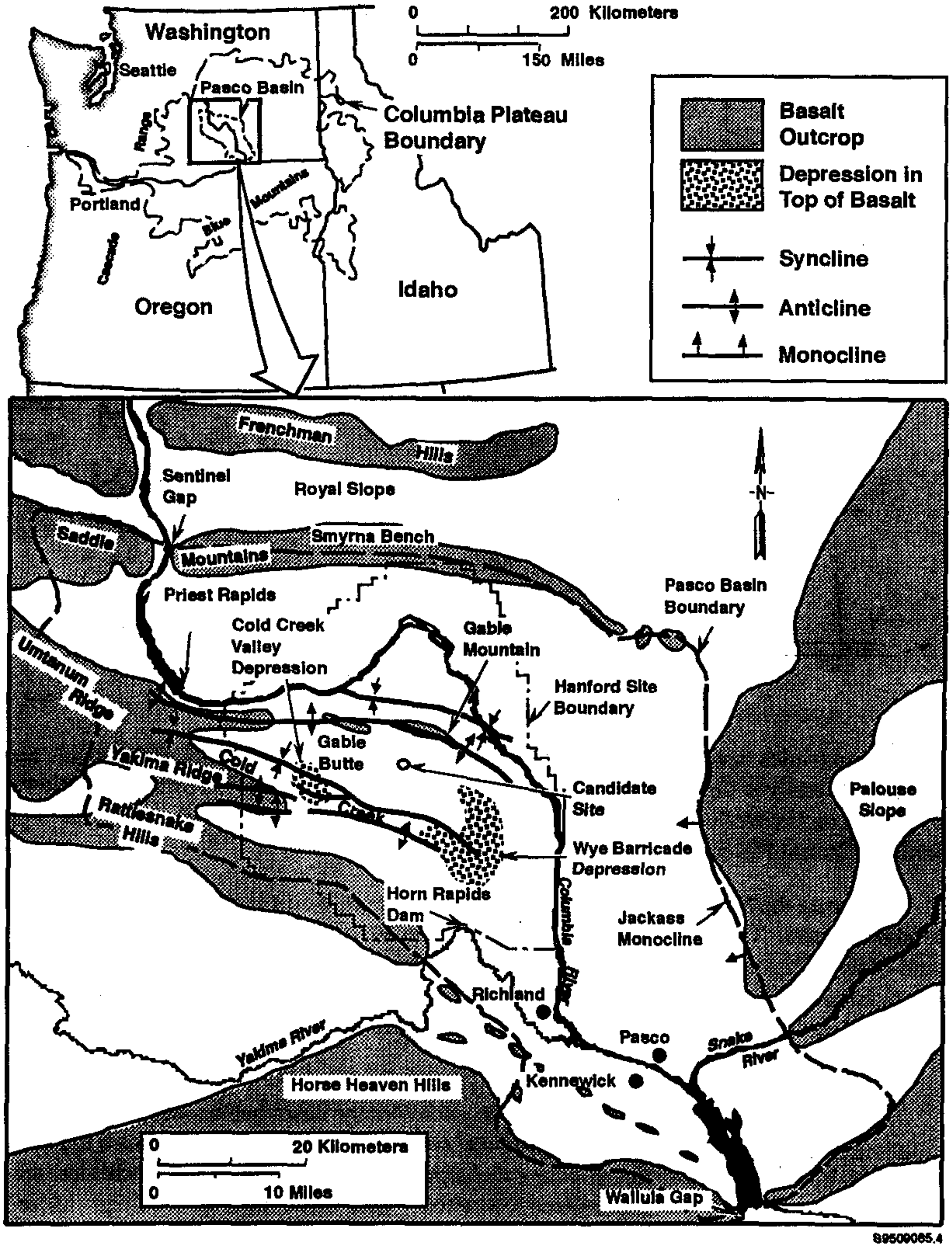
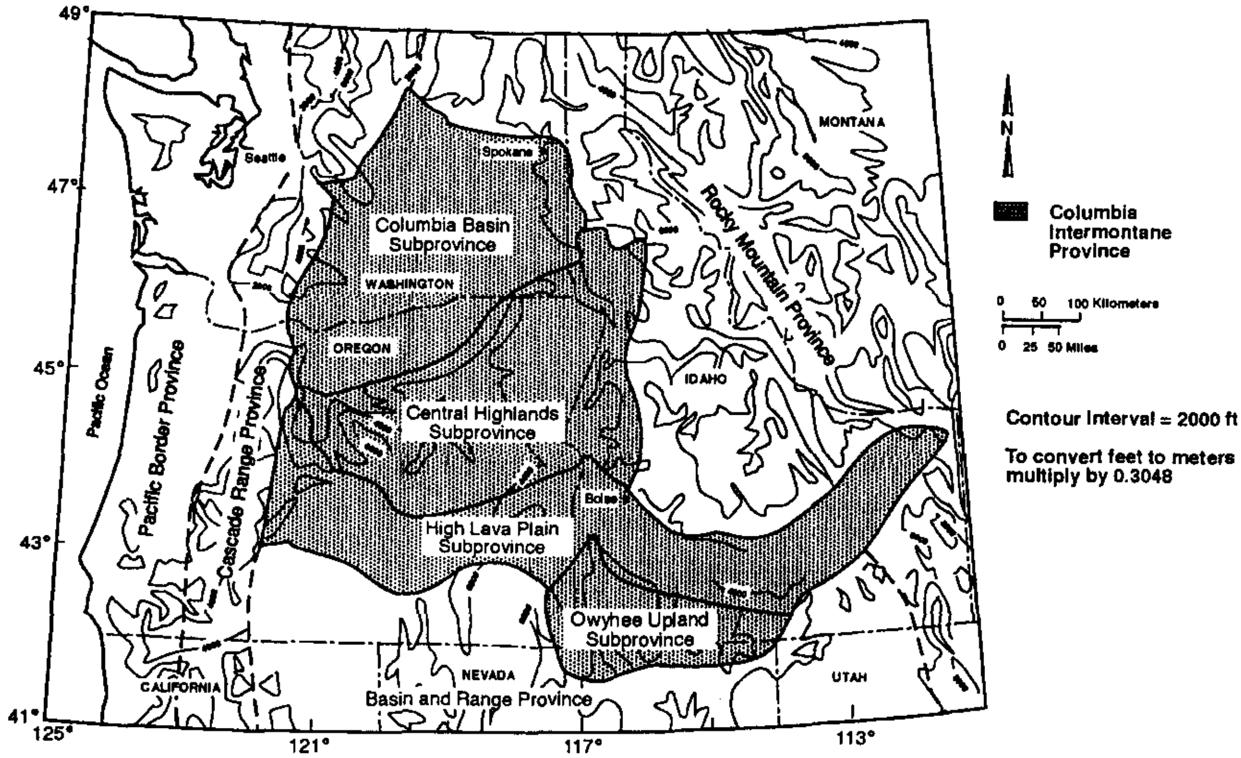


Figure 2-6. Divisions of the Intermontane Physiographic and Adjacent Snake River Plains Provinces.



Landslides have had a limited effect on physical geography. Previous landslide activity in the area generally is limited to the White Bluffs area east of the Hanford Site and Rattlesnake Mountain, on the western edge of the Hanford Site. No landslide activity is observed in the Hanford Central Plateau.

During the Holocene Epoch (the last 11,000 years), winds have locally reworked the flood sediments. The winds deposited dune sands in the lower elevation and loess (very fine wind-blown silts) around the margins of the Pasco Basin. Generally, anchoring vegetation has stabilized sand dunes. However, they have been reactivated where vegetation has been disturbed. Most sand dunes on the Hanford Site are located southeast of the 200 East Area and are stabilized by vegetation.

The location of the Hanford Site in an intermontane basin helps maintain a semiarid climate with low recharge. Most topographical surface features that could disturb the near-surface hydraulic characteristics affecting recharge, such as sand dunes and landslides, are not found at the location of the immobilized low-activity tank waste disposal facilities. Moreover, sand dunes are indicators of past, cumulative wind directions. Their location approximately downwind of the new disposal facility site suggests that future dune formation over the facility is not likely.

2.2.7.3 Stratigraphy. The stratigraphy or geologic layering is not extremely complex in the Hanford Site region. Late Miocene to Pleistocene suprabasalt sediments (2 to 5 million years old) and Miocene-aged basalt (16 to 17 million years old) of the Columbia River Basalt Group lie beneath the Hanford Site. Miocene-aged basalt is exposed at some locations, including Gable Mountain and Gable Butte. The basalts and sediments thicken into the Pasco Basin and generally reach maximum thickness in the Cold Creek syncline, which is southwest of the disposal facility sites. Cenozoic (25 to 65 million years old) sedimentary and volcaniclastic rocks underlying the basalts are not exposed at the surface near the Hanford Site.

Table 2-1 delineates the general stratigraphy of the suprabasalt sedimentation that makes up the vadose zone sediments beneath the locations of the disposal facilities. This table illustrates the degree of heterogeneity and discontinuity in the sediments. The sedimentation is composed largely of Ringold Formation and Hanford formation sediments, with the Hanford formation above the Ringold Formation. At the disposal facility sites, the Hanford formation makes up most of the vadose zone.

Table 2-1. Stratigraphy of the200 East Area.

Nomenclature Used in this Report		Equivalent of Lindsey (1994a), Lindsey (1996), and Reidel (1992)	Equivalent of Reidel (1994a, 1994b)
Eolian			Qd
Hanford formation		H	Qfs and Qfg
Sandy Sequence	Layer 3	H2	Qfs_3
	Layer 2	H2	Qfs^2
	Layer 1	H2 and HZA	Qfs_1(?)
Basal Gravel Sequence		H3	Qfs_1(?)
Ringold Formation, Member of Wooded Island		Ringold Formation, Member of Wooded Island	P_L~~M~~
	Unit E	Unit E	P_L~~M~~-cg
	Lower Mud	Lower Mud	P_L~~M~~-c
	Unit A	Lower A	P_L~~M~~-cg

? indicates an uncertain assignment
P_L relates to Pleistocene era
~~M~~ relates to Miocene

The suprabasalt sedimentary sequence at the Hanford Site is about 230 m (750 ft) thick in the west central Cold Creek syncline. This sedimentary sequence pinches out against the Saddle Mountains anticline, Gable Mountain/Umtanum Ridge anticline, Yakima Ridge anticline, and Rattlesnake Hills anticline. The suprabasalt sediments are dominated by laterally extensive deposits assigned to the late Miocene- to Pliocene-aged Ringold Formation and the Pleistocene-aged Hanford formation (Table 2-1). Locally occurring strata assigned to the informally defined Plio-Pleistocene unit and pre-Missoula gravels compose the remainder of the sequence.

The following sections describe the geology of the Ringold Formation and the Hanford formation sediments in some detail. These sediments are the basis for determining vadose zone hydraulic and geochemical properties for contaminant transport modeling.

2.2.7.3.1 Ringold Formation. The Ringold Formation varies in thickness throughout the Hanford Site. It is up to 183 m (600 ft) thick in the deepest part of the Cold Creek syncline south of the 200 West Area and 170 m (560 ft) thick in the western Wahluke syncline near the 100 B Area. It pinches out against the Gable Mountain, Yakima Ridge, Saddle Mountains, and Rattlesnake Mountain anticlines (Figure 2-5). It is mostly absent in the northern and northeastern parts of the 200 East Area and adjacent areas to the north near West Pond.

The Ringold Formation consists of fluvial and lacustrine sediments deposited by the ancestral Columbia and Clearwater-Salmon river systems between about 3.4 and 8.5 million years ago. Lindsey (1996) described the Ringold Formation in terms of three informal members: the member of Wooded Island, the member of Taylor Flat, and the member of Savage Island. Of these, only the member of Wooded Island is present beneath the 200-East Area.

The member of Wooded Island consists of five separate units dominated by fluvial gravels (conglomerate). The gravels are designated (from bottom to top) as units A, B/D, C, and E. Fine-grained deposits typical of overbank and lacustrine environments separate the gravel units. The lowermost of the fine-grained sequences is designated the lower mud unit. Only gravel units A and E are present beneath the 200-East Area and the Ringold Formation is entirely absent beneath the north and northeast parts of the 200-East Area (Lindsey 1992, 1994b).

The Ringold Formation conglomerate is a variably indurated clast- and matrix-supported, pebble to cobble gravels with a fine to coarse sand matrix (Lindsey 1996). The most common lithologies are basalt, quartzite, and intermediate to felsic volcanics. Interbedded lenses of silt and sand are common. Cemented zones within the gravels are discontinuous and of variable thickness. In outcrop, the gravels are massive, planer bedded, or cross-bedded. Lying above the Ringold gravels are silts and sands of the upper Ringold, the member of Taylor Flats, which is not generally present beneath the 200-East Area.

2.2.7.3.2 Hanford Formation. The Hanford formation (an informal designation) is up to 64 m (210 ft) thick in the Cold Creek bar near the 200 Areas. It is absent on ridges approximately 360 m (1,180 ft) above sea level.

The Hanford formation overlies the Ringold Formation. The Hanford formation consists of glaciofluvial sediments deposited by cataclysmic floods from Glacial Lake Missoula, Pluvial Lake

Bonneville, and ice-margin lakes. Hanford formation sediments resulted from at least four major glacial events and were deposited between about 1 million years and 13 thousand years ago. The formation consists of pebble to boulder gravel, fine- to coarse-grained sand, and silt to clayey silt. These deposits are divided into three facies: gravel-dominated facies, sand-dominated facies, and silt-dominated facies (Reidel 1992; Lindsey 1992, 1994a, 1994b). These facies are referred to as coarse-grained deposits, plane-laminated sand facies, and rhythmite facies, respectively, in Bjornstad (1987) and Baker (1992). The Hanford formation is present throughout the Hanford Site and is as much as 380 ft (116 m) thick (Delaney 1991).

Gravel-Dominated Facies. This facies generally consists of coarse-grained basaltic sand and granule to boulder gravel. These deposits display an open framework texture, massive bedding, plane to low-angle bedding, and large-scale planar cross bedding in outcrop. Silt content is variable and local interbedded silt and clay have been observed in outcrop. Clay and silt have been found as coatings on clasts but generally not filling open spaces between clasts. The gravel-dominated facies was deposited by high-energy floodwaters in or immediately adjacent to the main cataclysmic flood channelways.

Sand-Dominated Facies. This facies consists of fine- to coarse-grained sand and granule gravel. The sands typically have high basalt content and are commonly referred to as black, gray, or salt-and-pepper sands (Lindsey 1992). They may contain small pebbles and rip-up clasts, pebble-gravel interbeds, and silty interbeds less than 1 m (3 ft) thick. The silt content of the sands varies, but where it is low, a well-sorted and open framework texture is common. The sand facies was deposited adjacent to main flood channelways during the waning stages of flooding. The facies is transitional between the gravel-dominated facies and the silt-dominated facies.

Silt-Dominated Facies. This facies consists of thin bedded, plane-laminated, and ripple cross-laminated silt and fine- to coarse-grained sand. Beds are typically a few centimeters to several tens of centimeters thick and commonly display normal grading (Myers 1979; Bjornstad 1987; DOE 1988b). Local clay-rich beds occur in the silt-dominated facies and paleosols have been observed in cores from the 200-East Area. Sediments of this facies were deposited under slack water conditions and in back flooded areas (DOE 1988b).

2.2.7.3.3 Clastic Dikes. Clastic dikes are vertical to subvertical sedimentary structures that cross cut normal sedimentary layering and could effect the vertical movement of water and contaminants. Clastic dikes are a common geologic feature of Pleistocene flood deposits of the Hanford formation although they also have been found in the underlying Ringold Formation and in Columbia River Basalt Group and intercalated sedimentary interbeds. Clastic dikes on the Hanford Site have been described in detail by Fecht (1998).

Clastic dikes typically occur in swarms and occur as regularly shaped polygonal patterns; irregularly shaped polygonal patterns; preexisting fissure fillings; and random occurrences. Regular polygonal networks resemble 4- to 8-sided polygons. Dikes in irregular-shaped polygon networks generally are crosscutting in both plane and cross-section, resulting in extensive segmentation of the dikes. Clastic dikes often occur in zones of preexisting weakness.

Clastic dikes typically show a wide range in widths, depths, and lengths. The vertical extent of clastic dikes has been observed to range from 30 cm to greater than 55 m. Clastic dike widths ranges from about 1 mm to greater than 2 m and their length varies from as little as 0.3 m to more than 100 m.

In general, a clastic dike is composed of an outer skin of clay with coarser infilling material. Clay linings are commonly 0.03 mm to 1.0 mm thick, but linings up to about 10 mm are known. The clay skins may have a great influence on transport both within and adjacent to the clastic dikes. The width of individual infilling layers range from as little as 0.01 mm to more than 30 cm and their length can vary from about 0.2 m to more than 20 m. Infilling sediments are typically poor to well-sorted sand, but may contain clay, silt, and gravel.

Clastic dikes have been noted in the Hanford formation sand sequence in the existing disposal site (Lindberg 1993) and are suspected to occur but have not been identified at the new disposal site. At the existing disposal site, clastic dikes have not been mapped and their number and distribution are not known. Clastic dikes have been found in numerous locations on the 200 Area plateau where they occur primarily in polygonal networks with dimensions ranging from 30 to 240 m (Fecht 1998). The total depth of the clastic dikes in the existing disposal site also is unknown, but they extend below the bottom of the excavations for the former Grout Treatment Facility (Lindberg 1993).

2.2.7.3.4 Surficial Deposits. Holocene surficial deposits consist of silt, sand, and gravel that form a veneer less than 4.9 m (16 ft) thick atop much of the Hanford Site. These sediments were deposited by wind and local flood processes.

2.2.7.4 Soils. Hajek (1966) lists and describes the 15 different soil types on the Hanford Site, varying from sand to silty and sandy loam. The following soils are found in the south-central part of the 200 East Area:

Burbank Loamy Sand. This soil is dark-colored, coarse-texture soil underlain by gravel. Surface soil is usually about 40 cm (16 in.) thick but can be 76 cm (30 in.) thick. Gravel content of the subsoil ranges from 20 to 80 percent.

Ephrata Sandy Loam. The surface is dark colored and subsoil is dark grayish-brown medium-texture soil underlain by gravelly material, which may continue for many feet.

Rupert Sand. This soil is brown to grayish brown coarse sand grading to dark grayish-brown at about 90 cm (35 in.). Rupert sand developed under grass, sagebrush, and hopsage in coarse sandy alluvial deposits that were mantled by wind-blown sand.

2.2.7.5 Earthquakes. Seismic events can accelerate the degradation of a disposal facility and of the waste form.

2.2.7.5.1 Faults and History of Earthquakes. The Hanford Site lies in the Pasco Basin near the eastern limit of the Yakima Foldbelt. The Site is underlain by basalt of the Columbia River Basalt Group, which is covered by up to 213 m (700 ft) of relatively stiff sediments. It is in an area of low-magnitude seismicity and is under north-south compressional stress, which is reflected in the deformation of the Yakima folds. The following sources are major contributors to the seismic hazard in and around the Hanford Site:

Fault sources related to the Yakima folds

Shallow basalt sources that account for the observed seismicity within the Columbia River Basalt Group and are not associated with the Yakima Folds

Crystalline basement source region

Cascadia Subduction Zone earthquakes.

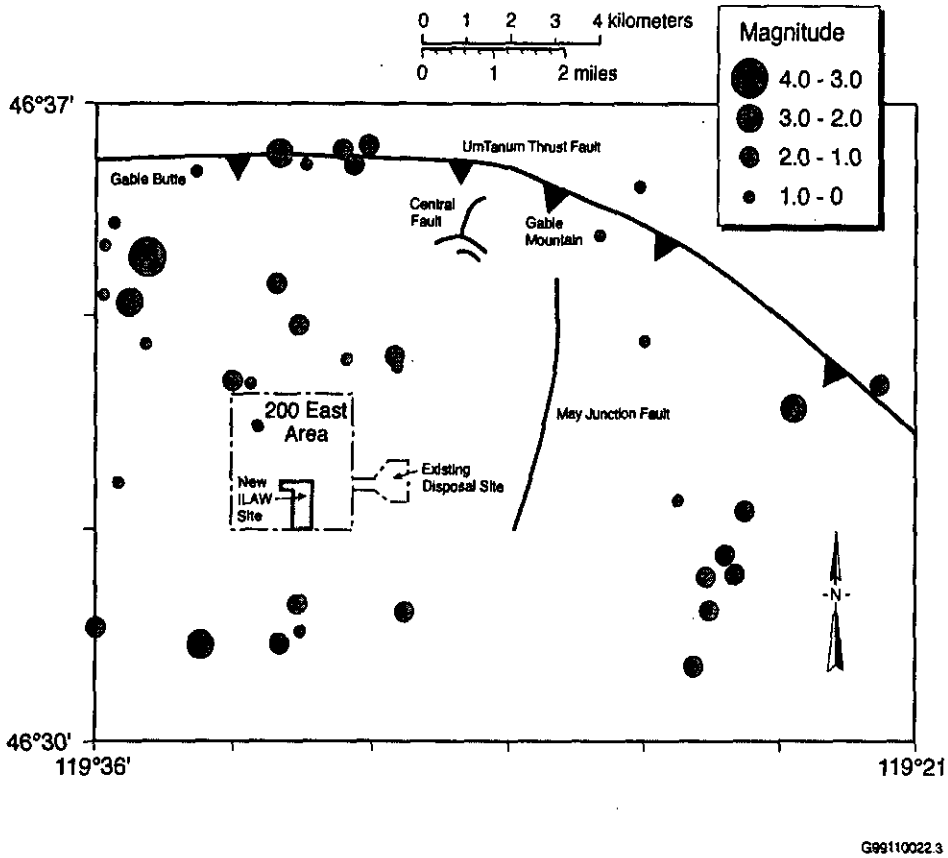
Earthquake activity at the new and existing disposal sites is typical of the Hanford Site. Figure 2-7 shows the location of earthquakes that have occurred near the 200-East Area since monitoring began at the Hanford Site in 1969. Most of the earthquakes have been less than coda magnitude 3.0. Coda magnitude is a local magnitude and is an estimate of the Richter magnitude. Thirty-three percent of the earthquakes shown on 2-7 occurred in the Columbia River Basalt Group. Sixteen percent were in the subbasalt sediments and 51 percent were in the crystalline basement.

The principal geologic structures described in *Geologic Map of the Richland 1:100,000 Quadrangle, Washington*, Open File Report 94-8 (Reidel 1994a), are reproduced in Figure 2-7. Comparing the location of earthquakes to the geologic structures shows no apparent pattern.

The largest historical earthquake in the Columbia Plateau occurred in 1936 near Milton-Freewater, Oregon, approximately 90 km (54 mi) east of the site. The earthquake had a magnitude of 5.75 and was followed by a number of aftershocks. The ground motion from this event is estimated to have been less than 0.03 g at the Hanford Site.

A seismic monitoring network has been operated in and around the Site since 1969. The network, operated by DOE, can locate all earthquakes of magnitude 1.5 and larger on or near the Hanford Site, and those of magnitude 2.0 and larger throughout south-central and south-eastern Washington State. The largest recorded earthquake on the Hanford Site had a magnitude of 3.8 near Coyote Rapids in 1971 and was felt in the 100 N Area.

Figure 2-7. Map Showing the Location of Earthquakes Detected From 1969 to 1999.



2.2.7.5.2 Seismic Hazard Assessment. This section explains the earthquake ground motions that the facility is expected to experience during the performance period. Deformation and cracking from earthquake ground motion may physically degrade the engineered system.

A probabilistic seismic hazard analysis was recently completed for the Hanford Site (Geomatrix 1996). Previous seismic hazard analyses were done for Energy Northwest's WNP-1/4 and WNP-2, which also are located on the Hanford Site (Power 1981). Woodward Clyde Consultants (WCC 1989) later applied the Energy Northwest study to the Hanford Site areas under DOE control. The mean seismic hazard curves for the 200 West, 200 East, and 400 Areas are shown in Figure 2-8. The 200 West Area ground motion values are shown for the selected time period in Table 2-2. (See Geomatrix [1996] for details including response spectra).

Table 2-2. Approximate Probability of Exceeding Given Ground Motions During Selected Time Periods.

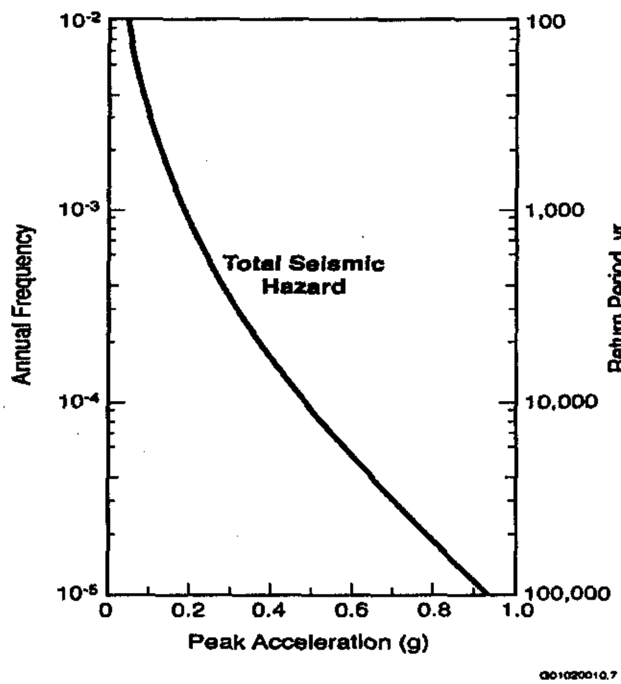
Ground Motion (g)		Return Period (Years)	Annual Probability of Exceedence (p)	Exceedence Probability (EP)[a] over 50 years (%)	EP over 1,000 years (%)	EP over 10,000 years (%)
Horizontal	Vertical					
0.19	0.11	1,000.0	$1 X 10^{-3}$	5.0	63	100
0.26	0.16	2,000.0[b]	$5 X 10^{-4}$	2.0	39	99
0.37	0.25	5,000.0	$2 X 10^{-4}$	1.0	18	86
0.48	0.33	10,000.0	$1 X 10^{-4}$	0.5	10	63

[a] EP = $1-(1-p)^n$ where

p = the annual probability of exceedence,
n = the performance life
EP = the probability of exceedence over the performance life.

[b] Performance Category 3, DOE Order 5480.28.

Figure 2-8. Total Mean Seismic Hazard for 200 Area Plateau, Hanford Site.



2.2.7.6 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 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.

2.2.8 Geology of the Proposed Immobilized Low-Activity Tank Waste Disposal Facility Locations

The information in this section is based on *Geologic Data Packages for 2001 Immobilized Low-Activity Tank Waste Performance Assessment*, HNF-SD-WM-TI-707 (Reidel 1999).

2.2.8.1 Previous Studies. The ILAW disposal site is an area where no previous construction or disposal sites exist so no major geologic studies have been carried out there. Studies relevant to the site are summarized in Tallman (1979), DOE (1988b), Lindsey (1992, 1994a, 1994b, 1996), and Reidel (1998a, 1998b). The first major activity was drilling borehole 299-E17-21 in 1998 at the southwest end of the site and obtaining the first high-quality data from the area [Reidel 1998a and Reidel 1998b].

2.2.8.2 Site Stratigraphy. The stratigraphy at the ILAW disposal site consists of the Hanford formation and Ringold Formation overlying the Columbia River Basalt Group. Surfacial sediments are mainly eolian deposits consisting of reworked Hanford formation sands and silts.

The stratigraphy and the stratigraphic model developed for this study is based on the boreholes depicted in Figure 2-9 and summarized in Table 2-1 and Figures 2-10, 2-11, and 2-12. This diagram is based on more detailed cross sections (Figures 2-13 through 2-16). Figure 2-11 represents a summary diagram for stratigraphy, west to east, across the middle southern part of the disposal site (between boreholes 299-E-18-1 and 299-E24-17 (see Figure 2-9). Figure 2-13 represents a summary diagram for stratigraphy, northwest (NW) to southeast (SE), across the northern part of the disposal site (between boreholes 299-E33-1 and 299-E24-17 (see Figure 2-9).

Figure 2-9. Map Showing Borehole Locations in the New ILAW Disposal Site.

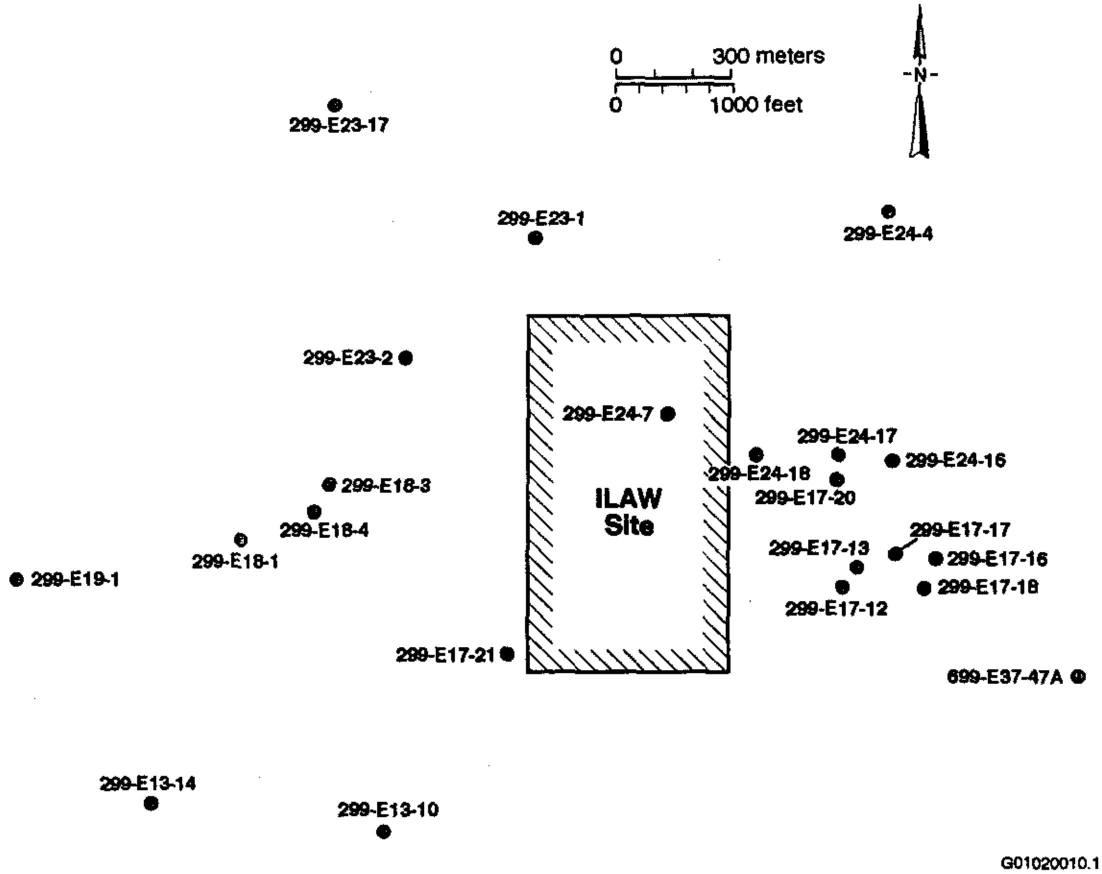


Figure 2-10. Fence Diagram of the ILAW Disposal Site and Vicinity.

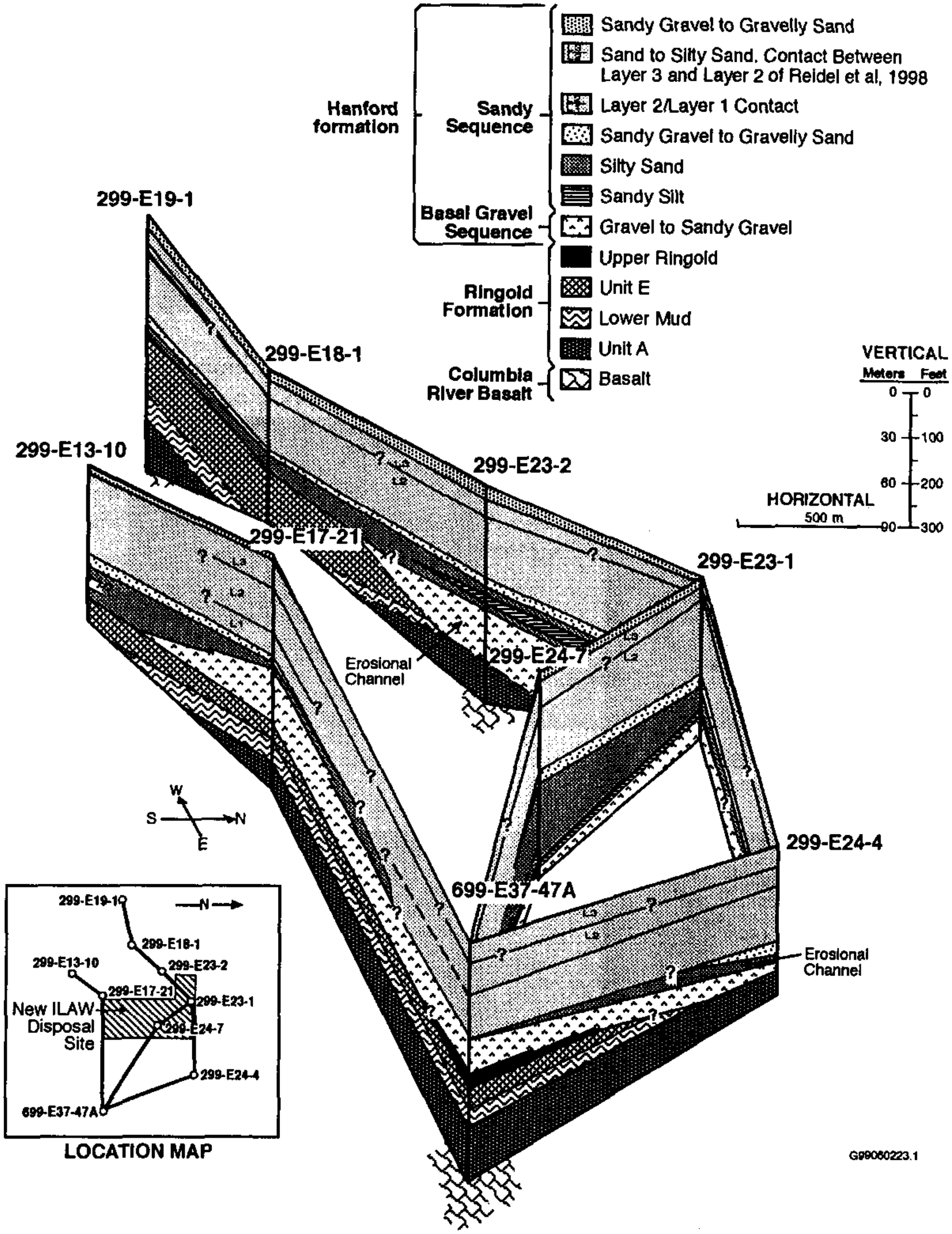


Figure 2-11. Summary Diagram of a West to East Cross-Section for the New ILAW Disposal Site.

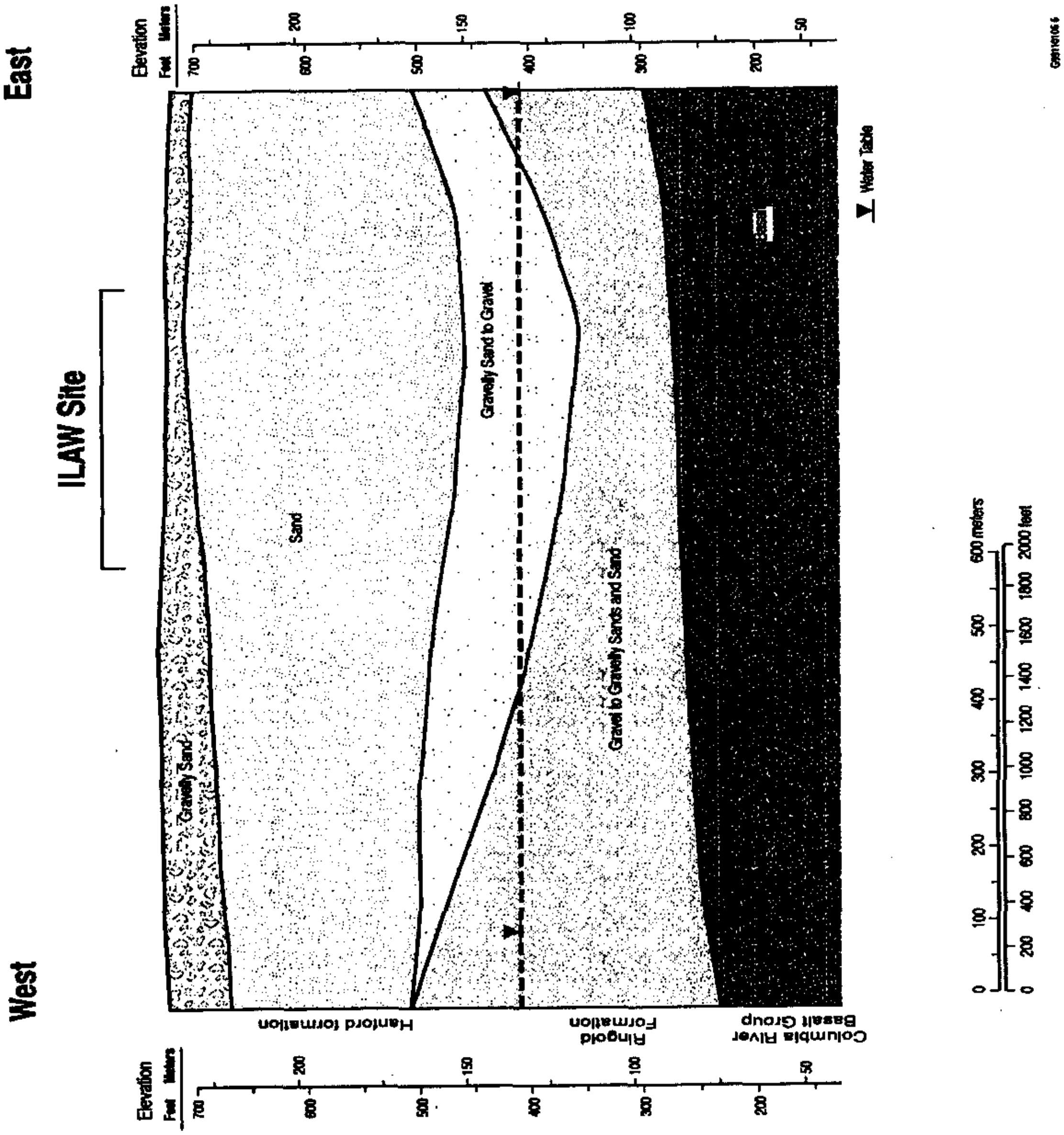


Figure 2-12. West to East (Southern Section) Cross-Section for the ILAW Disposal Site.

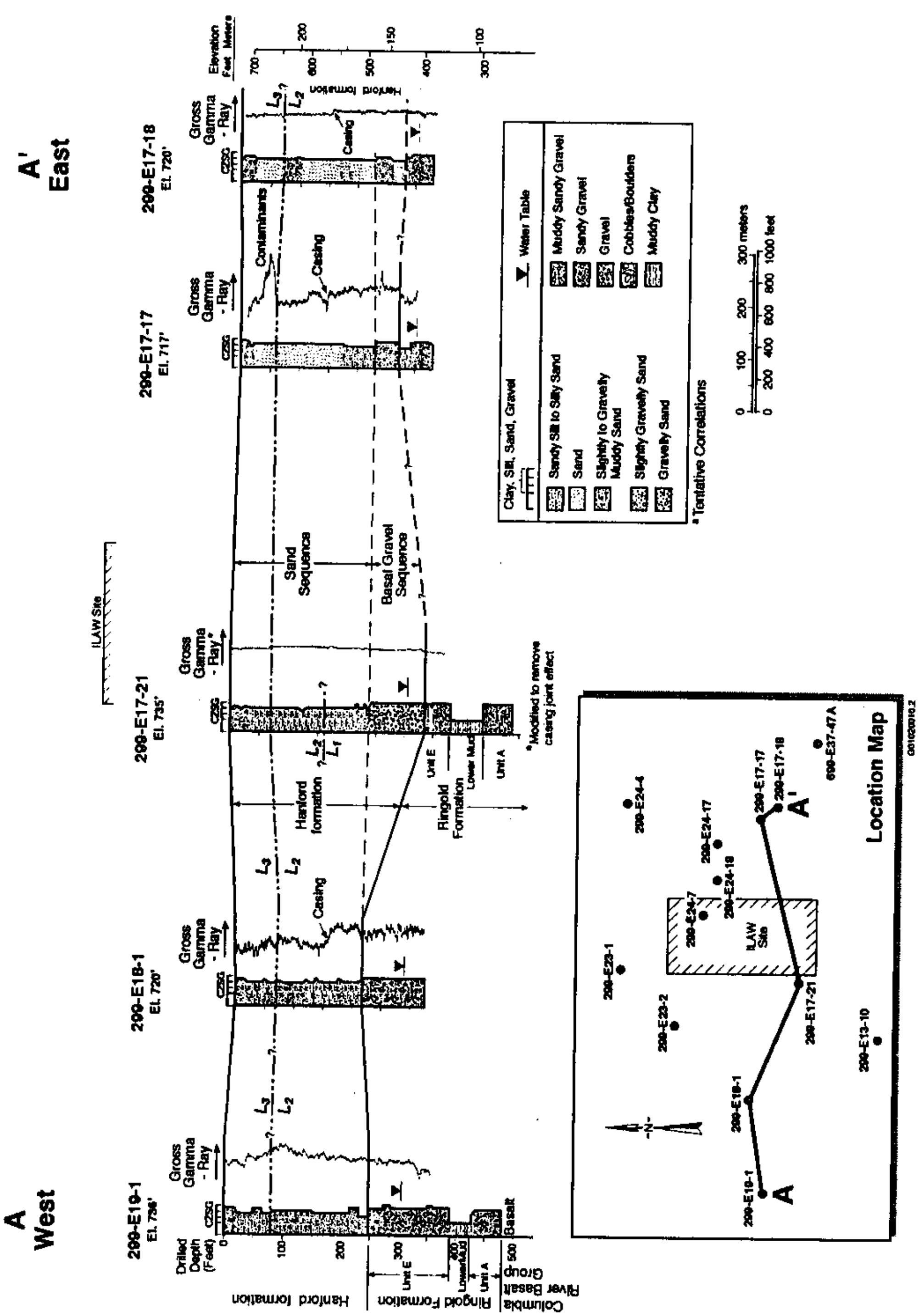


Figure 2-13. West to East (Northern Section) Cross-Section Across the ILAW Disposal Site.

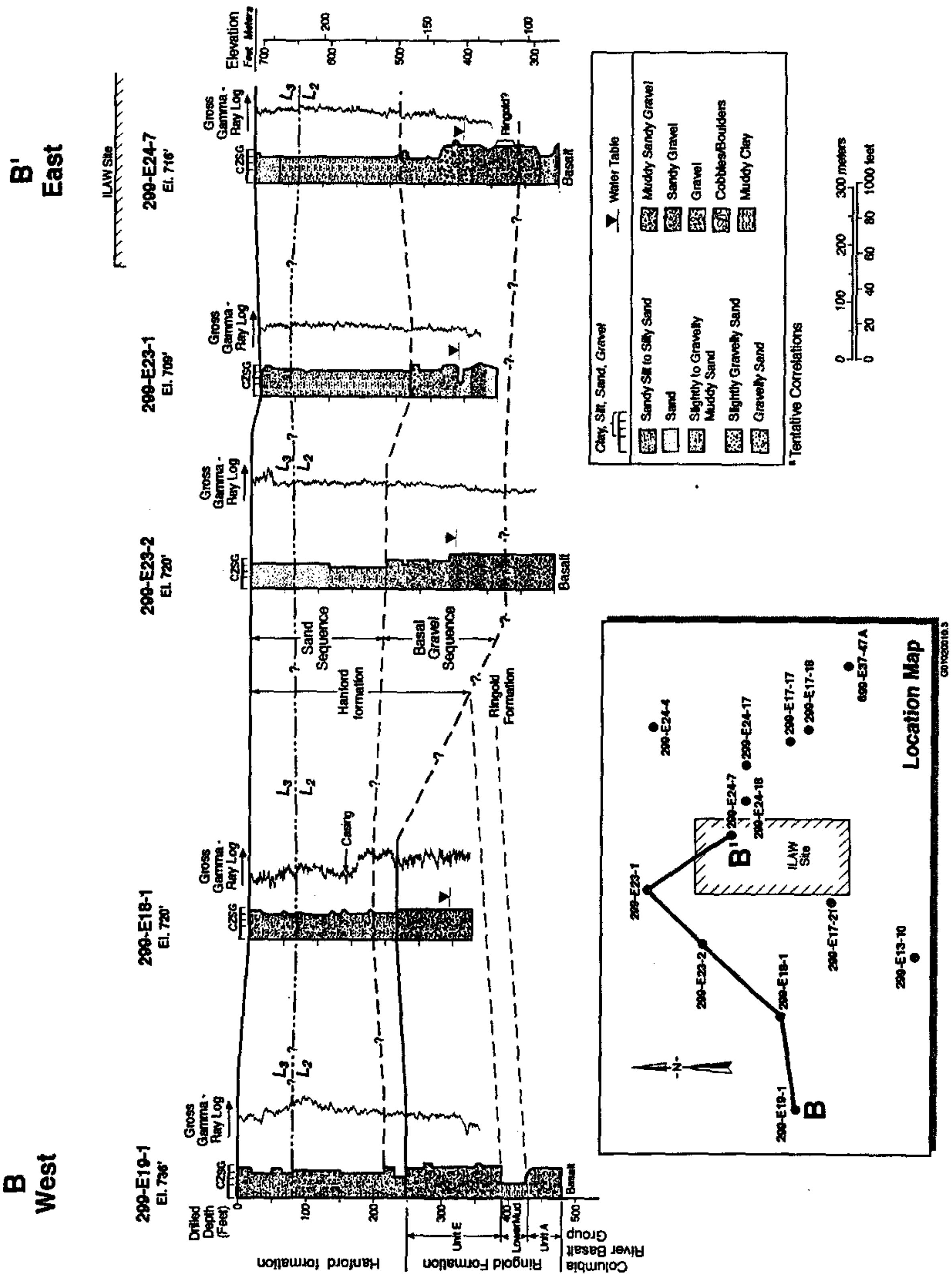


Figure 2-14. Alternate West to East Cross-Section Across the New ILAW Disposal Site.

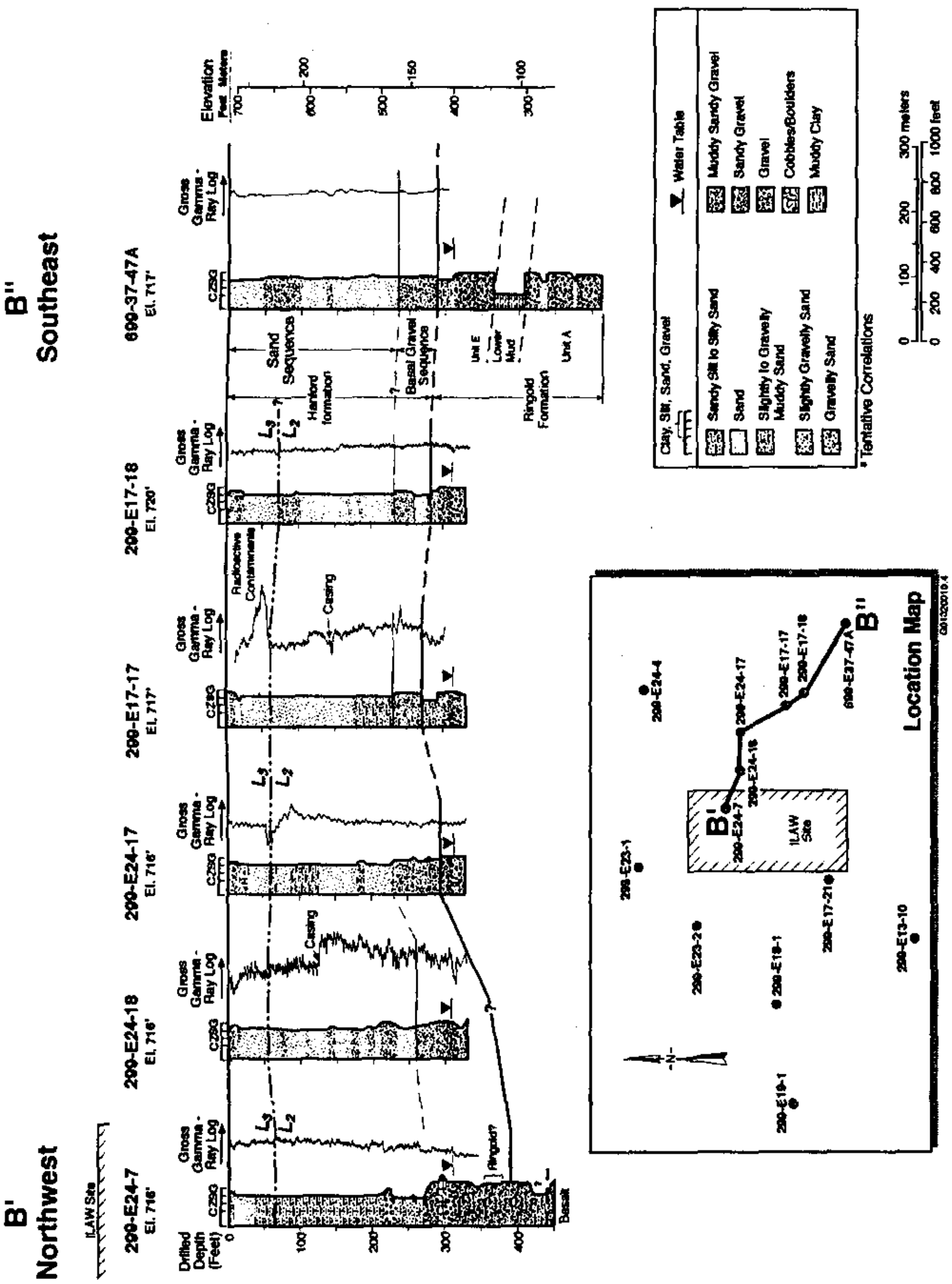


Figure 2-15. Southwest to Northeast Cross-Section Across the ILAW Disposal Site.

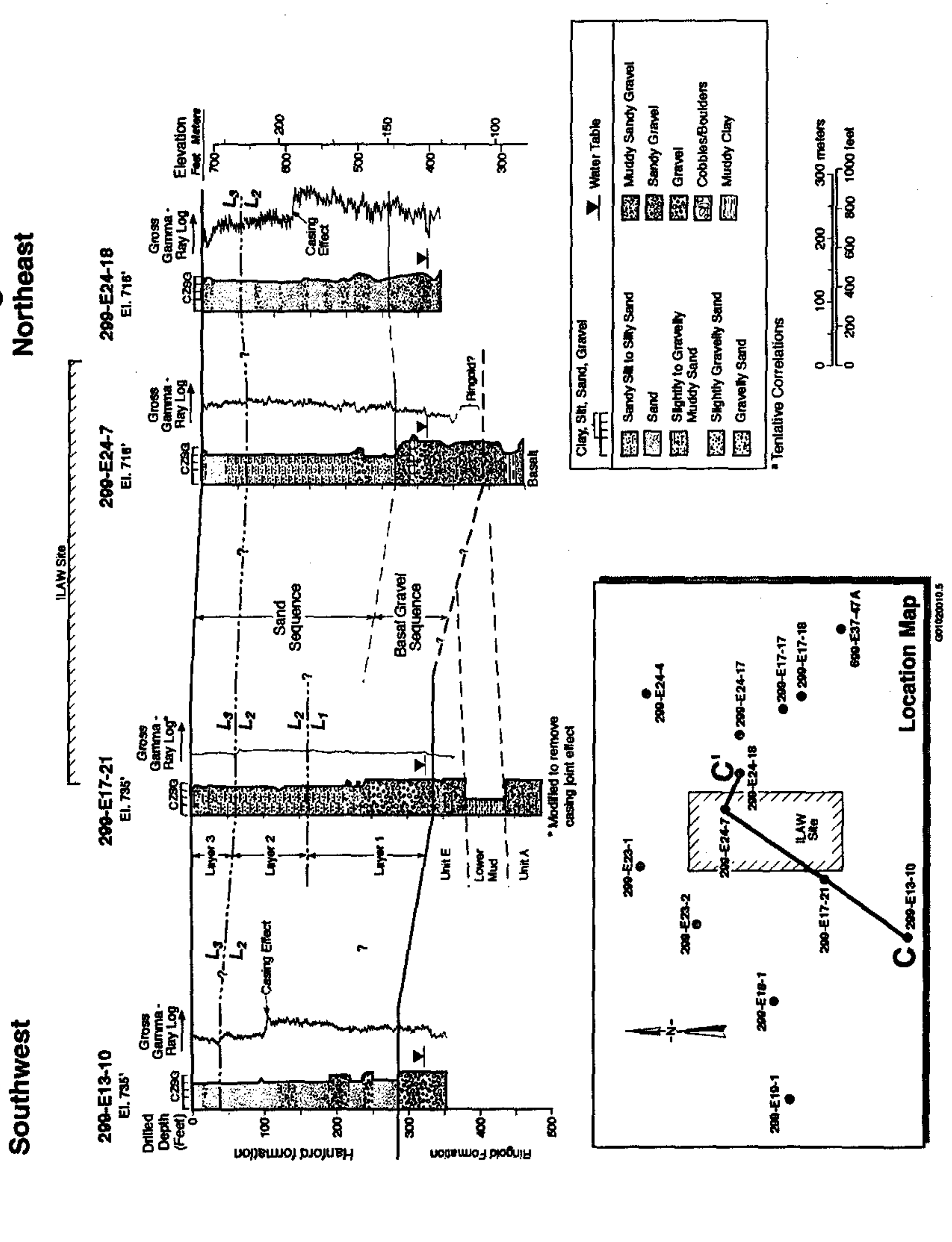
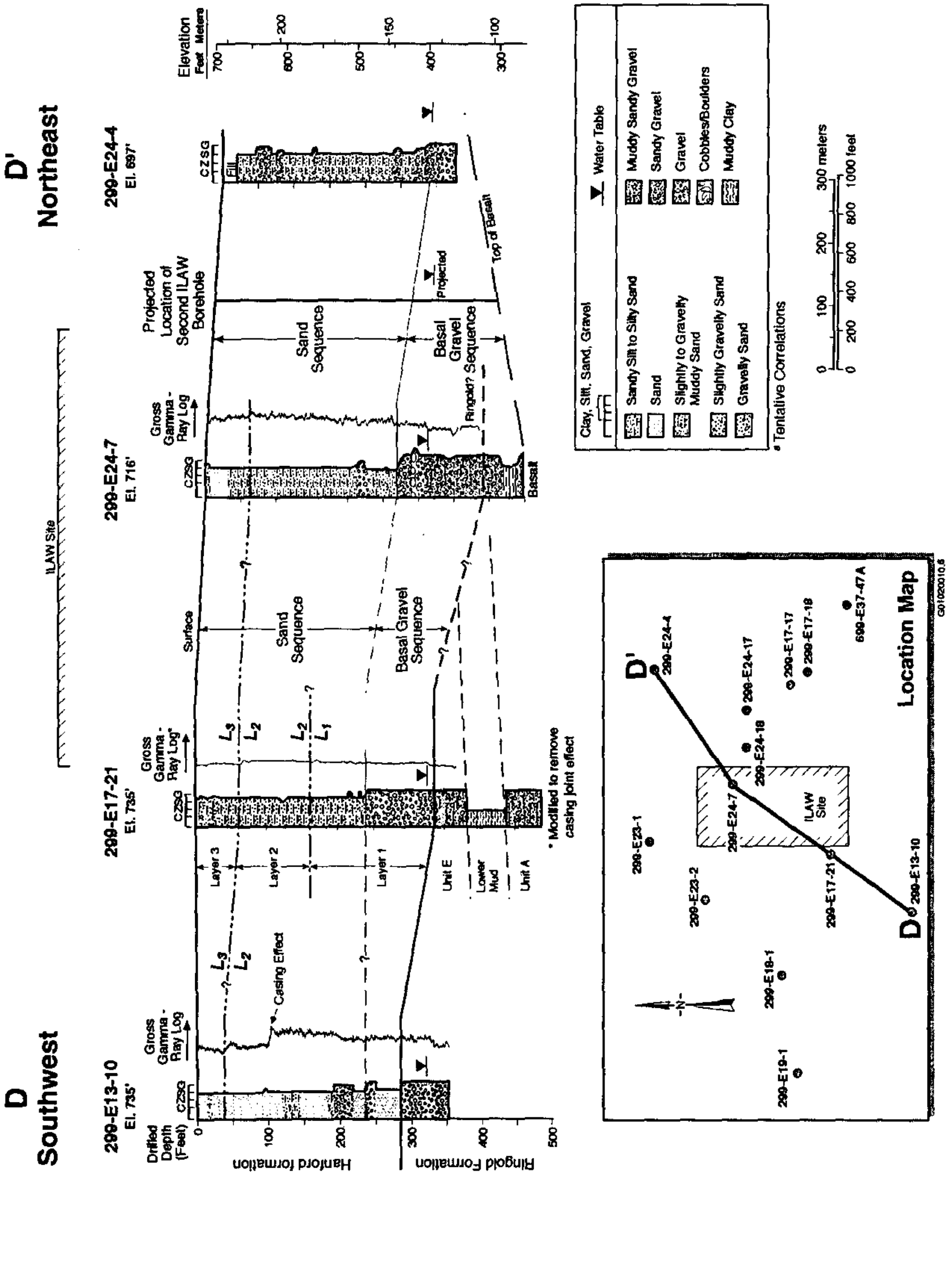


Figure 2-16. Alternate Southwest to Northeast Cross-Section Across the ILAW Disposal Site.



The stratigraphy of the new ILAW disposal site is divided from youngest to oldest into the following units:

Eolian deposits

Hanford formation, sandy unit (H2 of Lindsey 1994b)

-Layer 3 (extends into upper gravelly unit)
-Layer 2
-Layer 1

Hanford formation, basal gravel units (H3 of Lindsey 1994b)

Ringold Formation

-Unit E
-Lower Mud
-Unit A

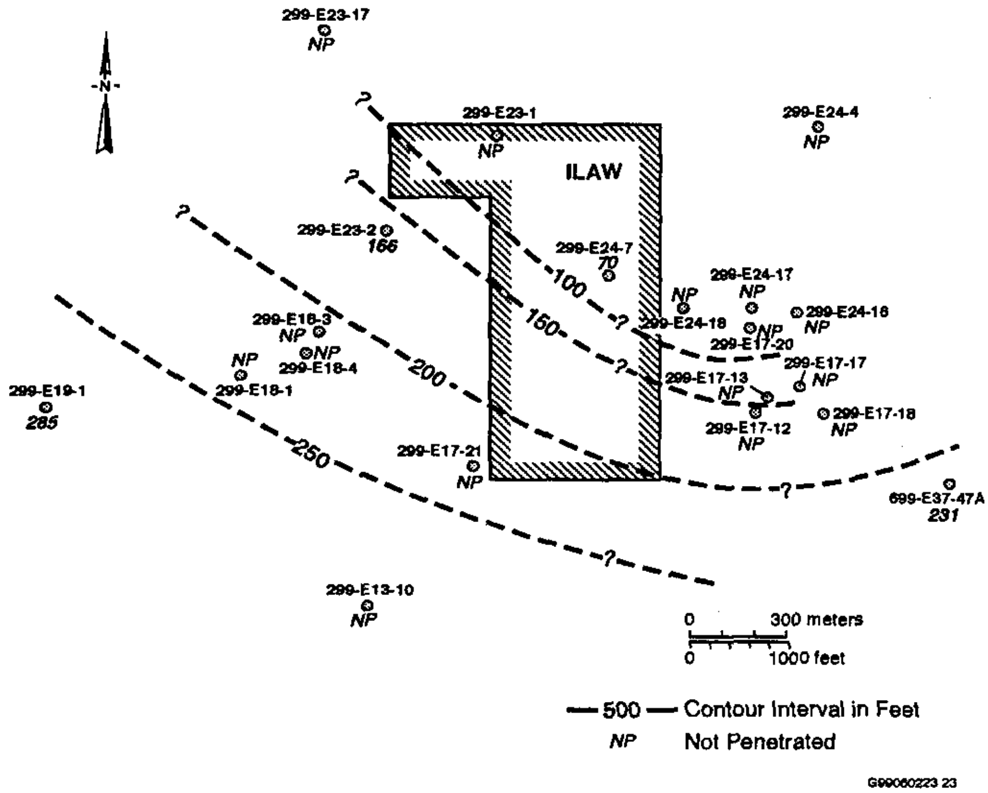
Columbia River Basalt Group.

Sequences of sandy gravels to gravelly sands (G1, G2, G3, G4) and sand to silty sand units (S, S1, S2, S3) can be recognized in the Hanford formation layers (Table 2-1) but correlation across the area is tentative at this time because of the distance between boreholes, the poor quality of some data, and the local nature of thin units in the Hanford formation. Additional boreholes will be necessary to verify these correlations.

2.2.8.3 Columbia River Basalt Group. Previous studies (DOE 1988b; Reidel 1994a) have shown that the youngest lava flows of the Columbia River Basalt Group at the 200-East Area are those of the 10.5 million-year old Elephant Mountain Member. The Elephant Mountain Member is continuous beneath the new disposal site. No erosional windows are known or suspected to occur in the new ILAW disposal site area.

2.2.8.4 Ringold Formation. Because few boreholes penetrate much of the entire Ringold Formation at the new ILAW disposal site (Figure 2-17), data are limited. The Ringold Formation reaches a maximum thickness of 95 m (285 ft) on the west side of the new ILAW disposal site and thins eastward. It consists of three units of Lindsey's (1996) member of Wooded Island. The member of Taylor Flats has been identified in borehole 699-47-37A (Lindberg 1997) east of the site but this correlation was tentative. The deepest unit encountered is the lower gravel, Unit A. Lying above Unit A is the Lower Mud and overlying the Lower Mud is an upper gravel, Unit E. The upper Ringold (sand and silt of the member of Taylor Flat) is not present at the ILAW disposal site (Figure 2-10). Unit A and Unit E are equivalent to mapping unit P_LMcg (Table 2-1), Pliocene-Miocene continental conglomerates of Reidel (1994a, 1994b). The Lower Mud is equivalent to the mapping unit P_LMc, Pliocene-Miocene continental sand, silt, and clay beds of Reidel (1994a, 1994b).

Figure 2-17. Isopach Map of the Ringold Formation at the ILAW Disposal Site.



2.2.8.4.1 Unit A. Only three boreholes penetrated Unit A in the study area. Unit A is 61 ft (19 m) thick on the west side of the ILAW site but thins to the northeast (Figure 2-10). Unit A is described on borehole logs as a sandy gravel consisting of both felsic and basaltic rocks.

It is interpreted as Lindsey's (1996) fluvial gravel facies, which consists of conglomerates. There are sporadic yellow to white interbedded sands and silts with silt and clay lenses. Green-colored, reduced-iron stain is present on some grains and pebbles. Although the entire unit appears to be partially cemented, the zone produced abundant water in borehole 299-E17-21 (Reidel 1998b).

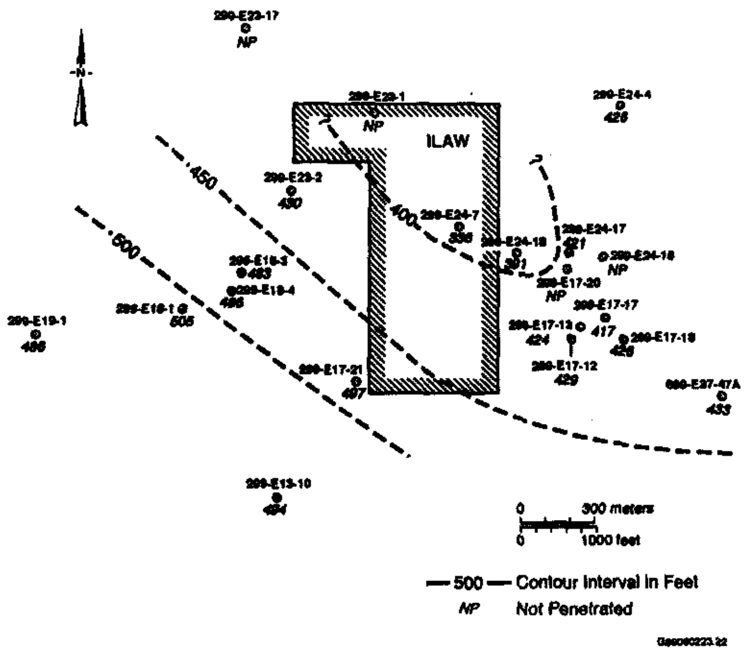
2.2.8.4.2 Lower Mud. Sixty-one feet (19 m) of the Lower Mud was encountered at the new ILAW site characterization borehole (299-E17-21). The upper most part (about 4 ft [1 m]) is described on borehole logs as a yellow sandy to silty mud and is interpreted as Lindsey's (1996) lacustrine facies, which consists of clays, silts, and silty sands. The silty clay grades downward into about 34 ft (10 m) of blue clay with beds of silt to slightly silty clay. The blue clay, in turn, grades down into 23 ft (7 m) of brown silty clay with organic rich zones and occasional wood fragments. The Lower Mud is absent in the center of the ILAW site (Figure 2-10; boreholes 299-E23-1 and 299-E24-7).

2.2.8.4.3 Unit E. Unit E is described on borehole logs as a sandy gravel to gravelly sand. It is interpreted to consist of as much as 50 ft (15 m) of conglomerate with scattered cobbles up to 10 in. (25 cm) in size. The conglomerate consists of both felsic and basaltic clasts which are well rounded with a sand matrix supporting the cobbles and pebbles. Cementation of this unit ranges between slight and moderate. The upper contact of Unit E is not easily identified at the new ILAW site. In the western part of the study area, unconsolidated gravels of the Hanford formation directly overly the Ringold Unit E gravels. The dominance of basalt in the Hanford formation and the absence of any cementation are the key criteria used for distinguishing them here (Reidel 1998b). In the central and northeastern part of the study area, Unit E is interpreted to have been eroded (e.g., boreholes 299-E24-7 and 299-E17-21, Figure 2-10). Unconsolidated gravels and sands typical of the Hanford formation replace them.

2.2.8.4.4 Upper Ringold (Member of Taylor Flat). The upper Ringold is not present at the new ILAW disposal site but has been tentatively identified in the southeast corner of 200 East Area in borehole 699-E37-47A (Lindberg 1997). These sediments do not appear to be present at the ILAW disposal site (Figure 2-10).

2.2.8.4.5 Unconformity at Top of Ringold Formation. The surface of the Ringold Formation is irregular in the ILAW disposal site area (Figure 2-18). A NW-SE trending erosional channel or trough is centered along the northeast portion of the site (Figures 2-10 and 2-18). The deepest portion of the trough occurs near borehole 299-E24-7 in the northern portion of the new ILAW disposal site. This trough is interpreted to be a smaller part of a much larger trough under the 200 East Area resulting from scouring by the Missoula floods or post-Ringold fluvial incision before the Missoula floods.

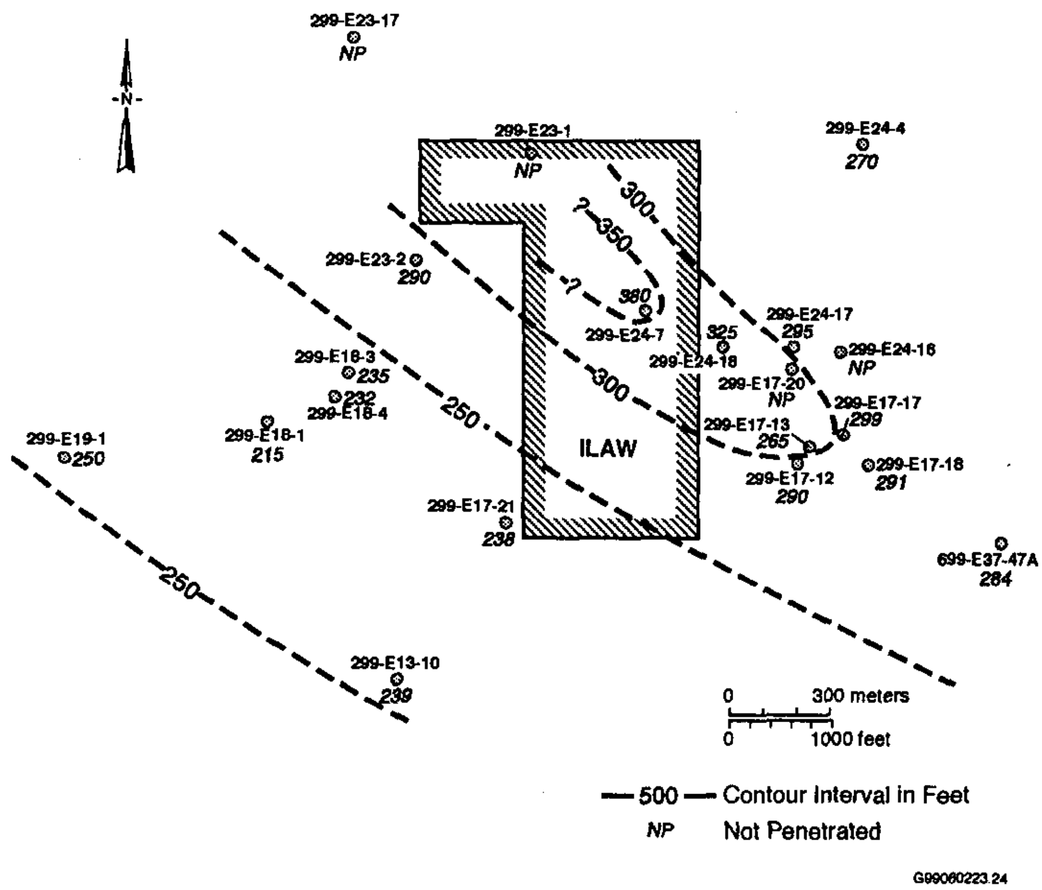
Figure 2-18. Structural Contour Map on the Surface of the Ringold Formation.



2.2.8.5 Hanford Formation. The Hanford formation is as much as 116 m, (380 ft) thick in and around the ILAW disposal site (Figures 2-10 and 2-19). It thickens in the erosional channel cut into the Ringold Formation and thins to the southwest along the margin of the trough. It may thin northeast of the trough but this is based on only one data point (Figure 2-19).

At the ILAW disposal site, the Hanford formation consists mainly of sand-dominated facies and lesser amounts of silt-dominated and gravel-dominated facies. It has been described on borehole logs as poorly sorted pebble to boulder gravel and fine- to coarse-grained sand, with lesser amounts of interstitial and interbedded silt and clay. In previous studies of the ILAW disposal site (Reidel 1998b), the Hanford formation was described as consisting of three units: an upper and lower gravel-dominated facies and a sand-dominated facies between the two gravel facies. The upper gravel-dominated facies appears to be thin or absent in the ILAW disposal area.

Figure 2-19. Isopach Map of the Hanford Formation at the New ILAW Disposal Site.



2.2.8.5.1 Basal Gravel Sequence. The lowermost 27 m (88 ft) of the Hanford formation encountered in borehole 299-E17-21 consists of gravel-dominated facies. Drill core and cuttings from this borehole indicate that the unit is clast-supported pebble to cobble gravel with minor amounts of sand in the matrix. Cobbles and pebbles are almost exclusively basalt with no cementation. In outcroppings these deposits display massive bedding, plane to low-angle bedding and large-scale planar forset cross-bedding, but such features typically cannot be observed in borehole core. This unit either pinches out west of the new ILAW disposal site or becomes more sand rich. It thickens to the northeast. The gravel is interpreted to be Missoula flood gravels deposited in the erosional channel carved into the underlying Ringold Formation (Figure 2-18).

This basal gravel sequence is equivalent to unit H3 of Lindsey (1994b) (Table 2-1), and is equivalent to mapping unit Qfg1, Missoula Outburst flood gravel deposits of Reidel (1994a, 1994b). The sand unit overlying this gravel has reversed polarity, indicating that these units are older than 780 thousand years old.

2.2.8.5.2 Sandy Sequence. The upper portion of the Hanford formation consists of at least 73 m (240 ft) of sand-dominated and silt-dominated facies. These deposits have been described as fine- to coarse-grained sand with minor amounts of silt and clay and some gravelly sands. This sequence is equivalent to unit H2 of Lindsey (1994a), and is equivalent to the following mapping units of Reidel (1994a, 1994b): Qfs1, Qfs2, and Qfs3, Missoula Outburst Flood Deposits consisting of sand, silt, and clay (Table 2-1).

Three paleosols (soils) were identified in core and drill cuttings from borehole 299-E17-21 (Reidel 1998b). Paleosol Horizon 1 occurs at 49 m (163 ft) drilled depth (Figure 2-10), paleosol Horizon 2 at 18 m (58 ft) drilled depth, and paleosol Horizon 3 at 1.5 m (5 ft). The paleosol horizons are as much as 15 cm (6 in.) thick with a sharp upper surface. The horizons have a light brown color compared to the darker sands below and some $CaCO_3$ cementation. The lack of well-defined bedding laminations rhythmics like the sands below suggests some bioturbation but no root casts were observed in the core. The paleosol grades downward into normal sands.

The three paleosol horizons represent time intervals when soil development took place and are interpreted to represent three time periods between Missoula flood deposition. Reidel (1998b) called the layers defined by the paleosols: Layer 1 as that part of the Hanford formation extending from the paleosol horizon at 49 m (163 ft) to the top of the basalt gravel at 75 m (247 ft). Layer 2 extends from the top of the second paleosol horizon 18 m (58 ft) to the top of the first paleosol at 49 m (163 ft). Layer 3 extends from the top of the third paleosol horizon at 1.5 m (5 ft) depth to the second paleosol horizon at 18 m (58 ft) drilled depth. The presence or exact depth of these layers is not known elsewhere at the ILAW disposal site and can only be inferred.

Layer 1. Layer 1 is 26 m (84 ft) thick in borehole 299-E17-21. It is a zone of sand and silt with a poorly developed caliche layer at the top. Only the upper several inches are cemented but $CaCO_3$ extends to a depth of about 3.3 m (10 ft) below the top. $CaCO_3$ fragments or grain coatings were found to a depth of at least 66 m (218 ft).

The lower 6 m (20 ft) of Layer 1 consists of interbedded sands and gravels. The basal gravel sequence underlying Layer 1 appears to grade upward into a sequence of interbedded sands and gravels. At least three upward fining zones of gravels to sands were recognized in Layer 1. These zones are equivalent to unit H2A of Lindsey (1994a).

Planar-laminar sands with minor silt lenses dominate the upper 54 ft (16 m) of Layer 1. This sequence consists of fining upward sands, well-compacted, slightly $CaCO_3$-cemented sands, and well-laminated sands. $CaCO_3$ associated with development of the paleosol extends well down into this layer.

Layer 1 is part of unit H2 of Lindsey (1994a), and is equivalent to mapping unit Qfs1 of Reidel (1994a, 1994b) (Table 2-1). Mapping unit Qfs1 is a Missoula Outburst Flood Deposits consisting of sand, silt, and clay that is 780 thousand years old and has a reversed magnetic polarity. A Paleomagnetic study by the University of California, Santa Cruz, has shown that this layer has reversed magnetic polarity. Layer 1 has only been identified in borehole 299-E17-21. Data from surrounding boreholes is of too poor of quality to identify this layer.

Layer 2. The upper 27 m (90 ft) of Layer 2 is principally the sand- and silt-dominated facies. They have been described as fine- to medium-grained sand with minor amounts of interstitial silt. Throughout the sands are disseminated flakes of $CaCO_3$ and $CaCO_3$-cemented sand grains. Several fining upward zones were recognized as well as highly compacted zones of sand and silt with faint laminations. Layer 2 was correlated to other boreholes using geologists logs and archived chip samples. In addition, the paleosol that forms the top of this layer appears to responsible for zones of lateral spreading of contaminants under waste disposal sites immediately east of the ILAW disposal site.

Layer 2 is also part of unit H2 of Lindsey (1994a), and may be equivalent to mapping unit Qfs2 of Reidel (1994a, 1994b) (Table 2-1). The mapping unit is a Missoula Outburst Flood Deposits consisting of sand, silt and clay that is older than 13 thousand years and younger than 780 thousand years. Mapping unit Qfs2 has a normal magnetic polarity.

Layer 3. Layer 3 is 16 m (53 ft) thick in borehole 299-E17-21. The paleosol at the top of Layer 3 is a 3 cm (1.1 ft) thick, oxidized and leached zone of pebbly, fine-grained sand and silt with some pebbles with a 10-cm (4-in.) poorly developed caliche zone (sand and silt cemented by $CaCO_3$). Several distinct gravelly sands are present within several feet of the paleosol at the top of this layer. This forms the surface of much of the new ILAW disposal site north of the eolian deposits.

The lower 8 m to 10 m (25 to 30 ft) of Layer 3 consists principally of sand with interstitial silt and minor silt beds that are interpreted as lenses. Several minor silt beds are locally present. Gravelly sand, as described on geologists logs, marks a transition to finer grained sand with more silt at a drilled depth of approximately 8 m (25 ft).

Layer 3 is interpreted to consist of the upper gravelly sequence and the upper part of the sandy sequence defined in previous studies. It is part of unit H2 of Lindsey (1994) and is equivalent to mapping unit Qfs3 of Reidel (1994a, 1994b) - Outburst Flood Deposits consisting of sand, silt, and clay that is about 13 thousand years old. An ash from the 13 thousand year old eruption of Mt. St. Helens (Set S Ash) is typically found near the top of this unit in many places throughout the Pasco Basin. The ash was not recognized in any of the boreholes near the ILAW disposal site but has been identified in an excavation 100 m west of the site.

2.2.8.5.3 Eolian Unit. Eolian deposits cover the southern part of the ILAW disposal site. Borehole 299-E17-21 was sited on a stabilized sand dune. The eolian unit is composed of fine- to coarse-grained sands with abundant silt. Calcium-carbonate coating found on the bottom of pebbles and cobbles in drill core through this unit is typical of Holocene caliche development in the Columbia Basin. This unit is equivalent to mapping unit Qd, Holocene Dune Sand, of Reidel (1994a, 1994b) (Table 2-1).

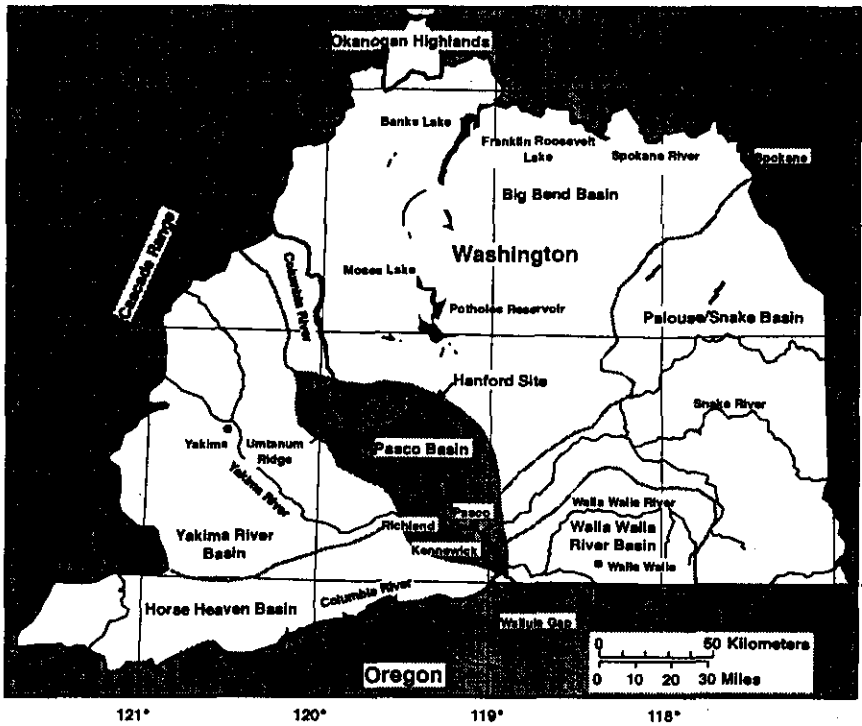
2.2.8.5.4 Clastic Dikes at the ILAW Disposal Site. Clastic dikes have not been observed at the ILAW disposal site. Clastic dikes, however, have been observed in excavations surrounding the site (e.g., PUREX, U.S. Ecology, and Canister Storage excavation). At the new ILAW site, clastic dikes are probably not observed because they are covered by wind blown sediments and a cover of "old growth" sagebrush. The ubiquitous presence of clastic dikes in the 200 East Area suggests that they are probably present at the site.

2.2.9 Regional Hydrology

This section describes the concept of recharge rate for the surface and subsurface hydrology of the Hanford Site region and the disposal facility sites. The surface hydrology is important in determining possible surface pathways for dissolved or suspended contaminants, as well as for identifying sources of infiltration. The groundwater hydrology helps determine possible flow paths for contaminants released from a disposal facility and provides a basis for determining vadose zone thickness.

2.2.9.1 Surface Hydrology. The hydrology of the Pasco Basin (Figure 2-20) is characterized by a number of surface sources and aquifers. Surface drainage enters the Pasco Basin from several other basins, including the Yakima River Basin, the Horse Heaven Basin, the Walla Walla River Basin, the Palouse/Snake Basin, and the Big Bend Basin. Within the Pasco Basin, major tributaries, the Yakima, Snake, and Walla Walla Rivers, join the Columbia River. Two intermittent streams, Cold Creek and Dry Creek, cut through the Hanford Site. Water drains through these pathways during wetter winter and spring months. No perennial streams originate within the Pasco Basin.

Figure 2-20. Hydrologic Basins Designated for the Washington State Portion of the Columbia Plateau (DOE 1988b).



S9509085.3

The total estimated precipitation over the basin averages 16.0 cm/y (6.3 in./y) (Section 2.2.5.2). Mean annual runoff from the basin is estimated to be less than 3.1×10^7 m^3/y (2.5×10^4 acre ft/y), or approximately 3 percent of the total precipitation. The remaining precipitation is assumed to be lost through evapotranspiration, with perhaps a few percent contributing to the recharging of the groundwater (DOE 1988b).

The Hanford Site has one pond, West Lake, and various water disposal ponds. West Lake, located 2.7 km (1.7 mi) north of the 200 East Area, is a shallow pond with an average depth of about 1 m (3 ft) and a surface area of 4 hectares (10 acres). While described as a natural lake, the source of recharge to the lake is groundwater that is locally mounded because of infiltration from 200 Area operations. The pond is a topographic depression that intersects the artificially elevated water table (DOE-RL 1993b-1). 200 Area disposal activities are scheduled to halt within a few decades. As this happens, the water table will drop and West Lake will become an intermittent seasonal pond (DOE-RL 1993c). Waste water ponds, cribs, and ditches associated with nuclear fuel processing and waste disposal activities, although present on the Hanford Site, will not be an important source of water in the future.

No surface streams are near the proposed disposal facilities, but current disposal ponds have an artificial influence on net contributions to the water table. These disposal ponds and related facilities are not expected to exist after current operations end, so their long-term influence is not considered in this performance assessment.

The surface drainage characteristics of the Hanford Site and regional area indicate that the Columbia River and its tributaries are the major surface drainage pathways. The Columbia River is the dominant pathway. The large volume of flow in the Columbia River (typically 1,000 to 3,000 m^3/s [Dirkes 1999-1]) through the Pasco Basin and downstream greatly dilutes any contaminants that reach the river.

DOE conducts routine water-quality monitoring of the Columbia River for both radiological and nonradiological parameters. The Pacific Northwest National Laboratory (PNNL) has been reporting the water quality data since 1973. Ecology has issued a Class A (excellent) quality designation for Columbia River water from Grand Coulee Dam, through the Pasco Basin, to McNary Dam (*Washington Administrative Code* [WAC] 173-201). This designation requires that all industrial uses of this water be compatible with other uses, including drinking, wildlife habitat, and recreation. The Columbia River water is characterized by a low suspended load, a low nutrient content, and an absence of microbial contaminants (Dirkes 1999-1).

2.2.9.2 Flooding. Neitzel (2000-5) describes flooding potentials at the Hanford Site. Except for catastrophic glacier flooding, which is not expected for tens of thousands of years, no floods are expected to affect the Hanford Central Plateau.

The flows for the three largest probable Columbia River flood scenarios range from 17,000 m^3/s to 600,000 m^3/s (600,000 to 21 million ft^3/s). The probable maximum flood on the Columbia River (DOE 1986b), based on natural conditions, has been calculated to be 40,000 m^3/s (1.4 million ft^3/s). This is greater than the 500-year flood. A landslide resulting in Columbia River blockage, followed by flooding could yield a maximum flow of 17,000 m^3/s (600,000 ft^3/s). The U.S. Army Corps of Engineers estimated that a 50 percent breach in the Grand Coulee Dam, the largest dam in the region, would yield flows of 600,000 m^3/s (21 million ft^3/s). None of these flow rates are large enough to cause the Columbia River waters to reach the Hanford Central Plateau.

A flood risk analysis of Cold Creek (west of the 200 West Area) was conducted to characterize a basaltic repository for high-level radioactive waste (Skaggs 1981). Based on this evaluation, the probable maximum flood would be 8 km (5 mi) to the west of the new disposal facility site and its closest approach would be about 6 km (3.6 mi) to the south. The distance would be even greater for the existing disposal facility site.

2.2.9.3 Groundwater Hydrology. The groundwater pathway is considered the most likely pathway for contaminants released from an immobilized low-activity tank waste disposal facility for the following reasons:

Low precipitation in the Pasco Basin

Lack of surface transport pathways near the disposal facilities

Subsurface location of the disposal facilities

Near-surface lysimeter measurements showing downward movement of water

Samples showing the existence of radioactive contaminant plumes in the groundwater because of past Hanford Site operations.

Evaluating this pathway will require information about the types of aquifers present, depths to the water table, regional flow paths, and the net recharge rate.

The hydrology of the Pasco Basin is characterized by a multiaquifer system. This system consists of four hydrologic units corresponding to the upper three formations of the Columbia River Basalt Group (Grande Ronde Basalt, Wanapum Basalt, and Saddle Mountains Basalt) and the overlying suprabasalt sediments (the Hanford formation and Ringold Formation). The basalt aquifers consist of the tholeitic flood basalts of the Columbia River Basalt Group and relatively minor amounts of intercalated sediments of the Ellensburg formation. Confined zones in the basalt aquifers are present in the sedimentary interbeds and/or interflow zones that occur between dense basalt flows. The main water-bearing portions of the interflow zones are networks of interconnecting vesicles and fractures in the flow tops and bottoms (DOE 1988b).

The uppermost aquifer system consists of fluvial, lacustrine, and glaciofluvial sediments. Within the Pasco Basin, this aquifer is regionally unconfined and is contained primarily within the Ringold Formation and the Hanford formation. The main body of the unconfined aquifer usually occurs within the Ringold Formation. The water table in the southwestern Pasco Basin is generally within Ringold fluvial gravels. In the northern and eastern Pasco Basin, the water table is generally within the Hanford formation. Hydraulic conductivities in the Hanford formation are usually greater than in the gravel facies of the Ringold Formation (Graham 1981). However, fine-grained deposits in the Ringold Formation form locally confining layers for Ringold fluvial gravels.

The base of the uppermost aquifer system is defined as the top of the uppermost basalt flow. This aquifer system is bounded laterally by anticlinal basalt ridges and is about 152 m (500 ft) thick near the center of the Pasco Basin. Within the Hanford Site, this uppermost aquifer system lies at depths ranging from less than 0.3 m (1 ft) below the ground surface near West Lake and the Columbia and Yakima Rivers, to more than 107 m (350 ft) in the central portion of the Cold Creek syncline.

Because the uppermost unconfined aquifer is considered the primary pathway for possible contaminant transport from an immobilized low-activity tank waste disposal facility, it is especially important in this performance assessment.

Before the liquid waste disposal systems, such as B Pond, began operating, and before the onset of large regional irrigation projects, the groundwater table for the Hanford Site could be represented by a 1944 water table map (Figure 2-21). This water map includes limited irrigation near the former towns of White Bluff and Hanford, but not the extensive irrigation now common in Cold and Dry Creeks. The 1944 water table contours suggest that groundwater flow is easterly toward the Columbia River with a relatively uniform hydraulic gradient (approximately 1.5 m/km [5 ft/mi]). Regional groundwater flow was generally toward the east-northeast, although flow north of Gable Mountain was more to the north.

Effluent disposal at the Hanford Site has altered hydraulic gradients and flow directions of the uppermost aquifer system, particularly near the 200 Areas. Figure 2-22 shows a recent water table map influenced by effluent disposal actions. Regional irrigation projects had a minor influence on the changes shown in Figure 2-22. Groundwater flow is still nominally easterly toward the Columbia River, but mounding occurs in the 200 East Area near B Pond. Groundwater flow north of Gable Mountain now trends in a more northeasterly direction as a result of mounding near reactors and northerly flow through Gable Gap between Gable Mountain and Gable Butte. South of Gable Mountain, flow is interrupted locally by the groundwater mounds in the 200 Areas. Some groundwater from the 200 Areas flows to the north between Gable Mountain and Gable Butte. For the time periods considered in this performance assessment, effluent disposal operations will have stopped.

Figure 2-21. Hindcast Water Table Map of the Hanford Site, January 1944 (ERDA 1975).

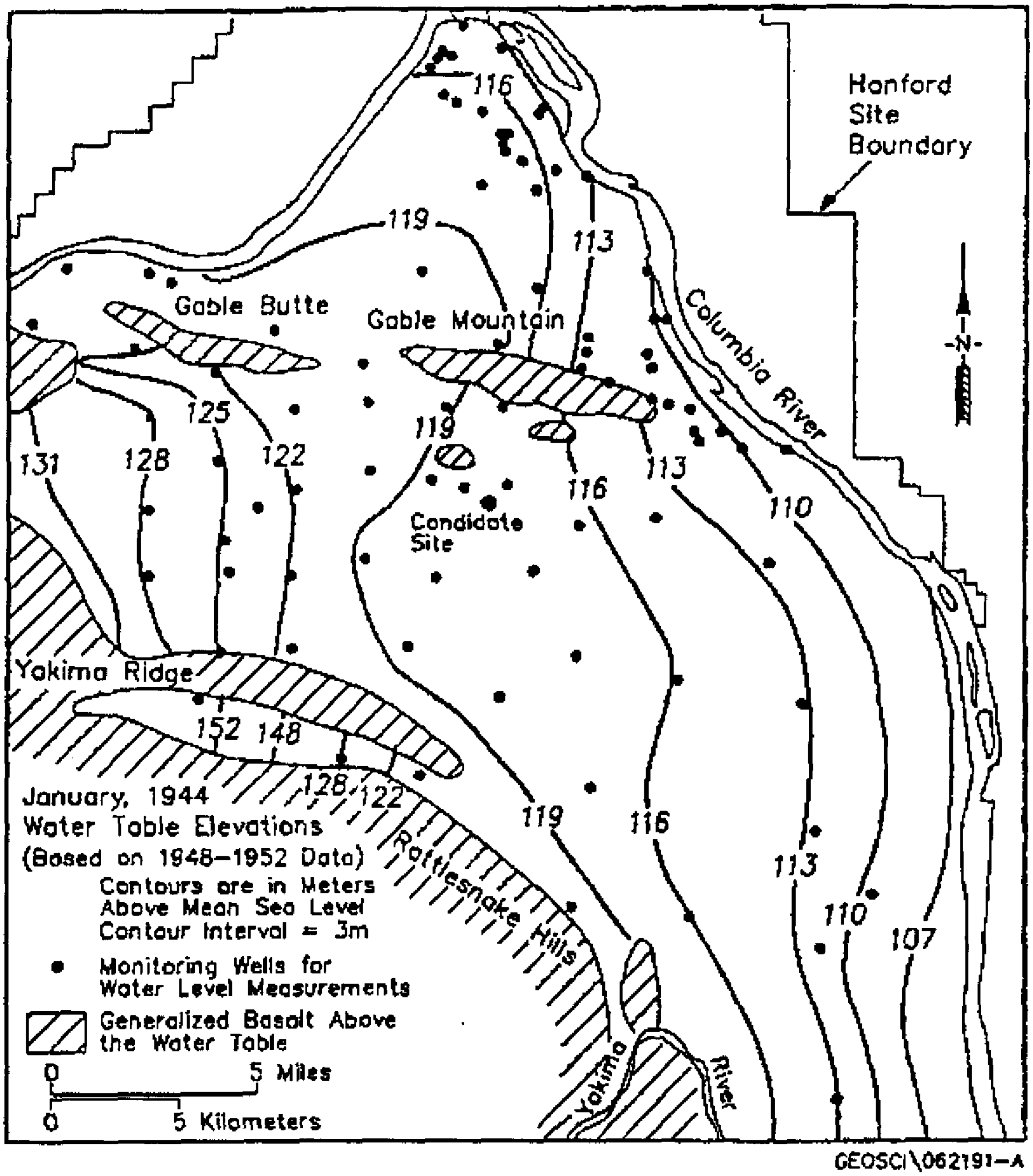
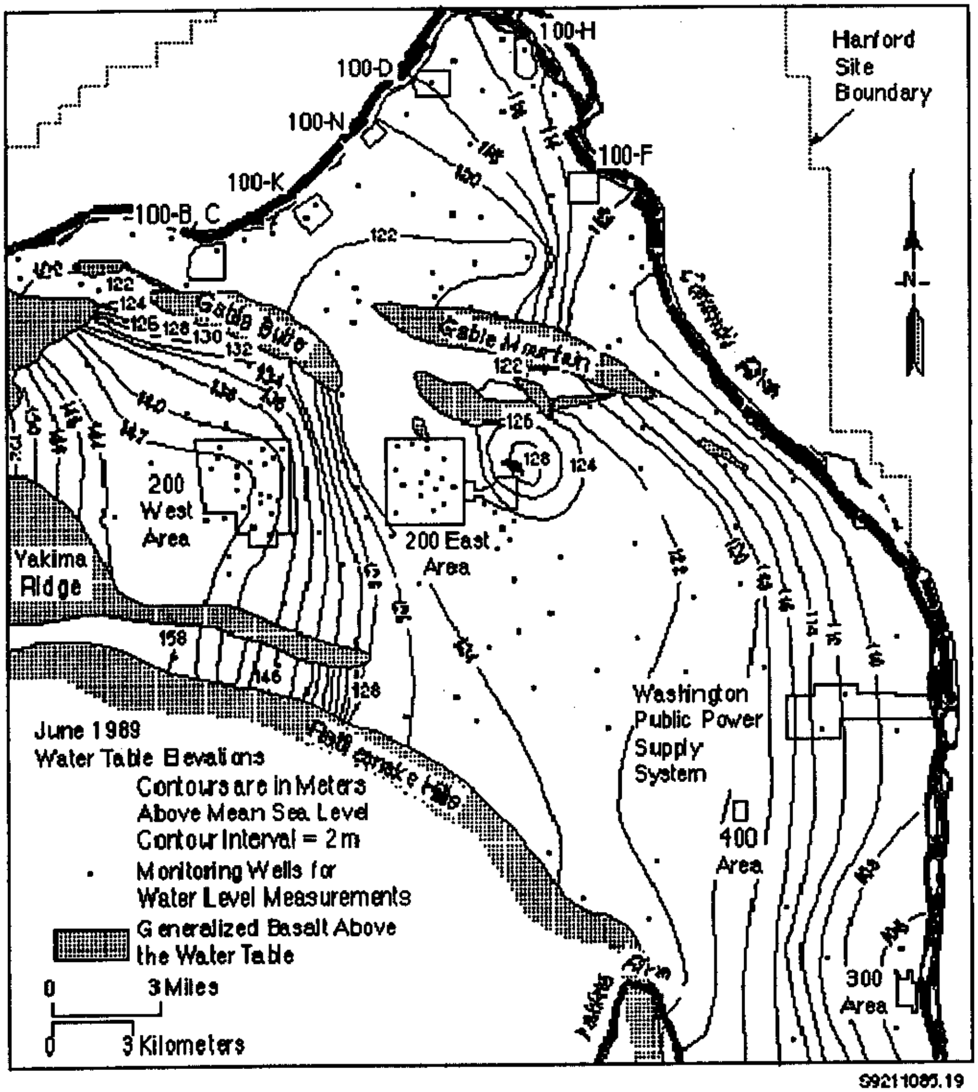


Figure 2-22. Hanford Site Water Table Map, June 1989 (Smith 1990).



2.2.9.4 Natural Recharge Rates. The information in this section is based on *Recharge Data Package for the Immobilized Low-Activity Waste 2001 Performance* Assessment (Fayer 1999). Recharge is the amount of total precipitation that infiltrates into the unsaturated zone (vadose zone) after runoff, evaporation, and transpiration by plants have occurred. Recharge from rain and snow melt is a major hydrologic variable affecting contaminant transport from an immobilized low-activity tank waste disposal facility.

Studies conducted over the last 25 years at the Hanford Site are summarized in the following paragraphs. These studies indicate that long-term recharge can vary greatly depending on factors such as climate, vegetation, land use, and soil texture. As noted in Section 2.2.5, most of the very small amount of precipitation at the Hanford Site falls in the winter and spring. Because of the dry conditions at the Site, most of the precipitation is stored in near-surface soils until used by plants or evaporates during the hot summer months. Natural plants have adapted to use all the water in the near-surface zone. Because of the large storage capacity of the near surface soils, water rarely (on just a few days per decade) exits downwards from this near-surface zone. Such rare events typically occur following the rapid melting of a snow pack.

Most recharge rate data at the Hanford Site have been measured directly using a combination of drainage and weighing lysimeters (Rockhold 1995, Gee 1992). These lysimeters are vertical tubes as much as 5 m long in the ground filled with various type of soils and covered with various types of vegetation. At the bottom of the lysimeters, the water that passed through the tube of soil is collected and measured (by volume or weight). The measurements can be used to determine the rate at which moisture escapes the near-surface part of the vadose zone. Because no mechanisms are known to exist that trap the moisture, the measured rate from the lysimeters is considered a good approximation for the recharge rate of the conditions (soil, vegetation, and precipitation) simulated by the lysimeter.

The recharge rate depends on the seasonal distribution of precipitation, type of surface soil and vegetation, and climatic conditions. Maximum recharge events occur following the wettest winter periods. Under normal conditions, the recharge rate is highest in coarse-textured soils without vegetation and is at the measurement threshold in fine-textured soil with or without vegetation. Coarse soil surfaces that are either vegetated with shallow-rooted species or bare exhibit recharge on the order of 50 percent of the precipitation.

Fayer and Walters (Fayer 1995) estimated recharge rates based on measurements (lysimeters, tracers, and regional studies) and on numerical modeling. Estimates made using these methods were assigned to specific soil-vegetation combinations and distributed across the Hanford Site using a soil map and a vegetation-land use map. The long-term average rates varied from 2.6 mm/y (0.1 in./y) for several soil and vegetation combinations in the 200 Areas (including the immobilized low-activity tank waste disposal facility sites) to 127.0 mm/y (5.0 in./y) for basalt outcrop with no vegetation at the crest of Rattlesnake Mountain (Fayer 1995).

For the sites of interest to ILAW disposal, surface soils are dominated by Rupert Sands and Burbank Loamy Sand. Fayer (1999), summarized in Section 3.4.6 along with the human influences on recharge, estimates that the natural recharge rate through the two types of soils are

0.9 mm/y and 4.2 mm/y, respectively. It should be noted that the Burbank Loamy Sand soil type was not considered in the 1998 ILAW PA (Mann 1998a). See Section 3.4.6 for a fuller description of recharge rates and the choice of values used in this performance assessment.

2.2.10 Geochemistry

The information in this section is taken from *Mineralogy of Selected Sediment Samples from Borehole 299-E17-21*, (Mattigod 2000). This section discusses the mineralogy of the ILAW disposal site, based on recently obtained samples from the borehole located at the southwest edge of the ILAW disposal Site (Reidel 1998a). Information about Geochemical methods and parameters used in the performance assessment analysis is given in Section 3.4.3.3.

The dominant minerals in the sand fractions of all samples were quartz (about 66 to 82 percent by mass) and feldspars (about 15 to 31 percent) (Table 2-3). These minerals (quartz and anorthite and orthoclase feldspars) constituted approximately 92 to 99 percent of the total mass of the sediment samples. Trace quantities of muscovite mica, chamosite (a type of chlorite) and ferrotschermakite (an amphibole mineral) also were detected in sand fractions. The silt fractions of these samples also were dominated by quartz (about 61 to 76 percent) and feldspars (about 19 to 44 percent). Compared to sand fractions, the silt fractions contained higher amounts of muscovite and chamosite (about 1 to 5 percent), and ferrotschermakite (1 to 10 percent). Illitic mica was the dominant mineral at about 42 to 60 percent by mass in clay fractions of all the sediment samples (Table 5). About 14 to 17 percent chlorite and about 21 to 28 percent kaolinite also were found in clay fractions. Minor amounts (3 to 12 percent) of smectite (a mineral important for its geochemical reactivity) also were detected in clay fractions of all samples. Overall, quartz and feldspars dominated the sand fractions, whereas the clay fractions were dominated by illitic mica and chlorite. These size-dependent mineral distributions are typical of primary (quartz and feldspars) and secondary (illite, chlorite, kaolinite, and smectite) mineral occurrence in soils undergoing chemical weathering. The mineralogy of these sediments was typical of published mineralogy of other Hanford formation sediments (Schramke, 1988).

Layers of high $CaCO_3$ (calcite) are found in the 200 West Area. Calcite can affect the mobility of certain contaminants and tends to buffer pore moisture. However, Mattigod (2000) found less than 5% of calcite in any of the samples they analyzed from the ILAW disposal site. Moreover, such layers are readily visible in geologic logs and have not been seen in other boreholes near the ILAW disposal site.

Based on the semiquantitative mineralogy data and the mass distribution of particles in each size fraction (Table 2-3), the mineral distribution was computed on the bulk soil basis. As expected, in all samples (predominantly sandy in texture), the minerals that are dominant in sand and silt fractions, quartz and feldspars, also dominate the mineralogy of bulk soils at approximately 91 to 95 percent). All other minerals occur in minor to trace concentrations in these soils.

Although the mineralogy of these soils are dominated by quartz and feldspar minerals, other minerals such as illite, chlorite, smectite and kaolinite, which have characteristics such as high surface areas, ionizable exchange sites, and specific adsorption interlayer sites significantly influence bulk soil chemical properties such as cation exchange capacity (CEC). Therefore, calculations were made to assess the contribution of each mineral to the overall CEC of whole soil. The results show that although the minerals mica, chlorite, smectite and kaolinite together constitute only about5 to 9 percent of the total soil mass, they account for about 40 – 60 percent of the total exchange capacity of the whole soils. Only trace amounts (less than 0.6 percent) of smectite were detected in these soils however, because of this mineral's very high surface area, it accounts from about 4 to 17 percent of the CEC of the whole soils. Also, it is well established that minerals such as illitic mica in Hanford formation sediments specifically adsorb radionuclides such as ^{137}Cs (Mattigod et al. 1994a, 1994b). Therefore, mica although constituting only about 3 to 5 percent of the soil mass would significantly affect the specific adsorption of alkali cations such as cesium and potassium by the whole soil.

Also, the calculated CEC of the whole soils agreed reasonably well with the measured CEC values except in the case of samples 24A, 31A, and 35A. The measured CEC values for these samples were about twice as high as the calculated values. Because the mineralogy of these samples were not significantly different from other core samples, the anomalously high measured CEC values were attributed to the presence of trace amounts of carbonates present in these sediments.

Table 2-3. Semiquantative Estimates (wt%) of Minerals in Selected Sediments from ILAW Borehole (from Mattigod 2000).

		Fraction	Quartz	Feldspar	Mica	Chlorite	Amphibole	Smectite	Kaolinite
7A	Sand	0.921	62	12	1	1	--	--	--
	Silt	0.055	12	5	1	1	--	--	--
	Clay	0.024	--	--	3	1	--	Tr	1
	All		74	17	5	2	--	Tr	1
10A	Sand	0.821	63	21	1	1	--	--	--
	Silt	0.146	8	3	Tr	1	--	--	--
	Clay	0.033	--	--	2	Tr	--	Tr	1
	All		71	23	3	2	--	Tr	1
14A	Sand	0.794	59	28	1	1	1	--	--
	Silt	0.136	3	2	Tr	Tr	Tr	--	--
	Clay	0.070	--	--	3	1	--	Tr	1
	All		62	30	2	2	1	Tr	1
16A	Sand	0.947	66	19	1	1	1	--	--
	Silt	0.038	6	3	Tr	Tr	Tr	--	--

Table 2-3. Semiquantative Estimates (wt%) of Minerals in Selected Sediments from ILAW Borehole (from Mattigod 2000).

		Fraction	Quartz	Feldspar	Mica	Chlorite	Amphibole	Smectite	Kaolinite
	Clay	0.014	--	--	2	Tr	--	Tr	1
	All		72	22	3	1	1	Tr	1
20A	Sand	0.090	65	18	1	1	1	--	--
	Silt	0.088	6	2	Tr	1	1	--	--
	Clay	0.012	--	--	2	1	--	Tr	1
	All		71	20	3	3	2	Tr	1
24A	Sand	0.913	59	28	1	1	--	--	--
	Silt	0.061	5	2	Tr	Tr	Tr	--	--
	Clay	0.026	--	--	2	1	--	Tr	1
	All		64	30	2	2	Tr	Tr	1
31A	Sand	0.884	53	16	1	1	1	--	--
	Silt	0.100	17	5	Tr	Tr	Tr	--	--
	Clay	0.015	--	--	2	1	--	Tr	2
	All		70	22	3	2	1	Tr	2
35A	Sand	0.983	68	25	1	1	1	--	--
	Silt	0.011	1	--	--	--	--	--	--
	Clay	0.006	--	--	1	1	--	Tr	1
	Allk		69	25	2	1	1	Tr	1

Tr: Trace quantity < 0.5%.

2.2.11 Natural Resources

The Central Plateau of the Hanford Site has no important natural resources. No major mining operations exist in the Hanford Site area. Oil and gas exploration have occurred; however, no economically viable accumulations were found. Some local gravel processing is being done in the area.

As noted in the hydrology section (Section 2.2.9), the unconfined aquifer is not a significant resource for water. Monitoring wells on the Hanford Site normally have screen lengths of 6.1 m (20 ft) (Evans 2000).

2.2.12 Regional Background Contamination and Hanford Site Monitoring

The Hanford Site has an extensive monitoring program. Studies have been directed at determining background levels of possible contaminants in the soil (DOE-RL 1994b and DOE-RL 1995b) and in the groundwater (Johnson 1993). Also, reports are issued annually covering general environmental conditions (Dirkes 1999) and groundwater monitoring (Hartman 2000).

2.2.12.1 Soil Background Levels. Low concentrations of ^{90}Sr, ^{137}Cs, and ^{239,240}Pu were measured in samples of soil and vegetation during 1998 (Dirkes 1999-2). The levels were similar to those measured in previous years. No discernible increase in concentration could be attributed to current Hanford Site operations. DOE-RL 1995b summarizes all the measurements taken to determine radionuclide background levels at the Hanford Site. Table 2-4 displays the average of the measurements.

Table 2-4. Activity of Radionuclides in Hanford Sitewide Background Data Set (DOE-RL 1995b).

Nuclide	Activity (pCi/g)	Nuclide	Activity (pCi/g)	Nuclide	Activity (pCi/g)
^{40}K	15.4	^{60}Co	0.00132	^{90}Sr	0.0806
^{137}Cs	0.417	^{154}Eu	0.0083	^{155}Eu	0.0234
^{226}Ra[a]	0.686	^{232}Th+D	0.687	^{235}U+D	0.0271
^{238}U+D	0.675	^{238}Pu	0.00158	$^{239/240}$Pu	0.00935

"+D" indicates that daughters are included

[a] ^{226}Ra is part of ^{238}U decay chain and is included in that entry.

2.2.12.2 Groundwater Background Levels. Sample results from environmental monitoring can vary depending on local operations, so a regional baseline study was conducted using these and other Sitewide monitoring results (Johnson 1993). Groundwater background values and trigger threshold levels are shown in Table 2-5.

Table 2-5. Background Values for Hanford Site Groundwater. [a]

Constituent (Concentration)	Groundwater Background Values [b]	Provisional Threshold Values
Aluminum (ppb)	<2	<200
Ammonium (ppb)	<50	<120
Arsenic (ppb)	3.9 ± 2.4	10
Barium (ppb)	42 ± 20	68.5
Beryllium (ppb)	<0.3	<5
Bismuth (ppb)	<0.02	<5
Boron (ppb)	<50	<100
Cadmium (ppb)	<0.2	<10
Calcium (ppb)	40,400 ± 10,300	63,600
Chloride (ppb)	10,300 ± 6,500	NC
Chromium (ppb)	4±2	<30
Copper (ppb)	<1	<30
Fluoride (ppb)	370 ± 100	1,340, 775[c]
Iron-mid (ppb)	NA	291
Lead (ppb)	<0.5	<5
Magnesium (ppb)	11,800 ± 3,400	16,480
Manganese (ppb)	7±5	NC
Mercury (ppb)	<0.1	<0.1
Nickel (ppb)	<4	<30
Nitrate (ppb)	NA	12,400
Phosphate (ppb)	<1,000	<1,000
Potassium (ppb)	4,950 ± 1,240	7,975
Selenium (ppb)	<2	<5
Silver (ppb)	<10	<10
Silicon (ppb)	NA	26,500
Sodium (ppb)	18,260 ± 10,150	33,500
Strontium (ppb)	236 ± 102	264.1
Sulfate (ppb)	34,300 ± 16,900	90,500
Uranium (pCi/L)	1.7 ± 0.8	3.43

Table 2-5. Background Values for Hanford Site Groundwater. [a]

Constituent (Concentration)	Groundwater Background Values [b]	Provisional Threshold Values
Vanadium (ppb)	17 ± 9	15
Zinc (ppb)	6 ± 2	NC
Field alkalinity(ppb)	NA	215,000
Laboratory alkalinity (ppb)	123,000 ± 21,000	210,000
Field pH	NA	(6.90, 8.24)
Laboratory pH	7.64 ± 0.16	(7.25, 8.25)
Total organic carbon (ppb)	586 ± 347	2,610, 1,610[c]
Field conductivity (μmho/cm)	NA	39
Laboratory conductivity (μmho/cm)	380 ± 82	530
TOX, LDL (ppb)	NA	60.8, 37.6[c]
Total carbon (ppb)	NA	50,100
Gross alpha (pCi/L)	2.5 ± 1.4	63, 5.79[c]
Gross beta (pCi/L)	19 ± 12	35.5, 12.62[c]
Radium (pCi/L)	<0.2	0.23

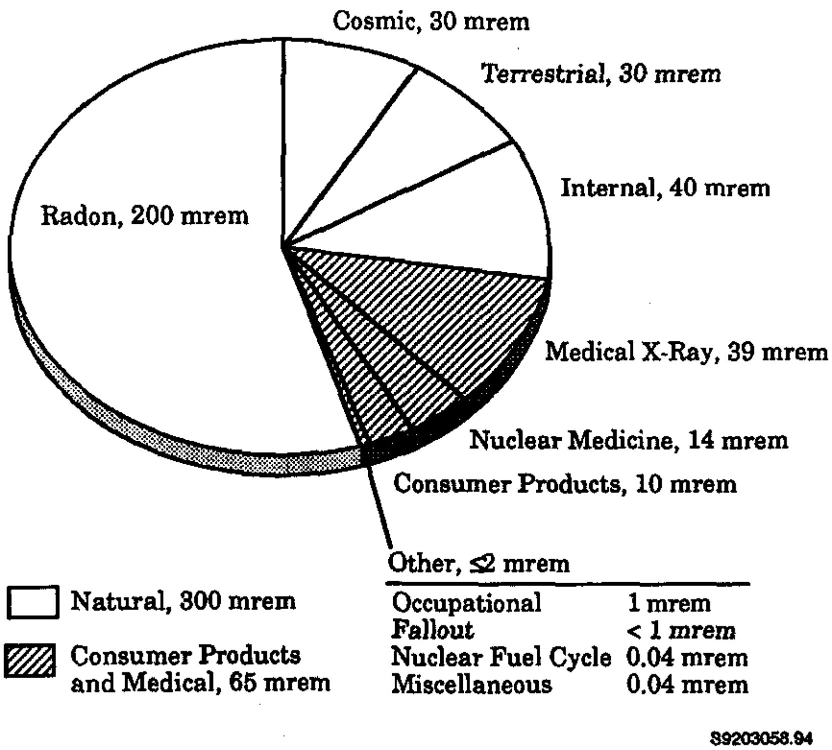
[a] From Tables 5-9 and 5-11 of DOE-RL 1992.
[b] Results shown are mean ± one standard deviation, unless only an upper limit is given.
[c] Potential outlier observation(s) were removed.

LDL = lower detectability limit
NA = not available
NC = not calculated
TOX = total organic halides

2.2.12.3 Radiation Background Levels. Various natural and human-produced sources contribute to radiation doses. These sources include natural terrestrial and cosmic background radiation, medical treatment and x-rays, natural internal body radioactivity, and inhalation of naturally occurring radon. Figure 2-23 shows the national average dose from each of these sources to an individual. Of the contributions shown in Figure 2-23, natural background contributes 300 mrem to the estimated per capita annual dose to individuals living near the Hanford Site. Human-produced sources contribute an additional 65 mrem. In contrast, annual Hanford Site environmental reports (e.g., Dirkes 1999-3) estimate that the maximum annual dose to an individual from Hanford Site operations in 1998 was about 0.02 mrem. This is similar to values seen over the last 4 years.

The public is exposed to radiation at or near the Hanford Site from industrial sources other than DOE operations. These sources include the low-level radioactive waste burial site operated by U.S. Ecology, the nuclear generating station operated by Energy Northwest, the nuclear fuel production plant operated by Siemans Nuclear Power Corporation, the low-level waste compacting facility operated by Allied Technology Corporation, and a decontamination facility operated by Pacific Nuclear Services. Based on information gathered from these companies, Dirkes (Dirkes 1999-3) conservatively determined that the total 1998 annual dose for the hypothetical maximally exposed individual from those activities also was 0.02 mrem.

Figure 2-23. Averages for Natural and Human-Produced Sources of Radiation (NCRP 1987).



2.3 WASTE CHARACTERISTICS

2.3.1 Overview

The source of the waste material to be incorporated into a solidified waste form is the waste currently stored in the Hanford Site's single- and double-shell tanks. This section covers the activities from the current storage of special material production waste through the delivery of the treated waste at the disposal sites.

The TWRS record of decision (DOE 1997b) states that the waste will be retrieved from the tanks, then chemically separated to form the high- and low-activity radioactive waste fractions. The high-activity radioactive waste fraction will contain most of the radionuclides. This waste fraction will be vitrified, and the product stored until it can be transferred to a licensed high-level waste repository. The low-activity radioactive waste fraction contains the bulk of the nonradioactive chemicals and is predominantly the soluble components of the tank waste. This waste fraction will be solidified in a glass or other form that meets the DOE specifications.

It is proposed to dispose of the immobilized low-activity waste form on Site in a manner that allows the waste to be retrievable for at least 50 years, although this time period has not been adopted officially.

2.3.2 Underground Tank Storage

To store the liquid high-level radioactive waste generated by Hanford Site operations since 1944, 149 single-shell tanks and 28 double-shell underground tanks were built. The tanks are grouped into 18 tank farms containing over 204,000 m^3 (53.6 Mgal) [Hanlon 2000-1] of waste. The consistency of the tank waste ranges from dilute aqueous solutions to thick paste to hard solid.

Four basic chemical processing operations generated the radioactive waste solutions. These operations were the bismuth phosphate process, the REDOX process, the PUREX process, and the tributyl phosphate process. The first three processes recovered plutonium from irradiated reactor fuels. The last process recovered uranium waste generated in the bismuth phosphate process. Other specialized campaigns recovered ^{137}Cs, ^{90}Sr, and other special nuclear materials. The aqueous waste was made alkaline to control corrosion in the carbon-steel underground tanks. Anderson (1990) provides a history of the liquid waste generation and its subsequent handling and storage in the tank farms.

Most of the tank waste has undergone one or more treatment steps (for example, neutralization, precipitation, decantation, or evaporation). The neutralized waste contains sodium nitrate and nitrite, sodium hydroxide, sodium aluminate, sodium phosphate, various insoluble hydroxides and phosphates, usually small quantities of organic materials, and various radionuclides (approximately 250 MCi). The main effect of the treatment steps other than neutralization was to reduce the water content of the waste.

2.3.3 Tank Waste Retrieval

According to the Tri-Party Agreement (Ecology 1998), as much waste as possible, given current technology, must be removed from the tanks for treatment and immobilization. Unless limited by waste retrieval technology, the single-shell tank waste residues must not exceed 360 ft^3 (approximately 10 m^3) in each 200-series tank, which can hold 208 m^3 (55,000 gal) of waste. For the 100-series tanks, which have volumes above 2,000 m^3 (500,000 gal), the limit is 30 ft^3 (approximately 1 m^3). On a tank-by-tank basis, the DOE can request that the EPA and Ecology approve a higher residue limit.

2.3.4 Separations

The purpose of the separations step [DOE 1997b] is to separate the retrieved tank waste into the following two radioactive waste fractions:

> A low-activity fraction containing the bulk of the non-radioactive material and limited amounts of radionuclides. This waste will be immobilized and disposed in the 200 Areas on the Hanford Site.
>
> A much smaller high-activity fraction containing most of the radionuclides. This waste will be immobilized, then stored until a licensed Federal high-level repository is ready to receive it.

In the Tank Waste Remediation System Operation and Utilization Plan (TWRSO&UP) the best-basis tank-by-tank inventories (BBI) were partitioned into water-soluble and water-insoluble phases using the most recent water wash data for each tank (Hendrickson 1999). Caustic wash data (Colton 1997) were applied to the HLW feed calculations (Kirkbride 1999). The tank inventory components were distributed between liquid and solid phases in the TWRSO&UP by applying tank-specific wash factors for every BBI analyte (Hendrickson 1999). Global caustic leach factors were applied to the water-insoluble phases to model the LAW generated as part of the HLW feed preparation.

This strategy is intended to achieve reasonable waste disposal costs in comparison with the costs of disposing of all of the tank waste at the proposed high-level repository, while providing adequate protection of the public and the environment. DOE plans to accomplish the treatment of tank waste in two phases. Phase 1 is planned to be a demonstration with waste treatment and immobilization. In this phase about 10% of the tank waste by volume (or about 25% by activity) would be treated. In Phase 2, contractors would provide waste treatment and immobilization services and retrieve waste from the remainder of the tanks. In both phases DOE would store and dispose of the immobilized product.

ORP plans to use the following three-step approach during Phase 1 (2002 through about 2018).

1. Separate the soluble components from the insoluble components by means of in-tank "sludge washing" followed by settle-decant of the supernant liquid.

2. Treat the soluble fraction to provide a feed to the low-activity waste immobilization facility that is in accordance with the NRC's "incidental waste" classification for Hanford Site waste (Paperiello 1997). The NRC requires that the waste meet the following criteria.

   - The waste has been processed (or will be processed further) to remove key radionuclides to the maximum technically and economically practical extent possible.

   - The waste will be incorporated into a solid physical form at a concentration level that does not exceed the applicable concentration limits for Class C low-level waste as set out in 10 CFR 61 (10 CFR 61-2).

   - The waste is to be managed, pursuant to the *Atomic Energy Act of 1954* (AEA 1954), so that safety requirements comparable to the performance objectives set out in 10 CFR 61 (10 CFR 61 - 3) are satisfied.

3. Wash the insoluble fraction in the tank, then use enhanced in-tank sludge washing (alkaline leaching) to remove more soluble nonradioactive material from the feed going to the high-level waste vitrification facility. Any additional separations required will be performed in the separations facility.

Performance details may differ during the second production period, but equivalent separations are expected.

The NRC staff (Paperiello 1997) has indicated that such a separations activity along with an assessment consistent with NRC standards (10 CFR 61) would allow the NRC to treat the low-activity waste as 'incidental waste,' which does not come under NRC licensing authority.

2.3.5 Immobilization of the Low-Activity Waste

After waste-type separation, the low-activity waste will be immobilized into glass. Current plans involve vitrification in a joule-heated ceramic DuraMelter. The DuraMelter vitrification system imposes certain operational and process requirements on the glass formulations that include:

- Viscosity limits of 1 to 15 Pa· s at 1100°C
- Electrical conductivity limits of 0.2 to 0.7 S/cm at 1100 to 1200°C
- Liquidus temperature below 950°C.

Other factors affecting melter operations that are also important include:

- Ability to retain sulfur in the glass matrix without the formation of molten salt phases during processing; these phases are more corrosive, electrically conductive, and fluid than the glass melt, and have lower melting points.
- Compatibility of the glass melts with the projected glass contact refractory (primarily Monofrax K-3) and the metallic components of the melter (e.g., electrodes, bubblers, thermowells, etc.).

In addition to these processing constraints, the DOE imposes additional product acceptance constraints. Detailed specifications regarding waste package size, compressive strength, crystallinity, etc. have been developed (DOE/ORP 2000c).

A large number of LAW glasses has been formulated by staff at the Vitreous State Laboratory (VSL) in Washington D.C. that meet these processing and product acceptance requirements while achieving waste loadings ranging from 6 to 31 mass%. Supplemental to the VSL work, a set of 77 glasses has been formulated and is currently being tested under a project funded by EM-50 (Vienna et al., 2000). The combined set of these glasses covers a very wide-ranging, multidimensional compositional space. While no single method could accurately depict the entire range in compositional variability that has been considered, it is possible to capture the bulk of the range in variability by separating the glass into univalent, divalent, trivalent, and tetravalent metal oxides that make up the majority (>95%) of the glass composition. Two ternary diagrams can then be constructed, as shown in Figure 2-24, which provide insight with respect to the composition space investigated to date. In general, the EM-50 series of glasses has been formulated with lower amounts of divalent metal oxides than are currently being considered by the VSL. Discussions with VSL staff have indicated a desire to increase the concentration of CaO, which has been shown to increase sulfur solubility in the glass, and ZnO, which apparently retards corrosion of the melter refractories. In contrast, the EM-50 glasses bound very well the range in total alkali contents that have been considered by VSL. The reader should also note the position of LAWABP1 and HLP-31 glasses in Figure 2-24, which are the two glasses that form the base and sensitivity cases with respect to compositional effects on the glass release rate in this performance assessment.

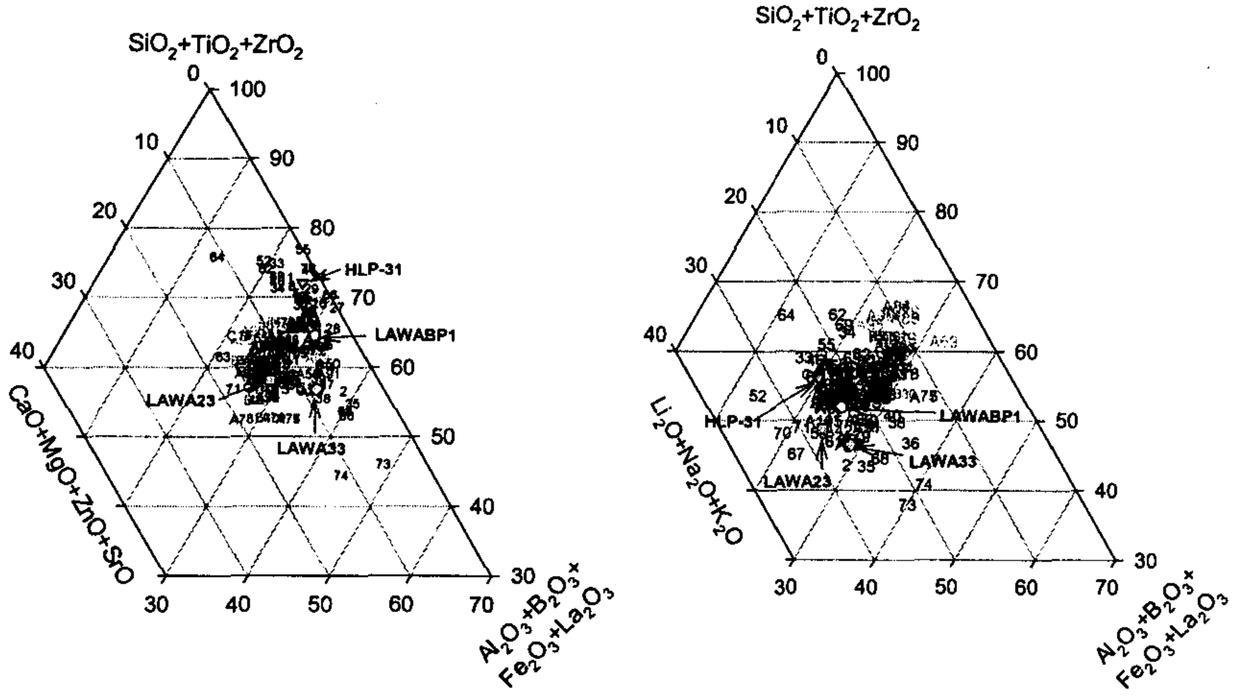


Figure 2-24. Ternary Diagrams Depicting Compositional Variability for ILAW Glasses. Symbols "A##" (Blue) are Envelope A glasses, low sulfur; "A##" (Cyan) are Envelope A glasses, high sulfur; "B##" (Green) are Envelope B glasses; "C##" (Red) symbols are Envelope C glasses; and (Black) symbols with numbers only are the EM-50 HLP series glasses. Reference ILAW glasses evaluated extensively for ILAW performance assessments are shown as diamonds (Yellow).

In addition to the processing and product acceptance requirements discussed previously, there are two acceptance specifications with respect to the chemical durability of the ILAW glass product of importance to this PA, which are as follows:

1. Product Consistency Test (PCT): The normalized mass loss of sodium, silicon, and boron shall be measured using a seven-day PCT run at 90°C as defined in ASTM C1285-98. The test shall be conducted with a glass to water ratio of 1 gram of glass (-100 +200 mesh) per 10 milliliters of water. The normalized mass loss shall be less than 2.0 grams/m^2. Qualification testing shall include glass samples subjected to representative waste form cooling curves. The PCT shall be conducted on waste form samples that are statistically representative of the production glass.

2. Vapor Hydration Test (VHT): The glass corrosion rate shall be measured using a seven day VHT run at 200°C as defined in the DOE concurred upon Product and Secondary Waste Plan. The measured glass alteration rate shall be less than 50 grams/(m^2-day). Qualification testing shall include glass samples subjected to representative waste form cooling curves. The VHT shall be conducted on waste form samples that are statistically representative of the production glass.

Figure 2-25 shows the available data with respect to VHT and PCT test results in comparison with the product durability specifications. The results show that most of the ILAW glasses that have been tested comply with the product specifications. The baseline glass formulation used in this PA (LAWABP1) plots in the middle range of product performance as measured by these two tests; however, HLP-31 glass (sensitivity case glass) violates both acceptance criteria. Although not the poorest performing glass that has been tested, HLP-31 does represent an extreme in terms of glass composition and durability with respect to the majority of the ILAW glasses tested to date. Figure 2-25 also shows that the short-term PCT-A test is a poor predictive test in terms of longer-term glass durability, which is better represented by the more aggressive VHT. For the majority of the ILAW glasses, PCT-A normalized release is between 0.2 and 0.6 g/m², a factor of 3 spread. However, these same glasses exhibit more than 4 orders of magnitude spread in their VHT corrosion rate. These data present a compelling argument for maintaining both PCT-A and VHT tests as combined product acceptance tests for ILAW.

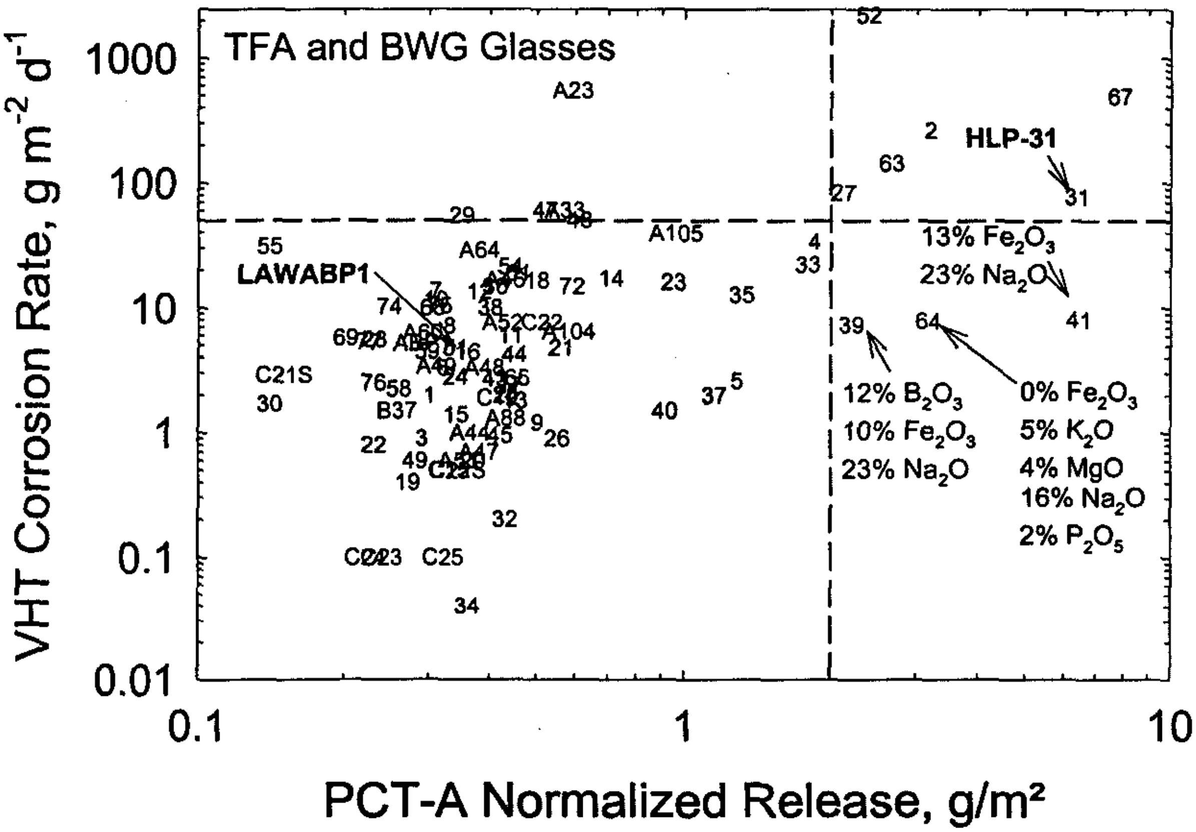


Figure 2-25. Comparison of VHT and PCT-A Test Performance of ILAW Glasses with Respect to DOE Product Acceptance Specifications

2.3.6 Packaging and Certification

The physical, chemical, and radiological properties of the waste at the time of disposal have not been completely determined. At the time of the start of this analysis, the waste form was expected to be contained in metal containers with external dimensions of 1.4 m by 1.4 m by 1.4 m (about 4.6 by 4.6 by 4.6 ft) (DOE-RL 1996). Modification 12 of the BNFL contract (see DOE/BNFL 1998) was issued on January 24, 2000, and required ILAW canisters in the form of right circular cylinders (1.22 m diameter by 2.29 m tall). This occurred after the data packages used in these analyses were issued and will not be explicitly addressed in this report. Future work will use the latest dimensions for the waste package and other facility information. However, a sensitivity case in this analysis shows that such a container size change is not significant to the conclusions of this performance assessment.

Based on Case 3 of the TWRSO&UP (Kirkbride 1999), Phase 1 produces a total of 117,605 MT of ILAW, which corresponds to approximately 19,295 ILAW packages. The Phase 1 contractor will deliver the ILAW product in 1.4 m cube-shaped packages. Each package contains 2.3 m^3, or 6095 kg, of glass. Phase 2 produces a total of 301,374 MT of ILAW, which corresponds to approximately 49,446 ILAW packages. Because no specific guidance is provided for Phase 2 ILAW packaging, the Phase 1 standard package was used for Phase 2. Table 2-6 summarizes the ILAW volume, mass, and number of packages for the reference case (Case 3 of the TWRSO&UP) (Kirkbride 1999).

Table 2-6. Summary of Phase 1 and Phase 2 ILAW Package Production.

	Total m^3 glass	Total MT glass	Total Packages
Phase 1	44379	117605	19295
Phase 2	113726	301374	49446
Total	158105	418979	68741

A product-acceptance strategy has been prepared (Westsik 1997) and is being revised to accommodate the latest waste form formulations. Implementing the strategy requires a product-acceptance process that consists of a series of steps over many years. The steps include developing and maintaining product specifications, conducting contractor qualification testing and evaluation before production, DOE verification testing before production, contractor certification testing and reporting during production, and DOE acceptance testing according to a not-yet-determined product acceptance procedure during ILAW production and operation of the disposal facilities.

2.3.7 Transportation and Waste Emplacement

After the DOE has approved a waste package for acceptance, DOE may choose to have the contractor store that package for up to 90 days. The details of this interim storage activity have not yet been defined. After the storage period has ended, DOE will transport the packages to the disposal site. Current plans call for the packages to be transported by a special truck. For remotely handled waste (all the waste considered in this performance assessment), cranes will remove the waste package from the vehicle and place it directly into the disposal facility.

2.4 DISPOSAL TECHNOLOGY

The design process for the disposal facilities evolved since the last performance assessment. Conceptual designs were developed for the modification and use of the existing disposal vaults (Pickett 1998a) and the construction of new concrete disposal vaults (Pickett 1998b). In December 1999, the DOE identified the remoted-handed (RH) waste trench as the baseline concept for ILAW disposal at the Hanford Site. The RH waste trench complex would be constructed in the same location as the new ILAW disposal facility.

Future disposal designs may include alternative trench disposal concepts, reuse of processing canyon facilities, and reuse of the storage tanks. Once plans are developed, the analyses of any of these options will be performed in future performance assessments.

Since the last performance assessment was issued, a preliminary closure plan was issued (Burbank 2000) and approved (Boston 2000).

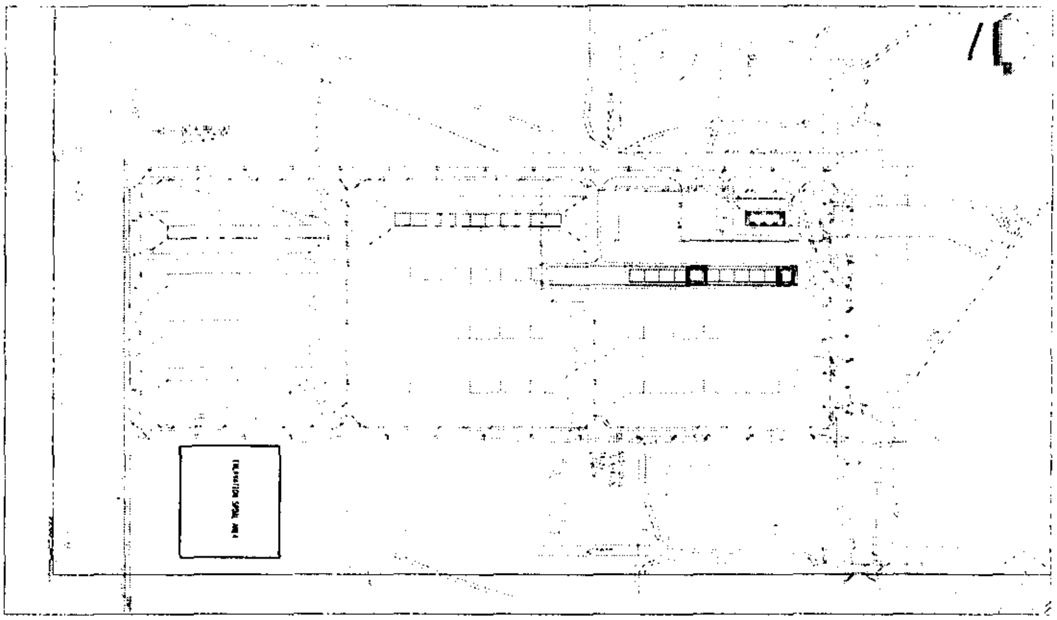
2.4.1 Current Remote-Handled Trench Planning

2.4.1.1 Preconceptual Design. The RH Waste trench complex would be constructed in the ILAW disposal site (see Figure 2-26 for the potential locations of trenches within the disposal site). The RH waste trench conceptual model is depicted in Figure 2-27. The RH waste trench internal dimensions are 260 m long by 80 m wide by 10 m deep. The trench sides have a 3:1 slope. Trench construction requires excavation of 1.9×10^5 m^3 of soil. The trench liner surface area is about 2.9×10^4 m^2.

The trench is provided with a primary and secondary liner as depicted in Figure 2-28. Beneath both the primary and secondary liner is an admix layer (bentonite clay/soil mixture) 0.5 m and 1 m thick, respectively. The operations layer consists of crushed concrete and soil. The thickness of this layer is assumed to be 0.9 m (3.0 ft). Because the liners have relatively short design lives (at most hundreds of years) compared to the waste form, the liners are not considered in the simulations.

The specific design shown in Figure 2-28 was taken from the remote-maintained Radioactive Mixed Waste (RMW) Land Disposal Facility (drawing H-2-131579 Rev. 3). The primary and secondary drainage gravel are for the two drainage (leachate) collection systems associated with RCRA-compliant disposal facilities. Both the primary and secondary drainage layers consist of a geocomposite drainage layer on top of high-density polyethylene (HDPE), as required by RCRA. The geocomposite cage consists of geonet bonded to geotextile. Geotextile is placed above each gravel layer. The specifications for these materials as used in the RMW Land Disposal Facility trenches are given in the WHC Project W-025 specifications (WHC 1994).

Figure 2-26. Layout of ILAW Disposal Facility.



Because the trench walls have a fairly shallow slope (3 m run for every 1 m rise) each successive layer can be increased in both length and width. Whereas the first layer could be 14 packages wide by 132 packages long (14-by-132 matrix), the second layer could be a 22-by-140 matrix (assuming 1.5 m center-to-center packing of the ILAW packages). The uppermost (fourth) layer could be a 42-by-160 matrix. This means that, while a baseline new ILAW disposal facility trench capacity is 11,088 ILAW packages, the RH waste trench capacity theoretically could be 16,448 packages.

Packing the ILAW packages in such large, contiguous matrix (42 by 160 packages for the fourth lift [a single layer of ILAW packages and cover soil]) would, however, create operational impediments. About 100 ecology blocks (i.e. shielding blocks) would be required to create a shielding array between the leading face and operations area of the fourth lift. When it became necessary to advance the ecology blocks, movement of such a large number would be a significant undertaking, potentially requiring several shifts to complete. During this period the trench would be unavailable to receive ILAW packages.

Figure 2-27. RH Waste Trench Conceptual Model.

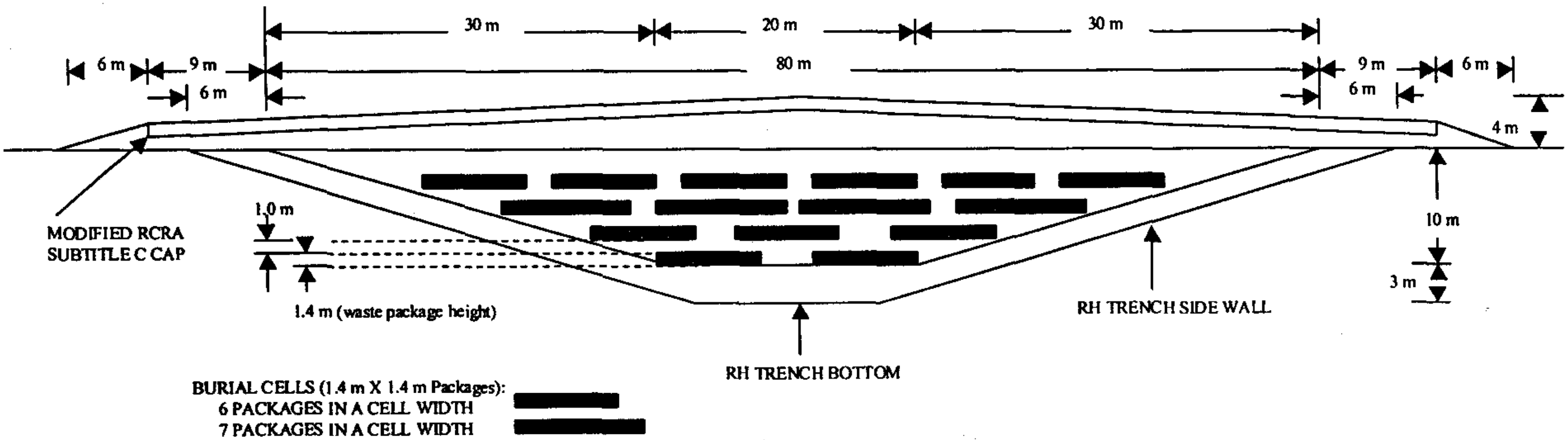
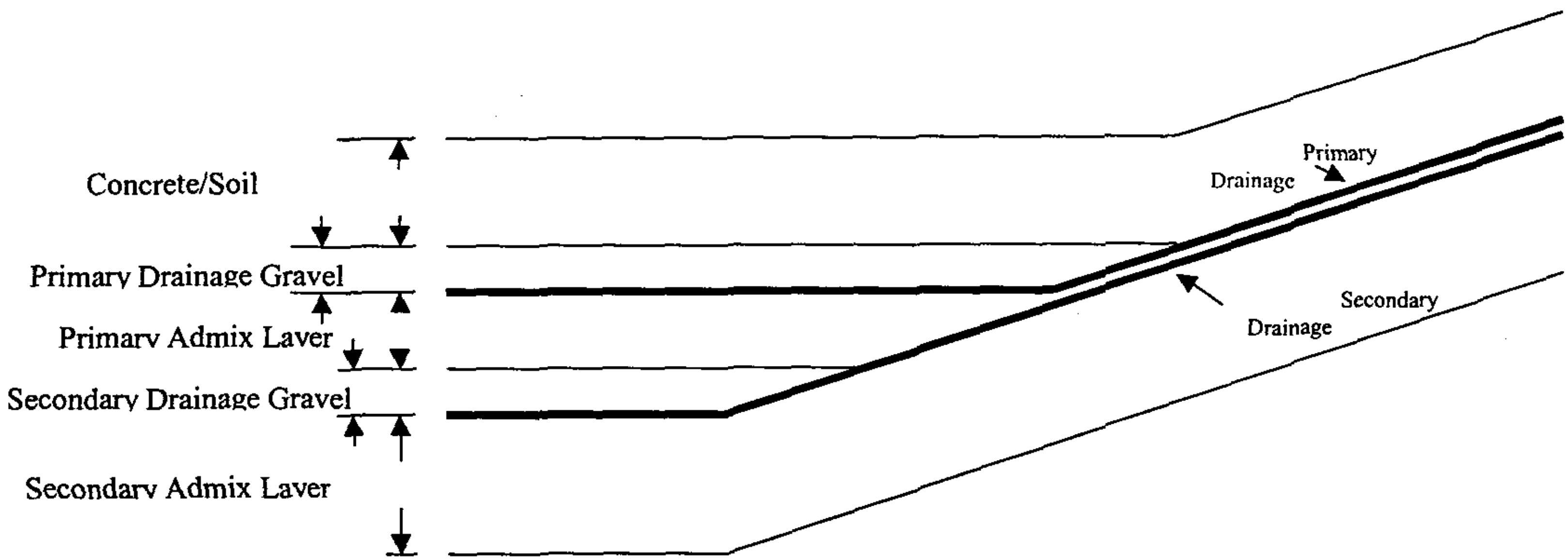


Figure 2-28. RH Waste Trench Liner Details.



To facilitate continuous receiving operations, the matrix is limited to a smaller size than that which would contiguously cover the entire layer. These smaller matrices, called burial cells, provide the following benefits.

Corridors are created within the disposal matrix to facilitate access for operational activities such as the placement of cover soil.

The size of the exposed leading face is minimized.

The number of ecology blocks required to establish an effective radiation shield is reduced to a number that can be moved easily in a single shift.

A larger portion of the trench can be covered with a rain curtain, thereby reducing the quantity of collected leachate that must be dispositioned.

Figure 2-26 shows a conceptual layout of a trench with these burial cells. Specific details of the trench packing are presented in Table 2-7. Given this packing density, approximately 6 trenches are needed to accommodate the entire Phase 1 and Phase 2 ILAW production.

Table 2-7. Trench Packing Characteristics.

Layer	Cells per layer	Matrix size per cell	Packages per layer
1	2	6 x 132	1,584
2	3	6 x 140	2,520
3	4	7 x 150	4,200
4	6	6 x 160	5,760
Total packages per trench			14,064

2.4.1.2 Trench Fill Material. The RH waste trench preconceptual model includes backfilled soil around and on top of the waste containers in the facility. The soil was included in this concept for the following three reasons:

For structural support. The initial design from *Immobilized Low Level Waste disposal Options Configuration Study*, WHC-SD-WM-TI-686 (Mitchell 1995) had void space between the immobilized low-activity waste containers and between the containers and the ceiling. Filling this space with soil would help prevent significant subsidence of the physical barriers when the components of the disposal system (waste container, waste form, disposal facility structure) fail and collapse into the void space.

To wick moisture away from the waste containers.

To provide radiation shielding for the facility workers.

2.4.1.3 Disposal Unit Closure. All the concepts have a similar barrier philosophy. The uppermost barrier is the surface barrier designed to minimize intrusion and recharge. Beneath the surface barrier, a sand-gravel capillary break will divert any moisture that may come through the surface barrier away from the trench. These two barriers implement the goal of minimizing the amount of water that enters the trench. However, the extent of the barriers differs for the different concepts. The current preconceptual design has a modified RCRA-compliant subtitle C barrier (Puigh 1999) with a 2 percent slope (see Figure 2-27). More information can be found in *Preliminary Closure Plan for the Immobilized Low Activity Waste Disposal Facility* (Burbank 2000), which was approved by Boston 2000b.

2.4.1.4 Disposal Site Closure. Disposal site closure is presumed to consist of applying the surface barrier between the units and placing passive controls on the surface. The intent of the surface barrier is to use evaporation and plant transpiration to minimize the influx of precipitation into the disposal system. The surface barrier includes a sand and gravel layer to work as another capillary break to deter burrowing animals, plant root intrusion, and inadvertent intruders.

Passive controls are assumed to be used to deter inadvertent intrusion. However, the type of passive controls has not yet been selected. However, markers, riprap stone, fencing, and administrative controls are being considered.

2.4.2 ILAW Concrete Vault Design—Alternative Concept

An earlier conceptual design for the ILAW disposal facilities (Pickett 1998b) uses a long concrete vault concept divided into cells. Each vault will be an underground, open-topped, concrete vault approximately 23 m (76 ft) wide and 207.8 m (686 ft) long. The total vault height was increased to 11.0 m to accommodate the new waste package dimensions. The top of the vault walls will extend 1 m (3.3 ft) above grade. Each vault will be divided into 11 cells, separated by concrete partition walls. The concrete vault concept is analyzed in this performance assessment to provide a relative measure of its performance when compared to the RH waste trench concept and as a general sensitivity case for facility design. Also, the immobilized waste program is considering the use of the existing concrete vaults for other disposal needs.

Each vault will be built above a RCRA-compliant leak detection and collection system. The leak detection and collection system consists of a cast-in-place reinforced concrete basin approximately 209.5 m (687.3 ft) long and 24.7 m (81 ft) wide with walls 1.07 m (3.5 ft) high. The basin floor is 0.6 m (2 ft) thick and contains steel reinforcing bars within. The catch basin is lined with two flexible membrane liners, and on top of these lie a layer of gravel with perforated collection pipe routed to sumps, one at each end of a vault. Liquids entering the sump can be removed using a portable pump lowered down a riser pipe.

Interim closure for each filled cell in the new disposal facility will consist of using inert backfill material followed by a "controlled density fill," unreinforced concrete. A waterproof membrane will be placed above the "controlled density fill." After all cells in the vault have been filled and interim closed, a closure cap consisting of a capillary break followed by a modified RCRA C cap will be placed over the entire vault.

2.4.3 Possible Future Disposal Concepts

The disposal alternatives and generation analysis (Burbank 1997) investigated a series of possible disposal facilities including the following:

- A land-filled trench (without RCRA-compliant double containment)
- Existing large concrete buildings
- Existing underground tanks.

The existing tank waste contains listed hazardous waste and, hence, falls under the jurisdiction of RCRA. Unless such waste is treated to no longer be hazardous and is "delisted" (formally removed from regulation), the RCRA requirements (40 CFR 260 to 40 CFR 268) apply. In Washington State, Ecology administrates these federal regulations under WAC 173-303. An important requirement is that the waste be double contained and monitored. That is, the waste volume must be monitored and a second containment system must be in place to hold any leaked waste until it can be collected. The proposed RH waste trench and the conceptual design for the concrete disposal vaults (Pickett 1998b) have such systems. The production of the immobilized low-activity waste (ILAW) will destroy all significant quantities of listed hazardous waste and the ILAW will have properties making it an extremely stable waste form. Thus ILAW should be able to be delisted. However, if the ILAW is not delisted, a RCRA-compliant facility would be needed (see Figure 2-28). Such a facility is estimated to add about 3 to 4 million dollars in construction costs for each row over a base construction cost of about 25 million dollars.

Because of the significant variation in expected tank waste compositions, many of the disposal packages may have radiation levels low enough to permit contact handling. Burbank (1997) investigated the possibility of configuring some of the disposal rows as contact-handled waste disposal trenches. The construction costs for such facilities (4.6 million dollars for a mixed waste trench and 1.3 million dollars for a non-mixed waste trench) are significantly lower than for concrete structures. Lifetime operating costs for the trenches (approximately 11 million dollars per trench) also would be significantly lower than for the concrete facilities (approximately 21 million dollars per vault row). However, the number and production timing of such contact-handled packages cannot be determined until further information is available concerning individual tank inventories, the tank retrieval sequence, efficiencies of waste separation, and vendors' separation plans. The program is actively considering this option for waste later in the program.

The Hanford Site's plateau has a number of facilities that are or soon will be considered surplused. Burbank 1997 investigated the use of both the very large process canyon buildings and the underground tanks presently storing the waste. It is estimated that the building could hold only as little as 24 percent of the ILAW packages in their interior. The per-package life-cycle cost of this option is about a factor of 2.5 higher than for new concrete structures, primarily because these large radioactive facilities need extensive modifications and a large closure area. If waste packages were placed outside these facilities as well, the life-cycle cost per package would be comparable to the concrete facilities costs. In neither case, have avoidance costs of demolishing the canyon buildings been considered. Note that none of the canyon buildings will be available for many years. However, the program is considering this option for waste received after 2010.

The use of single-shell tanks as the disposal facility for waste packages also was investigated by Burbank (1997). The conclusion was that the capital costs for opening the domes of the tanks to allow access for the current package shape was prohibitively expensive (100 to 300 million dollars per equivalent vault row).

3.0 ANALYSIS OF PERFORMANCE

3.1 OVERVIEW

This chapter describes the models, computer codes, and input data used to analyze the long-term performance of the proposed disposal facilities. For the analyses, the information discussed in Chapter 2 is translated into a conceptual physical model, then into a numerical model. The chapter also provides justification for the translations.

The strategy for this assessment was to define and analyze both a base analysis case and sensitivity cases bracketing the base analysis case. The base analysis case was developed using best information for the environmental, waste form, and disposal facility parameters and how the parameters will change with time. These best estimates are defined and justified in separate published reports that have been combined in *Data Packages for the Hanford Immobilized Low-Activity Tank Waste Performance Assessment: 2001 Version* (Mann/Puigh 2000a). Sensitivity cases were developed based on the uncertainty information provided in the data packages. The base analysis case was defined in *Simulations for Hanford Immobilized Low-Activity Tank Waste Performance Assessment: 2001 Version* (Puigh 2001), which also contains a list of sensitivity cases.

This chapter shows how the physical systems presented in Chapter 2 are translated into the numerical models that produce the results presented in Chapters 4 and 5. The chapter covers the following topics:

Inventory Source (Section 3.2). Describes the radionuclide inventories.

Pathways and Scenarios (Section 3.3). Explains the pathways and scenarios that were analyzed.

Values and Assumptions (Section 3.4). Presents the assumptions use in the analyses, including the actual data.

Performance Assessment Methodology (Section 3.5). Presents methodology used in the analyses, including the actual data used, respectively.

3.2 INVENTORY SOURCE

> Screening analyses reduced the number of relevant radionuclides to 31. A DQO process was used to reduce the number of chemicals to 10. This is the first Hanford Site PA that has addressed chemicals.

3.2.1 Relevant Contaminants of Concern

Both radionuclides and chemicals are treated in this performance assessment. For a fuller discussion of how the included chemicals were chosen, see Section 1.6.2.8.

3.2.1.1 Radioactive Contaminants. The anticipated tank waste inventories were prescreened (Schmittroth 1995a) to determine which radionuclides dominate human health impacts and hence are potential problems for the inadvertent intruder and groundwater pathway scenarios. This prescreening effort included the following activities:

- Calculating the quantities of all isotopes produced during materials production at the Hanford Site
- Calculating, using a simple one-dimensional steady-state model, the transport of such isotopes through the vadose zone beneath the Hanford Site (using both accepted Hanford Site geochemical retardation and unretarded contaminant transport)
- Converting groundwater concentrations to drinking water doses
- Calculating inadvertent intrusion using the homesteader scenario.

The study indicated that the following radionuclides are potentially most important for each scenario:

- Selenium-79, $^{93}Nb^{m}$ (from ^{93}Zr and ^{93}Mo), ^{99}Tc, ^{129}I, and uranium isotopes and their daughters for the groundwater scenario
- Uranium, plutonium, neptunium, and americium isotopes and their daughters for the groundwater scenario in which geochemical retardation effects are ignored
- Strontium-90, ^{99}Tc, ^{137}Cs, ^{126}Sn, ^{227}Ac, ^{239}Pu, and ^{241}Am for the inadvertent intruder scenario.

In the 1998 ILAW PA (Mann 1998a) the radionuclides analyzed were limited to the top 12 contributors from the groundwater scenario, the top 14 contributors from the unretarded groundwater scenario, and the top 10 contributors from the inadvertent intruder scenario. That analysis found that ^{99}Tc, ^{79}Se, and the uranium isotopes were the most important for the groundwater scenario and that ^{126}Sn was the most important one for the inadvertent intruder scenario. The *White Paper Updating the Conclusions of the 1998 ILAW Performance Assessment* (Mann/Puigh 2000b) found that ^{99}Tc, ^{129}I, and the uranium isotopes were most important for the groundwater scenario and that ^{126}Sn, ^{239}Pu, and ^{241}Am were most important for the inadvertent intruder scenario. The relative change in importance for ^{79}Se and ^{129}I were the result of recent geochemical work supporting this PA (see Kaplan 1999 and Section 3.4.3.3) in which laboratory measurements on Hanford Site soils show that Se is retarded, while iodine is not.

Previous Hanford Site performance assessments (Wood 1995a and Wood 1996) have shown that uranium, ^{129}I, and ^{99}Tc are the main radionuclides of concern. Because radionuclides in Hanford Site surface waters come from groundwater, radionuclides important for surface water protection are taken from the groundwater selection analysis.

For this 2001 ILAW PA analysis, the most important radionuclides screened by Schmittroth 1995a again were used. These 36 isotopes contribute over 99 percent of the dose for the scenarios.

3.2.1.2 Chemical Contaminants. A DQO process was performed (Wiemers 1998) to identify the important chemical contaminants. The organics included were those that had greater than 100 analytical detects in tank wastes or greater than 20 analytical detects in TWINS Solids/Liquid Hits. This is the first performance assessment at the Hanford Site to include chemicals.

3.2.2 Decay Data

Decay data (particularly half lives) are needed both for inventory estimates and for dosimetry calculations (see Section 3.4.7). The nuclear data used in this assessment are presented in *Dosimetry Data Package for the Hanford Immobilized Low-Activity Tank Waste Performance Assessment* (Rittmann 1999), and Appendix O of Mann/Puigh (2000a). Most half-lives are well known. As noted in the 1998 ILAW PA, however, the previously accepted half-lives of ^{79}Se and ^{126}Sn now are thought to be underestimates (Chunsheng 1997 and Zhang 1996). This underestimate for ^{126}Sn has been confirmed (Brodzinski 1998). Thus, the inventories for ^{79}Se and ^{126}Sn (as expressed in Ci) from Kirkbride 1999 have been reduced by factors of 0.08 and 0.4, respectively.

3.2.3 Inventory

Inventory values are based on detailed reactor histories and conservative analysis of separations processes.

The inventory for this study is from *Immobilized Low Activity Tank Waste Inventory Data* Package (Wootan 1999) except where noted. This study is based mostly on the best basis inventory program of the Hanford Tanks Program. These values are based on detailed simulations of reactor production histories, chemical separations, and waste processing simulations as verified and supplemented by actual measurements of constituents in various tanks. For the chemicals not listed in the tank inventories, concentration limits for land disposal (40 CFR 268) were used.

Forty-six radionuclides and 25 chemicals are explicitly treated in the best basis tank inventories. These materials were selected by the TWRS [Tank Waste Remediation System] Characterization Program (Kupfer 1999) as those important for safety, disposal, and processing requirements. This set includes all the radionuclides identified as significant in the 1998 ILAW PA (Mann 1998a), along with those identified in the screening studies for the ILAW PAs (Schmittroth 1995).

The nominal ILAW inventories for all the materials explicitly included are based on the *Tank Waste Remediation System Operation and Utilization Plan* (Kirkbride 1999). The best basis tank-by-tank inventories (BBI) as of October 1, 1998, were adjusted for waste transfers not accounted for in the BBI, and for non-BBI analytes that are in the waste treatment contract. The BBI inventories were adjusted to a common date (October 1, 1998). The BBI values are based on a tank-by-tank evaluation of measurements from a tank, as well as modeling results of transfers to and from the tank. The retrieval and feed delivery process was modeled by estimating liquid and solid partitioning (Hendrickson 1999) and following the April 1, 1999, DOE guidance (Taylor 1999b) on schedules and contract requirements. Vitrification losses (melters, stack emissions, secondary waste streams, etc.) were explicitly included in the model and are described in Kirkbride 1999. The total ILAW waste volume is estimated to be 1.581×10^5 m^3. The required number of waste packages needed to contain the projected ILAW inventory is estimated as 68,741. Kirkbride 1999 represents the ILAW project's official estimate until the next waste treatment plant contractor's flow sheets become available.

Table 3-1 provides the total inventory in the tanks and in the ILAW packages, as well as the expected average and maximum concentration in the ILAW packages for each radionuclide and chemical affecting the performance objectives and goals given in Tables 1-3 and 1-4. The upper bound ILAW inventory given in Table 3-1 represents the estimated upper bound for these inventories in ILAW. The upper bound estimates are based on either contract limits (for strontium, technetium, cesium, neptunium, plutonium, americium, and curium) or are taken to be the BBI tank inventories without separation. The average package concentration is calculated by dividing the total inventory for each contaminant by the number of waste packages estimated to be produced (68,471 packages). The maximum batch concentration is estimated from the comparison of the batch-to-batch variation in Kirkbride's (1999) flow process calculations to the average inventories in a waste package. These estimates reflect the tank-to-tank variation in inventory. For most components, the upper bound limit on total ILAW inventory was taken as the BBI tank inventory, ignoring any processing and separation losses. For radionuclides limited by the contract specifications (^{99}Tc, ^{137}Cs, ^{90}Sr, and transuranic), the contract limits (DOE/BNFL 1998) were used as upper bounds. Ignoring the processing losses between the tank inventory and the ILAW inventory provides a very conservative bounding value, but was used to compensate for the lack of information about the uncertainty of the separations factors (wash and leach effectiveness, off-gas treatment, solids retention).

Table 3-1. ILAW Inventories and Concentrations for Important Constituents.

(Curies, decayed to October, 1994, for radionuclide and kg for chemical and Ci/m^3 for radionuclide and kg/m^3 for chemical)

Material	Tank Inventory	ILAW Inventory	Upper Bound ILAW Inventory	Average Package Concentration	Maximum Batch Concentration
3-H	2.46E+04	0.00E+00	2.46E+04	0.00E+00	0.00E+00
14-C	4.38E+03	0.00E+00	4.38E+03	0.00E+00	0.00E+00
59-Ni	8.58E+02	1.67E+02	8.58E+02	1.06E-03	4.02E-03
60-Co	1.99E+04	4.18E+03	1.99E+04	2.64E-02	3.07E-01

Table 3-1. ILAW Inventories and Concentrations for Important Constituents.

(Curies, decayed to October, 1994, for radionuclide and kg for chemical and Ci/m^3 for radionuclide and kg/m^3 for chemical)

Material	Tank Inventory	ILAW Inventory	Upper Bound ILAW Inventory	Average Package Concentration	Maximum Batch Concentration
63-Ni	8.45E+04	1.62E+04	8.45E+04	1.02E-01	3.91E-01
79-Se	5.74E+01	4.80E+01	7.45E+01	3.03E-04	5.45E-03
90-Sr [a]	5.99E+07	4.50E+06	5.85E+06	2.85E+01	5.43E+01
93-Zr	4.12E+03	1.25E+03	4.12E+03	7.94E-03	3.37E-02
93m-Nb	2.53E+03	8.36E+02	2.53E+03	5.29E-03	4.47E-02
99-Tc	2.89E+04	5.79E+03	6.65E+03	3.66E-02	9.96E-02
106-Ru	1.27E+05	8.94E+02	1.27E+05	5.65E-03	2.59E-01
113m-Cd	1.67E+04	7.97E+03	1.67E+04	5.04E-02	2.14E-01
125-Sb	2.47E+05	5.20E+04	2.47E+05	3.29E-01	6.50E+00
126-Sn	4.64E+02	1.69E+02	4.64E+02	1.07E-03	4.17E-03
129-I	1.01E+02	2.20E+01	1.01E+02	1.39E-04	1.81E-03
134-Cs	8.71E+04	3.76E+02	4.89E+02	3.73E-01	1.35E+01
137-Cs [b]	6.37E+07	9.11E+05	1.18E+06	5.76E+00	7.80E+00
151-Sm	2.61E+06	7.80E+05	2.61E+06	4.93E+00	2.42E+01
152-Eu	1.45E+03	3.07E+02	1.45E+03	1.94E-03	4.21E-02
154-Eu	1.83E+05	3.77E+04	1.83E+05	2.38E-01	6.13E+00
155-Eu	1.76E+05	3.15E+04	1.76E+05	1.99E-01	7.36E+00
226-Ra [c]	6.31E-02	5.70E-02	1.14E+03	3.61E-07	1.56E-05
227-Ac [c]	8.76E+01	6.06E-02	8.75E+01	3.83E-07	1.76E-06

Table 3-1. ILAW Inventories and Concentrations for Important Constituents.

(Curies, decayed to October, 1994, for radionuclide and kg for chemical and Ci/m^3 for radionuclide and kg/m^3 for chemical)

Material	Tank Inventory	ILAW Inventory	Upper Bound ILAW Inventory	Average Package Concentration	Maximum Batch Concentration
228-Ra[c]	7.71E+01	3.30E+01	7.75E+01	2.09E-04	1.06E-03
229-Th[c]	1.81E+00	3.40E-01	1.81E+00	2.15E-06	1.14E-05
231-Pa[c]	1.56E+02	3.44E-01	1.53E+02	2.17E-06	1.05E-05
232-Th	4.40E+00	1.28E+00	4.40E+00	8.09E-06	5.97E-05
232-U	1.49E+02	3.46E+01	1.49E+02	2.19E-04	1.64E-03
233-U	5.72E+02	1.31E+02	5.72E+02	8.26E-04	6.22E-03
234-U	3.42E+02	4.41E+01	3.42E+02	2.79E-04	1.95E-03
235-U	1.46E+01	1.79E+00	1.46E+01	1.13E-05	7.97E-05
236-U	1.24E+01	1.43E+00	1.24E+01	9.03E-06	3.68E-05
237-Np	1.85E+02	8.10E+01	3.00E+02	5.13E-04	1.78E-03
238-Pu	2.70E+03	1.06E+02	3.94E+02	6.72E-04	2.69E-03
238-U	3.28E+02	4.83E+01	3.28E+02	3.06E-04	2.02E-03
239-Pu	5.55E+04	3.05E+03	1.13E+04	1.93E-02	9.50E-02
240-Pu	1.13E+04	5.25E+02	1.95E+03	3.32E-03	1.34E-02
241-Am	1.07E+05	1.08E+04	4.01E+04	6.85E-02	1.69E+00
241-Pu	1.66E+05	7.17E+03	1.66E+05	4.53E-02	1.98E-01
242-Cm	1.72E+02	5.76E+01	1.72E+02	3.64E-04	1.16E-02
242-Pu	1.07E+00	4.49E-02	1.66E-01	2.84E-07	1.69E-06
243-Am	1.76E+01	6.89E-01	2.55E+00	4.36E-06	9.01E-05

Table 3-1. ILAW Inventories and Concentrations for Important Constituents.

(Curies, decayed to October, 1994, for radionuclide and kg for chemical and Ci/m^3 for radionuclide and kg/m^3 for chemical)

Material	Tank Inventory	ILAW Inventory	Upper Bound ILAW Inventory	Average Package Concentration	Maximum Batch Concentration
243-Cm	3.47E+01	6.73E+00	2.49E+01	4.26E-05	5.18E-04
244-Cm	7.84E+02	1.01E+02	3.73E+02	6.36E-04	6.77E-03
Ag^{+} (silver)	1.51E+03	1.08E+02	3.03E+03	6.83E-04	5.68E-03
As^{5+} (arsenic)	2.08E+01	1.76E+01	4.15E+01	1.12E-04	7.42E-03
Ba^{2+} (barium)	1.70E+03	1.86E+01	3.39E+03	1.17E-04	7.24E-03
Be^{2+} (beryllium)	1.09E+02	6.14E-01	2.18E+02	3.89E-06	5.48E-04
Cd^{2+} (cadmium)	4.18E+02	6.30E+01	8.36E+02	3.98E-04	5.13E-03
Cl^{-} (chlorine)	9.37E+05	9.31E+05	9.37E+05	5.89E+00	1.55E+01
CN^{-} (cyanide)	1.09E+05	0.00E+00	1.09E+05	0.00E+00	0.00E+00
Cr (TOTAL)(chromium)	6.72E+05	2.74E+05	6.72E+05	1.73E+00	1.27E+01
Cu^{2+} (copper)	3.15E+02	7.33E-01	6.31E+02	4.63E-06	2.54E-05
F^{-} (fluoride)	1.20E+06	9.94E+05	1.20E+06	6.28E+00	2.75E+01
Fe^{3+} (iron)	1.40E+06	4.48E+04	1.40E+06	2.83E-01	2.86E+00
Hg^{2+} (mercury)	2.10E+03	1.92E+02	2.10E+03	1.22E-03	3.38E-02
Mn^{4+} (manganese)	1.96E+05	1.38E+04	1.96E+05	8.71E-02	4.20E-01
NH_3 (ammonia)	5.01E+05	0.00E+00	5.01E+05	2.53E+00	4.24E+01
Ni^{2+} (nickel)	1.80E+05	3.05E+04	1.80E+05	1.93E-01	2.96E+00
NO_2^{-} (nitrite)	1.26E+07	0.00E+00	1.26E+07	0.00E+00	0.00E+00
NO_3^{-} (nitrate)	5.25E+07	0.00E+00	5.25E+07	0.00E+00	0.00E+00

Table 3-1. ILAW Inventories and Concentrations for Important Constituents.

(Curies, decayed to October, 1994, for radionuclide and kg for chemical and Ci/m^3 for radionuclide and kg/m^3 for chemical)

Material	Tank Inventory	ILAW Inventory	Upper Bound ILAW Inventory	Average Package Concentration	Maximum Batch Concentration
Pb^{2+} (lead)	8.40E+04	7.83E+03	8.40E+04	4.95E-02	2.73E-01
Se^{6+} (selenium)	6.11E-01	5.33E-01	1.22E+00	3.37E-06	2.96E-05
SO_4^{2-} (sulfate)	3.91E+06	3.39E+06	3.91E+06	2.15E+01	9.12E+01
Tl^{3+} (thallium)	2.54E+04	NA	5.08E+04	0.00E+00	0.00E+00
Zn^{2+} (zinc)	2.89E+03	1.98E+03	5.79E+03	1.25E-02	1.19E-01
U (TOTAL) (uranium)[d]	7.61E+04	1.73E+04	7.61E+04	1.11E-01	2.16E+00
1,1,1-trichlorethane[e]	NA	0.00E+00	9.17E+02	0.00E+00	0.00E+00
1,1,2-trichloroethane[e]	NA	0.00E+00	9.17E+02	0.00E+00	0.00E+00
benzene[e]	NA	0.00E+00	1.53E+03	0.00E+00	0.00E+00
carbon tetrachloride[e]	NA	0.00E+00	9.17e+02	0.00E+00	0.00E+00
chloroform[e]	NA	0.00E+00	9.17E+02	0.00E+00	0.00E+00
ethyl benzene[e]	NA	0.00E+00	1.53E+03	0.00E+00	0.00E+00
methylene chloride[e]	NA	0.00E+00	4.59E+03	0.00E+00	0.00E+00
n-butyl alcohol[e]	NA	0.00E+00	3.98e+02	0.00E+00	0.00E+00
toluene[e]	NA	0.00E+00	1.53E+03	0.00E+00	0.00E+00
trichloroethylene (1,1,2-trichloroehylene)[e]	NA	0.00E+00	9.17E+02	0.00E+00	0.00E+00
xylenes-mixed isomers (sum of m-, o-, and p-xylene)[e]	NA	0.00E+00	4.59E+03	0.00E+00	0.00E+00
1,4-dichlorobenzene[e]	NA	0.00E+00	9.17E+02	0.00E+00	0.00E+00

Table 3-1. ILAW Inventories and Concentrations for Important Constituents.

(Curies, decayed to October, 1994, for radionuclide and kg for chemical and Ci/m^3 for radionuclide and kg/m^3 for chemical)

Material	Tank Inventory	ILAW Inventory	Upper Bound ILAW Inventory	Average Package Concentration	Maximum Batch Concentration

[a]The ^{90}Sr will have ^{90}Y daughter in equilibrium
[b]The ^{137}Cs will have ^{137m}Ba daughter in equilibrium
[c]These values have been adjusted based on the Kufper (1999) estimate for tank inventory. Inventories for radionuclides are as of 10/1/98.
[d]Total uranium is expressed as kg/m^3 (i.e. as a chemical).
[e]Tank inventories of specific organic compounds are not available; organic compounds are not expected to survive the vitrification process. "NA" indicates components for which inventory information is not available.

The ILAW packages must meet the land disposal restriction (LDR) treatment standards for compliance with RCRA and the "Washington State Dangerous Waste Regulations" contained in WAC 173-303. The LDR regulations are found in 40 CFR 268 and WAC 173-303-140. The privatization regulatory DQO (Wiemers 1998) identified a set of regulatory constituents that plausibly could be in the tank waste and might be considered during permitting activities supporting the treatment facility. The TWRS-P Project Dangerous Waste Permit Application (BNFL 1999) compared these constituents to the "Universal Treatment Standards" (40 CFR 268.48) and provided a list of components and LDR treatment standards. These LDR treatment standards provide an upper bound concentration for acceptability of the ILAW product. These maximum concentrations were multiplied by the total glass mass, along with a safety factor of 1.3 (assumed) to allow for uncertainty in the total glass mass, to provide bounding inventories of trace hazardous organic chemicals in the ILAW product.

The key materials are as follows:

^{3}H No tritium is expected to survive the vitrification process to end up in ILAW packages (Kirkbride 1999).

^{14}C No ^{14}C is expected to survive the vitrification process and end up in the ILAW packages (Kirkbride 1999).

^{79}Se Results are based on models, but are considered conservative, because the model ignores previous removals such as disposals to cribs.

^{90}Sr Values are constrained by the contract (DOE/ORP 2000c) based on Class C limit and assumption that this constraint applies to all ILAW waste.

^{99}Tc Values based on BBI (reference inventory) and phase 1 contract requirement (DOE/ORP 2000c) to remove 80 percent of the tank inventory from ILAW. Calculation assumes this requirement extends to Phase 2 ILAW production. The tank inventory estimate is felt to be conservative because any losses associated with the offsite shipments are not factored into the BBI inventory for ^{99}Tc. Based on the results on this performance assessment, studies are proceeding to study the benefits of eliminating the 80 percent removal requirement from the contract.

^{126}Sn Values are based on BBI estimate with a separations factor of 36 percent of the BBI (Kirkbride 1999). Few tank measurements for ^{126}Sn exist. The BBI estimates for ^{126}Sn in tanks 241-AZ-101 and 241-AZ-102 are higher than the measurements.

^{129}I Values are based on BBI and estimate for 0.22 captured and recycled into ILAW (Kirkbride 1999).

^{137}Cs Values are constrained by the contract (DOE/ORP 2000c) based on the Class C limit.

U Many of the values are based on total uranium analysis of samples.

Ra These are daughter products of uranium and thorium that were not treated correctly in the Hanford Defined Waste (HDW) model because uranium, thorium, and plutonium were decayed before separations (Kupfer 1999). The values in Table 3-1 have been adjusted based on the Kufper (1999) estimate for tank inventory.

^{227}Ac This is a daughter product of uranium and thorium that was not treated correctly in the HDW model because uranium, thorium, and plutonium were decayed before separations (Kupfer 1999). The values in Table 3-1 have been adjusted based on the Kufper (1999) tank inventory estimate.

^{229}Th This is a daughter product of uranium and thorium that was not treated correctly in the HDW model because uranium, thorium, and plutonium were decayed before separations (Kupfer 1999). The values in Table 3-1 have been adjusted based on the Kupfer (1999) tank inventory estimate.

^{241}Am The values are equal to approximately 10 percent of the total BBI tank inventory estimate (separations estimate from Kirkbride [1999]) and are felt to be conservative.

^{231}Pa This is a daughter product of uranium and thorium that was not treated correctly in the HDW model because uranium, thorium, and plutonium were decayed before separations (Kupfer 1999). The values in Table 3-1 have been adjusted based on the Kufper (1999) tank inventory estimate.

^{237}Np The values are based on the BBI and the large separations factor (44 percent of BBI) from Kirkbride (1999). The BBI estimate is felt to be conservative because the inventory estimate is 30 percent higher than the global estimate for all ^{237}Np produced by the reactors. Tanks 241-AN-103 and 241-AN-105 are thought to have 30 percent of the ^{237}Np, but only bounding value estimates are provided for these two tanks.

Pu Plutonium values are based primarily on weapons production accountability records and samples. Significant separation factors (5 percent of BBI) are taken from Kirkbride (1999).

Table 3-2 summarizes the changes that have occurred to the inventory estimates since the last ILAW performance assessment released in 1998 (Mann 1998a). The changes are given for the radionuclides found to be most important in this performance assessment. These changes can be grouped into the following categories: changes in the estimated tank inventories, changes in the half-life estimates, and changes to the estimated separation factors associated with the separation and processing of the tank waste stream into high-level and low-activity fractions.

Table 3-2. Inventory Estimate Changes from 1998 ILAW PA.

Radionuclide	ILAW Inventory Estimate (Ci)*		Sources of Changes			
	1998 PA	2001 PA	Tank Inventory*	Half-life	Separation Factor	Total
^{3}H	8.04E+04	0.00E+00	0.31	1.00	0.00	0.00
^{14}C	7.73E+00	0.00E+00	1.10	1.00	0.00	0.00
^{79}Se	1.03E+03	4.80E+01	0.70	0.08	0.84	0.05
^{90}Sr	1.61E+06	4.50E+06	1.12	1.00	2.49	2.80
^{99}Tc	2.23E+04	5.79E+03	1.06	1.00	0.24	0.26
^{126}Sn	1.58E+03	1.69E+02	0.73	0.40	0.36	0.11
^{129}I	6.62E+00	2.20E+01	1.53	1.00	2.18	3.32
^{137}Cs	4.51E+05	9.11E+05	1.41	1.00	1.43	2.02
^{231}Pa	1.45E+02	3.44E-01	1.08	1.00	0.00	0.00
^{233}U	2.58E+01	1.31E+02	1.33	1.00	3.82	5.08
^{234}U	1.80E+01	4.41E+01	1.14	1.00	2.15	2.45
^{238}U	1.78E+01	4.83E+01	1.10	1.00	2.46	2.71
^{237}Np	3.74E+00	8.10E+01	2.47	1.00	8.76	21.66
^{240}Pu	4.31E+02	5.25E+02	1.58	1.00	0.77	1.23
^{241}Am	4.25E+03	1.08E+04	2.02	1.00	1.26	2.54

* Tank and ILAW Inventories not adjusted for differences in decay dates for 1998 PA (01/01/10) and 2001 PA (10/01/94)

In Table 3-2 the tank inventory change is the ratio of the 2001 ILAW PA inventory estimate (Wootan 1999) to the 1998 ILAW PA inventory estimate (Mann 1998a). (The estimates were not corrected for the difference in inventory reference date, January 1, 2010 for the 1998 ILAW PA and October 1, 1994 for the 2001 ILAW PA). The tank inventory changes are due to the evolution in our understanding from the earlier estimates, based primarily on reactor production calculations and estimates for processing campaigns that initially generated the waste in the tanks, to more mature models for these processes and specific composition measurements conducted on waste samples from the tanks. From Table 3-2 the following radionuclide inventory estimates changed by more than 40%: ^{3}H, ^{14}C, ^{129}I, ^{137}Cs, ^{237}Np, ^{240}Pu and ^{231}Am.

In Table 3-2 the change in inventory estimate due to a change in the half-life estimate impacted the inventory, expressed in Ci, for ^{79}Se and ^{126}Sn.

The change in estimated separation factors between the 2001 ILAW PA and the 1998 ILAW PA are represented by the change in separation factor given in Table 3-2. The change in separation is estimated by dividing the ratio of ILAW inventory to tank inventory for the 2001 ILAW inventory (estimates given in Table 3-1) by the ratio of the ILAW inventory to the tank inventory for the 1998 ILAW inventory (estimates given in Table 3-1 in Mann 1998a). A separation factor value of one would correspond to the case where the same separation factors were assumed for both the 1998 and 2001 ILAW inventory estimates. The value of approximately zero indicates that those isotopes that were estimated to be important in the 1998 ILAW PA are essentially removed for the ILAW inventory estimates for the 2001 ILAW PA. Specifically, ^{3}H, ^{14}C, and ^{231}Pa are no longer important due to their separation from the ILAW waste form. Similarly, ^{237}Np separation factor is larger; and therefore, a larger fraction of the tank inventory is estimated to be in the ILAW waste form when compared to the 1998 ILAW PA.

Finally, the total source of changes given in Table 3-2 is the product of the tank inventory, half-life, and separation factor changes given in the table. This total represents the difference in the ILAW inventory estimates between the 2001 ILAW PA and the 1998 ILAW PA that are also given in Table 3-2. From an examination of these results the major sources of the differences in the ILAW inventory are indicated. Specifically, the relatively low inventories on ^{3}H, ^{14}C, and ^{231}Pa are attributed primarily to increased separation factors estimated for this performance assessment. The lower ^{79}Se inventory is associated with the change in the half-life estimate for this radionuclide. The lower ^{126}Sn inventory is attributed to lower estimate for the tank inventory, the longer half-life estimate, and increased separations when compared to the 1998 ILAW estimates. The lower ^{99}Tc inventory is due to the increased separations factor. The higher ^{129}I, U, ^{237}Np, and ^{241}Am inventories are due to higher estimates for the tank inventory and larger separation factors during processing.

3.2.4 Release Rate from Waste Form

The radionuclide source term used in the transport calculations is based not only on the inventory, but also on the release rate of the radionuclides from the ILAW packages. The release rate is a function of the waste form composition and the disposal facility design, which affects water transport and the resulting chemical environment in the disposal facility.

For an accurate determination of the source term, the chemical and physical processes controlling contaminant release from the waste form must be explicitly modeled. This assessment uses computer simulations for waste form corrosion and contaminant release. These simulations are described in Section 3.3.3. The release rates of radionuclides from the waste form actually used in the calculations are described in Section 3.4.4.3.

3.3 PATHWAYS AND SCENARIOS

This section covers the selection criteria, the pathways chosen and not chosen, and the exposure pathways chosen and not chosen. Special emphasis is given to justifying the choices. In this discussion, "pathways" refers to the environmental paths (e.g., groundwater) by which contaminants move from the waste form to the human environment. Scenarios are the environmental and human-caused events (e.g., human intrusion or irrigation) that influence how contaminants move or affect humans.

3.3.1 Selection Criteria

Relevant pathways and scenarios for these analyses were selected mainly based on pathways and scenarios used in earlier Hanford Site long-term environmental analysis documents (see Section 1.5). As noted in Section 1.5.1, five Hanford Site performance assessments for the disposal of low-level waste have already been done (Kincaid 1995, Mann 1998a, Wood 1995a, Wood 1995b, and Wood 1996). The most important environmental impact statements (EIS) have been the Hanford Defense Waste EIS (DOE 1987), the Tank Waste Remediation System EIS (DOE 1996b), and the *Final Hanford Comprehensive Land-Use Plan Environmental Impact Statement* (DOE 1999h) and its associated record of decision (DOE 1999i). These documents have been fairly consistent in their choice of pathways and scenarios.

After reviewing the relevant documents, reviews, and guidance, pathways and scenarios were selected for the current performance assessment (Mann 1999b). Selection was based on the relevance of the pathway or scenarios to the current disposal action and performance objectives.

3.3.2 Pathways

> The most important pathways are through the use of contaminated groundwater and inadvertent intrusion. The pathways remain unchanged from the 1998 ILAW PA.

The selection of pathways for this performance assessment is covered more fully in *Scenarios of the TWRS Low-Level Waste Disposal Program* (Mann 1999b). Possible scenarios were suggested by analyzing the performance objectives introduced in Chapter 1 and determining which pathways could lead to a level of exposure that could equal or exceed the specified performance objective. Postulated land use also was studied to determine possible additional pathways. Finally, likely natural events were identified (such as catastrophic glacial age flooding).

3.3.2.1 Release Mechanism. In previous Hanford Site performance assessments and environmental impact statements, the dominant pathway was through groundwater. Infiltration of moisture from precipitation entered the engineered system, where the moisture could cause the contaminants (for example in a glass-water interaction) to be released or could simply carry away already-released contaminants. The moisture and released contaminants travel downward through the vadose zone until the contaminants reach the unconfined aquifer where humans can encounter the radioisotopes through recovery of the groundwater resource for use in residential and agricultural settings. From previous analyses (Rawlins 1994, Mann 1995b, Mann 1998a, Mann/Puigh 2000a) supporting the Hanford Low-Level Tank Waste Program, this pathway again is expected to be dominant.

3.3.2.2 Future Land Use. In 1992 the HFSUWG was charged to determine potential future uses of the various parts of the Hanford Site. This group consisted of local, state, and federal officials, representatives of affected Indian tribes and 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 plan (DOE 1999h). The HFSUWG summary report (HFSUWG 1992a-2) states

> *"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 the disposal areas."*

The following four general land uses can be envisioned for the Central Plateau over the time of interest to a performance assessment.

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

The present land use is heavy industrial. If this use is maintained, records of past activities, particularly those for the disposal of nuclear materials, are likely to be kept. In addition, in an industrial area, liquid discharges to the ground would be highly regulated and kept small.

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 amount of irrigation 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 use for the land of the Horse Heaven Hills.

East of the Central Plateau, across the Columbia River, irrigated farming is extremely common. The water, however, does not come from the nearby stretches of the Columbia River. The water comes from the Columbia Basin Project, which uses water stored behind the 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.

Finally, 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 (Clinton 2000).

For the base analysis case, the land use assumption was that knowledge of the disposal activities has been retained and that water discharges to the ground are minimized. These assumptions are consistent with the assumptions of the HFSUWG, the DOE (DOE 1999h), and the local planning authorities, all of which are using a 50- to 100- year planning horizon.

3.3.2.3 Land-Use-Driven Scenarios. The pathways described here assume that some controls remain in place to prevent public intrusion into the disposal site. That is, the barriers and markers that are to be left will effectively prevent open use of the land over the disposal site. The land surrounding the marked area, however, could be farmed and could contain wells.

Based on previous analyses at the Hanford Site, the main exposure pathway is expected to be the contamination of the underground aquifer leading to various exposure scenarios. Other pathways include the upward diffusion through the engineered system into the air.

3.3.2.3.1 Unconfined Aquifer Contamination. Contamination of the unconfined aquifer is caused by water (natural or human-introduced) penetrating through the ground surface layer, interacting with the engineered structure (including the waste), then transporting contaminants down through the unsaturated sediments to the unconfined aquifer.

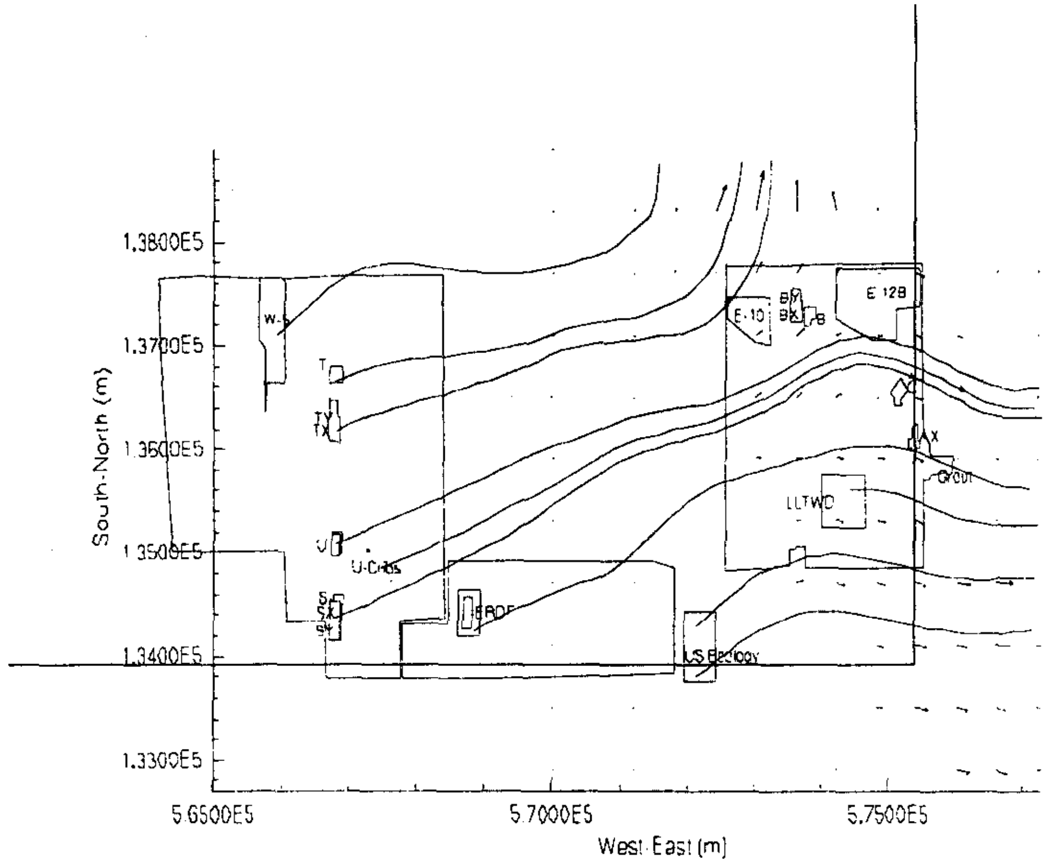
The main effects of land use on the analyses presented in this performance assessment are as follows:

- The amount of water penetrating through the ground surface layer above the disposal facility
- The direction and magnitude of flow of the unconfined aquifer from regional irrigation
- The amount of well water pumped to the surface.

Because the site of the disposal facility is assumed to be known to the surrounding population, it was assumed that the surface immediately above the disposal facility will not be used. Thus the only source of water would be natural rain or snowfall. The infiltration rate, the rate at which water actually penetrates through the surface layer and enters the sand-gravel capillary barrier, is described in Section 3.4.6 and is expected to be small (less than 5 mm/year).

The second major consequence of land use is on the flow of groundwater in the unconfined aquifer. Analysis (ERDA 1975) of groundwater flow before the start of Hanford Site operations shows a predominantly west-to-east flow (Figure 2-12). Current calculations for post-operation conditions (Bergeron 2000) predict a similar flow (Figure 3-1). These groundwater calculations form an important part in this analysis.

Figure 3-1. Predicted Groundwater Flowlines for Post Hanford Conditions.



The creation of ponds and the large amount of water discharged to the ground have altered the natural flow of groundwater (Dirkes 1997) (Figure 2-13). Possible irrigation on the Central Plateau that also would affect groundwater must be considered. No irrigation was assumed for the base analysis case because the energy requirements for irrigation in the Central Plateau are significantly higher than for other nearby regions and no known irrigation rights exist. However, irrigation on the plateau was considered in sensitivity cases to determine the effects of selected irrigation on the regional flow of the groundwater in the unconfined aquifer. Irrigation on the 200 Areas was considered unlikely because this area will be dedicated to waste disposal and irrigation would be considered an inadvertent intrusion.

The main impact of irrigation would be to change the water table and potentially the flow direction. Sensitivity cases chosen to investigate this effect were set up to change the regional recharge by a factor of three.

The last major effect is the amount of water being taken from a well. At the locations of the proposed disposal facilities, the unconfined aquifer contains only a limited amount of water. Because the amount of water is so limited, either only a small amount would be pumped from the unconfined aquifer or the well would extend much deeper and tap the confined aquifer instead of the unconfined aquifer. Thus, minimum distortion of the groundwater flow field in the unconfined aquifer was assumed for the base analysis case. Sensitivity cases were considered, however, to determine the effect of the amount of pumping on the groundwater flow field and the calculated doses.

3.3.2.3.2 Surface Water. The major surface water source in the region is the Columbia River. Here the main impact of land use is possible irrigation of land near the river. The Columbia River is a more likely source of water than the unconfined aquifer for irrigating farmland near the river because of the land's low elevation and nearness to the river. The current plan (DOE 1999i) is a preservation land use along the river. This is reinforced by the recent establishment of the Hanford Reach National Monument, which contains much of Hanford Site land near the Columbia River. For the base analysis case, the assumption was that no irrigation would occur downgradient from the plateau.

3.3.2.3.3 Air Resources. Gases and vapors could travel upward from the facility through the soil to the ground surface. This pathway is maximized with minimum downward water movement. No water flow is considered in the calculations for the protection of air resources.

3.3.2.4 Natural Event Scenarios. The main natural events to be expected are as follows:

- Wind erosion of the surface above the disposal facility
- Earthquakes
- Flooding caused by post-glacial events.

Wind erosion and earthquakes are considered drivers for changes in the engineered structure as a function of time. They are described in Section 3.4.5.7. Massive regional flooding has occurred many times during the past 50,000 years (see Section 2.2.7.2). The flood in the scenario, which is caused by the release of water during glacial retreat from a receding ice dam removes 30 m or more of ground, including the disposal units. In this scenario, the waste is assumed to be uniformly redeposited over an area equivalent to the Hanford Site. Seasonal flooding or flooding caused by collapsed dams would not affect the disposal site (see Section 2.2.9.2).

3.3.3 Contaminant Release Scenario

> Contaminant release from a glass waste form is a complex chemical-physical process that is becoming better understood.

The actual waste form that will contain the contaminants is not yet known. Glass formulations are evolving but borosilicate glasses having a relatively low silica content (~40%) and high sodium content (~20%) have received the most study. In the previous ILAW PA (Mann 1998a), glasses with higher silica contents were analyzed. Section 3.3.3.1 gives a general description of the contaminant release scenario. Section 3.3.3.2 focuses on what occurs during the water-waste form interaction for silicate glasses. The contaminant release rate used in the base analysis case calculations is described in Section 3.4.4.3.

3.3.3.1 General Description. The contaminant release scenario is based on a water-waste form interaction. Initially, the disposal facility design (Section 2.4) delays new moisture from entering the trenches. Eventually, water enters the trenches and moves downward to the waste packages. When it reaches a waste package, the water first interacts with the container, aiding its corrosion. Once the container is breached, water is assumed to reach the waste form. The water starts interacting with and breaking down the waste form. The waste form then releases the contaminants into the available water. The release rate will depend on the material, temperature, and the local chemical environment. The available water transports the contaminant from the waste package and through the disposal facility. If the trench contains a getter material that sorbs the contaminant, the effective contaminant release rate will be affected. Finally, the moisture and contaminants migrate to the vadose zone through cracks at the bottom of the disposal facility.

3.3.3.2 Contaminant Release Based on Glass Corrosion. Studies have shown (Cunnane 1994) that silicate glasses corrode over three stages.

> Silicate glasses corrode over three stages. During the second stage, the corrosion rate becomes very low. Unless the third stage occurs (resulting in corrosion rates approaching the forward rate), glass corrosion can stay small indefinitely.

The first stage occurs under dilute-solution conditions. Under these conditions, the water surrounding the waste does not contain significant concentrations of many elements released from the glass. The glass reacts at a characteristic initial rate (the "forward rate") that depends only on glass composition, temperature, and solution pH. During this time, the glass matrix dissolves and releases contaminants into the water.

The second stage occurs as the concentration of elements released from the glass in the contacting water increases. The rate of glass corrosion continually slows as the concentration of glass components in the solution increases. The reaction may reach a point where the glass corrosion rate cannot be distinguished from zero. This rate has been called the saturation rate where apparent saturation occurs with respect to the glass phase. The solution is not saturated in a thermodynamic sense because glass is metastable. The solution is saturated in a kinetic sense in that the corrosion rate approaches a very low constant value. Recent work by McGrail (2000) indicates that the rate of Na^+-H^+ ion exchange is the rate controlling process in this stage.

The third stage of glass corrosion *could* occur as secondary mineral phases begin to precipitate from the "saturated" fluid in contact with the glass. Precipitation of many of these mineral phases will cause the solution to become undersaturated with respect to the glass. This undersaturation may affect the glass corrosion rate. Mass transfer between the solution and the secondary mineral phases will maintain undersaturation. The resulting glass corrosion rate will depend on the specific chemistry of the secondary mineral phases that are formed and the kinetics of the precipitation. Glass corrosion could remain near the low rate attained during the second stage or could accelerate back to a rate near the forward rate. Both cases have been observed in the laboratory and in the field with natural glasses.

The glass corrosion process releases contaminants into the moisture in contact with the glass. However, the contaminant release rate is not necessarily proportional to the glass corrosion rate. Rather, each contaminant is subject to chemical reactions that can significantly alter the concentration of the contaminants in the moisture that eventually exits the disposal trench. These reactions include oxidation-reduction, dissolution-precipitation, and adsorption. Experiments and numerical analysis are proceeding to better understand the actual contaminant release process. Testing on reference low-activity waste glasses has been completed. Testing has begun on waste forms proposed by the RPP contractors.

3.3.4 Contaminant Transport

Outside the disposal trench, contaminant transport is treated as an extension of moisture movement using the K_d model.

Previous analyses (Kincaid 1995, Mann 1995b, Mann 1998a, Mann/Puigh 2000b,Wood 1995a, Wood 1995b, and Wood 1996) have shown that contaminants are transported mainly by their movement in the aqueous phase. Contaminant transport can occur as contaminants move with the water and diffuse through water. Other transport mechanisms involve vapor-phase transport of the gaseous contaminations and massive movements caused by catastrophic events such as glacial-age flooding. Sections 3.3.4.1 through 3.3.4.4 describe how the contaminant transport mechanisms were modeled. Appendix D contains the equations actually used in the models.

3.3.4.1 Moisture Movement. Two distinct moisture-content regimes are present during contaminant transport: the unconfined aquifer and the vadose zone. In the unconfined aquifer, all the pore space of the porous sediment matrix is filled with water; the matrix is water saturated. In the vadose zone, the pore space is only partially filled with water; the vadose zone is unsaturated.

Water flow through a saturated porous medium, such as the unconfined aquifer, is governed by the empirical relationship described by Darcy's Law (Freeze 1979) and by the conservation of mass. Darcy's law defines the discharge of water through a cross section of a porous medium. However, in contaminant transport, the average velocity of water flowing through the pores of the medium is needed. The average velocity of the pore water is determined by dividing the discharge, or Darcy velocity of the water by the water-filled porosity of the medium. Total porosity is defined as the ratio of void space to total volume.

In an unsaturated medium, the pores are not completely filled with water. For such a medium, moisture content is defined as the ratio of water-filled void space to the total volume and the average velocity of the pore water is determined by dividing the Darcy velocity by the moisture content. Additional effects (capillary forces, the dependence of hydraulic conductivity on moisture content, etc.) must be considered when analyzing an unsaturated medium. The Richards equation (Richards 1931) becomes the governing equation.

The important parameters in these equations are the following:

- Matric potential (or pressure head) as a function of moisture content (water retention function)
- Hydraulic conductivity as a function of moisture content (relative permeability function)
- The source or sink of moisture.

Under extremely dry conditions, water vapor diffusion may be important. Water vapor diffuses through porous media along vapor pressure gradients. The presence of water-soluble components (in the waste form, for example) depresses the water vapor potential and causes the water vapor to diffuse from the surrounding soils. This water then could condense at the location of the water-soluble material and leach contaminants from that surface. Important factors in this process are the level to which the water vapor pressure is depressed and the effective diffusion coefficient of water vapor.

3.3.4.2 Advective, Dispersive, and Diffusive Transport. The equation for the advective, dispersive, and diffusive transport of contaminants can be viewed as a mass balance on a differential volume.

The parameters important in this equation are as follows:

- The pore water velocity
- The dispersion coefficient
- The effective porosity of the soil layer
- The retardation factor that depends on the soil's density and wetted porosity and chemical distribution coefficient
- The effective diffusion coefficient.

An increase in the retardation factor increases the time for the contaminant to reach the aquifer. In the absence of an advective component, the diffusion process could bring water-soluble contaminants to the land surface via diffusion in a continuous liquid pathway.

Because of the very dry conditions present in Hanford Site soils and expected in the disposal facility, diffusive transport may be more important than advective movement in some cases. Because of the large storage capacity of the surface soils, the effect of large transient storms is confined to the top few feet of soil.

3.3.4.3 Vapor Transport. Some contaminants may move upward from the disposal facility to the surface in the vapor phase. In this document, gaseous contaminants are analyzed. Fick's law governs such movement.

3.3.4.4 Solid Transport. If another glacial-age catastrophic flood (such as the Missoula floods) occurs, the contaminants will be widely dispersed. For this case, the entire inventory is assumed to be mixed with soil to a depth of 20 m (66 ft) (the depth of the disposal facility) over the Hanford Site south of the Columbia River (an area of 906 km^2 [350 mi^2]). Glacial-age catastrophic floods have deposited soils over a far greater area (to the extent of carrying most of the soil all the way to the Pacific Ocean) and mixed the soil to greater depths than assumed here. The all-pathways scenario described in Section 3.3.5 is used to estimate the dose.

3.3.5 Exposure Scenarios

> **The two major exposure scenarios are drinking contaminated water and living on a small farm.**

Two major exposure scenarios considered are drinking contaminated water and exposures via all-pathways while living on a small farm (the all-pathways dose). The details of these scenarios and the justification for all the parameters used in them are found in Rittmann (1999). The expected characteristics of potential future agricultural activities at the Hanford Site are given in *Evaluation of the Potential for Agricultural Development at the Hanford Site*, (Evans 2000). Values for the parameters used in these scenarios are discussed in Section 3.4.7 and are given in Appendix B.

3.4 VALUES AND ASSUMPTIONS

This section describes and justifies the conceptual models and data for those models that were used in the analyses. It covers the selection criteria and key assumptions for the conceptual models; describes the models and their associated data, the waste form, release rate, disposal facility, and moisture and moisture infiltration rate. It also covers the dosimetry parameters. The models actually used in the computer simulations were derived from these conceptual models and are described in Section 3.5. Sensitivity cases are gathered together in Section 3.5.5 and illustrate both uncertainty and bounding conditions.

3.4.1 Selection Criteria

The following criteria are used to select between the alternatives:

- The ability to justify the choice

- The availability of experimental evidence
- The use of best calculational methods.

The overriding criteria were the ability to justify the data and the calculational methods selected. The justification process requires that all data, assumptions, and processes be questioned for applicability. *Does each selection realistically portray probable situations?* This process quickly identifies errors, misunderstandings, and false assumptions that can be corrected. It also provides insight into the true requirements for methods and the true need for data.

Whenever possible, direct experimental evidence is the basis for selecting data or approaches for the conceptual models. However, in most cases, collecting direct experimental evidence is not possible. Sometimes collecting all the evidence could take too long (e.g., observing the behavior of glass for 10,000 years). Sometimes the amount of data is too large to obtain (e.g., determining hydrologic parameters for the entire vadose zone).

When direct experimental evidence is limited, the available data are used to support analytical simplifications. This approach has two major facets. The first is extrapolating laboratory-measured data to field conditions, as in the case of hydrologic parameters. The second is measuring various effects of the total process to form a complete picture, as was done to determine the infiltration rate. The infiltration rate was determined by combining short-term lysimetry with mid- and long-term tracer measurements and moisture movement simulation studies.

Much experimental and analytical effort has been spent collecting information and producing the understanding needed for this analysis. This effort has been documented in a series of data packages. These have been consolidated in Mann/Puigh 2000a:

The large amount of experimental and analytical data used in this performance assessment have been documented in a series of data packages that have been reviewed.

- *Disposal Facility Data for the Hanford Immobilized Low-Activity Tank Waste* (Puigh 1999)
- *Evaluation of the Potential for Agricultural Development at the Hanford Site* (Evans 2000)
- *Exposure Scenarios And Unit Dose Factors For The Hanford Immobilized Low-Activity Tank Waste Performance Assessment* (Rittman 1999)
- *Far-Field Hydrology Data Package For The Immobilized Low-Activity Waste Performance Assessment* (Khaleel 1999)
- *Geochemical Data Package For The Immobilized Low-Activity Waste Performance Assessment* (Kaplan 1999)
- *Geologic Data Packages for 2001 Immobilized Low-Activity Waste Performance Assessment* (Reidel 1999)

- *Immobilized Low Activity Tank Waste Inventory Data Package* (Wootan 1999)
- *Near Field Hydrology Data Package for the Immobilized Low-Activity Waste 2001 Performance Assessment* (Meyer 1999)
- *Recharge Data Package for the Immobilized Low-Activity Waste 2001 Performance Assessment* (Fayer 1999)
- *Waste Form Release Data Package for the 2001 Immobilized Low-Activity Waste Performance Assessment* (McGrail 1999, McGrail 2001).

Each data package has undergone a hierarchy of reviews.

In addition, significant amounts of experimental effort are planned to support future performance assessments (see Section 6.4). The statements of work (Puigh 2000) outline the experiments that will be performed to determine geology, hydrology, glass performance, other material performance, and infiltration rate.

Analytical and calculational studies are a major part of the effort to provide data for processes, such as glass corrosion, that will be evolving over thousands of years. Analytical and computational tools were selected with the intention of using them to provide the most insight and accurate simulations of these processes.

3.4.2 Key Assumptions

Even though much of the Site-, facility-, and waste form-specific data needed for a performance assessment have been obtained, some additional assumptions must be made. The key assumptions are as follows.

- The location and layout of the disposal facilities, which dictates geology, stratigraphy, infiltration rate, and associated parameters, will not change.
- The waste form composition, which influences the release rate of contaminants, will be similar to that currently being proposed.
- Our knowledge of tank inventory and the separation and treatment processes used to produce the ILAW packages is adequate.
- The disposal facility design will not change significantly.

As noted in Section 2.2.2, the location for the new disposal facility has been decided. However, the layout of the facility on the reserved land may change as design activities accelerate. Sensitivity cases will be run to determine the impact of different layouts and trench positions at the disposal site.

As noted in Section 2.3.5, the waste form has not been determined. The composition may be varied to best treat the various compositions of tank waste. However, a strong connection continues to exist among the performance assessment team, those developing the glass compositions, and the basic research community. The main glass composition used in this analysis (LAWABP1) is expected to be typical of the glass actually produced. Sensitivity cases will be run for different compositions and for the uncertainties in the glass dissolution process.

The actual composition of the waste form (both radioactive and nonradioactive) is not known. This composition is based on what contaminants are presently in the tanks, the retrieval methods used, the separation processes used, and the glass production system. Although much is known about the composition in each of the 177 tanks presently containing the waste, the system is complex. Each tank has multiple layers containing different elements and compounds. Moreover, the method and timing of retrieval will affect the mixing of waste types in the tanks and, hence, the waste composition. Moreover, final design of the separations, vitrification, and recycling systems for producing ILAW has not begun and is subject to change. For these analyses, only the mean composition based on the estimated total radionuclide inventory was used. As retrieval scenarios and treatment designs are better defined and individual tank contents become better known, composition variations in the waste form will be determined. Possible variations are investigated through sensitivity cases in these analyses.

Finally, only conceptual ideas exist for the facility design (See Section 2.4). Important features have been identified and preliminary investigations have been done (Puigh 1999). Thus, certain design features can be included with some confidence. Much more work remains as the conceptual design ideas are translated into preliminary, then final, designs. An important part of such work will be experimental and analytical studies of how the design features behave over time.

3.4.3 Site

This section translates the geology, hydrogeology, and geochemistry described in Mann/Puigh (2000a) into a conceptual model and values that can be used in the analyses supporting this performance assessment. The location and stratigraphy of the disposal site are discussed first. Next, the hydrologic and geochemical properties of the vadose zone are addressed. Finally, the properties and structural features of the unconfined aquifer are examined.

3.4.3.1 Location and Stratigraphy. As noted in Section 2.2.2 of this report, the location of the disposal facility was determined (Rutherford 1997) to be in the south-central part of the 200 East Area. The main strata at this location are the Hanford formation and the Ringold Formation.

The proposed disposal site is in the 200 East Area of the Hanford Site.
The geology has been established by a series of boreholes.

The geology of the ILAW disposal site is given in *Geologic Data Package for the 2001 ILAW PA* (Reidel 1999), which is attached as Appendix G to Mann/Puigh (2000a). The Hanford Site lies in the Pasco Basin of the Columbia Plateau. The Columbia Plateau consists of a sequence of thick basalt flows laid down 4 to 15 million years ago. Overlying the basalt flows are sediments of the late Miocene, Pliocene, and Pleistocene ages, known as the Ringold

Formation and, nearer the surface, the Hanford formation. The Hanford formation arises from deposits from a series of post-glacier flooding from approximately 1,000,000 to 13,000 years ago, and consists mainly of unconsolidated sand and sandy gravel layers. The unconfined aquifer is near the interface between the Hanford formation and Ringold Formation throughout the Hanford Site. At the ILAW disposal site, the interface is about 103 m (338 ft) below the surface. Clastic dikes have been observed at the Hanford Site and are assumed to exist at the new ILAW site.

The stratigraphy at the ILAW disposal site has the top of the Columbia River Basalt Group at an elevation of approximately 84 m (275 ft) above sea level. The top of the Ringold Formation ranges between 91 m and 122 m (300 and 400 ft) (north to south). The Hanford formation gravel sequence is approximately 27 m to 46m (88 to 150 ft) thick (south to north); and the Hanford formation sand sequence varies from 64 m to 76 m (210 to 250 ft) (north to south). Within the sandy sequence, three paleosols were identified from borehole 299-E17-21 (Reidel 1998). Paleosol Horizon 1 occurs at 49 m (163 ft) drilled depth, paleosol Horizon 2 occurs at 18 m (58 ft) drilled depth, and paleosol Horizon 3 occurs at 1.5 m (5 ft) drilled depth. These paleosol horizons are as much as 15 cm (6 in.) thick with a sharp upper surface interface. Finally, Eolian deposits cover the southern part of the new ILAW disposal site and range in thickness between 3 m and 15 m (10 to 50 ft) (south to north). The current water table is in the Hanford formation gravel sequence below most of the new disposal site. See Figure 2-12 for a representative stratigraphy for the ILAW disposal site.

The large discharge of water from Hanford Site operations has significantly affected the level and flow of the unconfined aquifer. However, DOE has agreed to severely limit such discharges; at the time of this analysis no discharges are expected. Based on calculations using the Hanford Sitewide groundwater model (Cole 1997), the present location of the aquifer at the disposal site is 98 m (321 ft) below the surface level or 122 m (400 ft) above mean sea level. This model is in good agreement with measurements of changing water table levels over the past two decades. Computer simulations were used to define the level of the unconfined aquifer after Hanford Site operations cease. Current estimates of the post-Hanford Site-operations water table (Bergeron 2000) suggest this level will be 102 m (334 ft) below the surface level or 118 m (387 ft) above mean sea level. This level was used for the base analysis case. The post-Hanford unconfined aquifer is expected to be in the Hanford formation at the disposal site, because of the presence of the ancestral Columbia River channel.

To determine the sensitivity of hydrologic parameters in each layer, sensitivity cases were run that replaced the sandy layer with the gravelly sand and vice versa. In addition, a sensitivity case was run that included clastic dikes; another was run extending the vadose zone by 3 m. Similarly, for groundwater calculations, a sensitivity run was made changing the Hanford formation to the Ringold Formation.

3.4.3.2 Vadose Zone Hydrologic Parameters. Hydrologic processes describe how moisture moves through the subsurface. Because distinct regions are associated with subsurface flow and transport at the ILAW disposal site, the system has been divided into two parts: near-field and far-field.

> The vadose zone hydrologic parameters have been derived from laboratory measurements on local field samples. Gravel, upscaling, and other corrections have been applied for use in these analyses.

Near- and far-field hydrologic parameters (volumetric moisture content and hydraulic conductivity) for these analyses come from laboratory analyses of samples from construction materials and from strata found near the disposal site. Field samples were taken from locations near the disposal site. Corrections were made for the gravel content and for primary drainage. This resulted in moisture-retention data. A detailed discussion of the data and methods used to derive them can be found in the work of Khaleel (1999). The following paragraphs summarize the methods and data.

The moisture retention data can be described in an empirical relationship following the methods of van Genuchten 1980. The moisture retention function is

$$\theta(\psi) = \theta_r + [\theta_s - \theta_r] * \{1 + [\alpha\psi]^n\}^{-m} \quad (3.1)$$

where

- $\theta(\psi)$ = the volumetric moisture content [dimensionless]
- ψ = the matric potential or pressure head [m]
- θ_r = the residual moisture content [dimensionless]
- θ_s = the saturated moisture content [dimensionless]
- α = a fitting parameter (m^{-1})
- n = a fitting parameter [dimensionless]
- m = 1 - 1/n.

Using the Mualam 1976 model and this form for moisture retention, the hydraulic conductivity is

$$K(S_e) = K_s * S_e^{\,n} * \{1 - [1 - S_e^{\,1/m}]^m\}^2 \quad (3.2)$$

where

- $K(S_e)$ = the unsaturated hydraulic conductivity [m/t]
- K_s = the saturated hydraulic conductivity [m/t]
- S_e = effective saturation = $(\theta - \theta_r) / (\theta_s - \theta_r)$
- n = the pore-connectivity parameter [dimensionless], estimated by Mualam to be about 0.5 for many soils. In this work, n is taken to be 0.5.

The RETC code (van Genuchten 1991) was used to determine values for θ_r, θ_s, α, and n. Values for K_s were determined by fitting laboratory data to a lognormal distribution.

3.4.3.2.1 Near-Field Hydrology Data. The processes and data important for moisture flow in the zone between the surface and the bottom of the engineered disposal facility are described in *Near-Field Hydrology Data Package for the Immobilized Low-Activity Waste 2001 Performance Assessment* (Meyer 1999), which is Appendix L in Mann/Puigh (2000a). Physical and hydraulic properties (particle size distribution, particle density, bulk density, porosity, water retention, and hydraulic conductivity as a function of moisture content) and associated transport parameters (dispersivity and effective diffusion coefficient) are given for the surface cover materials, the vault structure, diversion layers, the water conditioning layer, and the backfill materials. Table 3-3 presents best-estimate parameter values for near-field materials. Best estimate values for transport parameters (which are relatively unimportant in this analysis) can be found in Meyer (1999) (Chapter 5).

Table 3-3. Best-Estimate Hydraulic Parameter Values For Near-Field Materials.

Material	ρ_p (g/cm^3)	ρ_b (g/cm^3)	θ_s	θ_r	α (cm^{-1})	n	K_s (cm/s)
Surface Barrier							
Silt loam-gravel admixture	2.72	1.48	0.456	0.0045	0.0163	1.37	8.4×10^{-5}
Compacted silt loam	2.72	1.76	0.353	0.0035	0.0121	1.37	1.8×10^{-6}
Sand filter	2.755	1.88	0.318	0.030	0.538	1.68	8.58×10^{-5}
Gravel filter	2.725	1.935	0.290	0.026	8.1	1.78	1.39×10^{-2}
Gravel drainage	2.725	1.935	0.290	0.006	17.8	4.84	2.0
Asphaltic concrete	2.63	2.52	0.04	0.000	1.0×10^{-7}	2.0	1×10^{-11}
Capillary Break							
Diversion layer sand	2.8	1.65	0.371	0.045	0.0683	2.08	3.00×10^{-2}
Diversion layer gravel	2.8	1.38	0.518	0.014	3.54	2.66	1.85
Trench/Vault							
Filler material	2.63	1.59	0.397	0.005	0.106	4.26	3.79×10^{-2}
Glass waste	2.68	2.63	0.02	0.00	0.2	3	0.01
Vault concrete	2.63	2.46	0.067	0.00	3.87×10^{-5}	1.29	1.33×10^{-9}
Backfill	2.76	1.89	0.316	0.049	0.035	1.72	1.91×10^{-3}

Table 3-3. Best-Estimate Hydraulic Parameter Values For Near-Field Materials.

Material	ρ_p (g/cm^3)	ρ_b (g/cm^3)	θ_s	θ_r	α (cm^{-1})	n	K_s (cm/s)

ρ_p = particle density ρ_b = dry bulk density

θ_s = saturated water content θ_r = residual water content

α,n = van Genuchten fitting parameters K_s = saturated hydraulic conductivity

3.4.3.2.2 Far-Field Hydrology. The processes and data important for moisture flow in the zone between the bottom of the engineered disposal facility and the water table are described in *Far-Field Hydrology Data Package for the Immobilized Low-Activity Waste Performance Assessment* (Khaleel 1999), which is Appendix M in Mann/Puigh (2000a). Two units of the Hanford formation make up this zone: the sandy unit and the Lower Hanford gravel unit.

Khaleel (1999) summarizes the hydraulic parameter estimates based on data from the ILAW borehole and data on gravelly samples from the 100 Area boreholes. Statistical fits (normal or log-normal) were made for each parameter, with Table 3-4 proving the best estimate (or mean) values affecting moisture flow. The document also describes the processes for upscaling such small-scale laboratory measurements to field-scale applications, and provides recommendations for determining which parameters to use at that scale. Best estimate values for transport parameters associated with the base-case effective transport parameters (bulk density, diffusivity, and dispersivity) also are described in Khaleel (1999).

Table 3-4. Best-Estimate Hydraulic Parameter Values For Far-Field Layers.

Formation	θ_s	θ_r	α (1/cm)	n	ℓ	K_s (cm/s)
Sandy	0.375	0.041	0.057	1.768	0.5	2.88×10^{-3}
Gravelly	0.138	0.010	0.021	1.374	0.5	5.60×10^{-4}

θ_s = saturated water content θ_r = residual water content

α,n = van Genuchten fitting parameters ℓ = pore size distribution factor

K_s = saturated hydraulic conductivity

Overall, compared to the sandy sequence, the gravelly sequence is characterized by a much smaller saturated water content, higher bulk density, higher log-conductivity variance, smaller log-unsaturated conductivity variance, a much smaller macroscopic anisotropy and smaller dispersivities (Khaleel 1999). An anisotropy ratio (ratio of horizontal to vertical hydraulic conductivity) in excess of one results in an enhanced lateral migration. To model restricted lateral migration (i.e., a conservative assumption), an isotropic model was used for both strata.

Longitudinal dispersivities of 200 cm and 30 cm were used for the sandy and gravelly sequences, respectively (Khaleel 1999). Lateral dispersivities were estimated to be $1/10^{th}$ of the longitudinal estimates. The effective, large-scale diffusion coefficients for both sandy and gravel-dominated sequences are assumed to be a function of volumetric moisture content, θ. VAM3DF uses the Millington-Quirk 1961 empirical relation:

$$D_e(\theta) = D_0 \frac{\theta^{10/3}}{\theta_s^2} \tag{3.3}$$

where

$D_e(\theta)$ is the effective diffusion coefficient of an ionic species
D_0 is the effective diffusion coefficient for the same species in free water.

The molecular diffusion coefficient for all species in pore water is assumed to be 2.5×10^{-5} cm^2/s (Kincaid 1995).

Sensitivity cases were run to test the sensitivity to different hydraulic properties (including diffusion).

3.4.3.3 Geochemical Retardation Factors.

> Geochemical parameters are based on laboratory measurements of field samples using a variety of fluids. Parameters are given for 5 zones and include corrections for gravel content and the surrounding chemical environment.

Chemical interactions with the facility, near-field materials, and the soil in the vadose zone can greatly slow the transport of contaminants. Geochemical effects are based on the discussion and values presented in *Geochemical Data Package for the Hanford Immobilized Low-Activity Tank Waste Performance Assessment* (Kaplan 1999), also provided in Appendix N of Mann/Puigh (2000a).

The geochemistry is described using two parameters: the distribution coefficient (K_d value) and the solubility product of a specified solid. The distribution coefficient is a thermodynamic construct. It is the ratio of the concentration of a species reversibly adsorbed or exchanged to a geomedia's surface site divided by the concentration of the species in solution. Parameters are given for the following five zones:

- **Near-Field.** Inside the disposal facility (K_d and solubility values)

- **Degraded Concrete Vault.** (K_d and solubility values)
- **Chemically Impacted Far-Field in Sand Sequence.** (K_d values only)
- **Chemically Impacted Far-Field in Gravelly Sequence.** (K_d values only)
- **Far Field in Gravel Sequence.** Unconfined aquifer (K_d values only).

The amount of slowing is described by a multiplicative factor known as the geochemical retardation factor, which involves the distribution coefficient. Geochemical retardation in unsaturated conditions is predicted to be

$$R_f = 1 + \rho K_d / \theta \qquad (3.4)$$

where

R_f	is the geochemical retardation factor (dimensionless)
ρ	is the bulk density of the material (g/cm^3)
K_d	is the chemical distribution coefficient (liter/g)
θ	is the volumetric moisture content (dimensionless).

A derivation of the general contaminant transport equation is given in the 1998 ILAW PA report (Mann 1998a, Appendix D, Section D.2.3). The chemical distribution coefficient (K_d) is measured in the laboratory by comparing the amount of material trapped in or on the soil matrix to the amount of material in the water phase.

Tables 3-5 and 3-6 provide estimates for K_d from recent measurements and for the K_ds used in the analyses in this report. Unless otherwise stated, the K_ds are provided for the chemically impacted far-field sandy sequence beneath the disposal facility (Table 3-5) and the near-field materials (Table 3-6). The "Probable K_d" is the best estimate for the K_d. Finally, the "K_d value used" refers to the value of K_d used in the analyses provided in this report.

For convenience in modeling, a subset of K_d values was used in these analyses. The computer code VAM3DF (See Section 3.5.3) treats the chemical distribution coefficients as point-estimate values, not as probability functions. Therefore, the actual K_d values used were reduced to one of eight value sets for the near and far fields (see Tables 3-5 and 3-6). This K_d value was conservatively chosen to be one of the following six values:

0	corresponding to technetium
0.6 mL/g	corresponding to uranium
4.0 mL/g	corresponding to selenium
10 mL/g	corresponding to strontium
80 mL/g	corresponding to tin and cesium

150 mL/g corresponding to plutonium.

These values are less than or equal to the probable K_d value provided in these tables. The elements selected were shown to be the most important in the 1998 ILAW PA. The values in parentheses provided in Table 3-5 are for the unperturbed (near neutral pH, ionic strengths between 0 and 0.01, and only trace contaminant concentrations) far-field sand sequence.

Because radionuclides spend significantly less time in the unconfined aquifer than in the vadose zone, no credit was taken in this analysis for increased travel time in the unconfined aquifer because of geochemical retardation.

Values are based on site-specific samples for the most part, but in a few cases depend on literature values or chemical similarity. Table 3-5 provides the best estimate K_d values for the chemically impacted far-field sand sequence. The gravel-corrected best estimate K_d values for the chemically impacted far-field gravel sequence are a factor of 10 smaller than the values given in Table 3-5. The values in parentheses in the table are for the unperturbed far-field sand sequence. The aqueous phase is assumed to be untainted Hanford formation groundwater except for trace levels of radionuclide and the solid phase is assumed to be natural Hanford formation sand-dominated sequence sediment. The literature values on which these values were based had an aqueous phase near neutral pH, ionic strength between 0 and 0.01, and trace radionuclide concentrations.

Table 3-5. Best-Estimate K_d Values For The Far-Field Sand Sequence.

Radionuclide	Probable K_d[a,b] (mL/g)	Value Used[a,c] (mL/g)
Ac	350.	150.
Am	350.	150.
C [(d)]	20. (5.)	4.
Ce	350.	150.
Cl	0.	0.
Cm	350.	150.
Co	300.	150.
Cs	80.	80.
Eu	350.	150.

Table 3-5. Best-Estimate K_d Values For The Far-Field Sand Sequence.

Radionuclide	Probable K_d[a,b] (mL/g)	Value Used[a,c] (mL/g)
^{3}H	0.	0.
I	0.	0.
Nb	80.	80.
Ni	80.	80.
Np	0.8	0.6
Pa	0.8	0.6
Pb	100.	80.
Pu	200.	150.
Ra	10.	10.
Ru	1.	0.6
Se	4.	4.
Sn	80.	80.
Sr	10.	10.
Tc	0.	0.
Th	300.	150.
U[(d)]	10. (0.6)	0.6
Zr	300.	150.

Table 3-5. Best-Estimate K_d Values For The Far-Field Sand Sequence.

Radionuclide	Probable K_d[a,b] (mL/g)	Value Used[a,c] (mL/g)

[a]The values in the table are for the chemically impacted far-field sand sequence. The aqueous phase is moderately altered from the cement and glass leachate emanating from the near field; pH is between 8 (background) and 11, and the ionic strength is between 0.01 (background) and 0.1. The solid phase is in the sand-dominated sequence and is slightly altered because of contact with the caustic aqueous phase.

[b]Probable K_d is the best estimate for K_d

[c]Value Used is the K_d value used in the analyses provided in this report

[d]The values in parentheses in the table are for the unperturbed far-field sand sequence. The aqueous phase is assumed to be untainted Hanford formation groundwater, except for trace levels of radionuclide and the solid phase is assumed to be natural Hanford formation sand-dominated sequence sediment. The literature values on which the values were based had an aqueous phase near neutral pH, ionic strength between 0 and 0.01, and trace radionuclide concentrations.

Other important geochemical data (e.g., near-field field values for important radionuclides) are displayed in Table 3-6. For the analyses in this PA, the K_ds for the unconfined aquifer were set equal to zero. Note that the K_d values in concrete used for uranium and iodine have been set equal to zero, which is conservative.

Because the vadose zone calculations are run in terms of K_d bins, rather than actual materials, it is possible to calculate the effect of changing K_d values after the vadose zone calculations are complete. Thus, sensitivities to K_d values will be given for the most important materials. In addition, a sensitivity case is run to determine the importance of a getter material just beneath the disposal facility.

Table 3-6. Other Important Geochemical Values.

Element	Probable Value[a,b]	Value Used[a,c]	Zone and Geochemical Value
Tc	1	0	Zone 1: Near-Field K_d (mL/g)
U	20	0.6	Zone 1: Near-Field K_d (mL/g)
U	1×10^{-7}	1×10^{-7}	Zone 1: Near Field Solubility (M)
I	2	0	Zone 2: Degraded Aged Concrete K_d (mL/g)
U	100	0	Zone 2: Degraded Aged Concrete K_d (mL/g)
U	1×10^{-7}	1×10^{-7}	Zone 2: Degraded Aged Concrete Solubility (M)

[a] The values in the table are for the chemically impacted far-field sand sequence. The aqueous phase is moderately altered from the cement and glass leachate emanating from the near field; pH is between 8 (background) and 11, and the ionic strength is between 0.01 (background) and 0.1. The solid phase is in the sand-dominated sequence and is slightly altered because of contact with the caustic aqueous phase.

[b] "Probable K_d" is the best estimate for K_d

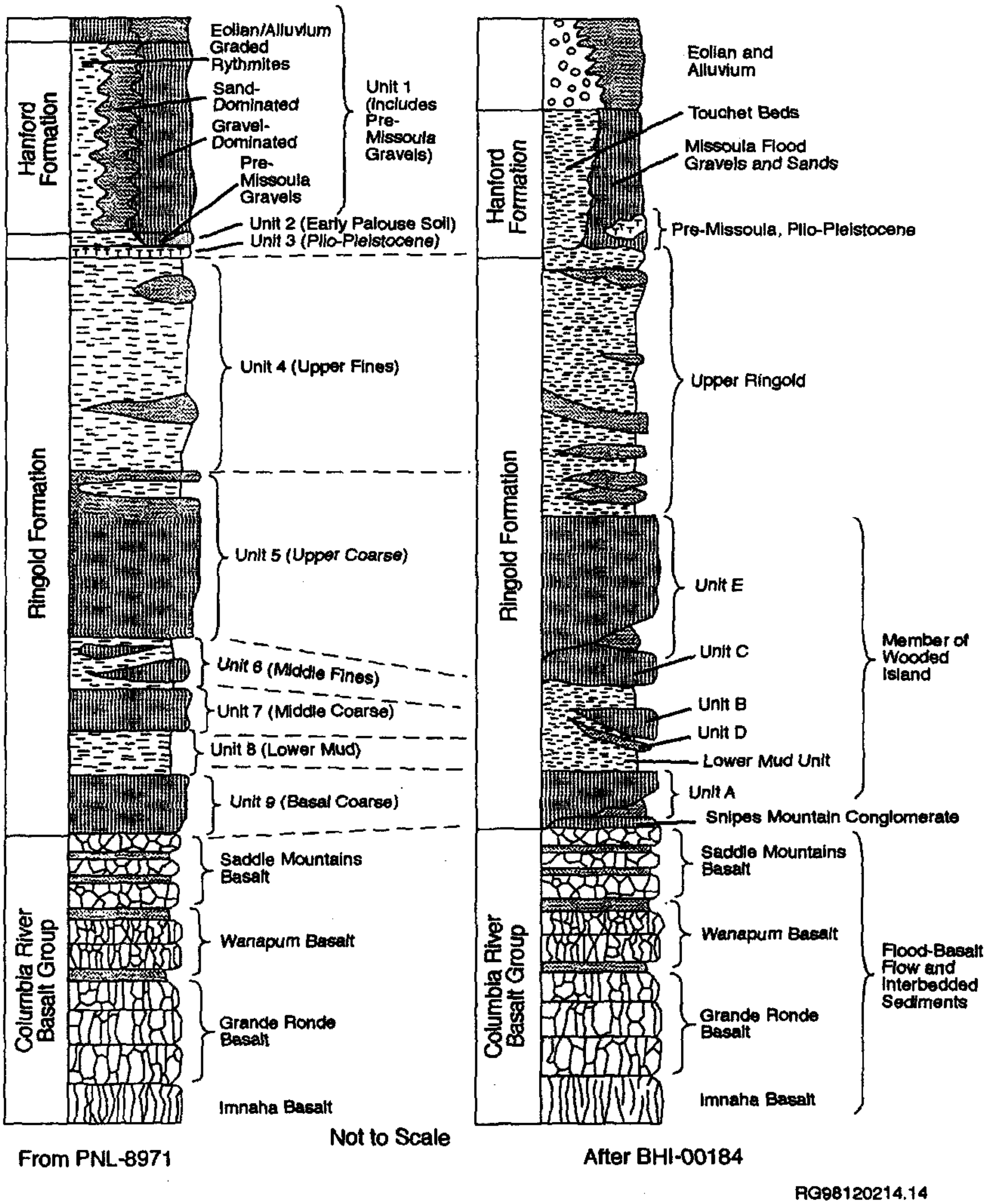
[c] "Value Used" is the K_d value used in the analyses provided in this report

3.4.3.4 Unconfined Aquifer Properties and Boundaries. Groundwater flow and contaminant transport were calculated with the current version of the Hanford Sitewide Groundwater model. This three-dimensional model, currently being used by the Hanford Groundwater Project and recommended as the proposed Sitewide groundwater model in the Hanford Site groundwater model consolidation process, is based on the Coupled Fluid, Energy, and Solute Transport (CFEST-96) Code (Gupta 1987). The specific implementation of this model is more fully described in Wurstner 1995 and Cole 1997. This specific model was most recently used in the Hanford Site Composite Analysis (Cole 1997; Kincaid 1998), which is a companion analysis to the 1998 performance assessment analyses of the ILAW disposal (Mann 1998a) and the solid waste burial grounds in the 200 East and 200 West Areas (Wood 1996 and 1995a). The composite analysis also is a companion document to the Remedial Investigation/Feasibility Study (RI/FS) (DOE/RL 1994a) done to support the Environmental Restoration Disposal Facility.

3.4.3.4.1 Hydrogeologic Framework. The conceptual model of groundwater flow is based on nine major hydrogeologic units in the left hand column shown in Figure 3-2. The basis for identifying these major hydrogeologic units in the aquifer system is more fully described in Thorne (1992, 1993, and 1994). Although nine hydrogeologic units were defined, only seven are found below the water table during post-Hanford Site operations conditions. Odd-numbered Ringold model units (5, 7, and 9) are predominantly coarse-grained sediments. Even-numbered Ringold model units (4, 6, and 8) are predominantly fine-grained sediments with low permeability. The Hanford formation combined with the pre-Missoula gravel deposits were designated model unit 1. Model units 2 and 3 correspond to the Plio-Pleistocene deposits. These units lie above the current water table. The predominantly mud facies of the upper Ringold unit identified by Lindsey (1995) was designated model unit 4. However, a difference in the definition of model units is that the lower, predominantly sand, portion of the upper Ringold unit described in Lindsey (1995) was grouped with model unit 5, which also includes Ringold gravel/sand units E and C. This was done because the predominantly sand portion of the upper Ringold is expected to have hydraulic properties similar to units E and C. The lower mud unit identified by Lindsey (1995) was designated units 6 and 8. Where they exist, the gravel and sand units B and D, which are found within the lower Ringold, were designated model unit 7. Gravels of Ringold unit A were designated unit 9 for the model, and the underlying basalt was designated model unit 10. However, the basalt was assigned a very low hydraulic conductivity and was essentially impermeable in the model.

The lateral extent and thickness distribution of each hydrogeologic unit were defined based on information from well drillers' logs, geophysical logs, and an understanding of the geologic environment. These interpreted areal distributions and thicknesses were then integrated into EarthVision (Dynamic Graphics, Inc., Alameda, California), a three-dimensional, visualization software package that was used to construct a database of the three-dimensional hydrogeologic framework.

Figure 3-2. Comparison of Generalized Geology and Hydrostratigraphic Columns.



3.4.3.4.2 Recharge and Aquifer Boundaries. Both natural and artificial recharges to the aquifer were incorporated in the model. Natural recharge to the unconfined aquifer system occurs from infiltration of 1) runoff from elevated regions along the western boundary of the Hanford Site; 2) spring discharges originating from the basalt-confined aquifer system, also along the western boundary; and 3) precipitation falling across the site. Some recharge also occurs along the Yakima River in the southern portion of the site. Natural recharge from runoff and irrigation in the Cold Creek and Dry Creek Valleys, up-gradient of the site, also provides a source of groundwater inflow. Areal recharge from precipitation on the site is highly variable, both spatially and temporally, and depends on local climate, soil type, and vegetation. A recharge distribution based on Fayer 1995 for 1979 was applied in the model.

The other source of recharge to the unconfined aquifer is wastewater disposal. A large volume of artificial recharge from wastewater discharged to disposal facilities on the Hanford Site over the past 50 years has significantly impacted groundwater flow and contaminant transport in the unconfined aquifer system. However, the volume of artificial recharge has decreased significantly in the recent past and the water table is expected to return to more natural conditions after site closure.

The flow system is bounded by the Columbia River on the north and east and by the Yakima River and basalt ridges on the south and west. The Columbia River represents a line of regional discharge for the unconfined aquifer system. The amount of groundwater discharging to the river is a function of local hydraulic gradient between the groundwater elevation adjacent to the river and the river-stage elevation. This hydraulic gradient is highly variable because the river stage is affected by releases from upstream dams. To approximate the long-term effect of the Columbia River on the unconfined aquifer system in the three-dimensional model, the CHARIMA river-simulation model (Walters et al. 1994) was used to generate the long-term, average river-stage elevations for the Columbia River. The river itself is represented as a constant-head boundary in the uppermost nodes of the model at the approximate locations of the river's left bank and channel midpoint. Nodes representing the thickness of the aquifer below the nodes representing mid-point of the river channel were treated as no-flow boundaries. This boundary condition is used to approximate the location of the groundwater divide that exists beneath the Columbia River where groundwater from the Hanford Site and the other side of the river discharge into the Columbia. The Yakima River was also represented as a specified-head boundary at surface nodes approximating its location. Like the Columbia River, nodes representing the thickness of the aquifer below the Yakima River channel were treated as no-flow boundaries.

At Cold Creek and Dry Creek Valleys, the unconfined aquifer system extends westward beyond the boundary of the model. To approximate the groundwater flux entering the modeled area from these valleys, both constant-head and constant-flux boundary conditions were defined. A constant-head boundary condition was specified for Cold Creek Valley for the steady-state model calibration runs. Once calibrated, the steady-state model was used to calculate the flux condition that was then used in the post-Hanford steady state flow simulation. The constant-flux boundary was used because it better represents the response of the boundary to a declining water table than a constant-head boundary. Discharges from Dry Creek Valley in the model area, resulting from infiltration of precipitation and spring discharges, are approximated with a prescribed-flux boundary condition.

The basalt underlying the unconfined aquifer sediments represents a lower boundary to the unconfined aquifer system. The potential for interflow (recharge and discharge) between the basalt-confined aquifer system and the unconfined aquifer system is postulated to be small relative to the other flow components estimated for the unconfined aquifer system. Therefore, interflow with underlying basalt units was not included in the current three-dimensional model. The basalt was defined in the model as an essentially impermeable unit underlying the sediments.

3.4.3.4.3 Flow and Transport Properties. To model groundwater flow, the distribution of hydraulic properties, including both horizontal and vertical hydraulic conductivity and porosity were needed for each hydrogeologic unit defined in the model. In addition, to simulate movement of contaminant plumes, transport properties were needed, including contaminant-specific distribution coefficients, bulk density, effective porosity, and longitudinal and transverse dispersivities.

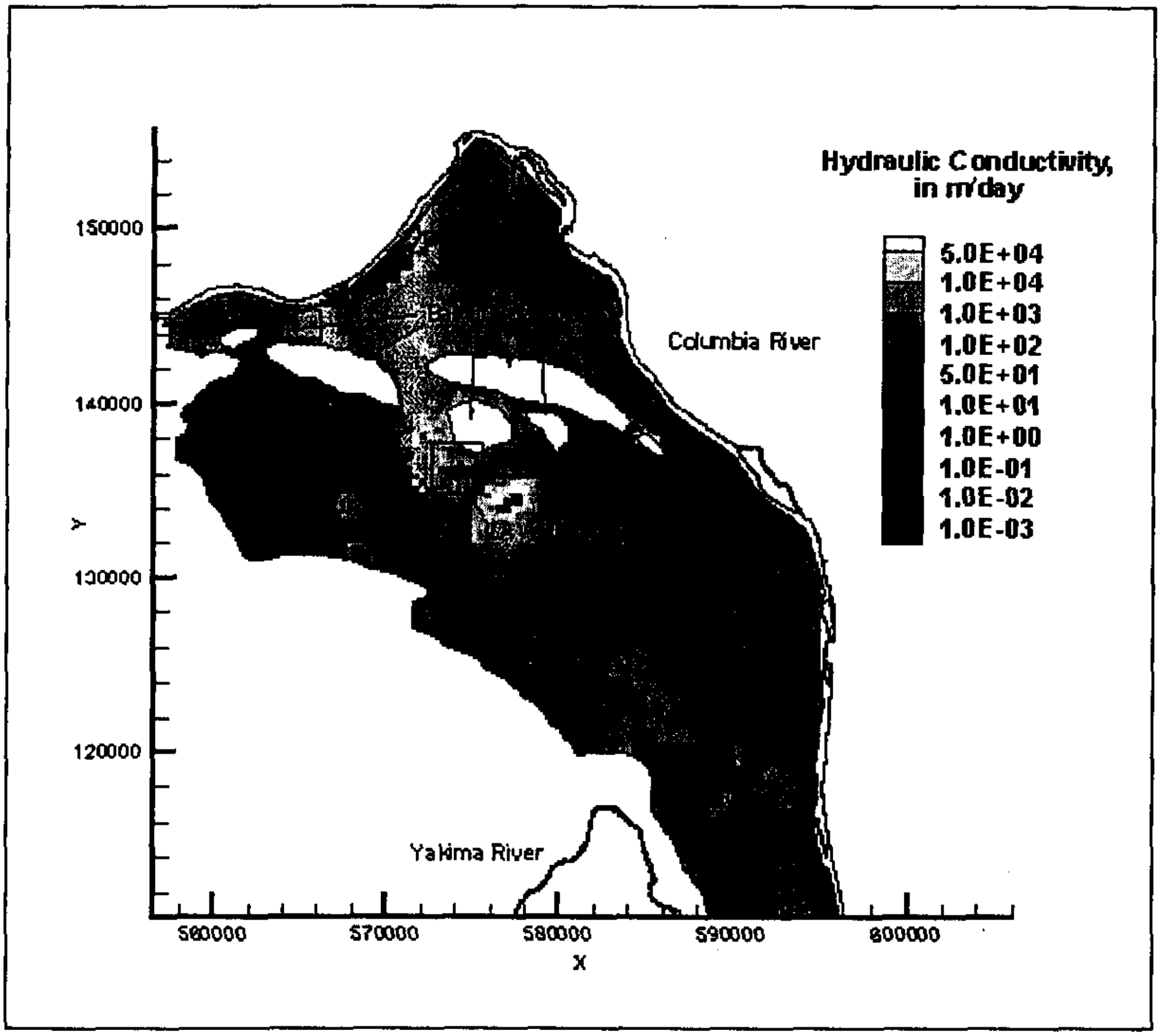
In the original model calibration procedure described in Wurstner 1995, measured values of aquifer transmissivity were used in a two-dimensional model with an inverse model-calibration procedure to determine the transmissivity distribution. Hydraulic head conditions for 1979 were used in the inverse calibration because measured hydraulic heads were relatively stable at that time. Details concerning the updated calibration of the two-dimensional model are provided in Cole 1997.

Hydraulic conductivities were assigned to the three-dimensional model units so that the total aquifer transmissivity from inverse calibration was preserved at every location. The vertical distribution of hydraulic conductivity at each spatial location was determined based on the transmissivity value and other information, including facies descriptions and hydraulic property values measured for similar facies. A complete description of the seven-step process used to vertically distribute the transmissivity among the model hydrogeologic units is described in Cole 1997. The hydraulic conductivity distribution resulting from this redistribution of aquifer transmissivity in the upper part of the aquifer is provided in Figure 3-3.

Estimates of model parameters were developed to account for contaminant dispersion in all transport simulations. Specific model parameters examined included longitudinal and transverse dispersion coefficients (D_l and D_t) as well as estimates of effective bulk density and porosity of the aquifer materials. This section briefly summarizes estimated transport properties.

In general, the horizontal dispersivity for aquifer transport is typically set at 10% of the travel length in the direction of flow and the transverse dispersivity is set at 10% of the longitudinal value. For predictions at 100 m (328 ft) downgradient of the facility, this would mean a longitudinal dispersivity of at least 10 m (32.8 ft) would be required. For this analysis, a lower longitudinal dispersivity of 5 m (16.4 ft) was selected to be within the range of recommended grid peclet numbers (P_e <4) for acceptable solutions. The 10-m (32.8-ft) estimate is about one-quarter of the grid spacing in the finest part of the local-scale model grid in the 200-Area plateau where the smallest grid spacing is on the order of 20 m by 20 m (65.6 ft by 65.6 ft).

Figure 3-3. Hydraulic Conductivity Distribution Obtained for the Uppermost Unconfined Aquifer from Inverse Calibration for 1979 Conditions.



The effective transverse dispersivity was assumed to be one-tenth of the longitudinal dispersivity. Therefore, 0.5 m (1.6 ft) was used in all simulations.

For purposes of this analysis, no adsorption was assumed in the groundwater transport modeling. All simulations were based the transport of a non-sorbed, long-lived radionuclide. Iodine-129 was used as the surrogate radionuclide in all calculations.

For purposes of these calculations, a bulk density of 1.9 g/cm^3 was used for all simulations. The effective porosity was estimated from limited measurement of porosity and specific yields obtained from multiple-well aquifer tests. The effective porosity values range from 0.01 to 0.37. Laboratory measurements of porosity, which range from 0.19 to 0.41, were available for samples from a few Hanford Site wells and were also considered. The few tracer tests conducted indicate effective porosities ranging from 0.1 to 0.25. Based on the ranges of values considered, a best estimate of an effective porosity value for all simulations was assumed to be 0.25.

Information on transport properties used in past modeling studies at the Hanford Site is provided in Wurstner 1995. Estimates of model parameters were developed to account for contaminant transport and dispersion in all transport simulations. Specific model parameters estimated included longitudinal and transverse dispersivity (D_l and D_t) and aquifer porosity. This section briefly summarizes estimated transport properties.

For the regional scale analysis, a longitudinal dispersivity of 95 m was selected to be within the range of recommended grid Peclet numbers ($P_e < 4$) for acceptable solutions. The 95 m estimate is about one-quarter of the grid spacing in the finest part of the model grid in the 200 Area plateau where the smallest grid spacing is on the order of about 375 m by 375 m. The effective transverse dispersivity was assumed to be 10 percent of the longitudinal dispersivity. Therefore, 9.5 m was used in all simulations.

3.4.3.4.4 Groundwater Sensitivity Cases. Groundwater sensitivity cases are run to determine the effect of different placement and orientation of the disposal facility, different pumping rates, different hydraulic properties of the aquifer, as well as different regional conditions.

3.4.4 Waste Package

> The waste package geometry is still evolving as design of the treatment plant and disposal facility continues.

3.4.4.1 Waste Package Geometry. The DOE intends to process approximately 10% of the waste from the Hanford tanks in an initial phase (Phase 1). (The plans in early 2000 identify a minimum of 6,000 packages [having cubic geometry with a side length of 1.4 m] and Kirkbride 1999 estimates that approximately 70,000 ILAW packages will be generated for all the ILAW in Phase 1 and Phase 2). The product description and specifications defined in this section are based on the DOE contract (DOE/BNFL 1998). The definition of the product form and specification for the remaining 91% of the Hanford tank waste are not defined at this time. For the purposes of this assessment activity, all the ILAW waste products are assumed equivalent to the DOE specifications for the Phase 1 contract and current plans.

The ILAW product consists of a silicate glass monolith sealed in a stainless steel (304L) package. The headspace above the silicate glass in the package is filled with silicate sand (BNFL 1998). The steel package has external dimensions of 1.4 m x 1.4 m x 1.4 m (-0 m/+0.05 m tolerances). The stainless steel side-wall thickness of the package is 6 mm. The package top is 12 mm plate and the bottom is 8 mm plate. Each ILAW package is planned to be filled to within 85% capacity (by volume) by ILAW and the void space would be filled with silicate sand such that the remaining free fill space is less than 5% (by volume). The top lid will be welded using the tungsten-inert gas (TIG) process.

Modification 12 of the BNFL contract (see DOE/BNFL 1998), which was issued on January 24, 2000, and the current contract with Bechtel Washington (DOE 2000c) require ILAW canisters in the form of right circular cylinders (1.22 m diameter by 2.29 m tall). This contract modification occurred after the data packages used in these analyses were issued and will hence are not part of the base analysis case. Sensitivity cases for the new dimensions were run, however. Future work will use the latest dimensions for the waste package and other facility information. However, a sensitivity case in this analysis shows that such a container size change is not significant to the conclusions of this performance assessment.

For the waste form calculations discussed in Section 3.5.3, the glass waste material was assumed to be fractured. Also, the surface area was assumed to be 10 times greater than that of an unfractured 1.4 m cube (Farnsworth 1985, Peters 1981). Hence,

$$A^S_{glass} = \frac{A_{glass}}{V_{glass}} = \frac{6(1.4)^2}{(1.4)^3} \times 10 = 42.8 \text{ m}^2\text{m}^{-3} \qquad (3.5)$$

where

A^S_{glass} = the specific surface area of the glass,

A_{glass} = the surface area of the glass, and

V_{glass} = the volume of the glass.

The surface area of the steel waste package was determined by assuming that both the inner and outer surfaces of the steel container were available to react.

$$A^S_{steel} = \frac{A_{steel}}{V_{steel}} = \frac{12(1.4)^2}{[0.012 + 0.008 + 4(0.006)](1.4)^2} = 272.73 \text{ m}^2\text{m}^{-3} \qquad (3.6)$$

where

A^S_{steel} = the specific surface area of the steel container,

A_{steel} = the surface area of the steel container, and

V_{steel} = the volume of the steel container.

3.4.4.2 Waste Form Release Rate. The 1998 ILAW PA (Mann 1998a) showed that the release rate from the waste form was one of the key parameters in the performance assessment. This rate is a major determinant of the impact of

> The waste form release rate is calculated as a function of the time- and spatial dependent chemical environment surrounding the glass forms. The parameters are based on a large series of experiments using different methods.

disposal as well as setting the temporal structure of that impact. The data for determining the waste form release rate are given in *Waste Form Release Data Package for the 2001 Immobilized Low-Activity Waste Performance Assessment* (McGrail 2001) and appendix K of Mann/Puigh 2001.

Dissolution of the glass waste form is the required first step to release a specific radionuclide. Because glass dissolution rate depends on a variety of parameters (amount of moisture, amount of silicic acid [the main by-product of dissolved glass] in solution, pH, amount and type of secondary phases) that will vary with time and location in the disposal system, the dissolution rate must be calculated. However, in order for the calculations to be technically defensible, they must be based on an accepted paradigm and an extensive database.

Over the last few decades, a general rate equation has been fashioned to described the dissolution of glass (and more ordered materials) into aqueous solution:

$$k = \vec{k} \alpha_{H^+}^{-\eta} e^{\frac{-E_a}{RT}} \left[1 - \left(\frac{Q}{K} \right)^{\sigma} \right] \prod_j \alpha_j^{\eta_j} \tag{3.7}$$

where:

k = dissolution rate, g/m²/d
$\vec{k}$ = intrinsic rate constant, g/m²/d
a_{H^+} = hydrogen ion activity
a_j = activity of the j^{th} aqueous species that acts as an inhibitor or as a catalyst of dissolution
E_a = activation energy, kJ/mol
R = gas constant, kJ/(mol K)
T = temperature, K
Q = ion activity product
K = pseudoequilibrium constant
η = pH power law coefficient
σ = Temkin coefficient.

Equation (3.7) is an approximation for glass because glass is metastable, and the reaction proceeds one way (i.e. glass dissolves). Equation (3.7) also just describes the net chemical reaction of glass matrix dissolution. There are a number of secondary chemical reactions that also need to be considered. One important reaction is the exchange of alkali ions in the glass for H^+ in water (McGrail 2000). The waste form contains high concentrations of sodium (up to 25 weight percent). At the temperatures of interest, the exchange of sodium in the glass with H^+ in the water is important because the reaction effectively increases the pH of the solution. Finally, dissolution/precipitation reactions are important because they can strip chemicals from the aqueous solution, affecting the glass corrosion rate or trapping important contaminants.

The parameters in these equations are established by a set of various experiments, performed at various temperatures and pHs:

- single-pass flow-through test
- product consistency test
- vapor hydration test
- pressurized unsaturated flow-through test.

The exact glass composition for ILAW has not been determined. The ILAW PA activity has worked with BNFL, Inc. and the DOE Tank Focus Area (Vienna 2000) to investigate a set of glasses in the BNFL, Inc. processing space. For the 2001 ILAW PA, the base analysis case uses LAWABP1 as the reference glass and HLP-31 glass as a sensitivity case. The LAWABP1 glass has the most extensive database of any glass in its processing space and its composition is based on the composition of preliminary BNFL, Inc. glasses. The corrosion reaction for LAWABP1 glass used in the waste form release calculations is:

$$\begin{aligned}
&\mathrm{LAWABP1} + 4.42\times10^{-1}\ \mathrm{H^+} + 1.89\times10^{-1}\ \mathrm{H_2O} \rightarrow 1.36\times10^{-1}\ \mathrm{AlO_2^-} \\
&\quad + 1.84\times10^{-1}\ \mathrm{B(OH)_3(aq)} + 1.13\times10^{-2}\ \mathrm{Cl^-} + 1.82\times10^{-4}\ \mathrm{CrO_4^{2-}} \\
&\quad + 1.46\times10^{-3}\ \mathrm{F^-} + 2.16\times10^{-2}\ \mathrm{Fe(OH)_3(aq)} + 1.54\times10^{-7}\ \mathrm{IO_3^-} \\
&\quad + 3.23\times10^{-2}\ \mathrm{K^+} + 8.48\times10^{-3}\ \mathrm{La^{3+}} + 1.71\times10^{-2}\ \mathrm{Mg^{2+}} + 4.46\times10^{-1}\ \mathrm{Na^+} \\
&\quad + 7.79\times10^{-4}\ \mathrm{HPO_4^{2-}} + 3.52\times10^{-8}\ \mathrm{PuO_2(CO_3)_3^{4-}} + 8.63\times10^{-4}\ \mathrm{SO_4^{2-}} \\
&\quad + 1.77\times10^{-8}\ \mathrm{SeO_4^{2-}} + 4.82\times10^{-1}\ \mathrm{SiO_2(aq)} + 6.59\times10^{-7}\ \mathrm{TcO_4^-} \\
&\quad + 2.15\times10^{-2}\ \mathrm{Ti(OH)_4(aq)} + 9.81\times10^{-7}\ \mathrm{UO_2(OH)_2(aq)} \\
&\quad + 2.20\times10^{-2}\ \mathrm{Zn^{2+}} + 2.94\times10^{-2}\ \mathrm{Zr(OH)_4(aq)}
\end{aligned} \tag{3.8}$$

The stoichiometric coefficients for I, Pu, Se, Tc, and U are based on the average package concentration from the *Immobilized Low Activity Tank Waste Inventory Data Package* (Wootan 1999).

3.4.4.3 Waste Form Data Used in this PA. The *Waste Form Release Data Package for the 2001 Immobilized Low-Activity Waste Performance Assessment* (McGrail 2001) should be referred to for a detailed discussion of the derivation of parameters used in this analysis. However, a few figures from that report are included here to provide the reader a feeling for the amount of data available and key findings from the experiments. Table 3-7 provides a summary of the best-estimate values for parameters important in calculating contaminant release from the LAWABP1 (and HLP-31) glass waste forms.

Table 3-7. Summary of Best Estimate Rate Law Parameters for LAWABP1 and HLP-31 Glasses at 15°C.

Parameter	Meaning	LAWABP1	HLP-31	Comments
$\bar{k}$	forward rate constant ($g\ m^{-2}\ d^{-1}$)	3.4×10^{6}	1.0×10^{7}	HLP-31 based on 26°C data only
K_g	apparent equilibrium constant for glass based on activity product $a[SiO_2(aq)]$	4.9×10^{-4}	ND	Not Defined. The HLP-31 glass dissolution rate did not change as function of $a[SiO_2(aq)]$
η	pH power law coefficient	0.35	0.35	HLP-31 value assumed same as LAWABP1
E_a	activation energy of glass dissolution reaction (kJ/mol)	68	68	HLP-31 value assumed same as LAWABP1
σ	Temkin coefficient	1	1	Assigned constant
r_x	Na ion-exchange rate ($mol\ m^{-2}\ s^{-1}$)	3.4×10^{-11}	0	No detectable ion exchange rate for HLP-31

Secondary Mineral Phase Reaction	Log K (15°C)
$Al(OH)_3(am)$ Φ $AlO_2^- + H^+ + H_2O$	-13.10
Analcime Φ $0.96AlO_2^- + 0.96Na^+ + 2.04SiO_2(aq)$	-9.86
Anatase + $2H_2O$ Φ $Ti(OH)_4(aq)$	-6.64
Baddeleyite + $2H_2O$ Φ $Zr(OH)_4(aq)$	-9.29
Goethite + H_2O Φ $Fe(OH)_3(aq)$	-11.09
Herschelite Φ $1.62Na^+(aq) + 0.50K^+(aq) + 2.26AlO_2^- + 4SiO_2(aq) + 0.14H^+ + 5.93H_2O$	-40.94
$La(OH)_3(am) + 3H^+$ Φ $3H_2O + La^{3+}$	22.55

Secondary Mineral Phase Reaction	Log K (15°C)
Nontronite-Na + $2H_2O$ Φ $0.330AlO_2^-$ + $2Fe(OH)_3(aq)$ + $0.330Na^+$ + $3.67SiO_2(aq)$	-43.33
PuO_2 + HCO_3^- + $0.5O_2(aq)$ Φ $PuO_2(CO_3)_3^{4-}$ + H_2O + H^+	-15.92
Sepiolite + $8H^+$ Φ $4Mg^{2+}$ + $6SiO_2(aq)$ + $11H_2O$	31.29
$SiO_2(am)$ Φ $SiO_2(aq)$	-2.85
Weeksite + $2H^+$ Φ $2K^+$ + 2 $UO_2(OH)_2(aq)$ + $6SiO_2(aq)$ + $3H_2O$	-5.25
Soddyite Φ $2UO_2(OH)_2(aq)$ + $SiO_2(aq)$	-20.24
Theophrastite + $2H^+$ Φ Ni^{2+} + $2H_2O$	13.33
$Zn(OH)_2(am)$ + $2H^+$ Φ $2H_2O$ + Zn^{2+}	14.44

Figure 3-4 displays the forward reaction rate (or intrinsic rate constant) as measured by the single-pass flow-through test for a number of glasses. Previous experience has shown that borosilicate glasses all have a similar forward reaction rate dependence on pH and temperature. The data in Figure 3-4 confirm this expectation. The glasses represented in Figure 3-4 represent both high and low-temperature melting LAW glass, and even a lanthanide borosilicate (LABS) that has no alkali content at all. We conclude that there is a high degree of confidence in being able to predict the forward rate of reaction as a function of pH and temperature for virtually any realistic ILAW glass composition. These data are also important in that they set the physical upper bound on the release rate from ILAW glasses, assuming the temperature and pH in the disposal system are known or can be calculated. However, an exception to this conclusion is HLP-31 glass. The forward reaction rate of HLP-31 glass is much higher than any other silicate-based glass we have studied. McGrail et al. (2001) found that HLP-31 was phase separated and attribute the high forward reaction rate to the formation of borate rich regions that leave portions of the glass susceptible to hydrolysis reactions. Clearly, glass homogeneity is an important consideration that impacts durability.

Figure 3-4. Forward Reaction Rate as a Function of Temperature and Solution pH for Several Borosilicate Glasses.

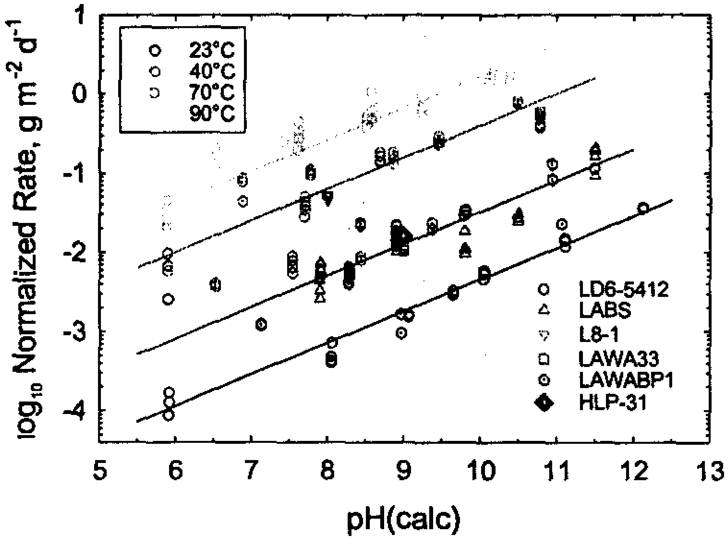
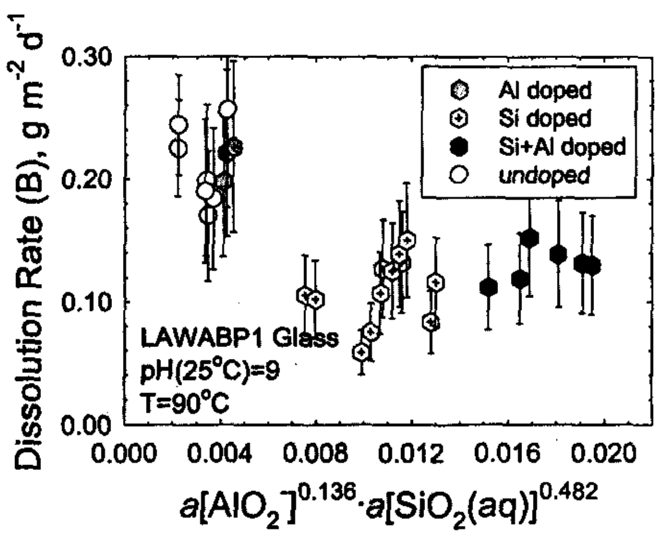


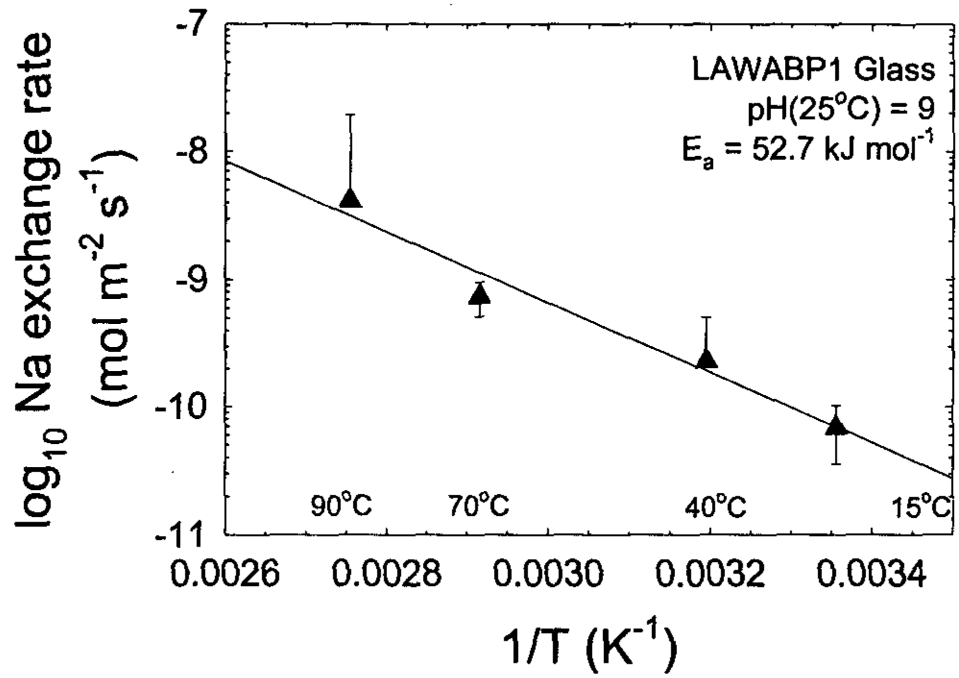
Figure 3-5 shows the effect of increasing the concentration of aluminum (as aluminate, AlO_2^-) and silicic acid on the dissolution rate of LAWABP1 glass. As the concentration of these species increases, the glass dissolution rate initially drops but then becomes invariant at higher concentrations. McGrail et al. (2001) discuss how alkali ion exchange controls the rate of glass dissolution in solutions with high concentrations of Si (and Al). The measured rate of Na ion exchange for LAWABP1 glass as a function of temperature is given in Figure 3-6.

Figure 3-5. Plot of Dissolution Rate at 90°C Versus Mixed Al-Si Activity Product. The exponents 0.136 and 0.482 are the mol fractions of Al and Si in LAWABP1 glass.



Longer-term dissolution behavior is determined by the other tests. Figure 3-6 shows the normalized release rates as measured from the PUF test. Differential rates of release are observed for the major glass components, which reflects their solubility behavior in water. Zinc, Zr, and Ti all form very insoluble hydroxides, which controls their release rate. In contrast, B and Na are highly soluble, and so have the highest elemental release rates. Bulk dissolution behavior is typically indexed by the rate of B release, as no solid phases are expected to form that would affect its solution concentration. Also note that the data from both the PUF and SPFT experiments is internally consistent. The high solid-to-liquid ratio in the PUF test establishes high concentrations of dissolved glass components. The average dissolution rate of LAWABP1 glass in the PUF test ($\approx$0.1 g m^{-2} d^{-1}) is essentially identical to the dissolution rate measured in SPFT experiments (0.12 g m^{-2} d^{-1}, Figure 3-5) in solutions near saturation with respect to amorphous silica. This is an important validation of the glass dissolution model.

Figure 3-6. Excess Sodium Release via Ion Exchange as a Function of Temperature for LAWABP1 Glass at pH(25°C)=9.



Another important validation of the underlying model is that the correct concentration of elements in solution released during long-term static tests can be predicted, as evidenced in Figure 3-8. In this case, the evolution of the solution composition in PCTs with LAWABP1 glass was predicted with the EQ3/6 geochemical code, along with a predicted paragenetic sequence of secondary phases shown in Figure 3-9. Secondary phases identified from these calculations along with phases directly observed from PUF and VHT experiments are listed in Table 3-7 and were included in the waste form release simulations with STORM.

The above discussion focuses on LAWABP1 glass, since it has been the most studied low-level waste glass. It is recognized that the actual glass produced will likely be (somewhat) different from LAWABP1. In Section 6.5, we show that the performance of LAWABP1 is in the middle of the performance space of the large number of ILAW glasses tested and so is representative of average performance that might be expected from actual ILAW glasses.

Figure 3-7. Normalized Release Rates in PUF Test with LAWABP1 Glass.

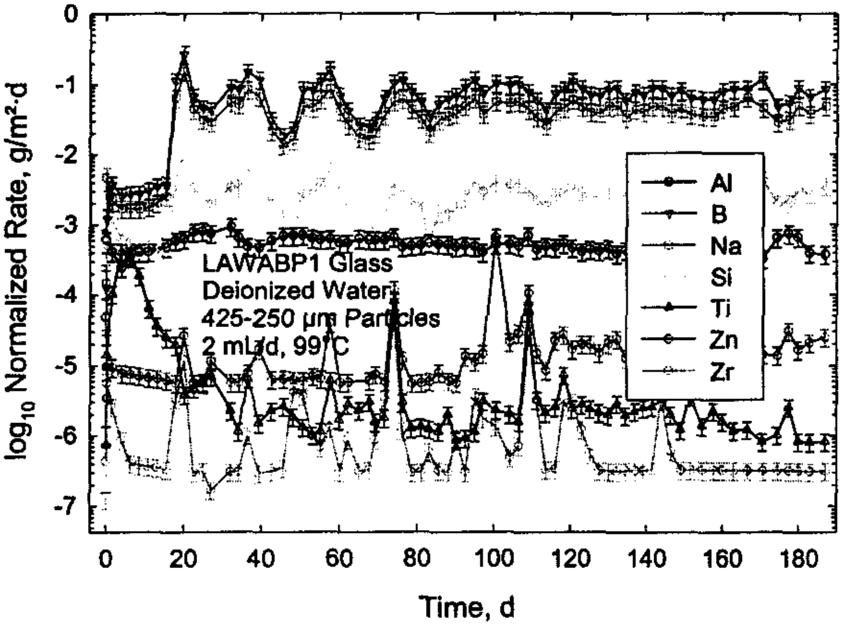


Figure 3-8. Comparison of PCT Solution Concentration Data with the Solution Composition Calculated with the EQ3/6 Code.

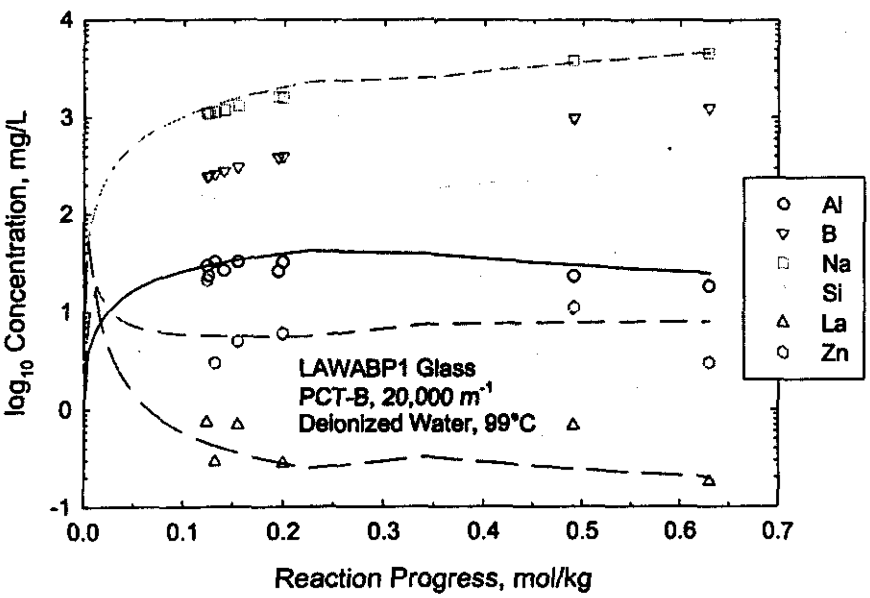
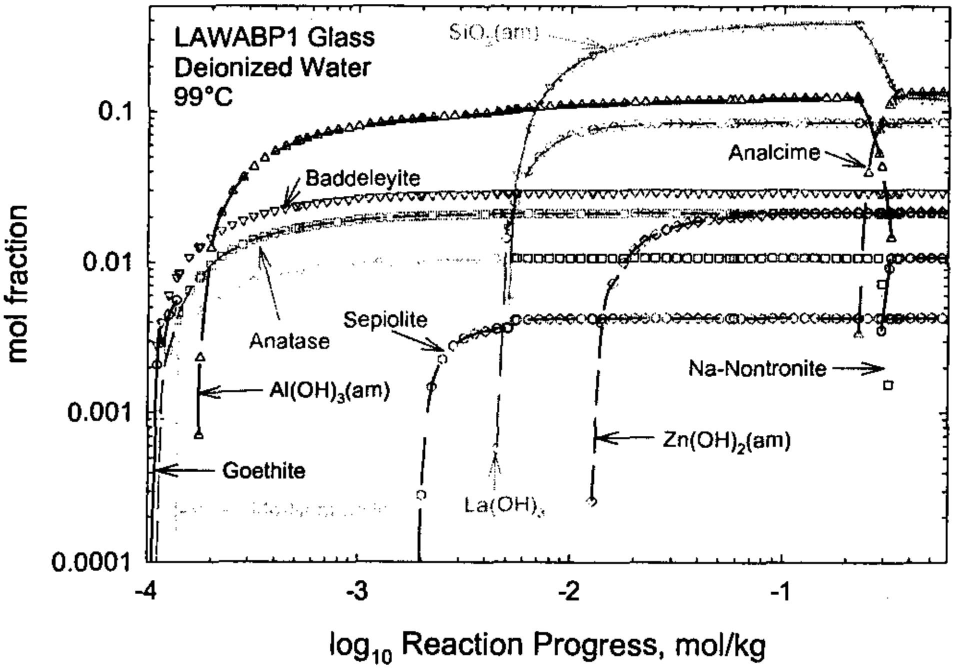


Figure 3-9. Predicted Paragenetic Sequence of Alteration Phases Formed During the Reaction of LAWABP1 Glass in Deionized Water. PuO_2 and soddyite were also predicted to form. However, they are not shown because of the very small mol fractions associated with these phases.



3.4.4.4 Sensitivity Cases. Because of the importance of waste form release to this performance assessment, a number of sensitivity cases are run. A large number of runs investigate the dependence of release on the amount of moisture entering the disposal facility (the rates being varied from 0.1 mm/y to 50. mm/y). Sensitivity cases are run to determine the importance of various glass dissolution mechanisms (e.g., pore water environment, Na-H ion exchange, secondary phases). Sensitivity cases were also run to determine the effect of surrounding materials (iron, concrete) and for how the packages are placed in the facility. A different glass composition is simulated, and laboratory results mimicking long term performance is given for a variety of glass compositions. Results from a two-dimensional calculation were also run to determine the sensitivity to the dimensionality of modeling. Finally, the model is extended to groundwater to estimate pH changes that might appear deeper in the vadose zone.

3.4.5 Disposal Facility

The disposal facility is modeled using the present conceptual designs for the facility discussed in Section 2.2. Unlike the 1998 ILAWPA, the disposal facility is proposed to be a series of large trenches.

The RH trench and concrete vault concepts summarized in Section 2.2 are used for the calculations. The RH trench has been chosen as the reference design for the base analysis case. The dimensions for the RH trench model are taken from Figure 2-25. The dimensions for the concrete vault model were taken from the description provided in Section 2.2.2.

The key components of the disposal system are the surface barrier, the sand-gravel capillary break, the trench (or vault) and the filler material. The surface barrier is assumed to be a modified RCRA-compliant subtitle C cap as described in Puigh 1999 (Section 4.0). Note that the cap is shaped like an inverted "v" and placed with its apex along the length dimension (north-south) and centered over each trench or vault. The slope of the cap is 2%. The cap extends 9 m beyond the inside edge of the RH trench (see Figure 2-25). (The surface cap extends 6 m beyond the long dimension edge of each new waste trench). This cap includes an asphalt layer and has a design life of 500 years. Beneath the surface cap is a sand-gravel capillary break. The sand layer is assumed to be 1 meter thick. A gravel layer is built up 3 meters at the apex and with a 2% slope to support the surface cap. This height assures that the waste packages are greater than 5 meters below the surface (per 10 CFR 61 requirements).

The trench and vault dimensions are as defined in Section 2.2. The leachate collection systems are ignored in the moisture and transport modeling. The leachate collection systems can be ignored because of the relatively short design life for these material (less than 500 years for concrete and 100 years for HDPE) compared to the travel time through the vadose zone (1,000-2,000 years). The 1998 ILAW PA (Mann 1998a) examined the potential impact of the concrete vault trapping water and then failing ("bathtub effect") and a similar case (see Section 3.5.5.6) is done in this document for the use of trenches. The analysis showed little effect on the estimated impacts at the time of compliance. The material between the packages in the trench (or vault) is assumed to be backfill material as defined in Meyer 1999. Additional details on the numerical model calculations for the facility can be found in Sections 3.5.2, 3.5.3, and 3.5.4.

A series of cases is performed to investigate the sensitivity to disposal facility design. The importance of surface barrier performance is investigated by varying the infiltration rate exiting the barrier. The best estimate case estimates the usefulness of the subsurface sand-gravel capillary barrier. Other cases look at the effect of shortening the surface barrier, the use of vertical barriers, and the consequences of a break in the capillary barrier. Finally, a set of calculations looks at the concrete vault design.

3.4.6 Infiltration Rate

The recharge rate is based on long-term lysimeter and tracer measurements combined with computer simulations.

The term recharge is used to denote the rate at which moisture flows past the root zone (that is, very near surface) into a region where moisture flow follows simpler models. Recommendations for recharge rates are taken from *Recharge Data Package for the Immobilized Low-Activity Waste 2001 Performance Assessment* (Fayer 1999), and are also provided in Appendix J of Mann/Puigh (2000a). Long-term estimates of moisture flux through a fully functional surface cover, the cover side slope, and the immediate surrounding terrain, as well as for degraded cover conditions are needed. These estimates were derived from lysimeter and tracer measurements collected by the ILAW PA activity and by other projects combined with a modeling analysis.

Values for the recharge are given in Table 3-8. Values are given for two separate surface soils, Rupert sands and Burbank loamy sands. The Rupert sands are located at the site of the existing grout vaults and at the southernmost 60% of the new ILAW disposal site. The Burbank loamy sand is located at the northernmost 40% of the new ILAW disposal site. Impacts from degradation of the surface barrier, vegetation change, climate change, and irrigation were considered in establishing the best estimate and bounding values.

For the base analysis case we have assumed the conservative position that the surface barrier has failed shortly after it was installed and used the recharge rate for Burbank loamy sand for just below the modified RCRA-compliant subtitle C surface cap.

Because of its importance to waste form release and to travel time, a number of infiltration rate sensitivity cases are run. Values range from 0.1 mm/yr to 50. mm/yr. Cases are run where the infiltration rate is time dependent and where it is spatially dependent.

Table 3-8. Recharge Rate Estimates (mm/year).[a]

Surface feature	Pre-Hanford	Construction	Cover and Post Cover Design Life
Surface cover	na	na	0.1 (0.01, 4.0)
Cover side slope	na	na	50 (4.2, 86.4)
Rupert sand	0.9 (0.16, 4.0)	0.9 (0.16, 4.0)	0.9 (0.16, 4.0)
Burbank loamy sand	4.2 (2.8, 5.5)	4.2 (2.8, 5.5)	4.2 (2.8, 5.5)
Construction	na	55.4 (50, 86.4)	na

[a]Best estimate case given, with values for reasonable bounding cases given in parentheses; na = not applicable

3.4.7 Exposure Parameters

Exposure parameters follow Hanford Site practices.

Dosimetry scenarios and parameter values are based on the discussion and values presented in *Dosimetry Data Package for the Hanford Immobilized Low-Activity Tank Waste Performance Assessment* (Rittmann 1999), and also appendix O of Mann/Puigh (2000a). The scenarios for human exposure to the hazardous materials associated with the ILAW glass are defined in appendix B (Mann, 1999b). Table 3-9 provides the unit dose factors (mrem per Ci exhumed) for the intrusion scenario where a post-intrusion resident lives near the exhumed waste associated with a well drilled through the disposal site. Table 3-10 provides the total unit dose factors for five exposure scenarios where the exposure includes contamination of the groundwater. These scenarios are for industrial, residential, agricultural, and population exposures as defined in the Hanford Site Risk Assessment Methodology (HSRAM) (DOE/RL 1991). The Native American subsistence resident exposure is discussed in DOE/RL 1997.

In the *Evaluation of the Potential for Agricultural Development at the Hanford Site* (Evans 2000), well screen heights in the local tri-county area were surveyed. The continued use of the 4.6-meter (15 foot) well screen height is justified, given that most screen heights are larger than this value.

Sensitivity cases are run to determine the difference caused by various dosimetry sets as well as different scenarios.

Table 3-9. Annual Unit Dose Factors for Post-Intrusion Resident (mrem per Ci exhumed).

Radionuclide	External	Internal	Radionuclide	External	Internal
H-3	0.0	$1.46x10^{2}$	U-234	$9.04x10^{-1}$	$2.68x10^{3}$
Se-79	$4.24x10^{-2}$	$1.24x10^{2}$	U-235+D	$1.66x10^{3}$	$2.51x10^{3}$
Sr-90+D	$5.15x10^{1}$	$2.00x10^{4}$	U-236	$4.81x10^{-1}$	$2.54x10^{3}$
Tc-99	$1.69x10^{-1}$	$7.93x10^{2}$	U-238+D	$2.61x10^{2}$	$2.45Ex10^{3}$
Sn-126+D	$2.41x10^{4}$	$1.05x10^{2}$	Np-237+D	$2.30x10^{3}$	$2.39x10^{4}$
I-129	$2.58x10^{1}$	$6.70x10^{3}$	Pu-239	$6.48x10^{-1}$	$1.18x10^{4}$
Cs-137+D	$6.80x10^{3}$	$1.23x10^{3}$	Pu-240	$3.34x10^{-1}$	$1.18x10^{4}$
Pa-231	$4.78x10^{2}$	$3.81x10^{4}$	Am-241	$9.98x10^{1}$	$1.23x10^{4}$
U-233	3.21	$2.74x10^{3}$			

Table 3-10. Total Annual Unit Dose Factors for Low-Water Infiltration Cases (mrem per pCi/L in the groundwater).

Nuclide	HSRAM Industrial [(a)]	HSRAM Residential [(a)]	All Pathways Farmer [(a)]	Native American Sustenance Resident [(a)]	Columbia River Population [(b)]
H-3	$1.62x10^{-5}$	$4.92 x10^{-5}$	$4.58 x10^{-5}$	$1.03 x10^{-4}$	$2.29x10^{-1}$
Se-79	$2.18x10^{-3}$	$7.26 x10^{-3}$	$1.15 x10^{-2}$	$3.10 x10^{-2}$	$5.03x10^{1}$
Sr-90+D	$3.83x10^{-2}$	$1.30x10^{-1}$	1.19E-01	$3.38 x10^{-1}$	$5.53 x10^{2}$
Tc-99	$3.65x10^{-4}$	$1.31 x10^{-3}$	$3.54 x10^{-3}$	$1.23 x10^{-2}$	$1.46 x10^{1}$
Sn-126+D	$5.28 x10^{-3}$	$4.07 x10^{-2}$	$5.63 x10^{-2}$	$1.20x10^{-1}$	$2.36x10^{2}$
I-129	$6.90 x10^{-2}$	$2.31x10^{-1}$	$3.77x10^{-1}$	1.21	$1.64x10^{3}$
Cs-137+D	$1.25 x10^{-2}$	$4.84 x10^{-2}$	$7.53 x10^{-2}$	$2.14x10^{-1}$	$3.25 x10^{2}$
Pa-231	2.68	8.87	7.08	1.84E+01	$3.40x10^{4}$
U-233	$7.51 x10^{-2}$	$2.45 x10^{-1}$	2.19^{-1}	$5.77x10^{-1}$	$1.04 x10^{3}$
U-234	$7.35 x10^{-2}$	$2.40 x10^{-1}$	$2.14 x10^{-1}$	$5.65x10^{-1}$	$1.02 x10^{3}$
U-235+D	$6.93 x10^{-2}$	$2.28 x10^{-1}$	$2.03 x10^{-1}$	$5.34x10^{-1}$	$9.62 x10^{2}$
U-236	$6.99 x10^{-2}$	$2.28 x10^{-1}$	$2.04 x10^{-1}$	$5.37x10^{-1}$	$9.65 x10^{2}$
U-238+D	$6.95 x10^{-2}$	$2.27 x10^{-1}$	$2.03 x10^{-1}$	$5.34x10^{-1}$	$9.60 x10^{2}$
Np-237+D	1.12	3.72	2.97	7.73	$1.42 x10^{4}$
Pu-239	$8.94x10^{-1}$	2.96	2.36	6.14	$1.13 x10^{4}$
Pu-240	$8.94 x10^{-1}$	2.96	2.36	6.14	$1.13 x10^{4}$
Am-241	$9.19 x10^{-1}$	3.05	2.43	6.32	$1.17 x10^{4}$

[(a)] Annual dose in mrem for a groundwater concentration of 1 pCi/L

[(b)] Annual dose in person-rem per Columbia River concentration of 1 pCi/L

3.5 PERFORMANCE ASSESSMENT METHODOLOGY

This section describes how the performance of the system was determined. That is, this section explains how the data and conceptual models presented in Sections 3.2 through 3.4 are translated into a numerical model suitable for computer simulation. First, the strategy of the computer simulation is introduced. Then the computer code selection criteria are summarized. The codes used are then described and their selection justified. Next the process of translating the disposal facility concepts and the natural system into computer models is described. Finally, the parameters used in the computer simulations are given.

Calculations of relatively simple equations (for example, gaseous diffusion or glacial-age catastrophic flood consequences) were done by hand. These equations will be treated in Chapter 4, where the results are discussed.

3.5.1 Integration

3.5.1.1 Strategy. Previous long-term environmental assessments at the Hanford Site have consistently shown that the groundwater pathway is the most important. This pathway also requires the most calculations. The conceptual model used for this and earlier Hanford Site performance assessments take the following eight steps:

1. The water leaves the very-near-surface soil region at the infiltration rate, which is a function of time due to facility degradation.

2. The water moves toward the waste form, but most of it is diverted by any intact capillary barrier.

3. The water that is not diverted is chemically modified by the local environment, interacts with the waste form, accumulates contaminants, and again is chemically modified by the local environment.

4. The water (possibly a reduced amount) leaves the disposal facility carrying contaminants with it. Some contaminants may interact with the material in the disposal facility, slowing the release of the contaminants to the surrounding natural environment.

5. The water moves through the undisturbed, unsaturated zone (vadose zone) below the disposal facility down to the unconfined aquifer. The contaminants also are transported through the vadose zone, again possibly undergoing some geochemical sorption.

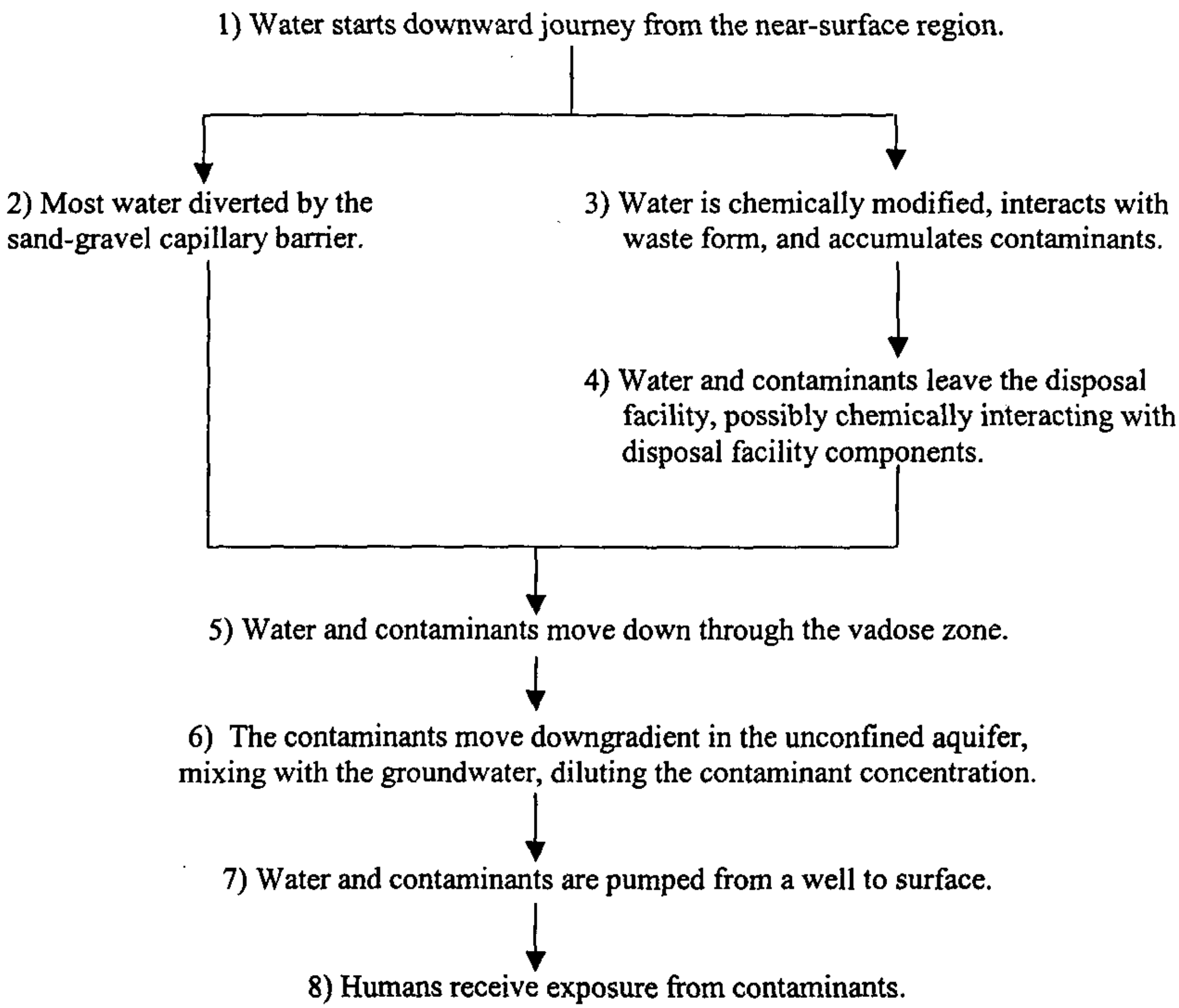
6. The water and contaminants move and mix with the water in the unconfined aquifer until they are extracted from the aquifer and brought to the surface or until they reach the Columbia River.

7. Contaminants are normally extracted by being carried to the surface with groundwater being pumped through a well.

8. The radionuclide contaminants then result in human exposure through a variety of pathways (ingestion, inhalation, and external radiation).

Figure 3-10 shows these eight steps as a flow chart.

Figure 3-10. Eight Sequential Steps for the Groundwater Pathway.



These groundwater analyses start at the time of disposal site closure. However, given the relatively short duration of disposal operations (2007 through 2028) compared to the travel time of the contaminants (thousands of years) or the release time of the waste form (hundreds of thousands of years), the exact definition of this start time is unimportant.

The results for each step are computed separately and used in the next step so that computations can be made more easily. Such an approach is taken to maximize computational efficiency. Some of the computer simulations take 100 hours of computer time; some take a few minutes. Each is a highly specialized calculation. However, the overall model is always considered at each step and consistent data are used throughout.

The strategy for the current computations is to define a base analysis case, then develop sensitivity cases derived from that base analysis case. In some instances the sensitivity cases are built on an alternative case, such as the one describing the concrete vault concept. The results for the base analysis case and the sensitivity cases are presented in Chapter 4. Chapter 6 combines the results of the computer simulations, the simpler calculations, and the other analyses to integrate and interpret how the contaminants will affect the environment in the long term.

3.5.1.2 Base Analysis Case. The base analysis case provides the "best" information on how the system may evolve given the information available. The base analysis case is not necessarily the way the system will behave. As more information concerning the waste form, the disposal facility design, and disposal site location is gathered, the definition of the base analysis case is expected to evolve. The approach used in the base analysis case is conservative, but reasonable. It should be noted that the base analysis case does not include the sand-gravel capillary barrier that is presently part of the conceptual design. As will be seen when the results of the best estimate case are given in Sections 4.3.7 through 4.3.11 and in the corresponding sensitivity cases, the impacts resulting from such a barrier depend on its detailed parameters that have not yet been established through a detailed design process. Thus, the inclusion of the capillary barrier is treated as a case separate from the base analysis case.

The details of the models and related data for the base analysis case are presented in Sections 3.5.3 and 3.5.4, respectively. The major features of the base analysis case are as follows:

- The location of the facility is that selected for the new disposal facility (Rutherford 1997)
- The future land use of the 200 Areas is as a protected area, without artificial recharge (for example, no irrigated farming occurs)
- The design of the disposal facility is based on a pre-conceptual design based on the Hanford Radioactive Mixed Waste Burial Trench and is documented in Puigh 1999 (Section 3.4.5)
- The long-term contaminant release rate from the waste form is calculated based on the scenarios described in Section 3.3.2
- The data for the natural system are those collected and interpreted for this performance assessment (Section 3.4.3).

The 1998 ILAW PA showed that the key variable in the analysis is the waste form release rate, which must be calculated over thousands of years. To conduct this calculation, we have pursued a methodology where the waste form release rate is evaluated by modeling the basic physical and chemical processes that are known to control dissolution behavior instead of using empirical extrapolations from laboratory "leaching" experiments commonly used in other performance assessments. We adopted this methodology for the following reasons:

- The dissolution rate, and hence radionuclide release rate from silicate glasses is not a state function, i.e. a constant that can be derived independent of other variables in the system. Glass dissolution rate is a function of three variables (neglecting glass composition itself): temperature, pH, and composition of the fluid contacting the glass. The temperature of the ILAW disposal system is a known constant. However, both pH and composition of the fluid contacting the glass are variables that are affected by flow rate, reactions with other engineered materials, gas-water equilibria, secondary phase precipitation, alkali ion exchange, and by dissolution of the glass itself (a classic feedback mechanism). Consequently, glass dissolution rates will vary both in time and as a function of position in the disposal system. There is no physical constant such as a "leach rate" or radionuclide release rate parameter that can be assigned to a glass waste form in such a dynamic system.

- One of the principal purposes of the ILAW PA is to provide feedback to engineers regarding the impacts of design options on disposal system performance. A model based on empirical release behavior of the waste form could not provide this information. For example, we have found little effect on waste form performance regardless of whether stainless or cast steel is used for the waste form pour canister. However, significant impacts have been observed when large amounts of concrete are used in constructing vaults for ILAW. The concrete raises the pH of the pore water entering the waste packages and so increases glass corrosion.

Unfortunately, the robust methodology we have employed does not come without some penalties. The principal penalty is the increased amount of information that is needed about the reaction mechanisms controlling the dissolution behavior of the waste form. Significantly more laboratory experiments are required to parameterize the models used for our simulations. Second, the model itself is markedly more complex. Execution times with today's fastest workstations can take weeks for one- and two-dimensional simulations and three-dimensional simulations can only be attempted on today's most sophisticated massively parallel computers. Still, we believe the benefits, particularly with regards to the technical defensibility of the methodology and results, far outweigh the penalties.

3.5.1.3 Best Estimate Case. The base analysis case assumes that there is no subsurface sand-gravel capillary barrier even though the current planning includes one. This is done because the exact properties of this subsurface barrier are not well known and such uncertainty could lead to misleading results. Thus, a separate case is performed with the subsurface sand-gravel capillary as part of the simulation.

3.5.1.4 Sensitivity Cases. The purpose of the sensitivity cases is to determine the uncertainty from the use of various parameters and the sensitivity of various assumptions. The data packages on which this assessment is based provide uncertainty estimates for the parameters used. The results of the sensitivity cases can provide the effects of these data uncertainties.

Larger uncertainties, however, arise from choices not yet finalized on waste form composition as well as disposal facility design, layout, and location. Most of the sensitivity cases investigate the effect of such choices.

3.5.2 Computer Codes

This section discusses the computer codes used for this performance assessment and justifies their technical adequacy. The general selection criteria used to select the major computer codes are first summarized. Sections 3.5.2.2 through 3.5.2.5 describe each major computer code used and the reason for its selection.

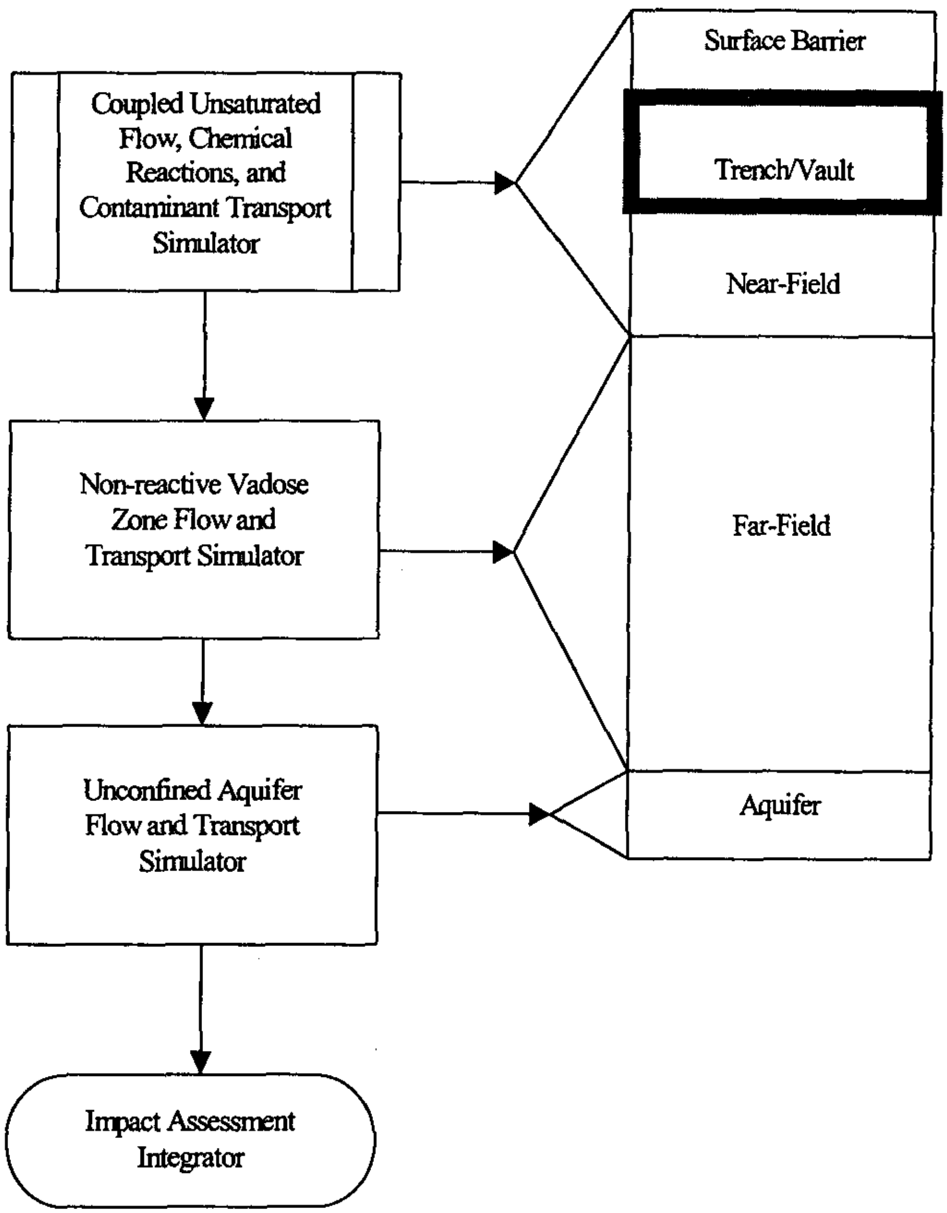
Computer codes will be used for four purposes:

- to calculate contaminant release rates from the waste packages and from the disposal facility,
- to calculate moisture flow and contaminant transport in the vadose zone (including moisture flow into the disposal facility),
- to calculate moisture flow and contaminant transport in groundwater, and
- to normalize and merge the results of the preceding codes.

Figure 3-11 illustrates also the overall computational strategy for the ILAW PA.

The near-field environment is defined as the domain through the trench or vault to some distance below the floor of the disposal facility. A coupled unsaturated flow, chemical reactions, and contaminant transport simulator (STORM) was used within the near-field (Bacon 2000). The plume exiting the region near the vault is expected to be of high ionic strength and pH, and will migrate down into the near-field vadose zone for some distance. However, at some distance from the disposal vaults, geochemical conditions will approach those more typical of the Hanford vadose zone and for which simplifying assumptions (such as linear sorption, negligible precipitation/dissolution, no changes in hydraulic properties, and no fluid density gradient effects) can be used. This region is defined as the far-field environment and can be simulated using standard, non-reactive (chemical reactions not specifically included in calculations) flow and transport codes. For the ILAW PA, computations in the far-field domain were done using VAM3DF (Huyakorn 1995), a variably saturated flow and transport code.

Figure 3-11. Modeling Strategy for Assessing ILAW Disposal System.



The primary reason for switching from the near-field simulator to VAM3DF is to apply a less complicated code for the far-field, and therefore a faster turnaround for the numerical simulations. The radionuclide flux exiting the far-field domain to the unconfined aquifer will be provided by VAM3DF and will be used as a boundary condition for the unconfined aquifer flow and transport simulator. Sorption to soils is treated by VAM3DF by the use of the effective chemical distribution coefficient (K_d) rather than by a set of chemical reaction equations. Calculations in the groundwater aquifer are performed using the Hanford Site model and associated code, CFEST-96, (Gupta 1987). The Hanford Site Groundwater Program has recommended this code for performing saturated flow and transport simulations for the Hanford Site. Finally, the results of each of the sequential calculations are combined to estimate the impacts from the disposal system using the INTEG program (Mann 1996b). This program combines the results from the far field calculations, the groundwater calculations, and the dosimetry data to estimate impacts related to the performance objectives.

3.5.2.1 General Selection Criteria for Computer Codes. The major computer codes used for this assessment were selected based on meeting general code selection criteria and functional criteria related to the simulation being done. Large computer codes were needed for computing in the following three functional areas:

- Calculation of the contaminant release rate from glass
- Calculation of water flow and contaminant transport in the vadose zone
- Calculation of water flow and contaminant transport in the unconfined aquifer.

The codes considered had to first meet the general code selection criteria.

The general code selection criteria were based on government code selection documents and the experience of others. The waste management code selection criteria of the DOE (Case 1988) and the NRC (Kozak 1989) were used to develop these selection criteria. The criteria were also shaped by the experience gained from other DOE performance assessments (WSRC 1992, Kincaid 1995, Mann 1998a) and codes selected for earlier Hanford Site risk assessments (DOE/RL 1991a). The general required selection criteria included the following:

- Having the appropriate scientific framework
- Having documentation covering the underlying theory, use, and verification
- Being under configuration control.

General desirable criteria included the following:

- Suitable hardware requirements
- Suitable complexity
- Flexible interfaces with other codes

- A bias against proprietary codes
- Familiarity of the users with the code.

Mann 1995c details the development of the general selection criteria and the complete criteria. A slight modification of these criteria were adopted by the major projects of the Hanford Groundwater / Vadose Zone

The actual codes selected also had to meet criteria related to the function being simulated. Sections 3.5.2.2 through 3.2.2.5 summarize the codes chosen and the reasons for their selection. References to specific functional criteria will be given in their sections or related appendices.

STORM was chosen as the code to estimate containment release rates from the waste form and subsequent transport in the disposal facility.

3.5.2.2 Calculation of the Contaminant Release Rate from Glass. The *Subsurface Transport Over Reactive Multiphases* (STORM) code (Bacon 2000) is the source-term code used for estimating the time-dependent flux of radionuclides released from the waste form and the subsequent transport of contaminants in the disposal facility. STORM contains two important factors that allow the code to simulate the processes in the disposal facility. First, the code is based on basic principles of physics, chemistry, and thermodynamics that provide the best estimate of contaminant release over the spatial and long time periods of interest. Second, the model for the disposal facility can be coupled with a model for radionuclide release, thus providing the ability to couple the effects of facility design with waste form performance.

Using chemical reaction rates (including the glass corrosion rates) and moisture values in the trench (or vault) fromVAM3DF (Section 3.5.2.3), STORM provides the source term for the vadose zone calculations. STORM calculates the following:

- The flow of moisture in the disposal facility
- The degradation of the waste form with corresponding release of radionuclides
- The chemical reactions that depend on time and space (including the formation of secondary mineral phases and the consumption of water)
- The transport of the water and contaminants through the disposal facility.

3.5.2.2.1 Selection. STORM was selected (McGrail 1998a) because it best met the criteria and requirements for the disposal system release model (McGrail 1994) and the general code requirements (Mann 1995c). The needed capabilities were identified from an analysis of the important physical and chemical processes expected to affect LAW glass corrosion and the mobility of radionuclides. The available computer codes with suitable capabilities were ranked in terms of the feature sets implemented in the code that match a set of physical, chemical, numerical, and functional capabilities needed to assess release rates from the engineered system. The highest ranked computer code was found to be the STORM code.

3.5.2.2.2 Code Description. STORM calculates the total mass flux of radionuclides leaving the disposal facility by solving a coupled set of equations. The set describes the radionuclide release from the waste form and the mass transport of the radionuclides from the waste form through the disposal facility, constrained by chemical reactions. This coupled set of equations is commonly known as the reaction-transport equation. The value for radionuclide release from the waste form is taken from either an assumed constant release rate or a simulation using a mechanistic glass corrosion model. More detailed documentation of the design and models used in the STORM code is found in the STORM User's Guide (Bacon 2000).

3.5.2.2.3 Code History. The STORM code was developed at PNNL for the U.S. Department of Energy for evaluation of arid land disposal sites. It is a merged version of the AREST-CT code (Engel 1995a and Engel 1995b) and the STOMP code (White 1996). AREST-CT was originally developed at PNNL to support the engineered-system performance analyses for the proposed high-level waste repository at Yucca Mountain, Nevada. It was used in the 1998 ILAW PA to estimate contaminant releases for some sensitivity cases. STOMP, also developed at PNNL, is a general, coupled non-isothermal multiphase flow and transport simulator. It has been used for a variety of Hanford Site analyses including the Hanford Site Composite Analysis (Kincaid 1998).

3.5.2.2.4 Verification. The verification studies for STORM are documented in Chapter 8 of *Subsurface Transport Over Reactive Multiphases (STORM): A General, Coupled Nonisothermal Multiphase Flow, Reactive Transport, and Porous Medium Alteration Simulator, Version 2, User's Guide* (Bacon 2000), which is included as Appendix D in Mann/Puigh (2000a).

3.5.2.3 Calculation of Water Flow and Contaminant Transport in the Vadose Zone. The VAM3DF code is used to estimate the moisture flow into the disposal facility and the moisture flow and contaminant transport from the disposal facility into groundwater.

VAM3DF calculates moisture flow and contaminant transport in the vadose zone.

3.5.2.3.1 Selection. Mandatory and desirable criteria for a vadose zone moisture flow and contaminant code were published (Mann 1998b). These criteria were based on the needs identified in the creation of the 1998 ILAW PA. They are also consistent with vadose zone code selection criteria recently published by other Hanford Site projects (Mann 1999c). The developers of the three codes, which have been historically, used the most for Hanford Site vadose zone calculations (PORFLOW, STOMP, and VAM3D-CG) submitted responses to the criteria. All three codes meet the mandatory criteria, but three independent evaluators (Voogd 1998) selected VAM3D-CG as the code best meeting the desirable criteria. A later version of VAM3D (labeled VAM3DF) is actually used in these calculations.

3.5.2.3.2 Code Description. VAM3DF (Huyakorn 1999) calculates saturated-unsaturated groundwater flow and solute transport with variable water table positions and highly non-linear soil moisture conditions. The code can simulate transient or steady-state problems in one, two, or three dimensions using a finite element model. Special grid elements (in the shape of hexahedrals) are used to define discrete volumes with irregular geometry. The size of these elements can vary. Many "fine" elements can be used in places where the geometry varies quickly. Such finer elements allow a better description of regions in which the values of parameters and variables are changing rapidly. An orthogonal curvilinear grid can also be used to represent flow domains.

3.5.2.3.3 Code History. VAM3DF is the latest in a series of variably saturated analysis model codes from HydroGeoLogic, Inc. to model moisture and contaminant movement for the vadose zone and groundwater. VAM codes have been used in many Hanford Site analyses. VAM3D-CG was used in the solid waste burial ground performance assessments (Wood 1995a and Wood 1996) and as the groundwater code in the 1998 ILAW PA (Mann 1998a). Relative to VAM3D-CG, VAM3DF includes decay chain nuclide analyses, data fusion (not used in this PA), as well as other improvements.

3.5.2.3.4 Verification. VAM3DF has been verified and validated by HydroGeoLogic, Inc. (Huyakorn 1999). A separate validation package was done for this performance assessment (Finfrock 2000a) and is included in the data packages for this PA.

3.5.2.4 Calculation of Water Flow and Contaminant Transport in the Unconfined Aquifer. The Richland Field Manager (Wagoner 1996) directed the Hanford Groundwater Program to establish a single groundwater model for the Hanford Site. The Hanford Groundwater Program has selected CFEST as the interim code. Documentation of code formulation, user's guides, and verification are given in Gupta 1987. Documentation of the specific application of the CFEST

CFEST is the groundwater modeling code.

code to the site-wide groundwater flow and transport model at Hanford is provided in Wurstner 1997, Cole 1997, and Kincaid 1998. Documentation of code selection is provided in DOE/RL 2000.

3.5.2.5 Integration of Results. INTEG (Mann 1996b) calculates a specific impact (whether dose rate or concentration level) based on the inventory, vadose zone transport, aquifer transport, and dosimetry factors. The dose rate calculated depends on the type of dosimetry factor (i.e., all-pathways, drinking water). The program solves the following equation for each year under consideration.

$$\mathit{Response} = \sum_i I_i(t)\,\Gamma_i(t)\,w_i\,D_i\,/\,(r\,A) \qquad (3.9)$$

where

I_i = the amount (or inventory) of radionuclide i (Ci). The time-dependent value is calculated by INTEG based on the initial inventory and on decay and the ingrowth from other radionuclides.

Γ_i = the flux of contaminants at the bottom of the vadose zone normalized to an unit source inventory for radionuclide i ([Ci/y]/Ci). The time-dependent value is calculated by VAM3DF.

w_i = the ratio of the concentration of radionuclide i at the well location relative to the contaminant concentration at the bottom of the vadose zone (dimensionless). This quantity was called the well intercept factor in earlier Hanford performance assessments. The peak value as calculated by CFEST is used.

D_i = the dose rate factor (mrem/y per Ci/m^3). The values are taken from the tables in Appendix B. D_i is unity when the response that is calculated is a concentration.

r = the recharge rate (m/y). The value at 10,000 years is used at all analysis times.

A = the area over which the contaminant flux enters the aquifer (m^2). The value used is the area of the disposal facility being modeled.

The program is modeled after GRTPA (Rittmann 1993), which served a similar function in earlier work (Rawlins 1994 and Mann 1995b). INTEG allows greater freedom in specifying data used in the integration. The code has been benchmarked against the results of GRTPA (Mann 1996b). An auxiliary code was written to translate the output of VAM3DF into a readable format for INTEG.

3.5.2.6 Spreadsheets. Commercial spreadsheets were used in determining inadvertent intrusion doses. The Excel spreadsheet was used for developing the spreadsheet cells and the calculations. The spreadsheet calculations were compared with hand calculations documented in Rittmann 1999 and verified as part of the review by the Hanford Environmental Dose Oversight Panel (HEDOP).

3.5.3 Computer Models

This section describes the numerical models used in this performance assessment: waste form release (STORM), disposal facility barrier and vadose zone (VAM3DF), and groundwater (CFEST). The actual data used is discussed in the next section.

3.5.3.1 Waste Form Release. Contaminant releases were calculated for both the trench and concrete vault designs, each having a different model. However, the model that applies to both types of disposal facility types is given first. More information can be found in *2001 ILAW PA Waste Form Release Rate Sensitivity Analysis* (Bacon 2001).

3.5.1.1.1 Waste Form Release Model. The waste package containers were assumed to consist of 304 stainless steel. The corrosion reaction for 304 stainless steel is given by Cloke 1997:

$$\begin{aligned} \text{Steel} + 2.9262\times10^{-2}\ \text{H}^+ + 1.7618\ \text{H}_2\text{O} + 3.4169\times10^{-1}\ \text{O}_2(\text{aq}) \rightarrow \\ 3.4667\times10^{-3}\ \text{HCO}_3^- + 3.4701\times10^{-1}\ \text{CrO}_4^{2-} + 1.1828\ \text{Fe(OH)}_3(\text{aq}) \\ + 3.5167\times10^{-2}\ \text{Mn}^{2+} + 9.9093\times10^{-3}\ \text{NO}_3^- + 1.8583\times10^{-1}\ \text{Ni}^{2+} \\ + 8.8004\times10^{-4}\ \text{HPO}_4^{2-} + 5.2008\times10^{-4}\ \text{SO}_4^{2-} + 1.7325\times10^{-2}\ \text{SiO}_2(\text{aq}) \end{aligned} \tag{3.10}$$

The 304L stainless steel corrosion rate was conservatively assumed to be a constant $6.87\text{x}10^{-14}$ mol cm^{-2} s^{-1} (Cloke 1997), taking into account changes in the steel corrosion rate due to changes in pH or water chemistry.

Other materials in the simulations, including vault concrete, backfill, Hanford Sand, and vault filler, contain additional solid phases. The backfill material was assumed to consist of 40% albite, 40% quartz, 10% K-feldspar and 10% illite (Mann 1998a). Degraded vault concrete was assumed to consist of backfill with 15% Portlandite added. The vault filler and Hanford Sand were assumed to have the same mineral composition as the backfill material. The dissolution reactions and equilibrium constants associated with each of these minerals are detailed in the *Waste Form Release Data Package for the 2001 Immobilized Low-Activity Waste Performance Assessment* (McGrail 2001).

Model grids were 5 cm in vertical resolution; this is slightly larger than the 3.66 cm grid spacing used in the 1998 ILAW PA. The time steps used in these calculations were calculated automatically by the code given a convergence criterion of $1\text{x}10^{-6}$. This ensures that predicted values of aqueous species concentrations and mineral volumes are accurate to 0.0001 percent between iterations for a given time step. If this cannot be achieved within a certain number of iterations, the time steps are automatically reduced. Numerous simulations were conducted to ensure that the grid spacing and convergence criteria chosen for the simulations were small enough to ensure accuracy, yet large enough to allow the simulations to finish in a reasonable amount of time. For comparison, the base case remote handled trench simulation was rerun with a grid spacing of 2.5 cm, and also with a convergence criterion of 5×10^{-7}. Results for these simulations were not significantly different than reported herein.

The flow simulations used the following boundary conditions: constant specified flux at the upper boundary and free drainage at the lower boundary. The reactive transport simulations used the following boundary conditions: specified aqueous species concentrations at the upper boundary and no diffusion across the lower boundary. The flux of the contaminant across the lower boundary is therefore limited to advection

$$f = c\rho_w v \tag{3.11}$$

where

c = concentration of the contaminant (mol kg^{-1})

ρ_w = density of water (mol m^{-3})

v = specific discharge (m s^{-1}).

The normalized contaminant flux to the vadose zone is calculated by summing all the fluxes across the bottom boundary of the model, and normalizing the total flux according to the amount of Tc in all the waste packages at the start of the simulation. The normalized flux of the contaminant across the lower boundary, F, in units of ppm/y, was calculated using

$$F = \frac{\sum_{i=1}^{N} f_i \Delta x_i \Delta y_i}{I} (3.1558\times10^7 \text{ s yr}^{-1})(1\times10^6 \text{ ppm}) \tag{3.12}$$

where

f_i = contaminant flux across the bottom of an individual grid block (μmoles m^{-2} s^{-1})
$\Delta x_i \Delta y_i$ = cross-sectional area of an individual grid block (m^2)
I = inventory of the contaminant in the waste packages (μmol), where

$$I = V_{wp}\left(1-\theta_T\right)V_G \rho_G \gamma_{Tc} \tag{3.13}$$

where

V_{wp} = volume of the waste packages (m^3)
θ_T = total porosity of the material representing the waste packages (0.02)
V_G = fraction of each waste package that is glass (0.85)

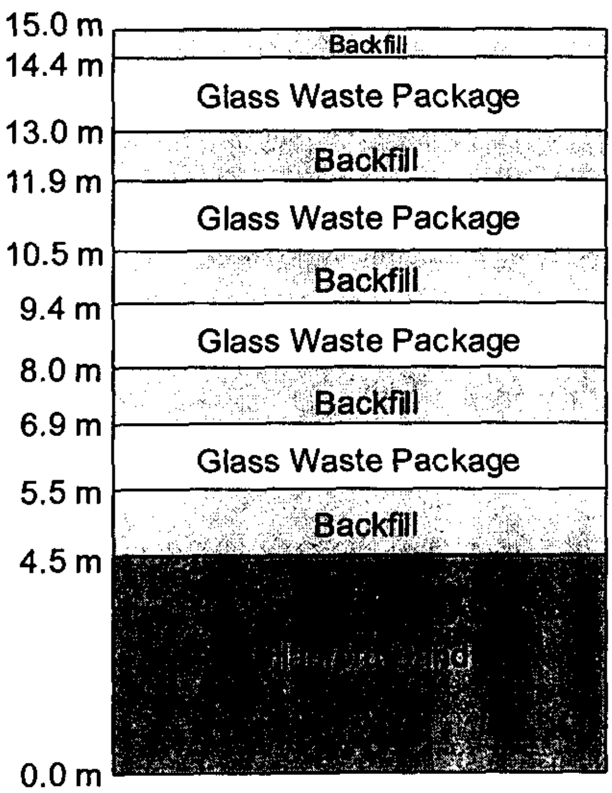
ρ_G = molar density of LAWABP1 glass (38776.1450 moles m^{-3})

γ_{Tc} = mole fraction of the contaminant in LAWABP1 glass (e.g., 6.59×10^{-1} µmoles Tc $mole^{-1}$ glass)

The volume of the waste packages, V_{wp}, was 5.6 m^3 for the RH Trench simulations and 8.4 m^3 for the new ILAW concrete vault simulations. For 1-D simulations the cross-sectional area of the grid block was 1 m^2. For the 2-D sensitivity case, the cross sectional area applies per meter of trench.

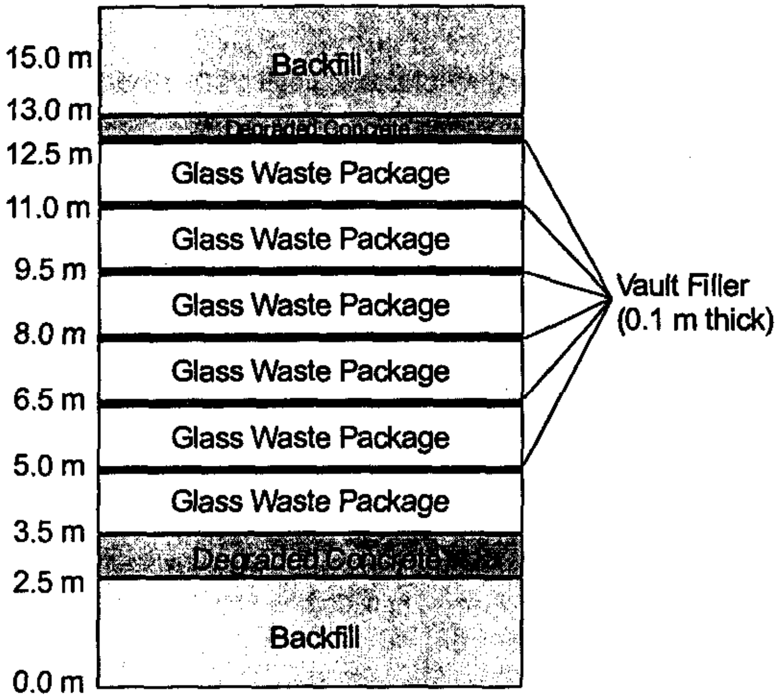
3.5.3.1.2 Waste Form Release Model for Trenches. The remote handled trench simulations encompass a 1-D vertical profile near the center of a single trench (Figure 3-12). It is assumed that the material representing the waste packages is 85% glass, 2% stainless steel and 13% filler by volume. The steel container was assumed to not provide a water barrier at the start of the simulation.

Figure 3-12. Material Zones for Remote Handled Trench Waste Form Release Simulations.



3.5.3.1.3 Waste Form Release Model for Concrete Vaults. The new ILAW vault simulations encompass a 1-D vertical profile at the center of a single vault (Figure 3-13). It is assumed that the material representing the waste packages is 85% glass, 2% stainless steel and 13% filler by volume. The steel container was assumed to not provide a water barrier at the start of the simulation.

Figure 3-13. Material Zones for New ILAW Vault Waste Form Release Simulations.



3.5.3.2 Disposal Facility Barrier and Vadose Zone. Because VAM3DF is used to both estimate the moisture flux into the disposal facility as well as the moisture flow and the contaminant transport from the disposal facility to the groundwater (the far-field problem) two types of model were used. More information can be found in *Near Field, Far Field and Estimated Impact Calculations for the Hanford Immobilized Low-Activity Tank Waste Performance Assessment: 2001 Version* (Finfrock 2000b).

3.5.3.2.1 Disposal Facility Barrier Model.

Model Description. The top of the near-field model corresponds to the bottom of the modified RCRA-compliant subtitle C' surface cap (which is not modeled), and is bounded below by an arbitrary contact immediately below the engineered facility. The lower boundary is located at – 15 meters below the pre-disposal site surface grade. The upper two meters of the near-field model represents a capillary barrier with a one-meter thick sand layer over a 1-meter thick gravel layer. The capillary barrier peaks at the center of the facility (the left side of the model) and slopes down at a 2% grade to where the cap ends. Beyond the end of the barrier, the model represents a 'side slope', consisting of backfill material, out to the right hand side of the model. The near-field region is modeled as a two dimensional, half cell that is symmetrical about the centerline.

The trench extends from the pre-facility surface grade down to –10 m depth. The floor of the trench extends horizontally from 0 to 10 m, then slopes upward at a 3:1 incline for 30 m. Sediments inside of the trench are classified as backfill while the sediments outside of the trench are Hanford sands. The capillary barrier over the trench peaks at 3.0 m above the pre-facility surface grade (at the centerline) and extends out 49 m to the end of the cap. Beyond this point, the downward slope continues with backfill material out to the right hand edge of the model (60 m).

For the concrete vault conceptual model the vault top is set 1 m above the pre-facility surface grade and extends down 8 m. The vault forms a box structure that extends 11.5 m out from the centerline. The vault is set in a trench that extends out 17.5 m from the centerline and then slopes up at a 1.5:1 incline for 13.5 m. Again, the material inside the vault, and the material surrounding the vault in the trench, is backfill and the material outside of the trench is Hanford sands. The vault walls are 1 m thick and are modeled as degraded concrete. The capillary barrier over the vault, peaks at 4.0 m above the pre-facility surface grade (at the centerline) and extends out 17.5 m to the end of the cap. Beyond this point, the downward slope continues with backfill material out to the right hand edge of the model (37 m).

Boundary Conditions. Boundary conditions include flux in at the top of the model and a constant hydraulic head condition at the model base of –15.1 m. The side boundaries are implicitly defined as no-flow by the numerical code.

Flux applied to the top of the model ranged from 1.0×10^{-4} m/y to 5.0×10^{-2} m/y, depending upon assumed surface recharge conditions. In the base analysis case recharge is assumed to be the natural recharge rate (4.2×10^{-3} m/y) over the region where the barrier is present and 5.0×10^{-2} m/y beyond the barrier. This case assumes that the barrier is no longer functional and recharge to the waste packages is at a steady-rate of 4.2×10^{-3} m/y from above. The near-field calculations are only performed on fluid flow so there is no contaminant flux included in the models.

Grid. The near-field model is simulated as a two dimensional, vertical slice through the ILAW site. Lateral girding is represented by the X coordinate and vertical girding is represented by the Y coordinate.

The near-field trench model consists of 121 x 58 quadrilateral grid blocks in the X and Y directions, respectively, for a total of 7018 nodes in an X-Y plane. A third dimension is required for definition of the model elements. The Z coordinates are 0 and 1, representative of unit depth. A minimum of two Z-planes is required to define the model elements. Therefore, the total number of nodes for the model is 14036, which encompass 6840 elements. Grid spacing in the X direction is uniformly 0.5. Grid spacing in the Y direction ranges from 0.5 m down to 0.01 meters where material interfaces exist.

The near-field vault model consists of 75 x 76 quadrilateral grid blocks in the X and Y directions, respectively, for a total of 5700 nodes in an X-Y plane. There are 11,400 total nodes for both required planes, which represent 5550 model elements. As with the trench, the X node spacing is 0.5 m and the Y node spacing is variable, ranging from 0.5 down to 0.01 meters at material interfaces.

3.5.3.2.2 Far-Field Model. The far field extends from the bottom of the waste disposal facilities to ground water. The material beneath the waste facilities is Hanford sand, which is projected to extend to a depth of 65 meters below surface level. Beneath the Hanford sand is the Hanford gravel that extends to the projected post-Hanford water table at 103 meters below land surface. Each material is represented as a homogeneous medium for the respective sediment types. The porous media is assumed to be isotropic, which means there is no spatial distortion caused by sedimentary layering or lateral pressure gradients in the system. Hydraulic and chemical parameters used in the model are derived from the data package of Khaleel (1999) and Kaplan (1999).

The far field is simulated as a two-dimensional domain, horizontally layered system for each of two waste disposal facility designs. The far field model is designed to correspond to the one half trench and one half vault lateral dimensions. Consequently, the RH trench model domain extends 50 meters from left to right and the new ILAW vault model domain is 21.5 meters across. The upper boundary of the model domain in the far field corresponds to the lower boundary used for the waste form calculations at 15 meters below land surface. The lower boundary is located at the water table at 103 meters below land surface.

The contaminant flux along the upper boundary for the far field calculation is given by the one-dimensional contaminant flux times the quantity of waste at a given distance from the model axis (y-axis in figures). For the concrete vault the quantity of waste is constant out to the edge of the stacked packages (10 m). For the RH trench the average waste package stack is 4 high over the first 9 m from the model axis and then decreases to three then two then one-package heights at the edge of the trench. For the RH trench we have assumed that the one-dimensional results are applicable to a waste package stacking of two or even one package since the pH and the LAWABP1 dissolution rates are comparable in each of the four waste package layers (see Section 4.2).

3.5.3.3 Groundwater Model. The model used for groundwater calculations is that one established by the Hanford Site Groundwater Program, a program separately managed by the DOE's Richland Field Office, not by the Office of River Protection. The base-case groundwater flow and transport of contaminants from the ILAW facility was calculated with the current version of the Hanford site-wide groundwater model. This three-dimensional model, currently being used by the Hanford Groundwater Project and recommended as the proposed site-wide groundwater model in the Hanford Site groundwater model consolidation process, is based on the Coupled Fluid, Energy, and Solute Transport (CFEST-96) Code (Gupta et al. 1987, and Gupta 1997). The Hanford Site groundwater model has been recently independently reviewed (Gorelick et al. 1999).

This model is described in Wurstner et al. (1995) and Cole et al. (1997), and was most recently used in the Hanford Site Composite Analysis (Cole et al. 1997; Kincaid et al. 1998), which is a companion analysis to the existing preliminary PA analyses of the ILAW disposal facility (Mann et al. 1997) and the solid waste burial grounds in the 200-East and 200-West areas (Wood et al. 1996, 1995). The Composite Analysis is also a companion document to the Remedial Investigation/Feasibility Study (RI/FS) (DOE 1994) that supports the Environmental Restoration Disposal Facility.

3.5.3.3.1 Simulation of Site-Wide Steady-State Flow Conditions. Past projections of post-Hanford water-table conditions have estimated the impact of Hanford operations ceasing and the resulting changes in artificial discharges that have been used extensively as a part of site waste-management practices. Simulated results of future transient behavior in the Hanford unconfined aquifer by Cole et al. (1997) showed an overall decline in the hydraulic head and hydraulic gradient across the entire water table over the entire Hanford Site. The results of these simulations indicate that the water table would reach steady state in 100–350 years in different areas over the Hanford Site.

Given the expected long delay of contaminants reaching the water from the disposal facility, the hydrologic framework of all groundwater transport calculations was based on a postulated post-Hanford steady-state water table as estimated with the three dimensional model. The predicted water table for post-Hanford conditions for these assumed steady-state conditions across the site and in the area between the ILAW new disposal facility and the Columbia River are illustrated in Figures 3-14 and 3-15. The overall flow attributes of this water table surface are consistent with the previously simulated flow patterns described in Wurstner et al. (1995), Cole et al. (1997) and Law et al. (1996). From the ILAW new disposal facility, groundwater moves southeasterly near the site and then in an easterly and northeasterly direction before discharging into the Columbia River north of the old Hanford town site.

3.5.3.3.2 Contaminant Transport Between Disposal Facilities and Columbia River. Flow conditions established with the site-wide model provide the basis for the transport simulations of contaminants released from disposal facilities toward the Columbia River. Constant mass releases equivalent to those used in the local-scale model were introduced into the site-wide at the approximate location of the ILAW disposal facilities. Concentration levels were evaluated in groundwater in close proximity to the Columbia River as well as several intermediate points between the disposal areas and the river. To establish consistency of the site-wide scale calculations with those made in the local scale models, concentrations levels were evaluated and compared at approximately 1-km down gradient of the source areas in both the local-scale and site-wide models. Predicted concentrations levels at 1 km in the site-wide and local-scale models are expected to be somewhat consistent with each other but will not be the same because of inherent differences in the grid resolution used in each model. Predicted concentration levels in the site-wide model close to the source areas will in general be expected to be somewhat lower than are predicted in the local-scale models.

Figure 3-14. Predicted Water Table for Post-Hanford Conditions for Assumed Steady-State Conditions (as Simulated after 350 Years).

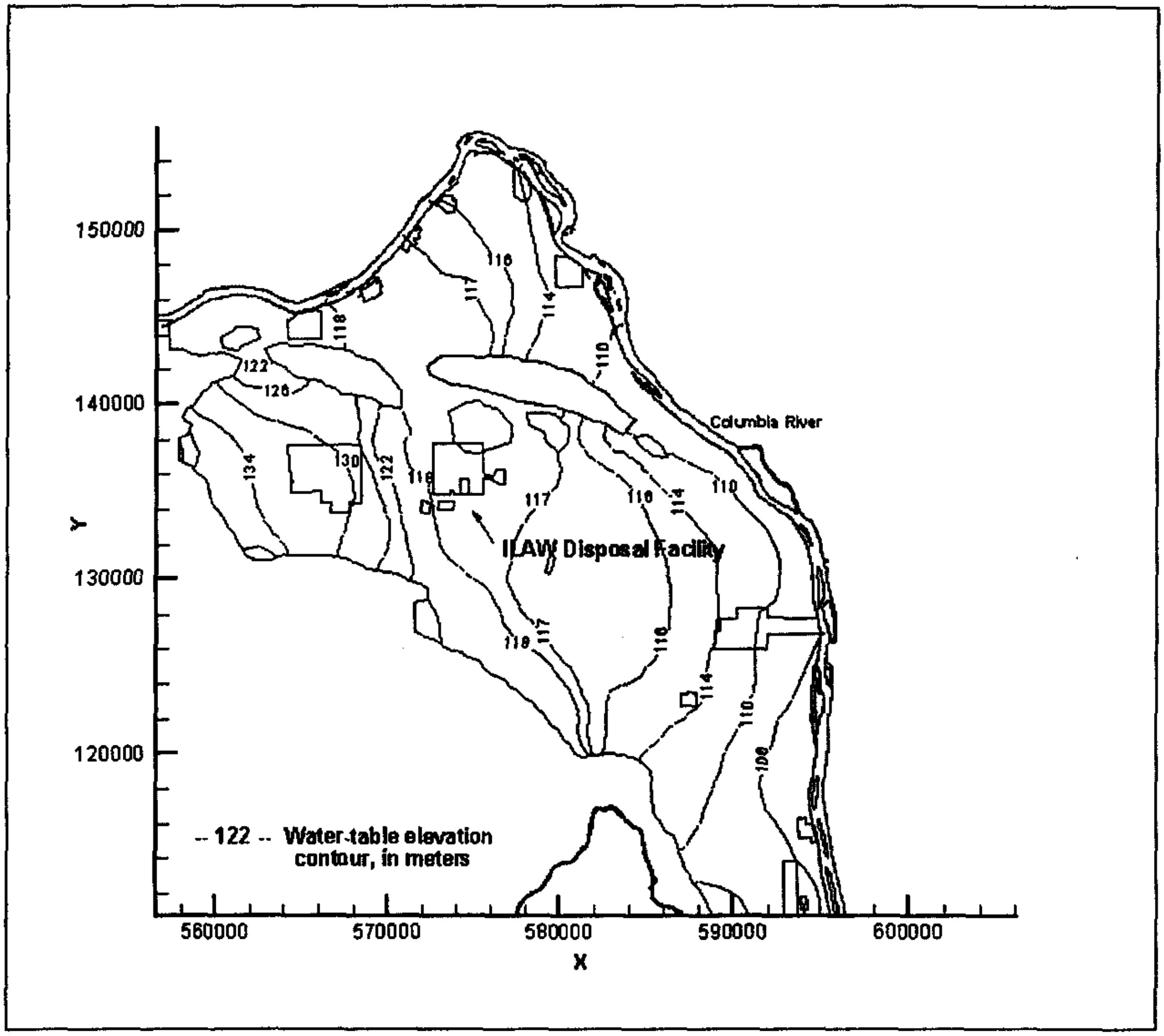
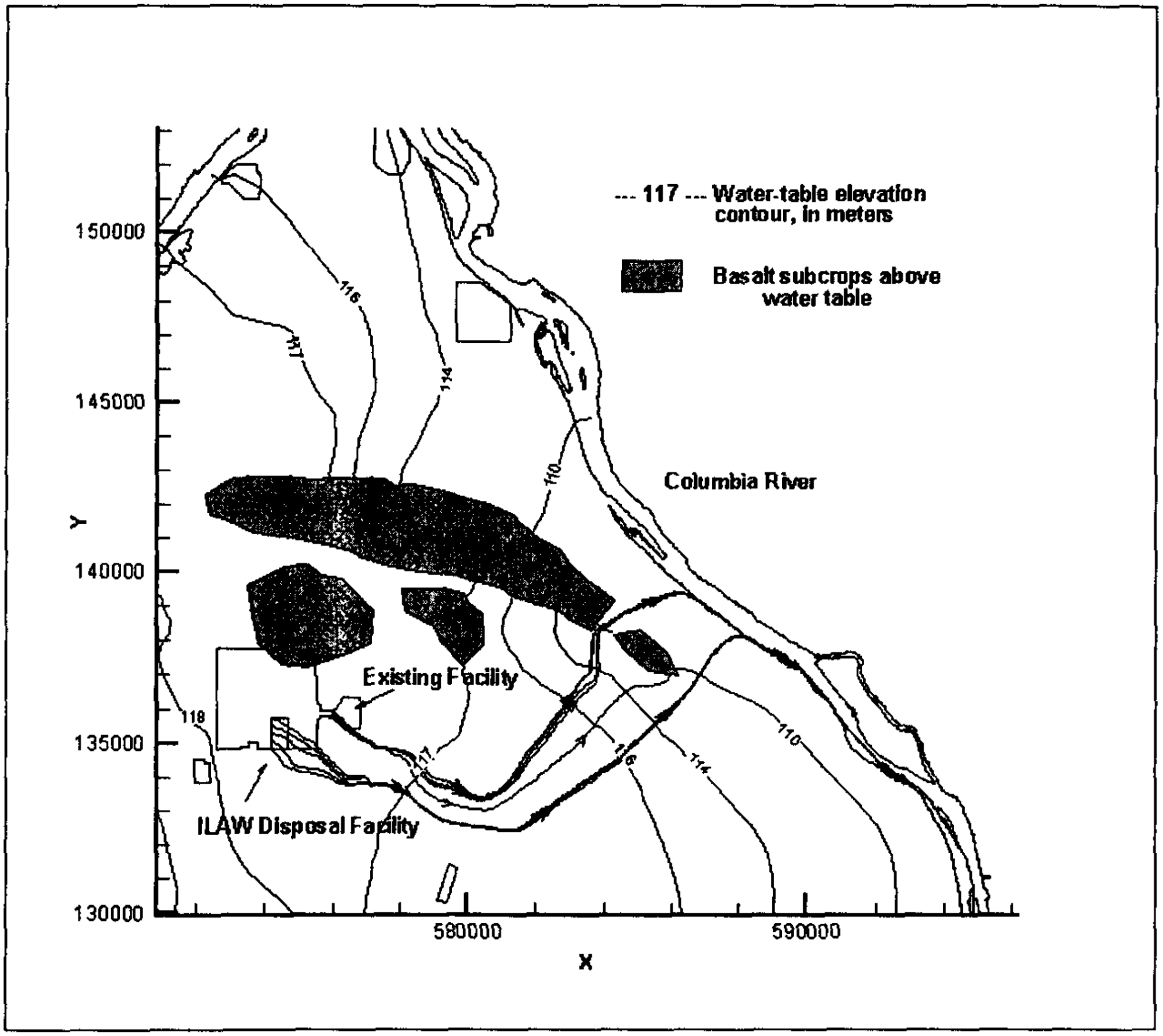


Figure 3-15 Predicted Water Table for Post-Hanford Conditions for Assumed Steady-State Conditions between ILAW Disposal Facility and Columbia River (as Simulated after 350 Years).



3.5.3.3.3 Local-scale Model Development and Description. The base analysis case for the groundwater flow and transport calculations included evaluated current disposal concepts at the new ILAW disposal facility that will be located in south-central 200 East Area. The approach used in this analysis was to construct a local-scale model to represent flow and transport conditions near these facilities to a hypothetical well 100-m downgradient. The boundary conditions for this local model were based on flow conditions calculated in the site-wide model.

Because the travel time in the aquifer (tens of years) is so short compared to the travel time in the vadose zone (thousands of years), the concentrations in the aquifer quickly adjust to the small changes in the contaminant flux entering the aquifer from the vadose zone. To be conservative, the footprint of the contaminant flux entering the aquifer was taken to be the same as the trench layouts.

3.5.3.3.4 Grid Design. The grid used in the local-scale model required refinement both areally as well as vertically. The discretized grid for the local-scale model telescopes in from the grid used in regional scale calculations. The grid extends over an area of about 4100 meters in the west to east direction and 4100 m in the north-south direction (See Figure 3-16). It progressively varies in size from the outmost subdivided coarse triangular grids made on the regional scale 375 m by 375 m grid spaces to the finest grid spacing of 20 by 20 m in vicinity of the ILAW disposal area. The total number of surface elements in the three-dimensional model is 9157 elements. The three-dimensional model, based on this surface grid, comprises a total of 31604 elements (9157 surface and 22,447 subsurface elements) and 32618 nodes.

The vertical grid spacing for the transport (as well as the flow) model consisted of multiple transport layers that subdivided the major hydro-stratigraphic units. The basic approach for this subdivision is the same was used in Kincaid (1998) to support groundwater transport calculations used in the Composite Analysis. The basic thickness of each of these transport layers was 8 m. The transport layers were defined from the water table surface to the basalt to account for the overall saturated thickness and to adequately represent contaminant concentrations in the three-dimensional model. At every model node each of the major hydro-stratigraphic units below the water table was represented by at least one transport model layer. Nonconductive (e.g., mud units) below the water table were always represented by at least 2 transport model layers regardless of their saturated thickness in order to assure the vertical flow and transport through these units was appropriately represented. For units whose saturated thickness was <12 m thick, the layer thickness was set to the actual saturated thickness of the unit. Nonconductive and conductive units whose saturated thickness was >12 m were divided into multiple transport model layers in the same manner. For all units with thickness >12 m, the transport layering algorithm is as follows: create as many uniform 8-m transport layers as possible until the remaining unaccounted for saturated thickness is >12 m but <=16 m, then create two additional transport layers set to half of the remaining saturated thickness of the hydrostratigraphic unit being layered.

At the local-scale, a total of six hydrogeologic units were found to be present: 1) the Hanford formation (unit 1) and several units belonging to the Ringold Formation, including Unit 5, 6, 7, 8, and 9). The three-dimensional distribution of these units in the local-scale model is depicted in Figure 3-17. A better description of the model design features and the hydraulic properties used to support groundwater calculations in this report can be found in Bergeron and Wurstner (2000).

Figure 3-16. Finite Element Grid Used in Local –Scale Model.

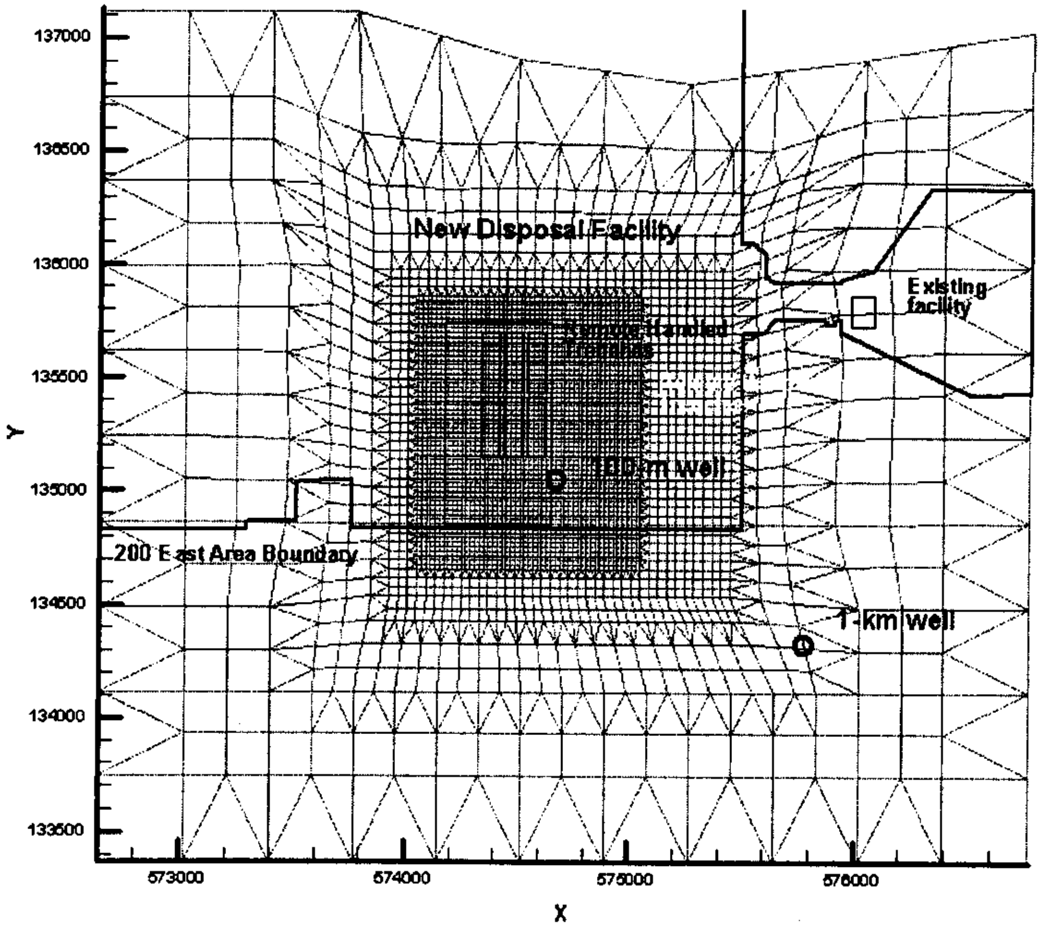
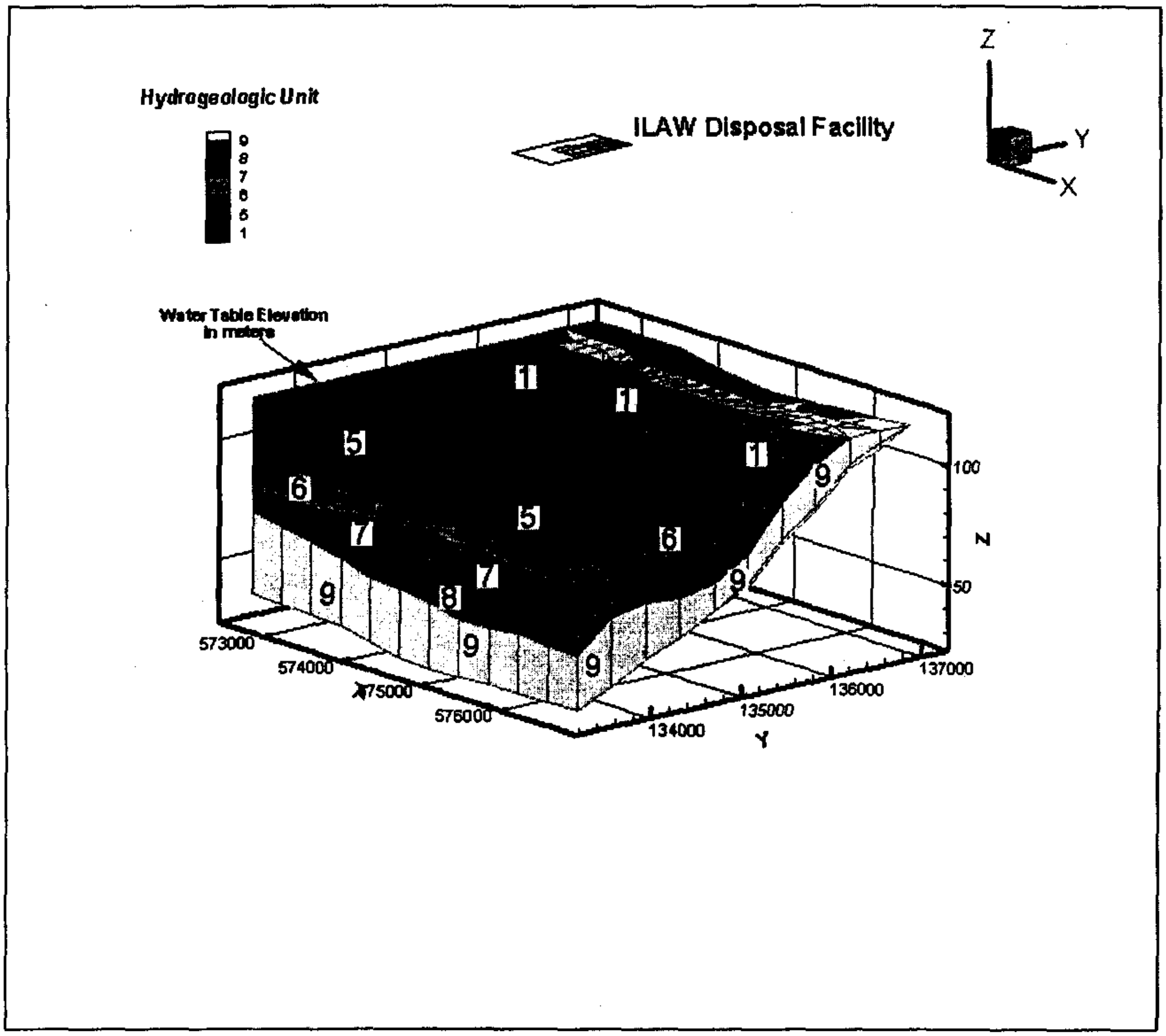


Figure 3-17. Three-Dimensional Distribution of Major Hydrogeologic Units in the Local-Scale Model.



3.5.4 Input Data

Table 3.10 summarizes the input data.

This section specifies the data actually used in the computer models for the base analysis case. The intent is to follow the data given in Sections 3.2, 3.3, and 3.4 as closely as possible. Data used in the sensitivity cases are given in Section 3.5.5.

3.5.4.1 Contaminant Release Data. The data for the calculation of contaminant release rate from the waste package and subsequent transport inside the disposal facility are those given in Sections 3.4.3, 3.4.4, and 3.4.5. Table 3-7 summarizes the important values used.

3.5.4.2 Vadose Zone Data. The input data used for the base analysis case are those given in Section 3.4.3 and are summarized in Table 3-11.

3.5.4.3 Aquifer Modeling. This section describes the hydraulic, transport, and other parameters of the Hanford Site groundwater model.

3.5.4.3.1 Hydraulic Properties. The hydraulic conductivity and porosity estimates used in the local-scale model were developed based on the following assumption: regional scale estimates of hydraulic properties in the site-wide model can be interpolated using local-scale model grid coordinates to represent local-scale properties in vicinity of the ILAW disposal facility area. The resulting two-dimensional distributions of these properties for each model unit is provided in Figure 3-18. The estimated values are, in general, indicative of the regional high trends in hydraulic properties found in the central part of the Hanford Site. Specifically, the ancestral Columbia River deposited very coarse alluvial deposits in a deep channel extending to the south of the ILAW site and to the north between Gable Butte and Gable Mountain. Estimated hydraulic conductivities directly below the disposal range from several thousand to tens of thousands m/day in the Hanford formation and several hundred m/day in the permeable parts of the Ringold Formation (Units 5, 7, and 9). Relatively low hydraulic conductivities are estimated for low permeability units within the Ringold Formation (Units 6 and 8).

The best estimate of an effective porosity of 0.25 used in the site-wide model were also used in all transport simulation made with the local-scale model.

Table 3-11. Base Analysis Case Input Data for the Disposal Facility.

Parameter	Value	Section with Justification for Using Value
Soil Layering (two dimensional model used)		
Hanford formation Upper Gravel Sequence Sand Sequence Lower Gravel Sequence	 6 m (20 ft) (on surface) 60 m (197 ft) 35 m (98 ft) (bottom)	Section 3.4.3.1
Ringold Formation Unit E	 30 m (98 ft), below Hanford formation	Section 3.4.3.1
Hydrologic Parameters		
Vadose Zone Soil Layer	Calculated based on curve-fitting parameters and saturated hydraulic conductivity. See reference section.	Section 3.4.3.2 (Values given in Table 3-4)
Construction Material	Calculated based on curve-fitting parameters and saturated hydraulic conductivity. See reference section.	Section 3.4.3.2 (Values given in Table 3-3)

Table 3-11. Base Analysis Case Input Data for the Disposal Facility.

Parameter	Value	Section with Justification for Using Value
Infiltration Rate		
At the Disposal Facility Side slope Everywhere else	 50.0 mm/y 4.2 mm/y	Section 3.4.6
Geochemical Parameters		
Chemical Distribution Coefficients (K_d) Tc, I, Chemicals, Others U, Np, Pa, Ru C Sr, Ra Cs, Nb, Ni, Pb, Sn Ac, Am, Ce, Cm, Co, Eu, Pu, Th, Zr	 0.0 mL/g 0.6 mL/g 4.0 mL/g 10.0 mL/g 80.0 mL/g 150.0 mL/g	Section 3.4.3.3
Contaminant Release Rate		
Relative Radionuclide Release Rate	Calculated release based on initial release rate and time-dependent surface area. See reference section	Section 3.4.4.3 (Values given in Table 3-7)

Table 3-11. Base Analysis Case Input Data for the Disposal Facility.

Parameter	Value	Section with Justification for Using Value
Disposal Facility Degradation		
Concrete	degraded at 500 years	Section 3.4.5.7
Natural materials	properties do not degrade, but system performance changes because of materials rearrangement	Section 3.4.6.7

3.5.4.3.2 Transport Properties. Estimates of model parameters were developed to account for contaminant dispersion in all transport simulations. Specific model parameters examined included longitudinal and transverse dispersion coefficients (D_l and D_t) as well as estimates of effective bulk density and porosity of the aquifer materials. This section briefly summarizes estimated transport properties.

In general, the horizontal dispersivity for aquifer transport is typically set at 10 percent of the travel length in the direction of flow and the transverse dispersivity is set at 10 percent of the longitudinal value. For predictions at 100 m downgradient of the facility, this would mean a longitudinal dispersivity of at least 10 m would be required. For this analysis, a lower longitudinal dispersivity of 5 m was selected to be within the range of recommended grid peclet numbers ($P_e < 4$) for acceptable solutions. The 5 m estimate is about one-quarter of the grid spacing in the finest part of the local-scale model grid in the 200-Area plateau where the smallest grid spacing is on the order of 20 m by 20 m. The effective transverse dispersivity was assumed to be one-tenth of the longitudinal dispersivity. Therefore, 0.5 m was used in all simulations.

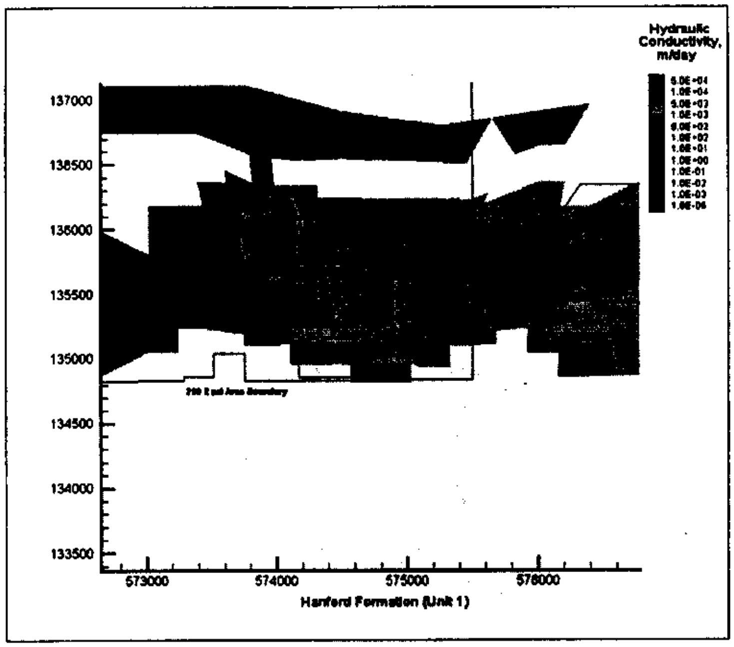
3.5.4.3.3 Base Case: Areal Sources Representing New Facility Disposal Concept. The remote-handled trench disposal concept was evaluated in the initial base case calculations. For this concept, the new ILAW disposal facility will consist of a set of seven remote-handled waste trenches in the configuration illustrated in Figure 2-24. Each waste trench will be an underground, open-topped, trench approximately 80 m wide, 260 m long and 10 m deep with 3:1 side slopes.

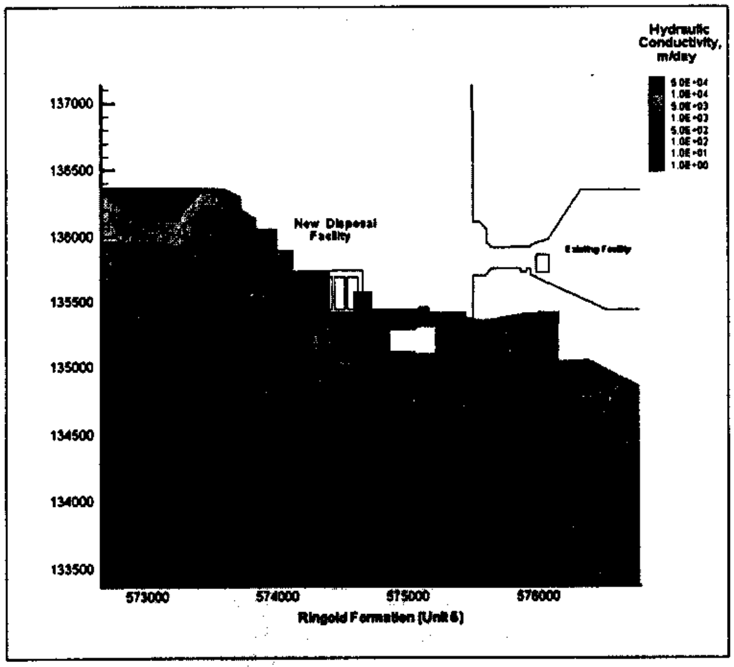
The primary objective of the groundwater flow and transport calculations were to determine the well-intercept factor. The well intercept factor (WIF) is defined as the ratio of the concentration at a well location in the aquifer to the concentration entering the aquifer. For purposes for these calculations, the bulk concentration of source entering was assumed to be 1 Ci/m^3. The rate of mass flux associated with this concentration is a function of the infiltration rate assumed for the disposal facility covered by the modified RCRA-compliant subtitle C cap. With an assumed rate of 4.2 mm/y assumed for the disposal facility, the resulting solute flux, which is a product of the contaminant concentration in the infiltrating water and the infiltration rate, entering the aquifer from each of the disposal concepts is 4.2×10^{-3} $Ci/y/m^2$.

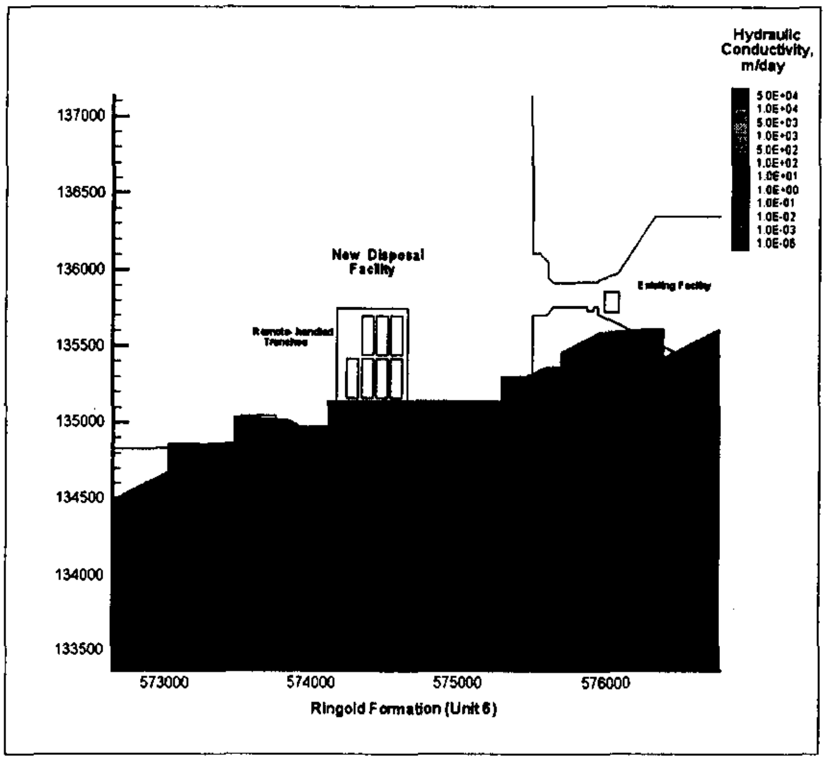
In all model simulations performed, the WIF was calculated at a hypothetical well located approximately 100 meters downgradient from the boundary of the disposal along the centerline of the simulated plume. A pumping rate of 10 liters per day was used at the hypothetical downgradient well location. This pumping rate would provide sufficient drinking water for a family of five at an assumed intake of 2 liters per person per day.

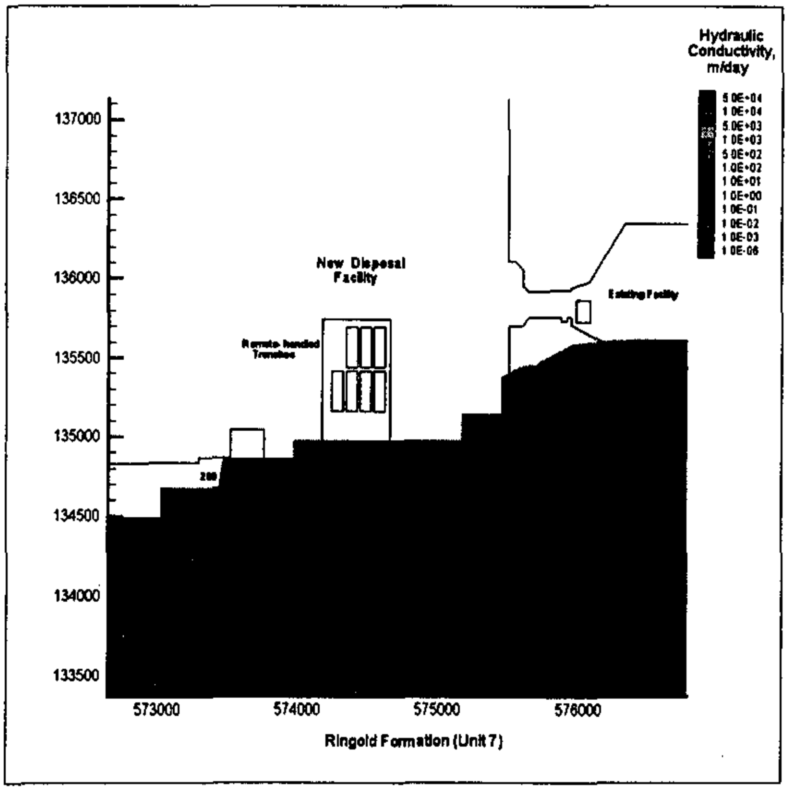
3.5.4.4 Integration of Results. In addition to data already discussed, the input data for INTEG were taken from the output of the vadose zone and the aquifer models. Inventories were taken from Section 3.2.2. Dose conversion factors were taken from Section 3.3.5.

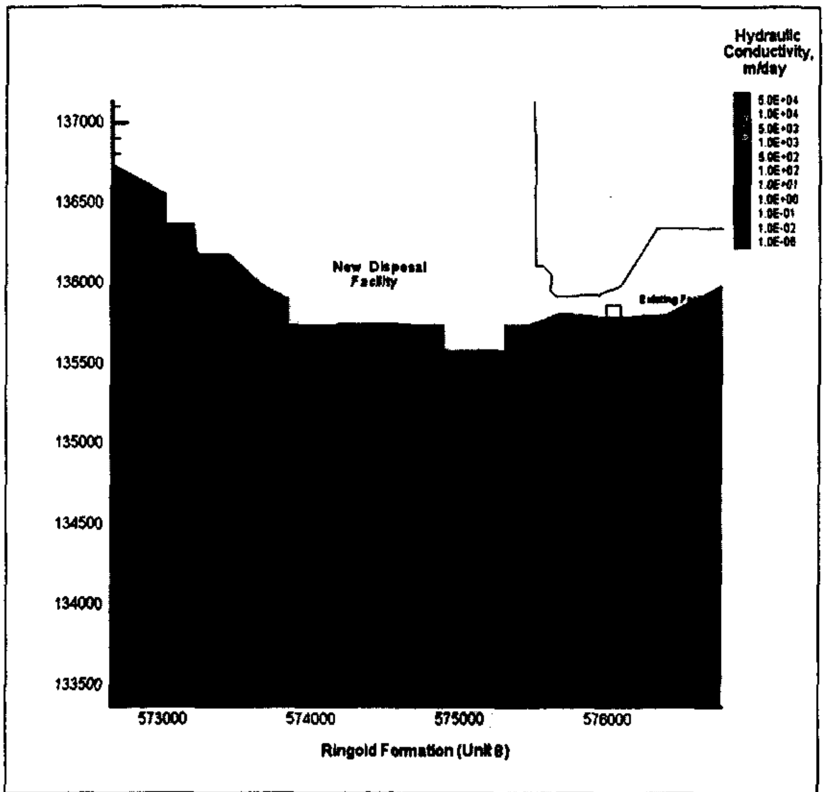
Figure 3-18. Distribution and Hydraulic Conductivities of Major Hydrostratigraphic Units in Local-scale Model.

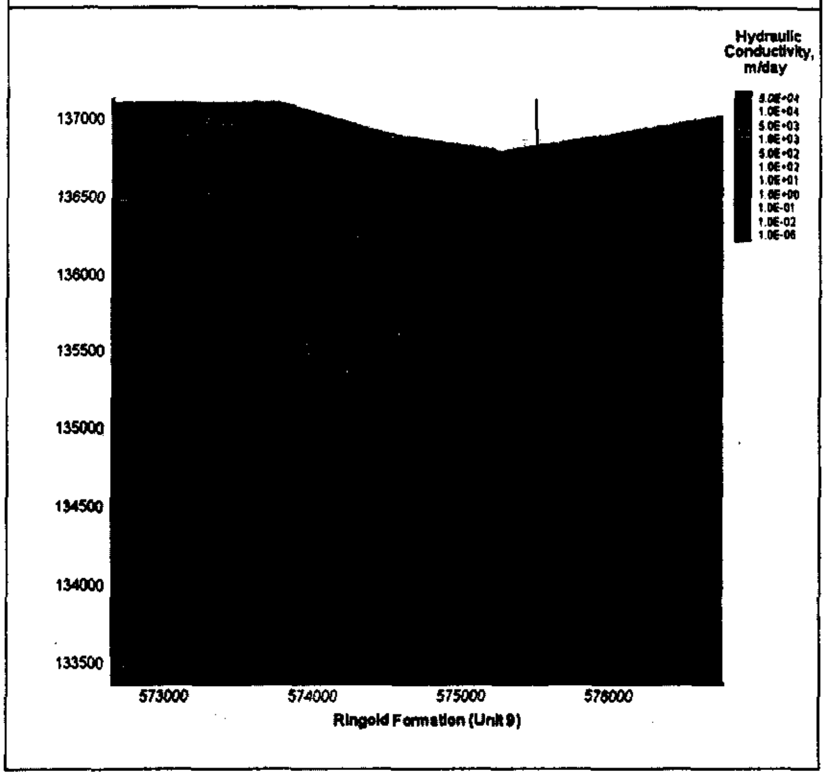





Hydraulic Conductivity, m/day
5.0E+04
1.0E+04
5.0E+03
1.0E+03
5.0E+02
1.0E+02
1.0E+01
1.0E+00
1.0E-01
1.0E-02
1.0E-03
1.0E-06
137000
136500
136000
135500
135000
134500
134000
133500
New Disposal Facility
Remote-handled Trenches
Existing Facility
573000
574000
575000
576000
Ringold Formation (Unit 6)


Hydraulic Conductivity, m/day
5.0E+04
1.0E+04
5.0E+03
1.0E+03
5.0E+02
1.0E+02
1.0E+01
1.0E+00
1.0E-01
1.0E-02
1.0E-03
1.0E-06
137000
136500
136000
135500
135000
134500
134000
133500
New Disposal Facility
Remote-handled Trenches
Existing Facility
573000
574000
575000
576000
Ringold Formation (Unit 7)


Hydraulic Conductivity, m/day
137000
136500
136000
135500
135000
134500
134000
133500
New Disposal Facility
573000
574000
575000
576000
Ringold Formation (Unit 8)


Hydraulic Conductivity, m/day
137000
136500
136000
135500
135000
134500
134000
133500
573000
574000
575000
576000
Ringold Formation (Unit 9)

3.5.5 Sensitivity Cases.

> Sensitivity cases are used to determine the robustness of the results obtained from the base analysis case.

Sensitivity cases were run to determine the effect of various assumptions and data values. For most sensitivity cases, only one parameter or one set of parameters differs from the base analysis case or another sensitivity case. Thus, the change, if any, in the final answer will indicate the effect of that parameter on the overall answer. Table 3-13 (at the end of this section) summarizes the sensitivity cases. Sections 3.5.5.1 through 3.5.5.12 discuss the sensitivity cases and explain why each case was run.

3.5.5.1 Scenario-Dependent Sensitivity Cases. The scenario-dependent sensitivity cases are selected analyses to determine the extent to which results related to a scenario depend on selected values or assumptions. Several scenario-dependent cases were developed. Land-use, drinking water, and catastrophic natural scenarios were considered (Section 3.3).

Because inadvertent intrusion is an artificial case, its parameters are quite uncertain. Some parameters (such as the inventory of key contaminants) will vary because of near-term decisions on waste treatment, while others will vary depending on the actions of the hypothetical inadvertent intruder. Such actions will include the drilling method used (which affects the size of the hole drilled and the size of the glass chunks unearthed) and the area over which the waste is spread. Sensitivity cases are run for each of these uncertainties to provide a feeling for the effect of such variations.

Predicting land use at the Hanford Site for the next 10,000 years is impossible. Natural conditions were assumed for the base analysis case (Section 3.3.2.2). For land-use sensitivity cases, the effects of various land uses were calculated. The following uses were examined:

- Irrigated farming on top of the disposal facility with an infiltration rate of 50 mm/y (1.85 in./y). Such irrigation is considered as an inadvertent intrusion. However, in this analysis such irrigation is calculated as part of the groundwater scenario, instead of part of the inadvertent intruder scenario.

- Irrigated farming in other parts of the Hanford Site Central Plateau with recharge three times the current values. This case could also mimic a change in climate resulting in more precipitation. Such increased recharge will distort the groundwater flow and change the water table height.

- Industrial use of the 200 Area, which is assumed to decrease the infiltration rate over the entire 200 Area by a factor of 3.

The point of compliance follows current requirements of the DOE order on radioactive waste management (DOE 1999g). However, because of the complexity of the Hanford Site, other points of compliance (for example, at the edge of the central site's buffer zone) could be chosen. Thus, impacts at a series of locations are estimated. In the base analysis case, the well is assumed to be 100 m (328 ft) downgradient from the disposal facility. To determine the effect of the well position, the well was located at various other distances (including the 200 Area fence line) along flow lines down to the Columbia River.

The drinking water scenario is based on the pumping rate and the location of the well. Minimal pumping (0.01 m^3/day = 10 liters/day [2.6 gallons/day], corresponding to a family of five using the well only to obtain drinking water) is assumed for the base analysis case. As pumping is increased, water is taken from a wider area, resulting eventually in drawing in water that is uncontaminated. Pumping rates of 10 to 1,000 m^3/day (2,640 to 2,640,000 gallons/day) were used to determine the effect of the pumping rate on the drinking water dose.

Finally, the effects of catastrophic natural events were evaluated. The base analysis case does not evaluate a catastrophic natural event. Neither seasonal flooding nor even the collapse of the region's largest dam would cause water to reach the disposal facility. However, a catastrophic ice-age flood similar to those that occurred over 10,000 years ago, would affect the disposal facility and is analyzed. However, such a flood is not expected to occur during the next 50,000 years.

3.5.5.2 Inventory-Dependent Sensitivity Cases. The inventory of radionuclides that will be in the waste form is uncertain. The inventory in the waste form depends on the amount and type of waste presently stored in the Hanford Site tanks, the process used to separate tank waste into low-activity and high-level waste streams, and the method of immobilization. At present, the separation process that will be used is unknown, as are the details of the immobilization method. These sensitivity cases are designed to evaluate the effect of different amounts of key radioisotopes.

Currently, the plan is to have a separate separations process to allow no more than 20 percent of the technetium in the tank waste to go into the ILAW package. To determine the impact of removing this process step (which is currently being studied by DOE/ORP), a sensitivity case having all of the technetium go into ILAW was analyzed.

The inventory data package (Wootan 1999) estimated the uncertainties in the inventory as well as bounding cases. These uncertainties and bounding values were used for the key contaminants (^{99}Tc, U, and ^{129}I for the groundwater pathway and ^{126}Sn, ^{239}Pu, and ^{241}Am for the inadvertent intruder case).

In the supporting document (WHC 1996) for the DOE petition to the NRC for the separated waste to be considered as non-high-level waste, various uncertainty bands are given. The amount of cesium separation may be different from what is assumed in the base analysis case. A sensitivity case increasing the amount of ^{137}Cs to 9.0 MCi was performed, a increase by a factor of 10 from the base analysis case.

3.5.5.3 Infiltration-Dependent Sensitivity Cases. Infiltration is important because it is a main driver for the waste form release and because moisture carries the released contaminants to the groundwater. The base analysis case uses an infiltration rate into the surface barrier of 4.2 mm/year, which corresponds to the natural recharge of the Burbank loamy sand soils of the site. However, the southern region of the site contains Rupert sands, which have a lower natural recharge rate of 0.9 mm/year. Moreover, the surface barrier is expected to have a quite low infiltration rate (<0.1 mm/year) and last at least 500 years. Finally, there is always the possibility that the surface is grossly disturbed or that large amounts of water are placed on the site. Each of these cases (0.1, 0.9, 4.2, and 50 mm/year) was investigated assuming that infiltration was time-independent. Finally, a sensitivity case was simulated that treats the barrier in a degraded form (i.e., the infiltration rate is 0.1 mm/yr for the 500 years of its design life, then immediately increases to the natural rate of the Burbank loamy sand soil – 4.2 mm/year).

3.5.5.4 Geology-Dependent Sensitivity Cases. Because the geology of the subsurface can only be inferred from a relatively few measurements, its exact three-dimensional nature remains uncertain. Because the 1998 ILAW performance assessment showed relatively little sensitivity to the geologic parameters, only a few cases were run in this assessment. The base analysis case treats the subsurface as a two-dimensional structure consisting of Hanford formation sands in the upper layer and Hanford gravels in the lower. Sensitivity cases were run that assumed the entire formation was Hanford sands and the entire formation were Hanford gravels. In addition, a case was run assuming that clastic dikes were present. Finally, the effect of increasing the depth of the vadose zone by 3 meters was performed as the equilibrium level of the water table has not yet been reached due to the conditioning effect of past Hanford operations.

3.5.5.5 Facility-Dependent Sensitivity Cases. The disposal facility is still undergoing design. Thus, many of the details of its structure can be impacted by this assessment. Two major design features are the surface barrier and the sand-gravel capillary barrier. Additionally, the effect of the material used to fill in between the ILAW packages was investigated. Although the base design is the trench concept, the project still has control over the 4 existing concrete vaults originally constructed for grout disposal.

Two important features of the surface barrier are its extension past the disposal facility and its transition from its elevated positions to natural ground level. A sensitivity case was run shortening the distance that the surface barrier extends past the disposal facility. In addition, the current design has a side slope that allows the change in elevation from the natural ground slope to the elevated level of the cap. A sensitivity case was run to investigate the effect if the infiltration rate of this side slope changed from its presumed value (50 mm/y) to the same as the natural condition (4.2 mm/y) of flat surfaces.

Previous calculations had shown that a sand-gravel capillary barrier would divert significant amounts of moisture from the disposal facility. The base analysis case assumed no such barrier (for ease of calculation). Thus, a sensitivity case was run with such a barrier over the facility. In addition, a sensitivity case was run with a vertical gravel barrier to the side of the disposal facility to see the effect of such a capillary barrier. The degradation of the sand-gravel capillary barrier was also simulated and is described in the next section.

Another sensitivity case replaces the backfilled material placed between the ILAW packages with sand to examine the effect of hydraulic parameters of the filler material. The hydraulic materials determine the amount of moisture surrounding the waste form and hence influence the contaminant release rate.

As noted the current design is a trench concept. However, because the project still has the four concrete vaults left from the grout disposal effort and because concrete vaults are the basis of the current waste disposal authorization statement, the effects of using concrete vaults was investigated. Fewer sensitivity cases were run than for the trench concept, as the concrete vault is no longer the baseline design.

3.5.5.6 Facility Degradation-Dependent Sensitivity Cases. Although the design of the trench concept is simple and uses mainly natural materials, it is recognized that the components of the disposal facility will not last forever. The main features of interest are the surface barrier, the sand-gravel capillary barrier, and the bottom surface. The design life of the surface barrier is estimated to be 500 years. As noted in Section 3.5.5.3, the base analysis case assumes that the surface barrier fails immediately, and that sensitivity runs assume the barrier lasts 500 years or for an infinite time. The failure of the sand-gravel capillary barrier is assumed to be a subsidence event that causes a meter-long length to drop 0.3 meter the entire long length of the barrier. Finally, there is the possibility that the bottom of the disposal facility will retain water (and hence contaminants) for an extended time causing a bathtub effect. The consequences of such a bathtub effect were stimulated assuming that the disposal facility was intact for up to 2,000 years. Since the time of compliance is 1,000 years, these results are only useful for determining peak values at much later times.

3.5.5.7 Hydraulic Parameter-Dependent Sensitivity Cases. Moisture flow is important to the performance assessment. Hydraulic parameters were varied to determine the effect on contaminant transport. The base analysis case treats the moisture flow to be anistropic as has been measured for the soil conditions of the Hanford Site. However, as this reduces vertical flow, a case assuming isotropic flow conditions was also run. The effect of different hydraulic parameters was treated by assuming different properties in the disposal facility (backfilled soils versus sand) and in the vadose zone (presumed geometry versus all sand or all gravels).

3.5.5.8 Waste Form-Dependent Sensitivity Cases. Because of the importance of waste form release to this performance assessment, a wide variety of cases were run. These included sensitivity to the

- Chemical reaction matrix used,
- Moisture infiltration used,
- Surrounding materials present, and
- Other effects.

The base analysis case uses a kinetic rate law involving $SiO_2(aq)$ to control the glass dissolution rate. Thus, as the glass dissolves, more silicon goes into solution, slowing the glass dissolution until there is enough silicon in solution to form secondary reaction products, which then control the total aqueous silicon concentration. It should be noted that the calculations do NOT simulate the incorporation of contaminants into secondary products as there is insufficient information about the mechanism of any such incorporation and whether the radionuclides would remain sequestered over the long time periods involved in this analysis.

Three sensitivity cases were run to investigate the impact of the chosen chemical reaction network. The first assumes that the amount of silicon in the solution has no effect on the glass dissolution rate. That is, the forward reaction rate of the glass is the reaction rate at all times. Since the forward reaction rate of glass depends on pH, and since the pH increases as more sodium is released from the glass, the actual glass dissolution rate increases as a function of time. The second sensitivity case assumes that the alkali ion exchange reaction that substitutes hydrogen in the water with sodium in the glass does not take place. Laboratory measurements show that such a reaction is important at the low temperatures expected in the disposal facility. Finally, a sensitivity case is run assuming that no secondary products are formed and hence the amount of silicon in solution is affected only by the rate of glass dissolution balanced by the rate of mass transfer out of the disposal facility.

Moisture is important in the waste form release calculations. It is the solvent; it forms the medium in which dissolved glass components interact; and it transports the contaminants through the disposal facility to the vadose zone. Infiltration rates from 0.1 to 50 mm/y (0.1, 0.5, 0.9, 4.2, 10, and 50 mm/y) were investigated. Infiltration rates must drop below 0.005 mm/y before there is not enough water to dissolve the glass.

As glass dissolution is a chemical reaction, surrounding materials can affect the reaction rate. Also surrounding materials can affect the moisture flow. Therefore, the presence or absence of the following materials were investigated: sand versus backfilled soil as a filler material between the ILAW packages, stainless steel containers for the ILAW packages, a conditioning layer above the ILAW packages, and a concrete vault.

Finally, other calculations were run to investigate a variety of effects. The most important is probably waste form composition. However, final glass compositions have not yet been determined. Therefore as a sensitivity case, LAWABP1 glass was replaced with HLP31 glass. This glass has a slightly higher waste loading (23% versus 20%), a higher silicon content (55.8% versus 48.2%), but a lower aluminum content (5.1% versus 13.6%). Table 3-12 lists the composition for the two glasses by oxide mass fraction.

The base analysis case used Tc as the contaminant transported in the disposal facility. To investigate the effect of retardation in the disposal facility, a case was run using uranium as the contaminant. Most of the waste form simulations used a one-dimensional model. A sensitivity case was run using a two-dimensional model to determine the sensitivity to dimension. Finally a case was run that included the vadose zone in the model so that it could be determined how far into the vadose zone chemical effects actually extended.

Table 3-12. Elemental Compositions of LAWABP1 and HLP31 (by mole fraction).

	LAWABP1	HLP31		LAWABP1	HLP31
Al	1.36E-01	5.06E-02	Mg	1.71E-02	1.47E-02
B	1.84E-01	2.22E-01	Na	4.46E-01	4.79E-01
Ca	-	1.15E-04	P	7.79E-04	5.45E-04
Cl	1.13E-02	5.82E-03	S	8.63E-04	6.44E-04
Cr	1.82E-04	7.64E-04	Si	4.82E-01	5.58E-01
F	1.46E-03	3.39E-04	Ti	2.15E-02	1.48E-02
Fe	2.16E-02	2.71E-02	Zn	2.21E-02	7.29E-03
K	3.23E-02	6.44E-03	Zr	2.94E-02	4.82E-03
La	8.48E-03	-	O	1.873	1.875

3.5.5.9 Geochemical-Dependent Sensitivity Cases. Although the calculations in the disposal facility use a chemical network approach, the calculations in the vadose zone use a simple K_d model. As noted just above, the chemical network approach was used in a sensitivity case to determine the adequacy of the K_d approach. Also, K_d values for key contaminants (Tc, U, I, and Se) were changed to determine sensitivity and, in addition, K_d values for all contaminants were set to zero to determine an extreme case. Finally, the K_d value for iodine and uranium was increased at the bottom of the disposal facility to model the high absorption of iodine and uranium in concrete.

3.5.5.10 Exposure Parameter-Dependent Cases. The manual for the new DOE order on radioactive waste management specify that EPA dose conversion factors be used in the performance assessment. A few cases were run using dose conversion factors from DOE and from previous Hanford studies. In addition, a variety of exposure scenarios (corresponding to the standard Hanford set) were investigated (see Appendix B). These range from industrial to Native American scenarios.

3.5.5.11 Location/Layout of the Facility. The current plan is to use east-west trenches in the south central part of the 200 East Area. However, final design has not yet been performed. Thus, the layout of the trenches as well as the location of the trenches on the site has not been determined. The effect of various choices was investigated. Also, it is possible that existing concrete vaults (about a kilometer east of the disposal site) could be used. The effect of this location was also investigated.

Table 3-13. List of Sensitivity Cases.

Except for intrusion scenarios, the performance measures calculated were the drinking water dose and the all-pathways dose. For the intrusion scenarios, the acute and continuous doses were calculated.

Discussion Section	Sensitivity Case (Unless noted all cases treat groundwater scenario)	Results Presented in Section
	Scenario	
3.5.5.1	Intrusion scenario (time of intrusion, amount of waste retrieved, stability of waste form, area of garden)	5.4.2
	Investigate regional change in recharge from irrigation or vegetation changes	4.7.5
	Investigate effects of different well locations	4.3.5
	Investigate effects of different pumping rates at well	4.7.3
	Treat natural events, such as glacier flooding	4.14
	Inventory	
3.5.5.2	Investigate assumption that all tank waste Tc in ILAW	4.8.2
	Investigate inventory uncertainty of key contaminants	4.8.2
	Investigate increasing the inventory in the inadvertent intruder cases	5.4.3

Table 3-13. List of Sensitivity Cases.

Except for intrusion scenarios, the performance measures calculated were the drinking water dose and the all-pathways dose. For the intrusion scenarios, the acute and continuous doses were calculated.

Discussion Section	Sensitivity Case (Unless noted all cases treat groundwater scenario)	Results Presented in Section
	Recharge	
3.5.5.3	Use natural recharge of Rupert sands – 0.9 mm/y (base analysis case uses 4.2 mm/y)	4.6.2
	Use high recharge rate – 50 mm/y	4.6.2
	Use low recharge rate – 0.1 mm/y	4.6.2
	Use low recharge for 500 years, then use 4.2 mm/y	4.6.2
	Geology	
3.5.5.4	Investigate effect if entire Hanford formation is sandy	4.6.3
	Investigate effect if entire Hanford formation is gravelly	4.6.3
	Investigate effect of having clastic dikes at disposal site	4.6.3
	Investigate effect of increasing depth of vadose zone by 3 meters	4.6.3

Table 3-13. List of Sensitivity Cases.

Except for intrusion scenarios, the performance measures calculated were the drinking water dose and the all-pathways dose. For the intrusion scenarios, the acute and continuous doses were calculated.

Discussion Section	Sensitivity Case (Unless noted all cases treat groundwater scenario)	Results Presented in Section
	Facility	
3.5.5.5	Use capillary break – best estimate case (base analysis case assumes no capillary break)	4.4
	Investigate effect of side slope – 4.2 mm/y (base analysis case assumes 50 mm/y)	4.4
	Investigate effect of adding vertical gravel break (base analysis case assumes no vertical break)	4.4
	Investigate short surface barrier	4.4
	Investigate the type of material to fill in between ILAW packages	4.4
	Investigate use of concrete vaults	4.4

Table 3-13. List of Sensitivity Cases.

Except for intrusion scenarios, the performance measures calculated were the drinking water dose and the all-pathways dose. For the intrusion scenarios, the acute and continuous doses were calculated.

Discussion Section	Sensitivity Case (Unless noted all cases treat groundwater scenario)	Results Presented in Section
	Degradation	
3.5.5.6	Failure of surface barrier	4.4
	Investigate failed capillary break	4.4
	Investigate bath tub effect	4.4
	Hydrologic Parameters	
3.5.5.7	Investigate effect of having hydraulic conductivity same vertically as horizontal (base analysis case assumes anisotropy)	4.4
	Investigate changing facility filler material to sand	4.5.5
	Investigate changing Hanford sand hydrologic properties to Hanford gravel hydraulic properties	4.6.3
	Investigate changing Hanford gravel hydrologic properties to Hanford sand hydraulic properties	4.6.3

Table 3-13. *List of Sensitivity* Cases.

Except for intrusion scenarios, the performance measures calculated were the drinking water dose and the all-pathways dose. For the intrusion scenarios, the acute and continuous doses were calculated.

Discussion Section	Sensitivity Case (Unless noted all cases treat groundwater scenario)	Results Presented in Section
	Waste Form	
3.5.5.8	Use forward rate of reaction (base analysis and best-estimate cases use full reaction network)	4.5.2
	Investigate simplifications to full reaction network (no ion exchange reaction, no secondary product production)	4.5.3
	Investigate waste form release as a function of the infiltration rate (0.1, 0.5, 0.9, 4.2, 10., and 50. mm/y). The base case uses 4.2 mm/y.	4.5.4
	Investigate effect of using sand as filler material (base analysis case using backfill)	4.5.5.1
	Investigate effect of having stainless steel containers (base analysis case ignores effect)	4.5.5.2
	Investigate effect of having a chemical conditioning layer (base analysis case assumes no such feature)	4.5.5.3
	Investigate the use of concrete vaults (base analysis and best-estimate cases use trench)	4.5.6
	Investigate different waste loading/glass composition – HLP31 (base analysis case uses LAWABP1)	4.5.7
	Investigate other effects (diffusion parameter, contaminant = U, 2d calculation, extend calculation to groundwater)	4.5.8

Table 3-13. List of Sensitivity Cases.

Except for intrusion scenarios, the performance measures calculated were the drinking water dose and the all-pathways dose. For the intrusion scenarios, the acute and continuous doses were calculated.

Discussion Section	Sensitivity Case (Unless noted all cases treat groundwater scenario)	Results Presented in Section
	Geochemical	
3.5.5.9	Investigate effect of chemical trapping of I and U in base of disposal facility	4.6.3
	Investigate the effect of changing U K_d to 0	4.6.3
	Investigate the effect of changing I K_d to 0.6 mL/g	4.6.3
	Investigate the effect of all K_ds to 0	4.6.3
	Exposure	
3.5.5.10	Investigate the use of different dose factor sets (base analysis case uses EPA)	4.8.4
	Investigate different ingestion, inhalation, and time of exposure	4.8.4

Table 3-13. List of Sensitivity Cases.

Except for intrusion scenarios, the performance measures calculated were the drinking water dose and the all-pathways dose. For the intrusion scenarios, the acute and continuous doses were calculated.

Discussion Section	Sensitivity Case (Unless noted all cases treat groundwater scenario)	Results Presented in Section
	Location/Layout of Facility	
3.5.5.11	Investigate various layout of trenches on disposal site	4.7.2
	Investigate use of existing concrete vaults	4.5.6