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DOE/RL-98-48
Draft C

Groundwater/Vadose Zone Integration Project Specification

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Groundwater/Vadose Zone Integration Project Specification

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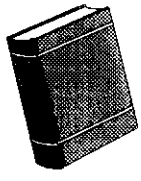
An Introduction to the Groundwater/Vadose Zone Integration Project Baseline

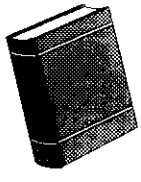
The Groundwater/Vadose Zone Integration Project baseline is presented in two documents: 1) the *Project Specification* (DOE/RL-98-48, Draft C); and 2) the *Baseline Cost/Schedule Summary* (DOE/RL-98-89, Draft A). The Long Range Plan, which provides a graphic depiction of the Integration Project's milestones, is also part of this baseline set.

An illustration of the baseline components is presented below.



Groundwater/Vadose Zone Integration Project Specification, DOE/RL-98-48, Draft C

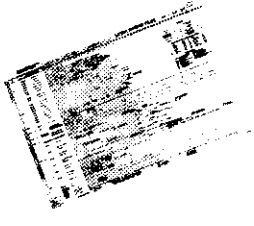
- *Project vision, mission, and strategic objectives*
- *Installation description, including operational history, environmental setting, and environmental conditions*
- *Project descriptions*
- *S&T plan and roadmap*



Groundwater/Vadose Zone Integration Project Cost and Schedule Baseline, DOE/RL-98-89, Draft A

- *Project summary*
- *Summary and detailed Long Range Plan schedules*
- *Time phased funding*
- *Core project backup information*

Groundwater/Vadose Zone Integration Project Long Range Plan



- *Graphical representation of scope, cost, and schedule baseline*

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SYNOPSIS

As the Hanford Site transitioned from weapons production to a cleanup mission in the late 1980s, the U.S. Department of Energy (DOE) established specific projects—such as the Tank Waste Remediation System (TWRS) Project and the Environmental Restoration (ER) Project—to accomplish this new mission. While each of these projects has been making progress in their assigned areas, this approach to achieving environmental cleanup has led to concerns that individual project decisions and goals (end points) may not always lead to an overall defensible end state for the Hanford Site. These projects have also prepared environmental impact documents that contain technical inconsistencies, and some associated technical knowledge needs are unmet because they are not required for an individual project. The combination of these issues has raised credibility concerns with the public. In response to these concerns, and in recognition of the potential for achieving efficiencies by integrating vadose zone and groundwater characterization activities, the DOE Richland Operations Office (RL) established the Groundwater/Vadose Zone (GW/VZ) Integration Project (Integration Project) in late 1997. DOE Undersecretary Moniz directed that the project be science-based, that it include strong participation from the DOE national laboratories, and that it incorporate a multi-tiered peer review process.

The Integration Project, in conjunction with stakeholders, has created this vision:

Completion of the mission will have established broad trust and collaboration that resulted in credible decisions, based on defensible science, that effectively and efficiently protected water resources.

To achieve this vision and to address such issues as fragmentation of the technical knowledge base, the need for an improved scientific basis for evaluating regional impacts, and credibility, the Integration Project will accomplish the following strategic objectives:

- *Integrate ongoing projects and planning*
- *Determine the cumulative impacts of Hanford Site wastes on the region and its peoples*
- *Apply sound science and technology*
- *Partner with the regulators, stakeholders, and Tribal Nations*
- *Establish a technical peer review.*

During the year since the Integration Project was established, the following accomplishments have been achieved:

- RL has established the authority of the Integration Project, so that the Integration Project can effect teamwork, coordination, and technical standardization activities across all Hanford Site projects that are involved in environmental assessments.

Synopsis

- Fiscal Year 1999 (FY99) funding has been committed for integrated management, peer reviews, development of a site-wide assessment capability, and science program development.

- This document, in conjunction with the *Cost and Schedule Baseline* and *Long Range Plan* (LRP), have established the baseline for the Integration Project.

- An integrated science-based plan has been developed for this *Project Specification*, which is part of the overall Integration Project *Baseline* and LRP documents. The national laboratories, participating with the projects and stakeholders, have developed an applied science plan and roadmap that are focused on providing a sound technical basis for cleanup and operational decisions at the Hanford Site.

- An open environment, encouraging public and Tribal Nation participation in project decisions, has been adopted.

- An Expert Panel has been established to provide technical recommendations and oversight of the Integration Project. The panel has provided initial input on project planning work, including an informal review of this *Project Specification*.

This first iteration of the *Project Specification*, along with the *Project Baseline* and LRP, has been developed with significant participation from regulators, the state of Oregon, the public and Tribal Nations. The Integration Project will continually seek broader input and review from all interested and potentially affected parties.

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ACRONYMS

AEA	Atomic Energy Act
ALARA	As Low As Reasonably Achievable
ALE	Arid Lands Ecology
ARAR	Applicable or Relevant and Appropriate Requirements
AME	Assistant Manager for Environmental Restoration
ASDP	Arid Site Demonstration Project
ASME	American Society of Mechanical Engineers
BHI	Bechtel Hanford, Inc.
BPA	Bonneville Power Administration
CERCLA	*Comprehensive Environmental Response, Compensation, and Liability Act*
CFEST	Coupled, Fluid, Energy, and Solute Transport
COC	Contaminants of Concern
CRBG	Columbia River Basalt Group
CRCIA	*Columbia River Comprehensive Impact Assessment*
CRE	Center of Risk Excellence
CRU	Columbia River United
CTUIR	Confederated Tribes of the Umatilla Indian Reservation
D&D	Decontamination and Decommissioning
DNAPL	Dense Non-Aqueous Phase Liquids
DNFSB	Defense Nuclear Facility Safety Board
DOE	U. S. Department of Energy
DOH	Washington State Department of Health
DQO	Data Quality Objective
DST	Double Shell Tank
DWP	*Detailed Work Plan*
DWS	Drinking Water Standards
Ecology	Washington State Department of Ecology
EIS	Environmental Impact Statement
EM	Environmental Management
EMI	electromagnetic induction
EMP	Environmental Monitoring Plan
EMSL	Environmental Molecular Sciences Laboratory
EMSP	Environmental Management Science Program
EPA	U.S. Environmental Protection Agency
ER	Environmental Restoration
ERA	Expedited Response Action
ERC	Environmental Restoration Contractor
ERDF	Environmental Restoration Disposal Facility
ETF	Effluent Treatment Facility
FDH	Fluor Daniel Hanford, Inc.
FFTF	Fast Flux Test Facility
FRC	field research centers

FSUWG	Future Sites Uses Working Group
FY	Fiscal Year
GPMP	*Groundwater Protection Management Plan*
GW/VZ	Groundwater and Vadose Zone
HAB	Hanford Advisory Board
HDW	Hanford Defined Waste
HEAL	Hanford Environmental Action League
HLW	High Level Waste
HRA-EIS	Hanford Remedial Action Environmental Impact Statement
HTI	Hanford Tanks Initiative
HQ	Headquarters
ILAW	Immobilized Low Activity Waste
IPL	*Integrated Priority List*
IRM	Interim Remedial Measures
Kd	Coefficient Distribution
LANL	Los Alamos National Laboratory
LAW	Low Activity Waste
LFI	Limited Field Investigations
LLBG	Low-Level Waste Burial Ground
LLW	Low-Level Waste
LRP	*Long Range Plan*
MOA	Memoranda of Agreement
MOU	Memoranda of Understanding
MTCA	*Model Toxic Control Act*
MUST	Miscellaneous Underground Storage Tanks
NABIR	Natural and Accelerated Bioremediation Program
NAPL	Non-Aqueous Phase Liquids
NAS	National Academy of Sciences
NASQAN	National Stream Quality Accounting Network
NEPA	*National Environmental Policy Act*
NPT	Nez Perce Tribe
NRC	U.S. Nuclear Regulatory Commission
NTS	Nevada Test Site
OBER	Office of Biological and Environmental Research
OBS	Organizational Breakdown Structure
OEA	Office of External Affairs
ORIGEN2	Oak Ridge Isotope Generation and Depletion
OST	Office of Science and Technology
OU	Operable Unit
PA	Performance Assessment
PBS	*Program Baseline Summary*
PCB	Polychlorinated biphenyl
PFP	Plutonium Finishing Plant
PHMC	Project Hanford Management Contract
PI	Public Involvement
PM	Project Manager

PMP	*Project Management Plan*
PNNL	Pacific Northwest National Laboratory
PRTR	Plutonium Recycle Test Reactor
PTS	Progress Tracking System
PUREX	Plutonium Uranium Extraction
RARA	Radiation Area Remedial Action
RCRA	*Resource Conservation and Recovery Act*
REDOX	Reduction Oxidation
RI/FS	Remedial Investigation/Feasibility Study
RL	Richland Operations Office
ROD	Record of Decision
S&M	Surveillance and Maintenance
S&T	Science and Technology
SAC	System Assessment Capability
SALDS	State-Approved Land Disposal Site
SARA	*Superfund Amendments and Reauthorization Act of 1986*
SEPA	*State Environmental Policy Act*
SESP	Surface Environmental Surveillance Project
SRS	Savannah River Site
SST	Single Shell Tank
STCG	Science and Technology Coordination Group
SWITS	Solid Waste Information Tracking System
TBP	Tributyl Phosphate
TDR	Time Domain Reflectometry
TEDF	Treated Effluent Disposal Facility
TIMS	Thermal Ionization Mass Spectrometry
TLD	Thermoluminescent Dosimetry
TRAC	Track Radioactive Components
Tri-Party Agreement	*Hanford Federal Facility Agreement and Consent Order*
TRU	Transuranic
TSD	Treatment, Storage, and Disposal
TWINS2	Tank Waste Information Network System
TWRS	Tank Waste Remediation System
UPR	Unplanned Releases
USGS	U.S. Geological Survey
VOC	Volatile Organic Compound
YIN	Yakama Indian Nation
WBS	Work Breakdown Structure
WIDS	Waste Information Data System
WIPP	Waste Isolation Pilot Project

1.0 INTRODUCTION

The Hanford Site environmental legacy represents one of the most complex technical, regulatory, and public policy challenges facing the nation. Past operations at the Hanford Site resulted in radiological and chemical contamination of soils (vadose zone), groundwater, and the Columbia River. While cleanup progress is being made, individual cleanup project decisions and goals (end points) do not necessarily lead to a technically defensible and publicly acceptable end state. At the Hanford Site, environmental characterization and assessment activities are often fragmented among projects, and are often conducted under different regulatory requirements. This has resulted in the inefficient use of technical and financial resources. Based on interviews, feedback, and overall comments and recommendations from Tribal Nations, regulators, advisory boards, and public interest groups, there is a need to improve trust and credibility.

To address this situation, the U.S. Department of Energy (DOE) has established the Hanford Site Groundwater/Vadose Zone (GW/VZ) Integration Project (Integration Project) in order to fulfill its commitment to assure the protection of water resources, the Columbia River environment, river-dependent life, and users of the Columbia River resources. The Integration Project will:

- Integrate all Hanford Site GW/VZ related work scope.
- Predict current and future impacts resulting from contaminants that have been (or are predicted to be) released to the soil column at the Hanford Site.
- Provide a sound science and technology (S&T) basis for site decisions and actions.
- Promote the open and honest involvement of Tribal Nations, regulators, and stakeholders so that project outcomes reflect expressed interests and values.
- Establish an independent technical peer review.

The Integration Project was established by the DOE in late 1997. DOE Undersecretary Moniz directed that the project be science-based, that it include strong participation from the DOE national laboratories, and that it incorporate a multi-tiered peer review process. The Assistant Manager for Environmental Restoration (AME) at the Richland Operations Office (RL) was assigned responsibility for the Integration Project. In December 1997, Bechtel Hanford, Inc. (BHI), which leads the Hanford Site Environmental Restoration Contractor (ERC) team, was assigned the responsibility for managing the integration of GW/VZ activities. Other major Hanford Site participants are Fluor Daniel Hanford, Inc. (FDH), which is the integrating contractor for the Project Hanford Management Contract (PHMC) team, and Battelle, which operates the Pacific Northwest National Laboratory (PNNL). The Integration Project also involves Tribal Nations, regulators, the state of Oregon, and other stakeholders in Integration Project decision-making processes.

1.1 MISSION AND VISION

The following mission and vision statements have been framed and adopted by the Integration Project through a series of Public Involvement (PI) meetings.

Mission

To ensure that Hanford Site decisions are defensible and possess an integrated perspective for the protection of water resources, the Columbia River environment, river-dependent life, and users of the Columbia River resources, the mission of the Groundwater/Vadose Zone Project is to develop and conduct defensible assessments of the Hanford Site's present and post-closure cumulative effects of radioactive and chemical materials that have accumulated throughout Hanford's history (and which continue to accumulate). To support this mission the Groundwater/Vadose Zone Project will also define those actions necessary to establish consistency and maintain mutual compatibility among site-wide characterization and analysis tasks that bear on decisions, receptor impact, and regulatory compliance. The Groundwater/Vadose Zone Integration Project will identify and oversee the science and technology initiatives pursued by the national laboratories (as necessary) to enable the assessment mission to be successfully completed.

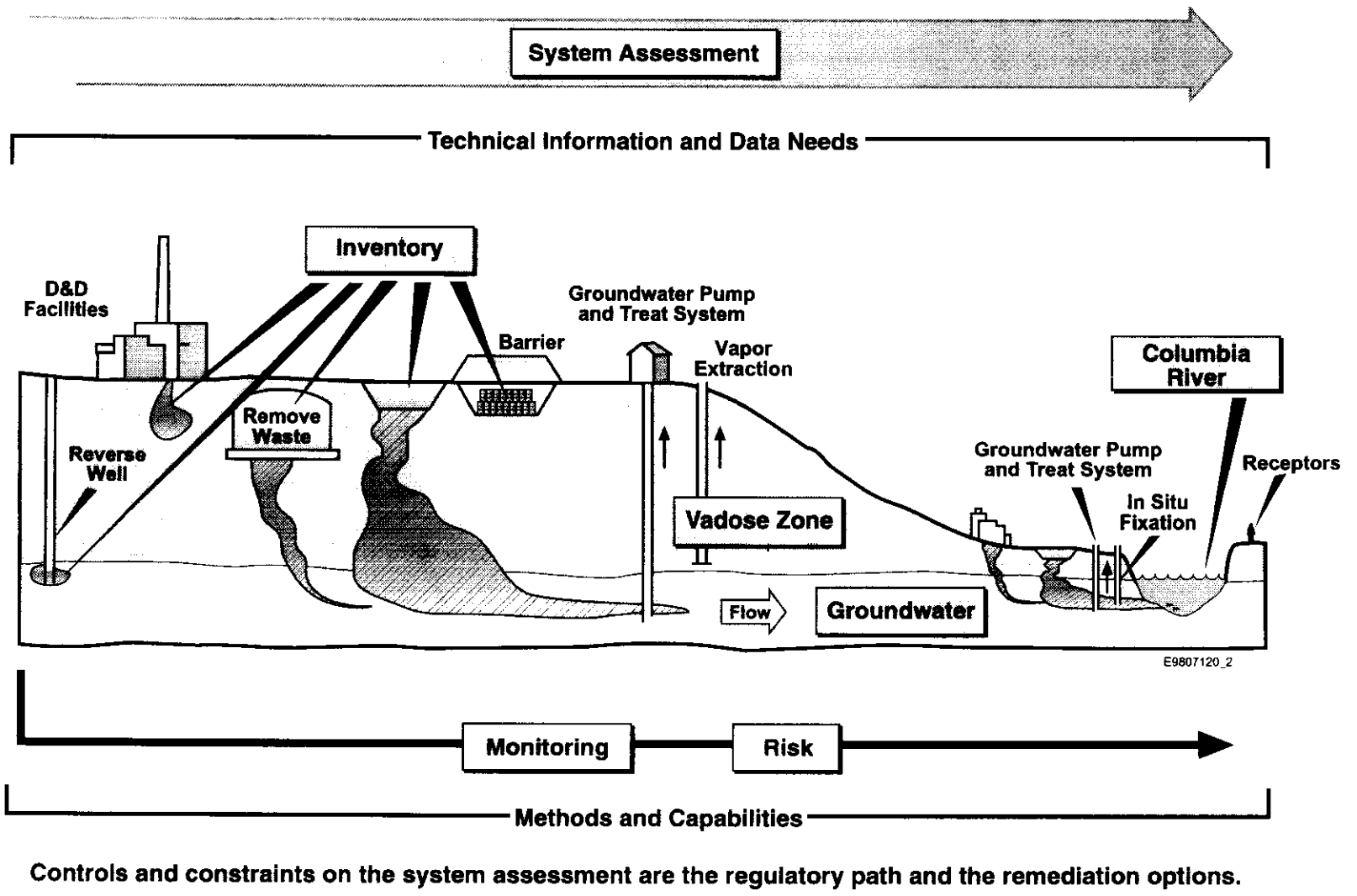
Vision

Completion of the mission has established broad trust and collaboration that resulted in credible decisions, based on defensible science, that effectively and efficiently protected water resources.

It is DOE's intent to provide responsible stewardship of local and regional water resources through appropriate protection of these resources from existing vadose zone contamination, as well as potential future releases to the vadose zone. Maintaining such stewardship throughout the Hanford Site cleanup mission, and beyond, will assure that existing and future generations are protected from unacceptable levels of contaminants. These activities will be conducted in an atmosphere conducive to trust and collaboration. Credibility and technical defensibility in the decision-making process will rest upon applying sound science and engineering principles.

1.2 PROJECT OVERVIEW

In order to accomplish its mission, the Integration Project is establishing the Hanford Site's technical foundation for predicting the transport of existing and future contaminants through the vadose zone, groundwater, and the Columbia River to receptors (i.e., affected organisms) (see Figure 1-1). The Integration Project is employing a systems approach to develop and assemble the scientific understanding, data, and capability required to evaluate the cumulative impacts of Hanford Site operations, as well as proposed corrective actions and remediation alternatives for regional water resources and receptors. This approach involves an iterative process for establishing an understanding of the system (a conceptual model), developing and exercising a System Assessment Capability (SAC) (models, analytical tools, and data needed for



Controls and constraints on the system assessment are the regulatory path and the remediation options.

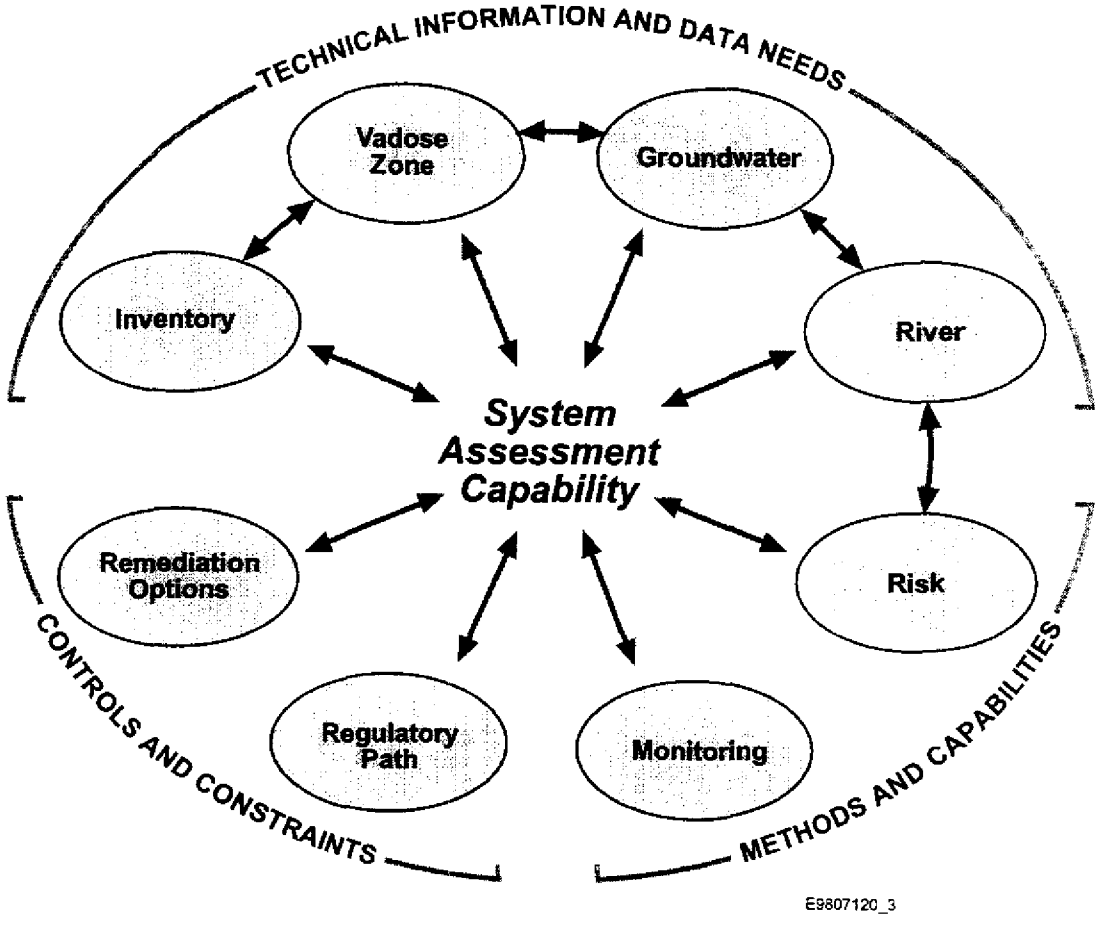
Figure 1-1. Major Elements of the System Assessment.

effects assessments), and defining uncertainties and requirements for science and data in order to fill gaps. The systems approach and the SAC are discussed in Section 5.0.

The Integration Project divides its work into eight technical elements, as illustrated in Figure 1-1. The relationships within and between elements are coordinated through the system assessment, as shown in Figure 1-2. The work scope for these technical elements is specifically defined in Appendix A. Through a series of workshops with local experts, scientists from the national laboratories, and interested members of the public, key deficiencies were identified for several of these elements. From this analysis, an applied S&T program has been developed for which a project-level S&T roadmap has been drafted. These are also discussed in Section 5.0.

Another important aspect of the Integration Project mission is to establish consistency and compatibility among the Hanford Site's characterization and assessment projects (core projects). Core projects were evaluated and opportunities for enhancements were identified in the context of a *Long Range Plan* (LRP) (Section 5.0). The LRP identifies near and long-term decisions requiring assessments of the potential regional effects of these decisions (utilizing the SAC). The LRP also identifies required interconnections and dependencies.

Figure 1-2. Integration Project Technical Elements.



1.3 OPPORTUNITIES FOR INTEGRATION

This first iteration of the Integration Project *Baseline* has resulted in the identification of opportunities for integration in the following four areas:

Project Assessments

Ongoing project assessments represent near-term opportunities that should be evaluated over the next several months and incorporated into FY 2000 planning efforts. Currently, ER 200 Area Remedial Actions, Tank Waste Remediation System (TWRS) Vadose Zone Characterization, immobilized low activity waste (ILAW) and Hanford Tanks Initiative (HTI) are all performing assessment activities in the 200 Area. Recommendations about efficiencies that will be gained by integrating activities within and across other Hanford Site Projects are as follows:

- The collection of field data will be based on technically defensible sampling and analysis plans that are integrated among the core projects to optimize sample collection and analysis, and to reduce assessment costs.

- The sampling and analysis plans will be based on a rigorous, cost-effective Data Quality Objectives (DQOs) process that includes representatives for all the associated projects, S&T, regulators, and stakeholders.

- The development of conceptual models is common to many of the projects and will be coordinated. Cost-effective methods need to be identified to optimize their preparation and maintenance.

- Requirements for a consistent approach in conducting performance/risk assessments will be developed for all Hanford Projects.

- A common set of inventory, vadose zone, groundwater and river data will be developed for modeling and assigned configuration controls.

- Characterization and monitoring of technology development and deployment needs to be coordinated among the core projects.

- Utilize information generated by non-DOE agencies (e.g., U.S. Geological Survey [USGS], the state of Oregon, Bonneville Power Administration [BPA]), and pursue opportunities for coordinated studies.

Science and Technology

- S&T will support both the SAC and Hanford Site project cleanup goals. S&T will be integrated with the planning and execution of field data collection, sampling and analysis, conceptual and numerical modeling, and the performance/risk assessment.

Operations and Remedial Actions

- Vadose zone monitoring activities will be integrated across the Hanford Site.
- Groundwater monitoring that has been integrated across the Hanford Site will be optimized to achieve additional efficiencies.
- Well services, which include well drilling, maintenance, rehabilitation, and decommissioning, should be integrated.
- The baseline remedial actions will pose significant logistical conflicts if they are implemented as currently planned and scheduled. The first action and basis for evaluating remediation activities should be to develop an path forward for remediation that minimizes implementation conflicts.

Coordination of Regulations and Orders

- Currently, assessment and cleanup activities are operating under numerous and sometimes overlapping regulatory requirements (for example, the *Resource Conservation and Recovery Act* [RCRA], *Comprehensive Environmental Response, Compensation, and Liability Act* [CERCLA], *National Environmental Policy Act* [NEPA], *Atomic Energy Act* [AEA], U.S Nuclear Regulatory Commission [NRC] policies, etc.). As a first step, the DOE would like to initiate discussions with regulators on potential approaches to developing an integrated regulatory framework for the 200 Area in early calendar year 1999. In the future, the DOE would like to expand this discussion to address the entire Hanford Site.

1.4 PROJECT ROLES, RESPONSIBILITIES, AND AUTHORITY

Within the DOE, the AME is the lead organization for the Integration Project, and is responsible for integrating the other applicable DOE offices with this effort. Other involved DOE offices include (1) the TWRS Project Office, which has responsibility for characterization of the 149 single shell tanks (SSTs), 28 double shell tanks (DSTs), and for past releases from tanks; (2) the Assistant Manager for Technology, which manages S&T; (3) the Waste Program Division, which manages operations of low level burial grounds, retrievable transuranic (TRU) waste sites, and liquid treatment discharge sites; and (4) the Environmental Assurance and Permits Division, which manages Columbia River monitoring work.

The formal assignment of roles and responsibilities for the AME project manager and the DOE offices managing core projects was established in a letter from the RL Manager to contractors dated November 25, 1998 (see Appendix B). The AME project manager is required to ensure development of the required data (characterization data and scientific information), as well as numerical tools for performing effects assessments for remedial action proposals on a schedule that supports the major Hanford Site projects. The authority to accomplish this is established in two ways. First, the AME project manager is authorized to provide direction to the core projects

assigned to the AME and to the Integration Project team. Second, for projects managed by other DOE offices, the AME project manager is authorized to either initiate direction to these projects through the managing DOE office, or concur on core project direction that is prepared by the managing DOE office.

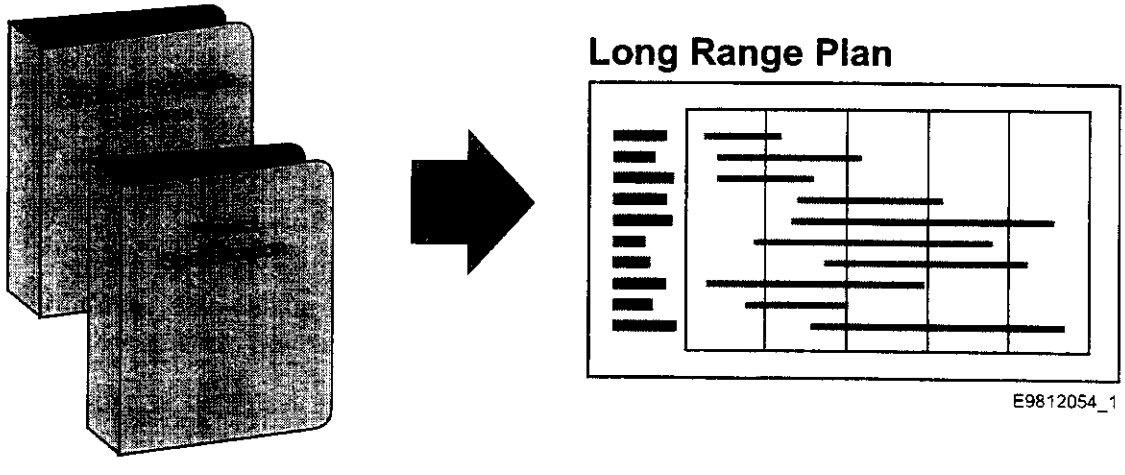
The DOE has also established a GW/VZ Executive Council, which reviews project progress, provides guidance, and resolves issues between DOE offices and contractors. The Executive Council consists of the AME, other DOE Assistant Managers responsible for core projects, and key managers from BHI and the other Hanford Site contractors responsible for core projects.

In response to the DOE management structure (above), BHI has formed a multi-contractor project team. Consistent with contract lines of authority, the BHI Integration Project Manager is required to transmit formal guidance, direction, or requests to other contractors through the DOE AME project manager. Formal working relationships among the contractors will be documented in a project management plan that will be issued in FY99.

1.5 PROJECT BASELINE

This document, along with the *Cost and Schedule Baseline* and LRP, represent the baseline for Integration Project. Figure 1-3 depicts this documentation set. The LRP is not a document but, instead, presents a graphical representation of inter-relationships between project activities. As such, the LRP is a key planning tool for the Integration Project.

Figure 1-3. Project Baseline.



While portions of the scope described in the proposed baseline (i.e. TWRS and ER) are currently part of the overall Hanford Site baseline, some of the scope (i.e., integration, SAC, S&T) is not. The integration, SAC, and a portion of the S&T activities are funded from within the FY99 Hanford Site budget. However, the remainder of the FY99 S&T work is dependent on other

funding sources (such as EM-50 and/or the Environmental Management Science Program [EMSP]).

To establish a baseline for these activities beyond FY99, scope will be added to the Hanford Site *Integrated Priority List* (IPL) and will be evaluated and ranked with other elements in the Hanford Site scope. This IPL process uses overall Hanford Site priorities (see Section 3.2) to establish a list of the scope that can be accomplished within the funding constraints for a particular fiscal year. The process includes reviews with regulators, stakeholders, and Tribal Nations. The detailed cost and schedule is then developed for the scope, and becomes part of the Hanford Site baseline through the formal change control process.

This *Project Specification* also fulfills selected requirements for a *Groundwater Protection Management Plan* (GPMP), as identified in DOE Order 5400.1 *(Environmental Protection Program).* Appendix C shows how the requirements of a GPMP are accommodated by the Integration Project documentation set.

1.6 ORGANIZATION OF THE PROJECT SPECIFICATION

This *Project Specification* is organized as follows:

Section 1.0 - Introduction - This section describes the purpose and scope of the *Project Specification*, and provides relevant background information. Section 1.0 establishes the mission, vision, and general Integration Project approach; it also identifies the primary Integration Project documents, and the relationships between these documents.

Section 2.0 - Hanford Site Setting - Information is presented on the Hanford Site's operational history, environmental setting, work management and waste disposal practices.

Section 3.0 - Where We Have Focused - This section discusses the *Hanford Federal Facility Agreement and Consent Order* (*Tri-Party Agreement*), as it pertains to the Integration Project, and the Hanford Site work scope prioritization approach. Integration Project management strategies for key work activities are also discussed in this section.

Section 4.0 - The Need for Integration - Information is presented on the rationale for the Integration Project. Particular emphasis is provided on the roles that stakeholders, regulatory agencies, Tribal Nations, and PI groups play in Integration Project decision-making processes.

Section 5.0 - Strategic Approach and Long Range Plan - This section describes the first iteration of a science-based plan that describes why, what, and how activities will be integrated to achieve the Integration Project's mission.

Section 6.0 - Path Forward. Details of the Integration Project's near-term approach are provided in this section.

Appendix A - Technical Element Descriptions. Specific details are provided about the scope of each technical element that is discussed in Section 1.0.

Appendix B - Hanford Letter of Direction for Integration Project Authority. This appendix contains the RL Letter of Direction that defines the roles and responsibilities for the Integration Project.

Appendix C - Matrix Comparison of Project Documents to Groundwater Protection Management Plan (GPMP) Requirements. This appendix identifies the locations in project documentation where GPMP requirements are addressed.

Appendix D - Operational History of Waste Disposal at the Hanford Site. An historical summary is provided for waste disposal operations at the Hanford Site.

Appendix E - Pertinent Federal and State Laws and Regulations. This is a summary listing of all laws and regulations applicable to those Hanford Site activities that fall within the technical scope of the Integration Project.

Appendix F - Requirements and Guidelines for the Development and Conduct of a Hanford Site Cumulative Effects Assessment. A summary of the requirements and guidelines for conducting a cumulative effects assessment for the Hanford Site is provided. The material in this section builds upon the approach and requirements described in Part II of the *Screening Assessment and Requirements for Comprehensive Assessments: Columbia River Comprehensive Impact Assessment*[*].

Appendix G - Current State of Technical Knowledge. The current state of knowledge, organized by technical elements, is described.

Appendix H - Applied Science and Technology Plan for Integrated Vadose Zone, Groundwater, and River System at the Hanford Site. Describes the current approach for addressing applied S&T needs in support of Hanford Site decisions. A version of the current S&T roadmap is provided.

Appendix I - Applied Science and Technology Roadmap for Integrated Vadose Zone, Groundwater, and River System at the Hanford Site. This is the first version of the S&T roadmap, including inventory, vadose zone, groundwater, and river technical elements.

How to Read This Document

This document is designed for a wide community of individuals who wish to understand the Integration Project. As there are varying levels of knowledge regarding the Hanford Site, and specific issues surrounding the establishment of the Integration Project, certain materials have

[*] DOE-RL, 1998, *Screening Assessment and Requirements for a Comprehensive Assessment, Columbia River Comprehensive Impact Assessment*, DOE/RL-96-16, Rev. 1, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

been included in both the text portions of this document (and in the appendices) that will be of more interest to general readers. Readers who wish to understand the specific actions and activities that the Integration Project is planning and currently engaged in should read the following sections:

- Section 1.0 - Introduction
- Section 4.0 - The Need for Integration (read at least through Section 4.1)
- Section 5.0 - Strategic Approach and Long Range Plan
- Section 6.0 - Status and Path Forward

2.0 HANFORD SITE SETTING

2.1 OPERATIONAL OVERVIEW OF THE HANFORD SITE

In 1943, under the auspices of the Manhattan Project, the U.S. Army Corps of Engineers selected the Hanford Site as the location for nuclear reactor and spent fuel processing facilities (Figure 2-1). The Hanford Site mission was to produce plutonium for nuclear weapons. This required a large military-industrial complex that included fuel manufacturing facilities, nuclear reactors (to produce plutonium), chemical processing (to separate and purify plutonium), waste management practices (to store and dispose of nuclear waste), and research (to support the overall Hanford Site mission). Table 2-1 summarizes the operational history of the primary facilities that supported the Hanford Site defense mission.

Beginning operations in 1944, nine production reactors located in the 100 Area of the Hanford Site irradiated uranium to produce plutonium. These reactors irradiated approximately 100,000 metric tons of uranium fuel. Eight of the reactors were graphite-moderated and used Columbia River water for once-through cooling. These reactors were shut down by 1971. The ninth reactor, a dual-purpose reactor (N Reactor), used recirculating water coolant and produced both plutonium and steam for electricity. N Reactor operated until 1987, and is now deactivated.

Two test reactors were also constructed and operated at the Hanford Site. The Plutonium Recycle Test Reactor (PRTR) was a heavy-water moderated test reactor located in the 300 Area. The PRTR is now retired and has been deactivated. The Fast Flux Test Facility (FFTF), a sodium-cooled reactor located in the 400 Area, was used to test fuels and materials for advanced nuclear power plants. In 1993 the FFTF began transitioning towards permanent shutdown. One commercial nuclear power plant, operated by the Washington Public Power Supply System, is located on the Hanford Site and is still operating.

Chemical processing operations during nuclear production generated high-level radioactive liquid wastes. About 245 million liters (65 million gallons) of high-level waste (HLW) are stored at the Hanford Site in 177 large underground tanks. The tanks, divided into 18 groups (or "farms"), are located in the 200 Area. Of the original single shell tanks, 67 of the 149 have leaked or are assumed to have leaked a combined amount of about 3.8 million liters (1 million gallons) of contaminated liquid to the soil column. Recent estimates of tank leaks push the estimates of volumes and curies lost much higher. The 28 DSTs built since 1968 have an improved design for better containment (a tank within a tank), and have not leaked.

The solid waste generated from past operations consists of low-level radioactive waste, low-level mixed waste, TRU waste, and hazardous waste. The current inventory of solid waste buried or stored in underground trenches and above-ground facilities is about 87,000 m^3 (114,000 yd^3) in the 100 Areas, 379,000 m^3 (495,000 yd^3) in the 200 Areas, and 159,000 m^3 (208,000 yd^3) in the 300 Area. A commercial low-level radioactive waste disposal facility, operated by US Ecology, is located on Washington State leased land southeast of the 200 East Area.

Figure 2-1. Hanford Site Location.

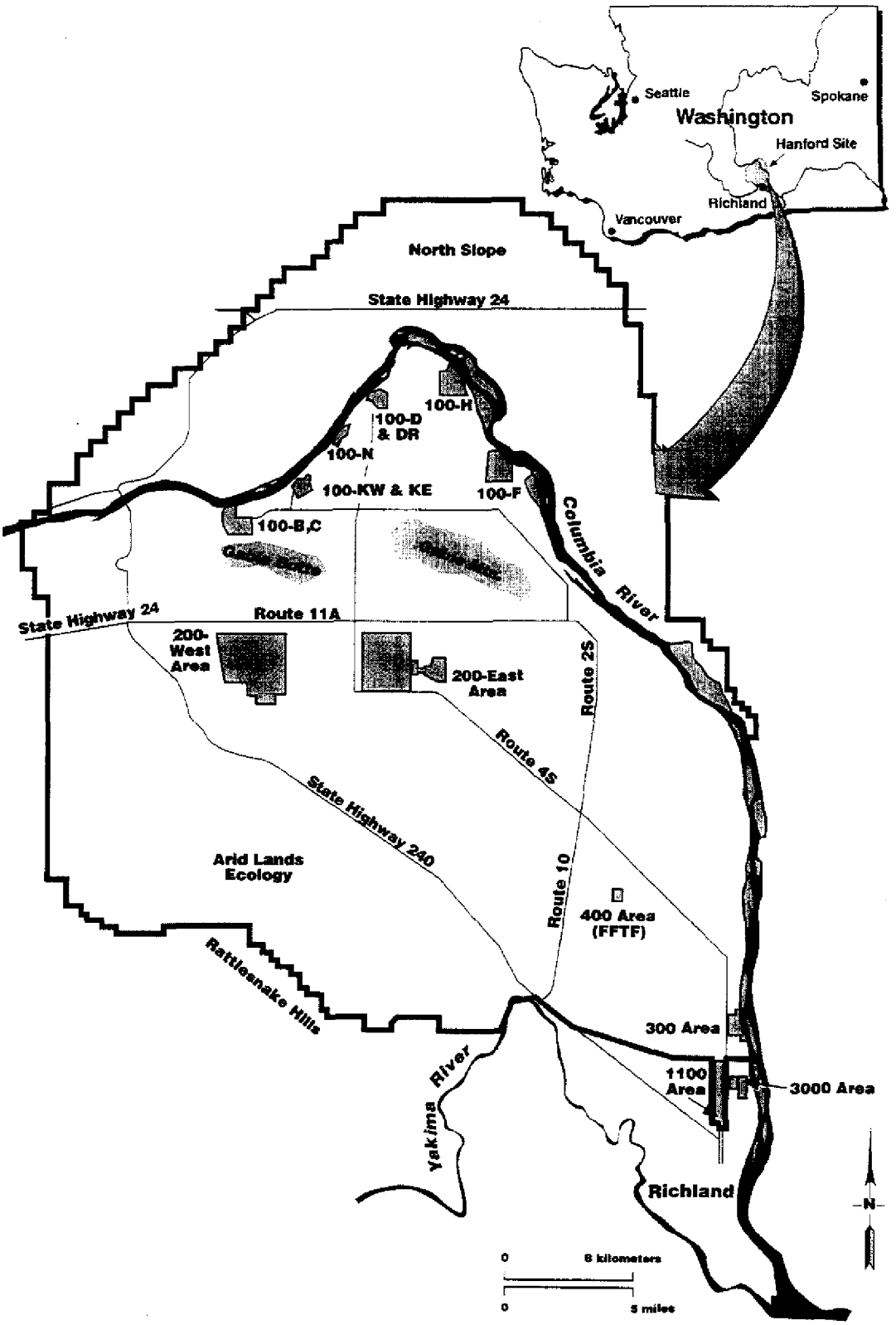


Table 2-1. History of Operations for EM Program Facilities at the Hanford Site.

Type of Operation	Operating Period	Hazardous Substances	Map Reference
Production Reactors			
105-B Reactor	1944 to 1968	AFP, TRU, Haz, Asb, Rad Equip	100-BC Area
105-D Reactor	1944 to 1967	AFP, TRU, Haz, Asb, Rad Equip	100-D Area
105-F Reactor	1945 to 1965	AFP, TRU, Haz, Asb, Rad Equip	100-F Area
105-H Reactor	1949 to 1965	AFP, TRU, Haz, Asb, Rad Equip	100-H Area
105-DR Reactor	1950 to 1965	AFP, TRU, Haz, Asb, Rad Equip	100-D Area
105-C Reactor	1952 to 1969	AFP, TRU, Haz, Asb, Rad Equip	100-BC Area
105-KW Reactor	1955 to 1970	AFP, TRU, Haz, Asb, Rad Equip, Irr Fuel	100-K Area
105-KE Reactor	1955 to 1971	AFP, TRU, Haz, Asb, Rad Equip, Irr Fuel	100-K Area
105-N Reactor	1963 to 1987	AFP, TRU, Haz, Asb, Rad Equip	100-N Area
Test Reactors			
PRTR	1961 to 1968	AFP, TRU, Haz, Asb, Rad Equip	300 Area
FFTF	1980 to 1994	AFP, TRU, Haz, Asb, Rad Equip, Irr Fuel	400 Area
Fuel Reprocessing			
T-Plant	1944 to 1956	AFP, TRU, Haz, Asb, Rad Equip	200-West Area
B-Plant	1945 to 1952	AFP, TRU, Haz, Asb, Rad Equip	200-East Area
REDOX	1952 to 1967	AFP, TRU, Haz, Asb, Rad Equip	200-East Area
PUREX	1955 to 1972	AFP, TRU, Haz, Asb, Rad Equip	200-East Area
Nuclear Materials Processing			
UO_3 Plant	1951 to 1972 and 1984 to 1989	AFP, TRU, Haz, Asb, Rad Equip	200-West Area
Plutonium Finishing Plant	1949 to 1980 and 1984 to 1992	AFP, TRU, Haz, Asb, Rad Equip, SNM	200-West Area
U-Plant Uranium Recovery	1952 to 1957	AFP, TRU, Haz, Asb, Rad Equip	200-West Area
Fuel Fabrication	1943 to 1967	Haz, Rad Equip, Asb Uranium	300 Area
By-Product and Waste Processing			
Waste Scavenging (U-Plant)	1953 to 1957	AFP, TRU, Haz, Asb, Rad Equip	200-West Area
Cs and Sr Recovery (B-Plant)	1967 to 1979	AFP, TRU, Haz, Asb, Rad Equip	200-East Area
Cs and Sr Encapsulation (WESF)	1974 to 1985	AFP, Haz, Asb, Rad Equip	200-East Area
Waste Evaporators	1951 to 1989, 1 of 3 remains in service	AFP, TRU, Haz, Asb, Rad Equip	200-East and West Areas
High Level Liquid Waste Storage			
Single Shell and Double Shell Tanks	1944 to Present	AFP, TRU, Haz, Rad	200-East and West Areas

AFP - Radioactive Activation and Fission Products
TRU - Transuranic Materials
Haz - Hazardous Materials
SNM - Special Nuclear Materials
Asb - Asbestos
Irr Fuel - Irradiated Reactor Fuel
Rad Equip - Radioactively Contaminated Equipment

After over 40 years of operations, the Hanford Site plutonium production mission has been completed, leaving a large amount of nuclear waste as part of its legacy. By volume, two-thirds of all the nuclear waste in the DOE complex is stored or disposed at the Hanford Site. Over 1,600 contaminated waste sites associated with reactor areas, chemical processing areas, and fuel processing areas have been identified. Starting in 1986, the Hanford Site mission began changing from plutonium production to environmental restoration and remediation.

2.2 ENVIRONMENTAL SETTING

The Hanford Site lies within the semi-arid Pasco Basin of the Columbia Plateau, in south-central Washington State (Figure 2-1). Public access to this land is restricted. Only about 6% of the total Hanford Site surface land area has been affected by Hanford Site operations.

2.2.1 Climate and Meteorology

The average annual precipitation at the Hanford Site is 16 cm (6.3 in.) Most precipitation occurs during the winter, with more than half of the annual amount occurring from November through February. The prevailing wind direction is from the northwest, in all months of the year, with frequent strong winds from the southwest. Daily maximum average temperatures range from 2°C (35°F) in late December and early January to 35°C (95°F) in late July. The annual average relative humidity is 54%. Humidity is highest during the winter months, averaging about 75%, and lowest during the summer, averaging about 35%.

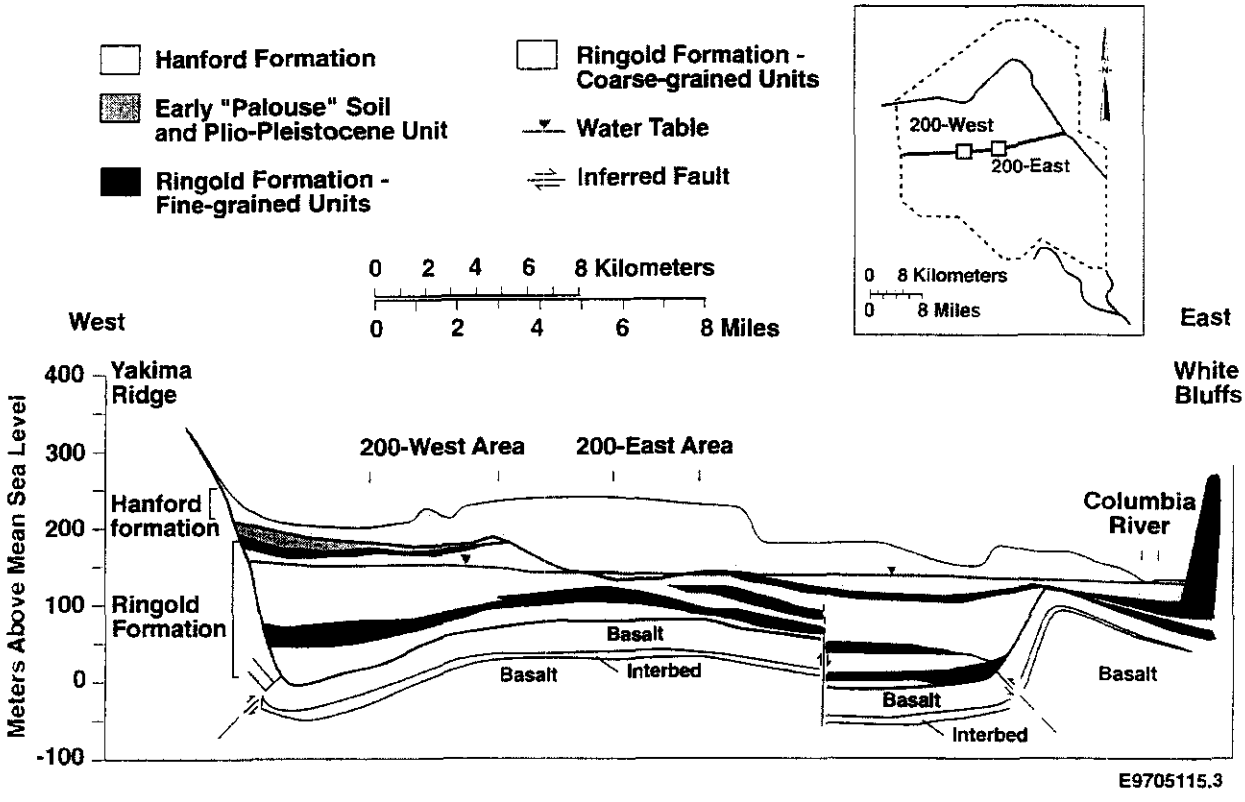
2.2.2 Geology

The major geologic units in the Hanford Site area are the Miocene Columbia River Basalt Group (CRBG) and intercalated sedimentary rocks of the Ellensburg Formation. These are overlain by younger (Mio-Pliocene) sedimentary rocks of the Ringold Formation, the early "Palouse" soil/Plio- Pleistocene Unit, and the Pleistocene cataclysmic flood deposits of the Hanford Formation (Figure 2-2).

The CRBG, which comprises the principal rock unit at the Hanford Site, is a sequence of flood basalt flows that erupted between 6 and 17 million years ago. The Ellensburg Formation consists of a series of sedimentary units that are interbedded between many of the basalt flows of the CRBG. The Ringold Formation overlies the youngest basalt flow, and consists of semi-consolidated clay, silt, pedogenically altered sediment, fine- to coarse-grained sand, and granule-to-cobble gravel. The primary facies of the Ringold Formation are fluvial gravels, fluvial sands, overbank deposits and paleosols, and lacustrine deposits. Ringold strata typically are situated below the water table.

The Plio-Pleistocene Unit is made up of sandy gravels that separate the Hanford Formation and the Ringold Formation in the east-central Cold Creek syncline and at the east end of the Gable Mountain anticline (east and south of the 200 East Area). These gravels are up to 25m (75 feet) thick. Along the western margin of the site, the "Palouse" soil separates the two formations. The Hanford Formation consists of pebble to boulder sized gravel, fine to coarse-grained sand, and silts of unconsolidated deposits from ice age flooding. The Hanford Formation generally lies above the water table throughout most of the Hanford Site, except in the 100 and 300 Areas.

Figure 2-2. Major Geological Units at the Hanford Site



2.2.3 Hydrology

2.2.3.1 Surface Water Hydrology. Surface water at the Hanford Site includes the Columbia River (northern and eastern sections), riverbank springs along the river, springs on Rattlesnake Mountain, and onsite ponds. In addition, the Yakima River flows along a short section of the southern boundary of the Hanford Site.

2.2.3.2 Vadose Zone Hydrology. The hydrology in the vadose zone is influenced by the texture of the geologic units in the Hanford Formation, the thickness of the unsaturated sequence, low precipitation, and high evapotranspiration. These conditions significantly influence the time required for contaminants to reach the water table. Perched water is known to occur beneath active release sites, and is located above fine grained sediments.

2.2.3.3 Groundwater Hydrology. The unconfined aquifer generally occurs in the semi-consolidated silts, sands, and gravels of the Ringold Formation. These sediments were deposited by the Columbia River as it meandered across the central Pasco Basin several million years ago. The Ringold Formation is less transmissive to water than Hanford Formation sediments. The aquifer ranges in saturated thickness from 0 m (near the margins of the Pasco Basin) to approximately 60 m (200 ft) near the center of the Basin.

Both natural and artificial sources of water recharge the aquifers within the Pasco Basin. The most significant volume source is irrigation water from the Columbia Basin Project, although this influence is limited to the area north of the Columbia River. Artificial recharge caused by Hanford Site operations historically has produced major groundwater mounds in the 200 East and 200 West Areas. The reduction or cessation of waste disposal has resulted in declines in water table elevations, and has changed contaminant plume characteristics.

Groundwater plumes move in directions that are approximately perpendicular to the water table elevation contours. Chemical and radiological contaminants detected in the groundwater above Drinking Water Standards (DWS) are shown in Figures 2-3 and 2-4. During the Hanford Site's operating history, changes in the volume of liquid waste disposed to the soil column have altered the shape of the water table, resulting in alterations to migration patterns.

The interaction between the groundwater and the Columbia River is an important element in assessing contaminant impacts on the river system. River water moves in and out of the banks during daily stage fluctuations, causing variable water quality characteristics in shoreline monitoring wells. In addition, the interface zone between the river and the aquifer has characteristics that may retard or modify contaminants that are transported by groundwater.

2.2.4 Water Quality of the Columbia River

The State of Washington has classified the stretch of the Columbia River from the Grand Coulee Dam to the Washington-Oregon border (which includes the Hanford Reach) as Class A, Excellent. Class A waters are required to be suitable for essentially all uses, including raw drinking water, recreation, and wildlife habitat. State and federal DWS apply to the Columbia River and are currently being met. Radionuclides detected in the river during 1997 included tritium, strontium-90, iodine-129, and uranium. Radionuclide measurements of total alpha and total beta approximately 5% (or less) of the applicable DWS of 15 and 50 pCi/L, respectively. Tritium measurements continue to be below state and federal DWS. Nonradiological constituents detected in the river consist mostly of metals and anions, in concentrations below state and federal DWS. All nonradiological water quality standards are met for this Class A-designated water.

Groundwater contaminants from the Hanford Site's past waste disposal practices continue to enter the Columbia River from riverbank springs and seeps, as well as from the interface between the river bed and groundwater. Aluminum, chromium, iron, manganese, nitrate, and trichloroethylene, as well as strontium, technetium, tritium, and uranium, are entrained in groundwater plumes that intersect the river along the 100 Area shoreline. Aluminum, iodine, iron, manganese, nitrate, technetium, and tritium entered the river along the portion of shoreline extending from the old Hanford Townsite to below the 300 Area. Chromium and uranium were discharged to the river along the 300 Area shoreline, in addition to the other contaminants. The contaminant concentrations in spring water are typically similar to, but lower than, those found in near-shore groundwater wells. Chromium in excess of federal ambient water quality criteria for the protection of aquatic life has been detected at the riverbed/groundwater interface along

Figure 2-3. Distribution of Chemical Contaminants in Groundwater.

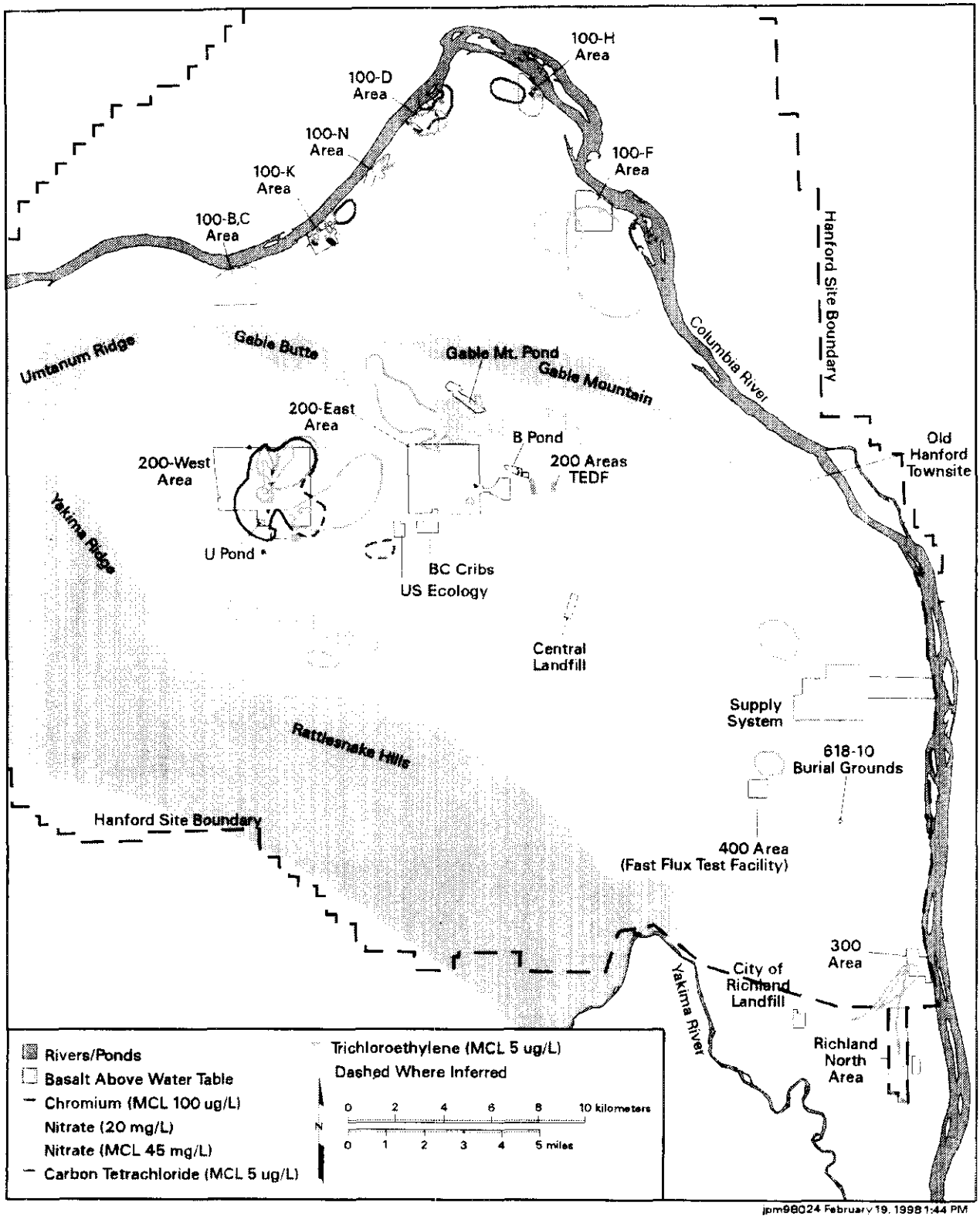
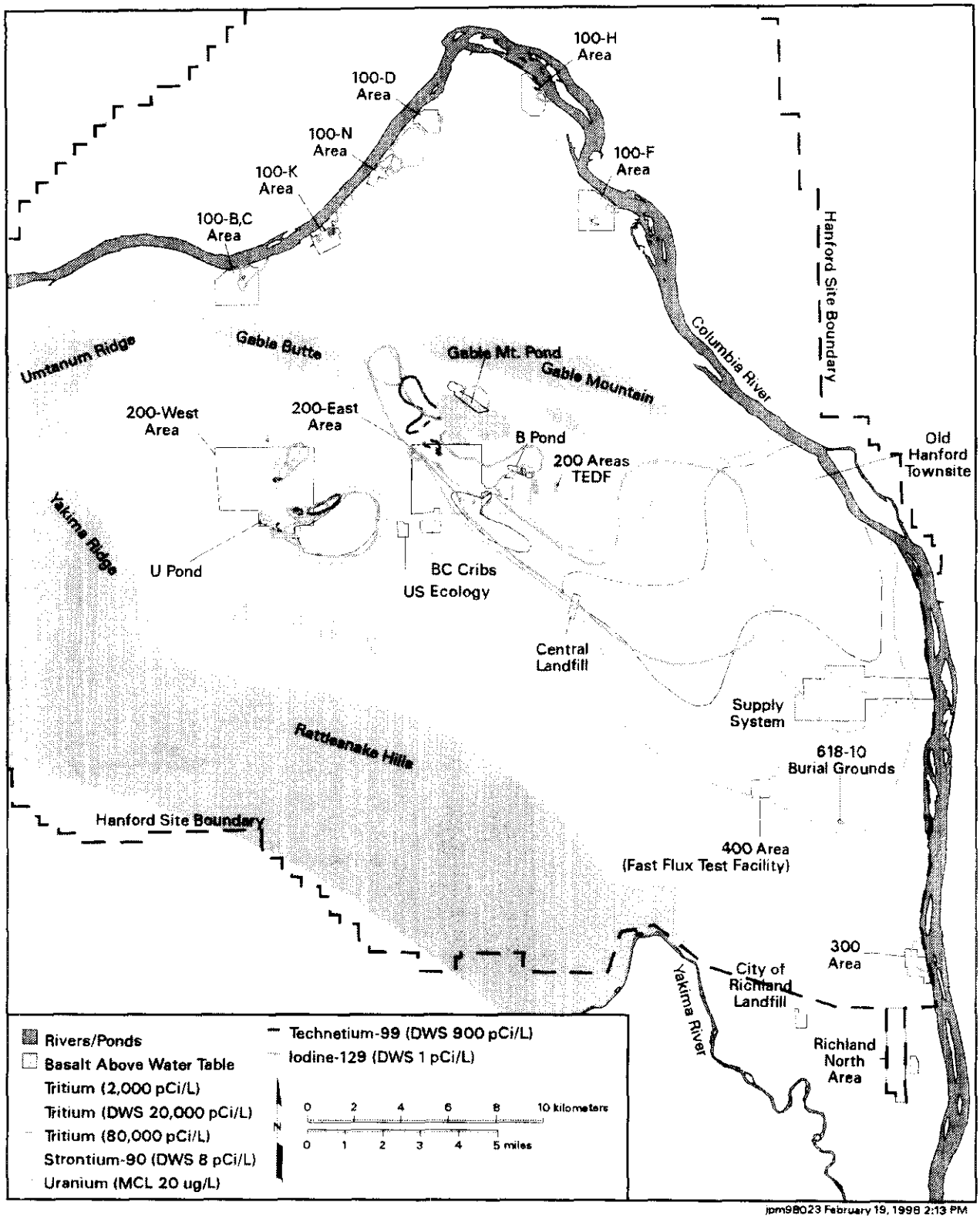


Figure 2-4. Distribution of Radioactive Contaminants in Groundwater.



portions of the 100 Area shoreline. Chromium levels in this pore water are above protective levels for salmon alevin hatched from salmon redds (nests) in the gravel river bottom in the Hanford Reach area of the river.

2.2.5 Ecology

The ecology of the Hanford Site is characterized as a shrub-steppe ecosystem. 15 different soil types have been identified, varying from sand to silt and sandy loam. Shrub-steppe ecosystems are typically dominated by a shrub overstory with a grass understory. The existing plant communities at the Hanford Site are becoming increasingly more important from an ecological perspective. Expanding agricultural and urbanization developments in the Columbia Basin region continue to destroy and fragment the few remaining large tracts of shrub-steppe habitat. The shrub-steppe habitat is considered a priority habitat by Washington State because of its relative scarcity, and because of its requirement as nesting/breeding habitat for several state and federal species of concern. A 1994 survey of Hanford Site plants and animals by the Nature Conservancy of Washington discovered 18 species of insects and 3 plants that are new to science. This report stated that the Hanford Site is now known to support more than 100 populations of 15 rare native plant taxa, making the Hanford Site a botanical "island of diversity" in the shrub-steppe of the lower Columbia Basin.

Several areas, totaling 670 km^2 (260 mi^2) on the Hanford Site, have been designated for research or as wildlife refuges. These include the Fitzner Eberhardt Arid Lands Ecology (ALE) Reserve; the Saddle Mountain National Wildlife Refuge (managed by U.S. Fish and Wildlife Service); and the Wahluke Slope Wildlife Area (managed by the Washington State Department of Wildlife).

2.2.5.1 Vegetation. Of the 590 species of vascular plants recorded for the Hanford Site, approximately 20% are considered non-native. Native shrublands occupy the largest area in terms of acreage, and comprise 7 of the 9 major plant communities at the Hanford Site. Of the shrubland types, sagebrush-dominated communities are the predominant type, with other shrub communities varying with changes in soil and elevation. Common shrubs include native big sagebrush, three-tip sagebrush, antelope bitterbrush, gray rabbitbrush, and spiny hopsage. Common native grasses include bluebunch wheatgrass, Sandberg's bluegrass, needle-and thread grass, Indian ricegrass, bottlebrush squirreltail, and prairie junegrass. Cheatgrass has replaced many native perennial grass species, and is well established in many low-elevation (<244 m [800 ft]) and/or disturbed areas. Trees afford unique terrestrial habitat at the Hanford Site. Currently, approximately 23 species of trees occur on the site. The most commonly occurring species are black locust, Russian olive, cottonwood, mulberry, sycamore, and poplar. Many of these non-native species are aggressive colonizers and have become established along the Columbia River (e.g., mulberry, poplar, Russian olive), serving as a functional component of the riparian zone.

Riparian habitat includes sloughs, backwaters, shorelines, islands, and palustrine areas associated with the Columbia River flood plain. Vegetation that occurs along the river shoreline includes emergent water milfoil, water smartweed, pondweed, sedge, reed canarygrass, and bulbous

bluegrass. Trees include willow, mulberry, and Siberian elm. Other riparian vegetation occurs in association with perennial springs, seeps, artificial ponds, and ditches on the Hanford Site.

Emergent riparian (wetland) habitat occurs infrequently along the Hanford Reach, and has important ecological significance because of the net loss of wetland habitat elsewhere within the region. Emergent species include reed canarygrass, common witchgrass, large barnyard grass, rushes, and sedges.

2.2.5.2 Wildlife. Included in the 290 species of terrestrial vertebrates observed on the Hanford Site are approximately 40 species of mammals, 240 species of birds, 3 species of amphibians, and 9 species of reptiles. Grasshoppers and darkling beetles are among the more conspicuous of the approximately 600 species of insects that have been found on the Hanford Site. Species of potential concern to remediation activities include mule deer, coyote, badger, beaver, black-tailed jackrabbit, Nuttall's Cottontail, the Great Basin pocket mouse, deer mouse, bald eagle, ferruginous hawk, Swainson's hawk, burrowing owl, loggerhead shrike, long-billed curlew, sage sparrow, mallard duck, and Canada goose.

2.2.5.3 Aquatic Ecosystems. The Columbia River is the dominant aquatic ecosystem at the Hanford Site, and supports a large and diverse community of plankton, benthic invertebrates, fish, and other communities. The Columbia River has been dammed both upstream and downstream from the Hanford Site, and the reach flowing through the area is the last free-flowing, but regulated, section of the Columbia River in the United States above Bonneville Dam.

There have been 44 species of fish identified in the Hanford Reach. Of these species, chinook salmon, sockeye salmon, coho salmon, and steelhead trout use the river as a migration route to and from upstream spawning areas and are of the greatest economic importance. Both chinook salmon and steelhead trout also spawn in the Hanford Reach. Other fish of importance to tribal entities and sport fishermen are whitefish, shad, sturgeon, smallmouth bass, crappie, catfish, walleye, and perch. The destruction of other mainstream Columbia spawning grounds by dams has substantially increased the relative importance of the Hanford Reach spawning areas.

2.2.5.4 Threatened and Endangered Species. Threatened and endangered plants and animals identified at the Hanford Site, as listed by the state and federal governments, are shown in Table 2-2. No plants or mammals on the federal list are known to occur on the Hanford Site. There are, however, three species of birds on the federal list of threatened and endangered species, and several species of plants and animals that are under consideration for formal listing by both state and federal governments.

Several state and federal species of concern use the shrub-steppe habitat for nesting/breeding activities. Because of its importance to these species, and its relative scarcity, the state of Washington considers the shrub-steppe a priority habitat.

Table 2-2. Threatened (T) and Endangered (E) Species.

Common Name	Scientific Name	Federal	State
Mammals			
Pygmy rabbit[a]	*Brachylagus idahoensis*		E
Birds			
Aleutian Canada goose[b]	*Branta canadensis leucopareia*	T	E
American white pelican	*Pelecanus erythrorhychos*		E
Bald eagle	*Haliaeetus leucocephalus*	T	T
Ferruginous hawk	*Buteo regalis*		T
Peregrine falcon[b]	*Falco peregrinus*	E	E
Sandhill crane[b]	*Grus canadensis*		E
Plants			
Columbia milk-vetch	*Astragalus columbianus*		T
Columbia yellowcress	*Rorippa columbiae*		E
Dwarf evening primrose	*Oenothera pygmaea*		T
Hoover's desert parsley	*Lomatium tuberosum*		T
Northern wormwood[a]	*Artemisia campestris borealis* var. *wormskioldii*		E
Insects			
Oregon silverspot butterfly[a]	*Speyerra zerone*	T	T
(a) Probably not currently occurring on the site. (b) Incidental occurrence.			

2.3 ENVIRONMENTAL CONDITION OF PROPERTY

Figure 2-5 presents the various levels of surface contamination of the property being remediated at the Hanford Site. Figures 2-6 and 2-7 illustrate the location of principal contaminants that have been identified in the vadose zone (the soil layer above the water table). Some of these contaminants remain fixed in the vadose zone, while other contaminants, of a mobile nature, have migrated to the water table and have contaminated the groundwater above DWS. These figures provide specific information derived from process knowledge, historical data, and characterization/remediation efforts that have been completed to date.

2.4 WASTE MANAGEMENT AND DISPOSAL PRACTICES SUMMARY

The waste management and disposal practices utilized through the nuclear production years resulted in the contamination issues discussed earlier in this section. See Appendix D for details of these management and disposal practices.

During the early years, the effort at the Hanford Site was focused on maintaining production goals. Waste management received less attention. This focus on production, coupled with a lack of attention to and understanding of environmental processes, led to the current levels of Hanford Site contamination. One of the principal drivers during the early production years was the lack of high-level storage space in the tanks. This led to decisions to dispose radioactive wastes to the soil. For example, in the mid 1950s, 4.8 million gallons of high level radioactive supernatant liquid waste and 1.9 million gallons of evaporator sediment from the B and T plants were disposed of in the soil. In the 1940s waste was cascaded through a series of tanks, to allow solids to settle out in the earlier tanks, and only the supernatant liquid reached tanks at the

Figure 2-5. Contaminated Release Sites.

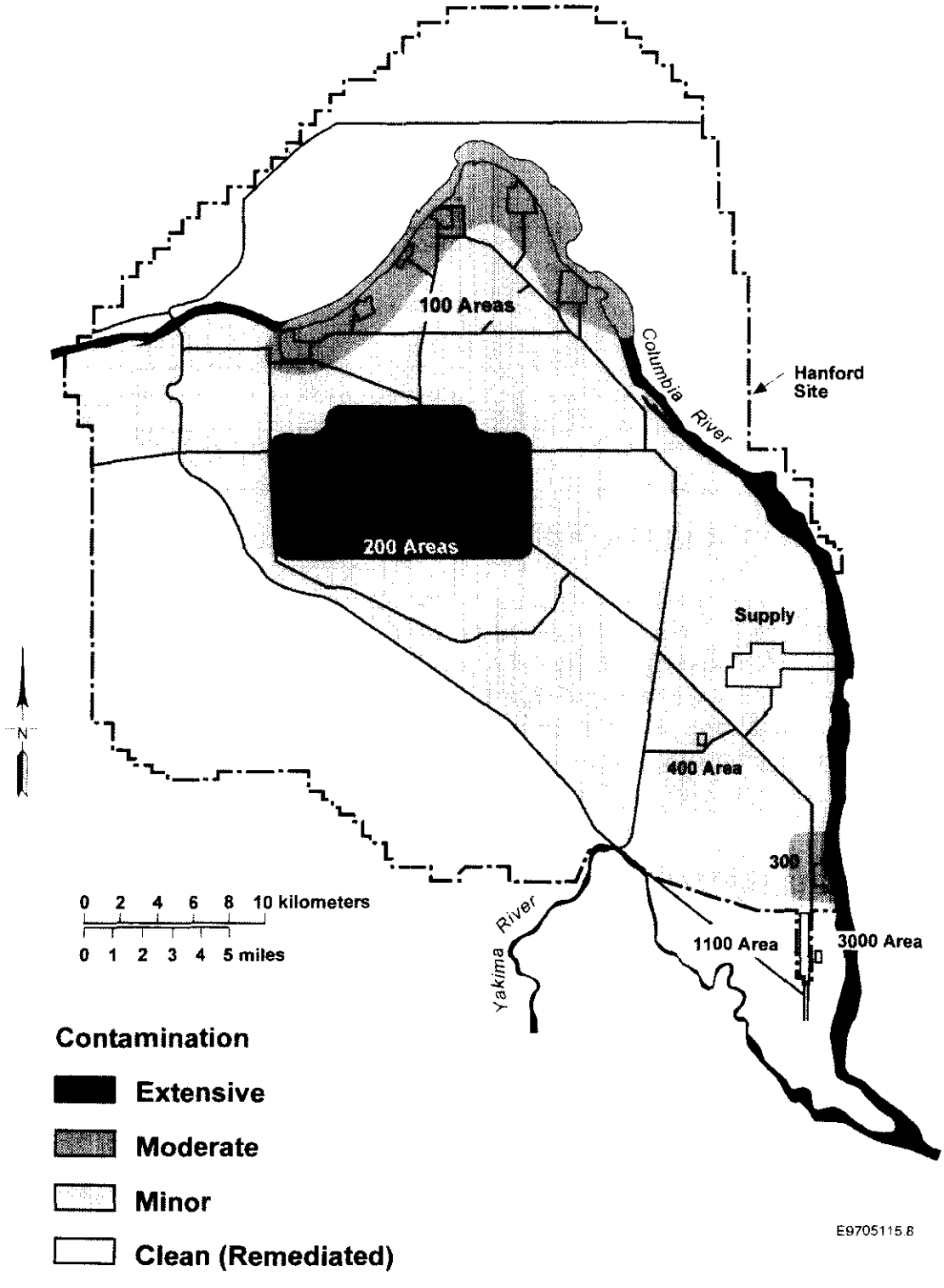


Figure 2-6. 100 Area/300 Area - Principal Contaminants of Concern.

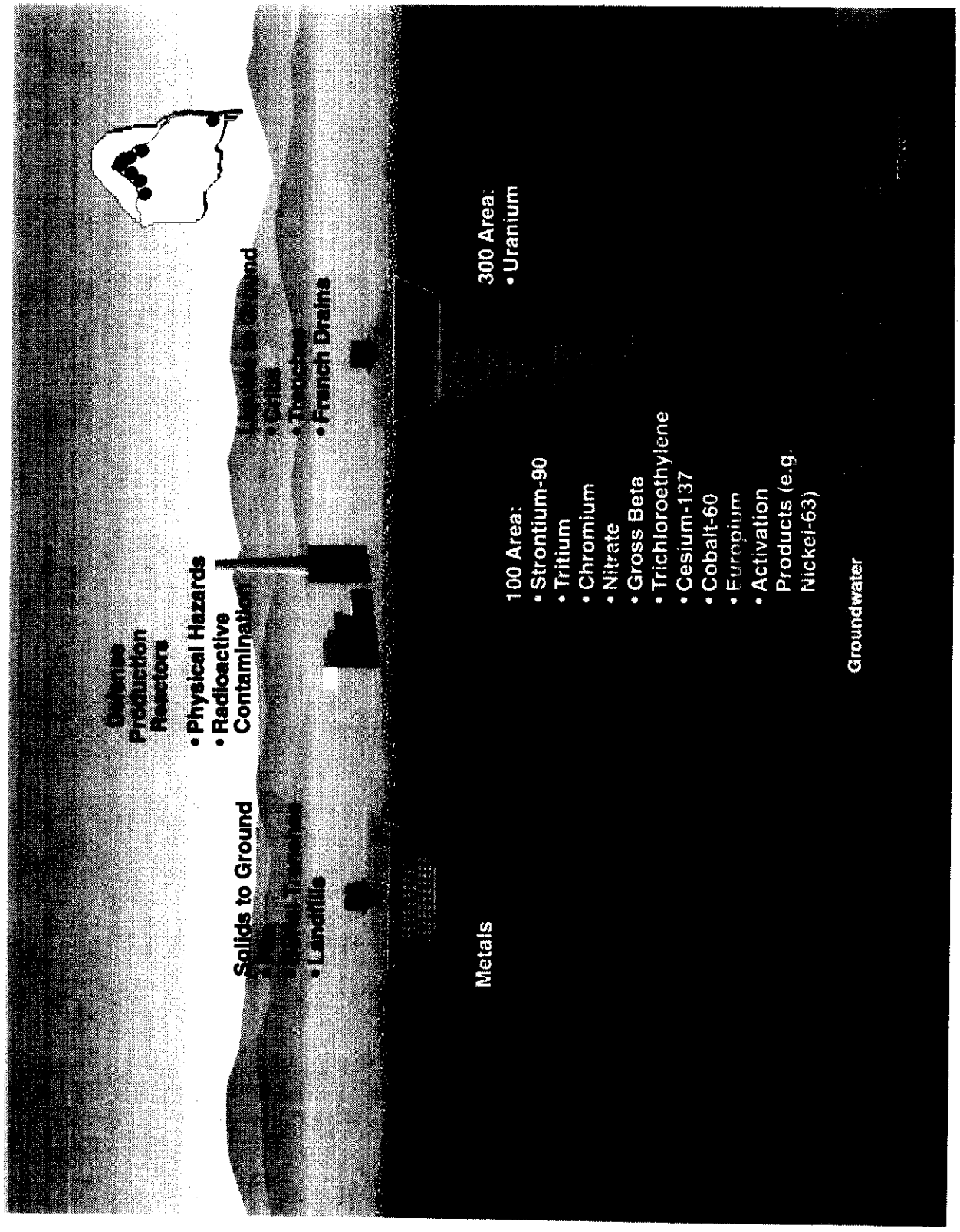
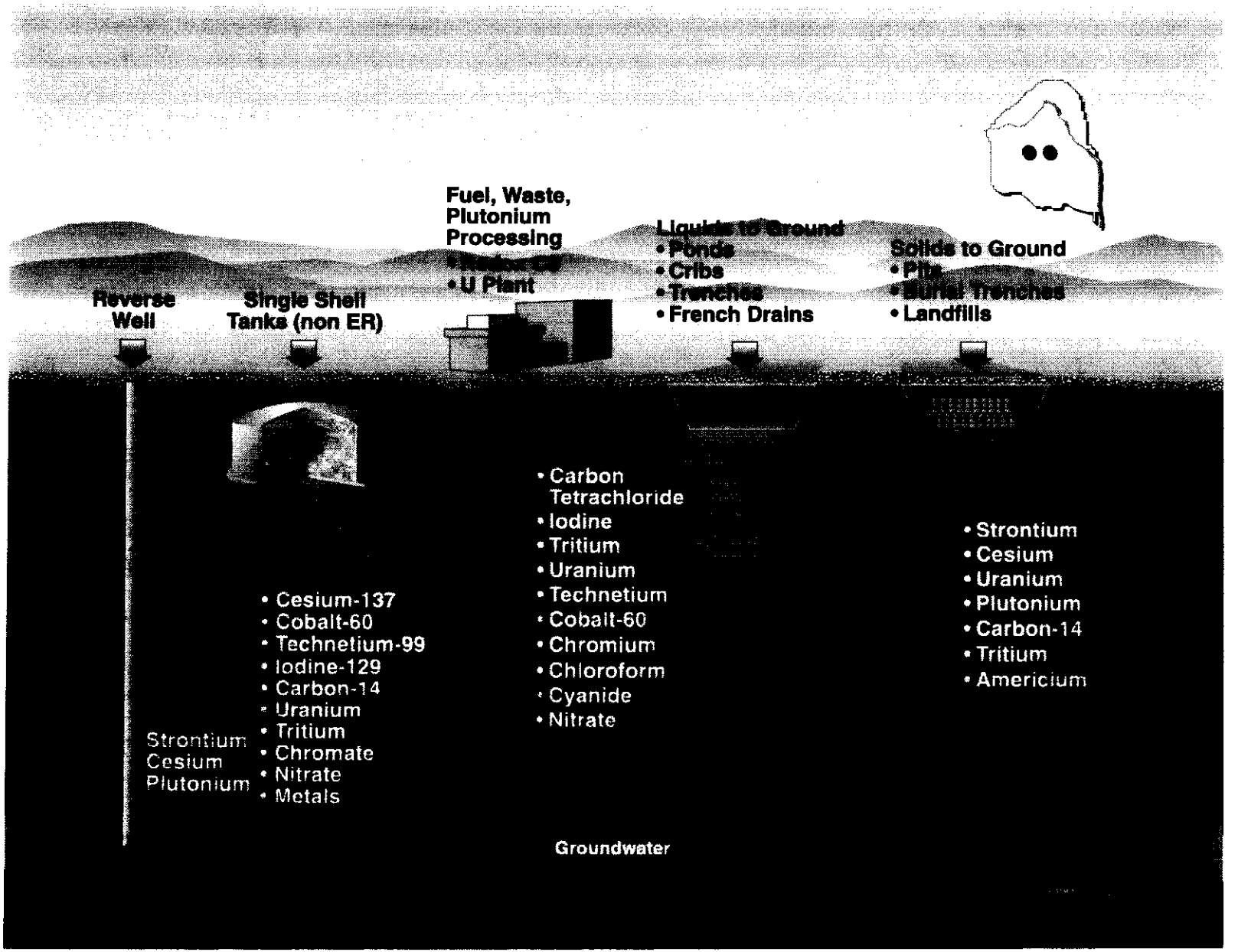


Figure 2-7. 200 Areas - Principal Contaminants of Concern.



end of the cascade. As tank capacity became strained, authority was granted to dispose of a portion of the HLW from the T and B plants to the soil after cascading through three tanks. This process is one of the factors that complicate inventory and source term calculations that are based on operational history.

The Hanford Site has, through an approximately 50-year period of chemical processing, discharged liquids to the ground with the intent of utilizing the soil's physical and geochemical capacity for retaining radioactive and hazardous chemicals. Throughout this period several waste disposal design assumptions concerning the soil's physical and geochemical capacity for retaining these materials have been proven to be overly optimistic.

Originally, highly active radioactive waste was scheduled for storage in the buried underground tanks. The low activity waste was scheduled to be mixed with the high volumes of uncontaminated cooling water and disposed in surface lakes. But the low activity waste volume was recognized as being too voluminous to store in tanks. Concerns about surface evaporation leaving exposed contaminated in soils that would be spread by frequent strong winds required another solution. The proposed solution involved reverse wells (injection wells) that ranged in depth from 150 to 300 feet. However, reverse wells were quickly regarded as a mistake due to plugging and difficulties in tracking the subsurface spread of contaminants. Shallow discharge to the soil by buried cribs and tile fields then became the standard mode of disposal for low activity/high volume liquid wastes. When tank storage space became critical, supernate was allowed to decant off of tank waste and cascade to cribs.

A report by Parker and Piper*, issued in 1949, recognized that "wastewater discharges to the soil in the 200 Areas had created two distinct mounds and a low bridging spur between the 200 East and 200 West Areas". It was postulated that "available data indicate that these mounds will continue to grow if disposal sumps are used as in the past, but this growth can be largely controlled as desired, by changing the sites of the disposal sumps". It was further postulated that such mounds would "act as groundwater dams behind which contamination can be controlled". In reality, the mounds became the driving forces that provided transport in the groundwater for such mobile contaminants as tritium, ruthenium, and nitrate.

Waste disposal to the soil occurred with the assumption that, in general, evapotransporation greatly exceeded rainfall and there was no net recharge from surface infiltration from precipitation. Rainfall and normal snowmelt was not expected to percolate through the soil column to the groundwater. This assumption was the fundamental basis for allowing large quantities of concentrated waste to be discharged to the soil in such engineered structures as cribs and specific retention trenches. Parker and Piper reported that exploration borings from the desert yielded subsurface samples that were "almost dusty dry". Their field observations indicated that "ordinarily, over most of the area at least, rainfall infiltrates to a depth of only a few inches or a few feet below the land surface, and that subsequent evaporation and

* Parker, G. G. and A. M. Piper, 1949, *Geologic and Hydrologic Features of the Richland Area, Washington, Relevant to Disposal of Waste at the Hanford Oeprations of the Atomic Energy Commission*, RHO-R-37-201, Rockwell Hanford Operations, Richland, Washington.

transporation dissipate that infiltrate". However, they also pointed out an inference "that infrequently – owing to rain of extraordinary intensity and duration, or to melting of an abnormal snowpack – some water infiltrates naturally below this relatively thin zone of intermittent wetting and desiccation by climatic processes". The authors also postulated that, if liquid wastes were continuous, exceeding the soil's specific retention capability, such excess would drain to the aquifer. This concern was countered by the assumption that, although wastewater might reach the aquifer, "such may not be true of dissolved or suspended constituents in those wastes, because such constituents may be extracted, transiently or permanently, through physical-chemical reaction with particles of the earth materials penetrated".

If vegetation is removed there is the potential for a net positive recharge. Surface manipulation practices such as gravel covers and herbicidal control of vegetation are commonly used to protect workers and limit the spread of surface contamination. These practices may provide conditions where surface infiltration of precipitation and snowmelt can percolate through contaminated soil to the groundwater. Gravel over tank farms, coupled with short circuiting of much of the soil depth by unsealed boreholes, are thought to be a major contributors to the movement of tank waste toward, and into, the groundwater. The extremely hostile chemical and physical properties of fluids that leaked from single-shell tanks and associated transfer structures have been postulated to alter (or overwhelm) the soil's capacity to hold up radionuclide transport in the vadose zone under the tanks, thus providing an increased likelihood of impacting the groundwater.

There is an extremely high stakeholder value placed on protection of the Columbia River. Offsite impacts historically have been estimated for impacts to the downstream users of the Columbia River. There is a strong desire to understand the effects of the upwelling groundwater from the Hanford Site into the gravels of the Columbia River, and to understand the effects of springs and seeps that are fed by contaminated groundwater.

3.0 WHERE WE HAVE FOCUSED

In 1986 the primary Hanford Site mission began changing from plutonium production to environmental restoration and remediation. The *Tri-Party Agreement*, which was first signed in 1989, forms the framework for working with Hanford Site regulators, stakeholders, Tribal Nations, and trustees in defining the scope and priorities for accomplishing the site mission. Elements of the *Tri-Party Agreement*, the Hanford Site work scope prioritization approach, and Integration Project management strategies for key work activities are discussed in this section.

3.1 TRI-PARTY AGREEMENT

The *Tri-Party Agreement* is a legally enforceable agreement signed by the DOE, Washington State Department of Ecology (Ecology), and the U.S. Environmental Protection Agency (EPA) for achieving environmental compliance at the Hanford Site. The agreement accomplishes the following:

- It defines CERCLA cleanup provisions for past contamination.
- It defines RCRA waste treatment, storage, and disposal (TSD) requirements, and corrective actions for waste management.
- It establishes the responsibilities for each agency.
- It provides a basis for budgeting.
- It establishes legally enforceable milestones for achieving cleanup and regulatory compliance.

The *Tri-Party Agreement* provides for the site-wide integration of RCRA and CERCLA requirements into Hanford Site remediation activities, and embodies the priorities of the DOE, Ecology, EPA, stakeholders, and Tribal Nations. The *Tri-Party Agreement* was modified in 1994, with new milestones added to reflect major changes in plans for tank waste remediation. The 1994 modifications also resulted in a fundamental change in the approach taken to Hanford Site cleanup, which emphasized remediation of unsafe sites along the Columbia River.

A listing of federal, state, and local laws and regulations that are relevant to the Integration Project is provided in Appendix E. Within Appendix E, Table E-1 presents applicable federal laws and regulations, along with DOE orders. Table E-2 presents state laws and regulations.

3.2 THE HANFORD SITE APPROACH TO ASSIGNING WORK PRIORITIES

The Integration Project must identify and apply criteria for determining work scope priorities, in order to achieve the project's objectives. The criteria established by core projects are more narrowly focused, and must also be incorporated. These criteria may conflict because of differing scopes, regulatory requirements, and scales of assessment. The Integration Project must ensure that core project priorities are maintained while the Integration Project adheres to its mission of addressing larger-scale issues. One of the primary criteria to be incorporated is the use of the SAC to identify priority work based on reducing uncertainty.

The Integration Project will use the process shown in Figure 3-1 to determine work priorities. The evaluation will define (1) what work is needed; (2) how it is to be done; (3) when it will be accomplished; (4) where the work will be applied; and (5) the purpose of the work.

Decision Criteria Formulation is the identification of criteria that will be applied to identify work scope priorities for the Integration Project. The Integration Project will ensure compliance with the Hanford Site's general criteria for establishing the priorities for any project. These criteria include the following:

Minimum Safe Operations: Those surveillance, maintenance, and support activities required to control existing material, waste, and facilities in a safe, stable condition. No remediation, stabilization or disposal will occur unless it is safety related. Activities that simply comply with regulatory requirements and agreements, but which are not necessary for safe operations, will not be included.

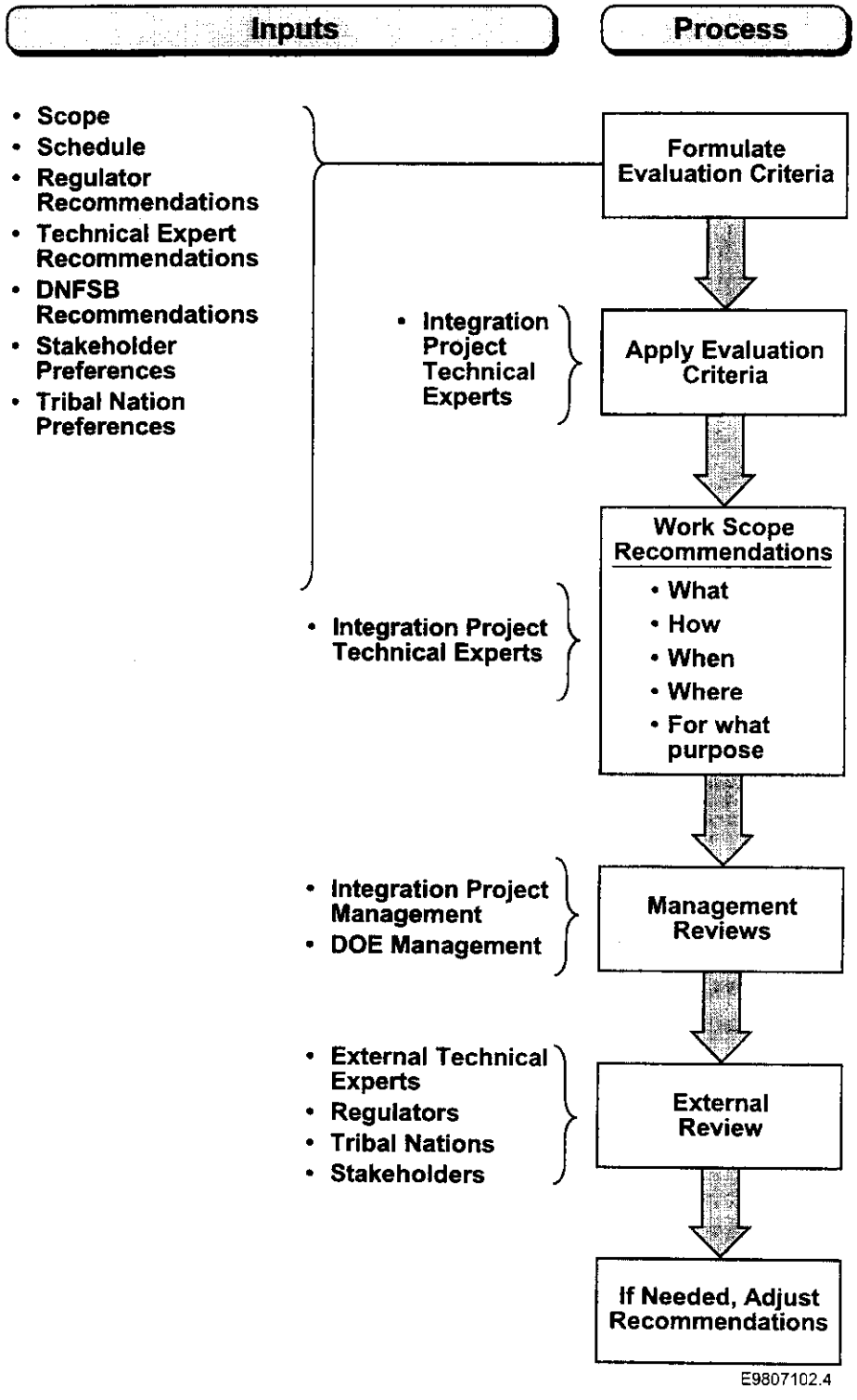
Essential Services/Activities: Those necessary services and activities required to support planned/budgeted activities (e.g., non-*Tri-Party Agreement* regulatory requirements, waste management services, infrastructure, site-wide planning and integration, hazardous materials management, emergency response, etc.).

Mitigate Urgent Risks: Those operations that are intended, designed, and carried out with the specific purpose of reducing the levels of public, worker, and environmental risk. The mitigation of urgent risks includes specific actions that reduce risks from a very high consequence (or likelihood of occurrence) to a medium or low likelihood of occurrence.

Compliance: Those activities necessary to maintain compliance with laws, orders, federal facility agreements (*Tri-Party Agreement*), consent orders, and Defense Nuclear Facility Safety Board (DNSFB) recommendations.

Once the Integration Project priorities and work scope have been defined, they will be integrated into the overall Hanford Site IPL. The IPL process uses overall Hanford Site priorities to establish a list of the scope that can be accomplished within the funding constraints for a particular fiscal year. The process includes reviews with regulators, stakeholders, and Tribal Nations. A detailed cost and schedule is then developed for the scope, and it becomes part of the Hanford Site *Baseline* through a formal change control process.

Figure 3-1. Work Priority Determination.



3.3 MANAGEMENT STRATEGIES

3.3.1 Vadose Zone

Visible progress towards remediation of contamination in the vadose zone was slow immediately after the 1989 signing of the *Tri-Party Agreement*. Initial plans called for intensive and thorough investigations prior to decision-making. Plans for such waste characterization investigations were burdened by heavily prescriptive and protracted review and approval processes, which were performed in a series of stages requiring formal review, comment, and comment resolution stages, which were then followed by public comment periods. Investigations were generally scheduled in a "worst first" priority, and were reflected in *Tri-Party Agreement* schedule milestones. Planned investigations to characterize the nature and extent of contaminants in soil sites were scheduled for up to eight years.

In 1994, *Tri-Party Agreement* negotiations resulted in several significant fundamental changes to the approach taken in Hanford Site cleanup milestones. Two key decisions that were made were as follows:

- A shift in emphasis from investigations to interim cleanup measures.
- Deferral of investigations in the 200 Area for four years, with resources applied to interim action cleanup in the 100 and 300 Areas (except for four groundwater interim actions located in the 200 Areas).

Consistent with the 1994 *Tri-Party Agreement* negotiations, the 200 Areas are in the early stages of assessment. Prior to the 1994 agreement, the DOE characterized cribs at the 200-BP-01 Operable Unit (OU) and initiated a treatability test for a permanent barrier. During FY96, the ER Project (in conjunction with Ecology and EPA) developed a strategic plan for characterization and remediation of source term waste sites where liquids and solid waste have been discharged to or buried in the ground. The plan was needed to improve streamlining of the assessment and remediation process, making it more cost-effective, more technically efficient, and enabling the DOE to capture the lessons learned from the 100 and 300 Areas portions of the cleanup.

To balance budget allocations, stakeholder values, and the *Tri-Party Agreement* milestones, current long-range plans show little activity in the near-term for the ER Project in the 200 Areas (due to the priority of emphasizing cleanup in the 100 and 300 Areas). However, current *Tri-Party Agreement* change proposals reflect a commitment to complete all RCRA closure/post-closure plans associated with the 200 Areas ER source operable unit by February 28, 2004. All CERCLA characterization is to be completed by December 31, 2008. All remediation is to be completed by December 31, 2028.

3.3.2 Groundwater/Columbia River

Groundwater protection actions at the Hanford Site have been based on a) compliance with requirements for water quality protection; and b) responses to prioritization by stakeholders,

Where We Have Focused

Tribal Nations, and regulators to focus on contaminants closest to the Columbia River. This approach has resulted in a) implementation of an extensive groundwater monitoring network in the 200 Areas, in compliance with the *Tri-Party Agreement* and RCRA/*State Dangerous Waste Regulations*; and b) focused investigations and interim remedial activities to mitigate groundwater impacts nearest the river in the 100 and 300 Areas (and selective groundwater remediation efforts in the 200 Areas). As part of the interim planning, each major groundwater plume was studied and assessed as to the need for immediate action. The result of this work was the construction of five pump-and-treat systems (DOE-RL, 1995)*. Vadose zone and groundwater investigations, and remedial activities, have progressed in the 100 and 300 Areas. Initial efforts are underway to initiate similar investigations and remedial activities in the 200 Area.

A site-wide Groundwater Management Strategy has been adopted to provide an integrated approach to management of groundwater resources. The strategy has, as its mission, the protection of the Columbia River, protection of human health, worker and environmental safety, treatment of groundwater contamination from past practices, and limiting the migration of contaminants from the Central Plateau (200 Areas). The strategy was adopted following consultation with Ecology and EPA, and with input from stakeholders and Tribal Nations. Implementation of the strategy includes continued surveillance of groundwater quality through the site monitoring network of approximately 800 wells, interim remedial actions at high priority operable units (to address contaminant plumes that pose risks to the Columbia River), and interim remedial actions for sites in the 200 Areas that pose risks to migration off the Central Plateau.

Groundwater remediation activities have focused on accelerated groundwater remediation activities in the 100-K Area to address hexavalent chromium in groundwater that discharges into the Columbia River. A groundwater-extraction-well network was designed to intercept a chromium plume. The extracted groundwater is passed through ion-exchange columns, where the chromium is removed; then the treated effluent is returned to the aquifer. Similar pump and treat systems were implemented in the 100-D/DR and 100-H Areas to address chromium discharges to the Columbia River. In the 200 Area two pump and treat systems have been established. These include a system for operable unit 200 UP-1 that was constructed to contain the highest portion of a uranium and technetium-99 plume and a system for operable unit 200-ZP-1 to contain the highest concentrations of a carbon tetrachloride plume. Additionally, in the 200 Areas, treatability studies were completed for two additional pump and treat systems. However, the studies determined that the systems were not feasible. EPA and Ecology concurred that the systems should not be installed. Contaminant plumes that are currently being addressed by accelerated remedial pump-and-treat systems are illustrated in Figure 3-2. The two plumes that did not require pump-and-treat actions are shown in Figure 3-3.

* DOE-RL, 1995, *Hanford Sitewide Groundwater Remediation Strategy*, DOE-RL-94-95, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland Washington.

Figure 3-2. Hanford Site Groundwater Pump and Treat Contaminant Plumes.

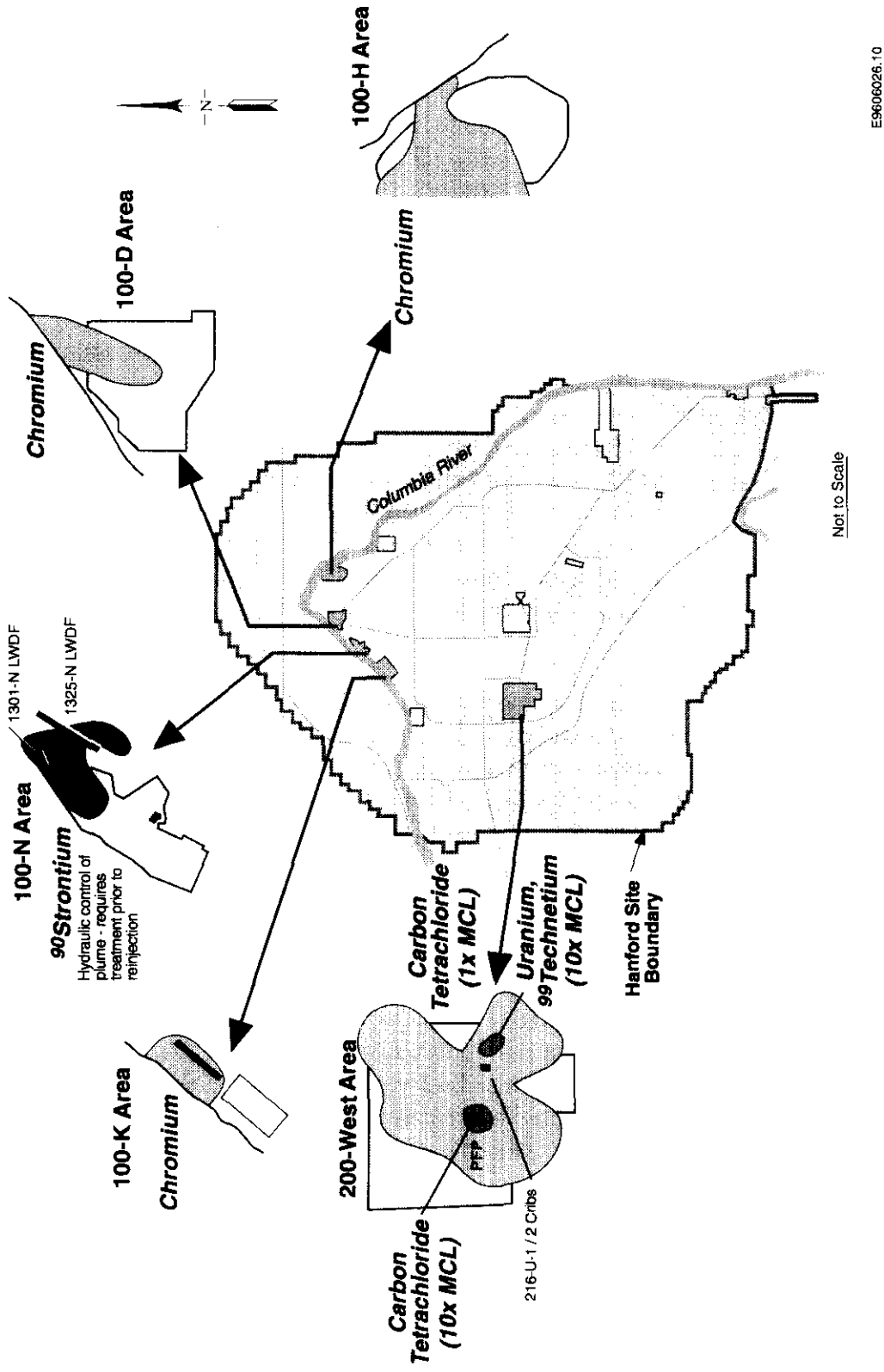
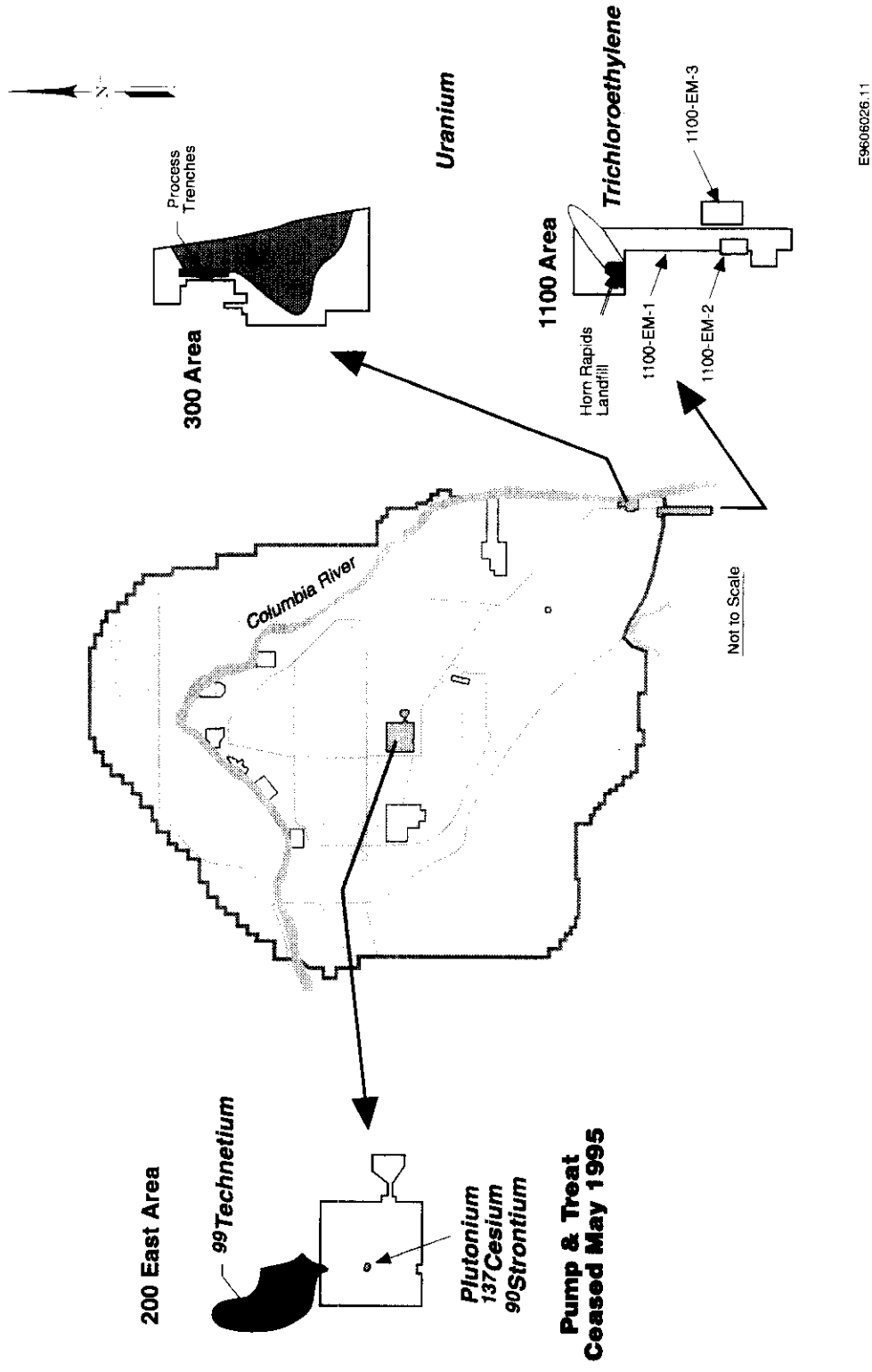


Figure 3-3. Hanford Site Groundwater Decisions Not Requiring Pump and Treat.



3.3.3 Tank Farms

The TWRS project mission is to store, treat, immobilize, and dispose of current and future Hanford Site tank waste in an environmentally sound, safe, and cost-effective manner. To accomplish this mission TWRS has focused on waste tank safety, waste characterization, waste storage, waste retrieval, waste immobilization and waste disposal.

Safety: The safe management of tank waste includes addressing a number of waste tank safety concerns that were identified in the late 1980s, resulting in Public Law 101-50, Section 313, *Safety Measures for Waste Tanks at the Hanford Nuclear Reservation* (also known as the Wyden Amendment). This Public Law placed special restrictions on 54 tanks that had serious potential for the release of highly radioactive material, in the event of uncontrolled increases in temperature or pressure. Without corrective action, these safety issues posed an unacceptable risk for continued operations. The four highest priority safety concerns included flammable gas, ferrocyanide, organics, and high-heat waste issues. The first three issues centered on the potential for in-tank reactions that could result in explosive or flammable conditions. The final issue focused on the potential for large leak loss from a tank to which periodic additions of water were required to cool the wastes. To date, the number of tanks with special safety concerns has been reduced from the original 54 to 38. There are also other lower priority safety concerns being addressed, such as tank integrity.

Waste Characterization: The waste characterization activity gathers and provides information on the quantity and characteristics (radiological, chemical, and physical) of the tank waste. Information is obtained from process records and a number of sampling and analytical methods. To date, 131 of the 177 tanks have been sampled, and characterization reports on 112 tanks have been approved by the regulators in accordance with *Tri-Party Agreement* requirements.

Waste Storage: The waste storage function includes a number of tank farm operations. Those of most importance are waste surveillance and maintenance (S&M), DST space management, interim stabilization, and tank farm upgrades.

S&M is necessary to ensure that the waste is safely stored until it can be retrieved for disposal. DST space management is essential since the 28 DSTs are the only tanks used for 1) receiving new waste; and 2) waste pumped from the SSTs. The DSTs also will serve as the blending and feed tanks to supply waste to the privatized treatment and immobilization facilities. Interim stabilization is an activity to remove all the pumpable liquid from the SSTs and transfer it to the DSTs. This reduces the amount of waste available to leak (should a leak develop). Finally, tank farm upgrades are necessary to ensure safe in-tank storage for another 20 to 30 years, while clean-up actions are taking place.

Waste Retrieval, Immobilization, and Disposal: The plan for disposing the tank waste is to 1) retrieve the waste from all of the tanks; 2) separate it into low-activity waste (LAW) and HLW fractions; 3) immobilize and dispose the LAW fraction containing the bulk of the chemicals, and a small amount of the radionuclides in on-site near-surface vaults; and 4) immobilize and store the HLW fraction onsite until it can be shipped to an offsite geologic repository for disposal. The overall disposal effort is divided into two phases. Based on the

current plan, Phase I will process approximately 6 to 13 percent of the waste, lasting 10 years (2002 to 2012). Phase II will increase the processing capacity, and complete immobilization of the remaining waste (2011 to 2028). The waste disposal function includes waste retrieval, waste processing (separations, treatment, and immobilization), and storage and disposal.

3.3.4 Spent Nuclear Fuels

The Spent Nuclear Fuels Project addresses the immediate need to move metallic spent nuclear fuel from the present degraded storage conditions in the 105-K East and 105-K West Basins to safe interim storage in the 200 Area. Major objectives include removing and repackaging K Basins spent nuclear fuel into multicanister overpacks suitable for downstream fuel handling and interim storage; drying the fuel to remove free water (to enable safe transport to and staging in the 200 Area); conditioning fuel to remove bound water for safe stable interim storage; removing sludge and debris collected in the K-Basins for disposition as low-level liquid waste or solid waste, in accordance with disposition plans being developed; treating water contained in the basins to maintain water quality; maintaining safe conditions within the K-Basins; reducing tritium levels; and consolidating non-defense production reactor spent nuclear fuel in the 200 Area, pending final disposition.

3.3.5 Other Hanford Site Activities

The Hanford Site contains many surplus facilities remaining from past plutonium production activities. These facilities are now aged and deteriorating. Because the facilities no longer have a production mission, they must be either maintained (to preserve their integrity) or removed to a) preclude the release of potentially hazardous substances to the accessible environment; or b) prevent unacceptable industrial safety risks. S&M activities are required for waste sites and facilities located throughout the site. The purpose of the S&M function for contaminated surplus facilities awaiting decommissioning is as follows:

- Ensure adequate containment of contamination.
- Provide physical safety and security controls.
- Maintain the facilities in a manner that will minimize potential hazards to the public and workers.
- Maintain systems/equipment that will be essential for decontamination and decommissioning (D&D) activities in a shutdown but standby/operational mode.
- Provide a mechanism for the identification and compliance with applicable environmental, safety, health, and safeguards/security requirements.

In addition, the S&M responsibilities include the transition activities involved with the ER Project's acceptance of new facilities from other DOE programs through deactivation processes. The S&M project is responsible for Radiation Area Remedial Action (RARA) of approximately

1,000 inactive waste sites, including 10 RCRA TSD units. The inactive waste sites include unplanned release sites, cribs, trenches, ponds, and burial grounds. The waste sites are located in the 100, 200, 300, and 600 Areas.

4.0 THE NEED FOR INTEGRATION

4.1 BACKGROUND

RL has established and implemented individual projects that are actively executing the Hanford Site cleanup mission. These projects, which include facility deactivation, building D&D, waste site remediation, groundwater remediation, tank waste retrieval and processing, and solid waste management, have resulted in the accomplishment of many important milestones that support Hanford Site strategic goals.

RL designed these projects to complement each other's individual missions. As a result, these projects rely heavily on one another for support, and in many instances "hand off" to one another as one phase of work completes and another begins. However, with a cleanup mission as complex as that at the Hanford Site, the potential exists for fundamental gaps, overlaps, and inefficiencies to occur among multiple projects. The Hanford Site's 200 Area, which includes different phases of *all* the individual projects, is the primary area of concern relative to the integration of multiple projects.

Current remediation plans for the Hanford Site will leave significant quantities of radioactive and hazardous waste in the 200 Area at the completion of the current mission. Extensive vadose zone contamination beneath the tank farms, and its recently confirmed impact on groundwater, have raised the awareness of the potential for degradation of groundwater resources by these waste sources. The baseline retrieval technology for tank waste (sluicing) could exacerbate these concerns. It could also increase the potential that contaminants may, at some point in the future, reach the Columbia River and result in unacceptable impacts to human health, welfare, and the environment.

Tribal Nations, stakeholders, and federal and state regulators have voiced their concerns over the current and potential threats these contaminants pose to the Hanford Site's groundwater and the Columbia River. The diverse groups that have expressed their values include the Tribal Nations, advisory boards, public interest groups, and the regulatory community. Based on interviews, feedback, and overall comments and recommendations from these groups, the following key drivers have been identified as essential to RL's establishment of this integration effort:

- The way that technical work has been organized and managed has resulted in key knowledge gaps and redundancies in the use of technical resources.
- Individual project decisions and end points may not lead to a common, defensible Hanford Site endstate.
- There is a need for trust and credibility.

The Need for Integration

The following provides a summary of the information that has either been solicited by or provided to the project by the Tribal Nations, advisory boards, public interest groups, and the regulatory community.

***Recent Interviews with Stakeholders*:** As part of the early planning associated with the Integration Project, a number of groups and individuals that have shown a strong interest in the project were interviewed. Values and expectations expressed in these interviews included the following:

- Protect the Columbia River from further contamination, to the maximum extent possible.
- Integrate activities to ensure a holistic approach to Hanford Site cleanup.
- Address all sources of contamination.
- Minimize further contamination of the GW/VZ.
- Develop adequate models for vadose zone contamination and contaminant transport mechanisms.
- Conduct independent expert and independent technical peer reviews.

***Regulatory Agencies*:** Values expressed by regulatory agencies are documented in records of decision (RODs) associated with remedial actions, and in permits for TSD facilities. Remedial actions must be designed such that their implementation does not result in a new threat to human health and the environment. An underlying value common to all regulatory agencies is that cleanup decisions, remedial actions, and operating facilities must comply with federal/state law and implementing regulations. For example, CERCLA requires that groundwater remedial actions currently in progress at several reactor areas along the Columbia River protect human health and the environment. More specific values are expressed in the objectives for proposed remedial actions. Likewise, under RCRA regulations to protect the environment, the monitoring associated with a permitted facility must be capable of detecting new contamination or assessing known contamination.

RODs also contain a "Responsiveness Summary" appendix. This summary contains public comment and agency responses to issues raised during the public review and comment period for proposed actions. The value of protecting the Columbia River from degradation as the result of contaminants from the Hanford Site is prominent in these comments.

***Advisory Boards*:** The Hanford Advisory Board (HAB) is composed of representatives from state agencies, Tribal Nations, public interest groups, and employees at the Hanford Site. Specific values and principles expressed by the HAB include the following:

- Protect the Columbia River ecosystem.

- Deal realistically and forcefully with groundwater contamination.

- Use a systems design approach that keeps endpoints in mind as interim decisions are made.

- Recognize the importance of cultural and ecological diversity, and recreational opportunities; enhance these opportunities as a result of cleanup and waste management decisions.

- Consider these concerns while promoting the most effective and efficient actions that will protect the environment, public health, and safety -- now, and for future generations.

***Tribal Nations*:** Several Tribal Nations and the Wanapum people have provided RL with comments on Hanford Site activities. The Tribal Nations include the Confederated Tribes and Bands of the Yakama Indian Nation (YIN), the Confederated Tribes of the Umatilla Indian Reservation (CTUIR), and the Nez Perce Tribe (NPT). A value common to all the Tribal Nations is the protection of the Columbia River's natural resources, which are used by tribal members for sustenance and in their traditional culture. Of special value is protection of the salmon fishery. For those tribes that used the Pasco Basin in earlier times, protection of cultural resources along the riverbanks is highly important. An underlying value for each Tribal Nation is the opportunity to participate in the selection of remediation alternatives and the design stages of environmental restoration projects.

Recent correspondence from the YIN emphasizes that new programs, like the Integration Project, should be developed by using the experience gained through such previous programs as the *Columbia River Comprehensive Impact Assessment* (CRCIA). A central value of the CRCIA is that assessment of impacts on the Columbia River that are related to Hanford Site contamination will be conducted in a holistic manner. The CRCIA assessment plan emphasized a broad, overarching analysis that spans Hanford Site contaminant sources, contaminant pathways to the river, sensitive receptors, and receptor impacts. The analysis must consider (1) a time scale that extends well into the future; and (2) impacts to natural and cultural resources.

The CTUIR provided a comprehensive statement of their values in a 1993 letter that commented on the initial plans for a comprehensive river impact evaluation:

"From salmon and sturgeon to tule reeds and eagle feathers, the ecosystem provides the very fabric of tribal culture. Any impact evaluation that considers the Columbia River environment should assist the CTUIR in understanding and evaluating the magnitude and future consequences of adverse impacts on natural resources."

The statement adds that *"cleanup of contamination is conducted in a manner that optimizes sustained net flow of tribal benefit through the conservation, management, and utilization of fish, wildlife, plant, and cultural resources, while protecting the integrity, sustainability, and diversity of the natural ecosystem."*

Correspondence from the NPT reinforces values expressed by other tribes concerning protection of Columbia River resources from degradation caused by Hanford Site contaminants. The NPT emphasizes that *"Tribal consultation, on future Hanford Site land use (which) directly impacts our most important resource, the Columbia River, is of utmost concern to the Nez Perce People."*

Public Interest Groups: Several public interest groups actively provide input to Hanford Site activities. A common value expressed by these groups involves the responsible use of public funds to address contamination and waste management issues at the Hanford Site. Some public interest groups actively supported scientific investigations to better define contamination characteristics along the Hanford Site shoreline, in order to provide a technical basis for cleanup decisions. An important value to many public interest groups is that the public should be an active participant in Hanford Site decisions, particularly the public living along the river downstream of the Hanford Site.

At this time, the *Tri-Party Agreement* agencies, as well as the State of Oregon, the Tribal Nations, and Hanford Site stakeholders, must re-examine strategic approaches to management of the investigation and cleanup of the 200 Area. Vadose zone issues are not currently being addressed to the satisfaction of Pacific Northwest stakeholders. The existing plans and approaches for the investigation of soil contaminants from tank leaks, and 120,000,000 gallons of direct discharges to soil and groundwater from the tanks, are not aligned and will not provide sufficient data for responsible decision-making in a timely manner and at a reasonable cost.

Additional common needs are as follows:

- Prior to the initiation of retrieval from single-shell tanks, leak loss limits must be established on cumulative risk terms. Characterization of previous tank leaks, specific retention trenches, cascading cribs, and other soil disposal of significant hazardous and radionuclide inventories is required to assess cumulative impacts. This holds for existing contamination, and for the end-state where tank retrieval losses and tank heel inventory will be added to the existing contaminant loading. An understanding of vadose zone transport parameters and waste interactions with the soil is also required. Mechanisms resulting in chemically enhanced transport and the effects of geologic features (such as clastic dikes) are no less important.

- Pumping the remaining approximately 5,000,000 gallons of liquids from the single-shell tanks is necessary to stop additional contaminants from increasing the contaminant loading of the soil column.

- Near-term actions (interim actions, expedited response actions [ERAs], or corrective actions) for the control of infiltration on the surface of tank farms, and other highly contaminated sites, is necessary to reduce the mobility of contaminants.

- Immediate and visible progress of waste site characterization, and interim actions to control waste leaks and transport, are needed to demonstrate the effectiveness of the *Tri-Party Agreement*.

- Such activities must also be carried out with ample opportunities for early and meaningful stakeholder participation.

To meet these common needs and to address the characterization of the 200 Area waste sites (including soils contaminated by tank leaks), an integrated approach is necessary. The approach must be efficient and effective, technically sound, and compliant with applicable regulations. Near-term visible progress and proactive stakeholder participation are required for public acceptance.

Lessons learned from the past nine years of characterization and cleanup must be applied and improved. Towards this end, detailed characterization plans should not be fully developed for waste sites where insufficient information or conflicting information makes the formulation of a conceptual model questionable. A preliminary conceptual model should first be developed from existing site information, and from similar sites. Scoping investigations should be used to verify the model and to provide the minimum information required for substantiating a working conceptual model. The conceptual model will be revised, based on the results of the scoping investigations, and only then should a detailed characterization plan be developed and implemented. Without this procedure, detailed plans that are developed will have to be redone after the first characterization borehole is drilled. At the completion of scoping investigations, interim remedial measures (IRMs) should also be evaluated.

Several activities need to be brought together and managed as a coordinated effort consistent with the *Tri-Party Agreement*, including the following:

- TWRS vadose zone characterization plans
- The Environmental Restoration *200 Area Strategy*
- RCRA groundwater assessments
- Groundwater Monitoring
- Groundwater Modeling
- Groundwater Remediation
- The GW/VZ/Columbia River Project
- Participation of the national laboratories
- Expert Panels
- Regulator, stakeholder, and Tribal Nations participation.

4.2 EXTERNAL OVERSIGHT ASSOCIATED WITH TANK FARMS

Much of the external oversight of the Hanford Site during the past 10 years has involved issues associated with tank farms. During the early planning stages for the Integration Project, a review of documents and correspondence was made to summarize major issues and recommendations concerning contamination in the vadose zone and groundwater beneath the tank farms, as viewed by outside organizations. The review included comments from the following organizations and stakeholders:

- National Academy of Sciences (NAS)
- General Accounting Office
- Expert Panels (chartered by DOE, Congress, etc.)

- HAB
- State and local regulatory agencies
- Tribal Nations (YIN, CTUIR, and NPT)
- Special Interest Groups (Hanford Environmental Action League [HEAL], Columbia River United [CRU], etc.).

Although numerous issues and recommendations were discovered that relate to the tank farms in general, a relatively small subset is directed at the vadose zone and groundwater. The following is a synopsis of these recurring issues:

- Significant uncertainties exist regarding the composition, concentration, and distribution of tank leakage in the soil column beneath the tank farms, and this limits the credibility of tank remediation decisions and environmental risk assessments.

- Organizational complexities and vested interests are barriers to solving difficult engineering and scientific problems associated with the tank farms. However, solving the engineering and scientific problems is not an insurmountable problem.

- The scope, schedule, and budget constraints imposed by the *Tri-Party Agreement* are frequently viewed as unrealistic, with an inadequate technical basis. Rigid adherence to these constraints is a hindrance to progress in solving tank farm technical problems.

- The DOE is not providing effective management of tank farm cleanup activities.

External reviewers frequently offered recommendations on how to address the issues that were identified. A synopsis of many of the recommendations is as follows:

- Uncertainties in available information can be reduced through (1) improved monitoring of conditions outside the tanks; (2) improved characterization of vadose zone stratigraphy (e.g., lithology and structures in sediments); and (3) improved understanding of how contamination moves in the vadose zone sediments.

- The tank farm project could benefit from new approaches and ideas for solving its variety of technical problems, including environmental contamination. Solutions might include (1) a revised project organizational structure; (2) more frequent independent peer reviews; (3) open competition for performance of key tasks; and (4) better communication with the public.

- A phased approach to final disposition of the tank farms is recommended, proceeding from accurate characterization of the wastes inside and outside the tanks, so as to understand how leaked contamination moves through the vadose zone, and to describe risks posed by the contamination that reaches the water table and is distributed through groundwater movement. Engineering solutions to tank waste removal and/or stabilization should proceed in parallel with characterization activities.

4.3 RECOMMENDATIONS FROM THE CRCIA TEAM

The stated purpose of the CRCIA team is to assess the effects of Hanford-derived materials and contaminants on the Columbia River environment, river-dependent life, and users of river resources for as long as these contaminants are hazardous.

The CRCIA team prepared an extensive list of requirements for inclusion in any Hanford Site assessment activity. These requirements reflect a much broader view of the Hanford Site's impact on the Columbia River than was previously available. Recommendations recently offered by the CRCIA team are outlined below:

- Decisions affecting waste isolation must consider and encompass (1) cumulative site-wide effects on the region; (2) uncertainty in the estimated effects; and (3) needed safety margins for disposal solutions, to offset uncertainties.

- Hanford Site endstates must be defined to (1) understand source of effects; and (2) provide descriptions for review by potentially affected people.

- Key decisions should be evaluated for Columbia River and regional impacts, including (1) shipment of offsite wastes to the Hanford Site; (2) the planned endstate for the 200 Area; (3) tank waste retrieval and storage; (4) the planned endstate for the burial grounds; and (5) containment performance of liners and subsurface barriers.

- Independent direction of the assessment's performing contractor is essential to acceptable results. It is common practice for the evaluator to be independent of the agent performing the work. The concept is consistent with DOE Headquarters' (HQ) independent project review process.

The CRCIA requirements have been adopted as a starting point for the effects assessment capability that the Integration Project is developing. The general requirements and guidelines for the assessment capability, as adopted from the CRCIA, are described in Appendix F.

5.0 STRATEGIC APPROACH AND LONG RANGE PLAN

5.1 CURRENT SITUATION AND INTEGRATED CLEANUP VISION

A summary of the current set of Hanford Site assessment/remediation milestones and decisions is shown in Figure 5-1. As noted in Figure 5-1, Hanford Site projects operate in response to multiple regulatory drivers that are documented in the *Tri-Party Agreement*. In the past, each project has independently conducted performance assessments and other effects analyses. This has led to inconsistencies and duplication of effort in the analyses. The capability does not yet exist to assess the cumulative effects of Hanford Site wastes.

There are also logistical issues relative to efforts among site-wide projects. For example, as shown in Figure 5-1, the remediation of the 200 Area waste sites is scheduled during the time frame where tank farms will still be undergoing retrieval and closure activities. If surface barriers are selected as the closure option for these waste sites (as called for in the current baseline), the construction of barriers may conflict with tank farm operations.

The Integration Project has developed a framework where cleanup decisions will be based on scientifically sound assessments of effects on the regional water resources and the living systems that rely on these resources. The vision for an integrated, science-based strategy for Hanford Site cleanup results in the following:

- Integration of all assessment activities, to assure consistency.
- The development of a required SAC to address key decisions (e.g., 200 Area waste site remediation, and SST tank retrieval plans).
- The initiation of an applied S&T effort that is focused on the needs of the SAC, and the projects.
- The merging of remediation activities into a coordinated effort.
- Integration of the separate regulatory drivers into a common framework that is used to complete the cleanup mission.

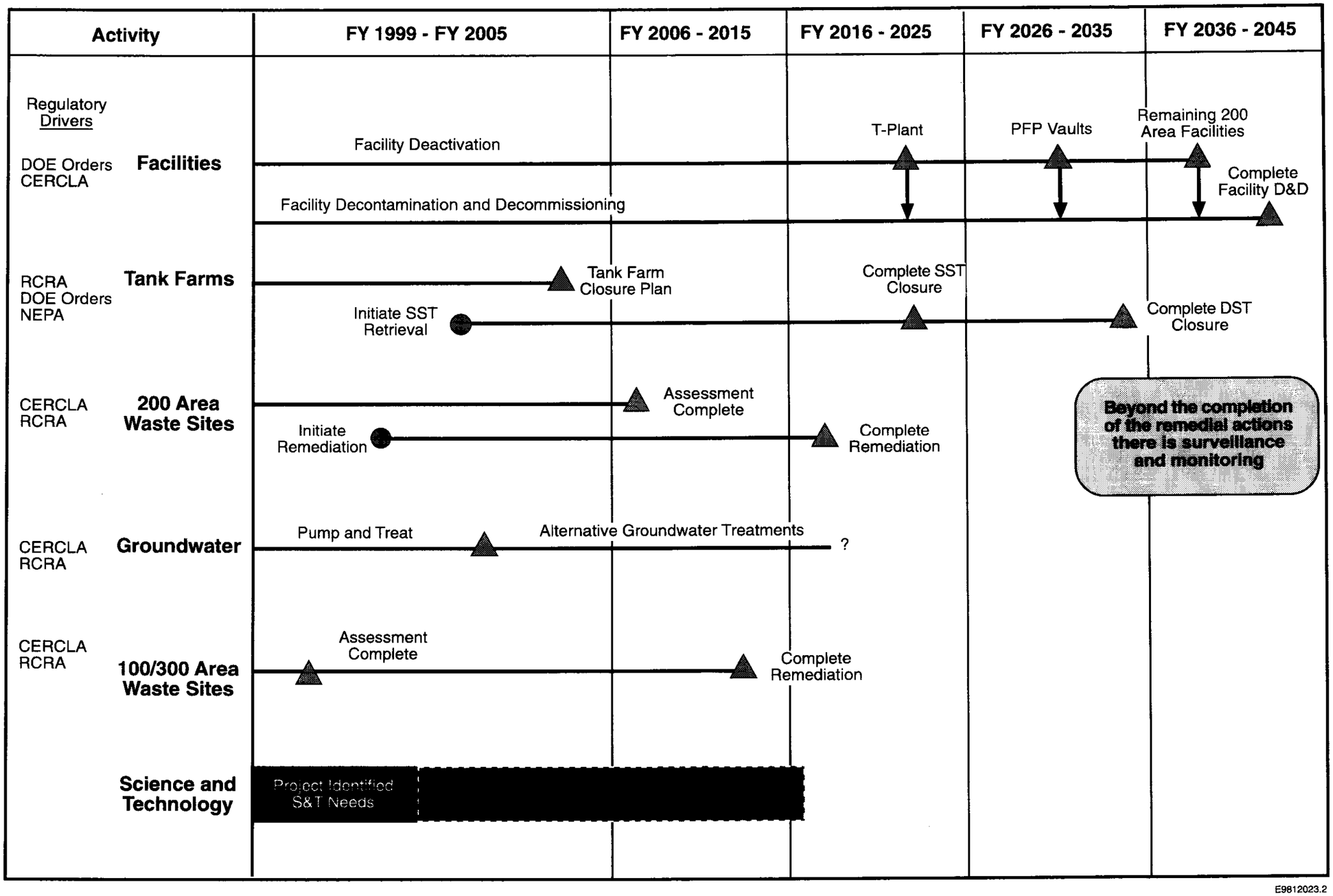


Figure 5-1. Hanford Site Summary Baseline.

5.2 STRATEGIC APPROACH

The Integration Project has established a working group with regulators (and stakeholders) to identify key areas where focus must be maintained in order to achieve the integrated cleanup vision. This working group defined the planning concepts, objectives, performance indicators, and challenges shown in Table 5-1.

Table 5-1. Project Planning Elements.

Focus Area	Planning Concepts	Objectives	Performance Indicators	Challenges
INTEGRATION	The Integration Project will support the *Tri-Party Agreement* objectives for Hanford Site cleanup planning. An integrated site strategy for an acceptable cleanup will drive the formulation of project activities.	Establish a consistent and integrated approach for characterization, assessment, and remediation activities for all Hanford GW/VZ projects, leading to an understanding of the Hanford Site contaminant transport pathways and processes, the mechanisms for receptor uptake, and expected impacts. Drive site planning towards achieving an integrated Hanford Site decision and regulatory framework for cleanup activities, within the context of the *Tri-Party Agreement.*	Prepare the first iteration of the integrated long range logic, which implements a strategic planning vision for Hanford Site cleanup, no later than January 1999.	Maintain a consensus among all participants in the cleanup process on a common vision for the desired condition of the Hanford Site at the end of cleanup activities. Maintain motivation to support an integrated regulatory framework for cleanup. Identify technical solutions that are achievable in the available timeframes for decisions.
SYSTEM ASSESSMENT CAPABILITY	The SAC will provide the set of data, information, knowledge, and supporting predictive tools to conduct credible evaluations of the effects of Hanford operations and cleanup decisions on human health, the environment, cultural, and socioeconomic needs. The SAC will operate at multiple temporal and spatial levels.	Develop a capability for assessing effects of Hanford Site wastes on the environment, the public, their cultures, and economies.	Develop an initial operational assessment capability by the end of FY 2000. Develop guidelines and requirements for the SAC, using the CRCIA Phase II document as a starting point.	Developing sufficient scientific support information for the assessment of effects. Producing a credible capability in the available timeframes for decisions.

Table 5-1. Project Planning Elements.

Focus Area	Planning Concepts	Objectives	Performance Indicators	Challenges
SCIENCE AND TECHNOLOGY	Predictions of transport and effects of Hanford Site contaminants require an applied science and technology effort to bring credibility to the decisions that are supported by the predictions. Numerical, laboratory, and field scale experiments are needed to demonstrate the level of understanding (and credibility) in the predictive tools used to estimate effects. Improved characterization and monitoring methods are needed to sufficiently characterize baseline conditions, and to demonstrate a basic understanding of transport phenomena.	Develop an applied science program to meet Hanford Site characterization and assessment needs in support of cleanup and site closure.	Prepare an applied S&T plan and roadmap, and initiate implementation in FY99. Develop a roadmap supportive of both short term and long term needs. Track and record key science and technology impacts on project decisions.	Maintain the focus of S&T plans on local project needs, with results available in a timely manner.
PUBLIC INVOLVEMENT	The involvement in the Integration Project by stakeholders, Tribal Nations, regulators, and the concerned public is key to the success of the Integration Project.	Implement an open and inclusive public involvement process that provides meaningful and acceptable ways for the regulators, Tribal Nations, stakeholders, and public to be involved in the project.	Record how project approaches, assessments of alternatives, and decisions are influenced by public input.	To effectively deal with diverse and conflicting inputs.
PEER REVIEW	Many technical elements of the Integration Project are subject to multiple interpretations that should be evaluated and resolved in an open forum by independent technical experts. This approach will foster discussion and improve the overall quality of actions taken by the Integration Project. The use of expert peer reviews will improve the acceptability and credibility of the work that is performed.	Establish a strong and effective independent technical review process that ensures timely discussion of technical issues.	Beginning in FY99, use recognized national experts in the review of technical plans and deliverables, and document their reviews as well as completed actions based on recommendations that are provided through the reviews.	Effectively address the recommendations that are provided through peer reviews.

The Integration Project strategy involves development and utilization of a SAC and a requirements-driven S&T program. The Integration Project has evaluated projects that are currently performing (or planning) characterization and assessments at the Hanford Site (core projects). Technical work within core projects (and historical Hanford Site studies) were analyzed by grouping activities along technical lines, which are referred to as technical elements (e.g., inventory, groundwater, etc.). These technical elements are presented in Section 1.2. The scope of each element is discussed in Appendix A.

The current state of Hanford's knowledge, in terms of technical elements, was documented through workshops involving core project staff, Hanford Site technical experts, scientists from the national laboratories, regulators, and interested stakeholders (see Appendix G). Using this as a basis to define gaps in understanding, a S&T plan was developed (see Appendix H). The technical elements provide the building blocks for the SAC and the Integration Project S&T roadmap, as described in the following sections.

5.3 DEVELOPMENT AND ANALYSIS OF THE LONG RANGE PLAN

The mission, vision, and objectives of the Integration Project will be achieved through the development and implementation of the overall Project Baseline. The Project Baseline includes this document (the *Project Specification*) and the details of scope, schedule, and budget for all of the core projects (as well as the LRP). The LRP is a graphical representation of the key elements and inter-relationships between these core project activities, in the context of Hanford Site milestones and decision points.

The Integration Project approached the development of the LRP through working groups and a series of meetings with the stakeholders, Tribal Nations, regulators, scientists from the DOE national laboratories, and key project and management personnel. Using the existing Hanford Site baseline, milestones and decisions relevant to assessments and cleanup were captured, along with the associated core project plans to meet these commitments. Within this framework, the development of the SAC is tied to key decisions and milestones. S&T initiatives were then developed and linked to both the SAC and the critical needs of ongoing projects.

5.3.1 Primary Planning Assumptions

The primary planning assumptions for the GW/VZ Integration Project are as follows:

- Major milestones/decisions are defined in accordance within existing project baselines.
- The core project baselines represent a compliance case (i.e., funding required to maintain compliance).
- The Integration Project has the authority to integrate ongoing core project direction and activities.

- Projects that are currently funding and performing assessments, interim corrective measures, and remediation activities will maintain these responsibilities.

- The DOE, regulators, and the core projects will work with stakeholders and Tribal Nations to define an integrated regulatory decision framework for the Integration Project and the 200 Area.

- The SAC is on the critical path for Hanford Site cleanup and closure decisions.

- A design framework of spatial and temporal scales, and compliance standards, can be defined for the SAC's initial development.

- Funding for the S&T roadmap implementation will be provided through the Hanford Site budget, EM–50, and EMSP.

- S&T roadmap implementation activities will be managed through the Integration Project.

- S&T roadmap implementation activities will be focused on solving Hanford Site issues, and will be responsive to schedule needs.

5.3.2 The Long Range Plan

The LRP has been developed at two levels of detail.

- A summary of the LRP (shown in Figure 5-2), which illustrates the following:

  - The major milestones and decisions that drive the critical path for the Integration Project.

  - The areas of opportunities for integration that will focus resources and provide a basis for moving forward.

  - The general relationship of the S&T plan and roadmap to the projects and SAC.

  - A summary of the path forward for the SAC, and the times when SAC products are required.

  - A summary of remediation activities.

  - A summary for the regulatory framework, peer reviews, PI, and project planning activities.

- A detailed graphic depiction of the LRP, which has been developed as an overall communication tool for Integration Project management decisions.

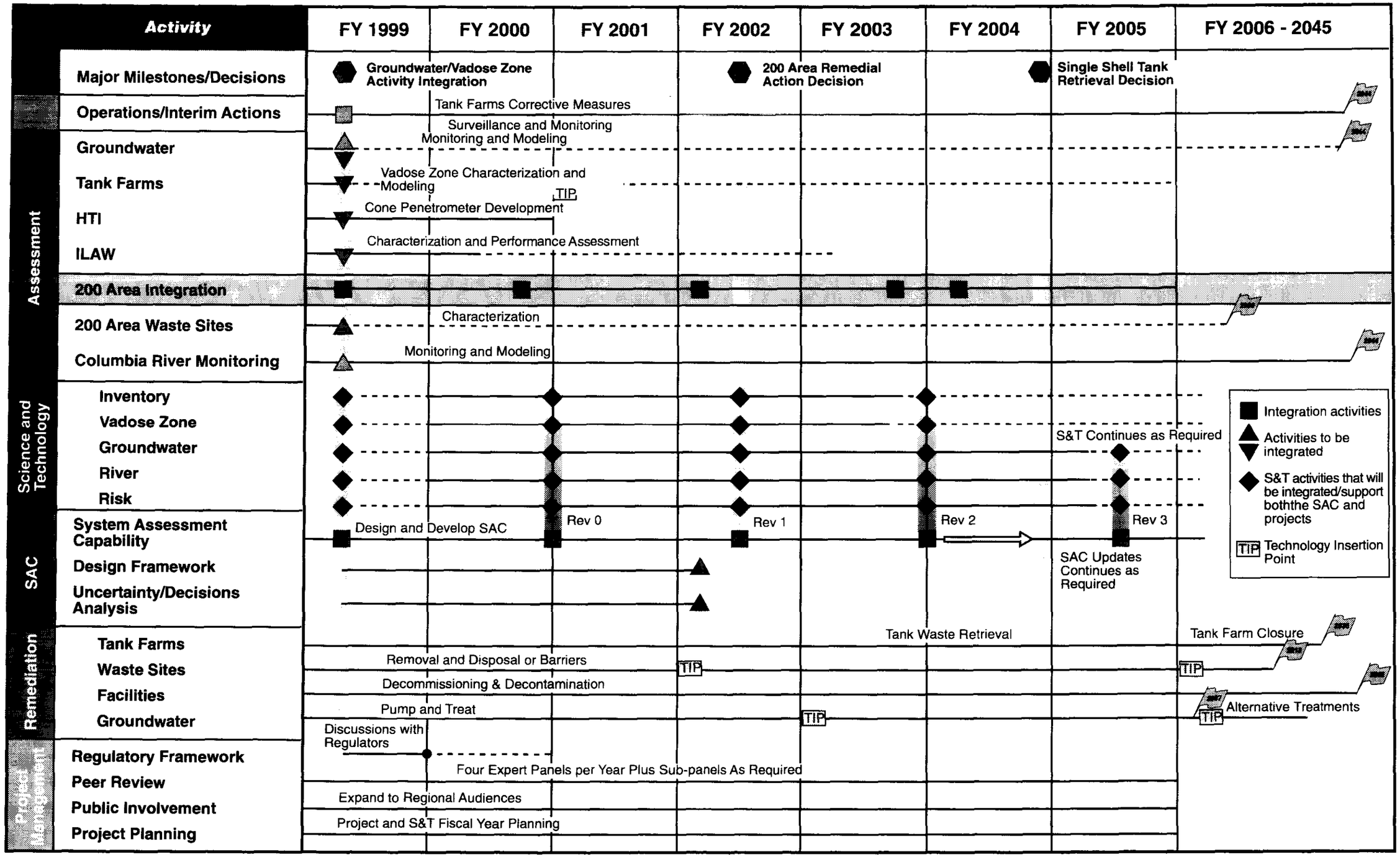


Figure 5-2. Groundwater/Vadose Zone Integration Project Summary Long Range Plan.

The following sections provide a summary description of each of the project areas and their relation to the LRP.

5.3.2.1. Major Milestones and Decisions. These are the major milestones and decisions for assessments and cleanup that the Integration Project will support. There are three near-term critical decisions that need to be made:

- The initial decision for the integration of ongoing assessment activities, which is based on the objectives of the Integration Project. This effort will be initiated in January 1999.

- In mid-FY 2002 there is a 200 Area Remedial Action decision that involves the scheduling of waste site group remediation within the 200 East and West Areas. Prior to FY 2002 there are three waste groupings that may proceed through assessment and into remediation without significant consequences to other ongoing projects, since the majority of these waste sites are outside the 200 East and West Area fences. The fourth waste site group that would initiate remediation in the mid-FY 2002 timeframe is located within the 200 West Area, adjacent to other ongoing projects. Depending on the alternative elements selected, the impact of the remediation both on ongoing projects and remaining risk–will need to be evaluated. An integrated path forward will need to be developed for the 200 Area remediation.

- The continuation of SST retrieval is the third critical decision. By the end of FY 2004, the SST project will have had operational retrieval experience with at least two tanks. This will provide critical information of the potential for operational losses, the effectiveness of retrieval technologies, and the ability to meet the 99% retrieval goal. Additionally, the SAC will have completed Revision 2, which will support an assessment of the impacts associated with the retrieval process.

5.3.2.2 Operations/Interim Actions. The operations/interim actions include surveillance and monitoring activities. This effort is included to track/highlight two activities:

1. The tank farm interim corrective measures, which are the subject of the current *Tri-Party Agreement* negotiations, and which will contribute to define assessment and S&T needs for the tank farms.

2. The ongoing monitoring activities for the vadose zone, groundwater, and Columbia River. While significant progress has been made in the integration of groundwater monitoring, this effort needs to be continuously examined in order to identify opportunities for integration. Vadose zone monitoring presents an opportunity to align and coordinate these efforts with site-wide integrated assessment needs. The entire set of monitoring activities needs to be evaluated, as an overall system, to determine if requirements are consistent among activities. These monitoring activities provide critical data for the ongoing projects, development of the SAC, and definition of S&T needs.

5.3.2.3 Assessments. Planned and ongoing assessments represent an immediate target of opportunity for integration. The are three ongoing assessments in the 200 Area: (1) the tank farm RCRA corrective actions, which are currently under negotiation; (2) the ILAW assessment,

which is driven by a planned procurement in FY 2000; and (3) the 200 Area waste sites characterization. The development of conceptual models and modeling are part of these assessment activities. As shown in Figure 5-2, these activities will be integrated into a coordinated site-wide effort (labeled 200 Area Integration) that is driven by the Integration Project. Because the ongoing efforts are part of the current Hanford Site baseline, these activities are shown as dotted (in the LRP) after integration occurs. The ILAW assessment does not show as dotted until later, because this assessment is on an established path to support a planned procurement in FY 2000. Improvements will be made by establishing a common DQO process, providing common data collection and management protocols, and involving the science community in all aspects of the work. This will result in better utilization and traceability of field data, as well as common assumptions and model parameters that will be utilized in the development of the SAC and definition of S&T needs.

5.3.2.4 SAC. The critical path activity for the Integration Project is the SAC. The SAC is a collection of the conceptual models, databases, analytical and predictive tools used to conduct site-wide effects assessments. These assessments support key decisions regarding remediation of the vadose zone, and groundwater, in order to protect the Columbia River. The knowledge collected through the SAC will also form the basis for site-specific assessments, thereby ensuring that the best scientific knowledge is used for all Hanford Site vadose zone/groundwater assessments. To be fully functional, the SAC will require data acquired through field sampling and from S&T activities. Hence, the SAC can be used to help guide data collection from the field, define monitoring requirements, and guide future S&T investments. The SAC approach is illustrated in Figure 5-3.

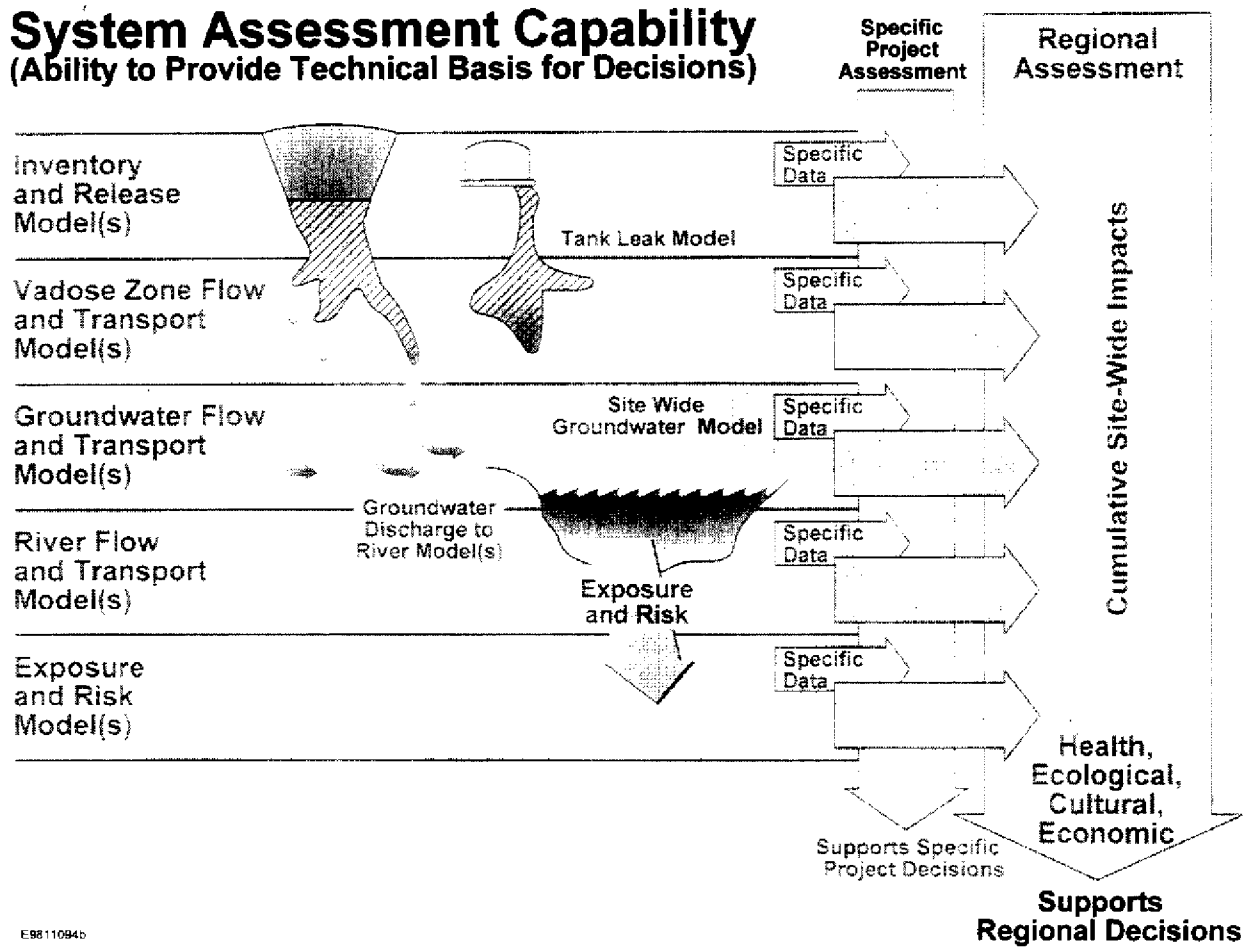
The DOE is committed to an open, requirements-driven design and development process for the SAC. The design effort for the SAC (what it must do, and how well it must do it) is currently underway. The starting point for this effort is the CRCIA. The SAC project staff have engaged a number of the same regulators, Tribal Nations, and stakeholders that prepared the CRCIA to assist in establishing the SAC design requirements. The current planned approach is as follows:

- Establish requirements for each technical element and the overall SAC. Intensive meetings are scheduled with interested parties to discuss each technical element, and to help define requirements and expectations. The CRCIA detailed appendices form the bases for these discussions.

- Develop and document criteria that allow candidate and study sets of capabilities to be determined. An important element of this approach is to be as complete as possible, and document what determines completeness (i.e., candidate sets). Approximately 12 candidate sets of capabilities are likely to be needed in the design. Criteria will be developed to progress from candidate sets to the smaller study sets.

- Identify and prioritize S&T needs. During the development of study sets it is expected that many areas and needed capabilities are outside the range of current capabilities, or beyond the resources that can be committed to conduct the first assessment.

Figure 5-3. System Assessment Capability.



- Conduct two major seminars (or workshops) to discuss issues in the areas of risk and effects assessment, and on the handling of uncertainty. These two areas are critical to the success of the development effort, and permeate the entire Integration Project approach.

- Document and review the planning results in a "Software Requirements Document," and the design in a "Software Design Document." These two documents will provide the details for the level of detail that will be included in the SAC.

- Build the initial model for use in the SAC, and conduct a risk/effects assessment.

- Improve the basis for the assessment and incorporate site planning changes. It is expected that most S&T work will take 3 to 5 years to reach fruition. This will significantly impact the initial effort. This work will be peer reviewed and incorporated into the SAC.

- Modify the initial model to include necessary improvements, and re-evaluate the past risk/effects assessment.

The SAC has interfaces with each technical element. Information and analyses in the technical elements are directed (in part) by the needs of the SAC. This more detailed information, along with studies and experiments conducted in the technical elements, feeds into the SAC and assures coordination among the elements.

The first iteration of the SAC, and the first preliminary assessment, will be completed in FY 2000 (see Figure 5-2). This initial iteration will represent an important milestone on the critical path for providing key information for making two important near-term decisions:

- The decision to proceed with remediation of the 200 Area in FY 2002.
- The decision on how to proceed with retrieval of tank contents in FY 2004.

This schedule allows approximately 18 months for development of the first version (Rev. 0) of the first SAC. Eighteen months later, the first revision (Rev. 1) of the SAC must be completed (with the necessary enhancements to support the 200 Area remediation decision). In the next 18 months Revision 2 will be produced, with further enhancements to support tank retrieval decisions. Data used in these assessments will come from previously collected data of known quality, ongoing assessments, and project-related data collection activities, as well as data collected by the Integration Project to address a specifically identified SAC need.

5.3.2.5 S&T – Plan and Roadmap. To define the S&T program, a series of national laboratory meetings were held in FY98. In these meetings, scientific experts in subsurface assessment and remediation met with the DOE, site remediation contractors, and local stakeholders. Many of these scientists had developed assessment capabilities for other DOE programs (such as Yucca Mountain). This diverse set of experience and capability was used to identify the scientific and technical challenges facing the Hanford Site, and to subsequently define an applied S&T program to address these challenges.

The resulting S&T scope, schedule, budget, and products for the next five years are presented in Appendix I. S&T products will be delivered to the SAC and individual projects that are supporting the two key decisions during this initial five-year period:

- 200 Area remediation assessment (in FY02).
- SST retrieval (in FY04).

In addition, the roadmap in Appendix I includes S&T products that are being delivered to provide a technically credible basis for making decisions on tank farm closure, remediation of soil sites, and the tank farms in the following five years.

This first version of the S&T roadmap includes the inventory, vadose zone, groundwater, and river technical elements. A placeholder for the risk assessment technical element, which is being developed by the Center of Risk Excellence (CRE) in early FY99, is identified in the roadmap. The DOE engaged the CRE in the GW/VZ Integration effort in early FY99. The risk activities

conducted by the project team to date have focused on a broad range of potential effects that could be associated with Hanford Site contaminants through long-term future scenarios. Building from this work, the CRE is preparing a technical risk report that will discuss approaches that can be used to effectively assess key potential impacts. The overall aim is to provide focused information that will support sound decisions for the site's EM program and related research needs. This report is being prepared in conjunction with ongoing project risk activities, for which continued close involvement of multiple stakeholders and Tribal Nations is essential. Current S&T activities being conducted for the remedial options technical element are also included. These latter needs (remedial options) were not developed through the national laboratory meetings; they were identified through the Hanford Site Technology Coordination Group (STCG)*. The monitoring technical element is not included in this version of the S&T roadmap. It will be developed in FY00 and incorporated in a future revision. The regulatory path technical element will not have S&T associated with it; consequently, it will only be included in the S&T roadmaps as a driver for S&T activities.

5.3.2.6 Remediation. The following remediation activities have been summarized to provide the framework for the assessment, S&T, and SAC activities.

- The tank farms focus is on SST retrieval and the eventual closure of the SST and DST farms. The waste sites summarize the initiation and completion of 200 Area remediation.

- The facilities D&D shows a continuous process that is scheduled to be completed in FY43.

- The groundwater effort highlights the technology insertion points for alternative groundwater treatments to current pump and treat activities.

5.3.2.7 Project Management. The project management section focuses on elements that are critical drivers for (or constraints on) the Integration Project. These elements are as follows:

- The development of an integrated regulatory framework for the GW/VZ Project and, in particular, the 200 Area assessment and remediation. Currently, assessment and cleanup activities are operating under numerous and sometimes overlapping regulatory requirements (RCRA, CERCLA, NEPA, AEA, NRC). The DOE would like to initiate discussions with the regulators on potential approaches to developing an integrated framework for the 200 Area, in early calendar year 1999.

- Peer review activities, which include the expert panel, associated sub-panels, and NAS reviews that will be an integral aspect of the project.

  - A technical expert panel has been established to address specific technical issues. The panel focuses on problem resolution and technical reviews. The purpose of the external panel is to provide DOE with technical observations and recommendations

* The STCG is a group of users and stakeholders at the Hanford Site. This group identifies technology needs that are submitted to the Office of Science and Technology (OST) on an annual basis. OST, through its national research programs, considers these needs in the development of its technology programs.

regarding the planning, execution, and interpretation of results from the Integration Project. In this way the panel functions in a review or consulting mode, depending upon the specific need being addressed, and the panel will thereby ensure appropriate technical reviews of project activities and deliverables. Areas of greatest importance for the reviews include, but are not limited to, those that have (1) a high degree of technical uncertainty; (2) significant impacts on project outcomes; and (3) unresolved issues resulting from differences in technical interpretation.

- The panel reports to RL. The expert panel operates under written procedures that address requirements, protocols, timeliness of producing panel reports, and a formal recommendation and comment resolution tracking and response process. The expert panel has the ability to establish subpanels that are comprised of experts who are focused on a narrow technical topic, according to project needs. The panel meets on a regular basis (four times a year, at the present time).

- Another process for independent review that is being pursued by the DOE is through the NAS. The DOE has requested that independent, external peer reviews be conducted by the NAS on a periodic basis. These reviews will be coordinated with the Expert Panel and conducted to avoid conflicts of interest or any bias potentially associated with conclusions and recommendations. In accordance with NAS standards, this review will consist of highly qualified technical experts.

- The PI effort enables effective and real time project participation, as well as involvement by all interested audiences. To this end, there are four main PI goals:

  - Provide interested audiences with timely and accurate information.

  - Actively encourage effective dialogue with interested audiences to assist project decision-makers.

  - Provide for various levels of involvement in the project. In-depth issue involvement will be encouraged.

  - Provide outreach opportunities for Northwest communities to inform the public of the project, and provide awareness of ways they can participate.

There are various ways of communicating with and participating in the Integration Project. Effective dialogue between the Integration Project Team and interested audiences will communicate issues, values, and concerns that affect decision-making processes. These methods include the following:

Tribal Governments. Direct discussions and involvement on an informal basis will be offered and conducted upon request, and/or based on project needs. Consultations, including a more formal interface with Tribal Governments, will be conducted in conjunction with RL's Office of External Affairs (OEA).

Hanford Advisory Board. Information will be provided to the HAB's Environmental Restoration (ER) Committee and PI Committee. The ER Committee will determine when project information should be presented to the full Board, and if draft advice should be presented to the full Board. The Integration Project Team will provide the ER Committee with current status information at their monthly meetings. The plan will be provided to the HAB's PI Committee for review and comment. Updated status information will be provided to the PI Committee at the *Tri-Party Agreement* Quarterly PI Planning meetings.

One-on-Ones. These are individual discussions held with interested audiences.

Media Relations. Regional communication of specific information will be made to general audiences through the media. The use of press releases, media availability, interviews, and other communication methods and mechanisms will be employed to meet communication and project goals.

Project Team Meetings. Project team meetings will be held routinely to facilitate a detailed dialogue. Meetings will be held at regular intervals, and will be open to all interested audiences. Detailed meeting notes will be distributed to the mailing list.

Focused Topic Working Groups. Focused working groups may be established to address particular topic areas. The groups are expected to be of limited duration, but may be extended dependent on the breadth of issues to be addressed. Meetings are open to all interested parties. Three working groups that have been established in FY99 address issues on policy, the *Strategic Plan* and LRP, and the SAC.

5.4 COST AND SCHEDULE BASELINE

Cost and schedule baseline information is contained in Volume Two of the overall Project Baseline.

Cost and schedule information were compiled from the existing core project baselines and fiscal year planning documentation. This detailed information provides the basis for (and has been rolled up to develop) the detailed LRP. Table 5-2 summarizes the Integration Project costs.

5.5 INTEGRATION PROJECT CRITICAL PATH

Hanford Site assessment and remediation activities will continue to support established *Tri-Party Agreement* milestones, while the development of the SAC and S&T proceed in parallel. As shown in Figure 5-4, the critical path for the Integration Project is through the SAC and associated S&T.

The activities to support Revision 0 of the SAC involve definition of requirements, selection of candidate and study sets, development of the computational framework, and the architecture of

Table 5-2. Integration Project Costs.

Activity Description		Lifecycle Base Total ($000)	Lifecycle Esc Total ($000)	FY 1999	FY 2000	FY 2001	FY 2002	FY 2003	FY 2004	FY 2005	FY 2006 thru FY 2044
Operations/Monitoring/ Interim Actions	Unesc	470,731		13,663	15,189	14,546	14,596	17,846	12,945	12,797	369,149
	Esc		730,555	13,663	15,523	15,193	15,581	19,469	14,433	14,582	622,111
Assessment	Unesc	200,236		12,263	32,284	39,042	28,882	24,465	12,250	9,823	41,227
	Esc		228,478	12,263	32,994	40,779	30,830	26,690	13,658	11,193	60,071
Science and Technology	Unesc	137,861		14,219	26,999	24,925	22,128	21,393	6,000	2,001	20,196
	Esc		155,339	14,219	27,593	26,034	23,621	23,339	6,690	2,280	31,564
System Assessment Capability	Unesc	33,068		1,869	2,958	2,946	3,028	3,028	3,040	1,001	15,198
	Esc		44,516	1,869	3,023	3,077	3,232	3,303	3,389	1,141	25,482
Remediation*	Unesc										
	Esc			0	0	0	0	0	0	0	
Project Management	Unesc	84,157		3,557	2,944	2,932	3,014	3,014	3,025	3,014	62,657
	Esc		131,785	3,557	3,009	3,062	3,217	3,288	3,373	3,434	108,844

*Note - Remediation funding is not currently included in the GW/VZ Baseline Life cycle cost summary. Remediation costs are included in the backup information.

the overall SAC. During this first phase, the S&T roadmap will be implemented and the projects will continue to gather characterization data from ongoing assessments, thereby providing input for Revision 0 of the SAC. The SAC will then provide insights on data requirements to both the S&T and characterization efforts, to assist in refocusing those activities.

Revision 1 of the SAC will include additional development and refinement of the models and information contained in the SAC. This revision will be utilized in assessment of the remedial alternatives associated with the 200 Area waste sites. Again, both the S&T and the characterization data from assessments will provide input for the Revision 1; the SAC provides feedback on requirements for refocusing those activities. This same pattern of inputs and feedback between the S&T, characterizations/assessments, and SAC is repeated for each revision of the SAC.

Revision 2 of the SAC is envisioned as the "minimum credible model," that is capable of supporting assessments for key site decisions. In order to establish this "minimum credibility," it will be necessary to perform rigorous comparisons to field data and conceptual models, and to evaluate SAC results against historical data. This version of the SAC will be used to support the decisions and plans for the SST retrieval process.

5.6 ANNUAL PLANNING CYCLE

Planning is performed annually by the Integration Project, following a four-step process. The steps are Deficiencies Assessment, Work Scope Development, Work Scope Review and Approval, and Work Performance and Evaluation. The cycle is shown in Figure 5-5.

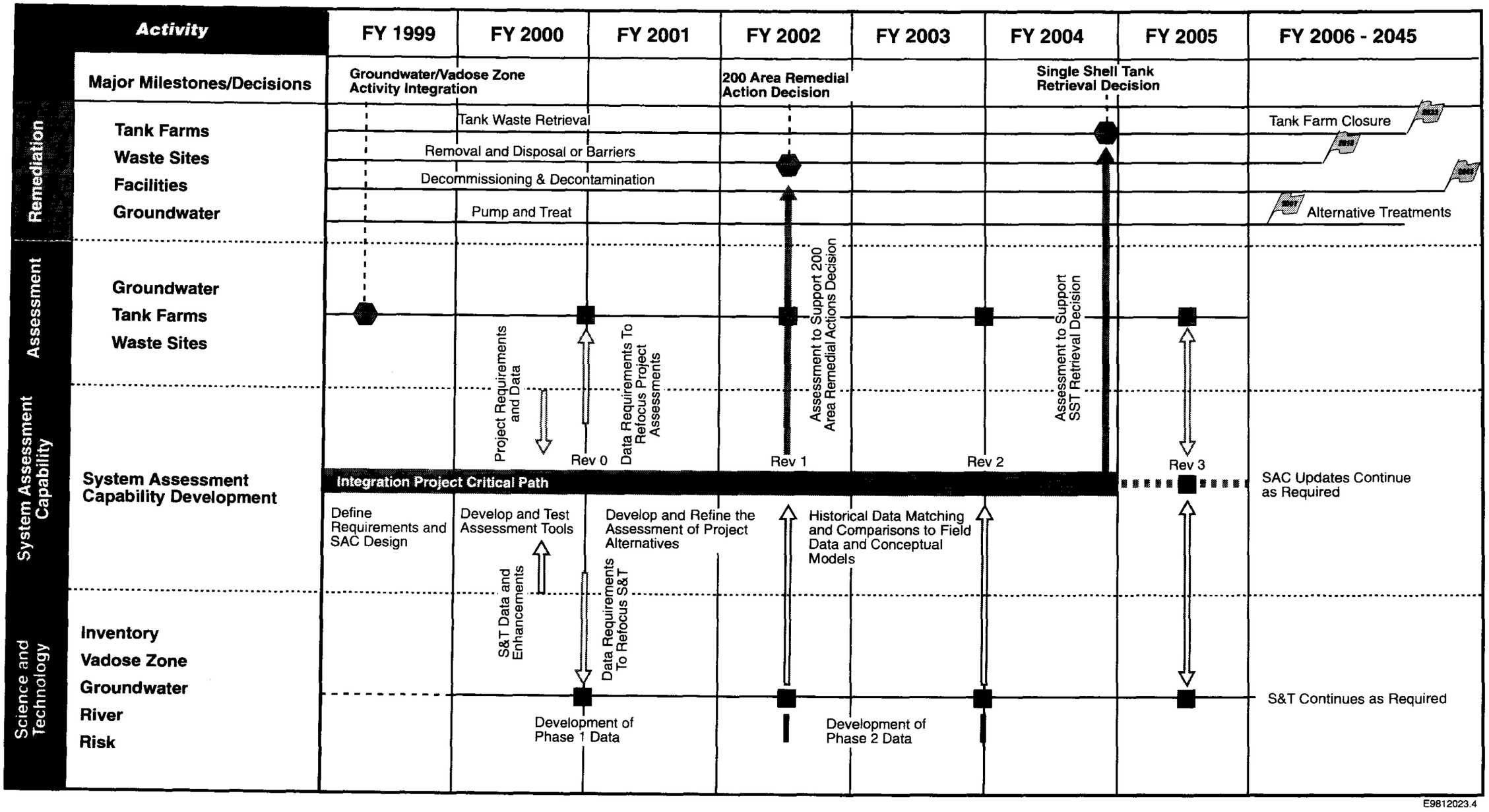
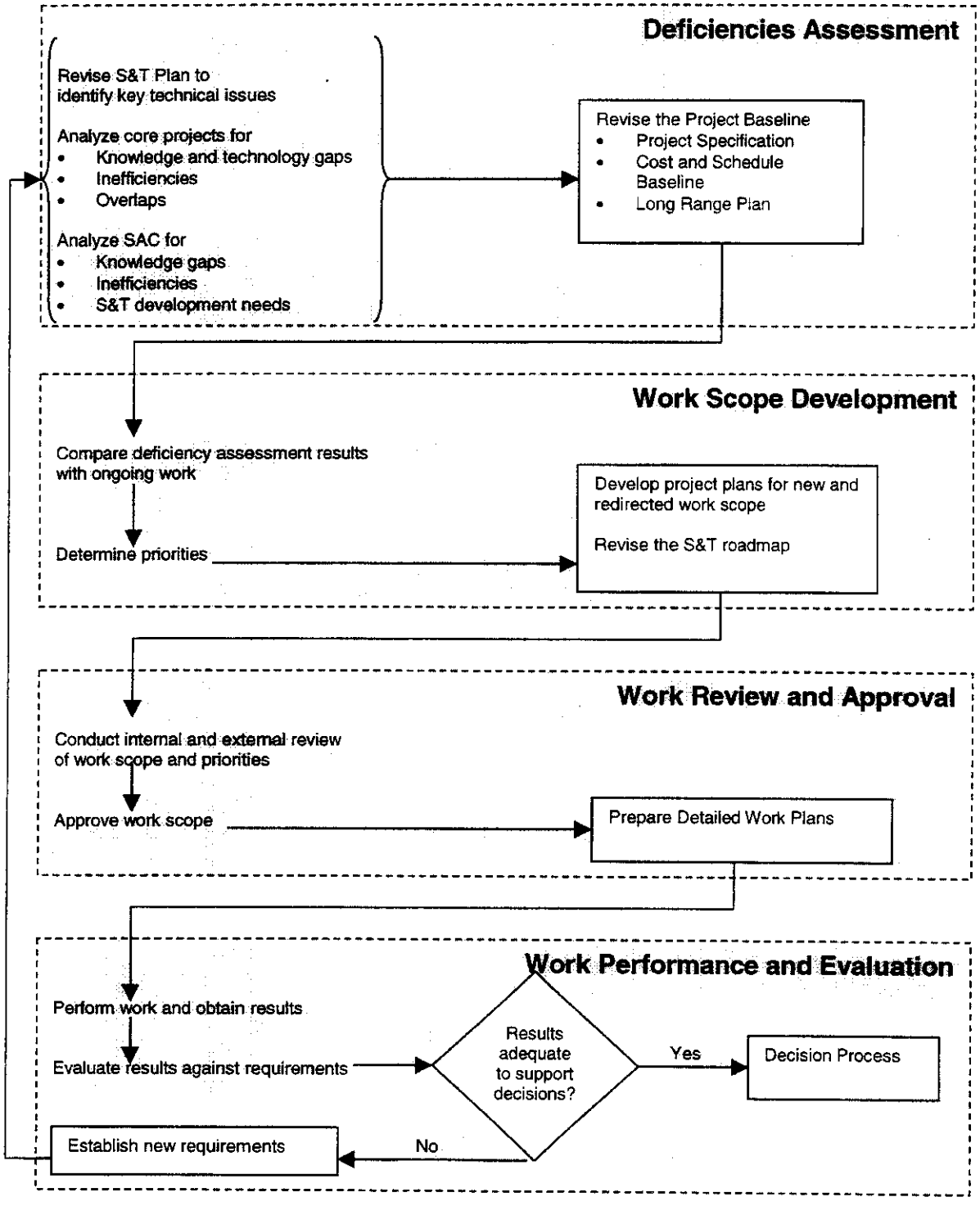


Figure 5-4. Groundwater/Vadose Zone Integration Project Critical Path.

Figure 5-5. Annual Planning Cycle.



The deficiencies assessment is designed to systematically review and evaluate the work scope, technical capabilities, and the technical knowledge base, by sorting, based on technical elements. There are three primary sources of input to the deficiencies assessment requirements. These are provided from the core projects, key technical issues from the S&T Plan, and SAC requirements. The current S&T plan is presented in Appendix H. The assessment identifies knowledge, data, and capability gaps, as well as inefficiencies or overlaps in work scope. Once the deficiencies have been identified they are sorted into one of four categories: site integration issues, core project work, SAC requirements, or S&T needs. The results are incorporated in the overall Project Baseline, and utilized in fiscal year planning.

Identified gaps, inefficiencies, and overlaps are compared to ongoing work activities that may provide data to resolve deficiencies. If ongoing work is unlikely to provide the information that is needed, new work scope is identified (or existing work is redirected). The determination of work priorities is focused on assuring that appropriate, essential work scope is completed on time, and that work activities constitute an appropriate expenditure of public funds. To establish a baseline for these activities the scope is to be added to the Hanford Site IPL and then evaluated and ranked with all of the other items that fall within the Hanford Site scope. This IPL process uses the overall Hanford Site priorities (minimum safe operations, mitigate urgent risk, essential services and compliance) to establish a list of the scope that can be accomplished within the funding constraints for a particular fiscal year. Detailed project plans are subsequently developed.

Detailed planning for the S&T scope is contained in the S&T roadmap, which is presented in Appendix I and described in Section 5.4. The EM-50 funding cycle generally aligns with the overall EM funding cycle, but includes an evaluation of needs and proposals prior to initiation of the cycle. The EMSP cycle occurs during the fiscal year for which funding has been authorized. The cycle includes submittal of proposals and science and relevancy reviews. Funding is awarded and authorized work is initiated in the second half of the fiscal year.

Final work review and approval involves internal and external review of the proposed work scope and assigned priorities. This process is open to public comment. Tribal Nations and stakeholders are encouraged to provide comments for consideration in the final approval process, before work scope is incorporated into detailed work plans (DWPs).

Once work has been performed, it is evaluated against the initial requirements. If the results are adequate to support a decision process (e.g., supporting the SAC or directly supporting a technical issue in a regulatory decision), the results are provided to that process. If the results are not adequate, then new requirements are established and provided back to the Integration Project for re-evaluation.

6.0 PATH FORWARD

The Integration Project has developed a vision and a science-based plan to systematically address the issues of fragmentation, defensible cleanup end points, and credibility in the Hanford Site's approach to achieving its environmental restoration mission. This is a first iteration of that plan.

This document, along with the LRP and *Cost and Schedule Baseline*, will be updated as additional input is provided from the public, and Tribal Nations, and as the Integration Project gains insight from the work initiated under the auspices of this plan. Through this plan the Integration Project will address five key focus areas. These are listed below.

- **Integration** – The Integration Project has defined the work scope (core projects) to be integrated at the Hanford Site, and is coordinating this work to the fullest extent possible. Core project team members are co-located and meet frequently to share information and plans. A detailed analysis of the work planned and underway in FY99 is being completed, and will provide the DOE with an opportunity to influence ongoing work. Additionally, other regional studies by the states of Oregon and Washington, and other agencies (U.S. Geological Survey [USGS], Bonneville Power Administration [BPA], U.S. Corp of Engineers, etc.), will be examined for applicability to Integration Project activities. The Integration Project will establish formal procedures and requirements in time for the development of an integrated project work plan for FY 2000. The DOE will transmit a letter to Ecology and the EPA outlining a proposed approach for developing an integrated regulatory framework for 200 Area assessment and remediation activities. The DOE would like to initiate discussions with the regulators in early calendar year 1999.

- **System Assessment Capability** – The Integration Project has initiated the development of the SAC, utilizing the CRCIA as the template. This work is being developed in conjunction with team members from the CRCIA, and other interested parties. The SAC will provide the tools to assess the impacts of all Hanford Site waste forms, in support of project cleanup decisions. The initial set of parameters for the assessment will be defined, the architecture designed, and design requirements established in calendar year 1999. The SAC development is an iterative process. As the SAC requirements are defined, they will be used to refocus the project assessments and S&T needs. Consequently, as project data and S&T data are developed, they will be used to refine the SAC. The Rev. 0 version of the SAC will be developed by the end of FY 2000. The development of the Rev. 2 (at the end of FY 2003) is considered to be on the critical path for the SST retrieval decisions.

- **Science and Technology** – The Integration Project's initial S&T plan and roadmap is complete for the Inventory, Vadose Zone, Groundwater, and River elements. The Risk element will be incorporated in an April update of the Project Baseline and LRP. The primary focus will be on addressing key uncertainties, the requirements of the core projects, and the SAC.

- **Public Involvement** – The Integration Project has adopted an open environment to encourage participation by interested parties. The project attempts to widely and effectively communicate plans and activities. Through these efforts, a level of credibility has been established with stakeholders, the Tribal Nations, and the public.

- **Peer Review** – An Expert Panel has been established to provide direction to and oversight of the Integration Project. The NAS may establish a committee to provide another level of independent review. The Expert Panel has provided an initial informal review of this plan. The panel will conduct a more detailed review in February.

Opportunities For Integration

This first iteration of the Integration Project *Baseline* has resulted in the identification of opportunities for integration in the following four areas:

Project Assessments

Ongoing project assessments represent near-term opportunities that should be evaluated over the next several months and incorporated into FY 2000 planning efforts. Currently, ER 200 Area Remedial Actions, TWRS Vadose Zone Characterization, ILAW and HTI are all performing assessment activities in the 200 Area. Recommendations about efficiencies that will be gained by integrating activities within and across other Hanford Site Projects are as follows:

- The collection of field data will be based on technically defensible sampling and analysis plans that are integrated among the core projects to optimize sample collection and analysis, and to reduce assessment costs.

- The sampling and analysis plans will be based on a rigorous, cost-effective DQOs process that includes representatives for all the associated projects, S&T, regulators, and stakeholders.

- The development of conceptual models is common to many of the projects and will be coordinated. Cost-effective methods need to be identified to optimize their preparation and maintenance.

- Requirements for a consistent approach in conducting performance/risk assessments will be developed for all Hanford Projects.

- A common set of inventory, vadose zone, groundwater and river data will be developed for modeling and assigned configuration controls.

- Characterization and monitoring of technology development and deployment needs to be coordinated among the core projects.

- Utilize information generated by non-DOE agencies (e.g., USGS, the state of Oregon, BPA), and pursue opportunities for coordinated studies.

Science and Technology

- S&T will support both the SAC and Hanford Site project cleanup goals. S&T will be integrated with the planning and execution of field data collection, sampling and analysis, conceptual and numerical modeling, and the performance/risk assessment.

Operations and Remedial Actions

- Vadose zone monitoring activities will be integrated across the Hanford Site.

- Groundwater monitoring that has been integrated across the Hanford Site will be optimized to achieve additional efficiencies.

- Well services, which include well drilling, maintenance, rehabilitation, and decommissioning, should be integrated.

- The baseline remedial actions will pose significant logistical conflicts if they are implemented as currently planned and scheduled. The first action and basis for evaluating remediation activities should be to develop an path forward for remediation that minimizes implementation conflicts.

Coordination of Regulations and Orders

- Currently, assessment and cleanup activities are operating under numerous and sometimes overlapping regulatory requirements (for example, the RCRA, CERCLA, NEPA, AEA, NRC policies, etc.). As a first step, the DOE would like to initiate discussions with regulators on potential approaches to developing an integrated regulatory framework for the 200 Area in early calendar year 1999. In the future, the DOE would like to expand this discussion to address the entire Hanford Site.

As with any undertaking of this nature and magnitude, there are vulnerabilities for the project that must be recognized and managed as progress is made. The following list identifies the primary areas of vulnerability over the next year.

- This project represents a different management approach, and a departure from tradition for the DOE. At the same time, the Integration Project still operates within existing project, contractor, and funding management systems. *Can the Integration Project efficiently and effectively execute its mission over the longer term, within the context of current management systems?*

- S&T, and the development of such a complicated tool as the SAC, is inherently difficult to manage on a critical path. *Can the Integration Project maintain its schedule with current levels of project participation and apparent funding constraints?*

- Commitment is required by the DOE, Washington state, and federal regulators towards the development of an integrated regulatory framework for the 200 Areas. *Can a consistent set of regulatory requirements be established within an overall framework to guide the assessment and cleanup activities at the Hanford Site?*

- Public and Tribal Nation participation and support is required for the Integration Project to be successful. The project has made progress in this area, but these relationships are still fragile. Trust and credibility must develop with time. *Can the Integration Project successfully manage in the face of diverse interests and reach a consensus among various interested parties regarding the project's direction, content, and decision making processes?*

The efforts made to date have been focused on developing the foundation and plans for a credible, science-based approach to solve Hanford Site problems. But, as stated by the Expert Panel: **"Planning is not progress, only a prelude to progress."** The Integration Project must now effectively execute its plans, with discipline.

APPENDIX A

TECHNICAL ELEMENT DESCRIPTIONS

APPENDIX A

Technical Element Descriptions

A.1 SYSTEM ASSESSMENT

The system assessment technical element quantifies the environmental consequences of past, present, and future Hanford Site activities on the vadose zone, groundwater, and the Columbia River. Assessment capabilities evaluate the affects of residual contamination from past activities, as well as potential future contamination. The scope of the system assessment technical element includes designing, developing, and applying assessment methods that meet the objectives of the Integration Project. This technical element also provides a vehicle to integrate activities and information generated by the other technical elements, so that coherent and consistent information is available for making major cleanup decisions. The iterative aspect of (1) defining requirements and objectives; (2) obtaining required information and data; (3) interpreting and using the new information; and (4) evaluating the new information in terms of the original requirements is part of this technical element.

The scope and results of assessments made for specific projects, which may be at physical and temporal scales that are more highly resolved than those for an overall system assessment, are coordinated within the system assessment technical element. This integration ensures that the system analysis is reasonably complete and adequate, and that it is internally consistent.

The system assessment scope is oriented toward site-wide and broader scales that consider the significant components of the natural system and waste management issues when evaluating environmental and human health consequences. As a result, system assessments tend to be directed at the longer-term consequences of contaminants in the environment. However, because of the need to evaluate mitigation and remediation alternatives, and impacts from past discharges to the environment, system assessment capabilities must also include near-term durations.

To ensure the coordination and overall consistency of analyses contributing to the system assessment, the system assessment technical element establishes common requirements for shared databases and consensus interpretations of the environmental setting. This technical element is responsible for data-sharing structures. The data-sharing structure recognizes the multiple temporal and spatial scales of observations and required assessments, and ensures that consistent methods are employed for scales ranging from an individual pore or mineral-grain surface to the regional aquifer and the Columbia River.

Once system requirements and standards are agreed upon, they are imposed for all technical elements and scales of analysis. This process ensures completeness and consistency for analyses conducted for other technical elements (e.g., the vadose zone and the groundwater technical elements). In turn, this ensures the applicability of results on a system-assessment scale.

The system assessment technical element is responsible for reconciling technical differences at interfaces between technical elements. For example, the vadose zone technical element provides

estimates of past and future releases of contaminants from the vadose zone to the uppermost aquifer. Similarly, the groundwater technical element provides estimates of current and future contaminants within the uppermost aquifer. If the estimate of past releases of vadose zone contaminants to the aquifer fails to agree with the estimate of contaminants in the aquifer, then the system assessment technical element, which uses results of both the vadose zone technical element and the groundwater technical element, must resolve the difference.

A.2 INVENTORY

Inventory is the total quantity of radiological and chemical constituents used and created at the Hanford Site, and their distribution in facilities, waste disposal sites, the vadose zone, groundwater, and Columbia River ecosystem. Information needs associated with inventory include (1) locations, amounts, and concentrations; (2) characteristics of the radionuclide or chemical compound; (3) mobilization and release mechanisms and rates; and (4) the change in inventory because of natural processes (e.g., decay), remediation activities, and Hanford Site operations.

In addition to inventory estimates, mechanisms must be identified that result in release of the inventory from facilities into the vadose zone, unconfined aquifer, or the Columbia River. Because the long-term configuration of the waste inventory depends on future remediation and land-use decisions, a baseline estimate of end-state inventory distributions must be defined.

To date, inventory estimates for radionuclides and hazardous chemicals have been developed within specific projects. These estimates tend to be conservatively high. No comprehensive analysis has been performed that compares and reconciles the estimates for each facility with estimates of the total Hanford Site inventory. A comprehensive integrated analysis will help ensure that estimates for key contaminants are sufficiently accurate, and credible, to support a site-wide assessment of environmental impacts and risks.

A.3 VADOSE ZONE

The scope of this technical element encompasses the unsaturated zone beneath the Hanford Site. The geographic focus is on areas that (1) underly liquid waste disposal sites; (2) have the potential for leaks or leaching; and (3) have experienced past leaks and spills. Also included are selected areas away from the focus areas, such as areas representative of background conditions, and areas that have the potential to become contaminated in the future. Numerical modeling may be made to support the characterization by simulating groundwater flow and contaminant transport processes believed to occur within the vadose zone. Specific topics include (1) subsurface contamination (i.e., characteristics of past disposal and leakage); (2) surface hydrologic features and processes (e.g., winter rain and snowmelt, water line leaks, infiltration, deep drainage, and evaporation rates); and (3) subsurface geologic and hydraulic features and processes (e.g., stratigraphy, structures, physical properties, geochemistry, and microbiology of the sediments above the water table). Information is needed to better understand the vertical and/or horizontal movement of contaminants to the water table.

Sufficient information will be collected to provide (1) an accurate depiction, at appropriate temporal and spatial scales, of contaminant distributions beneath waste, spill, and disposal sites; (2) early warning of potential surface or groundwater contamination problems so that corrective actions can be taken; and (3) credible numerical simulations that acceptably depict the movement and fate of contaminants in the vadose zone. Information generated by this technical element will support remedial actions, such as the design of surface and subsurface barriers, and in situ remediation techniques. This information also supports decisions regarding mitigative protective measures (e.g., interim surface covers), restrictions on artificial recharge and, therefore, future land use.

A.4 GROUNDWATER

This technical element provides the information, analytic capabilities, and understanding required for technically-sound assessments of Hanford Site impacts to groundwater resources and the Columbia River. The technical scope of the groundwater technical element complements that of the vadose zone element by extending the characterization work into the saturated sediments under the Hanford Site. The saturated zone includes the capillary fringe, the unconfined aquifer, aquitards, and uppermost confined aquifers. Major topics include (1) the distribution of contamination within the saturated sediments; (2) the hydrology, geology, geochemistry, and microbiology of the saturated zone; (3) groundwater flow and transport of contamination; and (4) numerical models that depict the movement of water and contaminants. Data management, presentation, evaluation, interpretation, and reporting are essential components of the technical element.

The geographic scale for groundwater information includes recharge from the uplands to the west of the Hanford Site. Numerical models that represent groundwater movement beneath the Hanford Site require boundaries that may be far removed from the areas of greatest interest, which are the pathways between the contaminant source and the Columbia River. Finer-scale modeling is required to describe and predict flow for specific contaminant plumes, and for interaction by groundwater discharges to the Columbia River.

Information needs include an accurate understanding of current conditions, and the ability to assess potential future conditions for near- and long-term scenarios. Assessment of groundwater impacts must permit differentiating contamination attributable to the Hanford Site from other sources, such as fallout from nuclear weapons testing and other human activities.

A.5 COLUMBIA RIVER

Technical scope associated with the Columbia River ecosystem extends from reference locations upstream of the Hanford Site to downstream locations appropriate for specific aspects of the system assessment. Environments of interest include the riparian zone, near-river groundwater, the hyporheic zone, and the Columbia River water column. Within each, a wide variety of information is needed to define physical, chemical, and biological characteristics.

The scope of this technical element starts with the zone in which groundwater from the Hanford Site meets the Columbia River. Key topics in this zone include mixing, geochemical conditions, preferential pathways, and biological activity. Credible conceptual and numerical models for processes occurring in this zone are crucial to (1) identifying impacts to the river's ecosystem; and (2) quantifying risks to aquatic and human receptors. This zone encompasses near-river groundwater and infiltrated river water (bank storage), and the hyporheos (sediment pore water and biota immediately beneath the free-flowing stream).

Once in the Columbia River, Hanford Site groundwater and any entrained contamination co-mingle with river water and disperse to a wide array of potential receptors. The scope of this technical element relates to information needs associated with the fate and transport of contamination within this river environment. These include the contaminant characteristics (type, nature, concentration, decay/attenuation qualities), physical movement in the dynamic flow of the river, and bioavailability. Interaction with the suspended load of the river, and with biological systems, is key to anticipating the fate of contaminants. Erosion and deposition patterns for the river are major topics for understanding where potential contaminant sinks are located, and where sensitive species and humans are at greatest potential threat of exposure. Understanding how the channel morphology and its distribution of sediments evolve (with time) is key to anticipating future conditions.

The Columbia River technical element scope includes the capability to provide information necessary to accurately and credibly assess of risk posed by Hanford Site contaminants to aquatic, terrestrial, and human receptors in the river environment. Key information needs include identifying (1) locations where contaminants enter a pathway to receptors; (2) various habitats in the river environment; (3) contaminant-sensitive receptors; and (4) exposure pathways to habitats and receptors.

An understanding of contaminant bioavailability is crucial for assessing potential impacts and risk. Contaminant-transfer coefficients and bioaccumulation rates are also needed for contaminant/species combinations of interest. The capability to differentiate Hanford-derived contamination from other sources is a part of this effort, as is analysis of the potential cultural consequences that may result from impacts to the natural resources of the river environment. The assessment of risk considers near-term conditions, as well as conditions extending far into the future.

A.6 MONITORING

The work scope of the monitoring technical element includes sampling and analysis design, logistics, and data management associated with spatial and temporal data for the vadose zone, groundwater, and Columbia River. The new data involve concentrations of radiological and chemical constituents, water level measurements, and other parameters (as required) to support characterization and numerical analyses. New measurements are compared to baselines (and previous trends) to evaluate if new areas of contamination are developing, if existing plumes are changing, and if remediation has had the desired effect.

The need to monitor any portion of the transport pathway between a contaminant source and the Columbia River is described in the vadose zone, groundwater, and Columbia River technical elements. Because not all waste sites and groundwater plumes can be fully monitored simultaneously, it is necessary to selectively monitor. A higher priority may be assigned based on potential or suspected new contaminant sources (e.g., leaks, spills), proximity to the Columbia River, and site-specific needs to support near-term remediation decisions. Monitoring is required to comply with RCRA, CERCLA, the Atomic Energy Act (AEA), and DOE orders.

Monitoring methods include collecting discreet samples of water and soil, in situ monitoring using pressure transducers for water level measurements, specific ion probes for water quality data, and moisture-sensing instruments. Geophysical tools lowered into boreholes are used for radiological monitoring. Monitoring locations include vadose zone boreholes (dry wells), groundwater wells, riverbank seepage sites, aquifer sampling tubes near the river shoreline, porewater sampling tubes in the riverbed sediments, riverbed sediment, and the river water column.

A primary task of monitoring is detecting (1) new sources of contamination; (2) changes in the movement of existing contamination; and (3) changes in the characteristics of contamination. An equally important task is supplying data to evaluate the performance of remedial actions. The geographic scope varies, depending on the requirements defined by other technical elements, but may extend from contaminant source areas on the Hanford Site to locations in the Columbia River downstream of the Hanford Site.

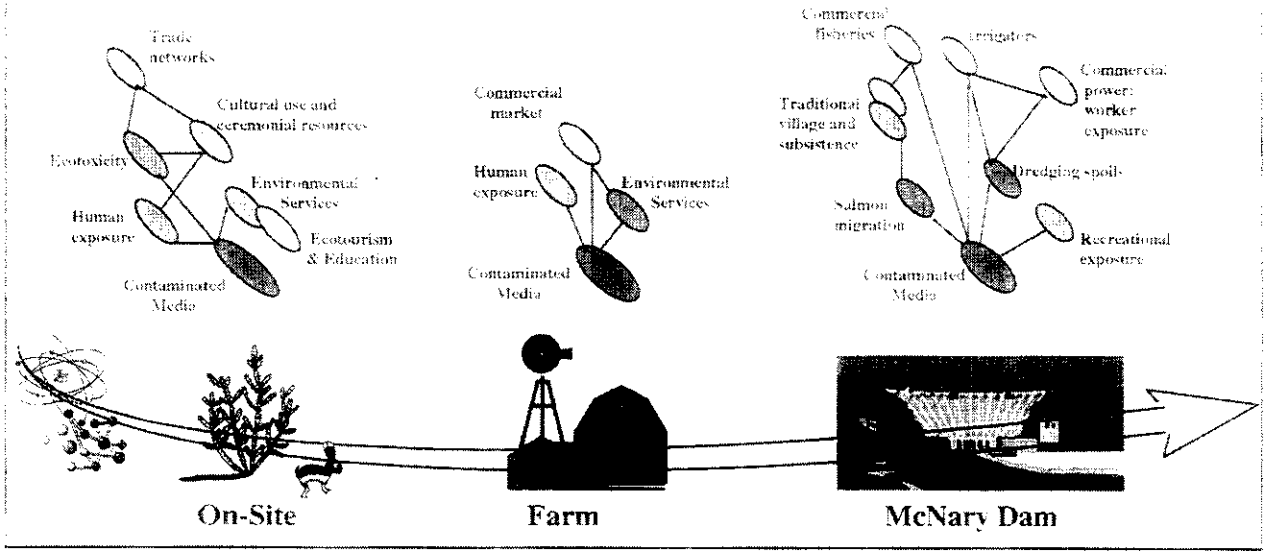
A.7 RISK

The risk technical element receives information from the other technical elements to address stakeholder questions relating to the risks posed by Hanford Site contaminants. Consequently, the questions that must be addressed in the system assessment are identified by the risk technical element.

The starting point for determining stakeholder concerns is the CRCIA Part II requirements, which can only be partially addressed by standard quantitative risk assessment methods. In order to address the breadth of stakeholder concerns, dependency webs have been proposed as a planning option that may be developed for specific classes of location and habitat types, such as the upland region of the Hanford Site, the riparian areas along the Reach, the open river environment (both free-flowing and in the slack water pools), and potentially estuary and coastal habitats. The dependency webs, utilizing a wide range of stakeholder group input, identify the potential impacts associated with contamination reaching receptors at these locations. These potential impacts extend beyond the traditional human health impacts to address impacts to ecosystems and cultural and natural resources, as well as economic impacts. An example of how stakeholder concerns change for different habitats and locations is captured in the dependency webs that are illustrated in Figure A-1. On the Hanford Site itself, stakeholder concerns focus on ecological toxicity and cultural and educational uses of natural resources. Once offsite,

Figure A-1. Dependency Webs for Different Locations.

As contamination moves through different areas, different resources are affected, different impacts occur, and different people will be concerned. In order to answer the questions people are asking, accuracy is more important than complexity, and innovative methods need to supplement conventional modeling tools.



stakeholder concerns shift to include effects on salmon migration, agriculture, power generation, and transportation.

Once the potential impacts to receptors have been defined, exposures, risks, and impacts can be estimated either qualitatively or quantitatively to (a) humans, (b) the environment, (c) specific cultures and quality of life, and (d) selected economies from radioactive and chemical contaminants at those locations. These impacts may be assessed for current contaminant distributions, as defined by monitoring data and information on historical operations, and for potential future conditions. The objectives are to evaluate the effects of various remediation options and land uses.

A variety of qualitative and quantitative tools are needed to conduct these risk assessments because of the relatively large geographic area influenced by the Hanford Site, the complexity of sources and characteristics of contamination, the migration of contaminants through a variety of environmental media, and the diversity of receptors. These tools address the release of contaminants, geochemistry, and transport through a several media (e.g., vadose and saturated zones, river, air, soil), exposures to humans and the ecosystem, human health, ecological, cultural, and economic impacts and risks from the exposure.

Human health risk involves generally accepted exposure pathways and scenarios originally developed and documented by the EPA. Recently, there has been increased interest (e.g.,

CRCIA and the *Hanford Remedial Action Environmental Impact Statement* [HRA-EIS]) in the assessment of "lifestyle" scenarios that may involve non-standard uses of resources and exposure patterns associated with specific groups, such as Native Americans (and others) whose lifestyles are closely tied to the Columbia River.

Ecological risk assessment is not as easily outlined as human health risk assessment, because of the larger number of potential receptors and pathways, which often result in the need for a very location specific analysis. Of particular interest for assessing ecological risk are locations where sensitive habitat and contaminants coexist, and where the potential uptake of contaminants is most likely. A critical location is one where the entry of contaminants into an exposure pathway and/or the food chain is likely to occur. The pathways or mechanisms by which receptors of interest are potentially exposed to contaminants are characterized as an integral part of a risk assessment.

The process of estimating risks to cultures and economies uses the same contaminant location, duration, and concentration information used by the human and ecological risk estimation process. Several models are being developed to address cultural impacts for tribal cultures and communities. These methods are sufficiently well developed, with published proof-of-principle reports, that they can be used by the Integration Project. It is essential, however, that Tribal Nation technical staff be involved in, or actually perform, the evaluation of risks to tribes, their cultures, their economies, and the determination of potentially disproportionate impacts to tribal communities. A standard economic impact analysis will be appropriate for non-tribal economies.

The last step in the risk and impact analyses is to assess cumulative risks and impacts for specific locations and populations. These risks or impacts will be placed into perspective with the other, non-Hanford impacts to the environment.

A.8 REGULATORY PATH

The scope of the regulatory path element involves (1) developing a site-wide approach to the vadose zone, groundwater, and Columbia River assessment that is unified, consistent, and practical; and (2) ensuring that all applicable regulatory requirements are fully addressed by the scope of the associated technical elements. The scope of this element includes the following:

Regulatory Authority. This defines the regulatory authority applicable to assessment activities. The lead regulatory authority and secondary authorities will define the process and requirements for regulatory compliance.

Land Use. In consultation with stakeholders, land use and associated exposure scenarios will be established for the Hanford Site, and the relationships will be defined between land use and remediation for RCRA*, CERCLA, *Model Toxic Control Act* (MTCA), and AEA. The exposure

* Although the term "RCRA" is used throughout this technical element, it is implicit that many elements of the federal RCRA program have been delegated to the state of Washington and are implemented through the state's Dangerous Waste Program.

scenarios will be a key element of the impact assessment. They will be used to define end states for each environmental media. Land use decisions must be made for the Hanford Site before progress can be made towards a unified and cost-effective system assessment.

Constituents of Concern. The full range of RCRA hazardous constituents and CERCLA hazardous substances will be identified to ensure consideration in planning data collection and impact assessment work.

Specific Requirements. Regulatory requirements specifically applicable to an activity will be identified to ensure consistency of application. Regulatory requirements and constraints will be considered early in planning specific work, and will be accorded attention equal to that given to technical requirements and constraints.

A.9 REMEDIATION OPTIONS

The ultimate goal of Hanford Site mitigation and remediation is to (1) prevent further degradation; and (2) reduce the impact of existing contamination on human health and the environment. Various options currently are being implemented or considered to attain this goal. Objectives that guide selection of remedial actions include the following:

Reduce or prevent contamination of the Columbia River.
Remediate areas of soil contamination consistent with land use goals.
Control and/or stabilize sources of contamination.
Contain and/or remove solid waste stored in landfills.
Remediate and/or contain groundwater contamination.

Interim Actions. Interim remediation is undertaken to mitigate a contamination problem prior to obtaining sufficient information to make a final closure or remediation decision. These actions include expedited response actions (ERAs) and interim remedial measures (IRMs). These activities are intended to accelerate cleanup, in order to control further spread of contamination at inactive facilities. Surveillance and monitoring activities at inactive facilities and waste sites are used to verify that an acceptable condition exists until full-scale remedial actions are initiated.

Remediation Alternatives. Selecting an alternative for near-term remediation involves evaluating the available options in light of site conditions and specific types of contamination. Remediation alternatives that have been successfully implemented on the Hanford Site, or that are considered to have potential application, include the following: no action; institutional controls; engineered surface barriers; removal and disposal; and pump-and-treat.

No action is required to be evaluated as a baseline for comparison with other remedial alternatives. For the no-action alternative to be selected, a site (in its current condition) must pose no unacceptable threat to human health and the environment.

Institutional controls involve the use of physical barriers (fences) and deed restrictions on access so as to reduce or eliminate exposure to contamination. Institutional controls are often coupled with groundwater, vadose, surface soil, biotic and/or air monitoring to ensure that exposures are limited by the imposed controls. Many access and land use restrictions are currently in place at the Hanford Site, and will remain during remedial work.

Engineered surface barriers (i.e., caps) function as hydraulic barriers to control the amount of water infiltrating into contaminated media, thus reducing potential leaching of contamination to groundwater. In addition to their hydraulic performance, barriers also function as a physical limit to direct human and biotic interaction with contamination. Barriers are engineered to limit wind and water erosion and, if needed, can control the release of accumulated gases or attenuate radiation.

Removal and disposal involves the excavation of contaminated material and ultimate disposal in a landfill or another environmentally safe configuration. Depending on the nature (e.g., radioactivity levels, hazardous waste classification) of the waste removed, ex situ treatment may be performed prior to disposal.

Removal and disposal are effective because contaminated materials are physically removed; there are no long-term requirements for monitoring and maintenance of the site; and there is greater flexibility in future land use. These methods are easily implemented at sites with shallow contamination. Requirements for safety, monitoring, and sampling are generally well understood. Radioactive waste requires special handing protocols, and may require remotely controlled equipment if radiation levels are sufficiently high to preclude the use of standard construction equipment.

Groundwater pump and treat involves the extraction and ex situ treatment of contaminated groundwater, and can be effective for a variety of contaminants. This alternative can also be used to hydraulically control the movement of contaminants in groundwater, to remove contaminant mass, and/or reduce contaminant concentrations. A variety of ex situ treatment processes, such as ion exchange, carbon absorption, and air stripping, are available to address a wide range of contaminants. Pump and treat is a well-developed and commonly used technology that can be easily implemented. Pump and treat systems have been applied at the Hanford Site to remove contaminant mass and/or control contaminant plume movement. The effectiveness of a pump and treat system to remove contaminants diminishes as contaminant levels decrease and, depending on cleanup goals, a shift to an alternative remediation technology (such as in situ treatment) may be needed.

Other Technologies. In situ treatment technologies include a broad range of processes in which waste, contaminated soil, or groundwater are treated or immobilized in place. This feature is advantageous when exposure or worker safety concerns are significant, such as during excavation or where deep vadose zone contamination exists and excavation or placement of surface barriers is impractical or ineffective. Examples of in situ treatments include in situ vitrification, in situ stabilization, soil vapor extraction, and in situ biotreatment. In situ vapor extraction currently is being used to remediate carbon tetrachloride contaminated soil at the 200-

ZP-2 operable unit. Examples of in situ groundwater treatments include air sparging and reactive walls.

Monitored Natural Attenuation. Natural attenuation is a passive rather than active treatment. It encompasses natural processes to reduce contaminant toxicity, mobility, or volume. Natural attenuation processes include radioactive decay, biodegradation, biological stabilization, volatilization, dispersion, dilution, chemical or biological stabilization, transformation or destruction, adsorption and desorption, and mineral precipitation.

APPENDIX B

HANFORD LETTER OF DIRECTION FOR INTEGRATION PROJECT AUTHORITY

APPENDIX B

Hanford Letter of Direction for Integration Project Authority

Department of Energy
Richland Operations Office
P.O. Box 550
Richland, Washington 99352

064070

NOV 25 1998

Mr. S. D. Liedle, President
Bechtel Hanford, Inc.
3350 George Washington Way
Richland, Washington 99352

Dear Mr. Liedle:

ROLES AND RESPONSIBILITIES FOR THE HANFORD GROUNDWATER/VADOSE ZONE PROJECT

Last year the U.S. Department of Energy (DOE), Richland Operations Office (RL) decided to integrate Hanford Site groundwater and vadose zone work scope under the Assistant Manager for Environmental Restoration (AME). This agreement was documented in the RL memorandum "Changes to the Memorandum of Agreement (MOA) to Integrate Vadose Zone Work," dated August 13, 1997. On December 3, 1997, RL assigned Bechtel Hanford, Inc. (BHI) as the lead contractor for this activity. Subsequently, BHI established a multi-contractor project team to manage and integrate the groundwater and vadose zone work. On April 30, 1998, RL approved the multi-contractor plan (DOE/RL-98-03, "Management and Integration of Hanford Site Groundwater and Vadose Zone Activities") to manage this work. The purpose of this letter is to clarify basic roles and responsibilities for management of the integration project.

Consistent with the RL decision, the RL AME Project Manager for the Groundwater/Vadose Zone Integration Project has been assigned the responsibility to develop the required data and numerical tools for performing effects assessments for Hanford remedial action proposals to regulators. This responsibility includes the integrated planning, authorization, and implementation of required work scope; technical and project change control related to both development and use of the data and numerical tools; and interaction with regulators, stakeholders, and tribes to accomplish the mission. The authority to accomplish this mission is embodied in the existing delegation to AME to direct the work of the project integrating contractor, Bechtel Hanford, Inc., and in this letter which establishes the roles and responsibilties of AME and BHI in working with other site projects through the appropriate RL office. Issues that arise in implementation of this letter will be brought to the project Executive Council (which consists of senior RL and contractor managers) for resolution. Should the Council not reach agreement, the issue will be referred to the RL Site Management Board or to me for a final decision.

The attached table provides further definition of the roles and responsibilities for the AME organization and BHI as the integrating contractor as well as the "core projects" which are DOE Hanford projects performing work scope included in the integration effort. The Groundwater/Vadose Zone Project Management Plan and associated project procedures will provide details on how AME, BHI, and the multi-contractor project team will perform the duties assigned to them in this matrix as well as how the core projects will interact with the team. All duties assigned will be conducted consistent with the current site contracts.

064070

Mr. S. D. Liedle -2- NOV 25 1998

RL is managing the site as a set of major projects with a defined mission. Each of the core projects has some direct or indirect association with the Groundwater/Vadose Zone effort and some of these projects directly support one of the Hanford Site major projects. RL believes that it is necessary that those projects directly supporting a major project continue to be directly managed by the project which they support. In those areas where groundwater/vadose zone decisions are being made or site impacts are being assessed, AME and BHI will provide necessary direction through the appropriate RL project office consistent with current site contracts.

This management structure requires close cooperation among RL and contractor staff. I am holding each of you and your contractors accountable to work together and, where necessary, overcome contract and lines of authority constraints in finding ways to make this effort successful. I will be reviewing progress and issues in weekly meetings with the project team. This activity has a high priority on the Hanford Site and is one of the key components in completing site remediation.

Please provide a copy of this letter and attachment to your staff and subcontractors involved in groundwater/vadose zone integration activities. If you have any questions, contact me or your staff may contact Mr. Rich Holten on 376-3963.

Sincerely,

John D. Wagoner
Manager

RP:RAH

Attachment

GROUNDWATER/VADOSE ZONE INTEGRATION PROJECT
AUTHORITY MATRIX

Rev 2, 10/28

ACTIVITY	CORE PROJECT	GW/VZ PROJECT (DOE AME + BHI)	BASIS FOR GW/VZ ACTION
[illegible]			
Sitewide Integrated Priority List	Participates/reviews/SMB approves	Participates/reviews	
Project Priority List	Prepares&submits/SMB approves	Concurs	Concurs consistent with GW/VZ LRP/Baseline & Gaps/Deficiency Prioritization
Work Plan Guidance	DOE Project prepares/approves	Concurs	Concurs consistent with GW/VZ LRP/Baseline & Gaps/Deficiency Prioritization
Core Project Detailed Work Plan	Prepares/DOE project approves	Participates/concurs	Schedule consistent with LRP Technical review per criteria
Core Project Change Requests	Prepares/DOE project approves	Concurs	Level of detail TBD; Concurrence basis same as for Detailed Work Plan plus consideration of acceptability of sitewide impacts
Core Project Baseline/MYWP	Prepares/DOE project approves	Participates/concurs	Concurs consistent with GW/VZ LRP/Baseline
Technology Proposals	Co-Prepares/concurs	Approves	Approval consistent with S&T roadmaps/LRP
GW/VZ Long Range Plan/Baseline	Co-Prepares/concurs	Approves	
GW/VZ Integrated DWP	Co-prepares/concurs	Approves	Prepared to level of detail set by GW/VZ
GW/VZ Project Monthly Report	Co-prepares/concurs	Approves	Prepared to level of detail set by GW/VZ
[illegible]			
Conceptual Model - Sitewide	Participates/concurs	Approves	
Conceptual Model - Site Specific	Prepares/approves	Participates/concurs	
GW/VZ Specification	Participates/concurs	Approves	
System Assessment Capability	Participates/concurs	Approves	
Sitewide Parameter Database	Participates/concurs	Approves	
Science & Technology Road Maps	Participates/concurs	Approves	
Sitewide Impact Analyses	Co-prepares/concurs	Submits/Reg approves	
Site specific parameters	Prepares/concurs	Participates/approves	Concurs for consistency with conceptual model/sitewide parameters and technical basis
Core Project Impact Analyses	Prepares/submits/Reg approves	Concurs	Same as above plus concurs on which numerical model used and how model used
Core Project Primary Documents	Prepares/submits/Reg approves	Concurs	Concurrence based on consistency with sitewide regulatory approach, technical basis, and consistency with sitewide knowledge base
Other Core Project Technical Documents	Prepares/approves	Reviews	
[illegible]			
Sitewide Issues/Interactions	Supports	Leads	
Core project Issues/Interactions	Leads	Reviews/supports	
TPA negotiations/issues	Prepares/submits/Reg approves	Concurs	Concurs for consistency with sitewide regulatory approach and LRP/baseline
Expert Panel interactions	Supports	Leads	
National Laboratory Interactions/support	Supports	Leads	

APPENDIX C

MATRIX COMPARISON OF PROJECT DOCUMENTS TO GROUNDWATER PROTECTION MANAGEMENT PLAN (GPMP) REQUIREMENTS

APPENDIX C

Matrix Comparison of Project Documents and Groundwater Protection Management Plan (GPMP) Requirements

This attachment provides a comparison between the requirements for a GPMP and the GW/VZ Project documentation that will address specific GPMP requirements. The GW/VZ Project will address the requirements through the *Project Specification*, the PMP, and the *Integrated Baseline*, which includes the DWP, implementation schedules, and other supporting documents. Designations included in the table are:

"A" – designates where the requirement will be primarily addressed.

"B" – designates where summary or additional information relative to the requirement can be found.

( ) – designates the section in the document where the information is located.

GROUNDWATER PROTECTION MANAGEMENT PLAN (DOE ORDER 5400.1) AND THE CORRESPONDING INTEGRATED PROJECT DOCUMENTATION			
Requirements from DOE Order 5400.1	**Project Specification**	**Project Mgmt. Plan**	**Integrated Baseline**
1. Groundwater Protection Management Program.			
a) Document the groundwater regime with respect to quantity and quality.	B (2.2.3, App. G.1.3)		A
b) Design and implement a groundwater monitoring program to support resource management and comply with applicable environmental laws and regulations.	B (App. G.1.3)		A
c) Establish a management program for groundwater protection and remediation, including specific Safe Drinking Water Act (SDWA), Resource Conservation and Recovery Act (RCRA) and Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) actions.	B (3.3.2, 5.1, App. E)	B	A
d) Summarize and identify areas that may be contaminated with hazardous substances.	B (2.0)		A
e) Provide for control of sources of these contaminants.	A (3.0, 5.0)	B	B
f) Provide for a remedial action program that is part of the CERCLA program required by DOE 5400.4.	A (3.1)	B	B
g) Provide for decontamination and decommissioning, and for other remedial programs contained in DOE directives.	A (3.0)	B	B

GROUNDWATER PROTECTION MANAGEMENT PLAN (DOE ORDER 5400.1) AND THE CORRESPONDING INTEGRATED PROJECT DOCUMENTATION			
Requirements from DOE Order 5400.1	**Project Specification**	**Project Mgmt. Plan**	**Integrated Baseline**
2. Groundwater Monitoring Program.			
a) A Groundwater Monitoring Plan shall be developed as a specific element of all environmental monitoring plans, and the Groundwater Protection Management Program. The Groundwater Monitoring Plan shall identify all DOE requirements and regulations applicable to groundwater protection, and will include a monitoring strategy. The elements of the Groundwater Monitoring Program shall be specified (sampling plan, sampling, analysis, and data management), along with the rationale and purpose for selecting these elements.			A
3. General Requirements of the Groundwater Monitoring Program			
a) Obtain data for the purpose of determining baseline conditions of groundwater quality and quantity.			A
b) Demonstrate compliance with the implementation of all applicable regulations or DOE orders.			A
c) Provide data to permit the early detection of groundwater pollution and contamination.			A
d) Identify existing and potential groundwater contamination sources and maintain surveillance of these sources.			A
e) Provide data upon which decisions can be made concerning land disposal practices and the management and protection of groundwater resources.			A
f) Identify site-specific characteristics that shall determine monitoring needs.			A
***Technical Standard for GPMP**	**Project Specification**	**Project Mgmt. Plan**	**Integrated Baseline**
1. Establish overall site-wide groundwater protection and remediation goals.			
a) Write goal statements that (1) provide specific, site-wide goals for setting and reviewing environmental objectives and targets; (2) account for present and future uses of the groundwater resource; (3) are measurable in terms of progress; and (4) are documented, implemented, maintained, and communicated to appropriate DOE and contractor staff.	A (5.2)		
b) Relate goal statements to site-specific groundwater and related conditions.	A (4.0, 5.2)		
c) Determine whether the groundwater protection and remediation approach will be risk-based or resource-based.	A (5.1, 5.3, 6.0)		
d) Evaluate progress toward accomplishing the goals.			A
2. Ensure that all Federal, State, and other requirements are being met.			
a) Identify applicable requirements.	A (App. E)		
b) Identify the organizational unit responsible for compliance with these requirements.		A	
c) Establish procedures.		A	
d) Document decisions to ensure compliance.		B	A

GROUNDWATER PROTECTION MANAGEMENT PLAN (DOE ORDER 5400.1) AND THE CORRESPONDING INTEGRATED PROJECT DOCUMENTATION			
Requirements from DOE Order 5400.1	**Project Specification**	**Project Mgmt. Plan**	**Integrated Baseline**
3. Provide a mechanism for integrating groundwater protection with all site-wide operations.			
a) Coordinate site-wide programs affecting groundwater. These programs may include, but are not limited to, the following: waste management (including low-level waste performance assessment); environmental monitoring; environmental remediation; facilities and operations; underground storage tanks; future-use (e.g., land-use) planning; and water use/disposal.	B (5.0, 6.0)	A	B
b) Establish a work group or committee consisting of appropriate representatives of both RL and contractors.		A	
c) Identify site-wide organizations and individuals with groundwater protection responsibilities.		A	
d) Establish regular communication mechanisms between all site-wide programs with groundwater responsibilities.		A	
e) Develop a site-wide self-assessment.		A	
4. Identify potential sources of groundwater contamination.			
a) Establish a source-water protection program that sets priorities to identify sources of contamination and current or potential uses of groundwater; identifies current or potential uses of groundwater; identifies potential sources of contamination; and develops a system for ranking potential sources by degree of risk.	B (3.0)	A	B
b) Inventory Class V miscellaneous injection wells.			A
c) Inventory injection wells under other classes.			A
d) Identify miscellaneous waste streams.			A
e) Identify the location of potential contaminants relative to particularly valuable groundwater or to groundwater that is highly vulnerable to contamination.			A
5. Identify control strategies for preventing future contamination and remediating existing conditions.			
a) Identify control strategies for prevention of future contamination. Aspects of many programs may be relevant to preventing future groundwater contamination (e.g., pollution prevention; waste minimization; spills prevention, control, and countermeasures; well closure and abandonment; purge water management; and management of other investigation derived wastes).	B (3.0)	B	A
b) Identify control strategies for integration of waste management.	B (3.0)	B	A
c) Identify control strategies for integration of environmental remediation	B (3.0)	B	A
6. Provide a network for monitoring groundwater quality.			
a) The design criteria used in developing the network should be clearly identified.	B (3.3.2, App. G.1.6)		A
b) Data management and reporting systems should be maintained in a coherent site-wide manner.		A	

GROUNDWATER PROTECTION MANAGEMENT PLAN (DOE ORDER 5400.1) AND THE CORRESPONDING INTEGRATED PROJECT DOCUMENTATION			
Requirements from DOE Order 5400.1	**Project Specification**	**Project Mgmt. Plan**	**Integrated Baseline**
c) On-going management (assessment and modification) of the monitoring network is needed to address changing contaminant distributions, site conditions, and budgets.	B (3.3.2, 5.0)	B	A
d) Identify innovative monitoring techniques that have the potential to provide better quality and less expensive data.	B (App. G.1.6)		A
7. Provide basic technical data on subsurface conditions.			
a) Identify subsurface investigation data needs that support the groundwater monitoring, resource evaluation, waste management, and environmental remediation objectives.	A (App. H., App. I)	B	B
b) Prioritize new studies and coordinate between areas or programs.	B (5.0, App. I)	B	A
c) Identify or establish a subsurface studies information repository.		A	
8. Identify specific technical methods for site-wide use to achieve comparable groundwater information.			
a) Identify standard subsurface investigation methods to be used site-wide, ensuring comparable protocols with acceptable QA/QC procedures, and which meet minimum data quality requirements.		B	A
b) Establish a process for adopting site-wide standard methods.		A	
c) Use best management practices where appropriate.		A	
d) Integrate procedures and methodology information with database design.		A	
9. Incorporate site outreach program efforts into groundwater protection programs.			
a) Define and fund an outreach program.		A	B
b) Identify external audiences and their interests.		A	
c) Decide on methods of communication.		A	
d) Plan a response system.		A	
e) Provide groundwater information to interested parties.		A	
f) Provide meaningful opportunities to participate in the process of developing the GPMP.		A	

**GPMP Standards Source: DOE Draft Guidance for Preparation of Groundwater Protection Management Plans*

• This requirement will be addressed in the Project Specification.

APPENDIX D

OPERATIONAL HISTORY OF WASTE DISPOSAL AT THE HANFORD SITE

APPENDIX D

Operational History of Waste Disposal at the Hanford Site

Note: The materials in this section are taken from "Waste Management" (D. H. Deford), which can be found at http://www.hanford.gov/docs/rl-97-1407/waste_mgnt/index.htm.

HIGH LEVEL RADIOACTIVE LIQUID WASTE

According to the US Department of Energy, high level radioactive waste is "highly radioactive waste material resulting from the reprocessing of spent nuclear fuel. It includes liquid waste produced directly in reprocessing and highly radioactive solid waste derived from the liquid.

Sources and Characterization

Five chemical separations plants were Hanford's primary sources of high level radioactive waste, although small additional quantities came from the Plutonium Finishing Plant and elsewhere. T and B Plants were the pioneer plants that operated from the mid 1940s through 1956. Improved technologies led to the Reduction-Oxidation Plant (REDOX) that operated from 1952 to 1967, and to the Plutonium-Uranium Extraction Plant (PUREX) that operated from 1955 to 1988. U Plant (221-U) operated from 1952 until 1958 to recover uranium from T and B Plant high level radioactive waste. All plants used complex, toxic and corrosive chemicals in their separation processes.

At each separations plant, operators dissolved the irradiated uranium fuel rods in nitric acid, first to remove the protective outer jacketing, and then to reduce the uranium metal to a liquid state. They then extracted plutonium from the uranium nitrate solution and sent it to the Plutonium Finishing Plant to be purified into plutonium metal.

Each step of the plutonium extraction process produced high level radioactive waste that was transferred through underground lines to large underground storage tanks located in tank farms near each separations plant. Much of this high level radioactive waste continues to be in storage today.

Each subsequent separations plant employed technologies that reduced the quantity of high level radioactive waste per unit of irradiated fuel processed. For instance, PUREX generated only about 250 gallons of high level radioactive waste per ton of irradiated fuel, a major improvement over the 10,000 gallons per ton generated by T and B Plants. However, production capacity also increased with PUREX processing an amazing 33 tons of fuel per day, compared with T or B Plant's mere 30 tons per month in their best and final years. Ultimately, nearly 245 million gallons of high level radioactive waste, containing 210 million curies of radioactivity, were

transferred to Hanford's 177 underground storage tanks from the five separations plants (Anderson 1990, Gephart and Lundgren 1997).

B and T Plants used bismuth-phosphate chemistry in a batch process employing repeated dissolution, precipitation, and centrifugation, which produced about 10,000 gallons of high level radioactive waste per day. Process chemicals included nitric acid, phosphoric acid, bismuth phosphate, sodium dichromate, bismuth nitrate, potassium permanganate, sodium nitrate, and others. All of these, plus aluminum, uranium, plutonium, and numerous fission products were included in the high level radioactive waste. The highly acidic waste was acid neutralized with large quantities of sodium hydroxide before transfer to the storage tanks (Anderson 1990).

REDOX came on line in 1952 with an improved separation process and different chemistry. Its solvent extraction process used methyl isobutyl ketone (hexone), aluminum nitrate, nitric acid, sodium dichromate, and other such chemicals. REDOX high level radioactive waste included all of these chemicals plus solutions containing ferrous ions.

PUREX became operational in 1955 as Hanford's final and most advanced separations plant. Designed to separate plutonium, uranium and neptunium from irradiated reactor fuel, PUREX used a continuous flow extraction process, involving tri butyl phosphate, saturated kerosene, nitric acid, oxolic acid, ammonium fluoride, ammonium nitrate, and numerous other chemicals. All became part of the PUREX high level radioactive waste stream. After passing through waste concentrators, a reduced and highly concentrated waste volume of 250 gallons per ton of processed uranium was achieved. Production, however, increased to a dramatic 33 tons per day, largely offsetting the net waste volume decrease that might otherwise have been realized (Anderson 1990).

High level radioactive waste is difficult to characterize. The differing chemical separation processes employed over time produced twenty-six different waste streams that were chemically dissimilar but which were combined in the underground tanks to form even more complex waste combinations. Exposure to air, heat, cascading, settling, radioactive decay, kinetics, and subsequent chemical treatments further complicated the nature of the high level radioactive waste with radical differences developing from tank to tank. The addition of sodium hydroxide, an acid neutralizer, caused portions of the waste to form solid particles and to separate into layers. Evaporation of liquids led to salt cake and slurry formation, causing further uneven distribution of chemical compounds and radioisotopes. Waste was transferred from tank to tank as it went through subsequent treatment and isotope recovery campaigns. All of these factors contributed to waste complexity and to the difficulty of sampling and characterizing in order to plan the remediation of the high level radioactive waste.

High level radioactive waste characterization is further complicated by the activities of U Plant, which was used from 1952 to 1958 to recover valuable uranium from T and B Plant high level radioactive waste. U Plant was originally constructed as a bismuth-phosphate chemical separations plant, identical to its sister plants, B and T. But its capacity proved unnecessary and it served only as a training facility until 1952 when it was redesigned for its new mission.

Since B and T Plants extracted only plutonium from the uranium fuel elements, the resulting high level radioactive waste remained rich in uranium. The high value of uranium drove a decision to convert U Plant to a uranium recovery mission. Using tri butyl phosphate and saturated kerosene chemistry, U Plant reprocessed T and B Plant high level radioactive waste to recover uranium. Its waste stream included tri butyl phosphate, saturated kerosene, nitric acid, oxalic acid, and other chemicals. Unfortunately, the U Plant uranium recovery process generated about twice as much waste as it processed, placing additional strain on the storage tank farms which were nearing capacity.

Facility Descriptions

Facilities associated with high level radioactive waste include the five chemical separations plants, the lines and encasements used to transfer high level radioactive waste about the 200 Areas, diversion stations, storage tanks, and evaporator buildings.

The primary method used to transport high level radioactive waste across the Hanford Site was through underground process lines that ran, for the most part, through concrete encasements. Most process lines are 3-inch diameter, stainless steel pipe with welded joints. Encasements are underground concrete fixtures designed to contain and protect from one to seven process lines. The encasements vary in width, depending on the number of lines within them. Diversion stations located at the process facilities and tank farms permit rerouting of high level radioactive waste through different lines to alternate locations.

For high level radioactive waste, the lines carried the liquid to underground storage tanks, clustered into tank farms. Storage tanks are of two types. Both types, single-shell and double-shell tanks, are cylindrical shaped concrete structures with carbon steel inner. Single-shell tanks have a single inner liner while double-shell tanks have two liners with a space between them. This space provides a pathway by which leakage from the inner liner may be trapped, collected, detected, and recovered. Leakage has occurred only from single-shell tanks.

Single-shell tanks are generally smaller but more numerous than double-shell tanks. Starting in 1945, 149 single-shell tanks were constructed, providing 94 million gallons of storage capacity. They range in capacity from 55,000 to 1 million gallons and are buried with their upper surfaces 6 to 11 feet below grade. The earth cover provides shielding from the intense radiation of the high level radioactive waste, permitting tank farm workers to move about the areas above the tanks. Numerous and various openings exist in the tank dome to accommodate vents, filters, detection tubes, probe access wells, pumps, cameras, and the many kinds of instrumentation necessary to monitor content of the tanks.

The 28 newer double-shell tanks provide a storage capacity of 31 million gallons. They range in size from 1 to 1.1 million gallons and are buried 7 feet below grade. Similar openings exist in the tank dome to provide instrumentation, process, and sampling access to tank contents.

To reduce the volume of waste, operators sent the waste from the tanks to the waste evaporator buildings. Waste evaporator buildings are large, rectangular concrete structures. The evaporators were steam-heated containers, which boiled the liquid out of the particulates, leaving a condensate from the evaporated liquid and concentrated slurry. The condensate could be treated as low level liquid waste and so was disposed of in nearby trenches or cribs. Evaporation generated thick, high level radioactive waste slurry that was returned to the high level radioactive waste underground storage tanks, where it cooled and formed salt cake. Approximately 200 million gallons of liquids were evaporated from high level radioactive waste storage tanks in this manner (Gephart and Lundgren 1997).

Waste Minimization

Waste minimization has been a key element of Hanford's high level radioactive waste management program. Reducing the volume of high level radioactive waste has taken several forms, the most successful being concentrating waste by REDOX and PUREX and evaporating off the liquid. Also, cesium-137 was scavenged from the high level waste, which changed its designation and allowed it to be handled as a low level waste. A chronological description of these waste minimization and other waste management activities demonstrates the importance in reducing the volume of high level radioactive waste to be stored in the limited underground tank resource.

1944-1945	First alkaline slurries of high level radioactive waste were transferred from T and B Plants to the 64 original, underground tanks. Waste was cascaded through a series of tanks to allow solids to settle out in the earlier tanks and only the supernatant liquid (liquid left on the surface) to reach tanks at the end of the cascade. T and B Plants originally produced over 10,000 gallons of high level radioactive waste for each ton of uranium processed.
1948	As underground tank storage capacity became strained, authority was granted to dispose of a portion the high level radioactive liquid waste from the T and B plants in the soil after cascading through three tanks.
1947-1948	42 new single-shell tanks constructed.
1949	Hot Semiworks (C Plant) began operations to pilot technologies for REDOX and PUREX processes and generated high level radioactive waste.
1950-1952	18 new single-shell tanks constructed.
1951	242-T and 242-B Evaporators began processing T and B Plant high level radioactive waste stored in tank farms to reduce volume by boiling off the liquid. Together they processed over 16 million gallons of waste, achieving over 80 percent reduction in volume. The concentrated waste was returned to the storage tanks and the evaporated condensate was disposed of in the soil.

1952 U Plant began a 2-year uranium recovery campaign, generating between 5,500 and 9,200 gallons of waste per ton of uranium in 1952. Waste evaporators reduced this rate to 3,600 gallons but could process only about 700,000 gallons per month, while U Plant generated over 1.7 million gallons per month of high level radioactive waste. Scavenging of U Plant high level radioactive waste with potassium ferrocyanide to settle out cesium-137 permitted disposal in the soil of 11.6 million gallons of relatively inactive supernatant liquid. Another 29 million gallons of high level radioactive waste were disposed of in the soil after scavenging at U Plant removed long half-life fission products (Anderson 1990).

Cesium-137 scavenging continued for many years with about 41 million gallons of supernatant liquid discharged in the soil. About 150 tons of ferrocyanide are thought to be contained in 18 underground tanks (Gephart and Lundgren 1997).

1952 REDOX began operation, generating high level radioactive waste at a rate of 4,378 gallons per ton of uranium in 1952.

1953 Self-concentration was approved for REDOX high level radioactive waste at S Tank Farm. Self-concentration involved disposing of vapor condensates in the soil instead of returning it to the underground tank. Over the life of the REDOX Plant, self concentration and REDOX process improvements reduced REDOX high level radioactive waste generation rates from 4378 gallons per ton of uranium in 1952 to 594 gallons per ton of uranium by 1964 (Anderson 1990).

1953-1955 21 new single-shell tanks constructed.

1954-1956 In addition to disposing of the low level liquid waste in the soil, the sediment on the bottom of the evaporators was also disposed of as low level waste. From 1954-1956, 4.8 million gallons (10,200 curies) of high level radioactive supernatant liquid waste and 1.9 million gallons (11,600 curies) of evaporator sediment from the B and T plants were disposed of in the soil. Disposal was limited to areas of soil capable of retaining liquid without its penetrating through to the water table (Anderson 1990).

Chemical scavenging of high level radioactive waste from the B and T plants was also accomplished during this period. Ferrocyanide compounds were added to high level radioactive waste to cause cesium-137 to settle out, thus allowing the resultant cesium-free supernatant liquid to be disposed of in the soil. From 1954-1956, 3.1 million gallons were disposed of in this manner. In total, these waste volume reduction efforts reduced the high level radioactive waste volumes in underground storage from the B and T plants by a factor of 3.25, reducing net waste generation from 17,000 gallons per ton of uranium to 5,240 gallons per ton of uranium (Anderson 1990).

1955	PUREX began operating, eventually generating high level radioactive waste at a rate of 250 gallons per ton of uranium and processing 33 tons of uranium per day. PUREX high level radioactive waste was sufficiently concentrated that its heat producing fission products caused the waste liquid to boil. This self boiling accelerated to a point in 1957 that boil off reached 10 gallons per minute, and it became necessary to add water to the waste liquids to maintain a reasonable level (Anderson 1990). Self-boiling ended the practice of cascading. All PUREX high level radioactive waste was acid neutralized with large quantities of sodium hydroxide, greatly increasing the waste volume.
1963-1964	4 new single-shell tanks constructed.
1966	Thorium recovery campaign generated 1.4 million gallons of high level radioactive waste.
1968-1988	28 new double-shell tanks constructed.
1968-1978	B Plant operated to recover cesium and strontium. This process recovered strontium-90 from high level radioactive waste sludge and cesium-137 from high level radioactive supernatant liquid waste stored in underground tanks. Removal of these isotopes from the high level radioactive waste had the effect of reducing the heat generating capacity of the waste. The strontium and cesium isotopes were encapsulated for the Oak Ridge National Laboratory isotope program. Remaining waste was evaporated with condensates disposed of in the soil and the concentrates returned to underground storage. A large inventory of encapsulated strontium and cesium remains stored at the 200 East Area Waste Encapsulation and Storage Facility.
1973-1976	Two new evaporator plants, 242-S and 242-A came online. 242-A remains operational today.

Over the history of the Hanford Site, the volume of high level radioactive waste that was stored was reduced by almost 80 percent. Of the approximately 245 million gallons of high level radioactive waste generated and stored from all processes, approximately 55 million gallons remain in the underground storage tanks today, awaiting treatment and permanent disposition. Approximately 190 million gallons were removed through the methods such as evaporation and scavenging or through tank leakage. (Gephart and Lundgren 1997, Anderson 1990).

Incidents

Numerous incidents relating to high level radioactive waste have occurred over the operating history of the Hanford Site. Two examples of incidents are given here to demonstrate the challenge and complexity of managing high level radioactive waste: a violent chemical reaction at a tank farm and leaking transfer lines.

One type of incident was a violent chemical reaction that occurred in 1953 in an underground vault at the U Tank Farm, causing surface contamination in the area adjacent to the vault. Cleanup crews placed lead sheeting over the contaminated area and covered the sheeting with clean soil to prevent spreading the contamination (GE 1953).

Another type of incident was leaks from transfer lines. Transfer line leaks occurred when line sections separated or when temporary connecting jumpers loosened, causing contamination of the soil adjacent to the leak sites. Because the resulting liquid contaminate was quickly absorbed by the gravel soil, cleanup crews typically remediated the problem by removing the contaminated soil for burial elsewhere or covering the contaminated area with an overburden of clean soil (Maxfield 1979).

An example of such a line leak occurred near T Plant in 1955 when leaking contaminants formed a pool on the surface that produced radiation readings of 100 rads/hour near the surface. The spilled liquids were allowed to soak into the soil which was then covered with fresh soil and then with asphalt (Maxfield 1979).

Storage Tank Leakage

Due presumably to the corrosive nature of high level radioactive waste, the temperature ranges generated by decaying fission products, and the aging of the storage vessels, some of the single-shell underground storage tanks have begun to leak. While the actual mechanism of leakage is uncertain, it seems probable that the causes include stress, corrosion, cracking, and mechanical tearing of the liner (Anderson 1990). Sixty-seven single-shell tanks (but no double-shell tanks) are known or suspected to have leaked.

The single-shell tanks are steel-lined concrete vessels with a design life of 20 years. That life has been exceeded by over 30 years and will have been exceeded by 50 years before workers can remove all waste by 2018 in accordance with the Tri-Party Agreement (Ecology 1994). Despite the 20-year life expectancy, leakage of the single-shell tanks began with a 55,000-gallon leak in 1956, only 10 years after the first tanks were built. The most severe tank leak occurred at the T Tank Farm in 1973 when 115,000 gallons of high level radioactive waste were released in the soil.

As tanks continue to age, additional instances of leaking are likely to occur. As of 1995, as much as 1 million gallons of waste may have entered the soil beneath the tanks. This volume is estimated to contain as much as 1 million curies of radioactivity, mostly from cesium-137 (Gephart and Lundgren 1997). Recent analyses identified that the original estimates are understated (Agnew, 1998).

Detecting leaks is difficult. The depth at which the underground tanks are buried, the hazardous nature of high level radioactive waste, and the impossibility of fully emptying tanks makes direct tank inspection nearly impossible. Workers must rely on indirect means to detect and gauge tank leakage by comparing measurements over a period of time. Approximately 800 vertical monitoring wells (dry wells) have been drilled near the single-shell tanks. Radiation readings

taken at different depths in the wells give indications of leakage that may have occurred. Lateral wells drilled laterally to extend beneath the tanks are also used (Gephart and Lundgren 1997).

In addition, groundwater monitoring wells are placed at hundreds of locations to detect and measure contaminants that may reach the underlying aquifer. Environmental monitoring has determined that the groundwater under the B-BX-BY tank farms, located in the 200 East Area, has been contaminated with chemical and radiological contaminants either from leaking tanks or spills (DOE 1998a).

When tanks are discovered to have leaked, cleanup crews applied several remedies. Waste was transferred to sound, usually double-shell tanks. Diatomite was added to some tanks to solidify the remaining liquids. Finally, tank evaporators were used to further reduce the fluid levels and minimize further leakage to soil.

LOW LEVEL RADIOACTIVE LIQUID WASTE

Low level radioactive waste is defined as any radioactive waste not classified as high level or transuranic waste, spent nuclear fuel, or byproduct material. It is typically contaminated with small amounts of radioactivity dispersed in large amounts of material, but some high activity and/or high concentrations can exist. Low level radioactive waste may exist in liquid or solid form. This section discusses low level radioactive liquid waste. Low level radioactive solid waste is discussed in the following section.

All Hanford program areas generated low level radioactive liquid waste that was disposed of into the soil near the facility generating the waste or into the Columbia River. Several methods were devised to dispose of low level radioactive liquid waste in the soil, including open ponds and trenches, reverse wells, French drains, and cribs. Some methods were discarded due to adverse environmental impacts. The method used was dependent on the degree of waste concentration and/or the presence of radioisotopes that gave off high-energy radiation. The following sub-sections discuss how these methods were used to dispose of low level radioactive liquid waste generated from the various Hanford Site areas.

100 Areas

Hanford production reactors generated low level radioactive liquid waste that was disposed of into the soil through cribs and trenches or directly into the Columbia River through effluent lines.

The eight original reactors used vast quantities of Columbia River water to cool the reactor cores to safe operating temperatures. This cooling water created the greatest volume of low level radioactive liquid waste. Hanford's ninth reactor, N Reactor, used a different cooling system design that did not discharge cooling water directly into the river.

The purified water entered the reactor cores at flow rates up to 200,000 gallons per minute. Passing in direct contact with the reactor fuel elements, the cooling water carried away heat created by the fission processes occurring in the fuel, and maintained the core temperature at desired levels. At exit, the water temperature had been raised to near boiling (90-95 C).

The high neutron flux of the reactor core activated elements in the cooling water, creating such isotopes as calcium-41, chromium-51, and zinc-65. The water was also contaminated with activation products from the reactor core and with fuel element fission products such as strontium-90 and cesium-137, and transuranics, such as uranium and plutonium when fuel cladding failures occurred (DeFord and Einan 1995). The radioisotopes of greatest environmental impact from this process were sodium-24, neptunium-239, arsenic-76, zinc-65, and phosphorus-32 (HEDR 1994).

After passing through the reactor, the cooling water was transferred through effluent lines to a retention basin located near the river where it was held for 2.5 to 4 hours, allowing it to cool and short-lived radionuclides to decay. From the retention basin, the water passed through an outfall structure and large underground followed by underwater pipes to the river bottom at mid channel. The outfall structure was designed to divert effluent to an open concrete spillway if the underground line were to become plugged.

The quantity of radionuclides released to the Columbia River in reactor effluent began high and increased over time. From five radionuclides alone, over 200,000 curies were released to the river in each of the first two full years of reactor operations, 1945 and 1946. This rate doubled three times between 1945 and 1960 to over 2 million curies in 1960. The volume of reactor effluent had increased ten fold as cold war demands for plutonium production led to reactor power level increases and the construction of five additional reactors. The year 1960 represented the all time high rate, and annual deposits of low level radioactive liquid waste to the river began to diminish after that as the reactors without closed-loop systems began to shut down at an approximate rate of one per year (Clukey 1957, HEDR 1994). Table 2-6.2 is a summary of curies released to the Columbia River from five radioactive materials between 1944-1972. For a more complete listing of radionuclides released to the Columbia River, see Table 2.3-9 in the Reactor Operations Section.

Table 2-6.2. Annual Summary of Curies of Five Radioactive Materials Released to the Columbia River from the Hanford Site, 1944-1971 (Heeb and Bates 1994, p. vii)

Year	Sodium-24	Phosphorus-32	Zinc-65	Arsenic-76	Neptunium-239
1944	905	216	708	1178	17060
1945	34900	2890	10518	20340	192100
1946	28360	2190	8688	14212	153400
1947	25450	1860	7457	12319	127840
1948	33970	2219	8362	15772	151100
1949	46870	3175	11713	24660	214600
1950	72590	4027	14546	30510	279900
1951	99020	3333	11153	23660	261700
1952	132690	5050	9037	34740	259000
1953	202500	8688	8691	98940	316200
1954	243400	7261	21910	91380	391600
1955	318000	7184	26670	139530	419400

Year	Sodium-24	Phosphorus-32	Zinc-65	Arsenic-76	Neptunium-239
1956	407800	7722	31940	134280	450300
1957	644700	12325	27560	212130	500100
1958	751400	18484	27180	293300	422300
1959	1019000	17993	32030	218400	275100
1960	1382900	19490	42720	236900	354800
1961	1096300	21526	47110	166890	243910
1962	1094200	13845	56010	86660	257100
1963	887900	11738	14920	100630	211800
1964	960000	12311	15710	114480	247500
1965	764500	12126	13379	124600	168400
1966	613000	7365	9656	74600	78950
1967	671900	10118	15360	94010	114970
1968	499500	8632	7734	71670	99790
1969	359200	5478	6451	61250	59820
1970	178041	1759	3394	20253	36879
1971	13200	235	386	2440	3540
Sum	12582196	229239	490993	2519734	6309159

N Reactor used a closed-loop cooling system that did not discharge cooling water directly to the river. Instead, water heated by the reactor core passed through a heat exchanger, yielding much of its heat, and then returned to the core in a continuous, closed, loop. As cooling water became contaminated, it was bled off and routed to a covered trench for disposal in the soil.

Workers disposed of low level radioactive liquid waste in numerous cribs from sources such as overflow of fuel storage basins, decontamination activities, drainage from building filters, and floor drains. Some reactor sites also used a crib to dispose of highly contaminated cooling water from a single process tube that had been contaminated by a ruptured fuel element. In some cases, this crib was merely an open pit into which effluent was directed through a hose attached to the rear face of the reactor (WIDS 1998).

Fuel element failures caused by a rupture in the cladding were an all-too-frequent occurrence at Hanford production reactors with nearly 2000 occurring between 1951 and 1965 (DeNeal 1965). Some were no more than a pin-hole-sized breech in the outer, protective cladding of a fuel element. Others were more severe and exposed much of the fuel element's irradiated uranium fuel to the cooling water, which became grossly contaminated with uranium, fission products, and trace quantities of plutonium.

In the early years of fuel rupture experience, water from only the affected process tube was diverted from the rear face of the reactor to a crib where it was disposed of in the soil. In later years, the cooling water from the affected process tube was allowed to mix with that from all other tubes and, after cooling in the retention basin, was either released to the river or to a large trench that had been excavated for that purpose. Water diverted to these riverside trenches was allowed to percolate into the soil rather than being released directly to the river. This provided

for ion exchange with the soil and for additional radioactive decay before the effluents eventually reached the river through the soil.

Experimental Animal Farm

An additional source of low level radioactive liquid waste was the Experimental Animal Farm located at the 100-F Area. The Experimental Animal Farm operated from 1945-1976 to measure the effects of ionizing radiation on living organisms. Early researchers focused on the effects of reactor effluents on Columbia River fish. Later, researchers included the use of swine, sheep, dogs, rats, and plants.
Operations varied widely depending on the nature and scope of the particular experiment but generally involved the introduction of radioisotopes into living tissue with follow-up study to identify and measure its effect over time. Researchers tested the effect of iodine-131, strontium-90, cesium-137, isotopes of plutonium and uranium and other isotopes by having the animals inhale, ingest, and absorb the isotopes or by inoculating the animals with them (DeFord 1993).

Low level radioactive liquid waste waste streams included contaminated cleaning water resulting from animal pen cleaning, waste from the radio-botany and pharmaceutical labs, and various liquid waste from the biology lab. Most low level radioactive liquid waste went to 100-F cribs or trenches. Some was injected into reactor effluent and flushed to the Columbia River through the reactor outfall or passed directly to the Columbia River through a separate waste line and outfall (DeFord 1993).

200 Areas

Numerous sources of low level radioactive liquid waste have existed in the 200 Areas. Five chemical separations plants generated many forms of low level radioactive liquid waste. The Plutonium Finishing Plant added its share, including waste such as carbon tetra-chloride. Waste evaporators, used to reduce the volume of high level radioactive waste, produced large quantities of low level radioactive waste in the form of condensate that was released in the soil. Scavenged waste from some high level waste tanks was also disposed of in the soil as low level radioactive liquid waste.

In 1945-1946, all 200 Area low level radioactive liquid waste that did not meet the prevailing criteria for high level waste was disposed of in the soil in open trenches and ponds. Narrow, radioactively contaminated beach zones developed, which were intruded upon by insect, bird, and animal life. These along with high winds spread contaminants to nearby downwind locations. After 1946 to protect personnel and the environment, only low level radioactive liquid waste with low activity continued to flow to open ponds and trenches. The deactivated ponds and trenches were flushed with fresh water and eventually backfilled (WIDS 1998).

Rather than dispose of low level radioactive liquid waste with higher activity in open ponds and trenches, in 1946 workers increasingly disposed of it below grade where contamination would be confined to sub-surface soil. To do this, numerous reverse wells were placed into service. These were deep, well-like shafts with perforated casings, which were drilled to a depth above groundwater. The wells had a tendency to become plugged with solids suspended in the low

level radioactive liquid waste and had the disadvantage of introducing the waste liquids near groundwater. Reverse well use was discontinued after about a year and no new ones were constructed.

French drains were constructed about the same time as reverse wells. French drains are shallow shafts used to dispose of low volumes of low level radioactive liquid waste with low activity. The shaft is typically a 3-6 foot concrete pipe about 36 inches in diameter, which is buried vertically and filled with rock or gravel. The liquid usually entered the shaft from a waste line at the top of the pipe, which was at ground level and flowed through the pipe to the soil below. French drains continued to be used through the operational history of the Hanford Site for disposal of low level radioactive liquid waste with low activity. Numerous French drains are scattered throughout the Hanford production areas.

French drains were largely replaced with cribs of various design. These were constructed with their upper surfaces only a few feet below grade to maximize the distance to groundwater, yet avoid the surface contamination problems associated with open ponds and trenches. Cribs are underground chambers used to dispose of large volumes of low level radioactive liquid waste. They were usually constructed of loosely spaced timbers, creating a chamber of more than 1000 cubic feet. The liquid would percolate through the chamber to the underlying soil. Numerous cribs exist in the 100, 200, and 300 Areas. Some cribs were used in conjunction with settling tanks in which waste solids would settle out before the supernatant liquid waste passed on to the cribs.

Over time, some cribs began to fail due to silt or chemical deposits, and overflow drain fields were attached to improve dispersal in the soil. These were not unlike the drain fields used in sanitary sewage systems, and they proved equally effective for low level radioactive liquid waste. Since 1960, many cribs have been constructed with drain fields, and a few drain fields have been constructed without cribs (WIDS 1998).

Open trenches and ponds as large as 50 acres continued in use for low level radioactive liquid waste with low activity or that was highly diluted, such as steam condensate and cooling water from certain contaminated facilities (WIDS 1998).

300 Area

Low level radioactive liquid waste management and disposal at the 100 and 200 Areas was largely decentralized, with each facility manager responsible for waste generated at that facility. Dedicated cribs, French drains, ponds, and trenches supported most facilities.

The 300 Area differed from its sister areas in that the management and disposal of low-level radioactive liquid waste was centralized. From their construction in 1944, the many 300 Area laboratories and fuel manufacturing facilities were connected to a common process sewer that collected low level radioactive liquid waste and disposed of it in a single process pond located east of the area near the river.

The original process pond, a 353,000 square foot by 5-foot deep facility, overflowed its banks in 1945, and a retaining dike was added. The cause was determined to be poor percolation to the soil resulting from buildup of impermeable precipitants on the bottom of the pond. Waste level rose over time and the dike failed in 1948, releasing over 14 million gallons of low-level radioactive liquid waste into the Columbia River. The dike was repaired, and the pond returned to service (Young and Fruchter 1991).

A second pond was constructed immediately north of the original, and the bottoms of both were periodically scraped with the scrapings piled onto the dikes to further reinforce them. The ponds continued in operation until 1974 when they were replaced by a pair of 1500-foot process trenches.
Additional low level radioactive liquid waste processing improvements occurred in the mid-1950s when the Radioactive Liquid Waste System was constructed to replace the aging and by then leaking process sewer. Of modern design and stainless steel materials, the Radioactive Liquid Waste System fed a low level radioactive liquid waste retention and neutralization facility capable of sampling and diverting high activity waste to tanker trucks for disposal at 200 Area cribs. Low level radioactive liquid waste with low activity continued to flow to the 300 Area ponds and trenches. A railroad load-out facility with shielded railcars was added in 1965 to replace tanker trucks (DeFord 1994).

The Waste Acid Treatment Facility became operational in 1975 to process waste acids disposed of by various 300 Area laboratories. This waste was sampled, neutralized, centrifuged, and otherwise processed before being released for disposal to various locations including 200 Area waste disposal sites. Prior to 1975, 300 Area acids were disposed of in 300 Area ponds and trenches along with all other low-level radioactive liquid waste (DeFord 1994).

A few cribs and French drains were used in the 300 Area as needed to meet specific and usually temporary needs of laboratories and other facilities (DeFord 1994).

400 Area and Fast Flux Test Facility

The Fast Flux Test Facility is a test reactor, with associated facilities located in the 400 Area. Although several French drains exist for disposal of cooling water and floor drain waste, no low-level radioactive liquid waste is known to have been disposed of in the soil at this facility.

Incidents

Several incidents involving low level radioactive liquid waste have already been mentioned in the preceding paragraphs. A few additional descriptions will help to demonstrate the scope and complexity of managing low level radioactive liquid waste.

- The groundwater has been contaminated by waste from U Plant. The 216-U-1 and 2 Cribs are side by side facilities that received U Plant cell drainage and other low level radioactive liquid waste during the operation of U Plant for its uranium recovery mission. About 4000 kilograms of soluble uranium were drained to the cribs and became insoluble as it reacted

with the soil beneath the cribs. Acid waste, inadvertently discharged to the cribs, combined with the uranium, making it both soluble and mobile in the soil column but in insufficient volume to move the uranium far enough in the soil to reach groundwater.

A new high volume, low activity waste crib, 216-U-16, was installed nearby. Low level radioactive liquid waste discharges to the new crib were sufficient by 1985 to collect atop an impermeable caliche layer located about 165 feet below the crib. The low level radioactive liquid waste moved laterally along the caliche layer, passing beneath the 216-U-1 and 2 Cribs and transporting the now soluble uranium through openings in the caliche layer to groundwater beneath. Groundwater contamination was detected soon thereafter and pump-and-treat techniques were used in 1985 to remove uranium contaminants from the groundwater. Uranium contamination levels were thereby reduced from 72,000 picocuries/liter to 17,000 picocuries/liter (Baker et al. 1988).

- The Process Waste Sewer has leaked in the 300 Area. Portions of the stainless steel lines in the 300 Area Process Waste Sewer have become rusted and have leaked low level radioactive liquid waste into the underlying soil.

- The reactor retention basin has leaked and overflowed. Each Hanford production reactor, except the N Reactor, used large metal or concrete retention basins to hold contaminated cooling water for a few hours before releasing it to the Columbia River. Each of these basins has developed leaks, allowing low level radioactive liquid waste to escape to the underlying soil. Also, basin outflow gates have become blocked, causing the basin to overflow and form, in one case, a deep erosion ditch flowing to the nearby river bank.

- Cribs have overflowed and vegetation has become contaminated. Occasional overflows would occur at cribs when low level radioactive liquid waste was introduced at rates greater than the underlying soil could absorb. In these cases, low level radioactive liquid waste would sometimes overflow through the crib vent pipes, contaminating the surface area at and near the crib. Deep-rooted vegetation, such as Russian thistle, would sometimes intrude into contaminated soil, resulting in the plant becoming contaminated. Burrowing animals such as rabbits and gophers would also intrude into underground contaminated soil, becoming contaminated in the process and spreading that contamination about in the wake of their movements.

LOW LEVEL RADIOACTIVE AND TRANSURANIC SOLID WASTE

Radioactively contaminated solid waste has been disposed of by shallow earth burial since the beginning of Hanford operations in 1944. Burial grounds were established in support of each of the Hanford production programs, including fuels manufacturing, reactor operations, chemical separation, plutonium purification, and research and development. Each burial ground has received vast quantities of low level radioactive solid waste. At least 28 sites in the 100 Areas, 28 in the 200 Areas, and 11 in the 300 and 600 Areas have been used for this purpose (WIDS 1998, Miller and Wahlen 1987).

Solid waste includes non-liquid, non-soluble material ranging from municipal garbage to industrial waste that contains complex and sometimes hazardous substances. Radioactive solid waste includes materials that are contaminated with radionuclides. Low level radioactive solid waste is defined as radioactive waste that is not classified as high level or transuranic waste, spent nuclear fuel, or byproduct material. Low level radioactive solid waste is frequently found mixed with non-radioactive hazardous waste and is called mixed low level waste. When mixed with transuranic waste, it becomes transuranic mixed waste.

Solid waste volumes at the Hanford Site since 1944 and including those that will be produced over the next 20 years have been estimated as follows (DOE 1992):

Hazardous Waste	6,100 cubic meters
Low level radioactive solid waste	89,000 cubic meters
Mixed low level waste	36,000 cubic meters
Transuranic mixed waste	22,400 cubic meters

Management practices for Hanford burial grounds may be generally described as follows (Dorian and Richards 1978):

1944 - 1954

- No intensive waste segregation program. Hazardous waste, low level radioactive solid waste, and transuranic waste were commingled for disposal
- Combustibles and non combustibles buried in the same trench
- Burial records contain minimal information
- Decentralized disposal with virtually all waste buried near point of origin

1955 - 1965

- Alternate disposal methods and sites studied, documented, and, in some cases, implemented
- Intentional burning of combustible low level radioactive solid waste in burial trenches began and ended in 1955
- Records improved

1966 - 1973

- Burial grounds centralized. Central landfill constructed for sanitary solid waste
- Measurement of burial materials improved

- Burial records much more complete
- Some segregation of waste by category
- Beginning in 1968, increasing amounts of low level radioactive solid waste transported to 200 Areas for disposal
- After May 1970, all transuranic waste stored or disposed of in the 200 Areas

Post 1973

- Sanitary solid waste disposed of at the Hanford Site Solid Waste Landfill
- All low level radioactive solid waste disposed of in the 200 Area burial grounds
- Environmental Restoration Disposal Facility constructed in 1995

Low Level Radioactive Solid Waste

Some types of low level radioactive solid waste, such as contaminated protective clothing, are common to all production programs and, therefore, to all burial grounds, while other waste types are unique to the facility that generated them.

General descriptions of the contents of low level radioactive solid waste burial grounds are available, but detailed content descriptions are typically available only for the latter years of Hanford operations. This results from minimal burial ground record keeping requirements during the early years.

100 Areas

Fuel elements received from the 300 Area were loaded into Hanford's production reactors and exposed to intense neutron bombardment (the process that causes small quantities of uranium to transform into plutonium). These reactor operations generated significant quantities of low level radioactive solid waste, which workers disposed of in the 100 Areas burial grounds and, after 1973 along with the Fast Flux Test Facility waste in the 200 Areas. Twenty-eight major reactor area burial sites exist in the 100 Area (Miller and Wahlen 1987).

The greatest portion of low level radioactive solid waste from the reactor area consists of large quantities of obsolete or failed reactor hardware. To this was added contaminated protective clothing, tools, and miscellaneous process related materials.

200 Areas

After irradiation in a reactor core, the reactor fuel was removed and delivered to one of Hanford's chemical separations plants (B Plant, T Plant, REDOX, and PUREX) located in the 200 Areas.

Here the reactor fuel was dissolved in acid and introduced to a complex, wet chemical process that extracted the small quantities of plutonium from the uranium matrix of the reactor fuel.

Low level radioactive solid waste generated in this and related processes was disposed of in 200 Area burial grounds. As with reactor operations, the majority of solid waste was contaminated process hardware made useless by failure or obsolescence. To these were added construction and demolition waste resulting from upgrades to the chemical system tools and protective clothing, and miscellaneous process related materials. Also included were soil and other materials contaminated by various chemical plant spills and leaks.

Some large, highly contaminated items are stored on flatbed railcars in the PUREX railroad tunnels that will require future decontamination or disposal in the 200 Area burial grounds (Anderson 1996).

The product of the chemical separations plants was an impure plutonium nitrate solution that was delivered to the Plutonium Finishing Plant for purification. The Plutonium Finishing Plant is located in the 200 West Area. Its processes generated low level radioactive solid waste that was disposed of in 200 West Area burial grounds. Again, obsolescent process hardware and materials such as tanks, pumps, piping, valves, and instrumentation provided the greatest quantity of waste. To these were added contaminated tools, protective clothing, rags, filters, and other materials.

300 Area

Fuel elements for the Hanford reactors were manufactured at Hanford's 300 Area from uranium stock. Using extrusion and cladding processes housed in the 306, 313, 314, and 333 Buildings, workers produced vast quantities of rod-shaped, reactor fuel elements and shipped them to Hanford's nine production reactors for irradiation. Numerous types of contaminated solid waste resulted from the fuel manufacturing processes, including industrial hardware and tools, protective clothing, equipment, glassware, swipes, and miscellaneous process related materials. The waste stream also included quantities of uranium millings, shavings, and dust resulting from fuel manufacturing processes. Large quantities of contaminated demolition waste were also disposed of during renovation activities at the fuel manufacturing buildings. Until 1973, all low level radioactive solid waste from fuel manufacturing was disposed of in the 300 and 600 Area burial grounds. After that year, 300 Area low level radioactive solid waste was disposed of in the 200 Area burial grounds.

Research and Development

Research and development played an essential role in improving the processes at all stages. Most research and development activities were housed in the 300 Area in laboratory facilities such as the Pile Technology, Radio-Chemistry, and Radio-Metallurgy laboratories, Plutonium Recycle Test Reactor, High Temperature Lattice Test Reactor, High Temperature Sodium Test Facility, and others.

All of these labs generated low level radioactive solid waste, most of which was buried in 300 and 600 area burial grounds. Some research and development labs, especially Radio-Chemistry, produced low level radioactive solid waste with remarkably high dose rates that required special handling and disposal procedures, discussed later in this section.

Two additional major research and development laboratories, Hot Semi-Works and the Critical Mass Facility, were located in the 200 East Area. Low level radioactive solid waste generated there was disposed of in the 200 Area burial grounds. Hot Semi-Works created an additional quantity of low level radioactive solid waste when in 1987 the laboratory was decommissioned and its contaminated demolition rubble was disposed of in the 200 East Area burial grounds (DOE 1998b).

Off Site Waste

Not all solid waste in the burial grounds was generated at the Hanford Site. While early records are incomplete, at least 58 off site waste generators are known to have shipped low level radioactive solid waste to the Hanford Site for disposal, essentially all going into the 200 Area burial grounds. These waste generators include universities, other DOE sites and laboratories, the military, and commercial companies that have been involved in government programs resulting in low level radioactive solid waste.

Types of programs that have generated low level radioactive solid waste disposed of at the Hanford Site include (Anderson 1996):

- Accelerator studies
- Animal studies in DOE facilities and universities
- Basic research
- Cleanup and restoration projects
- Department of Defense waste (U.S. Army and Navy)
- Reactor studies
- Irradiators and sources
- Fuel fabrication facilities
- Laboratory waste

An unusual form of off site waste received at the Hanford Site is more than 50 reactor compartments from nuclear submarines, which are disposed of in a 200 East Area burial ground. When U.S. Navy nuclear submarines are decommissioned, the entire reactor section of the hull is removed, sealed, and shipped to the Hanford Site for disposal. The intact section is transported by barge to a Hanford receiving dock where the section is loaded onto a massive wheeled trailer for transport to the burial ground.

TRANSURANIC WASTE

Transuranic waste contains radioactive materials contaminated with isotopes emitting alpha particles that have half-lives of over 20 years in concentrations of more than one ten-millionth of

a curie per gram of waste (DOE 1995a). Prior to 1970, transuranic waste was not recognized as a separate waste category and was disposed of in burial grounds as routine waste. Nearly all of it was buried in the 200 Area burial grounds with only small amounts entering a 100-F Area site and two 600 Area sites (Anderson 1996).

Atomic Energy Commission Immediate Action Directive 0511-21 defined transuranic waste and directed that after May 1970 waste with known or detectable contamination of transuranic waste radionuclides must be segregated from other waste categories. No further burial of transuranic waste was permitted, and it must instead be placed in retrievable storage. This was accomplished through use of a new style burial trench designed to permit transuranic waste recovery at a later date AEC Order 1511, issued in 1973, established a segregation limit of 10 nanocuries/gram. Transuranic waste with concentrations of radioactivity greater than 10 nanocuries/gram must be segregated and retrievably stored. Transuranic waste with lower concentrations need not be segregated. Since 1988, transuranic waste has been stored above ground in the Central Waste Facility.

Prior to 1980, liquid organic waste was sometimes disposed of in low level radioactive solid waste burial grounds. This type of waste was banned from burial ground disposal in 1980 due to its potential chelating effect on other waste in the burial trench and due to its potential damage to ion exchange properties of the soil. Liquid organics were subsequently stored in burial grounds in the same retrievable manner as transuranic waste.

To conform with Washington State Administrative Codes on waste storage, an additional low level radioactive solid waste category was defined in 1987. Hanford's Extremely Hazardous Waste has been segregated and stored as retrievable waste after this date. Also in 1988, mixed waste of fewer than 200 millirem/hour was to be retrievably stored and placed into a storage building to meet Washington State Administrative Codes. Mixed waste of greater than 200 millirem/hour would continue to be buried.

To meet the need for storage of extremely hazardous waste in buildings, the Central Waste Facility buildings were constructed. The first was completed in 1988 with another dozen completed shortly thereafter. These are 4000 square foot buildings that meet Washington State Code, RCRA (42 USC 6901), and other requirements for extremely hazardous waste and low level radioactive solid waste storage. Another seven, 35,000-50,000 square foot buildings have subsequently been constructed or are under construction (Anderson 1996).

Record Keeping

Burial ground record keeping was minimal in the early days of the Hanford Site with little information on the amounts and types of low level radioactive solid waste buried. During the 1950s and 1960s, some documents were issued on waste disposal activities, but these records are not complete. Studies have estimated the volume and radioactivity of previously unrecorded buried waste based upon the ratio of the radionuclides present in the fuel elements and on other known and deduced waste generation and disposal information.

Beginning in the late 1960s, routine reports of low level radioactive solid waste in the 100 and 200 areas became more complete and included the amount of land area used, volume of waste, curie content of the various waste radionuclides, and the coordinates of the burial location.

Since 1971, the contents of burial grounds have been tracked on automated databases. A succession of automated information systems have been used, culminating in the current system, the Solid Waste Information and Tracking System. The Solid Waste Information and Tracking System is a state-of-the-art waste inventory and projection system that can calculate the activity of all radionuclides in each waste container. Its query capabilities include waste generator, date, location where waste was generated, burial location, activity at time of burial, and current activity (Anderson 1996).

Waste Minimization

An essential element of waste management is waste minimization. This includes those practices calculated to minimize the quantity or volume of waste materials requiring disposal. Chief among these are manufacturing practices that are improved to produce less waste and waste volume reduction by compaction, incineration, or other methods. Hanford operations have used all of these and other waste minimization practices.

Low level radioactive solid waste was burned at some Hanford burial grounds to reduce the volume before the Clean Air Act of 1970 and other environmental legislation precluded the practice.

From 1962 to 1973 to salvage plutonium, workers incinerated plutonium contaminated waste that would otherwise have been packaged and buried. Such waste included contaminated filters, rags, paper, protective clothing, gloves, and other combustible items used at the Plutonium Finishing Plant, REDOX, and PUREX. Once incinerated, the plutonium was recovered from the residual ash. The incineration and removal of the plutonium resulted in a 98 percent reduction of this particular waste stream (Anderson 1996). See the sub-section on the 232-Z Incinerator in the Plutonium Finishing Section for more information on recovering plutonium via incineration.

A novel waste minimization activity at Hanford involves the regulated fleet of trucks, tractors, locomotives, railcars, and other high value vehicles that have become radioactively contaminated but continue in use as regulated equipment. Such contaminated equipment would otherwise be disposed of by burial and replaced with new equipment when it was no longer at once repairable. Instead, Hanford has established a program that keeps these regulated vehicles available for work in radiation zones where they are subject to additional contamination. Such vehicles continue in use as long as they may be safely used by operating personnel in protective clothing.

Burial Ground Descriptions

Burial grounds for low level radioactive solid waste vary widely in their size and configuration from small pits at reactor sites to mammoth trench excavations in the 200 Areas. Burial ground designs vary from simple, unlined excavations to lined excavations that permit recovery of pit contents to burial grounds that use underground caissons and burial pipes or vaults.

Burial grounds in the 100 and 300 areas are close to the Columbia River and are underlain with permeable materials. The 200 Areas burial grounds lie on a geologic plateau and are underlain by a considerable thickness of materials with low permeability. Waste buried there is 55 meters or more above groundwater. Groundwater movement beneath these 200 Areas burial grounds has extremely low flow rates and the soil has a large capacity for ion exchange. The slow movement allows time for ion exchange, which acts to remove and retain radionuclides (Anderson 1996).

Initially, almost all of the radioactive solid waste was buried near the area in which it was generated. Beginning in 1968, however, increasing amounts of waste were transported to the 200 Areas for disposal. Because of increased attention to all radionuclides discharged to the environment, by 1970 most low level radioactive solid waste was disposed of in 200 Area burial grounds. The last 300 Area burial ground closed in mid-1972 and only minor use was made of 100 Areas burial grounds until they fully closed in 1973.

100 Areas

With the exception of the 100-N Area, all 100 reactor sites used burial grounds to dispose of low level radioactive solid waste. Each site had at least one large burial ground and several smaller ones that varied from small burial pits to large burial trenches. For example, the main burial ground at the 100-F Reactor site measured 600 X 500 X 20 feet deep, while the 118-H-5 Thimble Pit, used to bury a single waste item, was only 30 X 2 X 5 feet deep (WIDS 1998).

The vast majority of 100 Area low level radioactive solid waste is reactor components and hardware that became irradiated and required disposal due to wear, failure, or obsolescence. These include items such as aluminum spacers, boron splines, graphite, process tubes, lead shielding, control rods, nozzles, and cadmium sheets. Also included are contaminated tools and protective clothing, glassware, swipes, and miscellaneous process materials (Miller and Wahlen 1987).

The quantities of low level radioactive solid waste from all reactors except N Reactor from 1944 through the end of reactor operations in 1971 are (Miller and Wahlen 1987):

• 1,700,000 aluminum fuel spacers	425 tons
• Lead-cadmium poison elements	1,059 tons lead 44 tons cadmium
• 142,000 boron-aluminum splines	652.5 tons aluminum 8.4 tons boron
• Carbon-14 (graphite and desiccant)	15,500 pounds
• 28,000 process tubes	266 tons aluminum

• Lead (brick, sheet, wool, casks)	258 tons
• Miscellaneous hardware	146 tons
• Cadmium sheeting	800 pounds
• Thermocouple Wire	372 pounds
• Soft waste (paper, plastic, clothing), which contains a very small percentage of total radionuclide inventory but makes up more than 75 percent of the total low level radioactive solid waste volume from all reactors except N Reactor	129,000 cartons

A few small burial sites in the reactor area were established for disposal of single, highly contaminated or irradiated waste items, such as a reactor test loop or a collection of contaminated fuel spacers. An unusual form of low level radioactive solid waste from the Experimental Animal Farm was buried at 100-F burial grounds. Extensive research was conducted on living animals and many were sacrificed as part of the research process. Contaminated animal carcasses were disposed of in a large, vented, steel tank which was periodically topped off with diesel oil and set afire to reduce waste volume. When the tank was no longer needed, it was dragged to the 118-F-6 Burial Ground and buried (DeFord 1993).

After 1973, most low level radioactive solid waste from the reactors, including all waste from the 100-N Reactor, was disposed of in the 200 Area burial grounds.

All 100 Area burial grounds are simple, unlined, trench or pit excavations. None remain in service and all have been backfilled to grade with native soil. Each is identified with signs and radiation warning devices. Most are unfenced with access only controlled through Hanford Site access security.

200 Areas

Because it was expedient to dispose of low level radioactive solid waste near the generating source, burial grounds were opened at nearly all Hanford areas. However, environmental considerations such as water table and proximity to the Columbia River have made 100 and 300 area sites less desirable. The 200 Areas burial grounds were recognized as superior sites in terms of environmental protection. In 1973, 200 Areas sites became the centralized burial grounds for all low-level radioactive solid waste at the Hanford Site (Anderson 1996).

Operating since 1944, these burial grounds are massive excavations that have received low level radioactive solid waste items as large as contaminated trucks and railroad locomotives. Some burial grounds are as long as 1500 feet and over 90 feet wide at the surface. Most are at least 18 feet deep. Bottom treatment varies with era and type of waste to be disposed. Most have bottoms of native soil with no special treatment. Those designated for retrievable storage may have

asphalt paving. For a time, transuranic waste drums were placed in V shaped burial grounds rather than the traditional flat bottom excavations to expedite retrieval of waste (DeFord 1991).

All burial grounds are identified by permanent concrete markers that identify the burial ground by number and flag it as a disposal site for radioactive waste. Most but not all 200 Areas burial grounds are protected by security fencing. Hanford drawings further delineate the location of burial grounds with each individual trench identified.

Prior to 1970, 200 Area burial grounds could be divided into six waste type categories.

- Dry waste burial grounds received low level radioactive solid waste packaged primarily in cardboard boxes containing various forms of dry waste. These included contaminated protective clothing, rags, paper, wood, and soil. Hardware contaminated with plutonium and various forms of off-site waste were also included.

- Industrial burial grounds received low level radioactive solid waste packaged in large wooden containers containing obsolete equipment from chemical plants and 300 Area labs that were heavily contaminated with fission products.

- Construction burial grounds received low level radioactive solid waste with low activity from construction and demolition work.

- Railroad tunnels at PUREX are used to store numerous large pieces of contaminated equipment on railroad flatcars.

- Underground vaults located at 222-B, T, and S Analytical Laboratories received small quantities of low level radioactive solid waste with high activity and dose rate from contamination by mixed fission products and plutonium.

- Caissons located at two burial grounds were used to dispose of low level radioactive solid waste with high activity from the 300 Area hot cells and low level radioactive solid waste with high plutonium content. Caissons are either tubular metal pipes buried vertically in the trench or larger circular tank-like containers made from corrugated metal or concrete, buried in the trench with offset feed chutes reaching above grade (DeFord 1994).

Environmental Restoration Disposal Facility

Constructed in 1995, the Environmental Restoration Disposal Facility is a centralized disposal facility for waste generated during the environmental restoration, deactivation and decommissioning efforts at the Hanford Site and is notable as Hanford's most advanced and most recent disposal site for low level radioactive solid waste.

The facility is a deep trench that will be the central landfill for large quantities of low level radioactive solid waste generated during environmental restoration work. Upwards of 12 million

cubic yards of contaminated materials may be stored at the facility. Hazardous and mixed waste will also be disposed of here. The facility is not authorized to receive transuranic waste.

The Environmental Restoration Disposal Facility is in the 200 West Area. The 200 West Area was selected because of its distance from the Columbia River, its elevation above groundwater, and its centralized access to transportation and utility systems.

The Environmental Restoration Disposal Facility has been designed as a series of cells, each of which is 500 feet by 500 feet at the bottom and 80 feet deep and will hold about 600,000 cubic yards of material. Each cell is double lined and built with a leachate to collect and remove moisture. Each will be backfilled to grade with native soil when waste capacity has been reached. Two such cells have been completed and are now receiving waste materials. Additional cells, up to a total of twenty, may be constructed to meet the needs of environmental restoration, deactivation, and decommissioning (DOE 1995b).

300 Area and 600 Area

Fuel manufacturing processes and research and development activities in the 300 Area generated large quantities of low level radioactive solid waste that before 1973 were buried in 300 and 600 area burial grounds. After 1973, 300 Area low-level radioactive solid waste was transported to the 200 Areas for disposal.

The distinction between 300 and 600 area burial grounds is sometimes confused. Essentially all waste disposed of in both area burial grounds was generated in the 300 Area. However, where other areas located their burial grounds within the area security fences, 300 Area did not. The 600 Area designation was devised to encompass all locations outside of area security fences and so includes those 300 Area burial grounds located adjacent to, but outside of, the 300 Area security fence. For that reason, 300 and 600 area burial grounds are included in this section.

The first burial ground to support 300 Area activities, 618-8, operated for only about a year in 1944. It was located north of the area under what is now an employee parking lot. A second burial ground, 618-1, was also north of the 300 Area and operated for 6 years beginning in 1945. The 618-2 Burial Ground followed in 1951 and operated until it caught fire in 1954. Another, 618-3, was excavated in 1954 but was filled to capacity the following year with demolition rubble from remodeling activities at the fuel manufacturing buildings (DeFord 1994).

Contamination repeatedly being spread, high dose rates, and waste fires in burial grounds near the 300 Area led to planning for burial grounds farther removed from facilities and employees. The 300 North Burial Ground, 618-10, was excavated in 1954 several miles north of the 300 Area and was followed by the 618-11 or Wye Burial Ground even farther north.

In addition to routine low level radioactive solid waste, these burial grounds received waste with a high dose rate from the Radio-Chemistry and Radio-Metallurgy laboratories. Dose rates as high as 5 roentgen/hour were measured during waste disposal activities, and revised disposal methods were developed. To reduce dose rate to burial ground workers who handled the waste during disposal, waste was transported in various kinds of truck-mounted, shielded casks. These casks

were designed so the waste containers could be dumped directly into metal caissons. The metal caissons had previously been buried in the disposal trench with only their openings visible at the surface. Once the waste with the high dose rate was dropped into the caisson, sand or gravel and sometimes concrete was placed in the caisson to reduce the dose rate at the surface.

Numerous instances of burial ground contamination were recorded at 300 and 600 area burial grounds. Most occurred during disposal when waste containers would rupture and contaminants would settle over the site. High dose rates also continued to be a problem until 1968 when nearly all 300 Area low level radioactive solid waste was transported to the 200 Areas for disposal. Disposal to the 300 and 600 area burial grounds were discontinued in 1970 (Gerber 1992).

300 Area burial grounds ranged in size from 4000 square feet to 40,000 square feet. The largest, 618-11, consisted of three burial trenches (each 900 x 50 x 25 feet deep), 50 pipe caissons, and at least 4 large diameter caissons. The pipe caissons were constructed by welding together five bottomless 55-gallon drums. The resulting 15-foot-long cylinders were buried vertically and spaced 10 feet apart in rows. Large diameter caissons were 10 feet high, 8-foot diameter corrugated steel tanks, each buried 15 feet below grade. The caisson was connected to the surface by an offset, 36-inch-diameter pipe through which waste could be dropped into the tank (DeFord 1994).

Incidents

Three categories of incidents involving low level radioactive solid waste occurred with some frequency, mostly in the 1950s and 1960s, and all of which resulted in contamination being spread to burial grounds and adjacent areas. These included fires in the burial grounds, burial containers that collapsed, and contamination spread when waste was in transit to burial grounds.

Fires occurred in 100, 200, and 300 area burial grounds. Most appear to have been caused by spontaneous combustion in waste materials with the fire spreading to adjacent refuse. The spread of contamination was sometimes severe, covered large areas adjacent to the burial grounds, and required major decontamination efforts by Hanford personnel. Fires in 100 and 300 Area burial grounds and the associated spread of contamination contributed to the decision to centralize the disposal of low level radioactive solid waste in the 200 Areas.

One of several burial ground fires in the 300 Area occurred in 1954 when a fire at the 618-4 Burial Ground spread contaminated particles as far as 1500 feet to the northeast with individual particles reading as high as 4.5 roentgen/hour (Anderson 1996).

The collapse of burial containers was an occasional problem at the 200 Area burial grounds where large boxes were frequently used to transport and bury contaminated hardware and apparatus from process facilities. The containers were placed on the floor of the burial trench and the trench backfilled. The weight of the backfill soil would sometimes collapse the burial box, causing a rush of contaminated air from the box interior to transport contaminants to the area of the trench and sometimes beyond. Areas as large as 4 square miles were contaminated in this manner (Anderson 1996).

Similar problems occurred at the burial ground in the 300 Area, especially the 618-10 and 618-11 burial grounds, when paper cartons or metal cans containing waste with high activity would rupture when dropped into pipe caissons, resulting in a column of contaminated air that rose upward in the pipe and onto the surface of the burial ground (Gerber 1992).

Contamination was an occasional problem when highly contaminated materials were transported to 200 Area burial grounds. Contaminants would sometimes escape and would contaminate the roadway, railroad, and/or transport vehicles, requiring significant decontamination over large areas. One such incident occurred in 1957 when a burial box containing REDOX hardware was pulled from its railcar when one of the box swing cables came loose and caught on a railroad tie. The ground where it landed was contaminated to a level of 2 roentgen/hour (Anderson, 1996).

Incidents were not the only source of hazardous conditions at the burial grounds. Even the routine handling of the waste could result in dose rates as high as 200 roentgen/hour (Anderson 1996). To dispose of the waste, employees often had to use heavy equipment with all the hazards incident to bulldozer and crane operations. Backfilling required skillful use of tractors working on steep slopes in soft soil conditions.

APPENDIX E

PERTINENT FEDERAL AND STATE LAWS AND REGULATIONS

APPENDIX E

Pertinent Federal and State Laws and Regulations

Table E-1. Federal Laws, Regulations, and DOE Orders.

Citation	Requirement	Application
Comprehensive Environmental Response, Compensation, and Liability Act of 1980, 42 USC 9602-9604, as amended		
National Oil and Hazardous Substances Pollution Contingency Plan, Subpart E, 40 CFR 300.400	Establishes the process to be followed upon discovery of a release of a hazardous substance, including notification, site evaluation, and remedial response. Establishes CERCLA remediation criteria consisting of a risk range of 10^{-4} to 10^{-6} for carcinogens and a hazard index of less than 1 for noncarcinogens.	CERCLA hazardous substances have been released to the vadose zone and groundwater and, as a result, the 100, 200, and 300 Areas are identified on the National Priorities List for action under CERCLA.
Designation, Reportable Quantities, and Notification, 40 CFR 302	Defines the comprehensive list of hazardous substances regulated under CERCLA. Imposes reporting requirements in the event of a release in excess or reportable quantities.	CERCLA hazardous substances are present in the vadose zone and groundwater.
Safe Drinking Water Act of 1974, 42 USC 300, et seq.		
National Primary Drinking Water Standards, 40 CFR 141	Establishes maximum contaminant levels (MCLs) and maximum contaminant level goals (MCLGs) that are drinking water criteria designed to protect human health from the potential adverse effects of contaminants in drinking water.	Groundwater at the Hanford Site is not a current drinking water source, but it is considered a potential future source of drinking water using EPA's groundwater classification strategy. In addition, Hanford groundwater is hydraulically connected to groundwater that is used for drinking water and to the Columbia River. MCLs and MCLGs should be considered in establishing cleanup levels that are protective of groundwater, points of compliance, and institutional controls.
National Secondary Drinking Water Standards, 40 CFR 143	Establishes secondary drinking water standards for use in establishing cleanup levels.	Federal secondary standards are not enforceable standards and are not typically applicable or relevant and appropriate requirements; however, the State of Washington Model Toxics Control Act requires that these standards be considered in establishing cleanup levels protective of groundwater.
Clean Water Act of 1977, 33 USC 1251, as amended		
Water Quality Standards, 40 CFR 131	Establishes the requirements and procedures for states to develop and adopt water quality standards based on federal water quality criteria that are at least as stringent as the federal standards. Provides EPA authority to review and approve state standards. Washington State has received EPA approval and has adopted more stringent standards under WAC 173-201A.	Not applicable (the requirement to develop standards applies to the states, not individual facilities) but relevant in establishing the basis for state regulation.

Table E-1. Federal Laws, Regulations, and DOE Orders.

Citation	Requirement	Application
Atomic Energy Act of 1954, as amended, 42 USC 2011, et seq.		
Department of Energy Occupational Radiation Protection, 40 CFR 835	These requirements set occupational dose limits for adults. Total effective dose equivalent is equal to 5 rem/yr	These standards are applicable when performing any assessment or response actions.
DOE Order 5400.5, Radiation Protection of the Public and the Environment, and 10 CFR 834 (Proposed)	This DOE order sets radiation standards for protection of the public in the vicinity of DOE facilities. The order set limits for the annual effective dose equivalent of 100 mrem, but allows temporary limits of 500 mrem if avoiding the higher exposures is impractical. The standard sets annual dose limits for any organ at 5 mrem. The order sets an annual dose equivalent from drinking water supplies operated by DOE at 4 mrem, and states that liquid effluent from DOE activities will not cause public drinking water systems to exceed EPA MCLs. The proposed rule, Radiation Protection of the Public and the Environment (10 CFR 834), in the March 23, 1993 Federal Register (58 FR 16268), promulgates the standards presently found in DOE Order 5400.5. The proposed rule identifies DCGs not as "acceptable" discharge limits, but to be used as reference values for estimating potential dose and determining compliance with the requirements of the proposed rule. Where residual radioactive materials remain, the proposed rule states that various disposal modes should address impacts beyond the 1,000-year time period identified in the existing DOE Order.	Both the DOE order and the proposed rule are relevant in assessing risks associated with existing contamination and identifying appropriate response actions.
DOE Order 5820.5, Radioactive Waste Management	These guidelines set performance objectives to limit the annual effective dose equivalent beyond the facility boundary to 25 mrem. Selected disposal methods must be sufficient to limit the annual effective dose equivalent to 100 mrem for continuous exposure, or 500 mrem for acute exposures when active institutional controls are removed.	The order is applicable to any radioactive waste that is present in Hanford Site waste management units, or for waste that might be generated during assessment or response actions.
Nuclear Regulatory Standards for Protection Against Radiation, 10 CFR 20	The regulation establishes standards for protection of the public against radiation arising from the use of regulated materials. Remedial alternatives need to limit external and internal exposure from releases to levels that do not exceed 100 mrem/yr total effective dose equivalent, or 2 mrem/hr from external exposure in unrestricted areas. These requirements also establish criteria for closing NRC-licensed sites, including a standard of 25 mrem/yr from all sources, and reducing residual radioactivity to levels that are as low as reasonably achievable (ALARA).	The regulation is not strictly applicable at the Hanford Site because it applies to NRC-licensed facilities. However, it is relevant and appropriate because it establishes standards for protection of the public against radiation.
EPA Memorandum, Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination," OSWER No. 9200.4-18	This memorandum provides guidance on cleanup levels at CERCLA sites. EPA has determined in this directive that dose limits established by the NRC in 10 CFR 20 (25 mrem/yr and ALARA) are generally not protective at CERCLA sites, and instead states that a cleanup level of 15 mrem/yr is protective of human health and the environment. EPA dose limits are to generally achieve risk levels in the 10^{-4} to 10^{-6} risk range.	The standard established in this memorandum is considered protective by EPA in lieu of the NRC standards and is relevant in establishing cleanup levels.

Table E-1. Federal Laws, Regulations, and DOE Orders.

Citation	Requirement	Application
Licensing Requirements for the Land Disposal of Radioactive Waste, 10 CFR 61	Requires that disposal systems be designed to limit the annual dose equivalent beyond the facility boundary below 25 mrem to the whole body, 75 mrem to the thyroid, or 25 mrem to any other organ. The systems must be relevant and appropriate to remedial actions that include land disposal or release radioactive effluent. Inadvertent intruder requirements for land disposal units are also contained in this regulation	The regulation is not strictly applicable because it applies to land disposal of radioactive wastes containing byproduct, source, and special nuclear material received from other persons. However, it is relevant and appropriate if radioactive waste will be left in place following remediation. Requirements to protect inadvertent intruders may also be relevant and appropriate in assessing risks and determining appropriate response actions.
Packaging and Transportation of Radioactive Material, 10 CFR 71	These requirements apply to the packaging, preparation for shipment, and transportation of licensed radioactive material.	The regulation is not strictly applicable because the Hanford Site is not NRC-licensed. However, radioactive waste might be generated during assessment or response actions, and subparts of this regulation are relevant and appropriate for packaging, testing, and preparation of packages containing radioactive material.
Environmental Radiation Protection Standards for Nuclear Power Operations, 40 CFR 190	Specifies the levels below which normal operations of the uranium fuel cycle are determined to be environmentally acceptable. The standard sets dose equivalents from the facility that are not to exceed 25 mrem/yr to whole body, 75 mrem/yr to thyroid, or 25 mrem/yr to any other organ.	These standards are not strictly applicable at the Hanford Site, because the standard excludes operations at disposal sites and uses a definition of the uranium fuel cycle that focuses on those processes that result in generation of electrical power. However, the standards are relevant and appropriate in the assessment because they address acceptable dose to the public.
Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level, and Transuranic Radioactive Wastes, 40 CFR 191	Establishes standards for management and disposal of spent nuclear fuel, high-level waste, and transuranic wastes at facilities operated by the DOE. The standard addresses all disposal methods. Subpart A applies to facilities regulated by the NRC, and sets maximum committed effective dose of 15 mrem/yr for any member of the public. Environmental standards set in Subpart B address protection of individual members of the public and groundwater at disposal facilities. Appendix A provides numeric standards for potential future releases.	The requirements are applicable because high-level wastes and transuranic wastes are present at the Hanford Site, and must be addressed during closure of waste units and/or remediation of environmental media.
Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings, 40 CFR 192	Standards for cleanup are set under this program, including groundwater protection requirements for radium-226, radium-228, and gross alpha particle activity, which are set at levels established under state and federal water quality criteria programs.	The standard is not strictly applicable because the Hanford Site is not a uranium or thorium milling site. However, standards for cleanup set under this program are relevant and appropriate to assessment and response actions conducted at the Hanford Site.
Resource Conservation and Recovery Act, 42 USC 6901, et seq.		
Criteria for Classification of Solid Waste Disposal Facilities and Practices, 40 CFR 257	Criteria specified under this standard are used to determine which solid waste disposal facilities and practices pose a reasonable possibility of adverse risk to human health and the environment.	Although Hanford has solid waste disposal facilities, most of the provisions of this chapter have been delegated to the state. (See Table B-2, Hazardous Waste Management Act.)

Table E-1. Federal Laws, Regulations, and DOE Orders.

Citation	Requirement	Application
Identification and Listing of Wastes, 40 CFR 261	This part establishes the framework for determining whether a waste is hazardous, including testing methods, criteria for characteristic waste, and definitions of listed wastes.	Although hazardous waste is present at the Hanford Site, and might be generated during assessment and response actions, most of the provisions relative to designation have been delegated to the state.
Generator Standards, 40 CFR 262, Standards Applicable to Transporters of Hazardous Waste, 40 CFR 263, Standards for Owners and Operators of TSD Units, 40 CFR 264 and 265	Establishes specific requirements for facilities that generate, transport, store, treat, and/or dispose of hazardous waste. Requirements cover such items as permitting, waste unit design and operation, training, and emergency preparedness planning.	Although hazardous waste is present at the Hanford Site and might be generated during assessment and response actions, most of the provisions relative to waste generation and management have been delegated to the state.
Groundwater Protection Standards, 40 CFR 264.92	Three remediation levels of groundwater protection established by this section are background, MCLs, and ACLs. MCLs are set at the same levels as SDWA MCLs. Where no SDWA MCL has been set, health-based ACLs may be established that are protective of human health and environment.	Groundwater restoration goals established by this section are relevant and appropriate in establishing soil cleanup levels that are protective of groundwater.
Corrective Action for Solid Waste Management Units, 40 CFR 264, Subpart S (proposed)	Identifies a process for implementing corrective action under RCRA, and establishes chemical-specific soil cleanup levels that are protective based on direct exposure.	Releases from solid waste management units will be considered in the assessment and in identifying response actions. Soil remediation goals established by this section may be pertinent to the establishment of soil cleanup levels. Because this is a proposed rule, it is not strictly applicable at this time.
Land Disposal Restrictions, 40 CFR 268	These requirements prohibit the placement of restricted RCRA hazardous wastes in land-based units until treated to standards considered protective for disposal. Specific treatment standards are included in the requirements.	These requirements are applicable if restricted waste is generated during assessment or response actions.
Toxic Substances Control Act (TSCA), 15 USC 2601 et seq.		
Regulation of PCBs, 40 CFR 761	These requirements identify standards applicable to the handling and disposal of PCBs above 50 ppm. Spills that occurred before May 4, 1987, are to be decontaminated to requirements established at the discretion of the EPA.	PCBs are known to have been used at the Hanford Site and might be present in waste units and/or might have been released to the environment. TSCA requirements for remediation, treatment, and disposal of PCBs are applicable in developing response actions if the PCBs are present at regulated levels.
Guidance on Remedial Actions for Superfund Sites with PCB Contamination, U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response	This document provides guidance for evaluating and selecting a remedy for sites contaminated with PCBs. The guidance presents a range of preliminary remediation goals for the cleanup of PCB-contaminated sites that are protective of human health and intended to meet the goals of the NCP and TSCA. EPA guidance notes that in selecting a response action under CERCLA, cleanup levels and disposal methods should be selected based on the form and concentration found at the site.	PCBs might be present at CERCLA waste sites at the Hanford Site.

Table E-1. Federal Laws, Regulations, and DOE Orders.

Citation	Requirement	Application
Clean Air Act of 1977, as amended 42 USC 7401, et seq.		
National Ambient Air Quality Standards, 40 CFR 50	Requirements of these regulations are applicable to airborne releases of criteria pollutants specified under the statute. Specific release limits for particulates are set at 50 $\mu g/m^3$ annually or 150 $\mu g/m^3$ per 24-hour period.	Applicable to airborne releases of criteria pollutants that might be generated during assessment or response actions.
Ambient Air Quality Monitoring, 40 CFR 58	This regulation presents the criteria and requirements for ambient air quality monitoring and reporting for local air pollution control agencies and operators of new sources of air pollutants.	Applicable to assessment or response actions that meet the regulatory definition of a new source. Also, these requirements may be considered relevant and appropriate to response actions that have the potential to emit air contaminants, even if they are not a new source.
Standards of Performance for New Stationary Sources, 40 CFR 60	These requirements provide standards for new stationary sources or modifications of existing sources.	Applicable if assessment or response actions include stationary sources.
National Emission Standard for Hazardous Air Pollutants (NESHAP), 40 CFR 61	40 CFR 61 provides general requirements and listings for actions that will generate regulated emissions at a regulated facility.	These requirements are applicable to assessment or response actions that release air emissions into unrestricted areas.
Subpart H, National Emission Standards for Emissions of Radionuclides Other than Radon from Department of Energy Facilities, 40 CFR 61	Subpart H sets emissions limits to ambient air from the entire facility, not to exceed an amount that would cause any member of the public to receive an effective dose equivalent of 10 mrem/yr. The definition of "facility" for the Hanford Site includes all buildings, structures, and operations collectively as one contiguous site. Radionuclide emission from stacks shall be monitored and effective dose equivalent values to members of the public calculated.	These requirements are applicable to assessment and response actions that have the potential to release air emissions to unrestricted areas.
National Emission Standards for Asbestos, Standard for Demolition and Renovation, 40 CFR 61.145 – 150	This section specifies that facilities are to be inspected for the presence of asbestos prior to demolition. The standard defines regulated asbestos-containing materials and establishes removal requirements based on the quantity present and handling requirements. These requirements also specify handling and disposal requirements for regulated sources having the potential to emit asbestos. Specifically, no visible emissions are allowed during handling, packaging, and transport of asbestos-containing materials.	These requirements are applicable if response actions require demolition of buildings or structures containing regulated asbestos-containing materials.
Hazardous Materials Transportation Act, 49 USC 1801, et seq.		
Hazardous Materials Regulation, 49 CFR 171	These requirements state that no person may offer to accept hazardous material for transportation in commerce unless the material is properly classed, described, packaged, marked, labeled, and in condition for shipment.	These requirements are applicable to hazardous material generated during assessment or response actions, which is sent offsite for disposal.
Hazardous Materials Tables, Hazardous Materials Communications Requirements, and Emergency Response Information Requirements, 49 CFR 172	Tables are used to identify requirements for labeling, packaging, and transportation based on categories of waste types. Small quantities of radioactive wastes are not subject to the requirements of the standard if activity levels are below limits established in paragraph 173.421, 173.422, or 173.424. Specific performance requirements are established for packages used for shipping and transport of hazardous materials.	These requirements are applicable if hazardous materials are transported offsite during assessment or response actions. In the event of a discharge of hazardous waste during transportation from the treatment facility to the disposal facility, this section is applicable.

Table E-1. Federal Laws, Regulations, and DOE Orders.

Citation	Requirement	Application
Executive Order 12856, Federal Compliance with Right- to-Know Laws and Pollution Prevention Requirements	Requires that federal agencies will comply with Emergency Planning and Community Right-To-Know Act of 1986 (EPCRA) and the Pollution Prevention Act of 1990 (PPA) to the extent that private entities would. The EO incorporates, by reference, all implementing regulations of EPCRA and the PPA. EPCRA requires tracking and reporting information on the storage, use, and release of extremely hazardous substances, hazardous substances, listed chemicals, and toxic chemicals to inform the public about the presence of such hazards in their community and to provide emergency planners and emergency response organizations with information needed to provide appropriate response to potential emergencies at the facilities. The PPA requires entities to implement practices that reduce or eliminate the creation of pollutants through increased efficiency in the use of raw materials, energy, water, or other resources; or protection of natural resources by conservation.	Applicable to federal agencies that either own or operate a "facility" as that term is defined in section 329(4) of EPCRA if such facility meets the threshold requirements set forth in EPCRA. Hanford meets the definition and threshold requirements.
DOE 1998, Draft Hanford Remedial Action Environmental Impact Statement, DOE/RL-98-X	The draft Hanford Remedial Action EIS will define land use decisions for the Hanford Site.	Land use and associated exposure scenarios are important in assessing risk and determining appropriate response actions.
National Historic Preservation Act of 1966, 16 USC 470	Requires that historically significant properties be protected. The act requires that agencies undertaking projects must evaluate impacts to properties listed on or eligible for inclusion in the National Register of Historic Places. An eligibility determination provides a site with the same level of protection as a site listed on the National Register of Historic Places. The regulations implementing the act require that the lead agency for a project identify, evaluate, and determine the effects of the project on any cultural resource sites that may be within the area impacted by the project. The implementing regulations require that negative impacts be resolved.	This law is applicable to assessment or response actions that could impact any of the various buildings/ structures at the Hanford Site that are eligible for the National Register.
Archeological and Historic Preservation Act, 16 USC 469a	Requires that actions conducted at the site must not cause the loss of any archeological and historic data. This act mandates preservation of the data and does not require protection of the actual facility. Where a site is determined to be eligible for the National Register and mitigation is unavailable, artifacts and data will be recovered and preserved prior to commencement of the action.	Archeological and historic sites have been identified at the Hanford Site, and therefore these requirements are applicable to activities that might disturb these sites.
Endangered Species Act of 1973, 16 USC 1531, et seq.	This act prohibits federal agencies from jeopardizing threatened or endangered species or adversely modifying habitats essential to their survival. If waste site remediation is within sensitive habitat or buffer zones surrounding threatened or endangered species, mitigation measures must be taken to protect these resources.	The Endangered Species Act of 1973 would be considered applicable if threatened or endangered species are identified in areas covered by the assessment. Their presence could dictate the approach to assessment or response actions that may be necessary.

Table E-1. Federal Laws, Regulations, and DOE Orders.		
Citation	**Requirement**	**Application**

ACL = alternate concentration level
ALARA = as low as reasonably achievable
CAMU = corrective action management unit
CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act
CFR = Code of Federal Regulations
DCG = derived concentration guide
DOE = U.S. Department of Energy
EPA = U.S. Environmental Protection Agency
HCRL = Hanford Cultural Resources Laboratory
MCL = maximum contaminant level
MCLG = maximum contaminant level goal
NESHAP = National Emission Standards for Hazardous Air Pollutants
NCP = National Oil and Hazardous Substance Contingency Plan
NEPA = National Environmental Policy Act
NPDES = National Pollutant Discharge Elimination System
NRC = U.S. Nuclear Regulatory Commission
PCB = polychlorinated biphenyls
RCRA = *Resource Conservation and Recovery Act*
SDWA = Safe Drinking Water Act
TBC = to be considered
TSCA = Toxic Substance Control Act.

Table E-2. State of Washington Laws and Regulations

ARAR Citation	Requirement	Application
Hazardous Waste Clean Up/Model Toxics Control Act, Ch. 70.105D RCW		
Model Toxics Control Act, WAC 173-340-700	Establishes a process and requirements for cleanup of contaminated sites in the state. MTCA regulations have been authorized for use in implementing RCRA corrective action in the state. Specifies that all cleanup actions be protective of human health; comply with all applicable state and federal regulations; and provide for compliance monitoring. Identifies the methods used to develop cleanup standards and their use in selection of a cleanup action. Specifies cleanup goals, which implement the strictest federal or state cleanup criteria. In addition to meeting requirements of other regulations, MTCA uses three basic methods for establishing cleanup levels. These methods may be used to identify cleanup standards for groundwater, surface water, soils, and protection of air quality. Cleanup levels for soils may be calculated using Method A – routine; Method B - standard method; and Method C - conditional standards. MCLs, MCLGs, and secondary drinking water standards are identified in the regulation as groundwater cleanup criteria.	Requirements of MTCA are applicable to RCRA corrective action sites at the Hanford Site and relevant and appropriate for other Hanford waste sites (e.g., CERCLA sites). State requirements that are not authorized through a federal program, such as MTCA, are not directly applicable to federal facilities.
Hazardous Waste Management Act, 70.105 RCW		
Dangerous Waste Regulations, WAC 173-303	Establishes the design, operation, and monitoring requirements for managing dangerous waste.	Dangerous waste is present in Hanford Site waste units and might be generated during assessment or response actions. Sections of this chapter are applicable to dangerous waste management activities and may be relevant and appropriate in certain situations even when they are not applicable. Key sections are discussed below.
Designation of Waste, WAC 173-303-070 through 110	Establishes the methods and procedures to determine if solid waste requires management as dangerous waste.	The requirements of this section are applicable because dangerous waste might be generated.
Land Disposal Restrictions, WAC 173-303-140	Identifies dangerous wastes that are restricted from land disposal and describes requirements for state-only restricted wastes; defines the circumstances under which a prohibited waste may be disposed.	Applicable to the disposal of restricted wastes.
Spills and Discharges into the Environment, WAC 173-303-145	Sets forth the requirements that apply when any dangerous waste or hazardous substance is intentionally or accidentally spilled or discharged into the environment such that human health and the environment are threatened, regardless of the quantity of dangerous waste or hazardous substance.	Applicable should dangerous waste or hazardous substances be spilled or discharged into the environment.
Requirements for Generators of Dangerous Waste, WAC 173-303-170 through 230	Requirements defined under this section include specific levels of training and emergency preparedness.	Applicable to actions performed at the site if dangerous waste is generated.

Table E-2. State of Washington Laws and Regulations

ARAR Citation	Requirement	Application
General Requirements for Dangerous Waste Management Facilities, WAC 173-303-280 through 395	General requirements include siting standards, training, emergency preparedness, security, inspections, contingency planning, waste analysis, and management of containers.	Applicable to actions that include treatment, storage, or disposal of designated dangerous waste.
Treatment, Storage, and Disposal Facility Requirements, WAC 173-303-600 through 695	Specifies closure and post-closure standards (which require compliance with MTCA cleanup levels), groundwater monitoring requirements, corrective action management unit/temporary unit requirements, air emission standards for process vents and equipment leaks, and specific unit requirements for containers, tanks, surface impoundments, land treatment units, waste piles, landfills, incinerators, drip pads, miscellaneous units, and containment buildings.	Applicable because permitted TSD units are present and/or assessment or remediation wastes may be managed in units that are TSDs.
Releases from regulated units, WAC 173-303-645	Establishes groundwater protection standards for releases to groundwater from dangerous waste management units.	The standard is applicable because TSD units are present.
Solid Waste Management, Recovery and Recycling Act, Ch. 70.95 RCW		
Minimum Functional Standards for Solid Waste Handling, WAC 173-304	These standards establish requirements to be met for the management of solid waste. Solid waste controlled by this Act includes garbage, industrial waste, construction waste, and ashes. Requirements for containerized storage, collection, transportation, treatment, and disposal of solid waste are included. These standards set groundwater MCLs at the same levels as the state drinking water standards.	These regulations are applicable when solid waste is generated during assessment or response actions, and may be relevant and appropriate to existing solid waste facilities at the Hanford Site.
Water Pollution Control/Water Resource Act of 1971, Ch. 90.48 RCW/Ch.90.54 RCW		
Surface Water Quality Standards, WAC 173-201A	These standards set water quality standards at levels protective of aquatic life.	Groundwater from the Hanford Site discharges to the Columbia River; therefore, surface water quality criteria established under this chapter are applicable in assessing risk and response actions.
Protection of Upper Aquifer Zones, WAC 173-154	This regulation directs Ecology to provide for protection of upper aquifers and upper aquifer zones to avoid depletions, excessive water level declines, or reductions in water quality.	This regulation is not applicable because it establishes the policy and program for Ecology. However, the regulation is relevant and appropriate because protection of the aquifer from adverse impacts caused by waste management units is a primary goal.

Table E-2. State of Washington Laws and Regulations

ARAR Citation	Requirement	Application
State Waste Discharge Program, WAC 173-216	The regulation establishes requirements for industrial and commercial operations that discharge to the groundwater, surface waters, or municipal sewerage systems. Specific discharges prohibited under the program are identified. The intent of the regulation is to maintain the highest possible standards, and the law requires the use of all known available and reasonable methods to prevent and control the discharge of wastes into the waters of the state.	Requirements of this program are applicable to assessment or response actions that include discharges to the ground.
Department of Health Standards for Public Water Supplies, WAC 246-290	The rule established under WAC 246-290 defines the regulatory requirements necessary to protect consumers using public drinking water supplies. The rules are intended to conform with the federal SDWA, as amended. WAC 246-290-310 establishes MCLs that define the water quality requirements for public water supplies. WAC 246-290-310 establishes both primary and secondary MCLs and identifies that enforcement of the primary standards is the Department of Health's first priority.	The requirements of WAC 246-290-310 are relevant and appropriate because the groundwater at the Hanford Site is classified as a potential future source of drinking water , based on the State classification strategy.
State Radiation Protection Requirements, Ch. 70.98 RCW		
Radiation Protection Standards, WAC 246-221	Establishes annual average concentration limits for radionuclides in gaseous and liquid effluents released to unrestricted areas from licensed nuclear facilities. Occupational dose to adults and minors are set in these requirements. Dose limits that individual members of the public may receive in unrestricted areas from external sources are also set. The standard identifies the methods required to demonstrate compliance and provides derived air concentration and annual limit on uptake values that may be used to determine an individual's occupational dose. The standard specifies requirements for monitoring personnel exposure for both external and internal exposure.	This regulation is not strictly applicable because the Hanford Site does not have licensed nuclear facilities; however, it might be relevant and appropriate because it establishes standards for acceptable levels of exposure to radiation.
Radioactive Waste-Licensing Land Disposal, WAC 246-250	Establishes the procedures, criteria, and conditions for licensing of low-level radioactive waste land disposal facilities. This section presents specific levels of radiation protection and technical requirements for land disposal of radioactive waste.	This regulation is not strictly applicable because the Hanford Site does not have licensed disposal facilities; however, it might be relevant and appropriate to the assessment if response actions allow radioactive waste to remain on site.

Table E-2. State of Washington Laws and Regulations

ARAR Citation	Requirement	Application
Washington Clean Air Act, Ch. 70.94 RCW and Ch. 43.21A RCW		
General Regulations for Air Pollution, WAC 173-400	The regulation requires that all sources of air contaminants meet emission standards for visible, particulate, fugitive, odors, and hazardous air emissions. This section requires that all emission units use reasonably available control technology, which may be determined for some source categories to be more stringent than the emission limitations listed in this chapter. The regulation requires that source testing and monitoring be performed. A new source would include any process or source that may increase emissions or ambient air concentration of any contaminant for which federal or state ambient or emission standards have been established.	Requirements of this standard are applicable to assessment and response actions that could result in the emission of hazardous air pollutants.
Controls for New Sources of Air Pollution, WAC 173-460	This standard requires that new sources of air emissions provide emission estimates for toxic air contaminants listed in the regulation. The standard requires that emissions be quantified and used in risk modeling to evaluate ambient impacts and to establish acceptable source impact levels. The standard establishes three major requirements for new sources of air pollutants: use of best available control technology; quantification of toxic emissions; and demonstration that human health is protected.	The standard is applicable to assessment and response actions where contaminants identified as toxic air pollutants are present and air emissions might be generated.
Ambient Air Quality Standards for Particulate Matter, WAC 173-470	These requirements set maximum acceptable levels for particulate matter in the ambient air and the 24-hour ambient air concentration standard for particles less than 10 μm in diameter (PM_{10}). The section defines standards for particle fallout in industrial, commercial, and residential areas. Alternate levels are set for areas where natural dust levels are high.	These requirements are applicable to assessment and response actions (e.g., drilling) that might emit particulate matter to the air.
Ambient Air Quality Standards and Emission Limits for Radionuclides, WAC 173-480	These requirements establish that the most stringent federal or state ambient air quality standard for radionuclides are enforced. The requirements define the maximum allowable level for radionuclides in the ambient air, which shall not cause a maximum accumulated dose equivalent of 25 mrem/yr to the whole body or 75 mrem/yr to any critical organ. However, ambient air standards under 40 CFR 61 Subparts H and I are not to exceed amounts that result in an effective dose equivalent of 10 mrem/yr to any member of the public. Emission standards for new and modified emission units shall utilize best available radionuclide control technology.	Requirements of this standard are applicable to assessment and response actions that might emit radionuclides to the air.

Table E-2. State of Washington Laws and Regulations

ARAR Citation	Requirement	Application
Emission Standards and Controls for Sources Emitting Volatile Organic Compounds (VOC), WAC 173-490	This chapter establishes technically feasible and attainable standards for sources emitting volatile organic compounds.	This regulation is applicable if assessment or response actions will result in airborne emissions of volatile organic compound.
Radiation Protection - Air Emissions, WAC 246-247	This regulation promulgates air-emission limits for airborne radionuclide emissions as defined in WAC 173-480 and 40 CFR 61, Subparts H and I. The ambient air standards under WAC 173-480 require that the most stringent standard be enforced. Ambient air standards under 40 CFR 61, Subparts H and I, are not to exceed amounts that result in an effective dose equivalent of 10 mrem/yr to any member of the public. The ambient standard in WAC 173-480 specifies that emission of radionuclides to the air must not cause a dose equivalent of 25 mrem/yr to the whole body or 75 mrem/yr to any critical organ.	This regulation is applicable to any assessment or response actions that would result in airborne emissions of radionuclides.
Radiation Protection at Uranium and Thorium Milling Operations, WAC 246-252	Radium-226 concentrations are required to be less than 5 pCi/g, averaged over the upper 15 cm, and not more than 15 pCi/g averaged over any 15-cm interval deeper than 15 cm from the surface. Groundwater protection standards established for gross alpha excluding radon and uranium are set at 15 pCi/L, and for combined radium-226 and radium-228 not to exceed 5 pCi/L.	This regulation is not strictly applicable because the Hanford Site does not have uranium or thorium milling operations; however, it is relevant and appropriate because it contains specific soil cleanup limits for radium-226 and radium-228 and groundwater protection limits.
Department of Game Procedures, WAC 232-012	This standard defines the requirements that the Department of Game must take to protect endangered or threatened wildlife.	These requirements may be applicable if endangered or threatened wildlife are identified in areas affected by assessment or response actions. The requirements of this chapter should be evaluated on an activity-specific basis.
National Area Preserves, RCW 79.70		
Washington Natural Heritage Program	The Washington State Natural Heritage Program is authorized under RCW 79.70, Natural Area Preserves, and serves as an advisory council to the Washington State Department of Natural Resources, Fish and Wildlife, the Parks and Recreation Commission, and other state agencies managing state-owned land or natural resources. The list of state endangered, threatened, and sensitive plants developed by the program, along with program-recommended levels of protection, are to be used to assist resource managers in determining which species of concern occur in their areas and recommend protection. The designations provided to plants by the Washington State Natural Heritage program are advisory and do not specify a regulatory level of protection.	The requirements of the Natural Heritage Program provide guidance that could affect assessment or response actions in areas where threatened or endangered plant species have been identified.

Table E-2. State of Washington Laws and Regulations

ARAR Citation	Requirement	Application
Water Well Construction, Ch. 18.104 RCW		
Minimum Standards for Construction and Maintenance of Water Wells, WAC 173-160	These requirements establish minimum standards for design, construction, capping, and sealing of all wells. The requirements set additional requirements, including disinfection of equipment, decommissioning of wells, and quality of drilling water.	These requirements are applicable because assessment or response actions could include construction of wells for groundwater extraction, monitoring, injection of treated groundwater, or resource protection, or geotechnical borings.
Rules and Regulations Governing the Licensing of Well Contractors and Operators, WAC 173-162	This regulation establishes training standards for well contractors and operators.	This regulation is relevant and appropriate because assessment or response actions could involve groundwater well installation or construction of geotechnical borings.
State Environmental Policy Act, Chapter 43.21C RCW		
SEPA Rules, WAC 197-11	These requirements establish compliance with the State Environmental Policy Act.	These requirements are applicable.
Water Quality Standards for Ground Waters of the State of Washington; WAC 173-200	Establishes groundwater quality standards to provide for protection of the environment and human health, as well as an antidegradation policy to protect existing and future beneficial uses of ground water.	WAC 173-200 standards do not apply to cleanup actions undertaken pursuant to the Model Toxics Control Act (MTCA) or the Comprehensive Environmental Response, Compensation, and Liability Act. Instead, MTCA establishes groundwater cleanup standards at such sites.
Sediment Management Standards; WAC 173-204-340, WAC 173-204 Part V	WAC 173-204-340 establishes freshwater sediment quality standards. Part V of WAC 173-204 establishes the process for establishing sediment cleanup standards and managing contaminated sediments.	WAC 173-204-340 is currently reserved and freshwater sediment standards are established on a case-by-case basis. Part V identifies specific sediment cleanup standards only for Puget Sound; cleanup standards for all other sites are established on a case-by-case basis.

CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act
CFR = Code of Federal Regulations
Ecology = Washington Department of Ecology
MCL = maximum contaminant level
MCLG = maximum contaminant level goal
MTCA = Model Toxics Control Act
NPDES = National Pollutant Discharge Elimination System
RCRA = Resource Conservation and Recovery Act
RCW = Revised Code of Washington
SEPA = State Environmental Policy Act
SDWA = Safe Drinking Water Act
TBC = to be considered
TSD = treatment, storage, and disposal
VOC = Volatile Organic Compounds
WAC = Washington Administrative Code.

APPENDIX F

REQUIREMENTS AND GUIDELINES FOR THE DEVELOPMENT AND CONDUCT OF A HANFORD SITE CUMULATIVE EFFECTS ASSESSMENT

APPENDIX F

Requirements and Guidelines for the Development and Conduct of a Hanford Site Cumulative Effects Assessment

F.1 INTRODUCTION

This Appendix presents requirements and guidelines for the development and conduct of a Hanford Site cumulative effects assessment and were developed collaboration with representatives of the CRCIA group. The Integration Project intends to use this information as a basis for guidelines for developing the System Assessment Capability (SAC). Every attempt has been made to provide clear, concise statements of principles, general requirements, and specific detail requirements that will be evaluated and incorporated into the SAC as it matures and evolves. The scope of these requirements and guidelines is extensive, and impacts many areas of the assessment. If principles and guidelines conflict, the first four principles (dominance, uncertainty, fidelity, and use of expert judgment) override all others. The *Columbia River Comprehensive Impact Assessment: Phase II* provides the original source material for this section.

The purpose of this section is to demonstrate the level of coordination and integration of the requirements of the CRCIA work into the Integration Project.

F.2 INTEGRATION PROJECT MISSION

To ensure that Hanford Site decisions are defensible and possess an integrated perspective for the protection of water resources, the Columbia River environment, river-dependent life, and users of Columbia River resources, the mission of the Integration Project is to assess the Hanford Site's present and post-closure cumulative effects in terms of the radioactive and chemical materials that have accumulated throughout Hanford's history and which continue to be received. To support this mission the Integration Project will also define those actions necessary to bring into consistency -- and maintain mutual compatibility among -- site-wide characterization and analysis tasks that bear on decisions affecting cleanup operations, planned and achieved waste disposal isolation performance, receptor impact, and regulatory compliance. The Integration Project will identify and oversee the science and technology (S&T) initiatives as necessary to enable the mission to be successfully completed.

F.3 INTEGRATION PROJECT APPROACH

Among other tasks, the Integration Project will develop the capability to estimate, and assess, impacts of the Hanford Site's waste management, remediation, and disposal activities. For Integration Project planning purposes, Hanford's cleanup decisions can be divided into three time frames: near-term, intermediate, and long-term. Near-term decisions are those that must be

made as quickly as possible to stabilize contaminants and materials that are escaping containment and/or pose a threat to safety that is so imminent that decisions must be made with the available information. Impacts across long-term time frames are generally associated with end state decisions (or decisions limiting end state options), where the implications of the solutions chosen now may not be experienced for decades (or centuries). The Integration Project will assess the expected environmental, human health, cultural, and economic impacts resulting from Hanford Site cleanup decisions over many decades. Assessments of this long term time frame necessitate development of a SAC that will be utilized iteratively throughout the period of cleanup operations to estimate the effects of various cleanup options, postulated environmental scenarios, and probable demographic changes. The analyses will consider a time horizon of sufficient duration to estimate major effects, so as not to inadvertently truncate important long-term effects of credible situations. The intermediate time frame is that time frame between the short term and long term where sufficient time exists to properly identify problems, frame a systematic approach, and collect information to implement a selected approach. Much of the Integration Project's planning related to the development of a system evaluation capability falls into the intermediate time frame.

The Integration Project is driven both by the practical need to minimize adverse impact to chosen lifestyles in the region, and the need to make remediation and mitigation decisions that are compliant with various federal and state statutes, laws, and regulations. It is of the utmost importance to the Integration Project that the support for these decisions has a fundamentally sound technical basis. It is also fundamentally important that cultural values of affected peoples and Tribal Nations be incorporated into the evaluation processes and techniques developed by the Integration Project. Therefore, the Integration Project will endeavor to provide the necessary leadership and resources to ensure that decisions are both technically and publicly credible.

The Integration Project considers the effective management of uncertainty to be essential to a prudent allocation of resources and rapid movement toward credible, technically sound decision making. The Integration Project is committed to conduct a systematic evaluation of the factors affecting the level of uncertainty of impact estimates. Primary sources of uncertainty will be identified and ranked in terms of their relative importance. It is expected that this analysis would be qualitative at first, and would become more quantitative as the Integration Project progresses and the SAC matures. The results of this evaluation will refine the approach and guide the allocation of resources. Sources of uncertainty will also be identified within each technical element.

The approach to the development of the SAC can significantly affect the identification of issues and the conclusions. The Integration Project will conduct a systematic assessment of the requirements of each technical element, and will adopt a controlled approach to identifying dominant factors in order to discard smaller contributors. Criteria will be developed (as appropriate) to support these evaluations.

The Integration Project recognizes that many requirements and guidelines will be difficult to meet. Some may require research and development. The details of the incorporation of each requirement into the Integration Project are also not developed at this time. Certainly, some requirements will not be met in early versions of the SAC.

F.4 PRINCIPLES

The following principles are applicable to all phases of the development of the SAC:

- **Dominance**. This is the principle that, in virtually all things, a relatively small number of factors dominate the outcome. This assessment must not leave out any factors that dominate the results. Yet, the magnitude of work and cost of the analysis must be responsibly managed. Sensitivity analyses, parametric analyses, and related methods will be used to identify and rank the factors that dominate the outcome of this assessment. These factors may be physical attributes of the Hanford Site, or effectiveness of waste disposal, or they may be technical characteristics and challenges within the study itself. Assumptions framed through expert judgment (in lieu of repeatable analyses) will not be used to identify dominant factors or discard smaller contributors. The resulting understanding of relative importance will be used to focus technical emphasis, management oversight, and assessment planning, as well as Hanford Site budget estimates and funding allocations.

- **Uncertainty**. System and technical element level uncertainty must be managed to support efficiently reaching Integration Project goals. The uncertainty inherent in assessment results will be qualitatively and quantitatively assessed, and used in the technical definition of the assessment as well as in the study's management and allocation of resources. The level of uncertainty that can be tolerated in the study results as a basis for cleanup decisions will be a guiding requirement. Ideally, uncertainty will be equalized across the various study tasks. The assessment of uncertainty will be used to determine the usefulness of spending additional effort to reduce uncertainty. Technical attention will be focused accordingly. It should also be recognized that uncertainty and the dominance principle are coupled. The quantification of uncertainty is a useful method and its use is supported by the Integration Project.

- **Fidelity of Assessment Results**. The level of detail of this assessment must enable detection of an impact and resultant effect that is (or will be) significant to the receptors affected by the cleanup and waste disposal decisions made at Hanford. In this context, fidelity includes the concepts of accuracy, resolution of information in both time and location, and statistical significance. Perhaps the primary consideration is that assessment results should have enough fidelity to distinguish among cleanup and disposal alternatives in the Hanford Site decision-making process. The analysts must be careful not to dismiss an effect that may be important from a cultural perspective simply because popular analytical approaches may discard such effects.

- **Use of Expert Judgment**. Experienced and knowledgeable analysts are expected to exercise their skills and judgment with the highest professionalism in planning and conducting this assessment. Substituting expert judgment for analytical quantification should, however, be avoided unless a convincing rationale is presented to the contrary. Clearly, time, available resources, and significance of the matter at hand must guide the analysts. The bases in

making such choices are credibility and reproducibility. The Integration Project's credibility and acceptance may be irreparably damaged if it appears that expert judgment was used to precipitate a predetermined favored result. Pivotal activities in the assessment must be reproducible by qualified professionals. The assessment must not be vulnerable to dispute because results cannot be independently reproduced.

- **Development and Use of Assumptions**. Arbitrary assumptions will be avoided in this Integration Project. The Integration Project's credibility and acceptance may be irreparably damaged if it appears that assumptions were deliberately imbedded in models (or other work) so as to precipitate a predetermined favored result. Assumptions will be documented and evaluated as part of the natural progression of the study. Assumptions made in the approach and in the technical elements must be traceable, documented, and made available to interested parties upon request.

- **Integration of Tasks within the Assessment**. As the assessment is subdivided into work tasks, care will be taken to ensure consistency and compatibility in the application of requirements, use of data, seamlessness of modeling, management of uncertainty, and treatment of related factors bearing on overall assessment quality.

- **Integration with Other Site Efforts**. Two areas require continuous management. First, the assessment must remain integrated with cleanup and waste disposal decisions, including related environmental impact statements, records of decision, conceptual design contract awards, planning bases for budget submittals, strategic planning, and Hanford Site project requirements documents. Second, integration must be achieved and maintained with other related analytical efforts, especially other studies involving the Columbia River. Relevant analyses performed by other organizations will be used to the maximum extent to which they are valid for the purpose and objectives of this assessment. Those performing other analyses should be asked to consider adopting this Integration Project's requirements in order to enhance usability.

- **Use of Other Study Results**. Care must be taken to avoid jeopardizing acceptance of results by including data that do not meet the requirements defined herein. This assessment will, however, use the Hanford Site disposition baseline for defining disposal methods and, if available, estimates of containment performance. Composite source term information compiled elsewhere may be used if it meets Integration Project requirements.

- **Science and Technology Development and Support of Analysis Methods**. Several of the important objectives of this assessment lie beyond conventional analytical practices. For example, in projecting mutagenic and cultural effects, existing methods will need to be modified and new techniques developed. Design and planning of the assessment must include definition of S&T needs in order to ensure that the proper analytical tools and technical information will be available (when needed), and that the resources of the Department of Energy (DOE) can be used for their development.

F.5 GENERAL REQUIREMENTS

- **Columbia River Area to be Assessed**. Bearing in mind the overarching principle of excluding from the assessment progressively less important factors and effects, the geographic section of the Columbia River to be assessed begins at the Priest Rapids Dam and proceeds progressively downstream as far as significant impacts are indicated to the river's mouth. Initially, the Integration Project will concentrate on the area between Priest Rapids and McNary dams. The final assessment will incorporate a geographic area that is defined by the extent of actual and potential impacts. The river area includes the riparian zone and both drinking water and irrigation water drawn from the river. It also includes the aquatic and upland terrestrial life that depends on the river for biological, social, or economic reasons. The water ingested from the Hanford Reach area includes undiluted, or only somewhat diluted, groundwater found in seeps and springs in the riparian zone, as well as groundwater upwelling in the river bottom where aquatic habitat is found.

- **Terrestrial Area to be Assessed**. In addition to the land area influenced by the Columbia River (as described above), the Integration Project should assess Hanford's effects throughout the Pasco Basin. (At this time, this terrestrial assessment is not included in the Integration Project workscope). Generally, the Pasco Basin is bounded on the North by the Saddle Mountains, on the West through South by the Umtanum, Yakima, and Rattlesnake Ridges, and on the East by geologic features more or less following highway 395.

- **Time Period of Potential Impact**. Hanford's impact on the region began with the federal government's acquisition of Hanford lands in 1943. The assessment's focus continues through the period during which the radioactive and chemical materials remain intrinsically harmful, including radioactive decay products and chemical reaction products. The generally recognized current regulatory horizon (about 30-50 years) is inconsistent with the long-term persistence of Hanford's wastes and materials. The assessment must be guided by the material's period of intrinsic hazard, rather than the regulatory period. However, to ensure that the assessment results are also useful in regulatory matters, points of time important in regulatory considerations will be identifiable in assessment results.

  It is beyond the scope of this Integration Project to estimate past injury or damages. Nevertheless, to the extent that past Hanford Site events have resulted in present day cumulative effects, or conditions that bear on future impacts, the past events must be understood and taken into account in this assessment.

- **Radioactive and Chemical Materials**. Calculations involving radioactive and hazardous materials data will include radioactive decay products and chemical compounds/properties estimated to occur with time and after reaction with other chemicals, soils, and river chemistry.

- **Impact Comparison Baseline**. "Impact," as used throughout this assessment, means (and will be compared with) conditions that would exist if no Hanford Site contamination had ever occurred. Generally, this pre-Hanford state will be equated with today's conditions

extending northward from Hanford to appropriate areas upstream (such as the area in the vicinity of the Priest Rapids Dam). It is recognized that Hanford contaminants are not entering a pristine ecosystem. Hanford's impact is the fractional contribution of total impacts resulting from Hanford contaminants entering into the existing system. Total impacts shall include the combined effects of Hanford contaminants and those originating elsewhere.

- **Assessment Metrics and Criteria**. Contaminant concentrations, doses, and impacts prescribed in regulations can be used in the assessment for general information and guidance. However, caution must be exercised to ensure that effects of interest are adequately considered in this assessment, even though they may be not adequately treated in current regulations. Additionally, other impacts of interest in this assessment are typically not addressed in regulations; for example, mutagenic effects, teratogenic effects, and cultural effects. Levels of contaminants elevated above those generally found in areas outside of Hanford's influence will not be ignored because they lie below regulatory levels or because of a void in research linking such contaminant levels to adverse effects. This requirement is especially important where two or more source terms potentially interact but are typically ignored in individual project's analyses. Consequently, individual project's point of compliance criteria ten meters down gradient, for example, may have little relevance in a cumulative assessment of multiple source terms. Criteria used by assessment analysts must include consideration of existing reference levels of the contaminants, the presence of multiple contaminants and multiple exposure pathways, general environmental cleanup experience, the body of regulatory experience, and historical environmental events (such as Chernobyl). Other considerations include health physics accepted practice; international standards, such as those of the International Commission on Radiological Protection; cause and effect correlations from the medical community; and new developments in ecology, toxicology, and risk assessment. In addition to the need for criteria for elevated contaminant levels, criteria also may also need to be developed for the aggregate tolerable contaminant load in groundwater and total plume size, both based on the presence of multiple contaminants. Development of criteria to assess some of these effects may require a S&T effort. However, by virtue of the research time required, these may necessitate planning for a inclusion in the assessment at a later time.

- **Required Results**. A primary result of the assessment is the actual or projected dose level, and its expected consequence, from Hanford-derived contaminants for each receptor and each dominant contaminant as it varies in spatial distribution throughout the time period of interest. A "receptor" in this assessment may be a human or a human population group, a cultural lifestyle, biota or ecological system, or a regional business economy. Estimates must be made for individual dominant contaminants, as well as multiple contaminants that, when assessed in combinations occurring at the same time, result in elevated toxicity levels. Analysts might expect to find suspiciously high levels of some contaminants for which biological effects are not well established. Any such findings must be retained and reported. Concern about specific impacts has been expressed by stakeholders and must be evaluated to determine the potential for their existence and their severity.

- **Assessment Control**. The aggregate of the requirements makes it indispensable to focus relentless attention on the control of the conduct of the assessment. Sensibly applying and maintaining the delicate balance among the principles of dominance, management of uncertainty, and fidelity require thoughtful conceptualization and planning of the assessment, as well as continual reassessment and rebalancing of the on-going effort.

- **Assessment Frequency**. As discussed in the Mission Statement and Project Approach sections above, this project will provide a technically defensible and publicly credible, integrated basis for Hanford cleanup decisions related to cleanup operations, the present site baseline, and changes thereto. Accordingly, the Integration Project will develop and maintain a SAC for use in evaluating the effectiveness of planned and actual site end states, proposed changes, and alternative technologies. It will be important to improve previous assessments by iterating the estimating process as (1) analysis methods mature; (2) field data become more complete; or (3) new environmental/ demographic information suggests new scenarios (or new paths) to decrease previous uncertainties.

- **Required Continuation of Columbia River Monitoring**. Much of the basis for detecting trends in changes to the river, which are very important to realistic assessment results, comes from monitoring current groundwater and river conditions. The monitoring program must be continued and periodically refocused to the findings and needs of this assessment.

APPENDIX G

CURRENT STATE OF TECHNICAL KNOWLEDGE

APPENDIX G

Current State of Technical Knowledge

The Integration Project team evaluates work from the perspective of technical information or capability needs for the system, rather than from a viewpoint constrained by the scope and objectives of individual projects. Work is evaluated by grouping activities by technical lines or technical elements. Knowledge gaps, overlapping work scopes, and project inefficiencies are assessed in this evaluation process.

This section briefly describes the current state of knowledge for the key technical areas of work that have been, and are currently being performed, at the Hanford Site. This discussion highlights key deficiencies that have been identified at this point in time. The key deficiencies that are being evaluated by national laboratory teams include the technical areas of inventory, vadose zone, groundwater, and river environment. The determination of risk and monitoring issues, along with underlying applied science needs is underway.

An applied science plan has been developed from this evaluation. This plan, which is linked to Integration Project priorities, is the basis for the Science and Technology (S&T) roadmap. Both the plan and roadmap are provided in Appendix H of this *Project Specification.*

G.1 STATE OF KNOWLEDGE

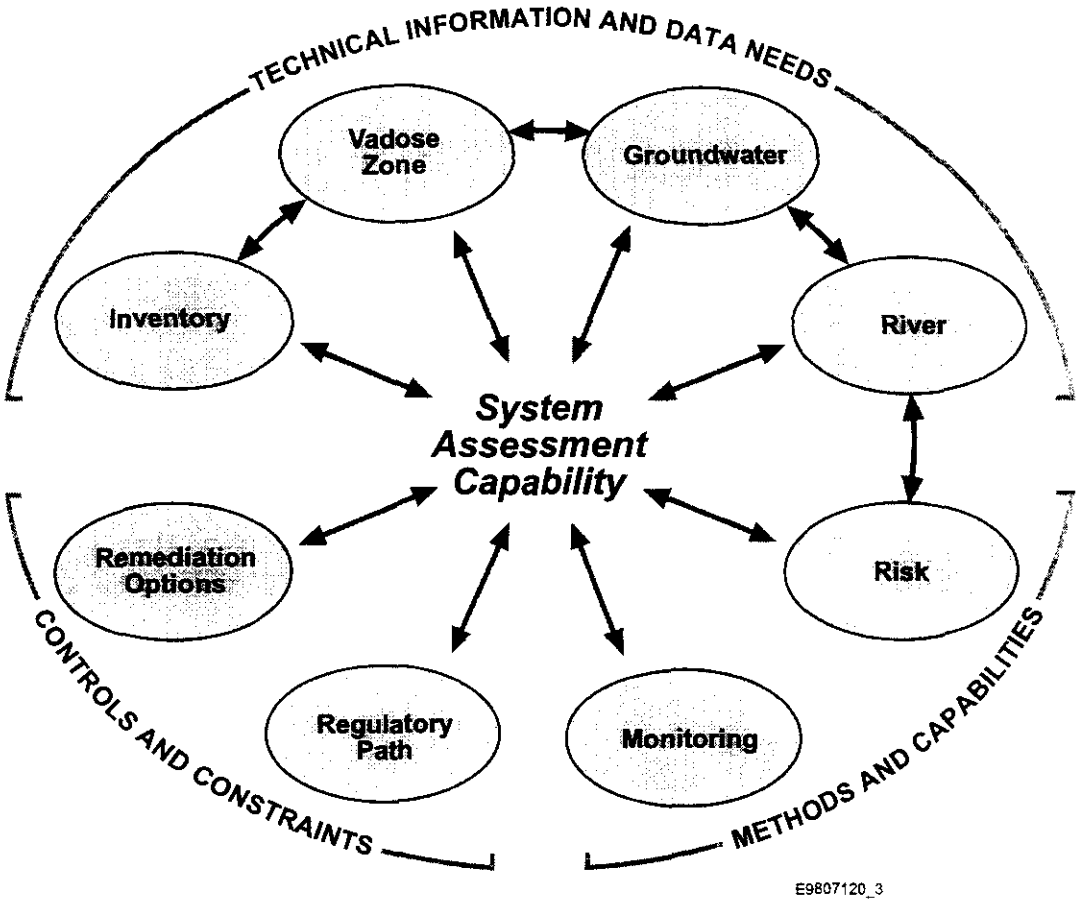
Four types of work scope are part of the overall Integration Project: (1) technical information and data needs; (2) methods and capabilities; (3) controls and constraints; and (4) integration. These categories are further subdivided into technical elements, as illustrated in Figure G-1. The work scope for these technical elements was defined with the assistance of stakeholders, through public workshops.

Technical Information and Data Needs. This category contains the Inventory, Vadose Zone, Groundwater, and Columbia River technical elements. The work scope associated with these elements involves characterization of various features and processes that are essential to development of conceptual models of how the natural system works. The term "information" includes interpretations of field observations, and the output from numerical analyses.

Methods and Capabilities. The Monitoring and Risk Assessment technical elements are included in this category, and contribute to the information and data needs elements. The work scope within the Monitoring element pertains to data collection methods and logistics. Risk assessment activities pertain to using various accepted methods, or developing new methods, to quantify risk to human health and the environment for various scenarios.

Controls and Constraints. This category describes the regulatory path (regulations and legally binding agreements) and remediation options (technological options available for mitigation and/or remediation). These elements form the principal basis for the project's technical work scope.

Figure G-1. Integration Project Technical Elements.



Integration. The elements above are integrated within the System Assessment technical element. The System Assessment technical element supplies the unifying focus for all the technical work performed to assess the impacts of contamination on the Hanford Site. This unifying focus is illustrated in Figure G-2. The work scope of this element consists of the iterative aspects of evaluating information relative to project objectives, and redefining or identifying additional work scope (as appropriate). The goal of the System Assessment technical element is to acceptably quantify the environmental consequences of past, present, and future U.S. Department of Energy (DOE) actions at the Hanford Site, in terms of their impact on human health and the environment. The system assessment capability can then be used for sensitivity and uncertainty analyses, to help set priorities for science and technologies. It can also guide the development of data quality objectives (DQOs) for characterization plans, and establish a consistent set of assumptions, data, and tools for evaluation of remedial options.

The site assessment must accommodate various spatial and temporal scales of interest that are defined by the diverse types and locations of contamination. A central concern is the time period to be assessed. Impacts of mobile contaminants released from past practices of discharging large

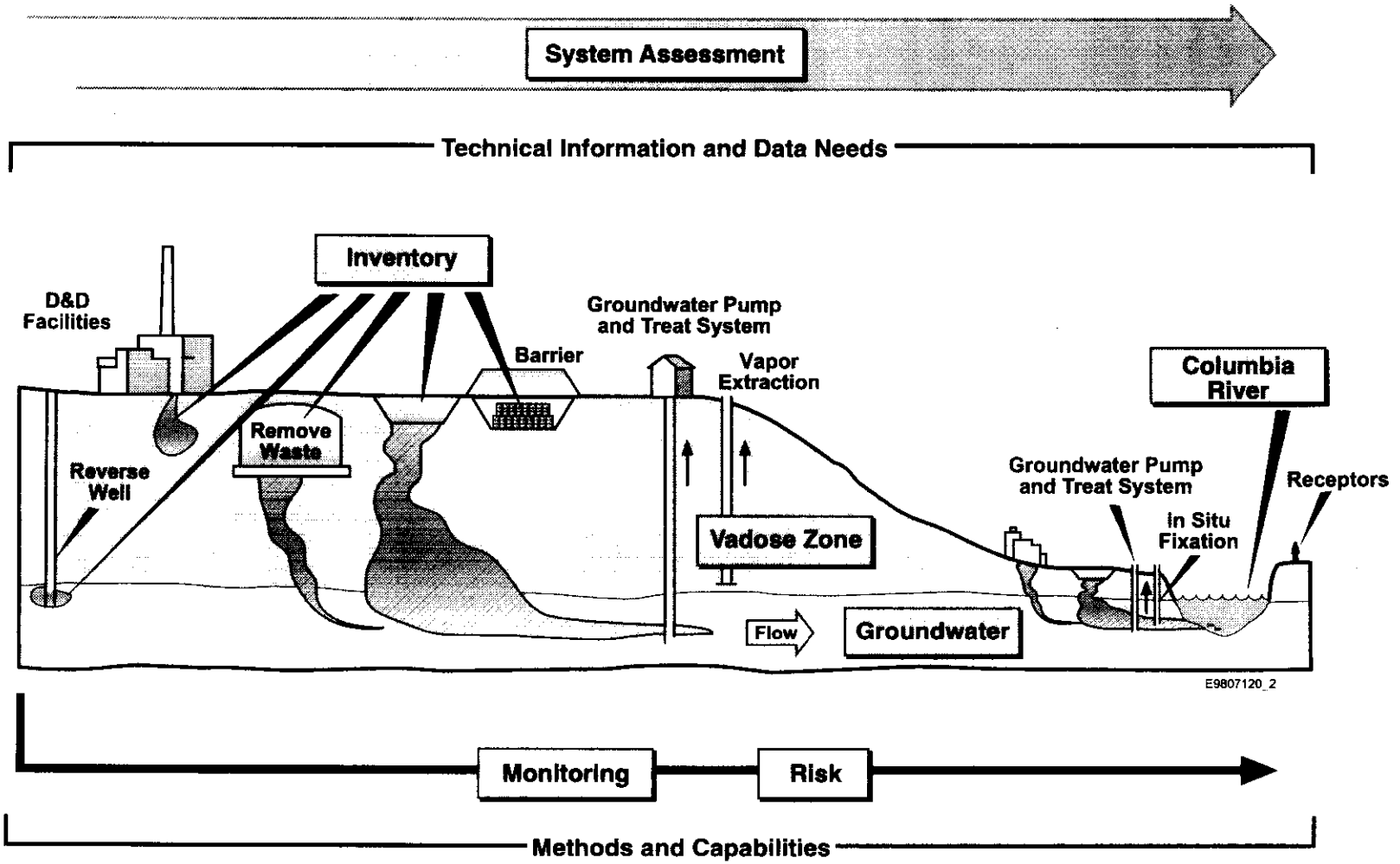


Figure G-2. Major Elements of the System Assessment.

Controls and constraints on the system assessment are the regulatory path and the remediation options.

volumes of liquid wastes to the subsurface may be seen within years or decades; however, long-lived radionuclides and chemicals also present longer-term threats to human health and safety. Methods for estimating potential impacts to the public require that areas of future public access and methods of exposure be unambiguously defined.

To achieve the goals defined above, the Integration Project must design, develop, and apply an assessment capability. A system conceptual model upon which the system assessment can be performed is shown in Figure G-3. Components of this capability currently exist, but they have not been linked in a system assessment model. Other components do not exist. The system assessment capability integrates and coordinates the linkages among the various other technical elements discussed in this section to provide the input that is needed. Through the coordination of input to the system assessment capability, the quality of the overall analysis will be enhanced and the consistency and completeness of the analysis will be improved.

The system assessment capability supports the deficiencies assessment process by identifying key data gaps and sources of uncertainty that affect the risk calculation that is provided to decision-makers. If the calculated risk is unacceptable, and work can be performed in areas of high uncertainty to help refine the calculation, these areas will be targeted for work. Work priorities will then be assigned accordingly.

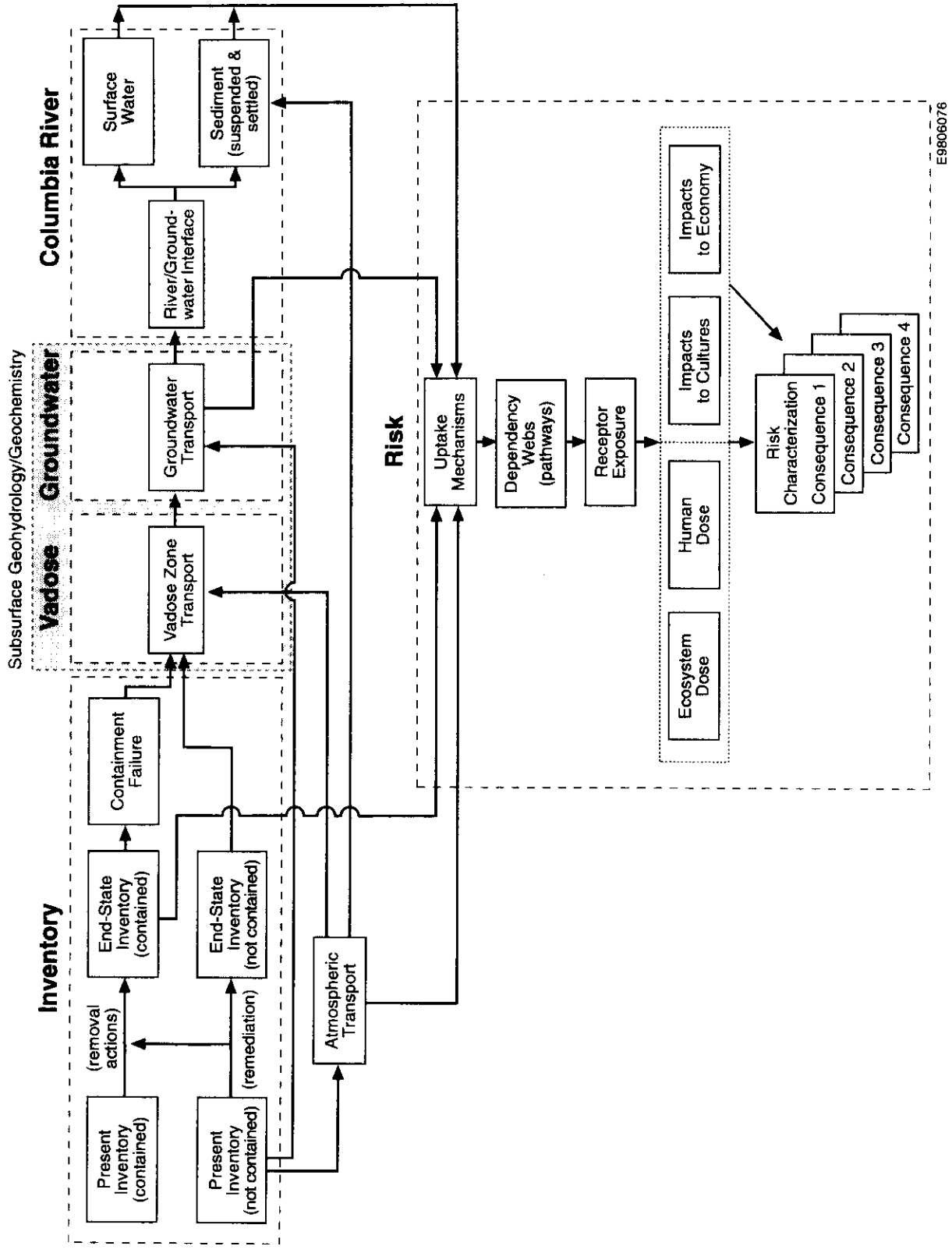
The technical element discussions provided in this section were initially developed by technical teams made up of representatives from each of the Hanford Site contractors. Materials have been provided to the national laboratory working groups (see Section G.1 for a discussion of these groups), and their recommendations have been integrated. Work on the system assessment, risk, and monitoring technical elements is in progress. The level of detail provided in each discussion reflects the input of the working groups and, therefore, variability exists between technical elements. All elements discuss three basic topics: the technical scope of the element, the current state of knowledge, and the key technical deficiencies that have been identified to date. The future roadmapping activity will identify the priority deficiencies and the S&T required to mitigate those deficiencies.

G.1.1 Inventory

G.1.1.1 Scope. Inventory is the total quantity of radiological and chemical constituents used and created at the Hanford Site, and their distribution in facilities, waste disposal sites, the vadose zone, groundwater, and Columbia River ecosystem. A good understanding of inventory is key to a system assessment because the potential groundwater and river contamination is proportional to the amount of radionuclides and chemicals that are disposed on the Hanford Site and capable of migrating from the Hanford Site. The technical information that is needed to determine this inventory includes the following:

- Locations, amounts, and concentrations.
- Characteristics of the radionuclide or chemical compound.

Figure G-3. System Conceptual Model.



- Mobilization and release mechanisms and rates.

- Change in inventory because of natural processes (e.g., decay), remediation activities, and Hanford Site operations.

In addition to inventory estimates, mechanisms must be identified that describe the release of the inventory from facilities into the vadose zone, unconfined aquifer, or the Columbia River. Because the long-term configuration of the waste inventory depends on future remediation and land-use decisions, a baseline estimate of end-state inventory distributions must be defined for a system assessment.

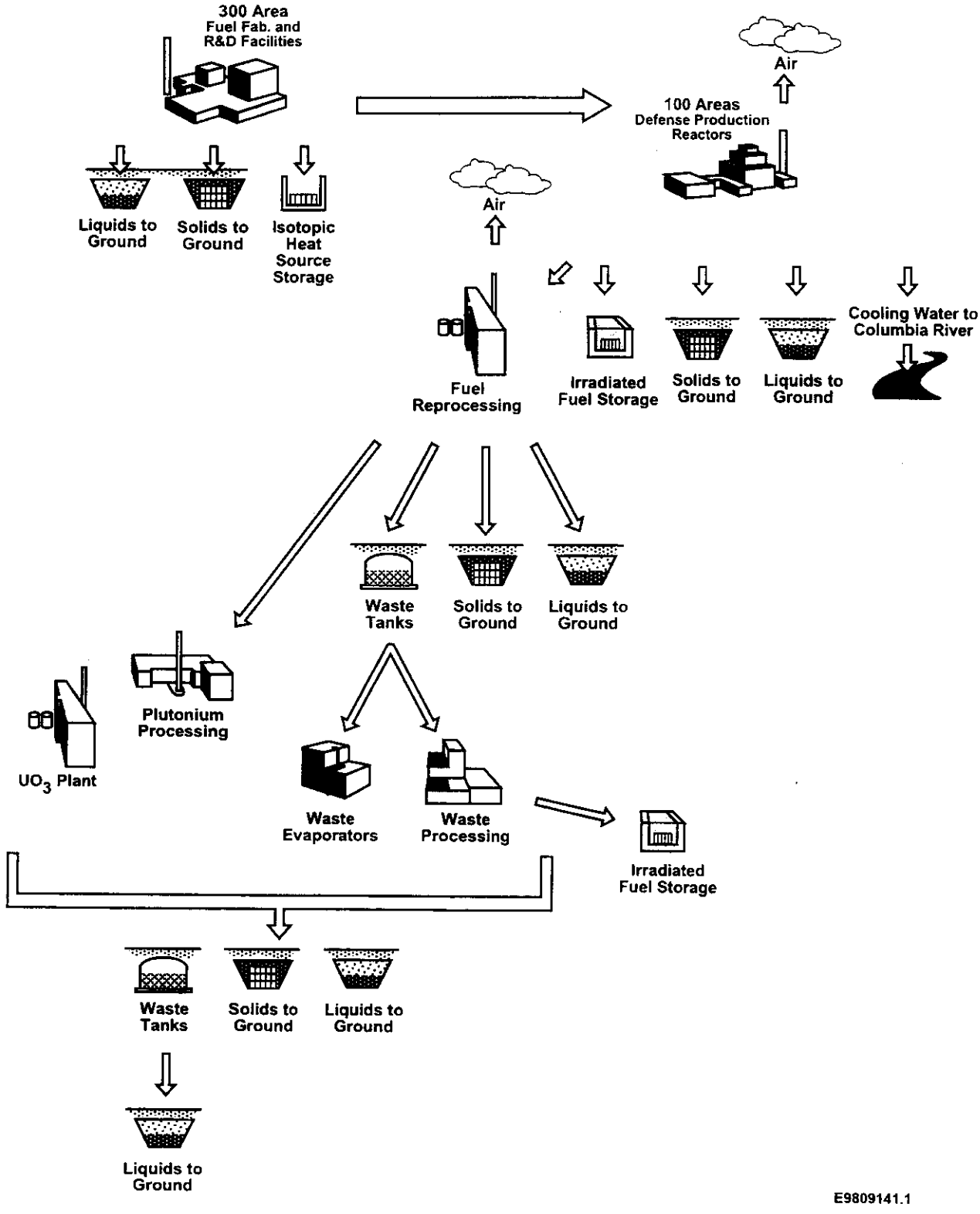
A holistic approach to quantifying site inventory is central to the inventory technical element scope. To date, inventory estimates for radionuclides and hazardous chemicals have been developed within specific projects. These estimates tend to be conservatively high. No comprehensive analysis has been performed that compares and reconciles the estimates for each facility with estimates of the total Hanford Site inventory. A comprehensive integrated analysis will help ensure that estimates for key contaminants are sufficiently accurate and credible to support a site-wide assessment of environmental impacts and risks.

G.1.1.2 Current state of knowledge. The vast majority of the radioactive waste inventory at the Hanford Site was created during the production mission. A conceptual model of the Hanford Site process is shown in Figure G-4. There were three distinct steps in the production process: fuel fabrication, fuel irradiation, and chemical separation. During the first decades of production work at the Hanford Site, it was common to locate waste disposal sites relatively close to waste-generating facilities. This practice resulted in numerous and varied disposal sites. The most dangerous radioactive wastes were stored in large single-shell tanks (SSTs) in the 200 Areas (Agnew et al. 1997; Kupfer et al. 1997). Large volumes of solid waste (e.g., contaminated tools and protective clothing) were disposed in burial grounds, and large volumes of liquid waste were discharged to shallow subsurface cribs, french drains, injection (or reverse) wells, and specific retention trenches.

More recently, all fuel fabrication and reactor operation activities ended and cleanup of past-practice units began in the 300 and 100 Areas. Low-level waste (LLW) from ongoing operations is disposed in specific burial grounds in the 200 West and 200 East Areas. Most liquid discharges of radioactive wastes have been discontinued, the exception being tritium disposal to the State Approved Land Disposal Site, which received treated water from the 200 Area Effluent Treatment Facility (ETF). Tritium is discharged by permit to this facility because it is not removed during ETF treatment.

A small group of mobile radionuclides and chemicals are known to be of primary interest relative to long-term groundwater contamination, because they have already contaminated the unconfined aquifer and are known to be chemically mobile. The list of radionuclides includes ^{99}Tc, ^{129}I, uranium, and tritium. Chemicals include carbon tetrachloride, trichloroethylene, nitrite, nitrate, cyanide, and chromium. Other radionuclides that are likely to be less mobile but present in groundwater due to direct injection are ^{137}Cs, ^{90}Sr, and plutonium.

Figure G-4. Hanford Process Conceptual Model.



Radionuclide inventory estimates have been made for waste sites containing large fractions of contaminants on the Hanford Site. A total radionuclide inventory estimate has been established on the basis of Hanford reactor fuel production records, and is considered to be reasonably accurate, but the distribution of inventory among the various waste sites and facilities is not well known. A companion Hanford site-wide inventory of potential groundwater contaminating chemicals has not been established.

Waste disposal sites in the 200 West and 200 East Areas included in the 200 Area Composite Analysis (Kincaid et al. 1998), and are shown in Figures G-5 and G-6, respectively. Major types of waste sites and documented inventory sources are discussed in the following paragraphs. Detailed summaries, including tabulated inventory summaries, are provided in Section G.2.

Tank Waste

Several efforts have been made over time to estimate tank waste radionuclide and chemical inventories. Most recently, a best basis estimate has been completed for current inventory in single- and double-shell tanks (Kupfer et al. 1997; Agnew et al. 1997). This estimate is derived from the Hanford Defined Waste (HDW) model based on processing records, tank operation records, and available tank analysis results (solids and liquids). This model also estimates inventory from tank waste discharged to cribs and leaked from tanks. Numerous tank characterization reports are also available that record sample and analysis data, including the Tank Waste Information Network System (TWINS2) that can be accessed on the Internet through the Hanford Web (http://www.proxy.rl.gov:1050).

Solid Low-Level Waste

The Solid Waste Tracking System (SWITS) database (Clark 1995) accounts for all waste disposed in the low-level waste burial grounds (LLBG). This database is kept current as waste is disposed. Inventories for both inactive and active burial grounds are recorded. Both radionuclides and hazardous chemicals are tracked in SWITS. The completeness of the records decreases for earlier disposed wastes. Radionuclide estimates are provided for all disposed waste, but chemical inventories are generally unavailable for waste disposed prior to 1980, and are only marginally available between 1980 and 1987.

CERCLA Remediation Sites

Inventory estimates for *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA) sites have been developed from process knowledge, and from sampling and analyses of site materials. CERCLA sites include cribs, ponds, and ditches in the 100, 200, and 300 Areas; decommissioned buildings (reactors, processing plants, auxiliary structures); and inactive solid waste burial grounds. Minimal radionuclide and chemical inventory data exist for many sites, and the process of collecting more detailed inventory information at specific sites is dependent on the remediation schedule. Recent CERCLA efforts have been concentrated on the most contaminated sites in the 100 and 300 Areas.

Figure G-5. Waste Disposal Sites in the 200 West Area.

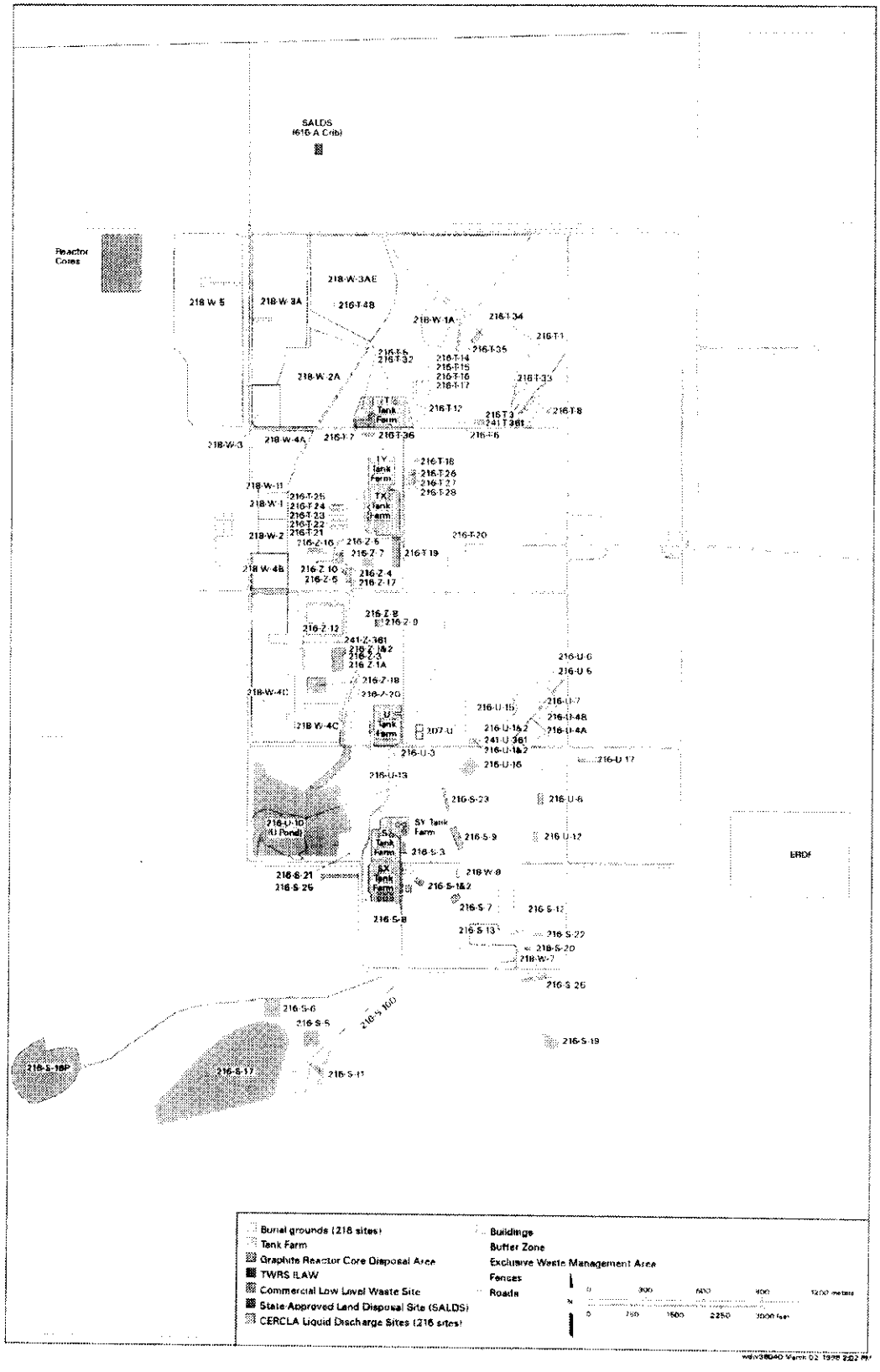
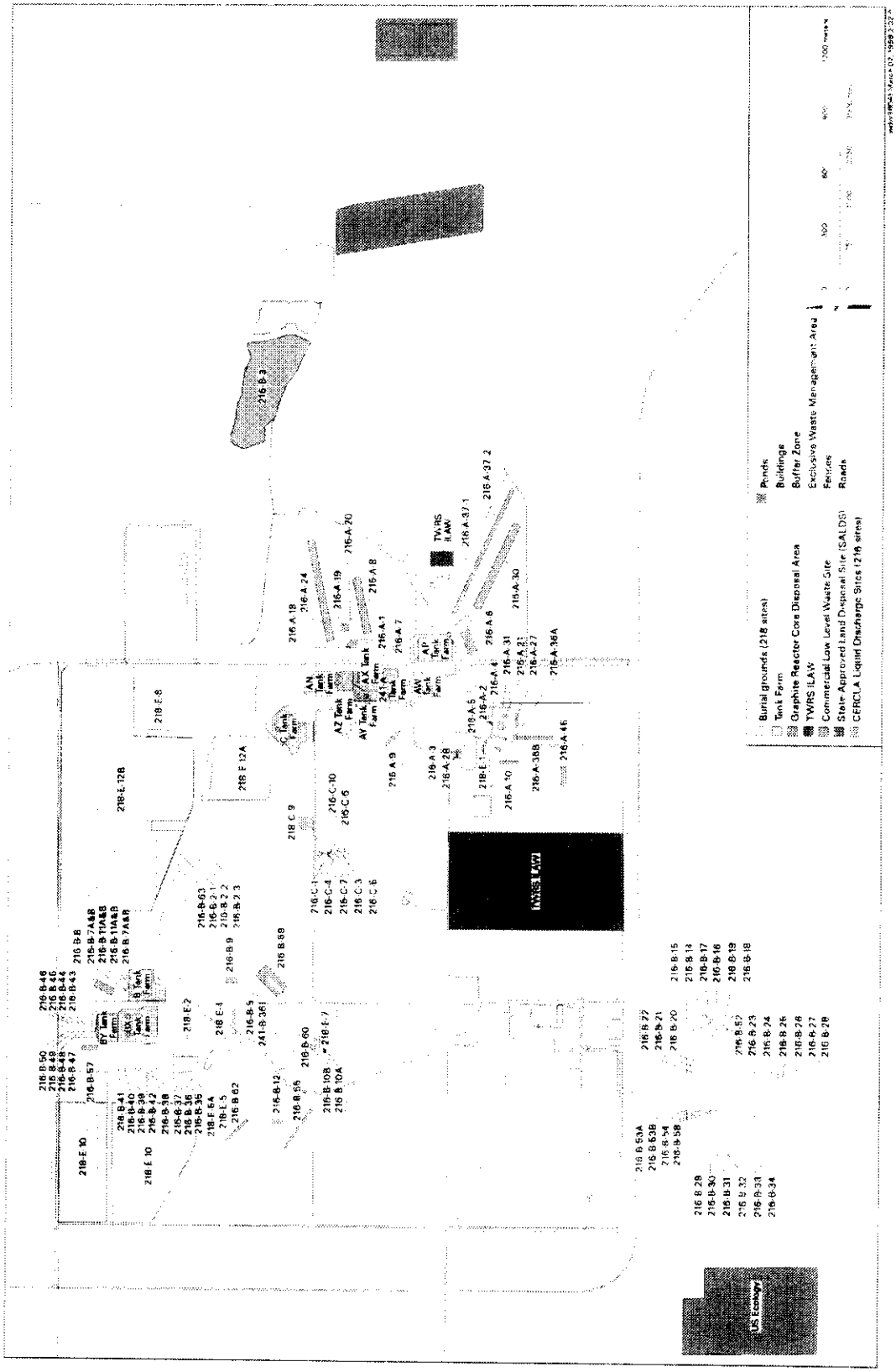


Figure G-6. Waste Disposal Sites in the 200 East Area.



In addition to waste site information, total radionuclide production estimates have also been made based on reactor operation history. Also, other waste streams are present at the Hanford Site that are planned to be disposed offsite (e.g., unprocessed spent fuel from N Reactor currently residing in K Basin and transuranic (TRU) waste stored in the LLBG). No attempt has been made to estimate total site inventories of hazardous chemicals.

Other than project-specific inventory estimates, the most recent attempt at radionuclide inventory estimates across projects is the Composite Analysis (Kincaid et al. 1998) that compiles all existing waste site inventories in the 200 Areas (Table G-1). This document illustrates the inconsistencies in inventory estimates from a partial Hanford site-wide perspective for a few key radionuclides that have been demonstrated to be important based on past performance assessments and other studies. Two other studies (Kupfer et al. 1997 and Schmittroth et al. 1995) are key references for the Composite Analysis.

Differences in the Kupfer et al. (1997), Agnew et al. (1997), and Schmittroth et al. (1995) Totals

Kupfer et al. (1997) and Agnew et al. (1997) present global estimates of waste inventories in the single- and double-shell tanks. In developing their estimate of the low-level fraction of tank wastes for immobilization and disposal, Schmittroth et al. (1995) present an estimate of total tank wastes in both double-shell tanks and SSTs. However, significant differences appear in the estimates of key radionuclides ^{14}C, ^{99}Tc, and ^{238}U, because different split factors were applied in these studies for the chemical processing steps that followed production of isotopes in the reactors.

In the case of ^{14}C, the difference may be related to the assumption in the more recent model (Agnew et al. 1997; Kupfer et al. 1997) that all ^{14}C was routed to the tanks. A portion is suspected to have been lost to the atmosphere during fuel dissolution. Differences with regard to ^{99}Tc are related to the assumed amount exported with uranium to other facilities in the DOE complex. Finally, the amount of ^{238}U is similar in Schmittroth et al. (1995) and Kupfer et al. (1997), 296 and 322 Ci, respectively, but different than in Agnew et al. (1997), 906 Ci in tanks.

The apparent over-prediction of the HDW model (Agnew et al. 1997) for uranium in the tanks can be attributed to the use of a conservative factor for the fraction of uranium metal waste that was not recovered.

Carbon-14

The greatest inventory of ^{14}C at the Hanford Site (42,200 Ci) is in the graphite cores of the production reactors. Significant inventories of ^{14}C are also associated with the Environmental Restoration Disposal Facility (ERDF) (3,800 Ci) and the commercial LLW disposal facilities (3,850 Ci).

Significant differences exist between the Schmittroth et al. (1995) estimate of 769 Ci and those of Agnew et al. (1997) and Kupfer et al. (1997), 4,910 Ci and 4,808 Ci, respectively. Global

Table G-1. Summary Table of Inventories Considered in the Composite Analysis.

Site Name	Radionuclide Inventories in Curies[a]					
	C-14	Cl-36	I-129	Se-79	Tc-99	U-238
Agnew[b] All Tanks	4.78E+03		6.30E+01	7.73E+02	3.26E+04	9.06E+02
Agnew[b] Cribs	1.24E+02		1.64E+00	2.63E+01	8.68E+02	1.31E+03
Agnew[b] Leaks	1.44E+01		2.04E-01	1.85E+00	1.07E+02	4.63E-01
Agnew[b] Total Site	4.91E+03		6.48E+01	8.01E+02	3.35E+04	2.22E+03
Kupfer[c] Global Tank Inventories	4.78E+03		6.61E+01	7.73E+02	3.26E+04	3.22E+02
Schmittroth[d] Total	7.69E+02		6.61E+01	1.03E+03	2.72E+04	2.96E+02
Total[e]	5.00E+04	3.45E+02	1.71E+01	1.05E+03	2.49E+04	6.60E+04
Total minus US Ecology	4.62E+04	3.11E+02	1.13E+01	1.05E+03	2.48E+04	5.50E+04
Total minus (cores + US Ecology)	3.95E+03	7.60E+00	1.13E+01	1.05E+03	2.48E+04	5.50E+04
Total minus (cores + US Ecology + ERDF)	1.50E+02	7.60E+00	1.13E+01	1.05E+03	2.48E+04	8.00E+02
TWRS ILAW	7.69E+00	0.00E+00	6.62E+00	1.03E+03	2.23E+04	1.78E+01
TWRS SST Leaks – cmplx[f]	3.15E-01	0.00E+00	5.99E-02	5.60E-02	5.22E+01	2.45E-03
TWRS SST Leaks – ncmplx[g]	4.11E+00	0.00E+00	6.78E-01	7.32E-01	4.59E+02	3.21E-02
TWRS SST Losses - cmplx	1.44E-01	0.00E+00	2.88E-03	7.47E-03	5.76E+00	3.14E-04
TWRS SST Losses - ncmplx	3.52E+00	0.00E+00	6.23E-01	6.27E-01	4.67E+02	2.75E-02
TWRS SST Residuals - cmplx	1.17E+00	0.00E+00	5.74E-03	2.79E-01	3.84E+00	3.24E-01
TWRS SST Residuals - ncmplx	2.86E+01	0.00E+00	1.54E-01	7.70E+00	1.06E+02	4.42E+00
TWRS DST Residuals - cmplx	8.28E+00	0.00E+00	0.00E+00	0.00E+00	8.62E+01	0.00E+00
TWRS DST Residuals - ncmplx	1.49E+01	0.00E+00	0.00E+00	0.00E+00	1.25E+02	0.00E+00
216[h] liquid discharges + 241[i]	3.65E+00	2.40E-01	1.94E+00	2.93E-01	9.37E+02	1.57E+02
218[j] 200 W[k] pre-1988	2.89E+01	1.45E+00	6.18E-01	1.77E+00	6.01E+01	1.92E+02
218 200 E pre-1988	7.94E+01	5.22E+00	4.25E-01	6.36E+00	2.15E+02	9.85E-01
218 200 W post-1988	1.74E+01	8.33E-01	2.10E-01	1.07E+00	5.15E+01	3.46E+02
218 200 E post-1988	1.35E-01	8.87E-03	4.21E-02	1.08E-02	3.66E-01	6.68E-02
ERDF	3.80E+03	0.00E+00	0.00E+00	0.00E+00	6.57E+00	5.43E+04
Production Reactor Cores	4.22E+04	3.03E+02	0.00E+00	0.00E+00	1.09E-01	4.00E-03
US Ecology	3.85E+03	3.44E+01	5.77E+00	0.00E+00	6.56E+01	1.09E+04

a Inventories have been decayed to a common date of 2050.
b See Agnew et al. (1997).
c See Kupfer et al. (1997).
d See Schmittroth et al. (1995).
e Sum of estimated inventories of sites included in the first iteration of the Composite Analysis.
f cmplx = complexed wastes.
g ncmplx = noncomplexed wastes.
h 216 refers to past-practice liquid disposals.
i 241 refers to tanks associated with reverse wells.
j 218 refers to solid waste burial grounds.
k W and E refer to the 200 West Area and the 200 East Area, respectively.

estimates of ^{14}C by Agnew et al. (1997) and Kupfer et al. (1995) were based on an assumed 100% delivery of ^{14}C in fuel to the waste tanks. Consequently, their estimates of ^{14}C may be high.

Significant differences exist between the Schmittroth et al. (1995) estimate of 769 Ci and those of Agnew et al. (1997) and Kupfer et al. (1997), 4,910 Ci and 4,808 Ci, respectively. Global estimates of ^{14}C by Agnew et al. (1997) and Kupfer et al. (1995) were based on an assumed 100% delivery of ^{14}C in fuel to the waste tanks. Consequently, their estimates of ^{14}C may be high.

Regardless of the inventory in the tanks, the future location of 99% of the tank inventory after chemical separation into high-level and low-activity waste streams and immobilization is not clearly identified. One percent (1%) of the tank inventory is assigned to the immobilized low-activity waste (ILAW). Ninety-nine percent (99%) is assigned to the immobilized high-level waste. However, the high-level waste may be a vitrified glass waste form, and it may not capture volatile iodine isotopes. Furthermore, the integrated database for spent fuel and radioactive waste (ORNL 1997) shows 4.42 Ci of ^{14}C in ILAW and only 0.0911 Ci in high-level waste glass canisters at the Hanford Site following completion of the chemical separation and immobilization campaigns.

Chlorine-36

As with ^{14}C, the graphite cores are the dominant source of ^{36}Cl at the Hanford Site (302 Ci). To investigate the potential significance of ^{36}Cl in other Hanford Site wastes, a 1-ppm level of ^{35}Cl contamination was introduced in the Oak Ridge Isotope Generation and Depletion (ORIGEN2) simulations of irradiated fuel. There are no data on the actual ^{35}Cl impurity levels in DOE fuel irradiated in the graphite core production reactors at the Hanford Site. However, it is believed the 1-ppm level is within an order of magnitude of the true value. This level of impurity has been used to forecast the level of ^{36}Cl in aged fuel. Fuel ratios and the inventory of ^{137}Cs were used to build ^{36}Cl inventory into inventories for solid waste burial grounds and liquid discharge sites. If significant impacts from ^{36}Cl are forecast, it is important to remember they may not be real. If such a forecast occurs, it will be important to determine chlorine impurity levels in DOE fuels and develop a true estimate of its potential contribution to dose.

Iodine-129

Total inventory values for ^{129}I are fairly consistent among the past and present Tank Waste Remediation System (TWRS) inventories. However, while ~65 Ci were projected to reside in Hanford Site tanks, fewer than 11 Ci were accounted for in the Composite Analysis as remaining at the Hanford Site after closure. Of this amount, the majority could reside in the ILAW from the tanks. Little of the highly volatile ^{129}I inventory may remain in the ILAW.

The total inventory estimate is based on the assumption that all ^{129}I was routed to the tanks. Such an assumption neglects losses of iodine to the atmosphere, disposals of iodine to solid waste burial grounds and cribs, and the storage of two silver reactors in the second Plutonium

Uranium Extraction (PUREX) tunnel.[1] Kupfer et al. (1997) estimated that 71% of the iodine may have been routed to tanks, and the remainder (i.e., 29% or ~18 Ci) to the atmosphere or ground.

The volatile character of iodine implies it will not be captured in a vitrified high-level waste and subsequently exported from the Hanford Site. Some may be identified as leaving the Hanford Site as TRU waste. With this exception, an upper bound for the final disposal of ^{129}I at the Hanford Site could include the entire inventory generated at the Hanford Site (~65 Ci). This is approximately a factor of six more ^{129}I than was accounted for in the first iteration of the Composite Analysis, in which an estimated 10% of the original tank inventory (6.6 Ci) was assigned to ILAW.

Selenium-79

The global inventories of ^{79}Se in the tanks were relatively consistent among the assembled inventories (i.e., Agnew et al. 1997, 773 Ci; Kupfer et al. 1997, 773 Ci; Schmittroth et al. 1995, 1,030 Ci). It was assumed that the entire ^{79}Se inventory in the tanks will be contained in the ILAW (Mann et al. 1997). Fewer than 20 Ci were assigned to the other tank inventories (e.g., tank leaks, solid waste burial grounds, and liquid discharges).

It is anticipated that ^{79}Se inventories for the Hanford Site will be reduced by a factor of eight in the near future, based on a recent update of the decay half-life of this isotope (Kupfer et al. 1997). The significance of ^{79}Se as a contributor to dose should decrease proportionately.

Technetium-99

The estimates produced by Schmittroth et al. (1995) for the ILAW disposal were used in this analysis to represent the ILAW. Schmittroth et al. (1995) estimated a total 27,200 Ci of ^{99}Tc in the tanks. Of that total, 22,300 Ci are to go into ILAW and the remaining 4,900 Ci are to go to high-level waste glass. Agnew et al. (1997) and Kupfer et al. (1997) present global estimates of the amount of ^{99}Tc produced at the Hanford Site and stored in the single- and double-shell tanks. The Agnew et al. (1997) and Kupfer et al. (1997) estimate of 32,600 Ci ^{99}Tc in the tanks is higher than the Schmittroth et al. (1995) estimate because they decided to show a bounding inventory value, and therefore neither took into account the ^{99}Tc exported from the Hanford Site. Schmittroth et al. (1995) documented that an estimated 20% of the ^{99}Tc produced at the Hanford Site was lost from the tank waste. Most of this 5,000- to 6,000-Ci inventory was co-processed with the uranium oxide metal and sent off site.

The different estimates of ^{99}Tc disposed to ground are inconsistent. Based on track radioactive components (TRAC) model results, it was estimated that liquid discharge sites have received ~930 Ci of ^{99}Tc (Waite 1991). Based on data in the tank characterization reports for liquid tank wastes, the tanks were estimated to have leaked ~460 Ci and to lose ~470 Ci of ^{99}Tc during retrieval. Based on the TWRS Environmental Impact Statement (EIS) database (DOE and Ecology 1996) and the assumption of 1% volume remaining following recovery operations, ~320

[1] Reddick, J., 1993, *PUREX and U03 Plant Inventory Estimates* (letter to D. Washenfelder, Westinghouse Hanford Company, September 29), Los Alamos Technical Associates, Kennewick, Washington.

Ci of ^{99}Tc will be in tank residuals. Based on aged-fuel ratios and the inventory of cesium, another 325 Ci of ^{99}Tc are assumed to reside in the solid waste burial grounds. These disposal inventories, which total ~2,500 Ci, are based on a number of different models.

Ultimately, aside from the ILAW, the 2,500 Ci inventory of ^{99}Tc estimated to be lost to or disposed in the subsurface environment at the Hanford Site is less than 10% of the total ^{99}Tc inventory at the Hanford Site. An effort to generate a fully consistent inventory estimate could yield lower estimates of losses and disposals. For example, because of its solubility, most of the ^{99}Tc should be removed from the tanks during the tank waste recovery campaigns, and less than the estimated 320 Ci here should remain in the tank residuals. Similarly, if sluicing methods are used to recover tank wastes, it is likely that contaminant concentrations in sluicing losses from the tanks will be lower than contaminant concentrations in tank wastes. Thus, the estimated 470 Ci of ^{99}Tc lost during tank waste recovery operations, which were based on tank waste radionuclide concentrations, would decrease. Finally, the Agnew et al. (1997) model provides an estimate of only 107 Ci of ^{99}Tc lost in past tank leaks compared to the 460 Ci estimated here. Clearly, a lower inventory of loss and disposal could result from a consistent or best-estimate inventory estimate. However, there is also uncertainty in the future ^{99}Tc waste streams that privatization contractors may generate and return to the DOE for disposal.

Uranium-238

Kupfer et al. (1997) reconciled the HDW model results for uranium (906 Ci of ^{238}U) and tank sample data (322 Ci), and decided that the sample data were more representative of the uranium inventories. The discrepancy among TWRS total inventory estimates of uranium is attributed to the factor used to describe the fraction of metal waste not recovered. However, estimates in Waite (1991) for uranium in tank waste discharges to cribs and specific retention trenches, and estimates provided by Coony[2], are much lower than estimates that appear in Agnew et al. (1997). Coony estimated 47.5 Ci of ^{238}U as compared to 1,310 Ci estimated by Agnew et al. (1997). The Agnew et al. (1997) inventory of ^{238}U sent to the ground in liquid discharges may also be an overestimate, because it is based on the factor assumed for uranium metal recovery.

An unrealistically high estimate of ^{238}U is included in the ERDF inventory (i.e., 54,300 Ci). This inventory estimate is based on maximum observed ^{238}U concentrations in sediments at CERCLA sites in the 100 and 300 Areas. The composition of uranium in ERDF has the signature of enriched uranium, but this is an artifact of using maximum observed concentrations of uranium isotopes to estimate the total inventory disposed. The US Ecology commercial LLW disposal facility also contains a considerable inventory of ^{238}U (10,900 Ci).

G.1.2 Vadose Zone

G.1.2.1 Scope. The scope of the Vadose Zone technical element encompasses the characterization, modeling, and monitoring of the unsaturated zone beneath the Hanford Site. The geographic focus is on areas that (1) underly liquid waste disposal sites and tanks; (2) have the potential for leaks or leaching; and (3) have experienced past leaks and spills. Also included

[2] Coony, F. M., 1997, *Questions on Crib Releases in the 200 Areas* (e-mail to C. T. Kinkaid, Pacific Northwest National Laboratories, November 5), Waste Management Federal Services, Richland, Washington.

are selected areas away from the focus areas, such as areas representative of background conditions, and areas that have the potential to become contaminated in the future. Numerical modeling supports the characterization by simulating flow and transport processes believed to occur within the vadose zone. Specific topics include (1) subsurface contamination (i.e., characteristics of past disposal and leakage including chemistries, volume, and distribution); (2) surface hydrologic features and processes (e.g., winter rain and snowmelt, water line leaks, infiltration, deep drainage, and evaporation rates); and (3) subsurface geologic and hydraulic features and processes (e.g., stratigraphy, structures, physical properties, geochemistry, and microbiology of the sediments above the water table). Information is needed to better understand the vertical and/or horizontal distribution and movement of contaminants to the water table. Monitoring confirms the movement through the vadose zone.

Sufficient information will be collected to provide (1) a representative and credible depiction, at appropriate temporal and spatial scales, of contaminant distributions beneath waste, spill, and disposal sites; (2) early warning of potential surface or groundwater contamination problems so that corrective actions can be taken; and (3) credible numerical simulations that acceptably depict the movement and fate of contaminants in the vadose zone. Information generated by this technical element will support remedial actions, such as the design of surface and subsurface barriers, and in situ remediation techniques. It also supports decisions regarding mitigative protective measures (e.g., interim surface covers), restrictions on artificial recharge and, therefore, future land use.

G.1.2.2 Current state of knowledge. The vadose zone is defined as the hydrologic region that extends from the soil surface to the water table. At the Hanford Site, the vadose zone can range from less than 1 m to more than 100 m, and contains waste inventories from past waste disposal practices (e.g., direct liquid waste disposal to the ground via engineered facilities) and from unplanned releases (e.g., SST leaks). The vadose zone is thickest in the 200 Areas and thinner in the 100 and 300 Areas. It generally consists of unsaturated sediments. However, saturated sediments are sometimes found in perched water table zones within the vadose zone. Transport of groundwater and contaminants through the vadose zone is influenced by texture, consolidation, and cementation of sediments; thickness of the vadose zone; moisture infiltration rates; and geochemistry of the waste form and the sediments. The current knowledge of the controls on contaminant movement and distribution in the vadose zone will be discussed first in this section.

Vadose zone characterization has been accomplished to date by drilling, sediment sample collection and analysis, and geophysical logging. Drilling around tanks, cribs, and trenches has provided considerable information about vadose zone lithology and stratigraphy, but only limited hydrologic and geochemical information has been obtained. In a few cases, drilling was used to identify tank leaks. Analyses of sediments for radionuclides, chemicals, and heavy metals have helped quantify the extent of contaminant plume migration at selected locations. Site-specific characterization data will be the second major topic presented in this section.

Finally, numerical modeling is used to assess contaminant migration through the vadose zone. The strengths and weaknesses of the current modeling approaches and codes are discussed in the final installment in this section.

G.1.2.2.1 Controls on contaminant movement and distribution. Physical and chemical controls constrain the movement of contaminants that enter the vadose zone environment. Three primary groupings of controls are described below:

- Geologic
- Hydraulic
- Chemical.

A summary of site conditions (specific to the 200 Areas) that may control contaminant movement and distribution is presented in Table G-2 (DOE 1997). With minor modifications (e.g., vadose zone thickness and vegetation), the summary is applicable to the Hanford Site in general.

Geologic Controls

Of the primary controls on contaminant movement and distribution on the Hanford Site, the knowledge of the general geology is the best understood. This is primarily because of concerted efforts to interpret the accumulated data from the drilling of numerous boreholes, especially in the vicinity of waste disposal operations. There are detailed characterization data for the site that reveal important differences in the geology of the waste site areas (Lindsey 1992, 1995; Lindsey et al. 1992; Hartman and Peterson 1992; Peterson et al. 1996; DOE-RL 1993f, 1994a, 1994b; Thorne et al. 1993; 1994).

The site is arid (average precipitation 160 mm) and, prior to waste operations, the surface typically consisted of eolian silts or sands and supported a shrub-steppe plant community (Dirkes and Hanf 1997). The waste disposal area excavations and corings have exposed two major geologic formations in the vadose zone, the Hanford formation (gravels, sands) and the underlying Ringold Formation (gravels, silt lenses). The Hanford formation is geologically young, having been derived from cataclysmic flooding during the Pleistocene (1.6 Ma to 13 Ka), while the Ringold Formation is composed of sediments deposited by the ancestral Columbia River between 8.5 Ma and 3 Ma. A buried soil (Plio-Pleistocene formation) exists at the top of the Ringold Formation in the 200 West Area, but is absent in the 200 East Area.

100 and 300 Areas. In the 100 and 300 Areas, the vadose zone is relatively thin, ranging from about 1 to 30 m in thickness. It is generally composed of recent surficial deposits and portions of the Hanford formation and/or Ringold Unit E. Sediments from the upper strata of the Ringold Formation within the 100 and 300 Areas are characterized by complex interstratified beds and lenses of sand and gravel. Ringold Formation deposits are generally more cemented and better sorted than those from the Hanford formation. Ringold strata typically contain a lower percentage of angular basaltic detritus than Hanford formation deposits. The Hanford formation is characterized by dark grayish-brown to dark olive-gray sandy gravel, typical of the gravel-dominated facies, with some silt and local sand stringers. The upper portion of the unit generally exhibits a pebble to boulder gravel, which becomes finer with depth, to a very fine-to-medium pebble gravel. Lenses of gravelly sand and sand occur locally. Detailed conceptual models for the 100 Areas are provided in Peterson et al. (1996).

Table G-2. Summary of Site Conditions That May Affect Contaminant Fate and Transport. (2 Pages) (from DOE 1997)

Parameter/ Property	Representative values/conditions for 200 Area sediments	General Considerations
Natural recharge	0 to 100 mm/yr via precipitation	Recharge via precipitation is affected by surface soil type, vegetation, topography, and year-to-year variations in precipitation. Gravelly surface soils with no vegetation facilitate recharge. Well-vegetated, fine-grained surface soils minimize recharge. Recharge may be impacted by episodic events including high-intensity rainfall events and rapid snowmelt. Evapotranspiration potential is moderate to high depending on time of year, lowest in winter when recharge potential and precipitation is highest. Waste sites that are vegetated and are capped with fine-grained soils (Radiation Area Remedial Action interim-stabilized sites) or impermeable covers should have little to no net precipitation recharge or leachate generation. Net infiltration is influenced by topography and soil hydraulic properties. In instances where precipitation or snow melt is sufficient to generate runoff, low-lying areas and gravelly surface soils/fill occupying may serve as collection basins for runoff and locally increase net infiltration.
Vegetation	Sparse to moderate densities	Vegetation of the 200 Areas Plateau is characterized by native shrub steppe interspersed with large areas of disturbed ground with a dominant annual grass component. The vegetation in and around active ponds and ditches (riparian zone) on the 200 Areas Plateau is significantly different and higher in density than that of the surrounding dryland areas and provides locally higher evapotranspiration potential and radionuclide uptake. Changes in vegtation (shrubs to grasses) induced by various disturbances (fires, excavation, etc.) alter rooting depths and may increase recharge. Vegetation may remove chemicals upward in or from the soil, bring them to the surface, and subsequently introduce them to the food web.
Soil moisture	2% to 10% by volume	Containment fluxes cannot be determined by soil moisture contents but depend on hydraulic conductivity and capillary pressure relationships which can be highly variable in Hanford's layered sediment. Ambient moisture contents are typically higher in finer grained sediments than in coarse-grained sediments. Much of the vadose zone Hanford sediment is coarse-grained. Waste sites that received sufficient discharges to maintain localized saturated conditions in the vadose zone maximize downward pore water velocities and associated contaminant movement.
Vadose zone thickness	55 to 104 m (central plateau)	The thicker the vadose zone, the greater the potential for contaminants to interact with sediments. Vadose zone thins out from the 200 West and 200 East Areas north to Gable Gap.

Table G-2. Summary of Site Conditions That May Affect Contaminant Fate and Transport. (2 Pages) (from DOE 1997)

Parameter/ Property	Representative values/conditions for 200 Area sediments	General Considerations
Soil chemistry	Alkaline pH Low oxidizing Redox state Ion-exchange capacity dependent on contaminant and % fine-grained soil particles Very low organic carbon content, <1%	The mobility of radionuclides and other inorganic elements depends on the chemical form and charge of the element or molecule, which in turn depends on waste- and site-related factors such as the pH, Redox state, and ionic composition. Buffering or neutralizing capacity of the soil is correlated with the calcium carbonate content of the soil. 200 Area sediments generally have carbonate contents in the range of 0.1% to 5%. Higher carbonate contents (10%) are observed within the Plio-Pleistocene caliche layer. Additional buffering capacity is provided by hydroxides of iron, aluminum, manganese, and silicon. Acidic solutions are buffered to more neutral basic pH values when contacting Hanford sediments. Many constituents/contaminants precipitate or adsorb to the soil under neutral to basic pH conditions. The vadose zone is generally an oxidizing environment. Redox-sensitive elements from highly oxidized waste streams may become less mobile (are reduced) when contacting the vadose zone, which has a relatively lower oxidizing potential. Conversely, reduced waste streams could be oxidized when introduced into the vadose zone and thereby increase the mobility of Redox-sensitive elements. Many contaminants of concern (COCs) in 200 Area waste streams are present as cations. Sediments have sufficient cation-exchange capacity to adsorb many of these cations. Considering the substantial thickness of vadose zone (50 to 140 m), the total cation-exchange capacity of a column of soil is substantial. 200 Area sediments have a poor affinity for anions because of their negative charge. Sorption to organic components is considered to be minimal considering the low organic content. Sorption to the inorganic fraction of soils may dominate over sorption to soil organic matter. Mineralogy affects the abundance of sorption sites as well as the availability of ions for precipitation. Soil components that contribute to adsorption of inorganic compounds such as clays and organic matter are generally minor components in 200 Area sediments. Diffusion of contaminants into micropores of minerals can occur. Microorganisms in the soil may degrade organic chemicals and inorganic chemicals.
Soil texture	High sand and gravel content (~70 to 80 wt%), moderate in silt content (10 to 20 wt%), and low clay content (<1 to 10 wt%) and stratified	Coarse-grained nature of sediments which dominate the Hanford Site, generally provides for a quick-draining media. However, variations of the soil stratigraphy with depth, such as the presence of low-permeability layers, impedes the downward movement of liquids. Sediments are generally more permeable in the horizontal direction than in the vertical direction because of the stratified nature of the sediments. This facilitates the lateral spreading of liquids in the vadose zone and reduces the downward movement. Under unsaturated conditions, coarse-grained layers overlain with finer grained materials retard the movement of pore water because of the capillary barrier effect. Under saturated conditions, layers of finer grained soil such as silt layers and the Plio-Pleistocene unit function as localized aquitards. Where substantial quantities of liquid waste were disposed, perched water may form above these layers. These phenomena increase the potential for lateral movement of liquids. If perched water is laterally expansive, it can mobilize wastes beneath adjacent waste sites. Sorption to sediments increases as particle size decreases. Suspended solids/particulates in waste streams are likely to be physically filtered by the sediments at the boundary of the waste site.

200 Areas. The vadose zone beneath the 200 Areas ranges in thickness from about 55 m in the western portion of the 200 West Area (beneath the former U Pond) to 104 m in the southern part of 200 East Area. Stratigraphy of the vadose zone differs significantly beneath the 200 East and 200 West Areas.

At the 200 East Area, the vadose zone is composed either entirely of Hanford formation sediments, or a combination of Hanford and Ringold sediments, depending on the specific location. Where Ringold sediments are above the water table in the 200 East Area, they are Ringold Unit A sands and gravels or, in a few places, the lower Ringold mud unit that overlies the Ringold A Unit (DOE-RL 1997e). However, the vadose zone in the 200 East Area is predominantly Hanford formation gravels and sands. The Hanford formation may be divided into the following subunits: gravel (H1), sand (H2), and gravel (H3). H1 ranges from 11 to 37 m thick, is dominated by the gravel facies, and contains significant interstratified horizons dominated by the sand facies. The unit is thinnest in the southwestern part of the site and thickens to the north and east. Outcrop observations show that silt-rich interbeds are present and are normally a few to tens of centimeters thick. Silty horizons as much as 1 m thick and continuous up to distances of at least several hundred meters also are present in H1. These horizons are capable of generating perched water conditions. The contact between unit H1 and underlying strata generally is very irregular. These irregularities are the result of the interfingering nature of these deposits, which results in the absence of a distinct bounding surface. The sands of unit H2 are thickest (up to 55 m) in the southwestern part of the site while pinching out toward the east and north. Unit H3, defined by the abundance of the gravel facies, thickens to the north and northeast, from 12 to 45 m thick. Like H1, interbeds of the sand and silt facies are present throughout unit H3. Also like H1, these silts have the potential to generate perched water conditions. The interstratified sands and gravels found at the base of H2, referred to as unit H2a, are locally well developed beneath the eastern to central part of the site. Although each of these units are defined on the basis of a dominate lithology, significant subordinate lithologies are intercalated in each unit (Wood et al. 1995).

Beneath the 200 West Area, three major stratigraphic units are present. From top to bottom, these are the Hanford formation, the Plio-Pleistocene unit, and the Ringold Unit E. The early Palouse soil is also found above the Plio-Pleistocene unit in some parts of the 200 West Area. Calcium carbonate content is typically less than 1% in the Ringold Formation Unit E, less than 1% in the upper Ringold unit, as much as 10% in the early Palouse soil/Plio-Pleistocene unit, and less than 2% in the Hanford formation (DOE-RL 1997e). The characterization of soil samples from wells indicates that small lenses of fine-grained material are interspersed in the Hanford formation. These appear to be no more than 3 to 6 m thick with a lateral extent of hundreds of feet or less (Wood et al. 1995).

More poorly understood than the general geologic framework are features that cross-cut the geology such as clastic dikes (i.e., vertical fissures), discontinuities in compacted zones, and the presence of unsealed or poorly sealed wells. All these features add to the complexity of moisture flow (Fecht et al. 1998) and contaminant movement (DOE 1997a-d), and may result in the rapid transport of contamination to the groundwater table with minimal interaction with the sediments.

Hydraulic Controls

The flow of water through unsaturated soils in the vadose zone depends in complex ways on several factors, including the rate of water infiltration at the soil surface, the moisture content of the soil, textural heterogeneity in the soils, and soil hydraulic properties. Hydraulic data for the vadose zone is limited. Data catalogs and reviews on hydrology can be found in Connelly et al. (1992a, 1992b); Hartman and Peterson (1992); DOE-RL (1993a, 1993c); Thorne et al. (1993, 1994), and Wurstner et al. (1995). Soil hydraulic properties are compiled in Khaleel and Freeman (1995), and recharge information is available in Gee (1987) and Fayer and Walters (1995). Programmatic data needs (e.g., remedial investigations at selected operable units) have also resulted in limited sampling of the deep vadose zone. No complete hydrologic property data sets exist for any of the tank farms or other key waste sites.

Infiltration of water to the vadose zone provides the driving force for downward migration of contaminants. Moisture may come from artificial sources such as waste water disposed to cribs, leaks from tanks, leaking water lines (etc.). Water may also come from natural rainfall and snowmelt. Disposal of water to cribs, ponds, and ditches has largely ceased. However, water is still disposed to a few regulated facilities. Recharge from natural precipitation across the Hanford Site is highly variable, both spatially and temporally, ranging from near zero to more than 100 mm/yr depending on climate, vegetation, and soil texture (Gee et al. 1992; Fayer and Walters 1995). It is highest in areas with coarse-grained soil at the surface and no vegetation cover, which is often the case in tank farms and at other waste sites.

Perched zones may form when water moving downward through the vadose zone accumulates on top of low-permeability soil lenses, highly cemented horizons, or above the contact between a fine-grained horizon and an underlying coarse-grained horizon. The Plio-Pleistocene unit and early Palouse soil is the most significant aquitard in the 200 West Area above the water table and a major component controlling the accumulation of perched water beneath sites where effluent was discharged. The Ringold lower mud sequence also represents a potential perching layer (DOE-RL 1997e).

Unsaturated hydraulic conductivities may vary by several orders of magnitude depending on water content. Water content measurements in the 200 Area vadose zone have historically ranged widely from 1% to saturation (perched water) from liquid disposal activities, but typically range from 2% to 10% under ambient conditions. Connelly et al. (1992a, 1992b) and Khaleel and Freeman (1995) summarized hydraulic conductivity measurements taken on 200 Area soils with various water contents. For Hanford formation samples taken in the 200 East Area, vadose zone hydraulic conductivity values at saturation ranged from about 10^{-6} to 10 cm/sec, with many of the values falling in the 10^{-5} to 10^{-3} cm/sec range. However, under unsaturated conditions at a 10% moisture content, hydraulic conductivity ranged from about 10^{-16} to 10^{-5} cm/sec, with many of the values falling in the 10^{-10} to 10^{-5} cm/sec range. Calculated unsaturated conductivities for Ringold Unit A gravel samples ranged from less than 10^{-18} to 10^{-10} cm/sec at water contents near 10%, and from 10^{-7} to 10^{-5} cm/sec at saturation water contents of 38% and 57%, respectively. Ringold lower mud samples had unsaturated hydraulic conductivities ranging from less than 10^{-18} cm/sec at a 10% water content to approximately 10^{-9} cm/sec at saturation (57%).

Geochemical Controls

Geochemical interactions in the vadose zone that affect the migration of contaminants are dependent on the chemical nature of the migrating waste and the chemical and mineralogic makeup of the sediments. Descriptions of waste forms and the mineralogic/chemical nature of Hanford Site sediments are documented in numerous summary documents (e.g., BHI 1995a-f, DOE-RL 1992a-d, DOE-RL 1993a-e, DOE-RL 1997e). A more limited set of references is available that summarizes key interactions (Serne and Wood 1990; Ames and Serne 1991). Much of the material presented in this discussion of geochemical controls has been developed by a team of contributors from the National Laboratories, as well as representatives from Richland Operations Office (RL), Hanford Site contractors, regulators, Tribal Nations, and stakeholders that met in Vadose Zone Chemistry working groups in three meetings during the period of April 1998 through September 1998.

Hanford waste migration in the vadose zone is best characterized as a multi-reaction suite that, at various times, can act to mobilize, transform, retard, or immobilize waste constituents. The migration rate of contaminants is affected by processes such as precipitation/dissolution, sorption, filtration of colloids and suspended particles, and diffusion into micro pores. Whether a given reaction series or physical process will predominate is dependent on the chemical identity of the contaminant waste form and the mineralogic, organic, and surface chemical properties of the subsurface strata the waste encounter. In general, Hanford soils are neutral to slightly alkaline, oxidizing, very low in organic carbon content (<1%), and have a variable ion-exchange capacity that is dependent on the fraction of fine-grained particles present. The presence of micro- or thin layers of finer grained sediments can have a significant effect on chemical interactions and waste migration. Other than for the ion-exchange capacity of select strata, the limited range for the chemically significant attributes means that little can be gained in attempting to further differentiate Hanford Site sediments. Most of the emphasis should be placed on defining the controlling reactions involved in the more chemically extreme waste forms.

One general measure of a contaminant's distribution between soil and water is the soil-water distribution coefficient (K_d). This coefficient is experimentally derived, and is usually expressed in units of milliliters per gram. A relatively high K_d value indicates that the contaminant will tend to be retained on the soil particles and thus indicates a relatively low mobility, whereas a relatively low K_d value indicates that the contaminant will tend to remain dissolved in water and thus indicates a relatively high mobility. The concept of K_d does not illuminate the mechanics of the reaction processes that control contaminant distribution. The specific suite of interactions between waste forms and the native sediment are least understood for wastes that are chemically aggressive (e.g., high ionic strength, high or low pH, complexant-rich). At some waste sites, the chemistry of the waste streams disposed to ground have appreciably altered the chemical environment of the near-field sediments. Such changes in geochemistry likely alter the sorption properties of the sediments, and may increase the relative velocity of contaminant migration until the contaminant reaches a zone where the chemistry has not been altered. How far contaminants in these highly aggressive waste streams (e.g., some tank wastes) migrate, and the dominant processes involved, is not well-understood from either laboratory studies or from field characterization efforts.

Away from the zone of aggressive chemical interaction, sorption tends to be the dominant process affecting contaminant mobility. The retention of contaminants by sorption has been described by the linear sorption isotherm model, assuming that the sorption process is fast and reversible (Serne and Wood 1990). The distribution coefficient, K_d, is a parameter that quantifies the retardation of contaminants in relation to water velocity in the linear sorption isotherm model. K_d values have been determined through laboratory experiments for many radioactive species in Hanford Site soils. A compilation of these values is provided in Appendix E of Kincaid et al. (1998), and a listing of relative contaminant mobilities is provided in Table G-3. Many contaminants may not exhibit a linear isotherm for various reasons, and it is important to characterize the concentration dependence of sorption over relevant ranges.

The K_d for a contaminant can be significantly affected by the following:

- Composition of the waste stream in terms of major and minor ions.
- The pH of the waste and the ionic strength.
- The mineralogic and organic composition of the sediments and surface saturating ions.
- The presence of organic and chemical complexants in the waste.
- Other processes (e.g., biodegradation, oxidation-reduction).

Effects of pH and Ionic Strength

The pH of the waste can increase the mobility of some contaminants. Many transition metals, lanthanides, and actinides are more soluble in acid solutions than in neutral or mildly basic (pH<= 10) solutions. When contacting Hanford Site sediments, acidic solutions are generally quickly buffered to more neutral pH values. As the pH increases, most metals and radionuclides react either by adsorption reactions onto hydrous oxides, carbonates, and clays, or precipitate as insoluble phases. The percent removal from solution usually dramatically increases over a very short span of pH values. For some metals, adsorption becomes essentially complete (100%) as pH increases from 2 or 3 up to 4 or 5 (Serne and Wood 1990). Although many contaminants become more mobile in an acidic environment, increased alkalinity can also have the effect of increasing the mobility of select contaminants. Plutonium, which is typically one of the least mobile of the Hanford Site contaminants (e.g., ^{90}Sr), has moderate mobility at pH values above 8.

For some inorganic contaminants (e.g., ^{90}Sr), ion exchange is the dominant mechanism leading to desorption. High ionic strength tends to drive the equilibrium toward desorption rather than sorption.

Effects of Sediment Composition

Because Hanford Site soils are generally neutral to alkaline, there is a net negative charge on the soil particles that facilitates sorption of cations. Conversely, anionic species are either only weakly sorbed or not sorbed at all.

Table G-3. Contaminant Mobility in Hanford Soils.
(2 Pages) (from DOE-RL 1997e)

Contaminant	Normal Mobility	Factors Affecting Mobility
Cobalt-60	Low	Highly sorbed by cation ion exchange at pH<9; readily reacts with organics and inorganic ions to form more mobile complexes (e.g., with ferrocyanide or phosphates).
Strontium-90	Moderate	Sorbs by cation ion exchange, but competes for sites with calcium. May immobilize as a coprecipitate in the mineral apatite formed by phosphate wastes. Highly mobile in acidic conditions. Mobility is increased by organics (e.g., tributyl phosphate).
Technetium-99	High	Generally present as pertechnetate anion, which is relatively nonadsorbing.
Ruthenium-106	High	Highly influenced by presence of nitrite or nitrate; short (1-year) half-life offsets high mobility.
Cesium-137	Low	Highly sorbed by cation ion exchange. Competes for sites with potassium and sodium. Mobile. Does not tend to form soluble inorganic or organic complexes. More mobile at low pH.
Uranium-238	High	Highly mobile at low pH and at pH>8 where soluble anionic carbonate complexes can form. However, uranium forms insoluble precipitates with phosphate that are highly immobile.
Plutonium-239/240	Low	Maximum sorption occurs in pH range of 4 to 8.5 as a result of formation of insoluble precipitates. Sorption is less at low pH (<4) and high pH (>8.5). Plutonium can form more mobile complexes with co-disposal of organics (e.g., tributyl phosphate, hexone, dibutyl butyl phosphate).
Americium-241	Low	Behaves similarly to plutonium.
Cadmium	Moderate to high	Mobile as a dissolved metal for most waste streams in Hanford soil column conditions.
Carbon tetrachloride	High	Used as diluent for Plutonium Finishing Plant (PFP) separations processes. Not highly sorbed by Hanford soils, which are low in organic carbon content.
Chloroform	High	Degradation product of carbon tetrachloride; may be formed during chlorine treatment of potable water supplies.
Chromium	High	Generally present as an anion (chromate), which is mobile in the +6 valence state.
Cyanide	High	Anionic species that is essentially nonadsorbing; forms complexes with cationic species, increasing their mobility.
Dibutyl butyl phosphonate	(a)	Used as a solvent with carbon tetrachloride diluent in PFP separations process for americium-241 removal. Potential for increased mobilization of americium-241 and plutonium-239/240 due to complexation.

Table G-3. Contaminant Mobility in Hanford Soils.
(2 Pages) (from DOE-RL 1997e)

Contaminant	Normal Mobility	Factors Affecting Mobility
Hexone (methyl isobutyl ketone)	(a)	Used as solvent for plutonium and uranium in REDOX separations process. May increase radionuclide mobility due to formation of organic complexes.
Hydrazine	(a)	Strong reductant, soluble in water. Breaks down into mobile amines or ammonium ions in water.
Nitrate	High	Anionic species, nonadsorbing, considered to travel with water.
Tributyl phosphate	(a)	Used as solvent in extraction of plutonium and uranium in PUREX and Uranium Recovery Program and for plutonium in PFP separations processes. May increase radionuclide mobility in soil column due to formation of organic complexes.
Trichloroethylene	High	Not highly sorbed by Hanford soils, which are low in organic carbon content.

[a] Organic compounds: Generally considered to be mobile due to low organic carbon content of Hanford soils.
Mobility factor: High = K_d 0 to 5; Moderate = K_d 5 to 100; Low = K_d >100.
K_d = soil-water distribution coefficient
PUREX = Plutonium Uranium Extraction
REDOX = Reduction Oxidation.

Mineralogy affects the abundance of sorption sites as well as the availability of ions for precipitation. Sorption is a reversible to partially reversible surface reaction. It occurs in Hanford Site sediments on the surfaces of oxides, layer silicates (micas, illites, vermiculites, and smectites), and calcium carbonate. Both ion exchange and surface coordination reactions are important. Hanford Site contaminants most susceptible to sorption reactions are ^{137}Cs, ^{90}Sr, uranium, and ^{60}Co.

Sorption increases as soil particle size decreases. Filtration and ion exchange also increase with decreased soil grain size. Filtration effects are more pronounced for contaminants that form insoluble precipitates.

For organic contaminants, partitioning to the soil from the water is affected by the organic carbon content of the soil. There is a soil/organic matter partition coefficient (K_{oc}) that is similar in concept to the soil/water partition coefficient (K_d). Hanford Site soils are low in organic carbon content (less that 0.1 wt%). Therefore, estimated K_{oc}s for the principal organics of concern are generally less than 1, indicating high mobility.

Effects of Organics and Chemical Complexants

Water-soluble aqueous complexes form between key Hanford Site radionuclides and dissolved ions (ligands) in wastewater or in the porewater. Strong complexation may shield the participating radionuclide from adsorption or precipitation reactions, allowing (facilitating) free movement of the contaminant through the subsurface. The solubilizing ligand may be natural

(CO_3^{2-}) or part of the waste stream ($EDTA^{4-}$, CN^{2-}). Examples of mobile complexes include $UO_2(CO_3)^{2-}$, CoCN, $CoEDTA^{2-}$, and PuEDTA.

Other Processes

Contaminant concentrations in waste streams may be changed through processes such abiotic/biotic reduction, biodegradation, and/or colloid genesis. Abiotic/biotic reduction is a transformation reaction that induces change of oxidized metal ion valence to a lower state where chemical behavior and reaction chemistry are different from the oxidized form. The reaction is heterogeneous and occurs on mineral surfaces where ferrous iron is present as a lattice substituent or a biogenic surface product. Hanford Site contaminants susceptible to surface reduction include plutonium (V), chromium (VI), uranium (VI), and technetium (VII). All form oxide and hydroxide precipitates with low solubility in the reduced states. Minerals in the vadose zone with sufficient reductive potential include illmenite, magnetite, pyroxenes, amphiboles, and basaltic glass. It is not known whether their surfaces are or are not passivated in the vadose zone by reaction with O_2.

Biodegradation affects the persistence of organics in the subsurface. Biodegradation of water-soluble organics is more rapid under the oxidizing conditions found in Hanford Site soils, whereas the rate of biodegradation of the less soluble organics tends to be very slow. Solvents such as hexone and NPH do not generally persist in Hanford Site soils because they have a low soil adhesion and greater biodegadability than other organics such as carbon tetrachloride.

Submicron-sized precipitates (colloids) may enter vadose zone porewater as acid and basic Hanford Site wastes are neutralized by geochemical reaction with Hanford Site sediments or as strongly hydrolyzing radionuclides (plutonium, americium) precipitate. Colloids may originate from the geomedia as cementing agents are dissolved by high or low pH waste solutions, or may precipitate from mineral dissolution/waste neutralization products (aluminum or silicon) or the waste components themselves [$Al(OH)^{4-}$]. Siliceous and aluminous colloids can adsorb or co-precipitate with contaminants and may facilitate their mobilization through coarse-textured Hanford Site sediments. The presence of plutonium and ^{60}Co in groundwater near the reverse well has been attributed to mobile colloid material. The migration of ^{137}Cs is also speculated to be colloid-assisted in select locations. Studies suggest that if colloids reach the water table from the vadose zone, they will flocculate (or otherwise be removed by diffusional processes), precluding colloid-facilitated transport of radionuclides from disposal sites.

G.1.2.2.2 Characterization summaries. Radioactive and hazardous waste in the soil column, burial grounds, and underground tanks at the Hanford Site are potential sources of vadose zone and groundwater contamination. Contamination from past-practice liquid waste disposal and tank leaks potentially have the largest future impact on groundwater contamination, as demonstrated in the first iteration of the Composite Analysis (Kincaid et al. 1998), which looked at superposition of groundwater plumes from waste sources in the 200 Area Plateau. Vadose zone contamination has occurred from solid waste disposal activities as well as liquid waste disposal.

Net infiltration data used to estimate recharge have been obtained external to waste sites by a lysimetry network (Gee et al. 1992). Currently, because most of these lysimeters are not operating, the data they provide are limited. Vadose zone characterization has been accomplished to date by drilling, sediment sample collection and analysis, soil-gas sampling, and geophysical logging (most recently, spectral gamma logging).

Vadose Zone Monitoring Wells (Dry Wells)

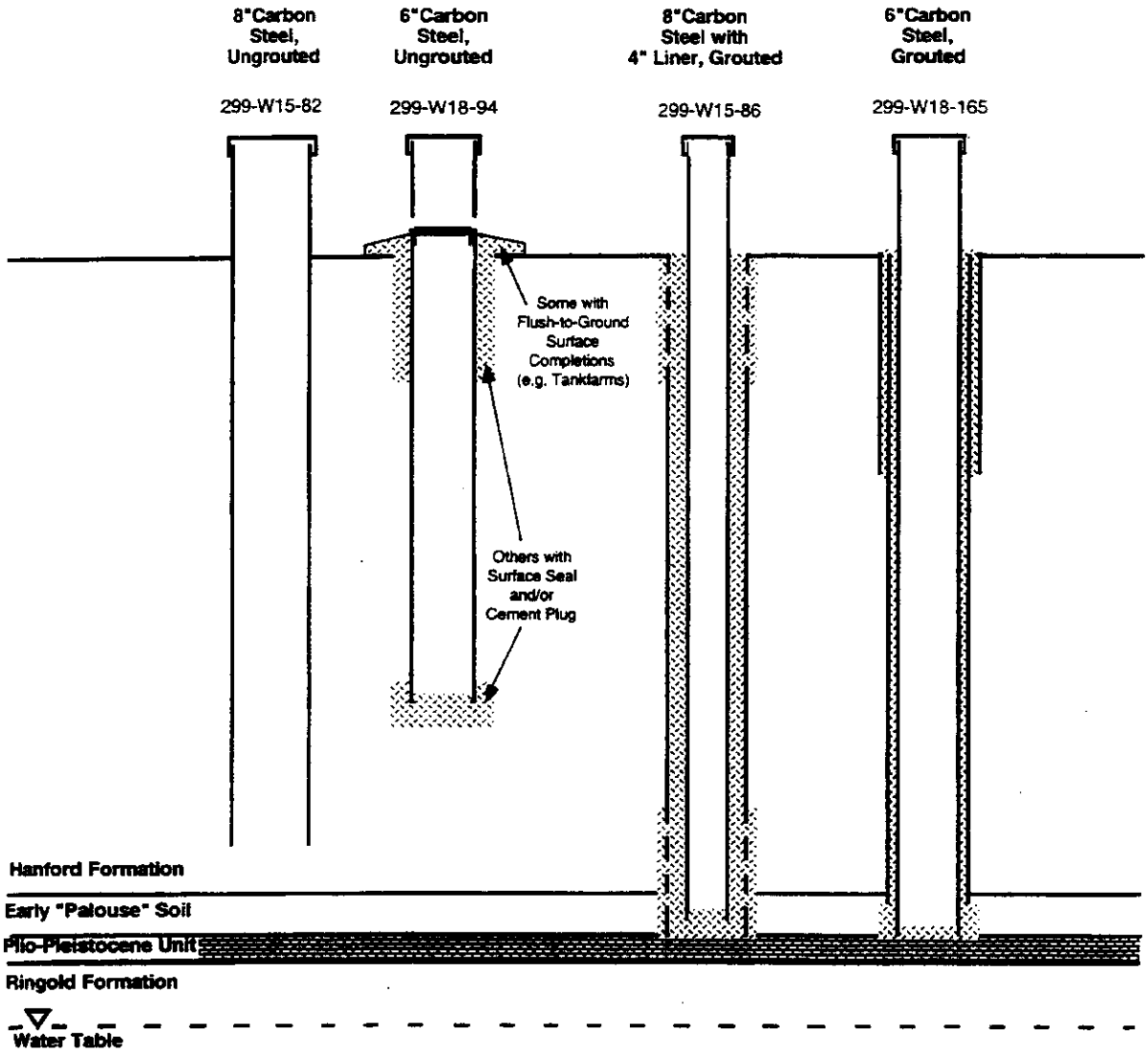
More than 1,370 dry wells (i.e., not penetrating to the groundwater) have been installed to monitor the vadose zone throughout the Hanford Site (Chamness and Merz 1993). Most of these dry wells are located in the 200 Areas, particularly in the tank farms. Over the years, many different well designs have been used. In addition, modifications have been made to many of the early designs to prevent downward migration of contaminants in areas of active liquid waste disposal. Figure G-7 illustrates some of the dry well designs being used to monitor the vadose zone (e.g., gamma logging) beneath the Hanford Site. Note that nearly all dry wells are cased with schedule 40 carbon steel, and that many (particularly near liquid waste disposal facilities) have multiple casings and/or cement grout seals to prevent contaminant migration down the outside of the casing.

Drilling around tanks, cribs, and trenches has provided considerable information about vadose zone lithologies and stratigraphy, but only limited hydrologic and geochemical information has been obtained from boreholes. In a few cases, drilling was used to identify tank leaks. Analyses of sediments for radionuclides, chemicals, and heavy metals have helped quantify the extent of contaminant plume migration at selected locations.

Soil-gas sampling has been done to characterize volatile contaminants in the vadose zone at a few select locations at the Hanford Site. Soil vapor extraction is being used to remove carbon tetrachloride from the vadose zone as part of an expedited response action (Hartman and Dresel 1998). The Nonradioactive Dangerous Waste Landfill was also recently surveyed for volatile contaminants in the vadose zone.

For decades, wells have been geophysically logged at tank farms (Price 1996) and at past-practice liquid waste/soil column disposal sites. The logging included both gross gamma and radionuclide-specific spectral gamma logs. Recently, a baseline spectral gamma logging study was undertaken on more than 700 dry wells (see above) for gamma-emitting radionuclides The most abundant contaminant detected by the spectral gamma monitoring in this study is ^{137}Cs, but ^{60}Co, uranium, ^{125}Sb, and ^{154}Eu have also been reported (Hartman and Dresel 1998). The current borehole logging does not address nongamma-emitting radionuclides (e.g., ^{14}C, ^{99}Tc, ^{129}I) or nonradioactive contaminants (e.g., chromium, nitrate), which are primary constituents of regulatory interest. Physical corings within tank farms have been helpful in a few cases in identifying extent of nongamma emitters at depth but, because of great expense, these data are sparse. The extensive duration for which gross gamma logs are available has been useful in distinguishing tanks that have continued to leak from tanks whose leaks have apparently stabilized. Mass balance, critical for vadose zone evaluations, has not been determined for the major leaks because the logging instruments are frequently ineffective (i.e., the spectral gamma detector becomes saturated by high activities) and record only a fraction of the radioactivity

Figure G-7. Examples of Dry Well Configurations Used to Monitor the Vadose Zone Beneath the Hanford Site.



present in the most contaminated zones. In addition, in spite of hundreds of monitoring points adjacent to known or suspected leaks, the vadose zone is under sampled with respect to critical hydrologic and geochemical parameters, and the sphere of detection for gamma logging is limited to the immediate vicinity of the logging well. Finally, the drilling operations have not been fully successful in eliminating the dragdown of contaminants along the well casing. Adequate differentiation of what contamination has been carried down the well casing, what has contaminated the inside of the well casing during drilling and sediment removal, and what contamination is in the formation currently is not available. In summary, logging of gamma emitters has identified areas of contamination in the vadose zone, but has severe limitations in identifying the full extent and migration of contaminant plumes, particularly when nongamma emitters are present, as is the general case.

In addition to the tank farms and past-practice sites in the 200 Areas, vadose zone contamination exists in the 100 and 300 Areas. For example, current leaks, as well as past-practice sites in the 100-K Area, are contributing a continuous input of ^{14}C to groundwater (up to 40,000 pCi/L in monitoring wells), even though it has been 27 years since gas condensates were discharged to cribs (Hartman and Dresel 1997). Other contaminants associated with the fuel storage basins in the 100-K Area include significant quantities of ^{90}Sr and ^{137}Cs suspected to be present in the vadose zone beneath the K-East basin and adjacent crib and injection well. Up to 25,000 pCi/L of ^{90}Sr has been observed in groundwater near these facilities (Hartman and Dresel 1997). Recharge from rainfall and snow melt, in addition to fire hydrant leakage, is the suspected driver for this migration through the shallow vadose zone into the groundwater. As another example, at the 100-N Area, approximately 3,000 Ci of ^{90}Sr, 5,000 Ci of ^{60}Co, 3,000 Ci of ^{137}Cs, and 22 Ci of plutonium were discharged to cribs. During operations, these facilities received discharges amounting to 7.2×10^5 mm/yr. In spite of these massive discharges to the cribs, only ^{90}Sr and ^{60}Co have migrated to the water table. Most of the radiochemical inventory still resides in the bottom of the cribs.

Data catalogs and reviews are available for geology (DOE 1988a) and geochemistry (Kaplan and Serne 1995; Kaplan et al. 1995; Serne and Burke 1997). Recently, cores collected from boreholes in the T and SX Tank Farms have provided chemical characterization data (Freeman-Pollard et al. 1996; Serne et al. 1998), and are providing information on distributions of radionuclides (^{137}Cs and ^{99}Tc) and other chemical species (e.g., chromium, nitrate) that have not been available in the past (e.g., Raymond and Shdo 1966; Womack and Larkin 1971; ARHCO 1973; Routson et al. 1980; DOE 1997a).

A timeline annotated with some of the key characterization reports for Hanford Site facilities is provided in Figure G-8. Concise summaries of some of the facilities/reports are provided in the following paragraphs.

216-S-1 and 216-S-2 Crib. Two investigations performed nearly a decade apart show that ^{137}Cs contamination remains located in the upper strata immediately beneath the crib site. Strontium-90 is more mobile than ^{137}Cs at this waste site, as indicated by its presence in the groundwater.

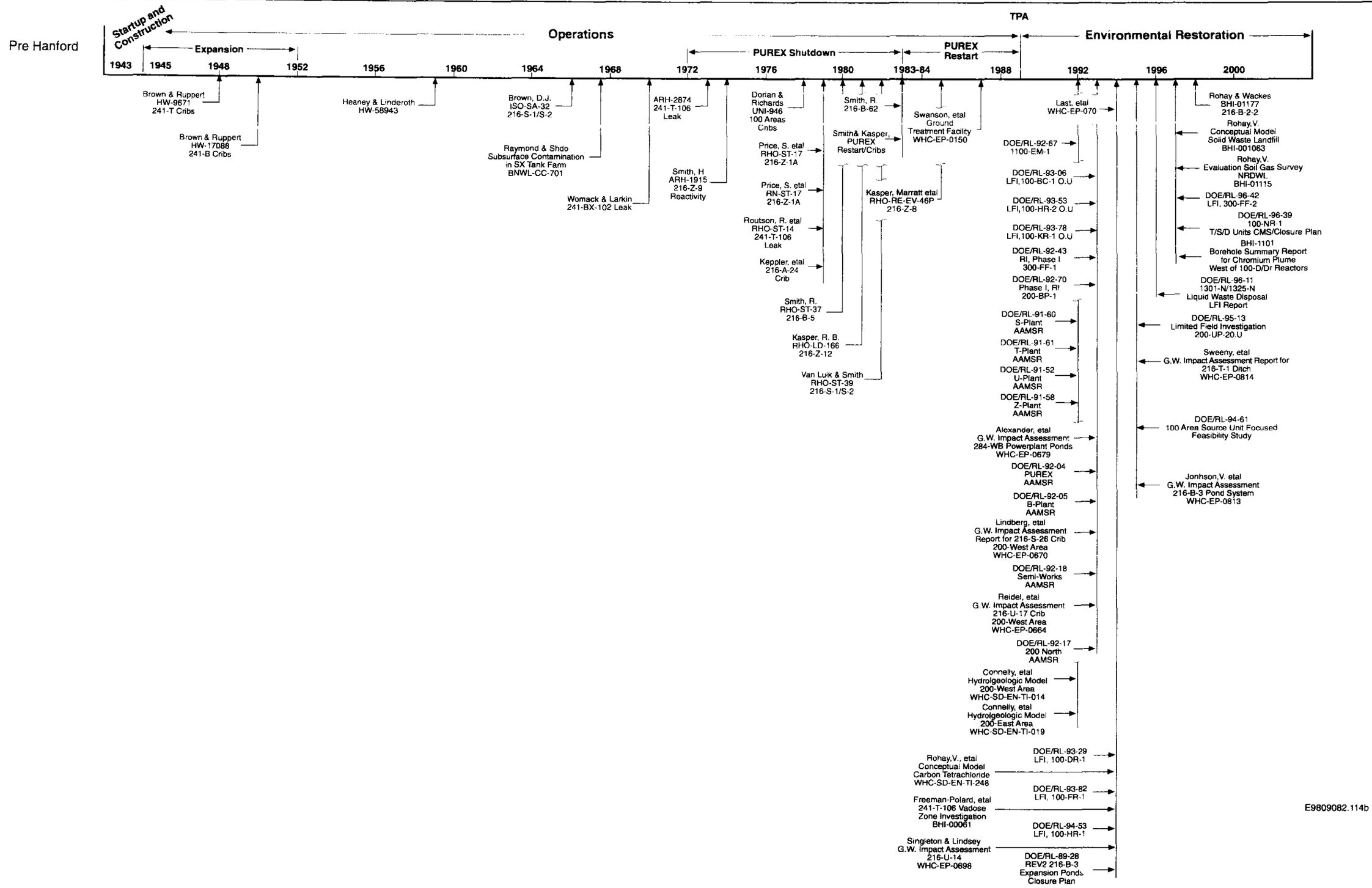


Figure G-8. Timeline of Waste Site Investigations.

The poor sorption of ^{90}Sr is attributed to the chemistry of the waste stream. Based on the distribution of ^{90}Sr, it is suspected that its presence at the water table is in part due to a failed well casing. Figure G-9 shows the results of two 216-S-1 Crib field investigations (Haney and Linderoth 1956; Van Luik and Smith 1982).

216-A-8 Crib. The 216-A-8 Crib was used from 1955 to 1958 and received 9.3 x 10^8 L of A and AX Tank Farm condensate waste and condenser cooling water from the 241-A-431 Building. The crib was reactivated in 1966 when tank farm condensate was routed back to the crib from the A, AX, and AY Tank Farms. During this campaign, the crib was used until 1978 when a total of 1.15 x 10^9 L of waste had been discharged to the crib. The condensates contained 50 g of plutonium, 112 Ci of ^{90}Sr, 1,080 Ci of ^{137}Cs, 995 Ci of ^{106}Ru, and 368 kg of uranium. The cesium and strontium were retained in the upper zone of the soil column beneath the crib as indicated by Raymond and McGhan (1967), but apparently some gamma-emitting contamination leaked down the side of a characterization borehole after the crib was reactivated in 1966. Figure G-10 (Smith and Kasper 1983) shows the distribution of cesium and gamma-emitting radiation in one borehole drilled through the crib. The crib was reactivated in the 1980s when PUREX last operated.

241-T-106 Tank Leak. A series of investigations have been performed over a period of two decades. Routson et al. (1980) concluded that all detectable ^{106}Ru movement occurred between 1973 and 1974. Cesium-137 movement is thought to occur at the same time. Maximum plutonium concentrations were found at 9.2 m depth in one well located adjacent to the tank (Routson et al. 1979; ARHCO 1973; Brown et al. 1979) (Figure G-11). Following the recommendations of a 1989 General Accounting Office audit finding (GAO 1989), another borehole was drilled in 1993. Data from that investigation showed two overlapping zones of radioactive contamination and discrepancies with historical lithologic data. Low levels of ^{60}Co and ^{99}Tc were detected at depths of 36 mand 44 m in Ringold Unit E.

216-Z-9 Trench. Samples from the upper few centimeters of the trench revealed high concentrations of plutonium (20 g/L of sediment). The highest concentration is near the center of the trench floor. Two forms of plutonium are present: particulate and nonparticulate. Actinide concentrations are highest just below the bottom of the facility and decrease within the first 2 m of the underlying sediment (Smith 1973; Price and Ames 1975).

216-A-24 Crib. Measurements from excavations performed as part of a characterization effort showed that the gravel layer retained significant amounts of ^{137}Cs. Soil above the gravel layers did not show contamination. Evidence of plant uptake of radionuclides was demonstrated with the detection of ^{137}Cs in rabbitbrush roots, the upper centimeter of soil, and in the leaf litter. At 15 cm depth, ^{137}Cs was not detected. No data on horizontal distribution or beneath the gravel layer were collected for this study (Klepper et al. 1979).

Figure G-9. Results of 1956 and 1966 216-S-1 Crib Field Evaluations.

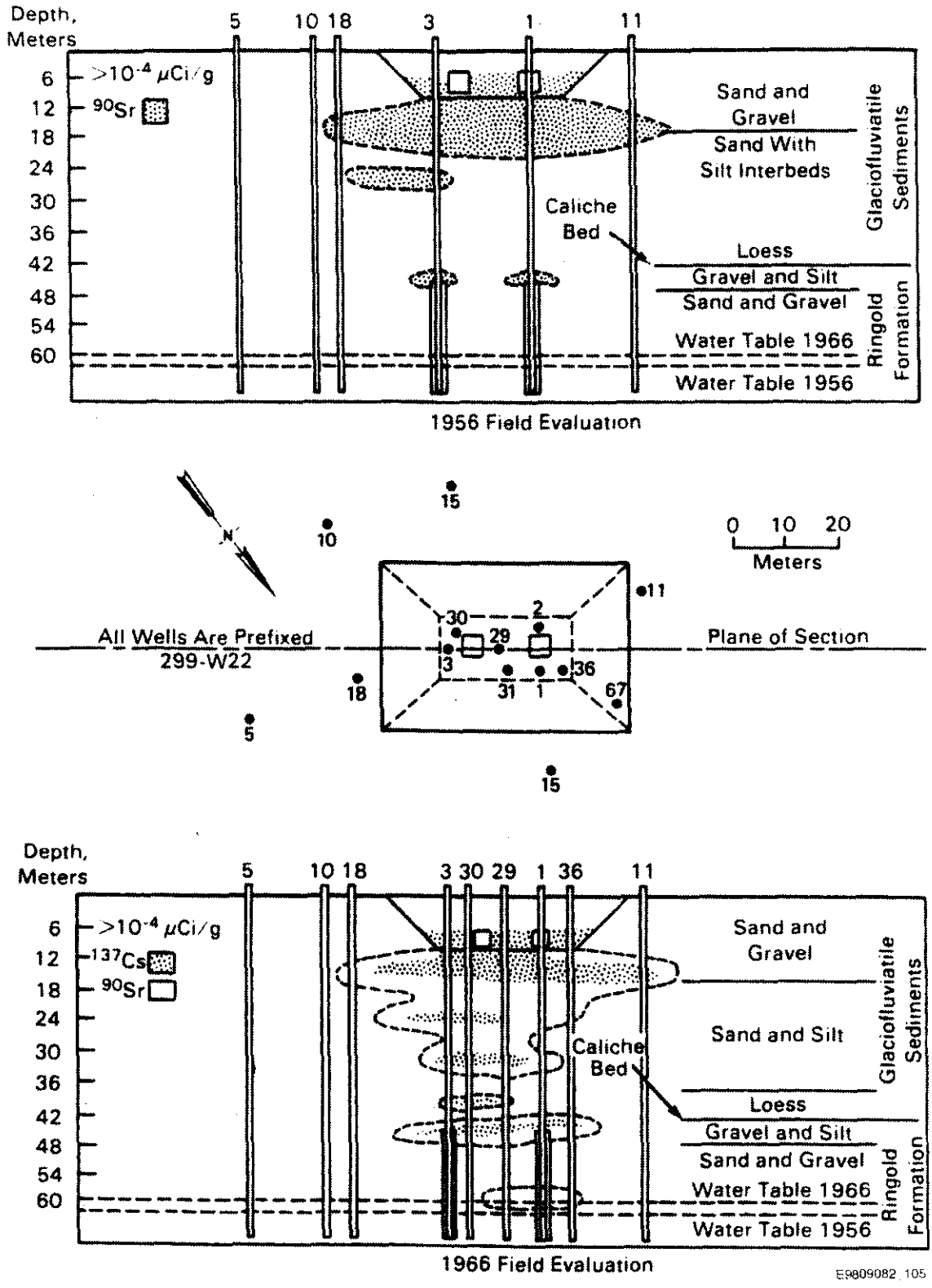


Figure G-10. Distribution of Cesium-137 and Total Gamma Activity in Well 299-E25-14 Near the 216-A-8 Crib.

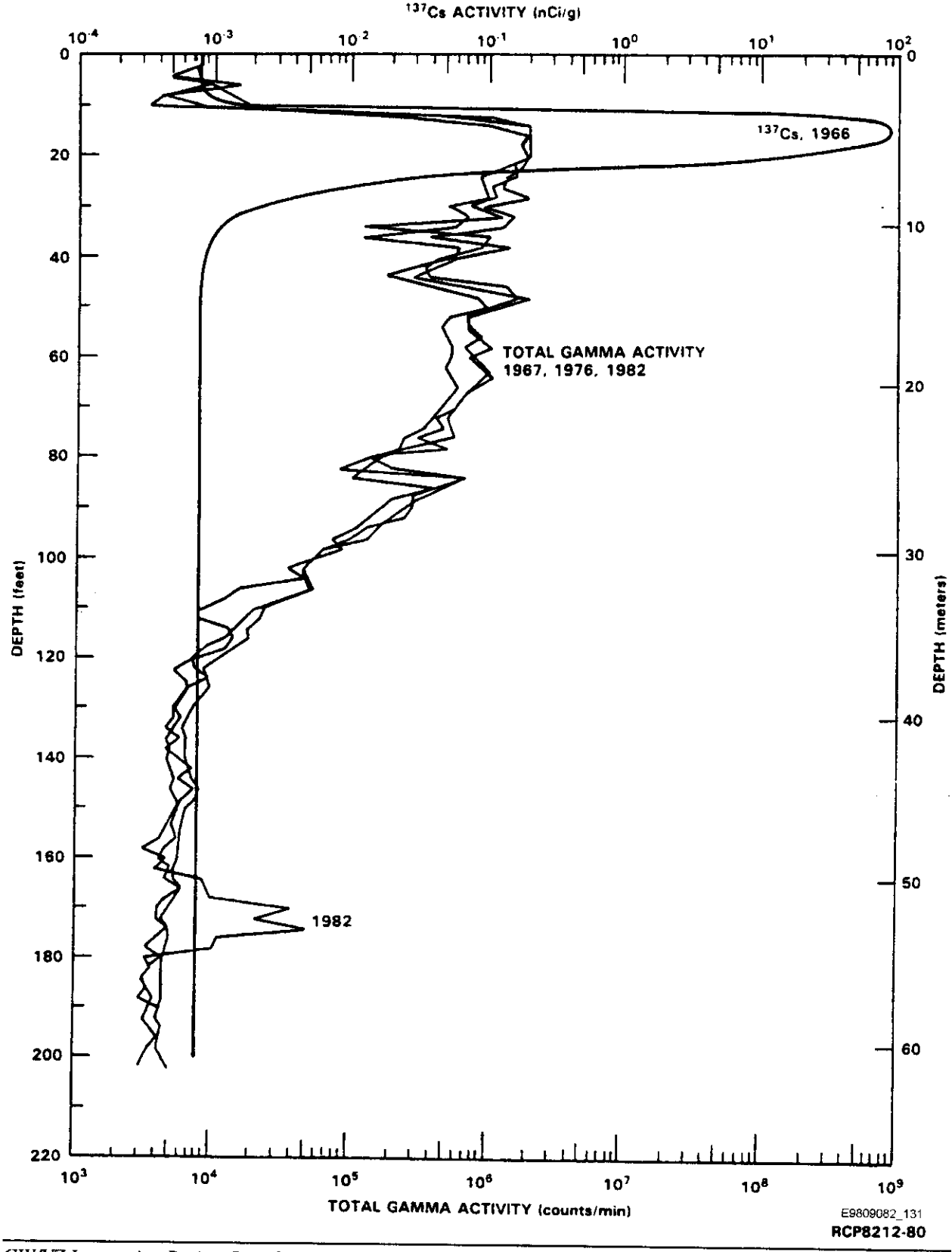
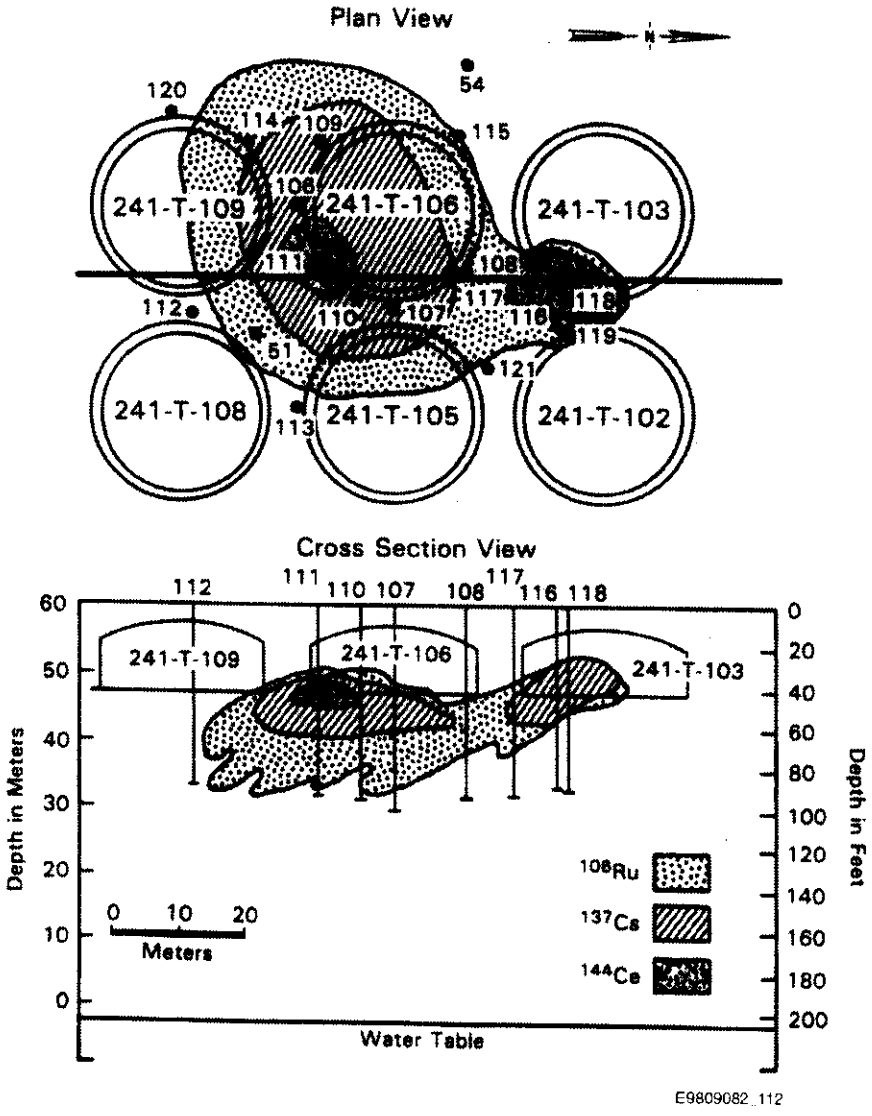


Figure G-11. 214-T-106 Tank Leak - Distribution of Radionuclides.



216-Z-1A Crib. The highest concentration of $^{239,240}Pu$ (4×10^4 nCi/g) and ^{241}Am (2.4×10^3 nCi/g) occurs within the first 3 m of sediment beneath the central distribution pipe. Concentrations of actinides in sediment generally decrease with depth, with the exception of silt-rich layers. The maximum vertical depth of actinide penetration is 30 m below the crib bottom. Estimated lateral extent is within a 10-m-wide zone (Price et al. 1979; Kasper et al. 1979). Figure G-12 shows the total TRU activity distribution for the 216-Z-1A Crib.

216-Z-12 Crib. The highest concentration of plutonium occurred in the sediment immediately below crib bottom (6×10^6 pCi/g). Plutonium concentration decreased rapidly with distance from the crib bottom. No plutonium activity greater than 1 pCi/g was detected from 12 to 30 m below the crib bottom. However, silt layers at 30 to 36 m (maximum depth sampled) show low plutonium and americium activity (Figure G-13) (Kasper 1981a, b; 1982).

216-U-12 Crib. The 216-U-12 Crib received neutralized process condensate and stack drainage from U Plant from 1960 to 1972, and then again from 1981 to 1988. The crib receive a total of 1.5×10^8 L of waste containing 104 Ci of ^{90}Sr, <0.1 Ci of ^{137}Cs, and 1,810 kg of uranium. Based on sediment samples collected from a borehole drilled near the crib, cesium was retained near the crib bottom, but the strontium has migrated down the soil column as shown in Figure G-14 (Smith and Kasper 1983). Smith and Kasper (1983) report that the pH of soil samples collected near the crib were 3.9 at a 6.9 m depth and 6.1 to 6.6 at depths between 33 m and 44 m below ground surface. These data indicate that a considerable amount of low pH wastes were discharged to the crib. This also was provided as the explanation for the depth to which the strontium had moved. The acidic discharge was reacted with the natural calcium carbonate in the soil, and dissolved the solid releasing high concentrations of calcium to compete with strontium for sorption sites. Groundwater in this area has been impacted by operation of the crib, as indicated by elevated levels of ^{99}Tc and nitrate detected in groundwater downgradient of the crib (Williams and Chou 1997).

216-A-10 Crib. The main use of the 216-A-10 Crib was from 1961 to 1973, but some startup wastes were discharged in 1956 and the crib was used sporadically during 1977, 1978, and 1981. During its major operational period, the crib received acidic, high-salt process condensate from PUREX with a pH that ranged from 1.5 to 7.3, and averaged about 2. A total of 2.87×10^9 L of waste was discharged to the crib containing 343 g of plutonium, 147 Ci of ^{90}Sr, 134 Ci of ^{137}Cs, 7,270 Ci of ^{106}Ru, and 204 kg of uranium. The cesium and strontium distributions in a borehole drilled immediately adjacent to the crib are presented in Figure G-15 (Smith and Kasper 1983). It is important to note the differential depths of cesium and strontium movement, even with billions of liters of water passing through the soil column. This crib received additional waste during the 1980s when PUREX was reactivated.

Figure G-12. Total Transuranic Activity Distribution for the 216-Z-1A Crib.

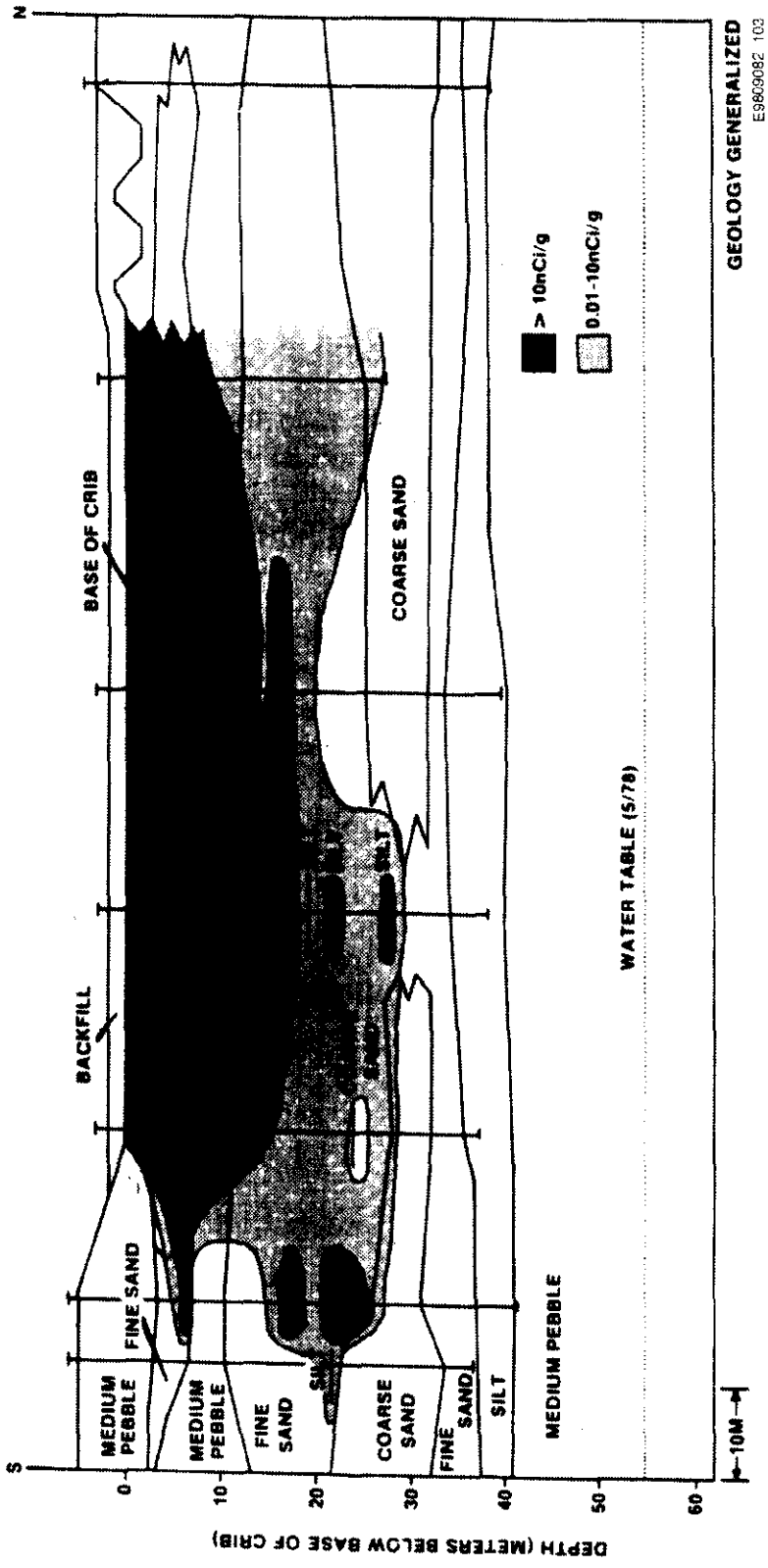


Figure G-13. Distribution of Plutonium Beneath the 216-Z-12 Crib.

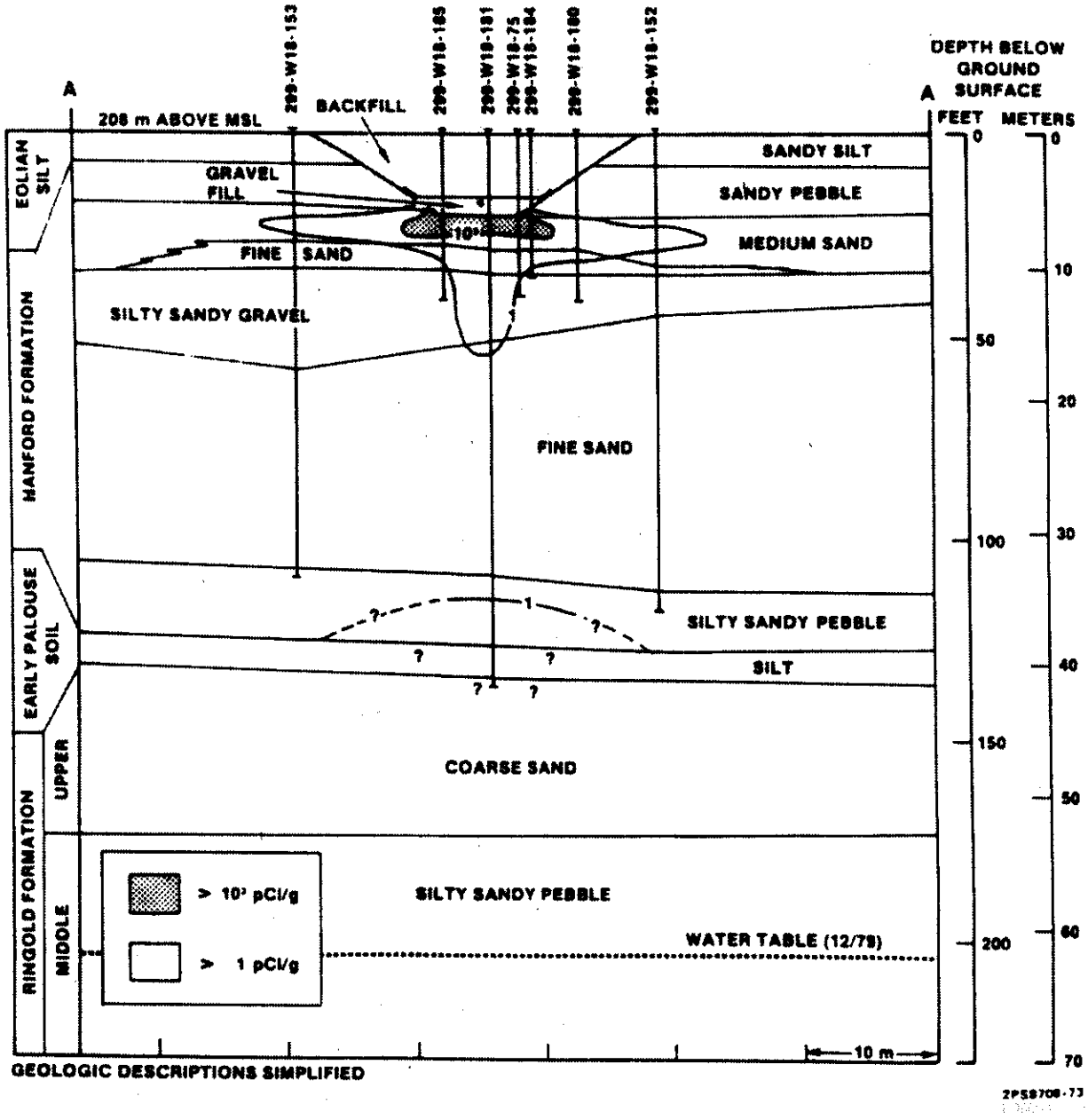


Figure G-14. Distribution of Cesium-137 and Strontium-90 in Well 299-W22-75 Near the 216-U-12 Crib.

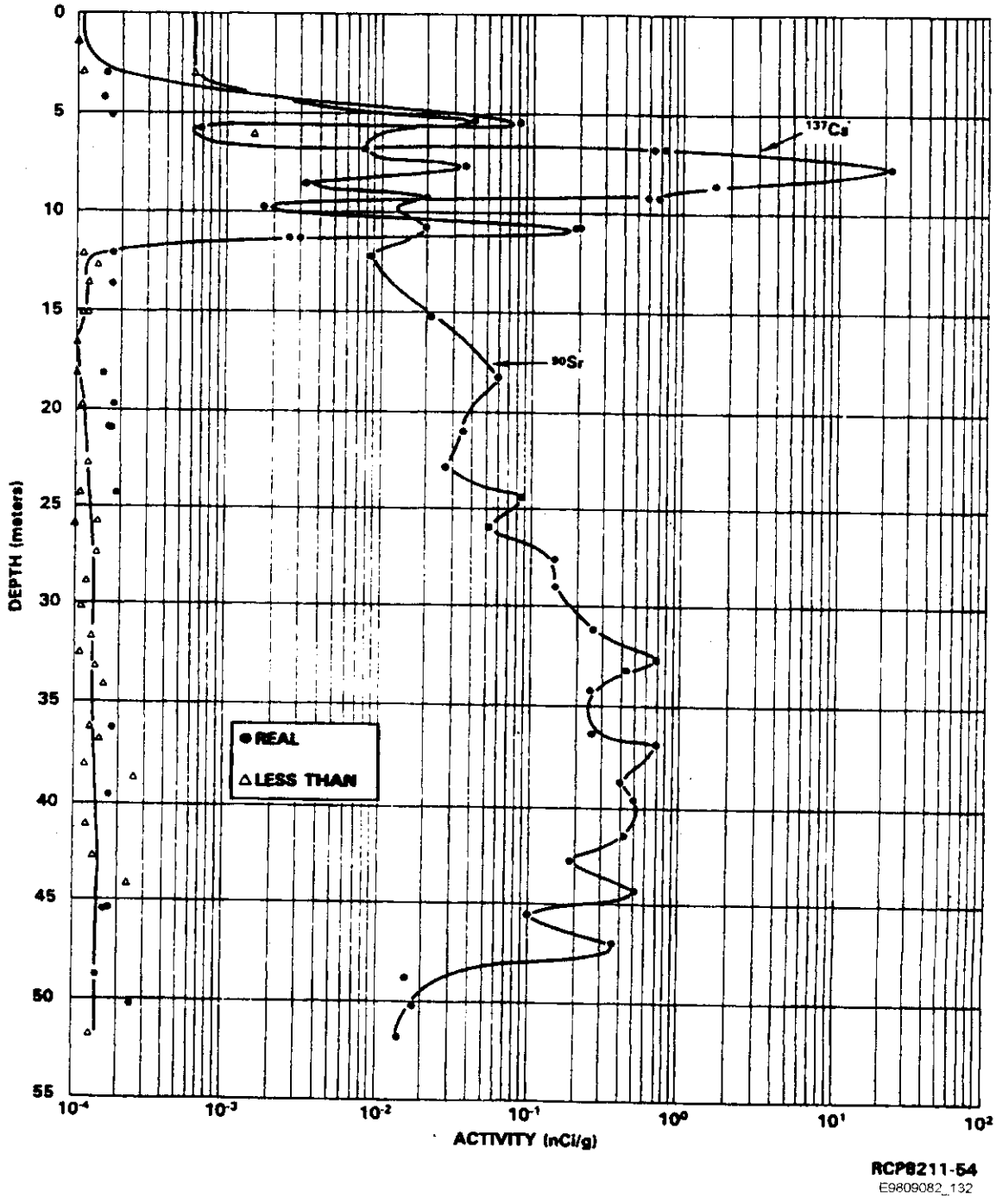
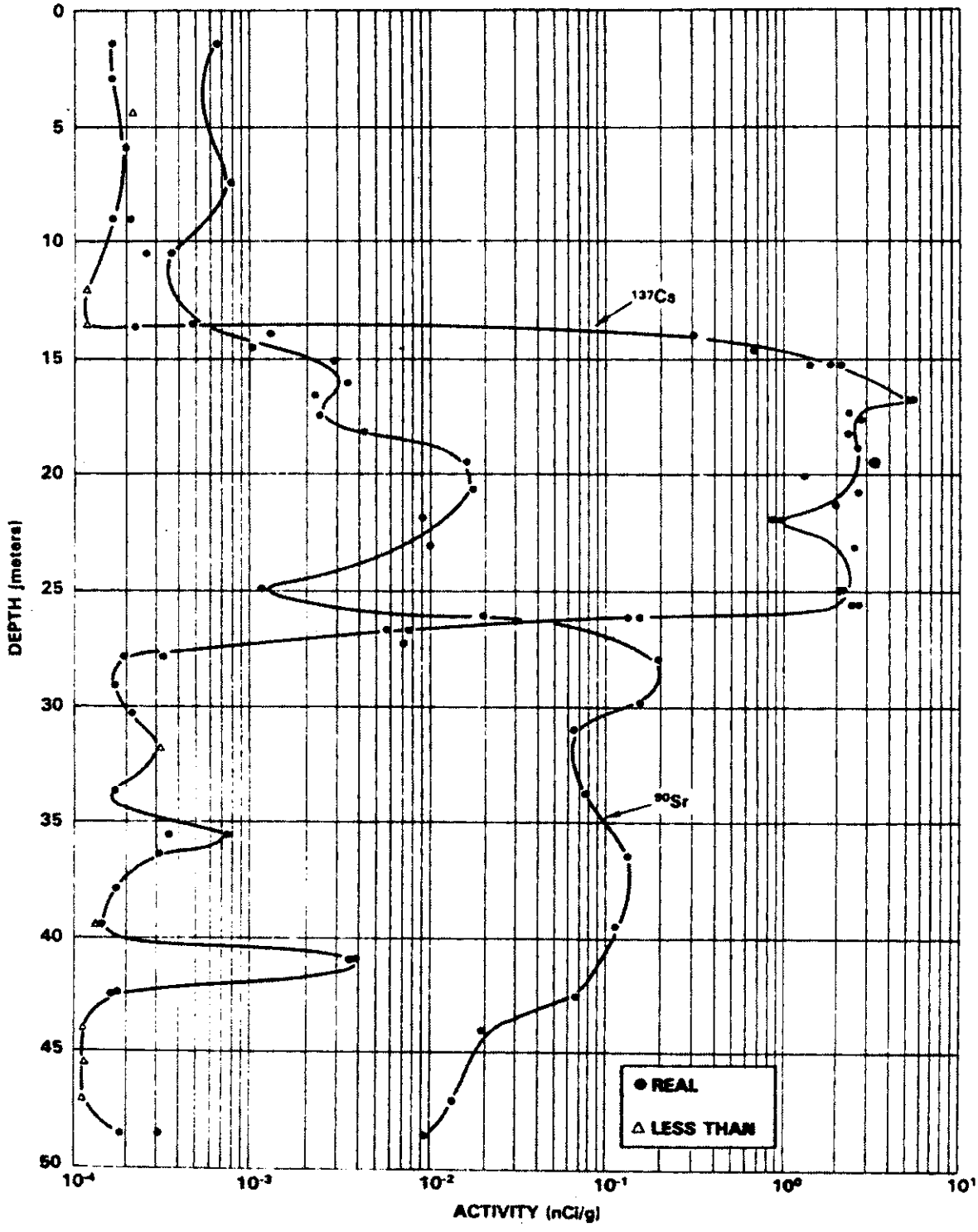


Figure G-15. Distribution of Cesium-137 and Strontium-90 in Well 299-E24-15 Near the 216-A-10 Crib.



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216-A-30 Crib. The 216-A-30 Crib received 4.30 x 10^9 L of low-salt, neutralized steam condensate from PUREX, and other miscellaneous liquid wastes from 1961 until 1981. It was then reactivated later in the 1980s when PUREX began operations. The crib received a total of 187 Ci of ^{90}Sr, 142 Ci of ^{137}Cs, 196 Ci of ^{106}Ru, and less than 20 kg of uranium. Results from a soil boring near the crib indicated that ^{90}Sr and ^{137}Cs remained near the bottom of the crib within 5 to 8 m below ground surface (Smith and Kasper 1983). When liquid discharges exceeded the infiltration capacity of the crib, the liquids backed up onto the ground surface around the crib and contaminated the shallow subsurface.

216-A-36B Crib. The 216-A-36B Crib receive ammonia scrubber waste from PUREX from 1966 to 1972. The crib received a total of 9.4 x 10^7 L of waste containing 177 g of plutonium, 408 Ci of ^{90}Sr, 427 Ci of ^{137}Cs 137, and 119 kg of uranium. The crib was originally a single crib with one perforated distributor pipe extending the length of the crib. During the first 5 months of its operation, the crib received a much higher than intended radionuclide inventory; therefore, it was decided to isolate the 33-m inlet end of the crib where most of the waste was thought to have infiltrated into the sediments. For the remainder of its life, wastes were discharged to the B portion of the crib. Based on gamma logging and soil borings, the total gamma and ^{90}Sr distributions beneath the crib are presented in Figures G-16 and G-17 (Smith and Kasper 1983). It is apparent that cesium contamination (as indicated by gamma contamination) migrated down well 299-E17-4. Strontium data are not available for this location because the well was drilled before the sediments had become contaminated, but it is likely that the strontium distribution would be similar to the gamma contamination.

216-B-62 Crib. The 216-B-62 Crib received alkaline, low-salt process condensate from B Plant from 1973 until 1986. The crib received a total of 2.8 x 10^8 L of waste containing 91 Ci of ^{90}Sr, 170 Ci of ^{137}Cs, and ammonium ion from 0.2M to 0.4M. The presence of ammonium was important because it competes very effectively with cesium for sorption sites on the soil column. This seemed to be the case based on total gamma logs for a nearby monitoring well as shown in Figure G-18 (Smith 1983). Based on sediment analyses conducted on samples collected from the length of the crib, neither ^{90}Sr nor ^{137}Cs migrated more than 30.5 m below the crib bottom as shown in Figures G-19 and G-20 (Smith 1983). It is interesting to note that, in this crib, the ^{137}Cs migrated deeper than ^{90}Sr, and is counter to most other observations. This difference was attributed to the elevated ammonium in the wastes that lowered the cesium sorption, resulting in a deeper migration in the soil column.

Figure G-16. Total Gamma Distribution Beneath the 216-A-36B Crib.

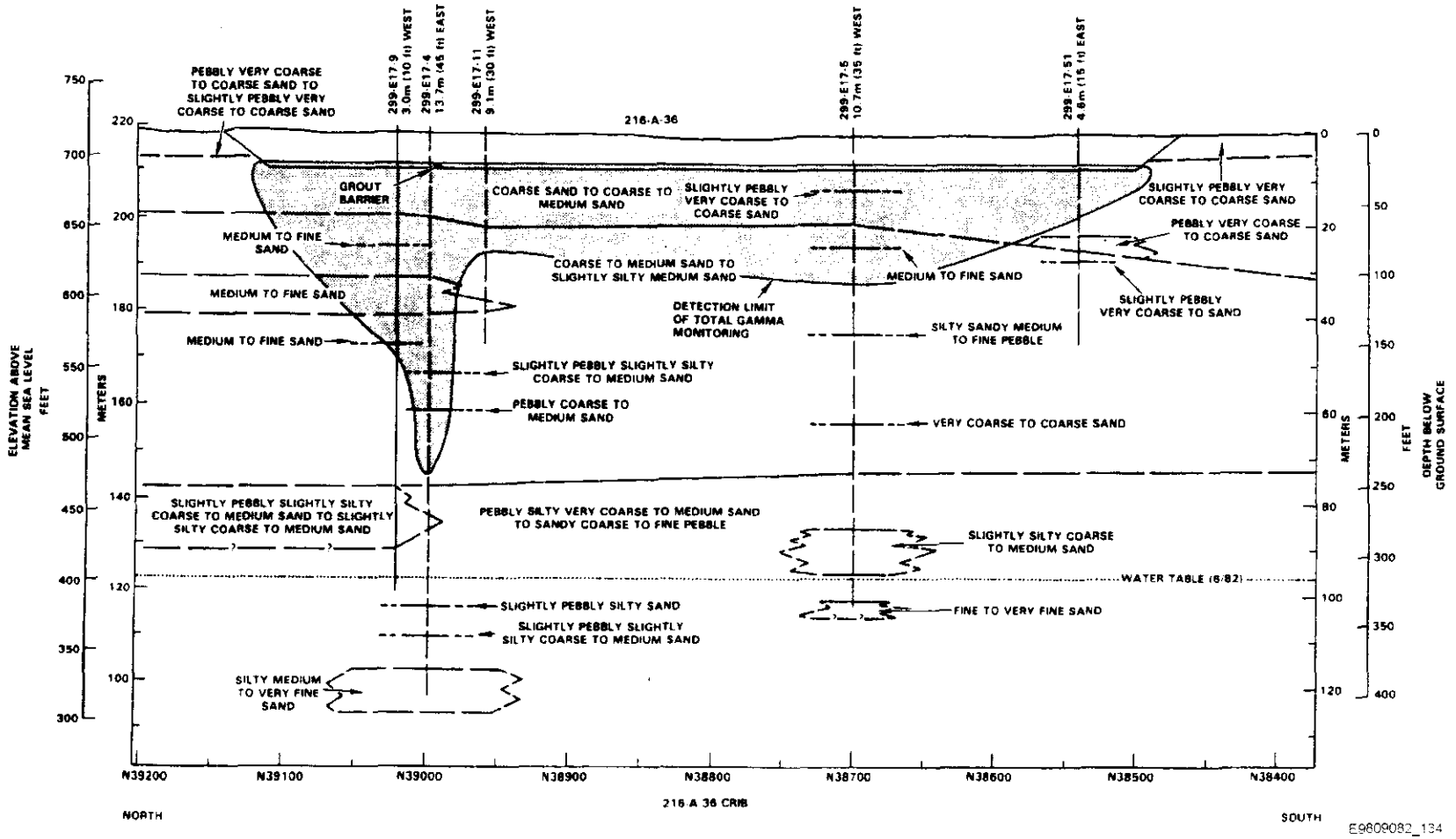


Figure G-17. Strontium-90 Distribution Beneath the 216-A-36B Crib.

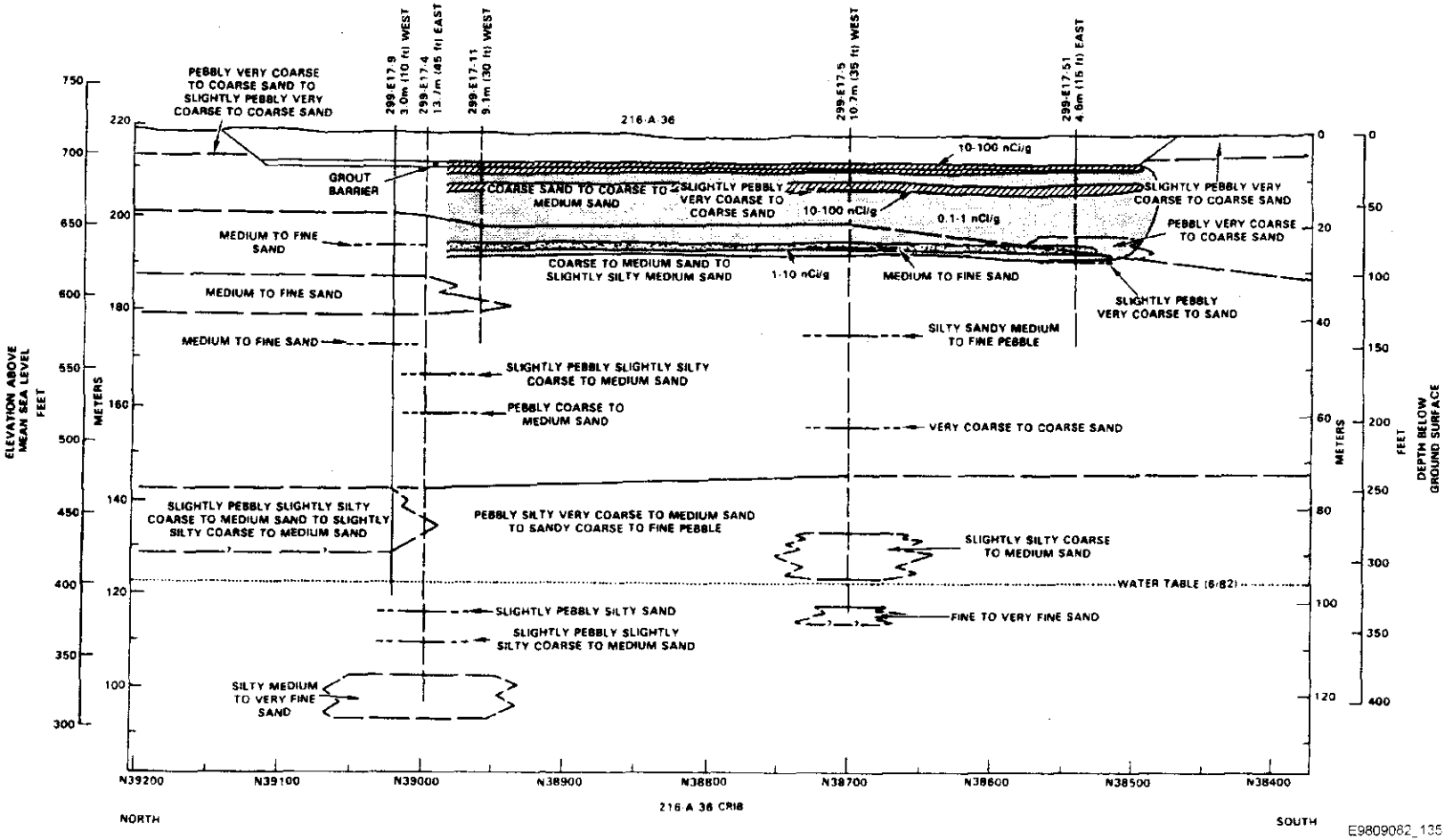


Figure G-18. Total Gamma Profiles for Well 299-E28-18 Near the 216-B-62 Crib.

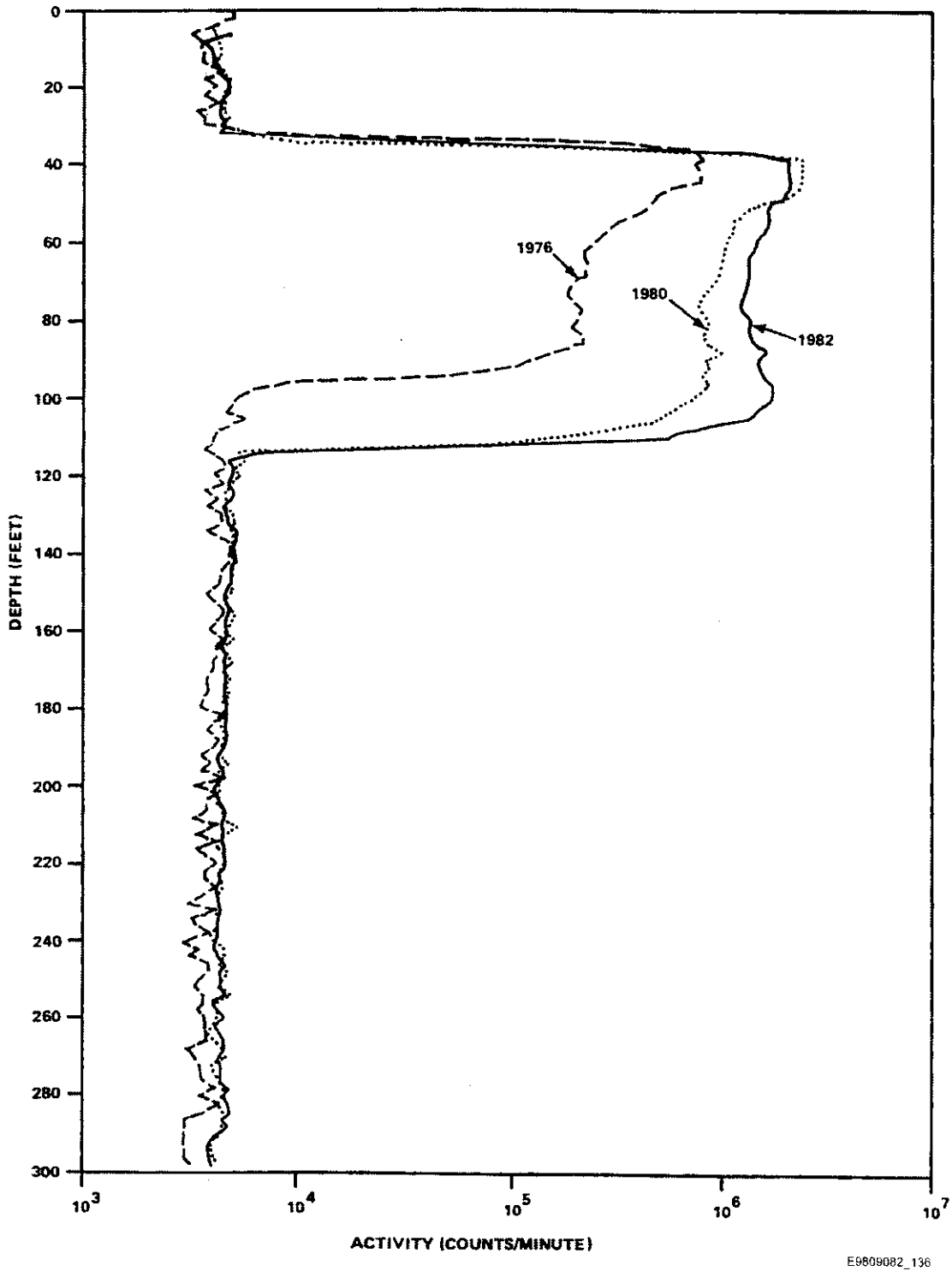


Figure G-19. Cesium-137 Activity >0.1nCi/g Distribution Beneath the 216-B-62 Crib.

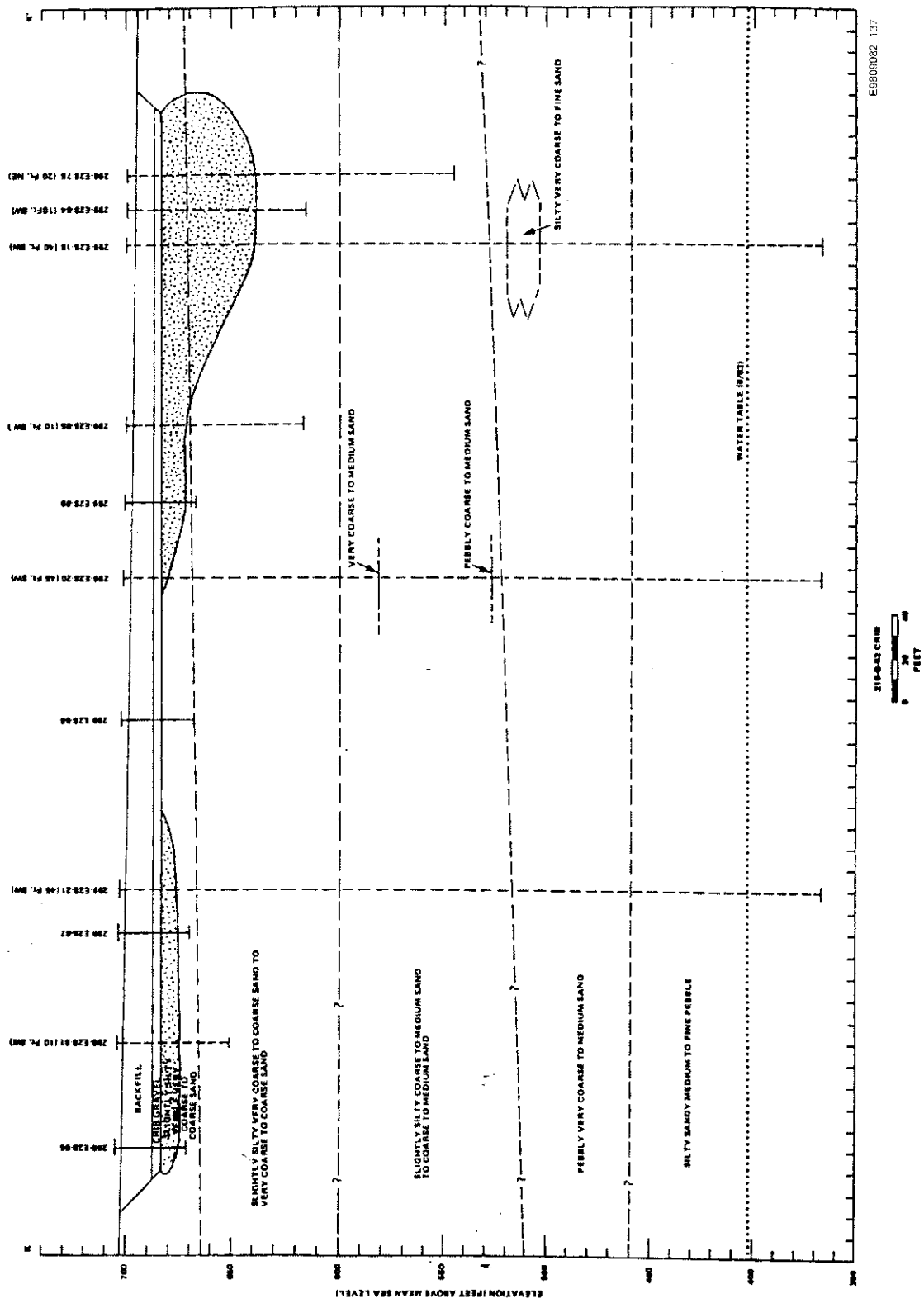
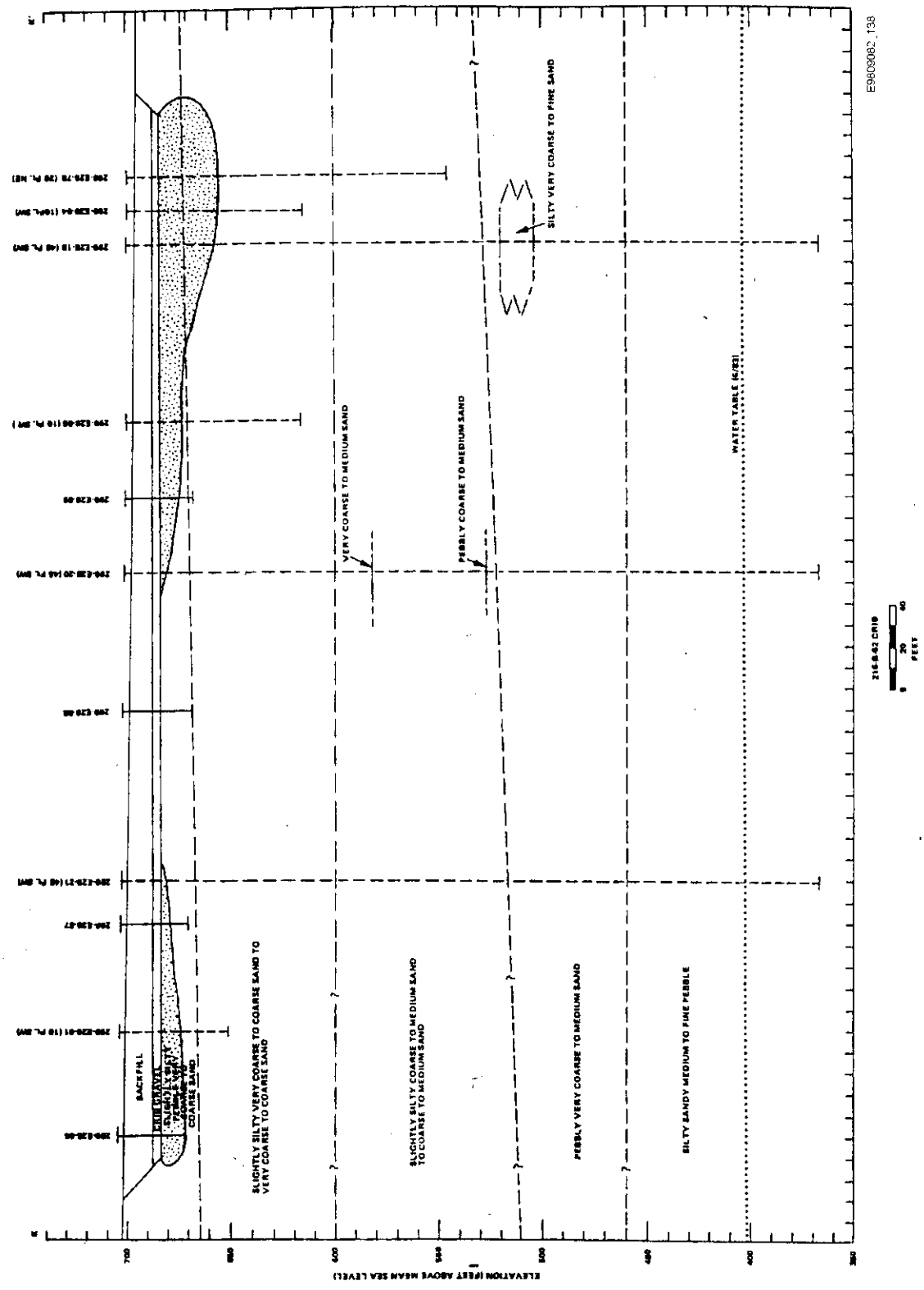


Figure G-20. Strontium-90 Activity >0.1nCi/g Beneath the 216-B-62 Crib.



216-U-1 and 216-U-2 Cribs. In February 1985, uranium concentrations increased abruptly to 0.1 kg of uranium per cubic meter in groundwater underlying the retired cribs. The cribs were estimated to have received over 4,000 kg of uranium between 1952 and 1967. Characterization showed the uranium was present as an anionic carbonate complex that was not sorbed by the soil. The uranium was mobilized by flow from a perched zone of water caused by disposal of cooling water to a nearby crib. Over a 6-month period, more than 30,000 m^3 of groundwater was pumped and treated prior to return to the soil column.

216-Z-8 French Drain. Plutonium and amercium activity was encountered in a zone extending 5 m from the bottom of the french drain (Figure G-21) (Maratt, Van Luik, and Kasper 1985).

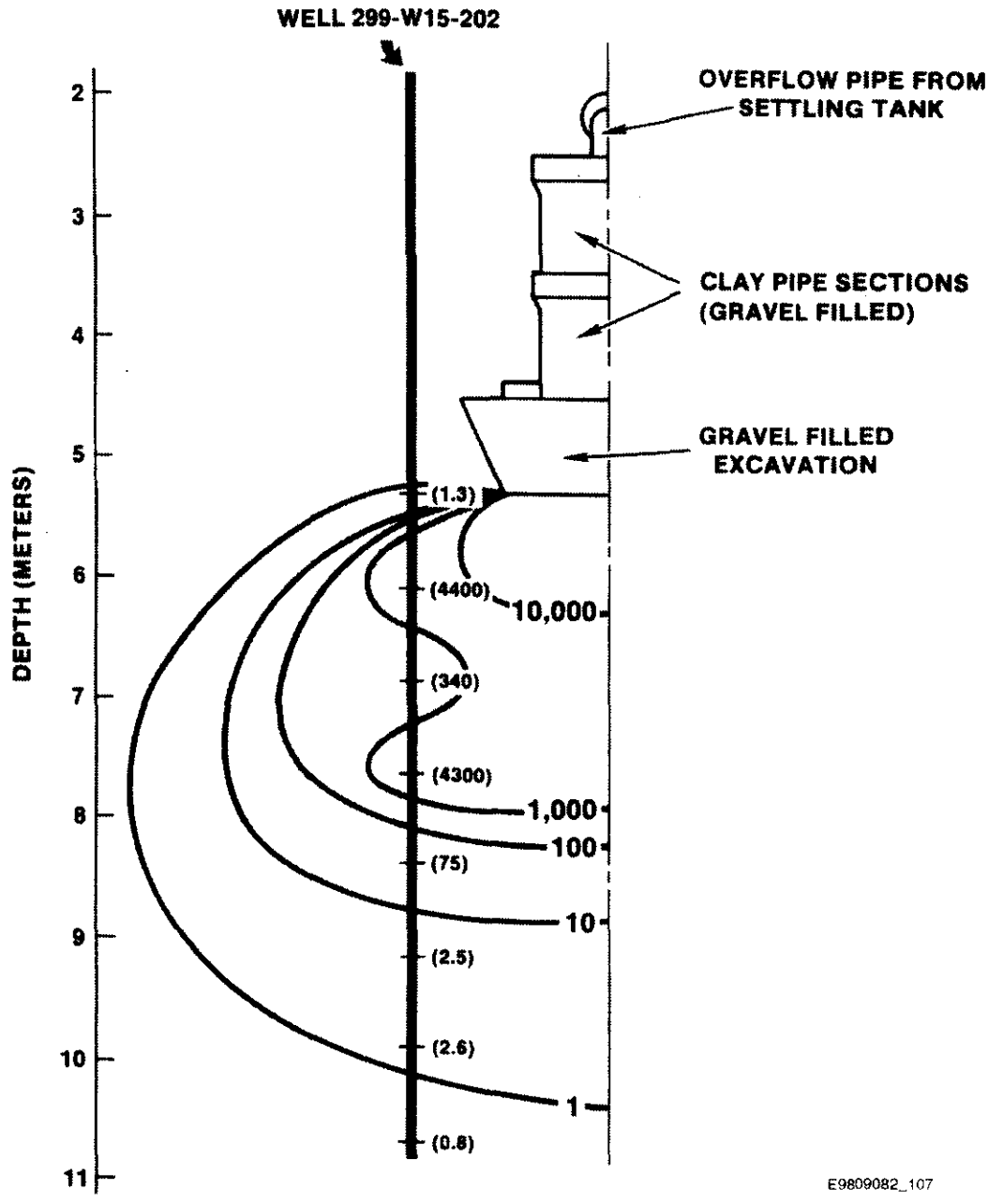
Groundwater Impact Assessments

An evaluation of impacts from liquid waste discharge sites in the 200 Areas was performed per *Tri-Party Agreement* Milestones M-17-00A and M-17-00B in the 1993-1995 timeframe, as followup studies to facility-generated liquid effluent study/waste stream-specific reports. These evaluations examined a number of the then-active ponds, cribs, and ditches to determine if continued liquid discharge would adversely impact the groundwater beneath the sites. Existing data were used where possible, and transport models were used to determine the potential for contaminant migration. In some cases, additional boreholes and test pits were required to characterize the vadose zone and groundwater beneath the waste disposal sites. Some of the sites examined under this program included the 216-B-3 Pond System (PUREX/242-A Evaporator cooling water and chemical sewer), the 216-T-1 Ditch (221-T Plant Headend cooling water and miscellaneous wastes), the 216-S-26 Crib (222-S Laboratory sink waste and steam condensate), the 284-WB Pond (steam generation and water treatment waste liquids), the 216-U-14 Ditch (221-U cooling water and steam condensate), and 216-U-17 (224-U UO3 process condensate).

200 Area Aggregate Area Management Study (AAMS) Reports and Hydrogeologic Models

A 1991 *Tri-Party Agreement* Milestone, M-27-00, specified the preparation of 10 AAMS reports based on a philosophy presented in the *Hanford Site Past-Practice Strategy* (DOE-RL 1991). The AAMS reports addressed the eight major processing areas/plants in the 200 Areas, plus the groundwater conditions beneath the 200 East and 200 West Areas. They represented an alternate approach to the process of characterizing waste sites by operable unit (OU) and sought to simplify the characterization process by using and building on existing data. The reports functioned as remedial investigation/feasibility study (RI/FS) scoping studies in that they gathered available representative environmental and operational information about all facilities as well as the liquid and solid waste sites within the geographic and operational influences of the eight major plants. The documents also outlined an approach for continuing the characterization process, identified preliminary remediation alternatives, identified applicable or relevant and appropriate requirements, defined preliminary conceptual models and assessed health and environmental concerns, identified data gaps for the DQOs, and provided recommendations for waste site characterization based on site hazard evaluations.

Figure G-21. Plutonium-239 Concentration (pCi/g) Beneath the 216-Z-8 French Drain.



One key set of supporting documents was the preparation of the following two groundwater modeling reports: *Hydrogeologic Model for the 200 West Groundwater Aggregate Area* and *Hydrogeologic Model for the 200 East Groundwater Aggregate Area* (Connelly et al. 1992a, 1992b). These reports compiled and evaluated available hydrogeologic and hydrochemical data collected in each area and developed conceptual hydrogeologic models of the groundwater, including distributions of radiological and chemical contaminants.

Limited Field Investigations Reports

A number of limited field investigations (LFIs) have been performed in the 100 Areas, and several have been performed in the 200 and 300 Areas. These reports consisted of data compilations and evaluations for characterization activities at specific OUs. The OUs in all areas were subdivided according to groundwater or vadose zone contamination, and characterized accordingly by boreholes, test pits, cone penetrometer, and other in situ techniques. Specific characterization goals and test parameters were presented in LFI plans. All 100 and 300 Area LFI reports are complete, and one LFI was conducted in the 200 Areas prior to a recent change in characterization strategy.

Tank Farms Vadose Zone Baseline Characterization

Background and Status

The purpose of baseline characterization is to determine the nature and extent of the vadose zone contamination that originated from tank leaks, pipeline leaks, and surface spills using existing monitoring boreholes. The program is intended to document the extent of the contamination and provide data that can be used to help develop an understanding of contaminant migration characteristics and mechanisms. This program also establishes the current conditions at each of the tank farms and provides a quantified baseline of the contamination against which future monitoring data can be compared to assess changing conditions in the vadose zone.

Spectral gamma-ray log data and the three-dimensional visualizations are the primary pOUucts of the baseline characterization project, and provide an understanding of the vadose zone contamination around the SSTs. This basic understanding of the gamma-emitting radionuclides can be correlated with other radionuclides that are not as easily quantified to develop a more comprehensive understanding of all radionuclide distributions and migration characteristics. Such a correlation is currently being performed for the T-106 contamination plume.

All existing boreholes surrounding the SSTs are being logged, and radionuclide concentration logs are being generated for each borehole, including logs of man-made contaminants (i.e., ^{137}Cs and ^{60}Co), as well as the naturally occurring radionuclides ^{40}K, ^{238}U, and ^{232}Th. The naturally occurring radionuclide logs are useful for defining and correlating the lithology.

Individual log data from boreholes surrounding a particular tank are correlated to develop an understanding of the three-dimensional contaminant plume distributions. These data are analyzed and interpreted along with historical information regarding geology, tank construction,

tank content information, and historical gross gamma-ray log data, and the results are reported in a tank summary data report for each tank.

Upon completion of the tank summary data reports for each tank in a farm, a tank farm report is prepared. The tank farm report assesses all of the data and information in the tank farm, correlates that information, and provides the results in the form of visualizations and text. The tank farm reports provide all of the information and interpretations resulting from the baseline characterization program.

Geostatistical analytical tools used to correlate the log data between boreholes and across the tank farm quantify the cross-borehole correlations that establish the distribution of the individual radionuclides and define major contamination plumes. The results of the geostatistical structural analysis have enhanced the understanding of the contaminant migration characteristics of each radionuclide.

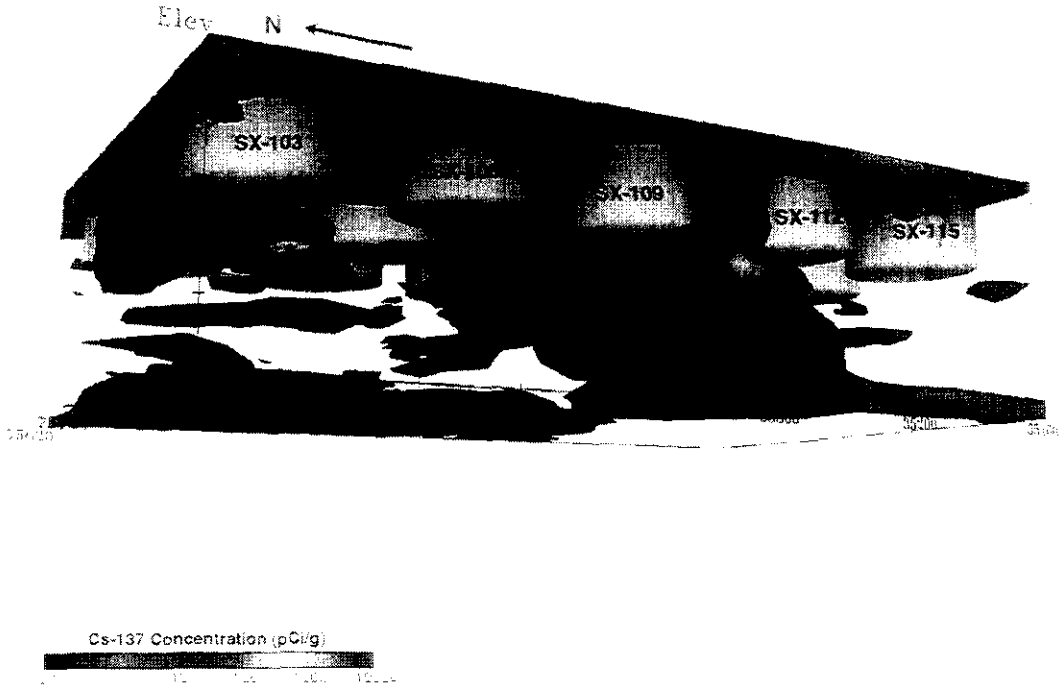
Three-dimensional numerical models of contamination plumes are created using the geostatistical structure, and visualization software is used to generate three-dimensional representations of the models. These three-dimensional visualizations can be viewed from different perspectives, enhancing the understanding of the contaminant distribution and extent of the contamination. In all cases, known or suspected inaccuracies or error in the visualizations are identified and discussed.

As of December 1998, logging of the boreholes surrounding 134 tanks has been completed, with approximately 758 boreholes logged; 114 tank summary data reports have been issued; and 9 tank farm reports have been issued. Tank farm reports for the S, SX, U, TY, TX, AX, BY, BX, and C Tank Farms are referenced as DOE (1998d, 1996, 1997b, 1998a, 1997c, 1997d, 1997a, 1998c, 1998b), respectively. References for the individual tank summary data reports and other project documentation are provided in the tank farm reports.

Findings by Tank Farm

SX Tank Farm. The SX Tank Farm was the first tank farm for which the geophysical logging was completed and for which visualizations of the contamination were created. Ten of fifteen tanks in this tank farm are suspected of having leaked. Some of the tanks are known to have leaked many tens of thousands of gallons of high-level waste. The SX Tank Farm has released more contamination to the vadose zone than any other tank farm. As a result, contaminant plumes consisting primarily of ^{137}Cs were identified in the vadose zone (see Figure G-22) more than 38 m (125 ft) in depth and more than 30 m (100 ft) from the suspected leak sources. A particularly deep ^{137}Cs plume is associated with commingled contamination attributed to leaks from tanks SX-108, SX-109, SX-111, SX-112, and SX-115.

Figure G-22. Summary of SX Tank Farm Gamma Logging Results.



NOTE: Internal borehole contamination data (low-level contamination) not removed from visualization.

The SX tanks contained waste from the reduction oxidation REDOX process, which was about a factor of 30 times more highly concentrated in fission products than the waste resulting from the bismuth-phosphate process (T Plant and B Plant) or from the tributyl-phosphate process (U Plant). As a result, ^{137}Cs is much more highly concentrated, and it was the dominant gamma-emitting radionuclide identified in the vadose zone. The high ^{137}Cs levels within the tanks cause the environmental contamination found here to differ considerably from the contamination plumes observed at the other tank farms.

The existence of deep ^{137}Cs contamination (>38 m [>125 ft]) was initially questioned and thought to be the result of contamination dragdown during drilling or from migration down the boreholes. To resolve this issue, two additional boreholes were drilled through one of the main contamination plumes. Data acquired from the new boreholes quantified the amount of contamination carrydown during drilling, and confirmed that the ^{137}Cs is actually in the formation and is not primarily the result of contamination dragdown.

The amount of contamination dragdown that occurred during the drilling of one of the new boreholes hastened the development and implementation of a gamma-ray spectrum shape factor analysis method. This analytical method is now routinely used along with other information to help interpret the potential for borehole contamination conditions.

In conjunction with the baseline characterization at the SX Tank Farm, Hanford Site groundwater hydrologists and Washington State Department of Ecology (Ecology) personnel reexamined groundwater sampling data and determined that ^{99}Tc in the groundwater originated

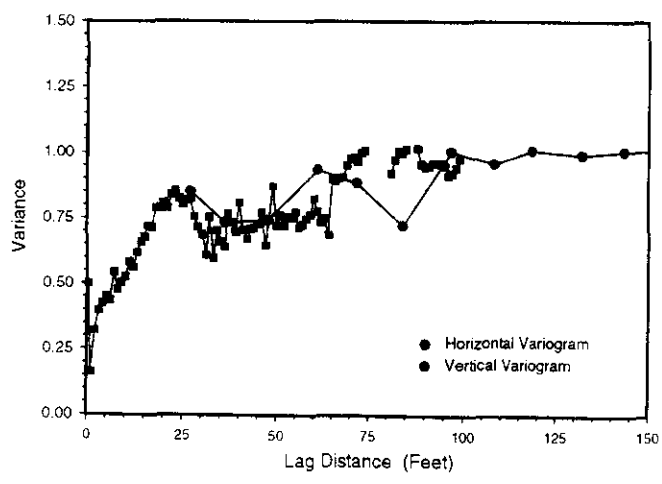
from the tanks. This was the first confirmation that tank waste from one of the tank farms had impacted groundwater.

The geostatistical analysis completed during development of the SX Tank Farm visualizations showed a poor spatial correlation for ^{137}Cs, indicating that ^{137}Cs plumes are likely discontinuous and thus difficult to detect and define. This high spatial variability of ^{137}Cs relative to other radionuclides indicates that closely spaced borehole placement would be required to properly define specific ^{137}Cs plumes, and even with the very high density of boreholes in the SX Tank Farm, the current number of boreholes is inadequate to quantify the ^{137}Cs contamination in the subsurface to a degree of confidence necessary to support mass balance calculations.

The second borehole (41-09-39) drilled to confirm the presence of ^{137}Cs deep in the vadose zone was placed about 1.5 m (5 ft) from an existing borehole (41-09-04). A comparison of the activity profiles of the two boreholes showed a good correlation with some differences in the profiles, indicating that the ^{137}Cs profiles are correlatable at least at 1.5-m (5-ft) spacings. Variograms from other tank farms such as that shown in Figure G-23 (BX Tank Farm) suggest the range of spatial correlation may only be about 6 m (20 ft). A more extensive geostatistical structural analysis is required to quantify the ^{137}Cs distribution at the SX Tank Farm.

Because of the relatively large number of tank leaks in the SX Tank Farm, the commingling of contamination plumes, and the high spatial variability of ^{137}Cs in the vadose zone, it is very difficult to determine the exact sources of the plumes.

Figure G-23. BX Tank Farm Variogram.



The unanticipated depth and extent of the ^{137}Cs contamination detected during the baseline characterization at the SX Tank Farm have raised questions regarding exactly how deep the ^{137}Cs has migrated into the vadose zone, and have also raised questions about the geochemistry of cesium and how a radionuclide that was previously thought not to migrate has reached depths of 38 m (125 ft) in such high concentrations. On the other hand, the high spatial variability of the ^{137}Cs distribution suggests that deep migration should not occur.

Because ^{137}Cs has migrated to such a great depth, questions are raised as to the location of major plumes of other more mobile radionuclides with significantly higher risk (i.e., ^{99}Tc). Analysis of groundwater data established that ^{99}Tc has reached the groundwater. The SX Tank Farm vadose zone work essentially disproved some long-held assumptions that the contamination from the tanks did not migrate and therefore was not a significant environmental risk.

The future focus of characterization should now be to identify where in the vadose zone mobile radionuclides may be found.

A reevaluation of tank chemistry and vadose zone geochemistry transport mechanisms is needed to explain the observations. Much more vadose zone characterization work is required at the SX Tank Farm.

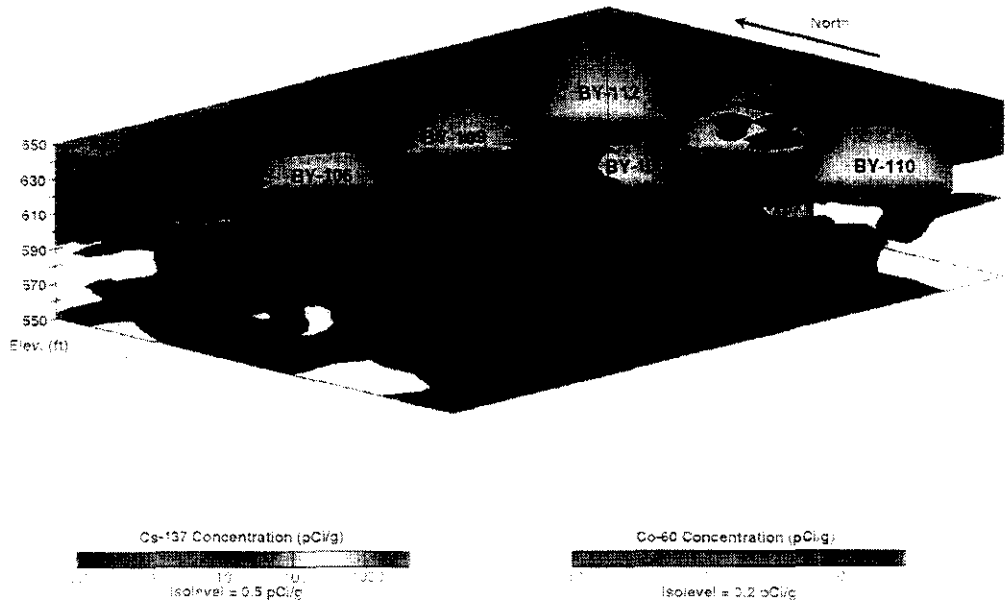
BY Tank Farm. Data acquired at the BY Tank Farm showed relatively extensive and continuous ^{60}Co plumes, some of which are shown in Figure G-24. ^{60}Co was detected in all but a few of the boreholes, which is not surprising, because the BY tanks were used for in-tank ferrocyanide scavenging operations. The ^{60}Co has been shown to form a chemical complex with ferrocyanide, increasing the mobility of an element that was already relatively mobile. However, because ^{60}Co has a short (5-year) half-life, it does not pose a serious long-term health risk.

Correlation of the old gross gamma data with the spectral data showed that ^{60}Co was an indicator of tank leaks in the BY Tank Farm under the previous gross gamma monitoring program. ^{60}Co caused the activity first detected at the wells from a tank leak.

Because ^{60}Co has a higher degree of spatial correlation than ^{137}Cs, plumes can be detected with sparse boreholes, and it is easily correlated between boreholes. The continuity of ^{60}Co plumes made it easier to identify probable contamination sources.

Cobalt-60 concentrations up to about 2 pCi/g were detected as deep as the bottoms of the boreholes at 30 m (100 ft) around tanks BY-103, BY-105, BY-107, and BY-108, as shown in Figure G-24. Compared to ^{137}Cs, this is not a high concentration; but for ^{60}Co, it is quite significant to find 2 pCi/g at the bottom of the boreholes. This high level is indicative of a ^{60}Co plume. Therefore, the total depth extent of the ^{60}Co is not yet known at the BY Tank Farm. It was previously known that ^{60}Co is present in the groundwater in the area, and the BY Cribs located just north of the BY Tank Farm are known to be a source of the contamination. It is not known if the BY Tank Farm has also contributed to the groundwater contamination.

Figure G-24. Summary of BY Tank Farm Gamma Logging Results.



NOTE: Internal borehole contamination data (low-level contamination) not removed from visualization.

In general, the occurrence of ^{60}Co in the subsurface is not associated with dragdown during drilling at the BY Tank Farm, because it is often detected at depth with no source farther up in the borehole and because it correlates well between boreholes, indicating that it is present as continuous subsurface plumes.

The distribution of ^{60}Co at the BY Tank Farm will probably prove to be a good indicator of the distribution of some of the higher risk, nongamma-emitting radionuclides once correlations are made between the gamma emitters and other radionuclides such as ^{99}Tc.

A ^{137}Cs plume at concentrations greater than 10,000 pCi/g is associated with a leak from tank BY-103, and ^{137}Cs is identified as somewhat isolated plumes elsewhere in the tank farm. The amount of ^{137}Cs contamination dragdown that has occurred in these boreholes has not been determined for this tank farm, and it is suspected that much of the low-level ^{137}Cs contamination shown at the lowest elevation in the visualizations is actually windblown particulate contamination that fell into the monitoring boreholes. Because these contamination data were not removed from the database that was used to generate the visualizations, the visualizations show false plumes in this instance.

Tank BY-111 may have been the source of a relatively low-volume leak; however, this tank is not identified as an assumed leaker. A discontinuous region of ^{60}Co identified on the west side of BY-111 may have originated from the tank.

Questions remain as to the location of some of the more mobile and higher risk radionuclides that leaked from the tanks. In addition, it is not known how deep some of the ^{60}Co and ^{137}Cs plumes have migrated because they were detected at the bottom of some boreholes, and the

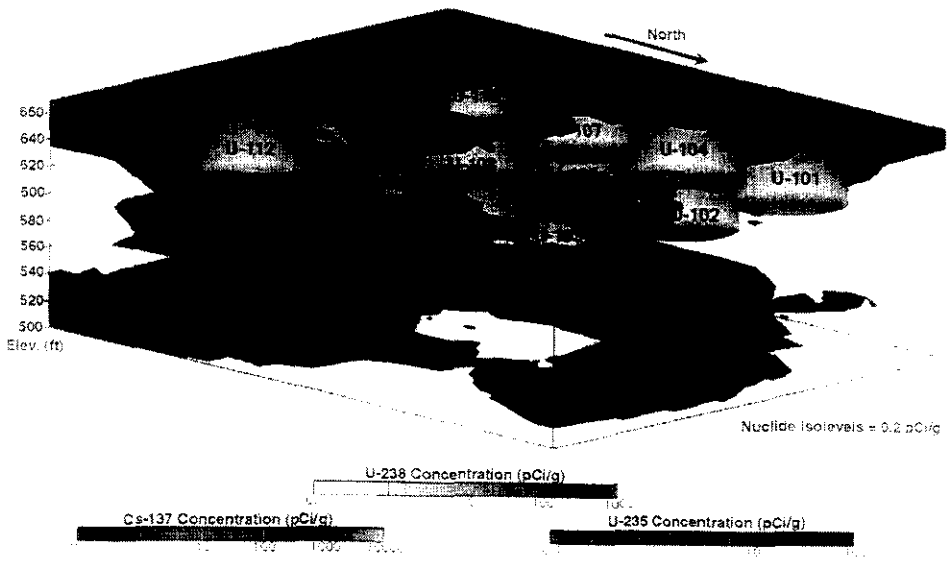
contribution of contamination dragdown during drilling is thought to be minimal. Also, it is not established what or if there has been a contribution of radionuclide contamination to the groundwater from the tanks.

U Tank Farm. The baseline characterization of the U Tank Farm revealed a region of very high ^{137}Cs contamination (>10,000 pCi/g) defined by the log from borehole 60-12-01. This contamination undoubtedly originated from a leak in tank U-112, which is designated as an assumed leaker. The amount of contamination dragdown that has occurred is not known, because shape-factor analysis has not yet been performed on the log data from this tank farm. It is possible that some or all of the contamination from 30 m (100 ft) to total depth of the borehole at 37 m (120 ft) was carried down when the hole was drilled. As with the SX Tank Farm, the ^{137}Cs contamination shows a relatively poor spatial correlation, and because there are no other boreholes in the immediate vicinity of borehole 60-12-01, there is no way to confirm that the plume occurs as deep contamination in the vadose zone.

Other areas of ^{137}Cs contamination are shown in Figure G-25. The surface contamination, some of which may be the result of dragdown, is extensive across the tank farm and extends to varying depths.

Another relatively large area of contamination was detected deeper and throughout much of the tank farm as low-level contamination shown in Figure G-25 between elevations of 152 and 165 m (500 and 540 ft). Some of this contamination may also have been the result of dragdown,

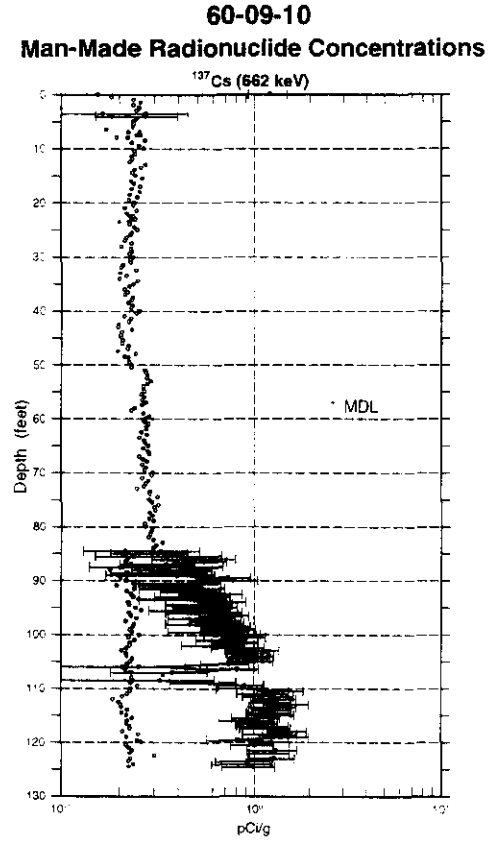
Figure G-25. Summary of U Tank Farm Gamma Logging Results.



NOTE: Internal borehole contamination data (low-level contamination) not removed from visualization.

and the visualization exaggerates the extent of the plumes. However, it is apparent that much of the contamination is actually within the formation, as shown by the log of borehole 60-09-10 (Figure G-26). This log shows almost no contamination near the ground surface or near the base of the tanks (12-m [40-ft] depth), yet a plume of contamination at levels up to 1.5 pCi/g is identified from 26 to 38 m (85 to 125 ft). This deep contamination was not dragged down during drilling because there is no source higher up in the borehole. Therefore, it is probable that this contamination represents a subsurface plume. Questions are now raised as to the depth of migration of the ^{137}Cs plume in this region of the tank farm.

Figure G-26. Cesium-137 Contamination Levels in Borehole 60-09-10.



Another significant plume shown in Figure G-25 is the uranium contamination below tanks U-104 and U-107. This plume covers a diameter of about 61 m (200 ft), but is only as deep as 30 m (100 ft). A larger horizontal extent compared to the vertical extent is not unexpected for this relatively mobile radionuclide. The total depth extent of this plume is established by the log data, and contamination dragdown is not suspected to have occurred in the boreholes defining this plume. Correlations of the distribution of uranium with other radionuclides can be accomplished with this plume, only in a more comprehensive characterization.

Historical groundwater monitoring data from wells surrounding the U Tank Farm have shown low concentrations of uranium and ^{99}Tc in the groundwater. The potential contributions of

contamination from tank leaks to the groundwater are unknown at this time, but cannot be discounted. It is suspected, but has not been established, that the source of the groundwater contamination is the adjacent U-14 Ditch.

The primary areas of concern for future investigations at the U Tank Farm relate to determining the true depth extent and distribution of ^{137}Cs contamination shown at the base of the visualization and the contribution of dragdown during drilling in that area and, of course, to determining the source of the groundwater contamination.

TX Tank Farm. The TX Tank Farm is the largest of all tank farms at the Hanford Site, with 18 SSTs, 8 of which are designated as assumed leakers. The baseline characterization of the TX Tank Farm identified ^{137}Cs, ^{60}Co, ^{154}Eu, and processed uranium contaminant plumes. Of greatest interest are the ^{60}Co and ^{154}Eu plumes in the southern portion of the tank farm.

Both the ^{60}Co and ^{154}Eu plumes appear to have originated from the south side of tank TX-107 and extend southward beyond tank TX-103 (Figure G-27). The ^{60}Co plume is more extensive than the ^{154}Eu plume and extends to the bottom of the boreholes immediately south of tank TX-107, making it impossible to determine the depth of the ^{60}Co contamination.

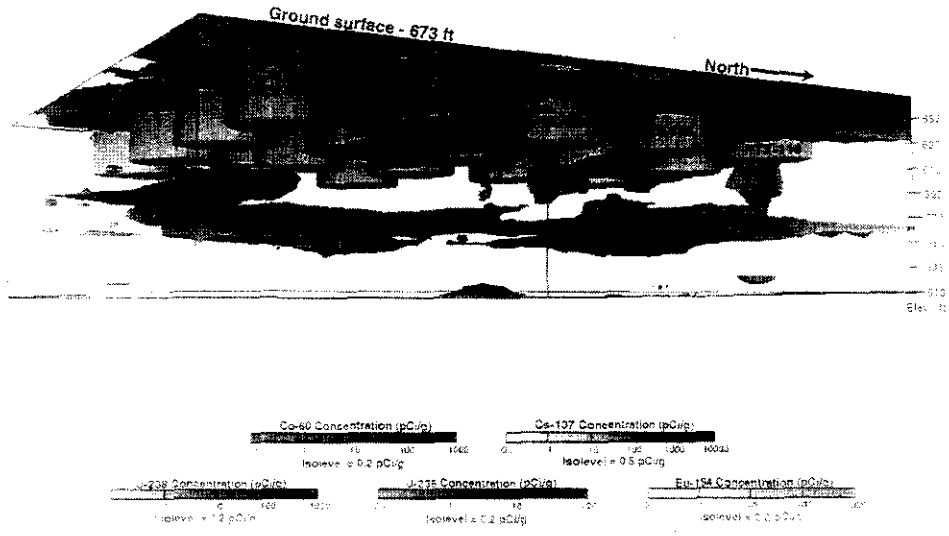
Historical gross gamma log data indicate the ^{60}Co contamination continued to exhibit horizontal migration for a period of at least 9 years after the leak is suspected to have occurred. The mechanism for the continued migration is not known; however, it is possible that chemical complexants may be involved, although based on the performance of ^{60}Co at other tank farms, it is not certain that ^{60}Co necessarily must be in a complexant form to be mobile.

Three subsurface ^{137}Cs contamination plumes were identified in the TX Tank Farm that are related to tank leaks. These plumes are located in the northern half of the tank farm and are visible in Figure G-27 just below tanks TX-109, TX-113, and TX-116. The migration of ^{137}Cs appears to have been controlled by the contact between the tank farm excavation backfill material and the undisturbed formation, indicating that the base of the tank farm excavation acted as a spreading surface for the contamination.

In addition to the three ^{137}Cs plumes noted previously, a widespread ^{137}Cs plume is shown in Figure G-27 at an elevation of about 175 m (573 ft). It is suspected that the low-level ^{137}Cs contamination shown at these elevations is actually windblown particulate contamination that fell into the monitoring boreholes. Because these contamination data were not removed from the database that was used to generate the visualizations, the visualizations show false plumes in this instance.

Two uranium plumes were identified in the southern portion of the tank farm. One plume is located around tanks TX-101 and TX-105, and the other is located around tank TX-104. The processed uranium plume beneath tanks TX-101 and TX-105 is the most extensive of the two plumes and extends to a depth of about 24 m (80 ft). The maximum depth extent of the uranium plumes beneath tank TX-104 is about 30 m (100 ft).

Figure G-27. Summary of TX Tank Farm Gamma Logging Results.



NOTE: Internal borehole contamination data (low-level contamination) not removed from visualization.

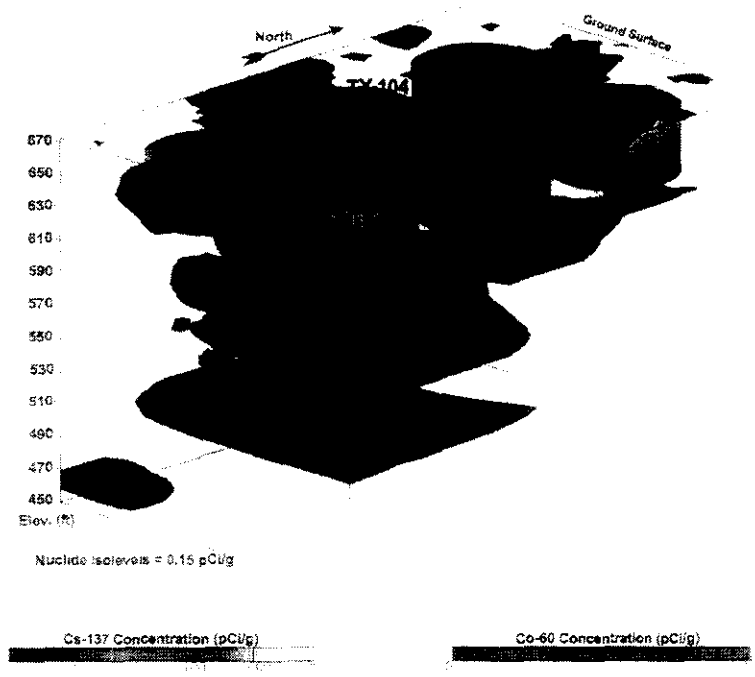
Future characterization at the TX Tank Farm should focus on determining the total depth extent of the ^{60}Co associated with the TX-107 tank leak. Future monitoring of the ^{60}Co plume is recommended to assess the stability of that contamination.

TY Tank Farm. The TY Tank Farm data were the first data set to be analyzed using shape-factor analysis methods. For any regions where shape-factor analysis or the associated data correlation and interpretation indicated that the contamination was not distributed in the formation, the contamination data were removed from the visualization data set prior to preparation of the visualizations. This improved the accuracy of the visualizations. A visualization of the contamination at the TY Tank Farm is shown in Figure G-28.

Plumes of ^{137}Cs and ^{60}Co were identified at the TY Tank Farm. The largest ^{137}Cs plumes were detected near the ground surface and resulted from surface spills.

Five of the six TY Farm tanks are designated as assumed leakers, and ^{137}Cs contamination plumes attributed to leaks from the tanks were identified at the base of each tank. In addition, a relatively small plume was identified in a single borehole adjacent to tank TY-102, showing about 4 m (12 ft) of ^{137}Cs contamination at the base of the tank with concentrations up to 80 pCi/g. Because this plume is located on the north side of tank TY-102, away from the other tanks, this contamination was attributed to a leak from the tank. Tank TY-102 is the only tank in the farm that is not designated as a leaker.

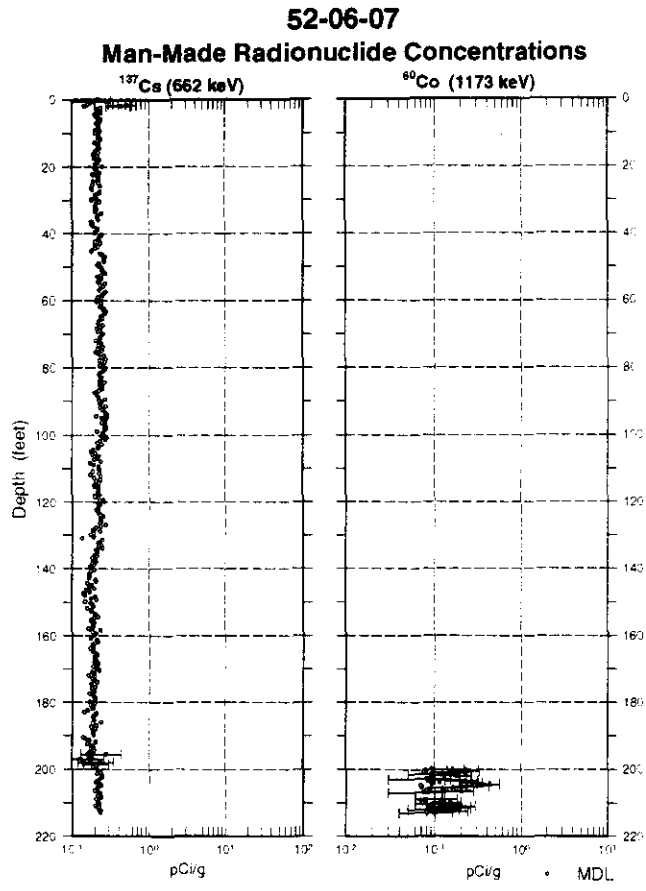
Figure G-28. Summary of TY Tank Farm Gamma Logging Results.



Deep ^{60}Co plumes were identified on the south side of the tank farm. These plumes originated from either tank TY-105 or tank TY-106, or both. As with the ^{60}Co plumes identified at other tank farms, the TY Tank Farm ^{60}Co plumes showed relatively high spatial correlation; they were low in concentration relative to the ^{137}Cs plumes, and they were detected much deeper than the ^{137}Cs plumes. There is virtually no possibility that contamination dragdown caused these plumes, because no high-concentration zones of ^{60}Co exist in the upper portions of the boreholes, which makes it impossible for the contamination to have been dragged down. Data acquired from several boreholes showed continuous ^{60}Co plumes at the bottom of the boreholes, indicating the total depth extent of ^{60}Co migration has not been defined and that ^{60}Co may be present beyond the bottom of the boreholes. This deep ^{60}Co is below the Plio-Pleistocene unit.

A plume of concern is shown in Figure G-28 in the southwest corner of the tank farm at an elevation of 140 m (460 ft). This plume is defined by the data from a single borehole (52-06-07). The log from this borehole is presented in Figure G-29. This plume consists of a layer of low concentrations of ^{60}Co just above the groundwater in the capillary fringe along with what would normally be considered "trace" amounts of ^{137}Cs. There is essentially no contamination in the upper portion of the borehole, including the region at the ground surface, so it is probable that this contamination was transported to the location of the borehole by migration through the groundwater regime. However, the borehole may also have been contaminated by some groundwater sampling equipment or particulate matter that was blown into the borehole.

Figure G-29. Cesium-137 and Cobalt-60 Contamination Levels in Borehole 52-06-07.

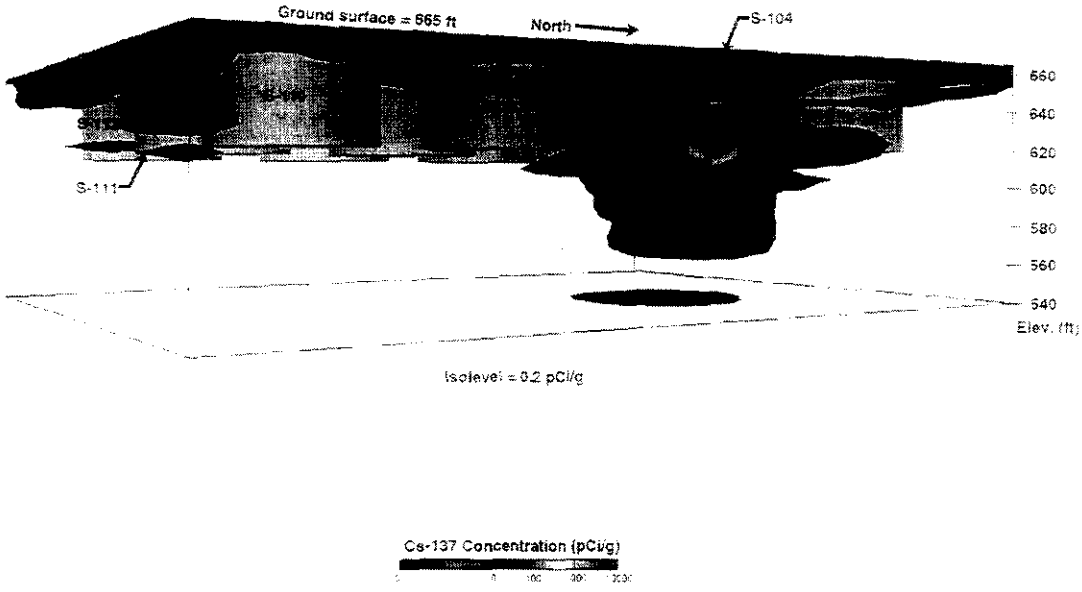


The significance of the contamination in the groundwater is that it suggests the groundwater has been impacted. The exact source of the contamination remains unknown, but there are no crib sources in the immediate vicinity of the borehole. The leaks from the tanks on the south side of the tank farm (TY-105 and TY-106), which are the primary sources of the deep cobalt contamination, are most likely the source of this contamination in the groundwater. Future investigation is required to determine the total depth extent of the contamination on the south side of the tank farm and to determine if that contamination is actually in the formation and the groundwater.

S Tank Farm. The S Tank Farm data showed a relatively clean vadose zone, as only one tank in this farm (S-104) is known to have leaked. The contamination plume from tank S-104 is shown in Figure G-30.

Like the SX Tank Farm, ^{137}Cs was the principal gamma-emitting radionuclide contaminant identified at the S Tank Farm because it too was used to store REDOX wastes. Some surface contamination is present, but compared to other tank farms, this surface contamination is limited.

Figure G-30. Summary of S Tank Farm Gamma Logging Results.



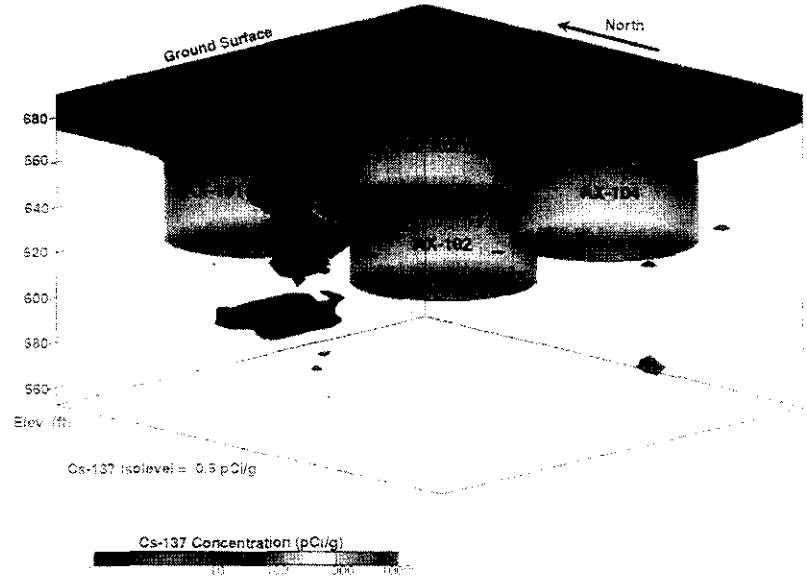
The S-104 plume shows contamination down to about 30 m (100 ft), the depth extent of the monitoring boreholes. The total depth of the plume has not been established, but there is evidence from the decrease in concentration in the gamma-ray log that the contamination is not much deeper than 30 m (100 ft). The leak volume estimate is 90,850 L (24,000 gal) and, although an extensive correlation between leak volumes and contaminant depth extent has not been made, the S-104 contamination depth extent is relatively consistent with that from other tank leaks.

Because the plume from the S-104 tank leak is relatively confined and the leak volume is well known, this tank leak would provide a good analogous plume for studying the geochemistry, the contaminant distributions, and the temporal changes associated with a REDOX waste leak.

AX Tank Farm. Cesiuum-137 is the main contaminant detected in the vadose zone at the AX Tank Farm. A plume was detected in the northern region of the tank farm between tanks AX-101 and AX-103 (see Figure G-31), but it was relatively limited in extent and concentration. The contamination interval is about 30 m (100 ft) thick and is attributed to leakage from a failed piping coupling at the surface. Both tanks AX-101 and AX-103 are designated sound.

Tanks AX-102 and AX-104 are designated leakers. Historical records of gross gamma logging leak detection data indicate that elevated gamma activity was detected in monitoring boreholes for both of these tanks, but that activity quickly decayed away. No significant subsurface contamination indicative of a tank leak was detected with the spectral gamma logging around these tanks. However, because there are no major apparent lithologic features beneath the AX Tank Farm that impede vertical migration, the main plumes of contamination that may have leaked from these tanks could have migrated downward and may have never reached the lateral extent necessary to be intersected by the monitoring boreholes.

Figure G-31. Summary of AX Tank Farm Gamma Logging Results.



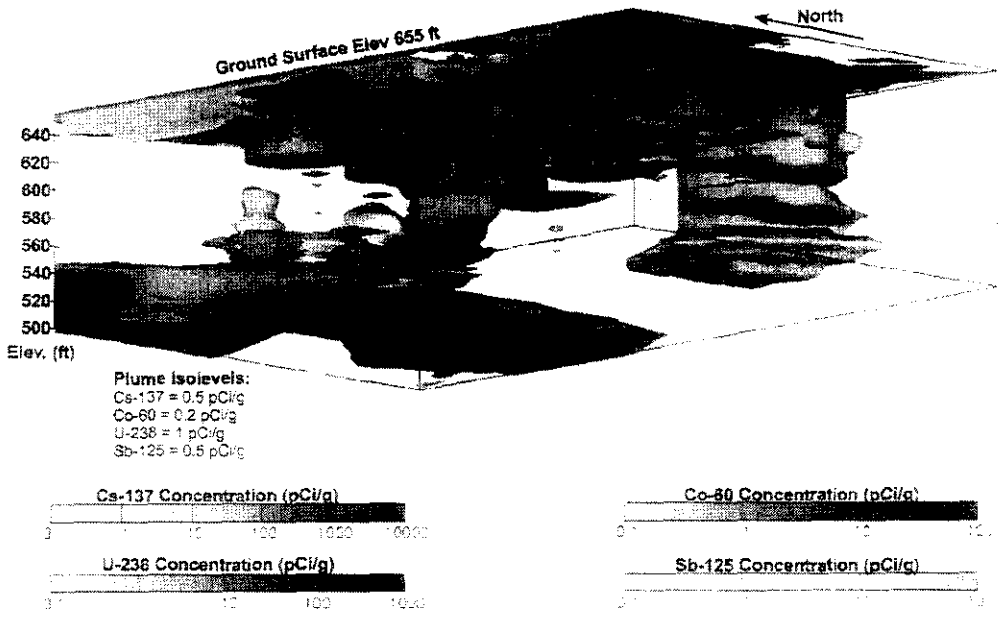
Cesium-137 contamination is present over 90% of the ground surface defined by the areal extent of the vadose monitoring borehole locations. At a depth of 6 m (20 ft), the contamination was only present over about 25% of this area. The highest near-surface ^{137}Cs concentrations, which are greater than 5,000 pCi/g, are north of tanks AX-101 and AX-103 and resulted from a piping leak. Minor occurrences of ^{60}Co, ^{154}Eu, and ^{125}Sb were detected near the ground surface, along with the ^{137}Cs. This contamination originated from surface spills and/or piping leaks.

There is no evidence that waste from tanks in the AX Tank Farm reached and contaminated groundwater beneath the tank farm.

Future vadose zone investigations at the AX Tank Farm should focus on determining if significant contamination leaked from tanks AX-102 and AX-104 and if that contamination can be found beneath the tanks.

BX Tank Farm. Extensive plumes of ^{137}Cs, ^{60}Co, ^{235}U, ^{238}U, ^{125}Sb, and ^{154}Eu occur adjacent to and east of tanks BX-101 and BX-102, the tanks from which the waste originated (see Figure G-32). These plumes range in thickness from 15 to 24 m (50 to 80 ft), and the contaminants have migrated laterally eastward more than 30 m (100) ft from these tanks (the eastern extent of the vadose zone monitoring boreholes). The contaminants from these two tanks have commingled to create a complex distribution. There has been substantial segregation of the individual radionuclides as they migrated through the vadose zone.

Figure G-32. Summary of BX Tank Farm Gamma Logging Results.



The extent of these plumes is not defined by the areal distribution and depths of the vadose zone monitoring boreholes. To the east of tank BX-102, the boreholes are 46 m (150 ft) deep and several contaminants are present at the bottoms of the boreholes, preventing determination of the total depth extent of the plumes. To the west of tank BX-102, the boreholes are only 30 m (100 ft) deep and have not intercepted contamination, but the possibility exists that there are deeper plumes in this area.

A laterally extensive plume of uranium can be traced from tank BX-102 downward and to the northeast, where it is identified in a groundwater monitoring well both within the groundwater and as a contamination plume within the capillary fringe.

Data acquired from one monitoring borehole adjacent to tank BX-102 show concentrations of ^{137}Cs through most of the borehole that are greater than the saturation limit of the spectral gamma logging system. This borehole extends down to the groundwater (to a depth of approximately 76 m [250 ft]). It is suspected that much of this contamination was carried down the borehole during drilling, but there are no other deep boreholes in the immediate area that can be used to evaluate if the contamination is in the formation or a result of dragdown. Shape-factor analysis could not be used to assess the radial distribution of contamination in this borehole because of the high activity.

Tank BX-106 is presently designated as a sound tank, but an isolated plume of ^{137}Cs, ^{235}U, and ^{238}U contamination was identified on the south side of the tank at a depth of 12 m (40 ft), which is the depth of the tank base. The contamination interval, which is about 5 m (15 ft) thick, was detected in borehole 21-06-05. The presence of this contamination indicates the tank leaked, and

because contamination was not detected in adjacent boreholes at this depth, borehole 21-06-05 is very close to the leak source. Also, because the plume is very limited in extent and there has not been a significant segregation of the uranium from the cesium, it is likely that the contaminants have not migrated far and the leak volume is not large.

Cesium-137 contamination was detected on the south side of tank BX-107 throughout the 30-m (100-ft) length of borehole 21-07-06. The source of this contamination may be a near-surface pipeline leak, or leakage from tank BX-107 itself. This tank is presently designated as sound.

Cesium-137 and ^{60}Co plumes were also detected below tanks BX-108, BX-110, and BX-111, all of which are designated leakers.

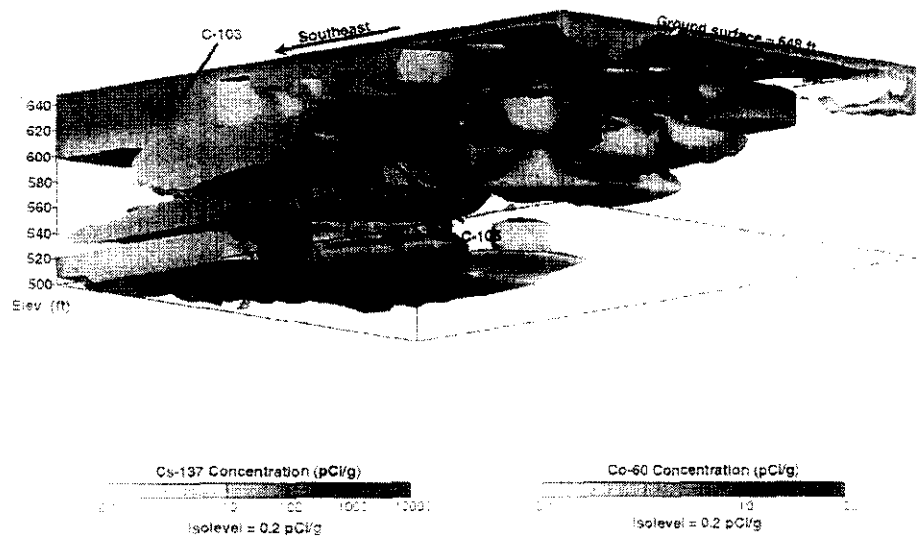
Cesium-137 contamination was detected over 90% of the near-surface region of the tank farm as defined by the monitoring borehole locations. At a depth of 5 m (15 ft) below the ground surface, only about 20% of the area is contaminated with ^{137}Cs. The highest ^{137}Cs concentrations of about 100 pCi/g were detected between tanks BX-107 and BX-110, suggesting a spill or pipeline leak occurred in this region.

Contamination of groundwater beneath the BX Tank Farm has been identified in groundwater monitoring wells located east and west of the tank farm. The source(s) of the contamination in the eastern well is postulated to be contamination originating from tank BX-102, as well as contamination from nearby crib facilities. Data acquired from two groundwater monitoring wells on the west side of the tank farm are also providing evidence of a dynamic condition with increasing ^{99}Tc values.

Future characterization work should focus on determining the depth and areal distribution of the uranium and ^{137}Cs plumes from the BX-102 tank leak. This tank leak can be considered to be an example of a plume from the original bismuth phosphate process and should be studied to understand the geochemistry and soil/waste interactions.

C Tank Farm. Significant ^{137}Cs contamination (and, to a lesser extent, ^{60}Co contamination) is present in the vadose zone at the C Tank Farm as shown in Figure G-33. The majority of the contamination detected during the baseline characterization cannot be directly associated with either tank leaks or leaks from tank farm ancillary piping or equipment. The contamination, as measured with the spectral gamma-ray logging systems, appears to indicate that tanks presently designated sound, such as C-108 and C-109, may have leaked. Conversely, the data indicate there is not much contamination surrounding tanks that are designated leakers, such as C-110 and C-111. The absence of contamination in boreholes surrounding some of the leakers may indicate the lateral extent of migration of leakage from these tanks did not reach the region of the vadose zone penetrated by the monitoring boreholes.

Figure G-33. Summary of C Tank Farm Gamma Logging Results.



The source(s) of the ^{137}Cs contamination below tanks C-104, C-105, and C-106, which are all designated sound tanks, is uncertain; however, a known source of contamination is a leak in the cascade line between tanks C-104 and C-105. Other possible sources include the extensive surface contamination that originated from spills at an adjacent waste loadout facility and the subsequent migration of contamination down along the domes of the tanks, or leakage from tank C-105 itself. Historical information regarding operations at these three tanks did not provide positive indication as to the source of this contamination.

The ^{137}Cs contamination in the vicinity of tanks C-104 and C-105 also shows a very high degree of spatial variability, but because there is a high density of boreholes in this area, the contamination is correlatable. This region would be a good area to study and quantify the spatial variability of ^{137}Cs in the vadose zone and to understand the ^{137}Cs geochemistry.

Extensive ^{137}Cs and ^{60}Co contamination was detected beneath tanks C-108 and C-109, both of which are presently designated sound tanks. This contamination may have resulted from leakage from either or both of these tanks, from leakage from the cascade line between the tanks, or from leakage from a source above the tank(s) that migrated over the dome and downward along the tank sides and spread laterally at the base of the tank farm excavation backfill. Some of the deeper ^{60}Co beneath tank C-108 may have originated from leakage from a nearby tank such as tank C-105. Regardless, positive determination of the source of this contamination could not be determined, and additional investigation into the source of this contamination is required.

Tanks C-201, C-202, C-203, and C-204, which are estimated to have leaked a total of about 6,624 L (1,750 gal) of waste, do not have monitoring boreholes; therefore, the vadose zone surrounding these tanks could not be characterized during this initial investigation. However, the contribution of these tanks to the vadose zone contamination at the C Tank Farm is estimated to be small.

Evaluation of groundwater data collected from monitoring wells surrounding the C Tank Farm indicates the leakage from tanks has not reached groundwater. Because a majority of the tank monitoring boreholes are only 30 to 37 m (100 to 120 ft) deep and groundwater is at a depth of about 76 m (250 ft), the lower portion of the vadose zone is uncharacterized and the potential for C Tank Farm waste to impact groundwater beneath the tank farm is unknown.

B Tank Farm. The boreholes in the B Tank Farm are currently being logged, and data are not yet available for this tank farm.

T Tank Farm. Logging operations at the T Tank Farm are almost complete, and tank summary data reports are being prepared.

A Tank Farm. Logging operations at the A Tank Farm are complete, and tank summary data reports are currently being prepared.

Summary and Conclusions

Characterization of the vadose zone is being accomplished by measuring the gamma-ray-emitting radionuclide concentrations in the sediment around the tanks, creating a database of the contamination, interpreting the data, and creating visualizations of the contamination.

The limitations in visualizations produced by the project have been identified. These limitations are present because only a limited geostatistical structural analysis is possible at this time and because of an inherent problem of contamination dragdown during the drilling of the monitoring boreholes. Spectrum shape-factor analysis methods were developed to interpret some of the borehole contamination conditions.

The SX Tank Farm was the first tank farm completed, and it has the largest volume of leakage of any other tank farm. In addition, this tank farm showed the largest and the deepest distribution of ^{137}Cs of any of the tanks farms completed to date. The total depth extent of contamination for this tank farm is not known, but it is evident that tank waste has impacted groundwater.

In all of the tank farms, the gamma-emitting radionuclide present in the vadose zone with the largest distribution and in the greatest quantity by far is ^{137}Cs. The ^{137}Cs plumes show a high degree of spatial variability, and it is often difficult to correlate the ^{137}Cs concentration data between boreholes. The discontinuity in the plumes often makes it difficult to sort out the contamination sources and properly define the extent of contamination.

Cobalt-60 was the next most abundant gamma-emitting radionuclide. It has a lower spatial variability than ^{137}Cs and therefore shows a much better borehole-borehole correlation. Plumes of ^{60}Co have migrated farther than ^{137}Cs and show much more uniform distributions.

At some tank farms such as at the SX or the BX Tank Farms, contamination was detected much deeper and more spatially extensive than expected. Several tank farms showed evidence of groundwater contamination, either direct evidence such as on the south side of the TY Tank Farm and from the BX-102 tank leak, or circumstantial evidence such as groundwater contamination at the SX Tank Farm or U Tank Farm.

Questions remain about the total depth of contaminants in the vadose zone at the AX, BX, BY, SX, TY, and U Tank Farms because significant contamination was identified as continuous plumes at the bottoms of some of the boreholes, indicating that the total depth of contamination has not been reached by the boreholes.

The most significant contamination plumes identified are associated with a leak from tank BX-102. High concentrations of ^{137}Cs (several thousand picocuries per gram) were identified from the base of the tank all the way down to the groundwater, although it is highly uncertain how much contamination dragdown has occurred and whether the contamination is actually in the formation. This tank leak resulted in multiple radionuclide plumes. Uranium from this tank appears to have migrated from the leak source down and into the groundwater at a nearby groundwater well, although knowledge of the total depth of the uranium in the vadose zone is limited to the total depth of the boreholes (46 m [150 ft[).

The work demonstrates a need for geochemical studies that can explain some of the observations of contamination deep in the vadose zone. Considering the depth and extent of some of the relatively immobile contaminants that were measured under this program, a great concern has been raised as to the distribution of the more mobile radionuclides such as ^{99}Tc, tritium, and ^{129}I that cannot be measured with gamma-ray detection systems. This concern will be addressed in a more comprehensive vadose zone characterization program.

G.1.1.1.1 Numerical modeling. Numerical modeling has been used to assess contaminant migration rates in the vadose zone at the Hanford Site. Although all numerical simulation methods have limitations, numerical codes such as VAM3D (Huyakorn and Panday 1994), PORFLOW, and STOMP (White and Oostrom 1996, 1997; Nichols et al. 1997) have been helpful in identifying key and controlling physical processes affecting transport of contaminants under waste disposal sites at the Hanford Site. For example, a three-dimensional model was used to evaluate leak migration rates as a function of variable recharge, fluid densities (i.e., salt brines), moisture changes and moisture-dependent anisotropy, multiple sloping layers with variable hydraulic properties, funnel flow, variable chemical distribution coefficients, and movement of contaminants down boreholes (Ward et al. 1997a). Other tank leak simulations are documented in Smoot and Sagar (1990), Smoot et al. (1989), and Jacobs (1998).

Other models have been used for water balance calculations to support surface barrier design and to assess the impacts of gravel surfaces on recharge rates (Fayer and Jones 1990; Smoot et al. 1990; Fayer et al. 1992). In addition, numerical codes have been used in the analysis of cumulative dose effects from radionuclide migration of low-level wastes via groundwater pathways (Kincaid et al. 1998), of tank waste remediation strategies for solid waste burial grounds (Wood et al. 1996), in the performance assessment of ILAW (Mann et al. 1998), and evaluations of tank waste retrieval and closure strategies (Jacobs 1998). Current efforts are under way to develop a reactive-transport model that can address impacts of extreme chemistry (from tank leaks) on the hydraulic properties (e.g., calculate the effects of chemical precipitation on hydraulic conductivity of Hanford Site sediments). The reactive-transport modeling effort is designed to address coupled processes of chemical, heat, and water flow in both liquid and vapor phases (Yabusaki and White 1998).

The past approach has been to use numerical models in an ad hoc way, on a site-specific basis, to evaluate problems and suggest solutions. With the current focus on vadose zone contamination, a more systematic modeling approach is needed that integrates the vadose zone data-gathering effort with consistent interpretations as conceptual models are developed and tested. Additionally, improved models are needed that incorporate and depict primary controlling physical and chemical processes in a realistic manner or so that their complex and interactive effects can be appropriately considered. It is important that consensus agreement be reached on the numerical models applied to understand and predict vadose zone transport events. Numerical models are key analytical tools needed to develop a complete picture of vadose zone hydrology and contaminant transport at the Hanford Site and that their utility and reliability will improve as understanding of the processes controlling migration of contaminants in the Hanford Site vadose zone is enhanced.

Field experiments will be performed at the Hanford Site under controlled conditions, at well-characterized, clean sites, to test conceptual and numerical models of flow and transport in heterogeneous systems. The emphasis will be on evaluating fluid phase transport by gaseous phase transport will also be considered. Key geohydrologic, chemical, and biologic processes that control plume migration in the vadose zone will be evaluated. Research will include investigations of the impact of lithological features, such as sediment layering, clastic dikes, and fractures on the flow regime. Field tests, with controlled source terms and boundary conditions, will be conducted to improve model testing and rigor and provide enhanced understanding of the processes that affect distribution, transport, and attenuation of contaminants in the Hanford Site vadose zone.

G.1.2 Groundwater

G.1.2.1 Scope. The Groundwater technical element provides the information, capabilities, and understanding necessary to perform technically sound assessments of the impacts of Hanford Site operations on the groundwater resource. The Groundwater technical element encompasses the characterization and modeling of the saturated zone environment and contaminants present in the saturated zone. The saturated zone includes the capillary fringe, the unconfined aquifer, aquitards, and confined aquifers. Major elements of the technical element include the following:

1. Evaluation of the distribution of contamination within the saturated sediments.

2. Assessment of the controls of the saturated zone hydrology, geology, geochemistry, and microbiology on the flow and transport of contamination.

3. Development and use of predictive models to credibly depict the flow and transport of contamination through the saturated zone.

The Groundwater technical element consists of a combination of data management, field measurement, and modeling capabilities. The technical element provides information and data that are used in performing risk assessments. Hanford Site groundwater is accessible to the environment at the Columbia River and in water-supply wells and is a pathway for contaminant transport to the Columbia River.

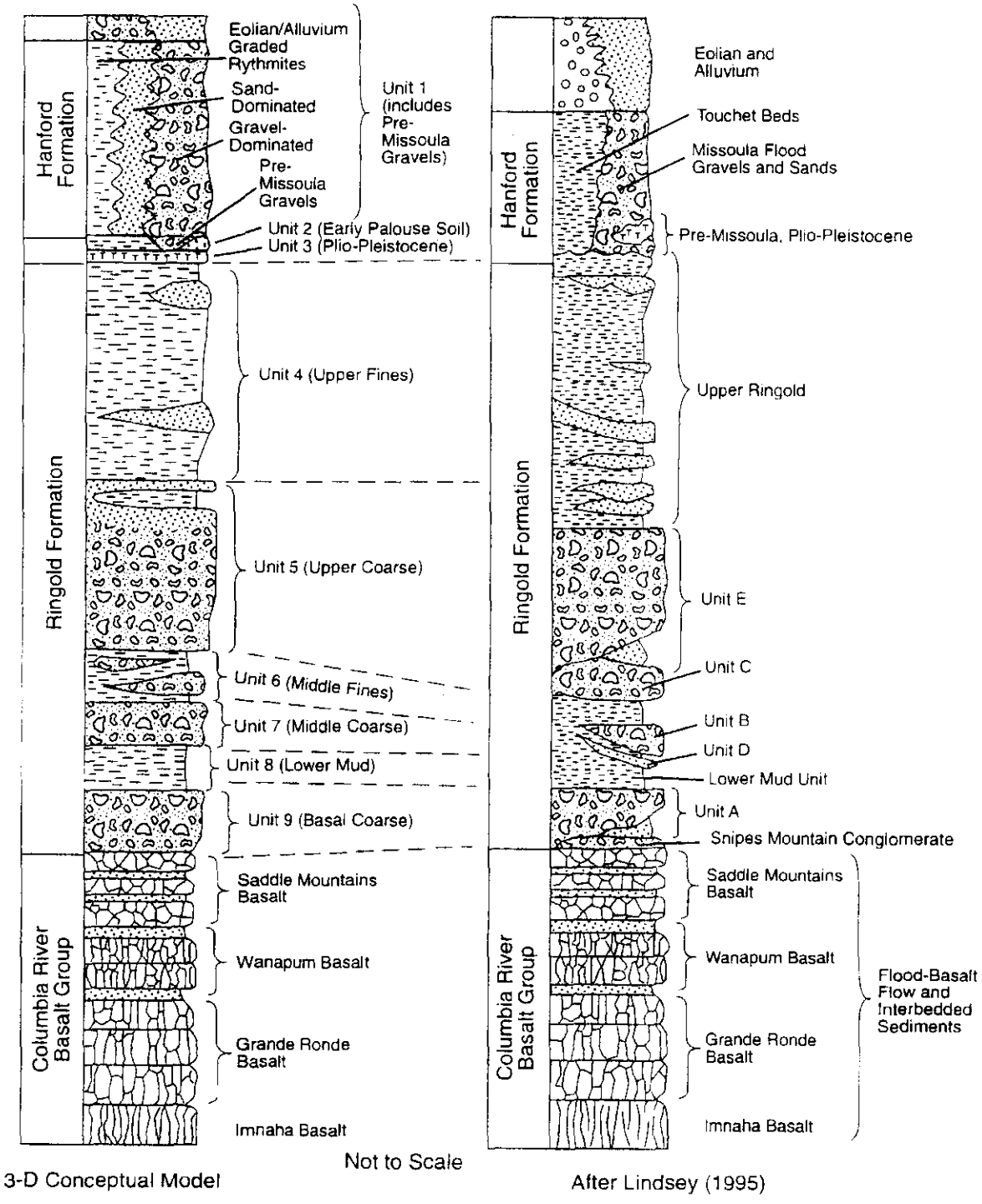
The technical element must provide an accurate understanding of current conditions and the ability to assess potential future conditions, near- and long-term. In addition, the evaluation must allow for the differentiation between contaminant contributions from the Hanford Site and other sources, natural background, and/or anthropogenic.

G.1.2.2 Current state of knowledge. The conceptual model of the Hanford Site unconfined aquifer system was developed from information on the hydrogeologic structure of the aquifer, spatial distributions of hydraulic and transport properties, aquifer boundary conditions, recharge and discharge, and distribution and movement of contaminants. Most information on the groundwater flow system comes from wells. Geologic information is obtained from descriptions of drill cuttings or core samples, and from geophysical logging of wells. Groundwater flow direction and gradient are inferred from water levels measured in wells. Groundwater chemistry and contaminant distributions are determined from water samples taken from wells. The greatest amount of information is available for the shallower portions (less than 10 m below the water table) of the unconfined aquifer system. Fewer wells penetrate the deeper part of the unconfined aquifer system or the basalt confined aquifers. However, the shallower unconfined aquifer is the most likely to be impacted by contaminants migrating through the vadose zone.

G.1.2.2.1 Hydrogeologic units. The lithofacies described by Lindsey (1995) have been regrouped into nine hydrogeologic units based on similarity in expected groundwater flow properties. Flow properties generally correlate to texture, sorting, and degree of cementation. Other geologic factors such as depositional environment, lithologic composition, and time of deposition were not considered in defining hydrogeologic units for the model. Therefore, the grouping of lithofacies was similar but not identical to that of Lindsey (1995). Hydrogeologic units defined for the conceptual model were designated by numbers. A graphical comparison of the groundwater conceptual model units with Lindsey's stratigraphic column is shown in Figure G-34. Odd-numbered units are predominantly coarse-grained sediments. Even-numbered units are predominantly fine-grained sediments with low permeability.

The Hanford formation, combined with the pre-Missoula gravel deposits, was designated as model Unit 1. Units 2 and 3 correspond to the early Palouse soil and the Plio-Pleistocene unit, respectively. The predominantly mud facies of Lindsey's upper Ringold was designated as

Figure G-34. Comparison of Hanford Conceptual Model Hydrostratigraphic Units with Stratigraphy.



Unit 4. However, a difference in the model units is that the lower, predominantly sand portion of Lindsey's upper Ringold was grouped with Unit 5, which also includes Lindsey's Ringold gravel Units E and C. Part of Lindsey's lower mud unit was designated as Unit 6. However, sandy portions of Lindsey's lower mud unit were assigned to Unit 7, which also includes Lindsey's gravel Units B and D. Portions of the lower mud that occur below Unit 7 were designated as Unit 8. Gravels of Lindsey's Unit A were designated as Unit 9.

Figure G-35 shows the distribution of wells used to define hydrogeologic structure for the groundwater conceptual model. Figures G-36, G-37, and G-38 show cross-sections of the Hanford Site delineating the conceptual model hydrogeologic units and the 1997 water table. Cross-section locations are shown in Figure G-35. The water table lies within the Hanford formation over most of the eastern and northern parts of the Hanford Site. The Hanford formation lies entirely above the water table in the western part of the Hanford Site and in some other localized areas. Figure G-39 is a map showing which hydrogeologic unit contains the 1997 water table over the Hanford Site.

G.1.3.2.2 Hydraulic and transport properties. To predict groundwater flow, the distribution of hydraulic properties, including both horizontal and vertical hydraulic conductivity, storativity, and specific yield, were needed for each hydrogeologic unit defined in the model. In addition, to simulate movement of contaminant plumes, transport properties including contaminant-specific K_ds, bulk density, effective porosity, and longitudinal and transverse dispersivities are needed. Hydraulic and transport properties are documented in DOE (1988a), Graham et al. (1981), Thorne and Newcomer (1992), Connelly et al. (1992a, 1992b), Thorne et al. (1993, 1994), Wurstner (1995), Cole et al. (1997), and other project-specific reports.

Transmissivity (the product of hydraulic conductivity and aquifer thickness) and storage information for the unconfined aquifer system has been obtained primarily from aquifer pumping tests and slug tests conduced at wells. Hydraulic conductivity has also been determined from laboratory tests of sediment samples. Values determined from aquifer pumping tests and slug-interference tests (Spane 1993; Spane and Thorne 1995) are considered to be more reliable than single-well slug tests or laboratory measurements. Transmissivity values from these types of tests were applied to an inverse flow model to develop a transmissivity distribution for the Hanford Site (Jacobson and Freshley 1990; Wurstner et al. 1995, Cole et al. 1997). Hydraulic 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 et al. (1997). Figure G-40 shows the distribution of transmissivity data from aquifer pumping tests and slug-interference tests. Figure G-41 shows the distribution of transmissivity determined from inverse flow modeling. Aquifer transmissivity is relatively high in the area between Gable Mountain and Gable Butte, and in the central part of the Hanford Site. Coarse-grained Hanford formation sediments with relatively high hydraulic conductivity are present below the water table in these areas, and the aquifer is relatively thick in the central part of the site.

Figure G-42 shows the range of hydraulic conductivity values calculated by dividing the measured transmissivity by the aquifer thickness. The areal distribution of hydraulic conductivity for the uppermost saturated unit across the Hanford Site is shown in Figure G-43.

Figure G-35. Distribution of Wells Used to Define Hydrogeologic Structure and Cross-Section Locations.

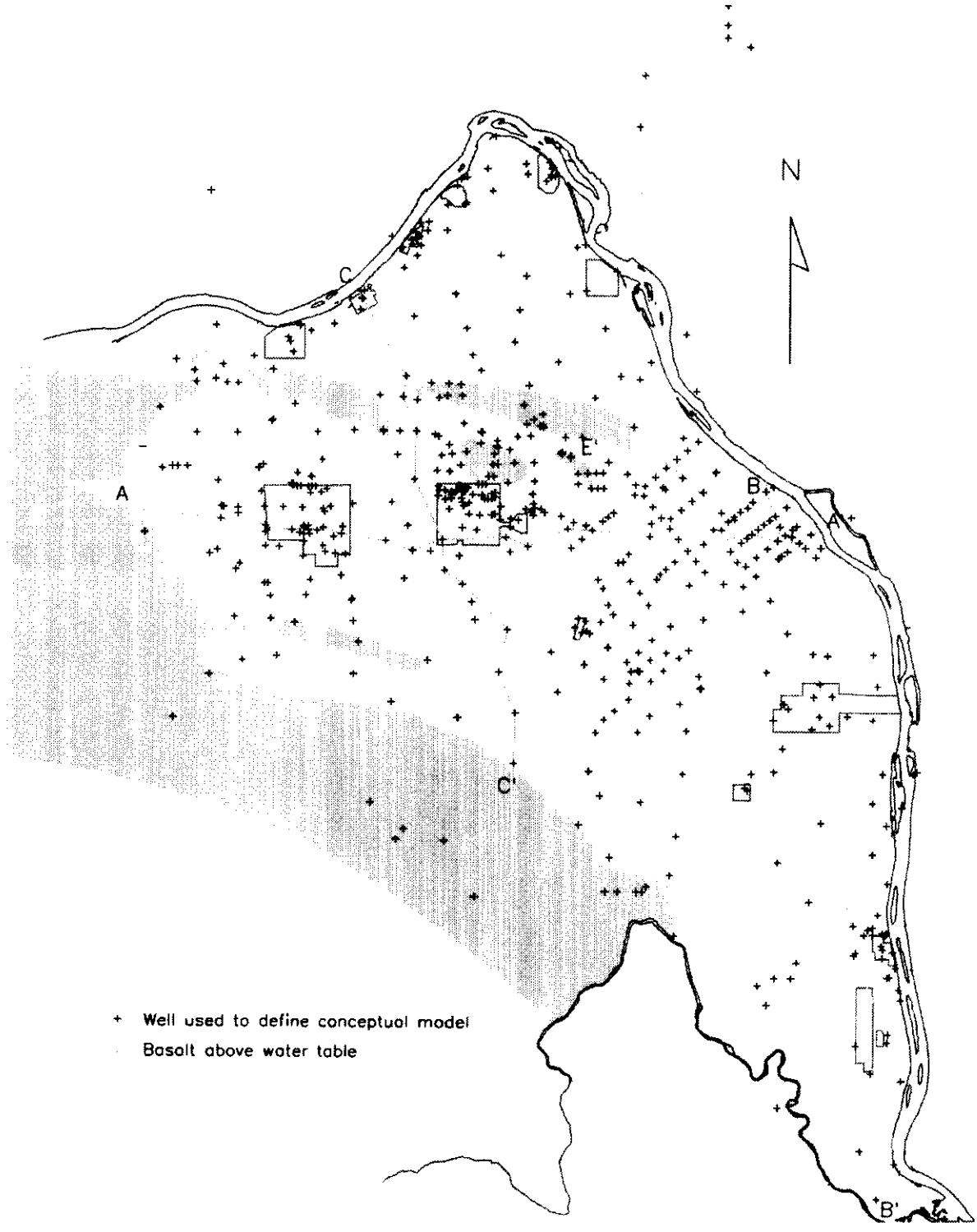


Figure G-36. East-West Cross-Section (A-A) of Hydrogeologic Units of the Hanford Site.

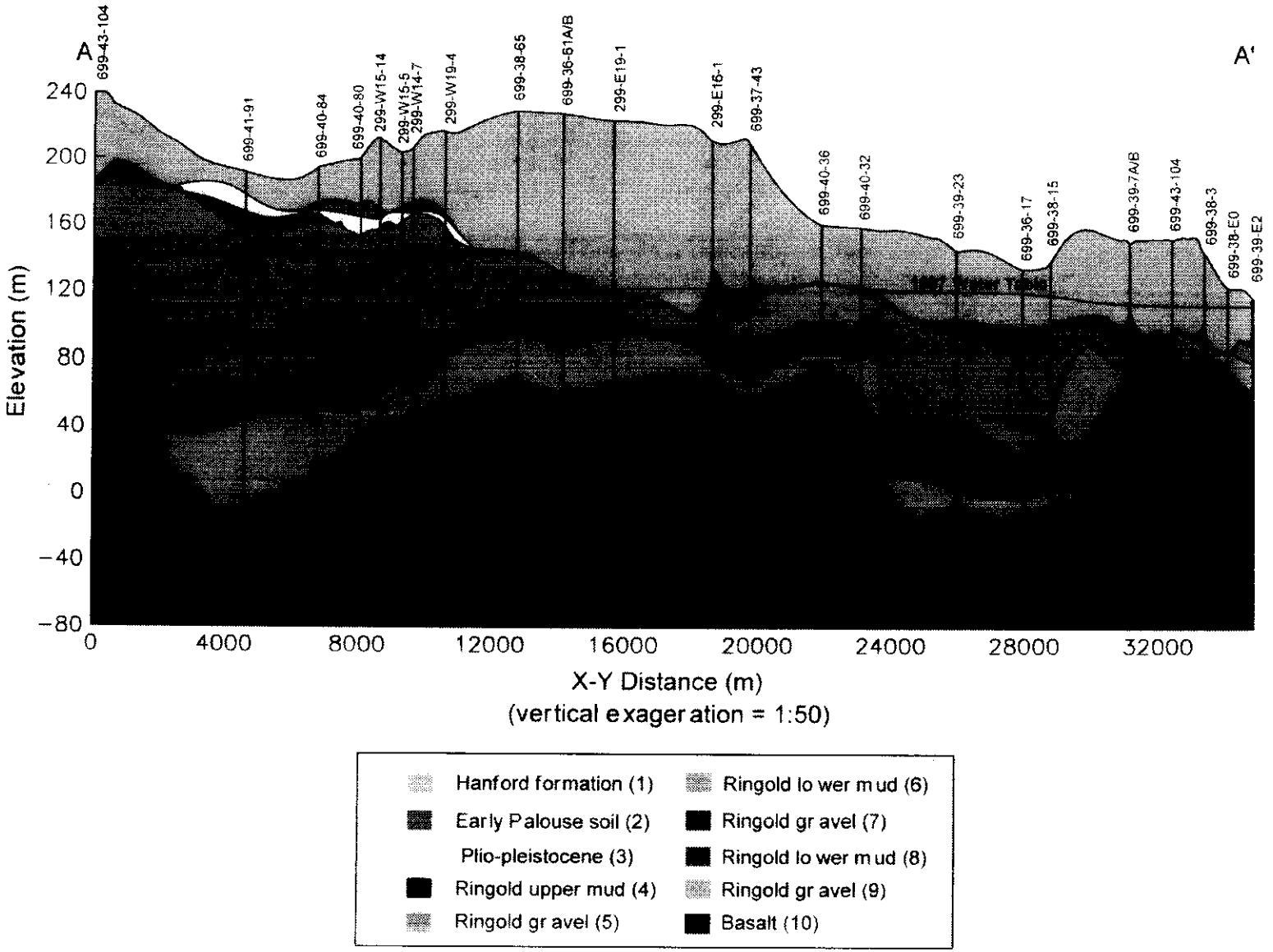


Figure G-37. North-South Cross-Section (B-B) of Hydrogeologic Units Along the Eastern Portion of the Hanford Site.

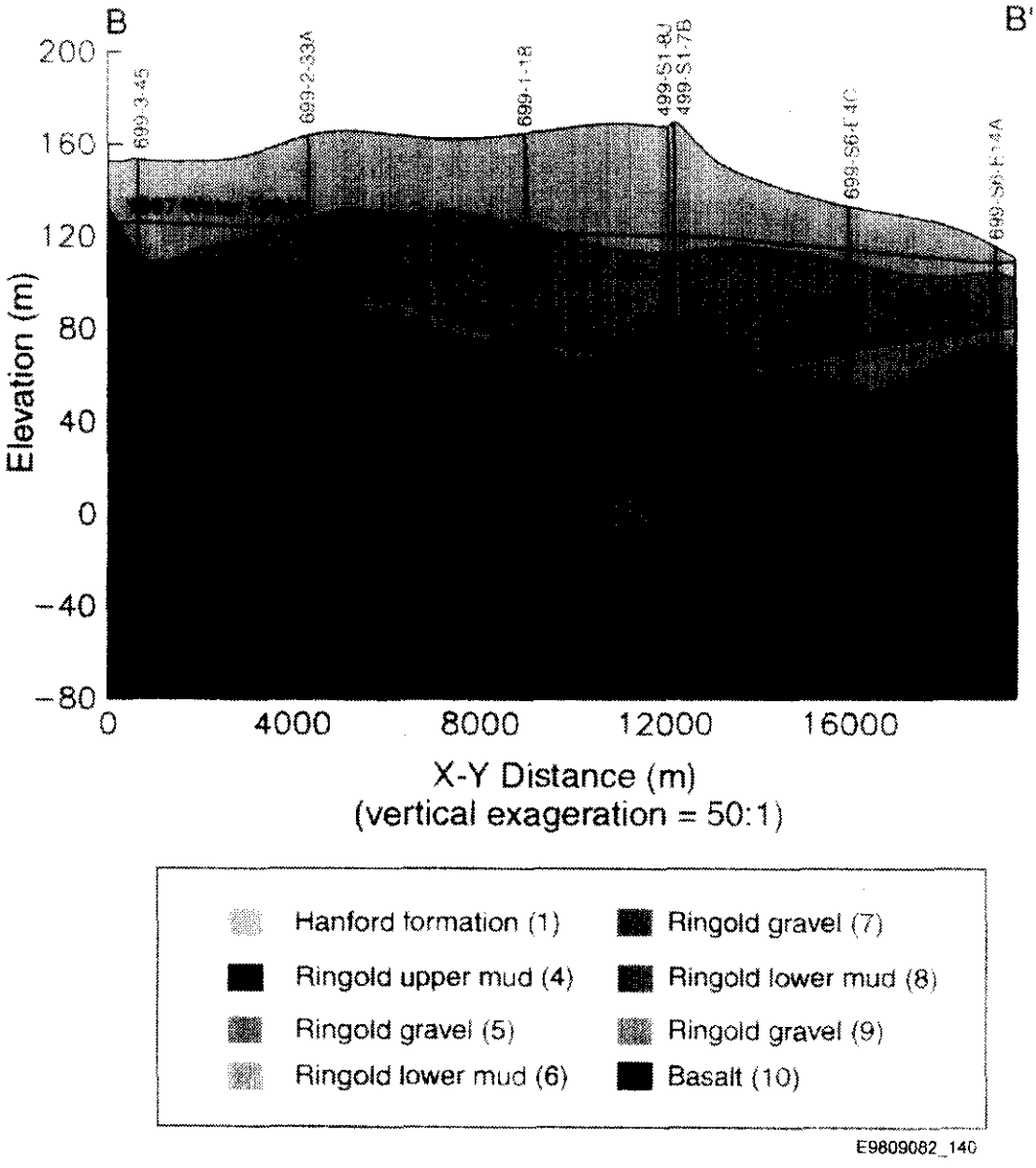


Figure G-38. North-South Cross-Section (C-C) of Hydrogeologic Units Through the Central Portion of the Hanford Site.

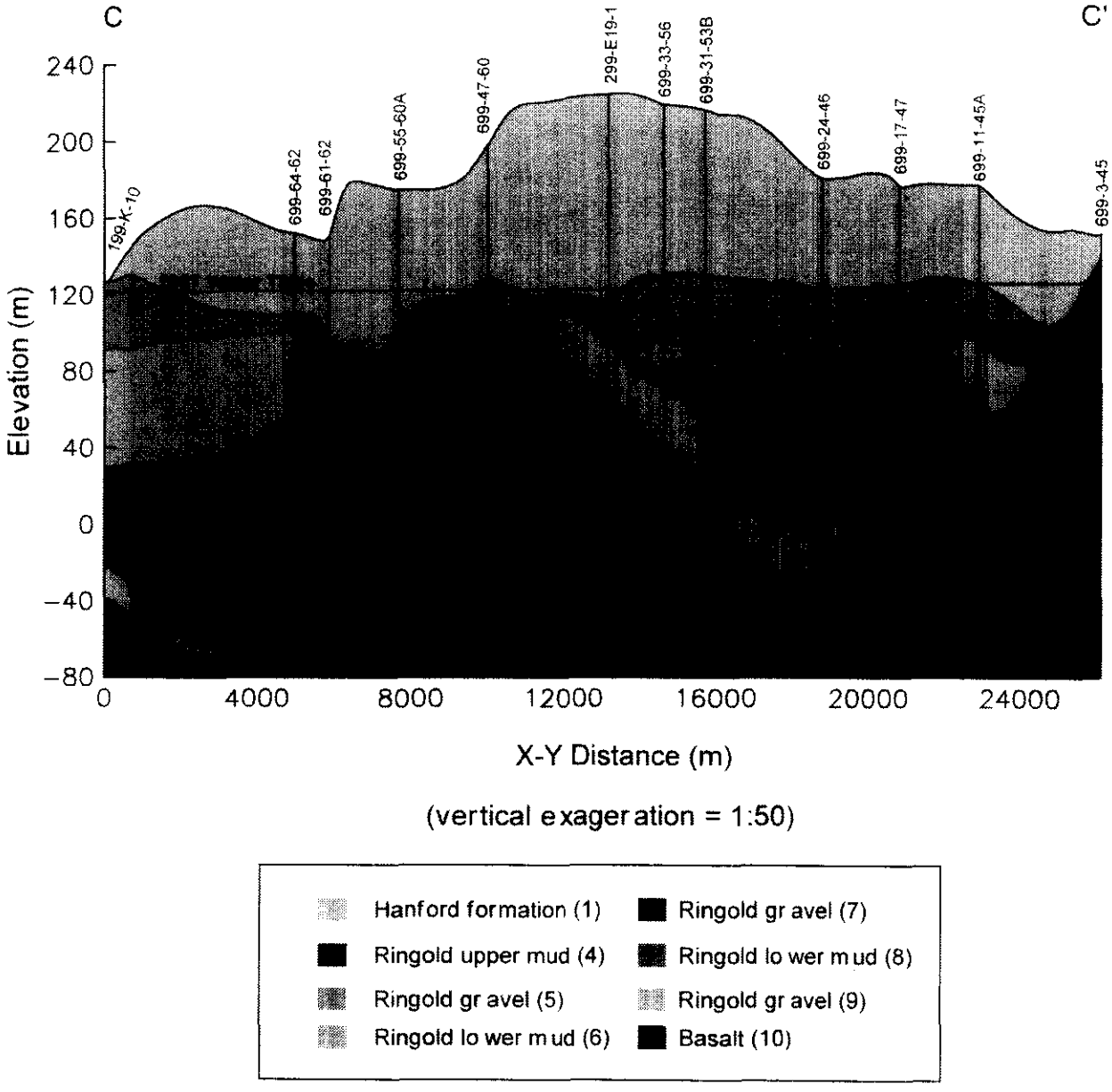


Figure G-39. Hydrogeologic Units Intersected by Water Table (1997).

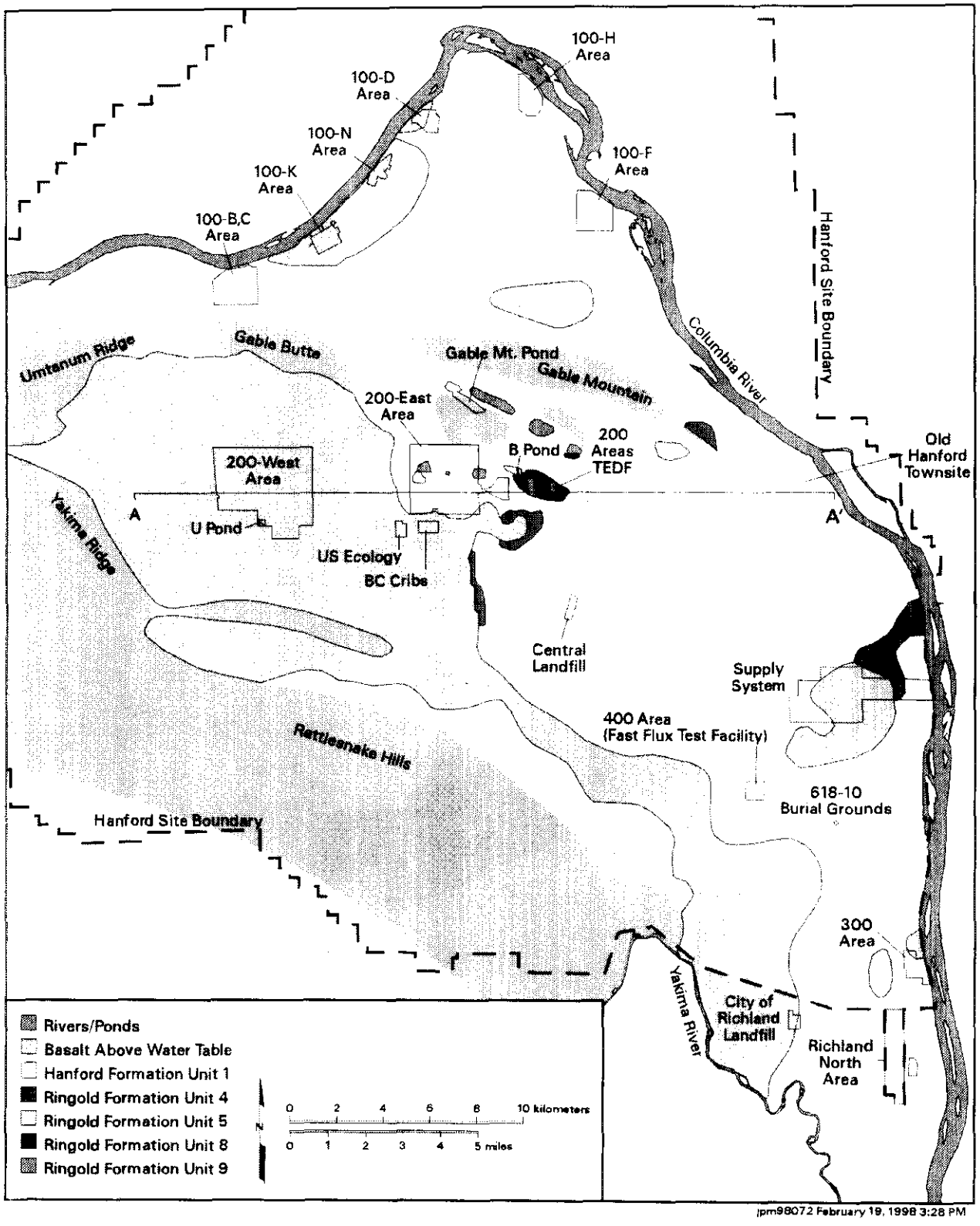
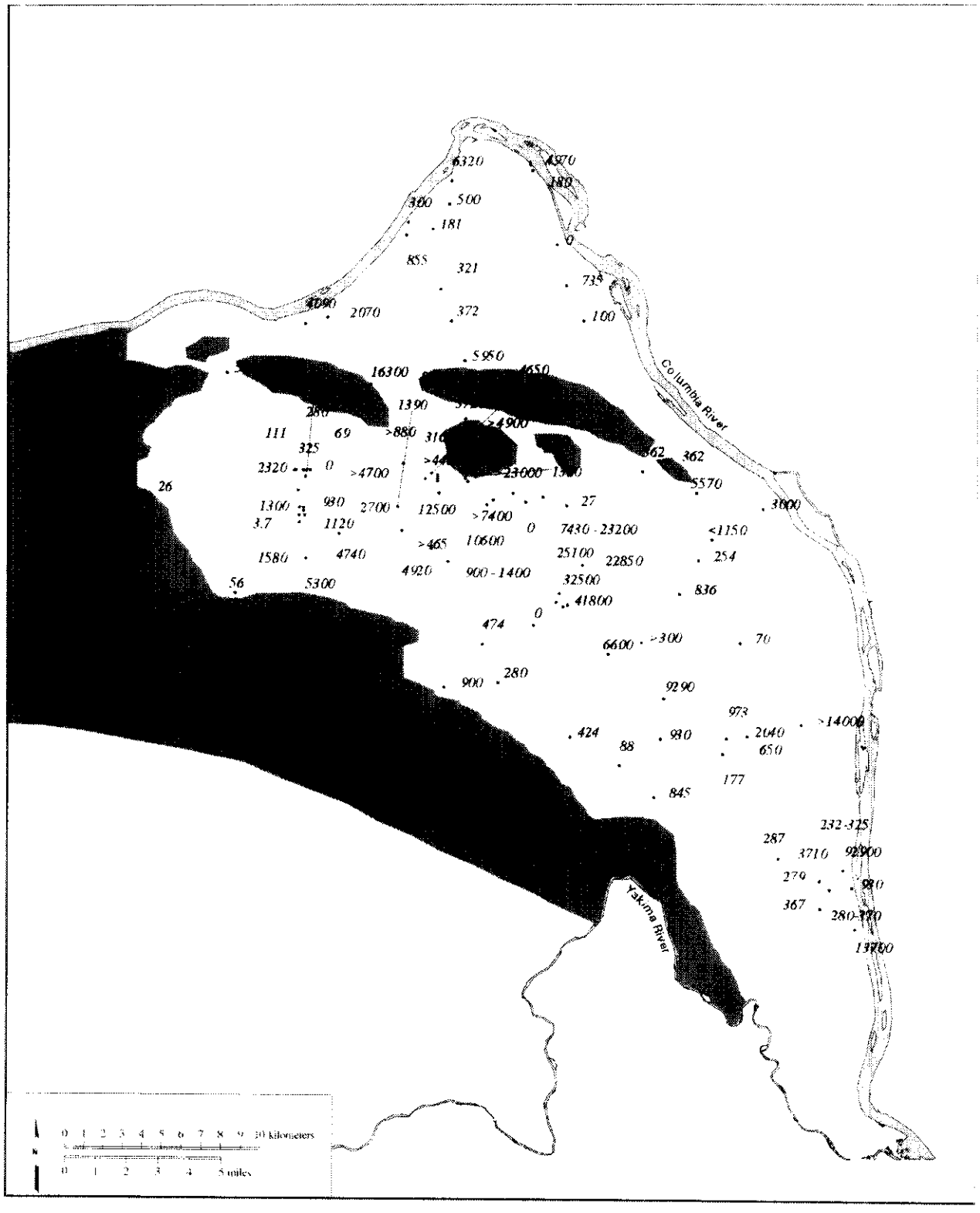


Figure G-40. Areal Distribution of Transmissivity Data.



skw98002.eps January 02, 1998

Figure G-41. Transmissivity Distribution from Model Calibration.

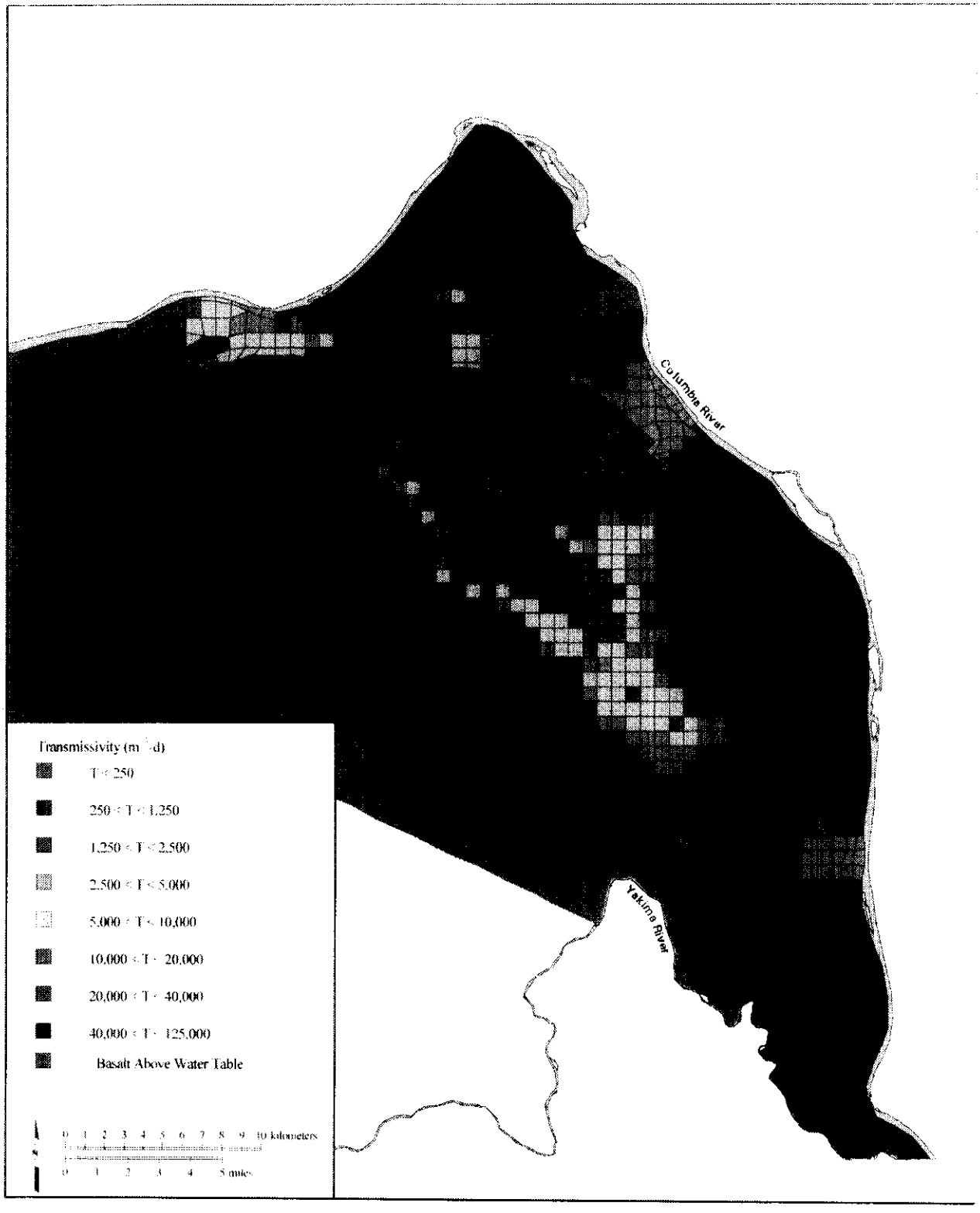


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Figure G-42. Range of Hydraulic Conductivities.

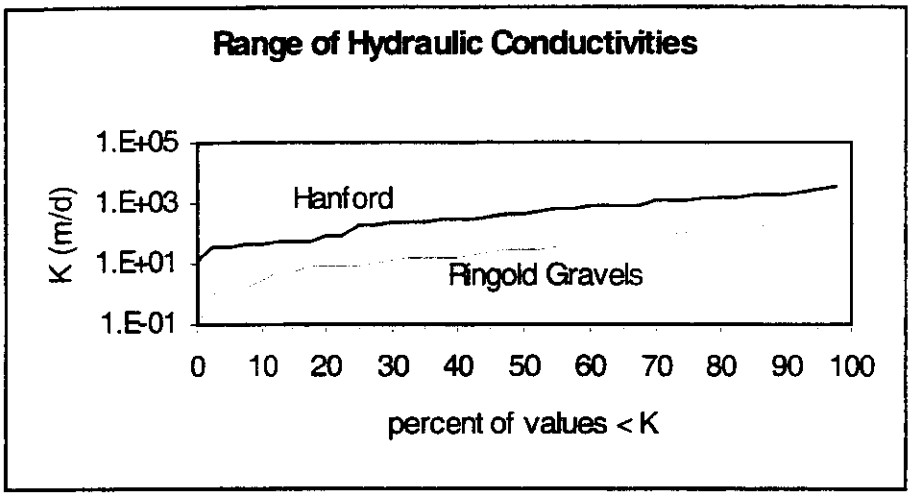
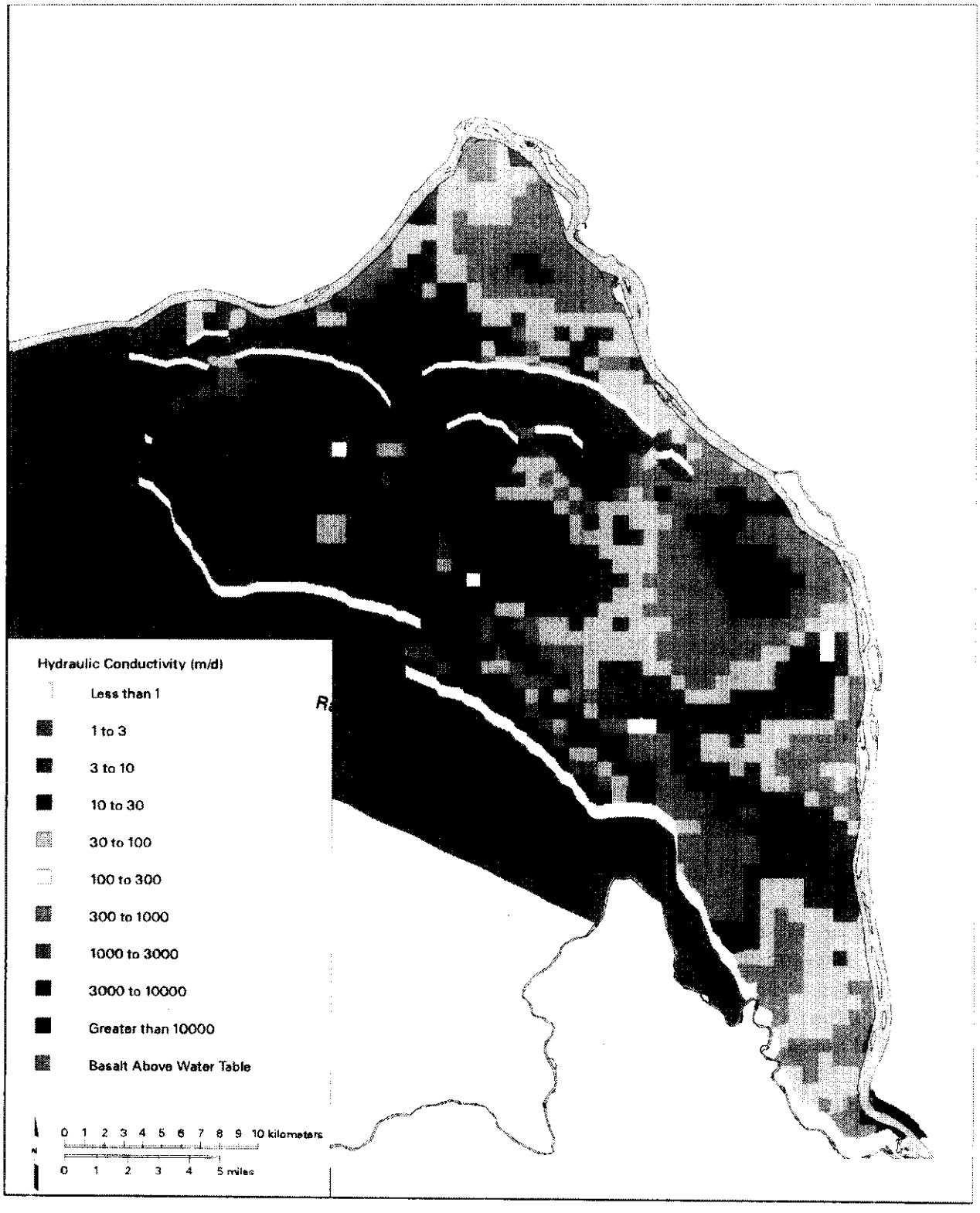


Figure G-43. Hydraulic Conductivity Distribution in the Uppermost Hydrogeologic Units of the 3-Dimensional Model.



97skw022.eps October 21, 1997

Hydraulic conductivity of the Hanford formation is generally an order of magnitude greater than the hydraulic conductivity of the Ringold Formation. However, measured hydraulic conductivity of both of these units varies laterally by more than two orders of magnitude. This is a result of aquifer heterogeneity. The aquifer also displays vertical anisotropy. Results of a few multiple-well aquifer tests suggest that the ratio of vertical to horizontal hydraulic conductivity is in the range of 0.01 to 0.1. Because Hanford formation sediments are so much more permeable than Ringold sediments, the Hanford formation tends to dominate groundwater flow where the water table is in the Hanford formation.

Less reliable data are available on aquifer storage properties because they are difficult to measure accurately. Only multiple-well aquifer tests provide valid estimates, and these are affected by nonideal aquifer conditions and well configuration (Spane 1993). Measured aquifer storage properties are documented in Wurstner et al. (1995). Specific yield was estimated to range from 0.1 to 0.3 for the Hanford formation and from 0.05 to 0.2 for Ringold Formation gravel units. Storativity was estimated to range from 0.0001 to 0.0005 for the Hanford formation and from 0.0001 to 0.001 for Ringold Formation gravels.

Wurstner et al. (1995) and Cole et al. (1997) provide information on transport properties used in past modeling studies at the Hanford Site. Transport parameters, including effective porosity and longitudinal and transverse dispersivities, are also needed for transport simulations. Effective porosity was set equal to specific yield for the unconfined aquifer (e.g., 0.1 for the Ringold Formation and 0.25 for the Hanford formation). Dispersivity is theoretically expected to have an asymptotic value that can be related to the scale of uncharacterized aquifer heterogeneity (Farmer 1986). In contaminant transport simulations, large values of dispersivity result in lower peak concentration estimates, but give rise to earlier first arrival times that can increase arrival concentrations of radionuclides with short half-lives. For the Composite Analysis (Kincaid et al. 1998), a longitudinal dispersivity of 95 m and a transverse dispersivity of 20 m were selected. Dispersivity and the basis for this selection is discussed in detail in Kincaid et al. (1998). Distribution coefficients for various contaminants in the Hanford Site unconfined aquifer system have been determined from laboratory tests and from the literature. These quantities are affected by water chemistry, grain size, and mineralogy. The selection of K_ds and bulk densities for application in model is discussed in detail in Cole et al. (1997) and Kincaid et al. (1998).

G.1.3.2.3 Aquifer boundaries. Peripheral boundaries for the Hanford Site unconfined aquifer system are formed by the Columbia River on the north and east and by basalt ridges and the Yakima River on the south and west. At the Cold Creek and Dry Creek Valleys, the unconfined aquifer extends westward beyond the boundary of the Hanford Site. The Columbia River represents a point of regional discharge for the unconfined aquifer. The amount of groundwater discharging to the river is a function of local hydraulic gradient between groundwater elevation alongside and beneath the river. This hydraulic gradient is highly variable because the river stage is affected by seasonal variations in precipitation and runoff in other regions of the river drainage system. The river stage is also impacted by weekly and daily changes in river flows caused by dam operations. Because the stage elevation of the Yakima River is higher than the water table in the adjacent aquifer, it represents a potential source of recharge in the southern part of the Hanford Site.

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 largely unquantified, but is postulated to be small relative to the other flow components estimated for the unconfined aquifer system.

G.1.3.2.4 Aquifer recharge and groundwater flow dynamics. Groundwater in the unconfined aquifer generally moves from recharge areas along the western boundary of the site eastward and northward toward the Columbia River, which is a discharge location for the aquifer. However, this flow pattern has been altered locally by the formation of groundwater mounds resulting from wastewater discharge. The direction of groundwater flow is inferred from measurements of hydraulic head in wells. A sitewide network of wells is measured annually for this purpose, and some wells are measured more frequently to track water level fluctuations or to monitor groundwater flow around critical facilities. The water table elevation is mapped and reported in the annual *Hanford Site Groundwater Report* (e.g., Hartman and Dresel 1998). Figure G-44 shows a contour map of water table elevations for the unconfined aquifer for 1997. Figure G-45 shows water table elevations for the upper basalt confined aquifer for 1997.

Natural recharge occurs from infiltration of runoff from elevated regions west of the Hanford Site and infiltration of precipitation falling across the Hanford Site. Other potential sources of natural recharge are the Yakima River and the basalt confined aquifer system. Recharge from the western boundary of the Hanford Site enters primarily from the Cold Creek and Dry Creek drainages. These are ephemeral streams on the Hanford Site. Estimates of combined recharge from the Cold Creek and Dry Creek Valleys have ranged from 0.10 to 0.34 m^3/sec (Law et al. 1986).

Recharge from precipitation across the Hanford Site is highly variable both spatially and temporally, ranging from near zero to more than 100 mm/yr depending on climate, vegetation, and soil texture (Gee et al. 1992; Fayer and Walters 1995). A natural recharge map (Figure G-46) was developed by Fayer and Walters (1995) based on distributions of soil and vegetation types. The average recharge from precipitation across the Hanford Site (901 km [560 mi]) was estimated as 0.27 m^3/sec (0.59 mm/yr).

The total volume of recharge from the Yakima River is not well known. However, low-permeability sediments adjacent to the Yakima River appear to limit leakage into the aquifer. Comparison of Yakima River stage and water levels in an adjacent well showed little correlation (Wurstner et al. 1995).

Another potential source of recharge (or discharge) for the unconfined aquifer system is interaquifer communication with the upper basalt confined aquifers. The volume and distribution of water movement between the aquifer systems has not been quantified. Over most of the site, the amount of interflow is thought to be small because of the low hydraulic conductivity of the basalt separating the two aquifer systems. However, areas of increased vertical communication have been previously identified in the Gable Mountain and Gable Butte

Figure G-44. Water Table Map (June 1997) of the Hanford Site and Outlying Areas.

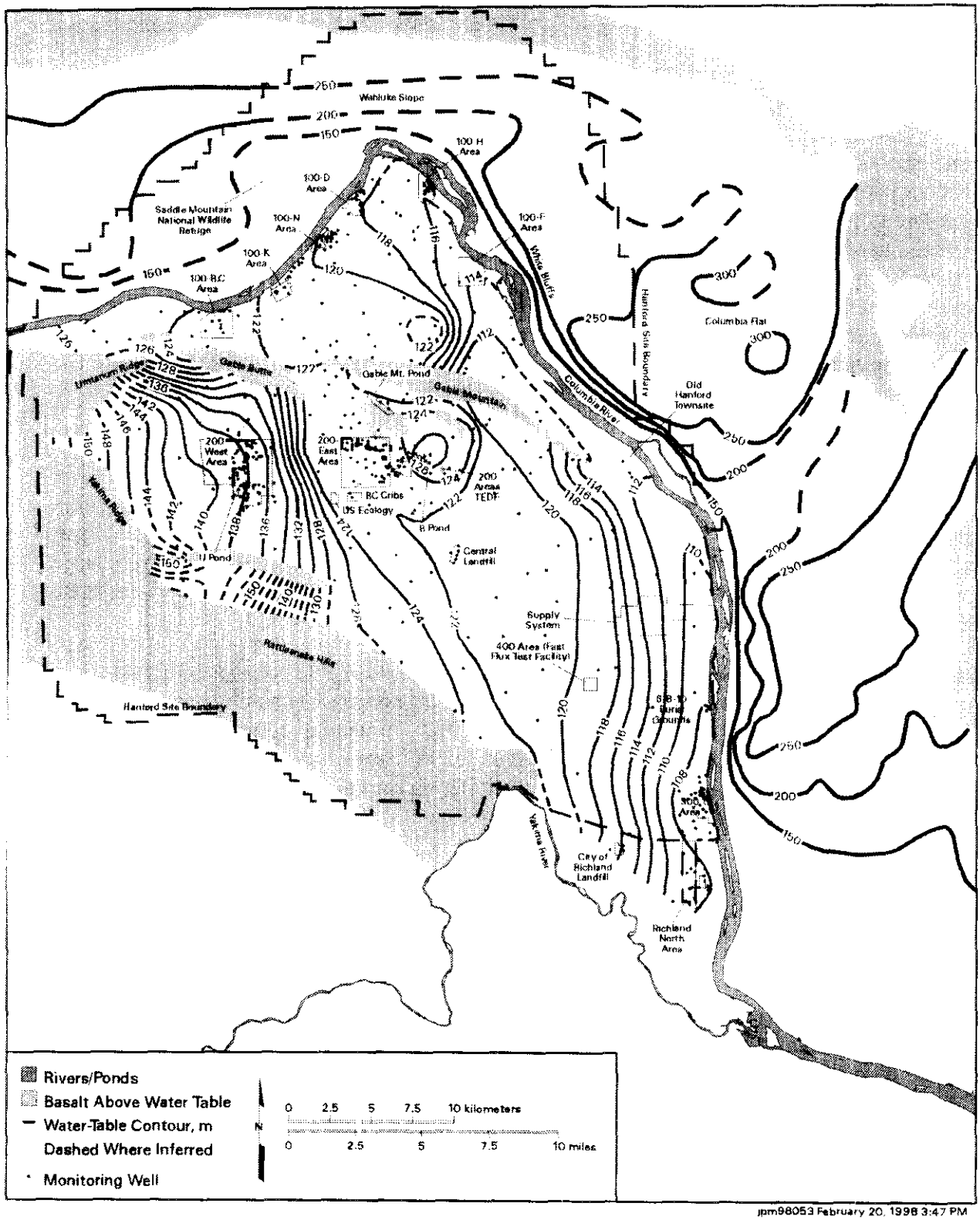


Figure G-45. Potentiometric Map of Upper Basalt Confined Aquifer System (June 1997).

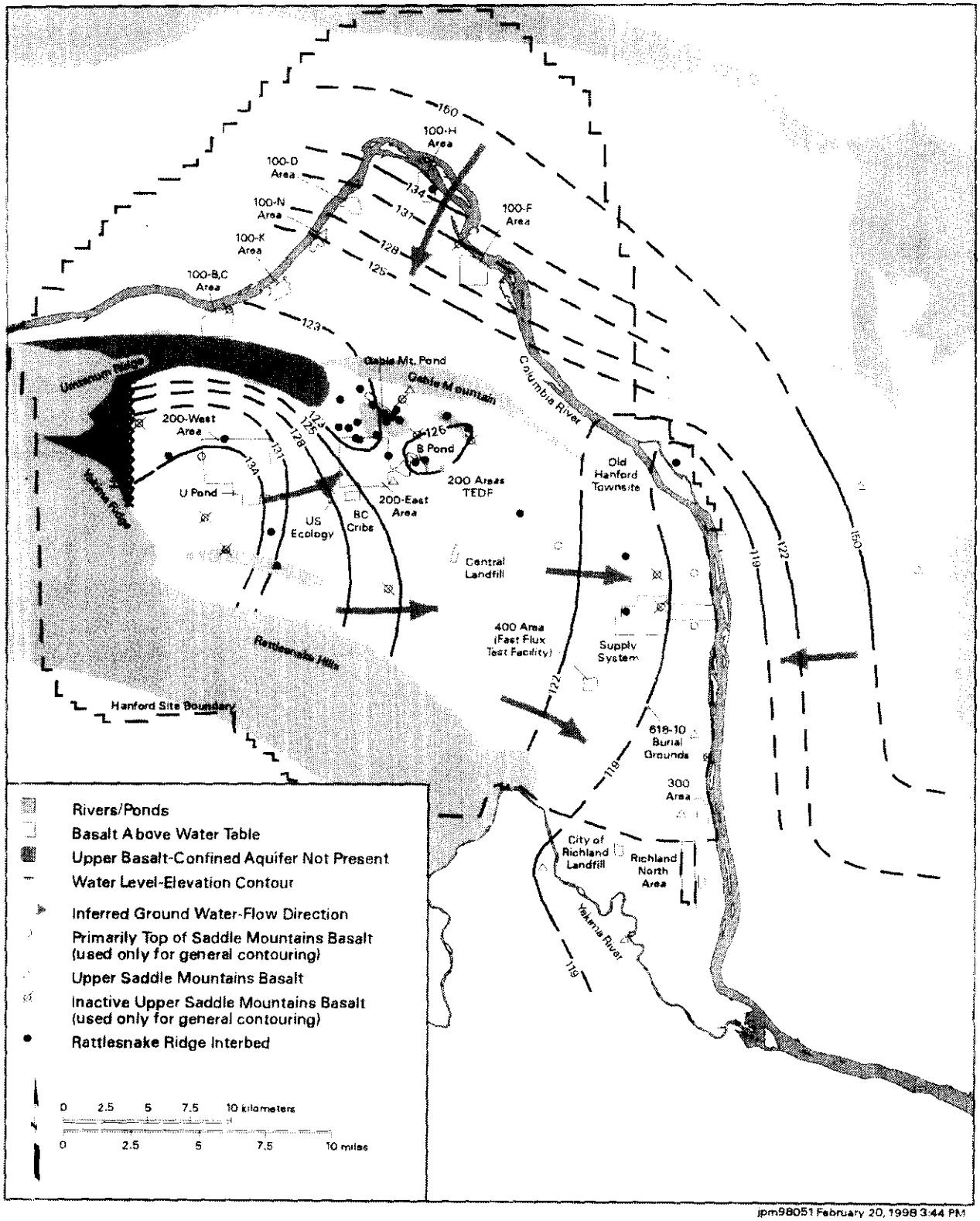
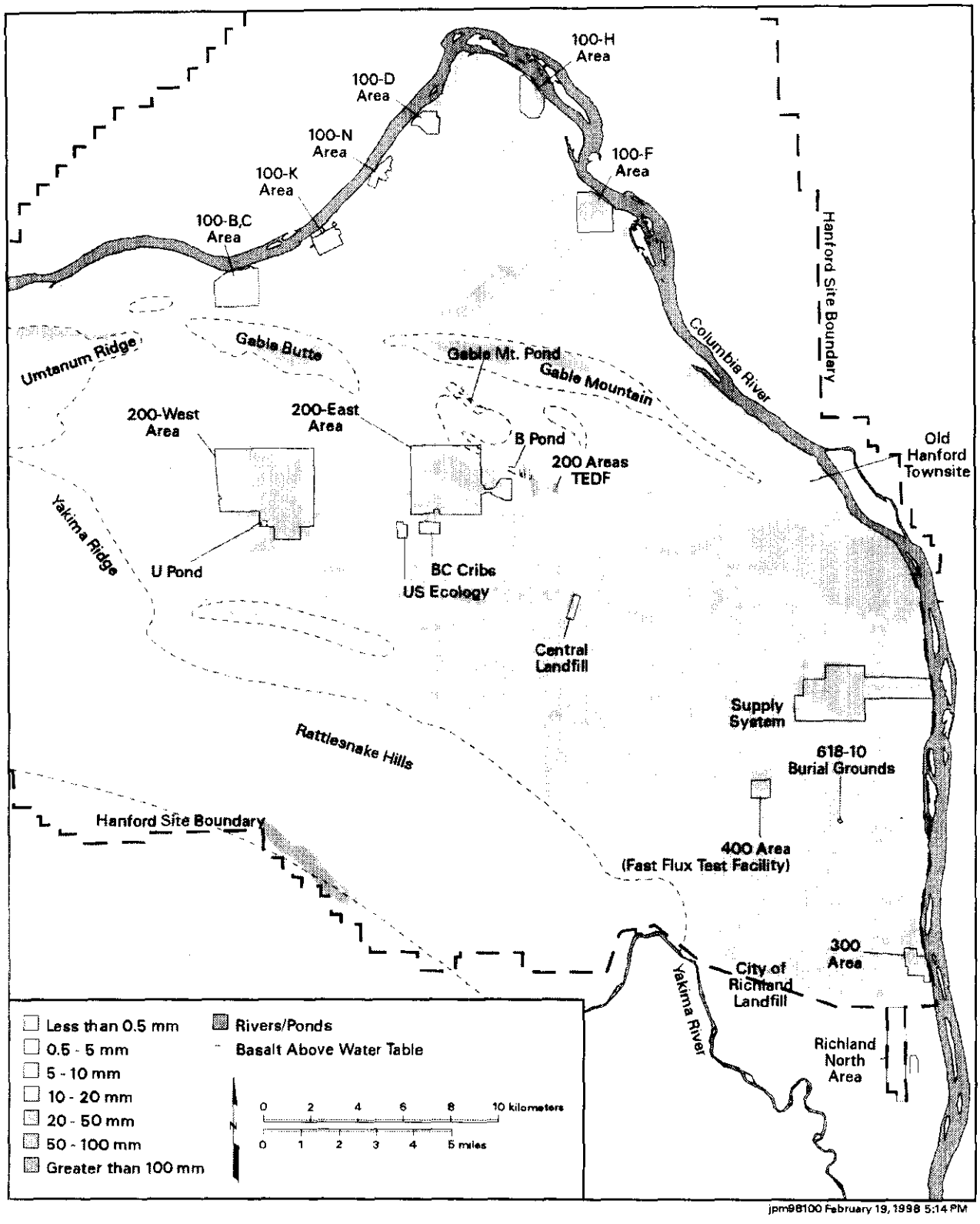


Figure G-46. Estimated Recharge from Precipitation and Irrigation.



area on the basis of chemistry data (Graham et al. 1984; Jensen 1987). The increased communication in the area results from erosional channels that penetrate in the upper basalt confining layer. Hydraulic head data for the uppermost confined basalt aquifer also indicate the potential for water to discharge from this aquifer upward into the unconfined system in the northeastern part of the Hanford Site (Spane and Webber 1995).

Since the start of Hanford Site operations in the mid-1940s, artificial recharge from wastewater disposal facilities has been greater than the estimated recharge from natural sources. Sources and volumes of artificial recharge are summarized in Wurstner et al. (1995). Figure G-47 graphically shows volumes of wastewater discharged in different areas of the Hanford Site since 1945. The disposal of large volumes of wastewater to the ground has caused an increase in the water table elevation over most of the Hanford Site and the formation of groundwater mounds beneath major wastewater disposal facilities. However, during the past 5 years, all production activities on the Hanford Site have been curtailed, resulting in a decrease in wastewater disposal and decreases in water table elevation over much of the Hanford Site. Figure G-48 shows the change in water table elevations between 1944 and 1979, when the water table was near its peak level. Figure G-49 shows the change in table elevations between 1979 and 1995.

G.1.3.2.5 Groundwater contaminant distributions. Groundwater conditions and recent activities are summarized annually in the *Hanford Site Groundwater Monitoring Report* (Hartman and Dresel 1998). Information about groundwater contamination is also included in the annual *Hanford Site Environmental Report* (Dirkes and Hanf 1997). This report integrates the results of monitoring, remediation, and groundwater investigations by all Hanford Site contractors.

Groundwater quality is monitored in more than 700 wells annually. Unconfined aquifer and basalt confined aquifer monitoring wells sampled in 1997 are shown in Figures G-50 and G-51, respectively. The most widespread contaminant plumes are tritium, nitrate, and ^{129}I. Smaller plumes of chromium, fluoride, organic contaminants (carbon tetrachloride, chloroform, trichloroethylene, and cis-1,2-dichloroethylene), ^{14}C, ^{90}Sr, ^{99}Tc, ^{137}Cs, uranium, and plutonium also are present at levels above drinking water standards. The distribution of radionuclide contamination is shown in Figure G-52, and the distribution of chemical contaminants in Figure G-53. The tritium plumes are shown in Figure G-54 between 1964 and 1988. This plume provides insight into characteristics of the groundwater flow.

The vertical distribution of contaminants in the unconfined aquifer has been studied in a limited number of wells, and contaminant concentrations generally are highest near the water table and decrease with depth. The vertical extent of contamination is least well characterized in the source areas where groundwater mounding and possible density-driven flow may have moved contaminants deeper in the aquifer. In certain locations, open boreholes may have provided a conduit for downward contaminant migration. Wells completed in the basalt confined aquifer are also sampled, although the number of these wells is limited. Tritium, cyanide, ^{60}Co, and nitrate have been detected in some of the confined aquifer wells.

The mobility of contaminants in the aquifer is currently estimated from sorption K_ds. K_ds have been estimated by laboratory testing for most of the contaminants found in the groundwater at

Figure G-47. Annual Summary of Volume of Water and Wastewater Discharged to Ground at Hanford Site and City of Richland.

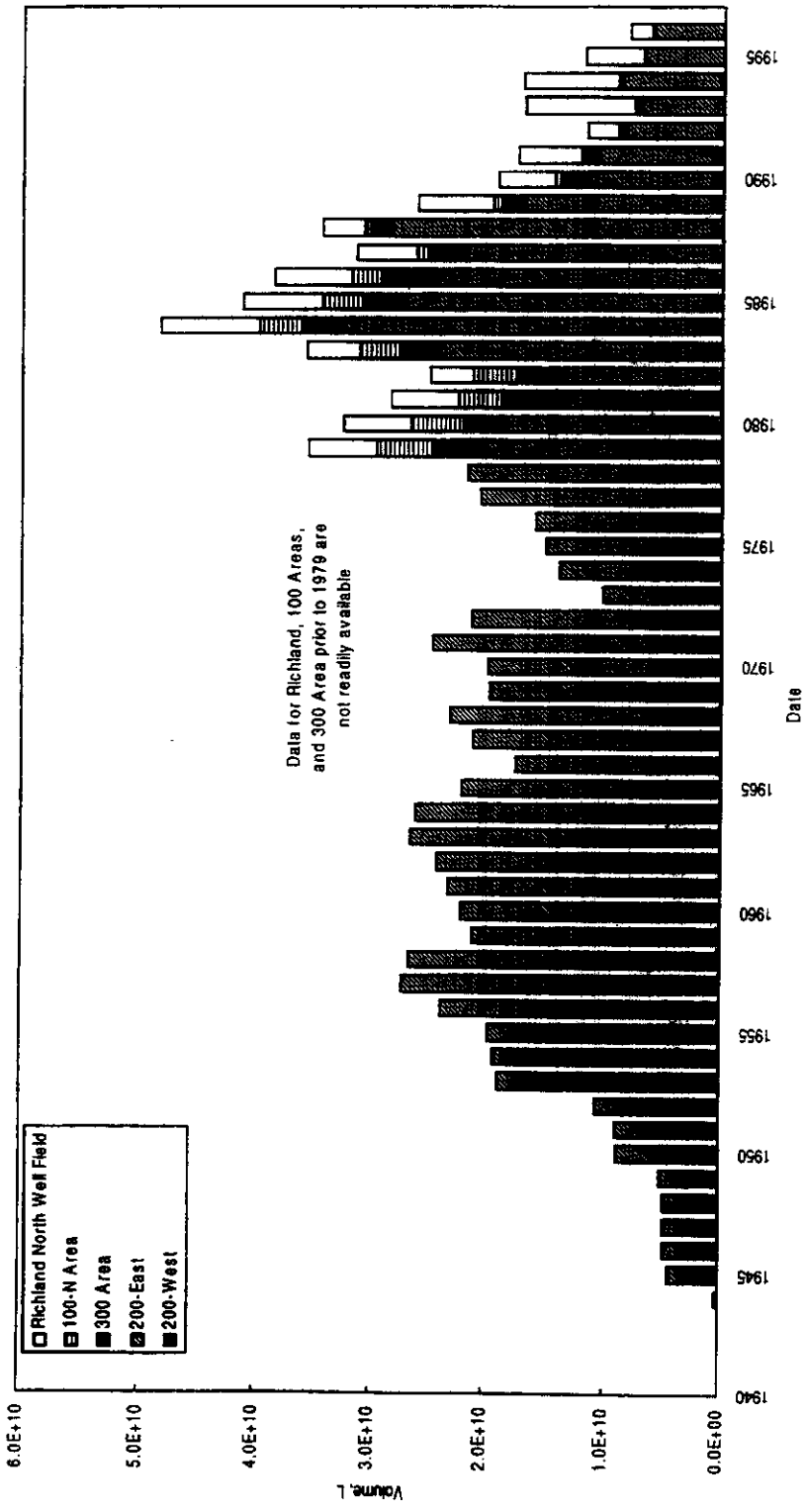


Figure G-48. Rise of Water Table Elevations from 1944-1979.

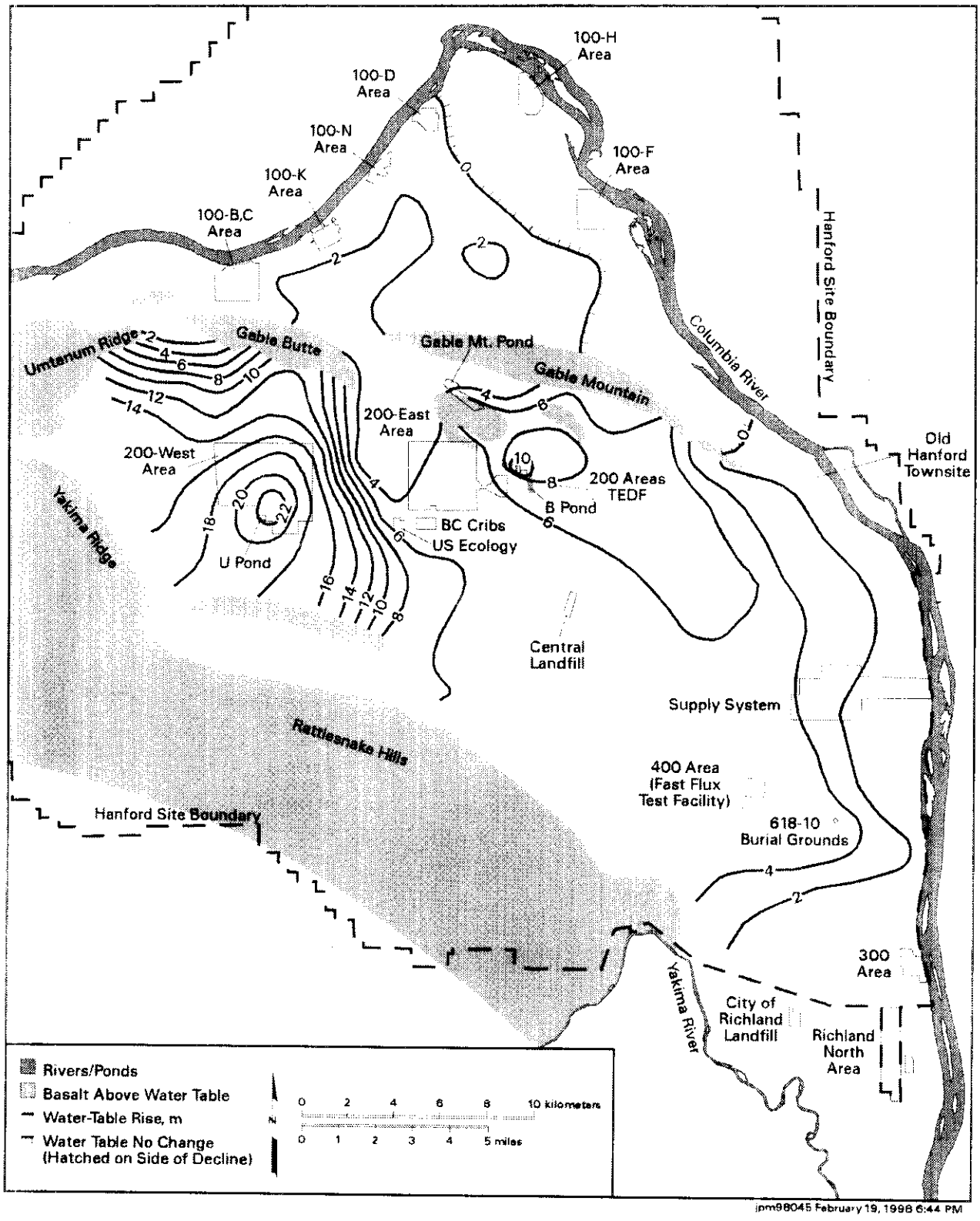


Figure G-49. Decline of Water Table Elevations from 1979-1995.

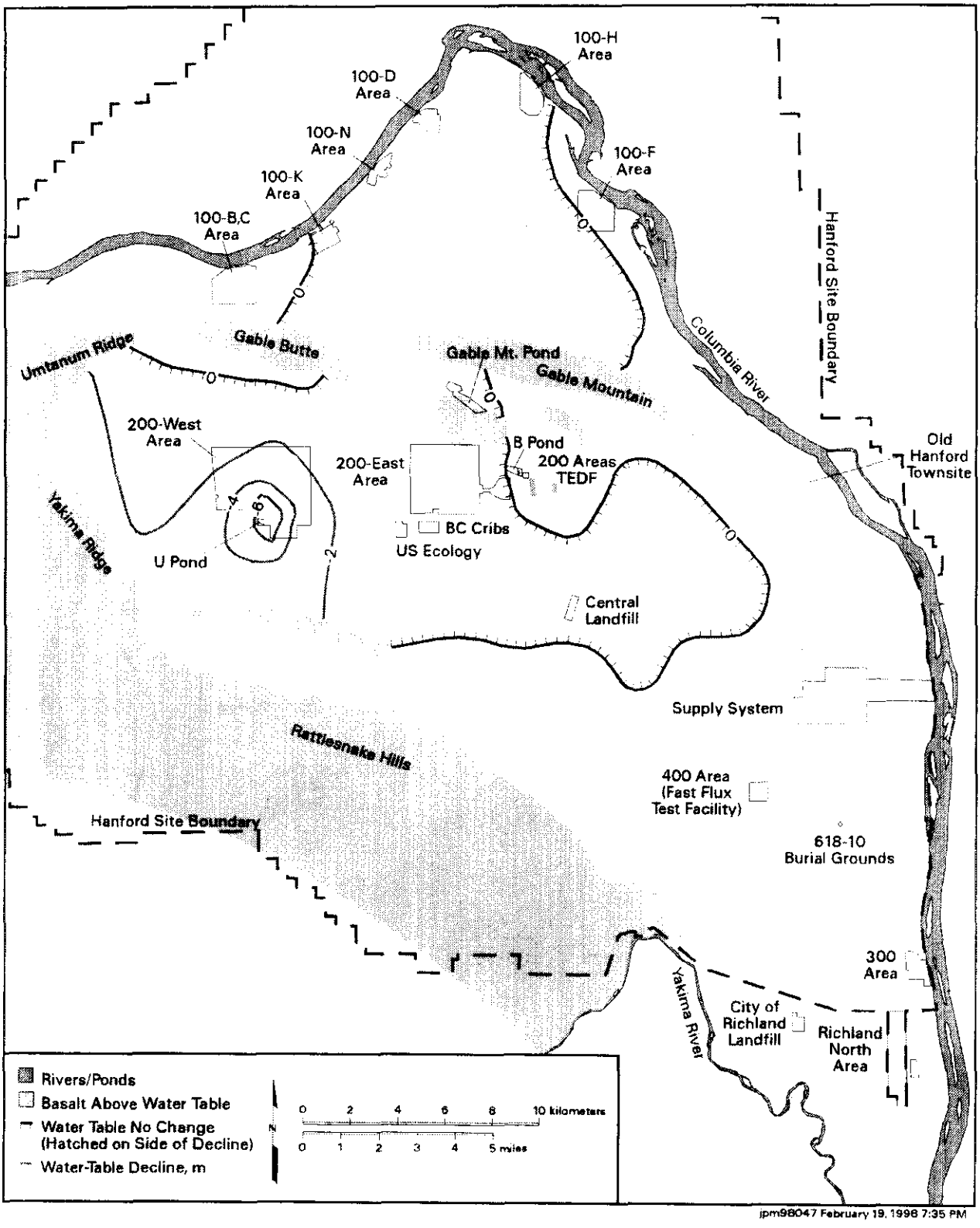


Figure G-50. Location of Unconfined Aquifer Wells Sampled in FY 1997.

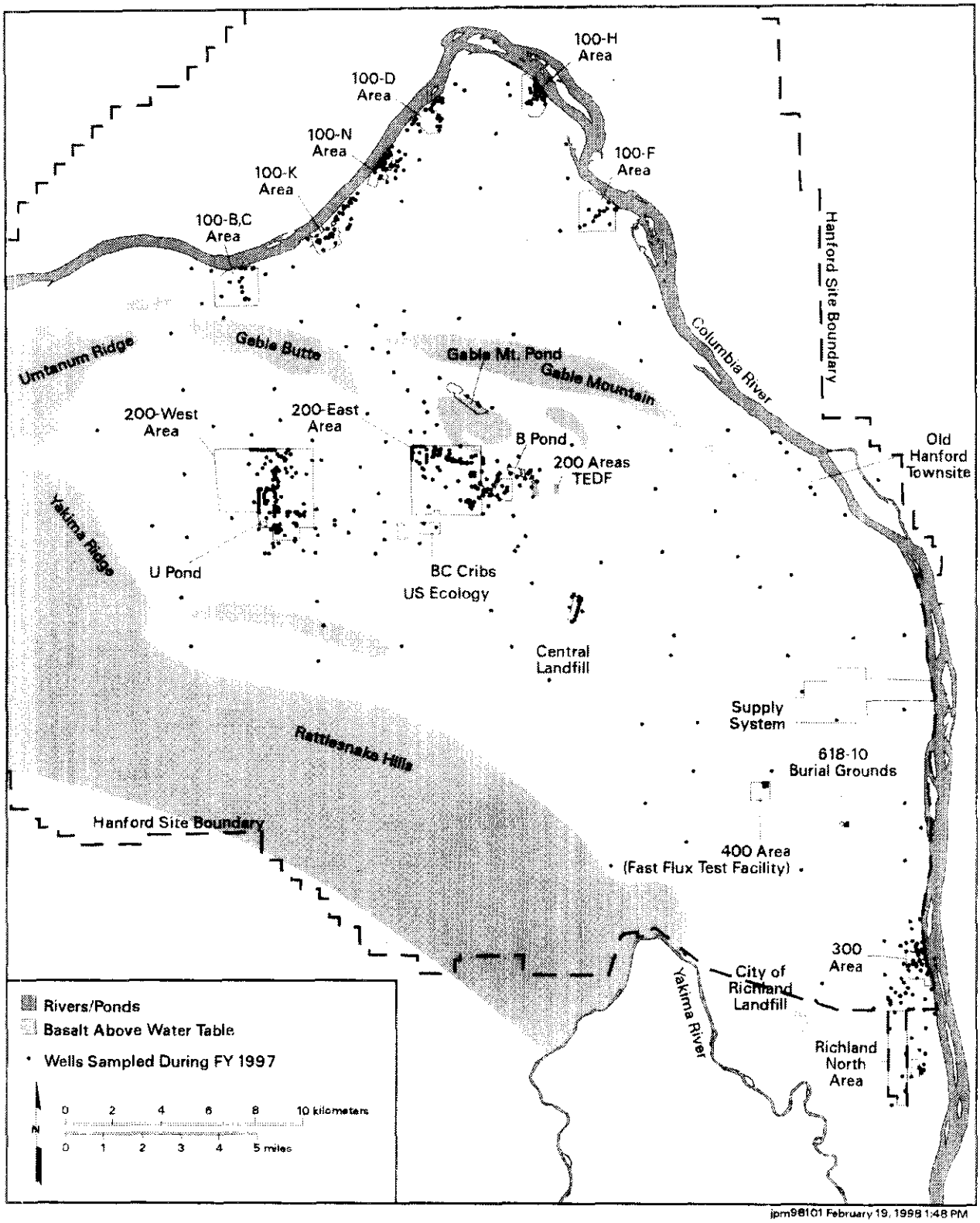


Figure G-51. Location of Confined Aquifer Wells Sampled in FY 1997.

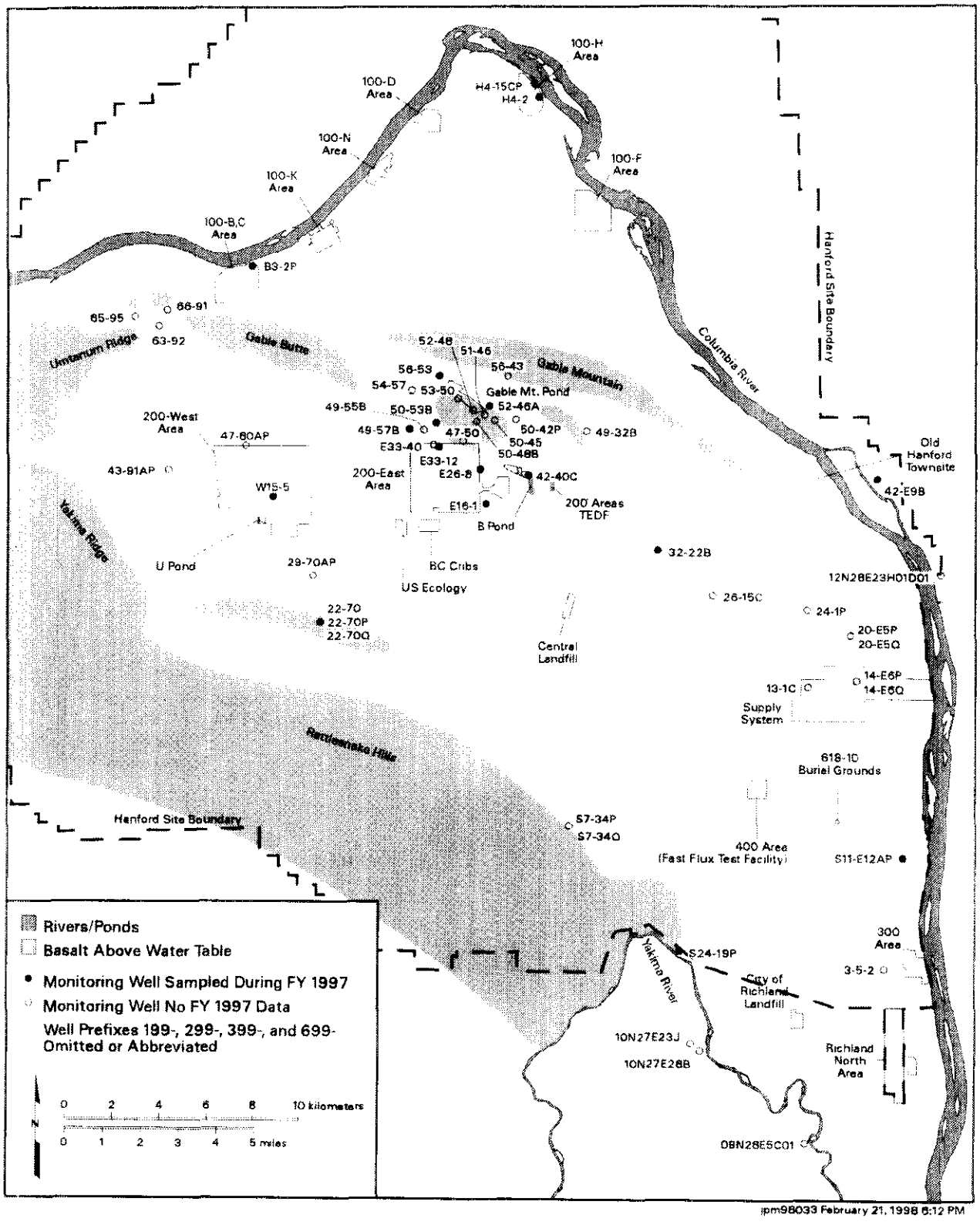


Figure G-52. Distribution of Major Radionuclides in the Unconfined Aquifer.

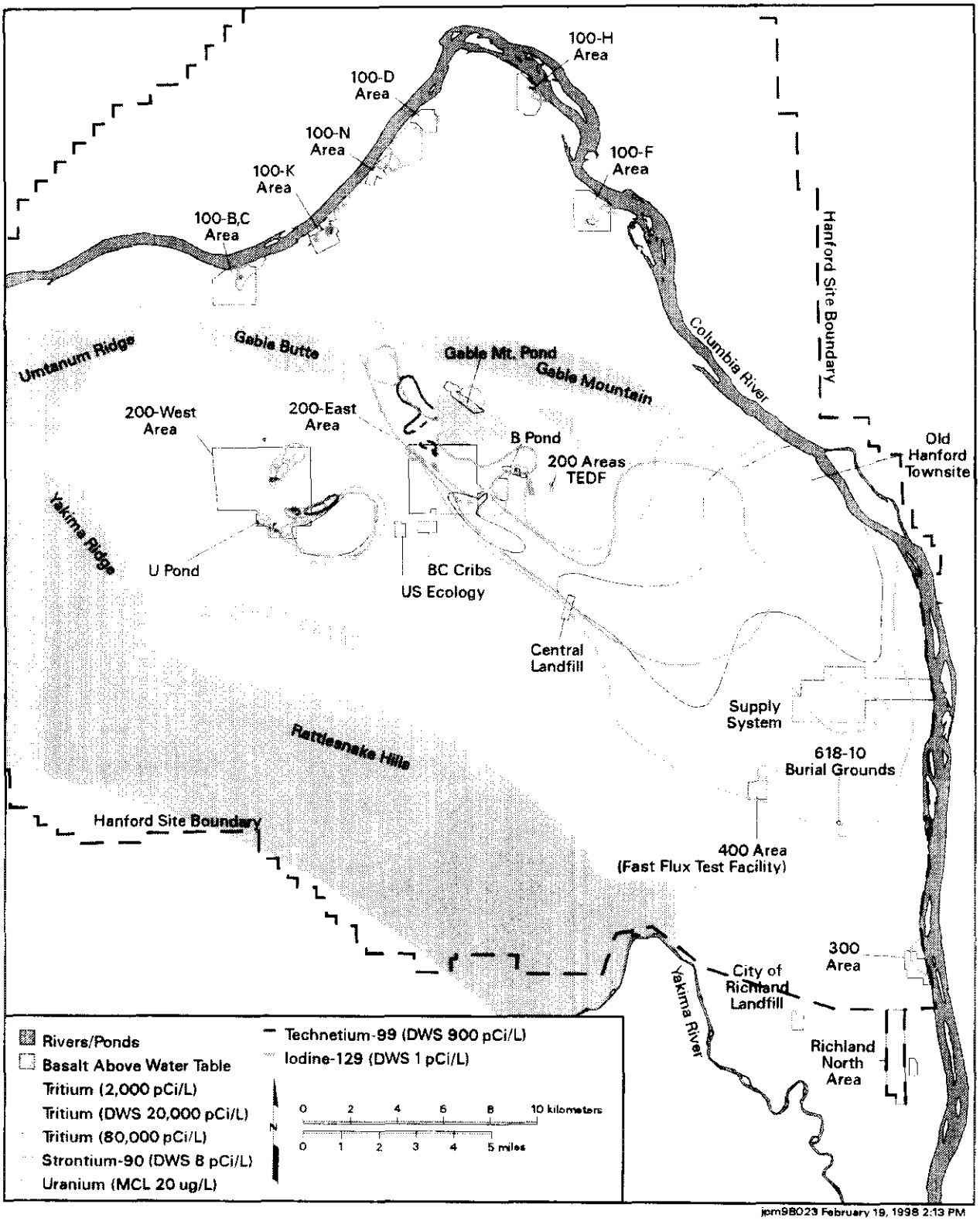


Figure G-53. Distribution of Major Hazardous Chemicals in the Unconfined Aquifer.

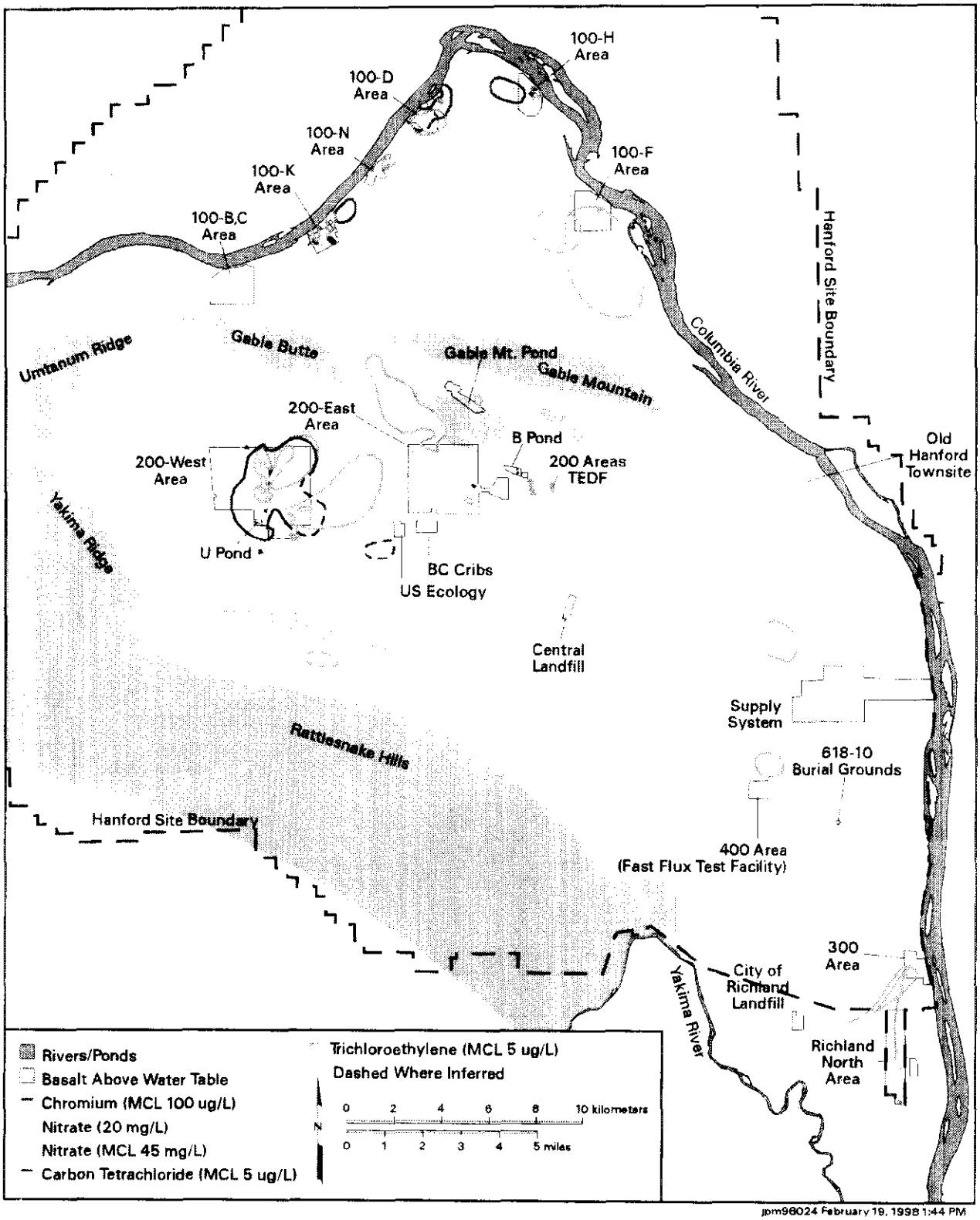
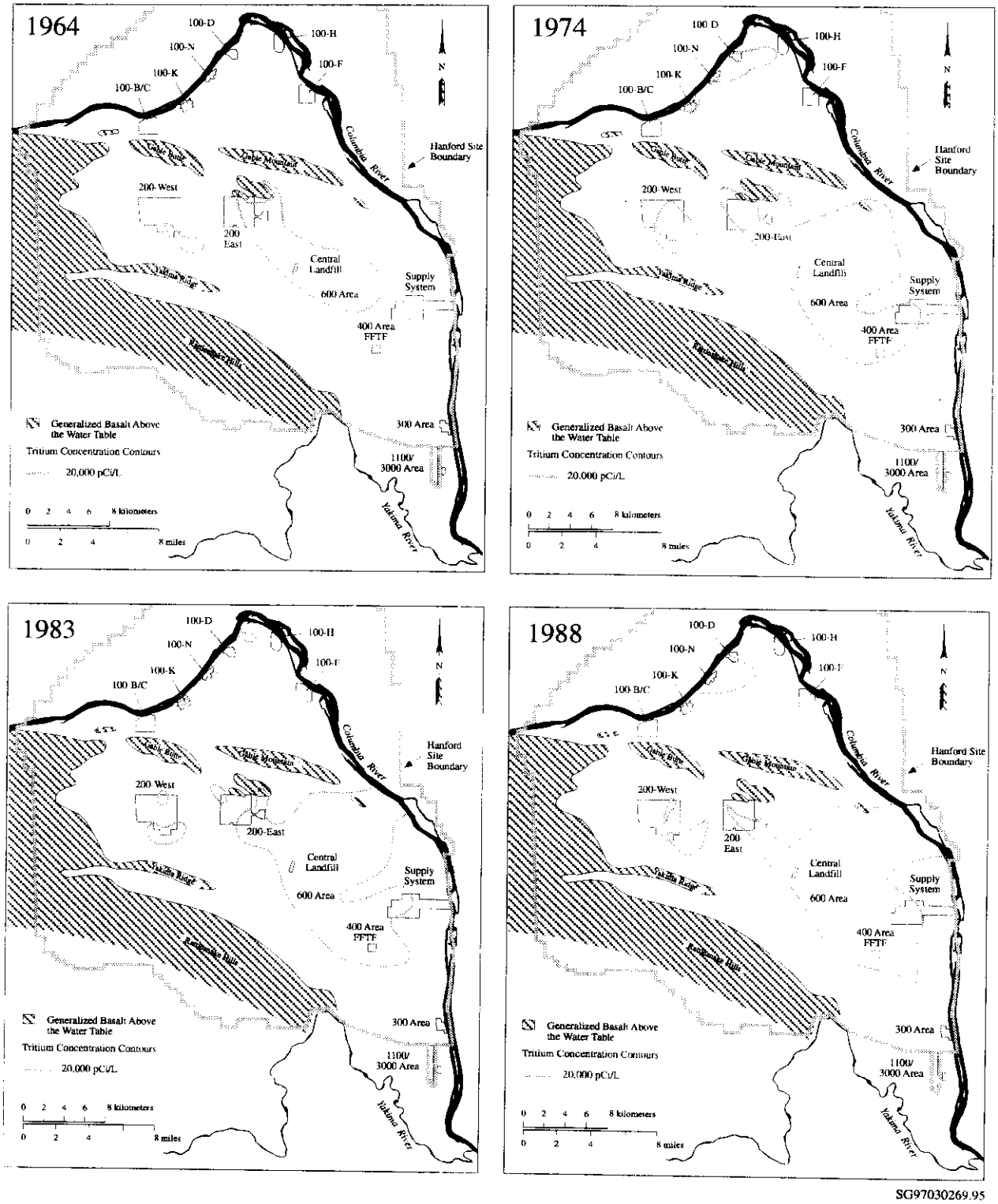


Figure G-54. Tritium Plumes: 1964 Through 1988.



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the Hanford Site (Kincaid et al. 1998). The chemical form, or species, of contaminants also affects mobility. For example, chromate (Cr+6) is much more mobile and more hazardous than Cr+3. Studies in the 100 Areas have shown that most of the chromium in groundwater and discharging to the river is Cr+6. Oxidizing conditions appear to be present in the upper part of the unconfined aquifer, but conditions may be somewhat more reducing deeper in the aquifer. The natural groundwater composition is predominantly calcium bicarbonate-sulfate with slightly alkaline pH and low amounts of dissolved organic matter. The dominant complexing agents for contaminants are carbonate and sulfate, although study of the influence of natural organic and co-disposed manmade organic ligands merits further study. Contaminant transport may also be influenced by colloidal transport of sorbed constituents. The most recent compilation of K_ds for application on Hanford Site problems was done as part of the composite analysis and is provided in Appendix E.

100 Areas Hydrology

The hydrology of the 100 Areas is unique because of their location adjacent to the Columbia River. The water table ranges in depth from near 0 m at the river edge to 30 m. The groundwater flow direction is generally toward the Columbia River. However, during high river stage, the flow direction may reverse immediately adjacent to the river. The unconfined aquifer in the 100 Areas is composed of either the Ringold Unit E gravels or a combination of the Unit E gravels and the Hanford formation. As shown in Figure G-39, there are two large areas where the water table is within the Ringold Formation (Lindsey 1992) and the Hanford formation is unsaturated. In the 100-H and 100-F Areas, the Ringold Unit E gravels are missing and the Hanford formation lies directly over the fine-grained Ringold lower mud unit. In most of the 100 Areas, the lower Ringold mud forms an aquitard and the Ringold gravels below the mud are locally confined. Additional information on the hydrology of the 100 Areas is available in Hartman and Peterson (1992) and Peterson et al. (1996).

200 Areas Hydrology

In the 200 West Area, the water table occurs almost entirely in the Ringold Unit E gravels, while in the 200 East Area, it occurs primarily in the Hanford formation and in the Ringold Unit A gravels. Along the southern edge of the 200 East Area, the water table is in the Ringold Unit E gravels. The upper Ringold facies were eroded in most of the 200 East Area by the Missoula floods, which subsequently deposited Hanford Site gravels and sands on what was left of the Ringold Formation. Because the Hanford formation sand and gravel deposits are much more permeable than the Ringold gravels, the water table is relatively flat in the 200 East Area, but groundwater flow velocities are higher. On the north side of the 200 East Area, there is evidence of erosional channels that may allow communication between the unconfined and uppermost basalt confined aquifer (Graham et al. 1984; Jensen 1987).

The hydrology of the 200 Areas has been strongly influenced by the discharge of large quantities of wastewater to the ground over a 50-year period. Those discharges have caused elevated water levels across much of the Hanford Site, resulting in a large groundwater mound beneath the former U Pond in the 200 West Area and a smaller mound beneath the former B Pond, east of the 200 East Area. Water table changes beneath 200 West Area have been greatest because of the

lower transmissivity of the aquifer in this area. Discharges of water to the ground have been greatly reduced, and corresponding decreases in the elevation of the water table have been measured. Water levels in 200 West Area have also been affected by pump-and-treat operations associated with 200-ZP-1 remedial actions. Figure G-55 shows cones of depression and a water table mound associated with this activity. The decline in part of the 200 West Area has been more than 7 m (Hartman and Dresel 1998). Water levels are expected to continue to decrease as the unconfined groundwater system reaches equilibrium with the new level of artificial recharge (Wurstner and Freshley 1994).

300 Area Hydrology

The unconfined aquifer water table in the 300 Area is generally found in the Ringold Formation at a depth of 9 to 19 m below ground surface. Fluctuations in the river level strongly affect the groundwater levels and flow in the 300 Area, just as they do in the 100 Areas. Groundwater flows from the northwest, west, and even the southwest to discharge into the Columbia River near the 300 Area. Schalla et al. (1988) and Swanson (1992) have provided more detailed information on the hydrogeology of the 300 Area.

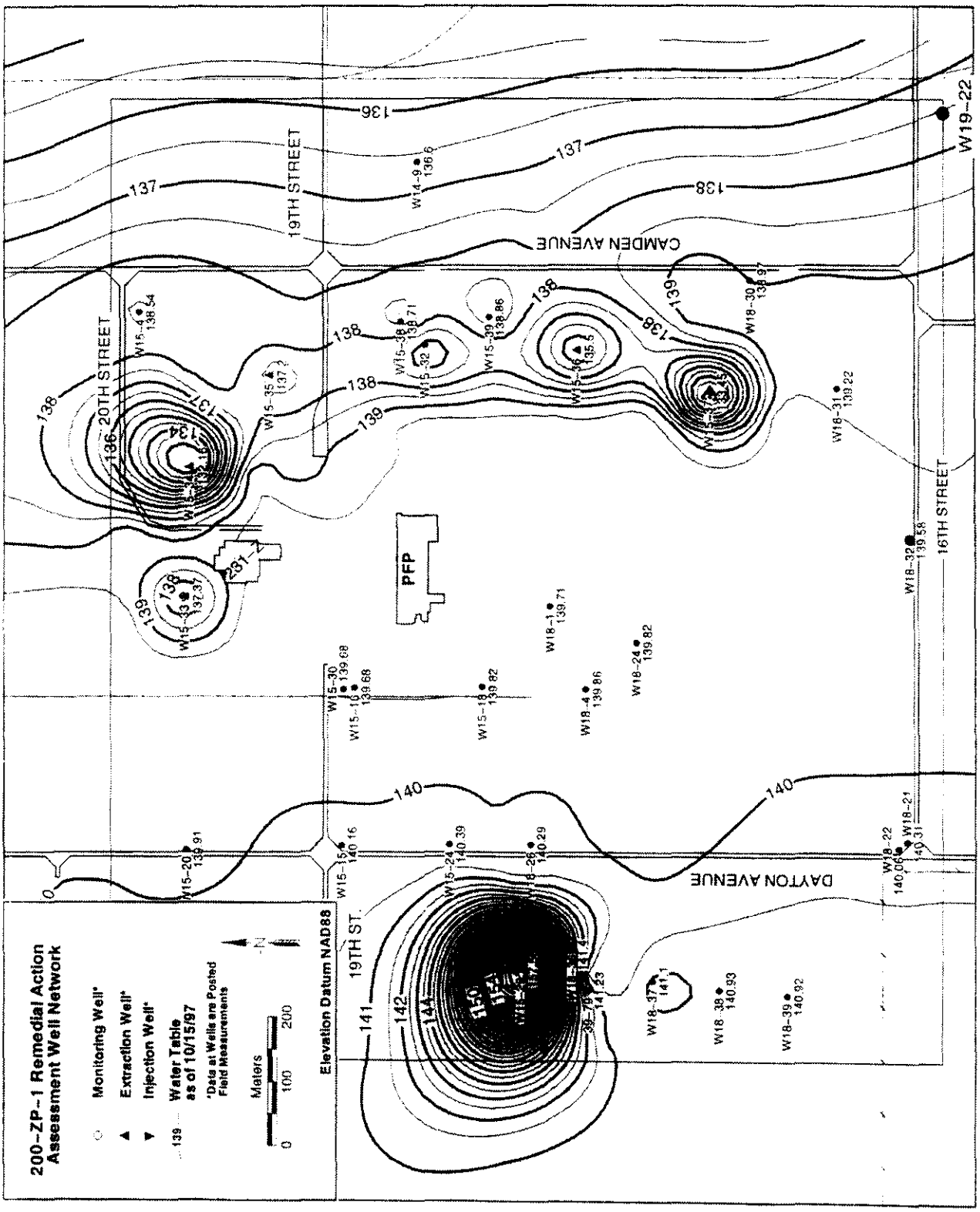
1100 Area and North Richland Hydrology

The groundwater in the southeastern portion of the Hanford Site is less impacted by Hanford Site operations than by offsite activities. In addition to natural recharge, artificial recharge is associated with the North Richland recharge basins (used to store Columbia River water for Richland water use) south of the 1100 Area, and irrigated farming near the Richland North Area and west and southwest of the 1100 Area. Although pumping to obtain water also occurs from the unconfined aquifer in these areas, there is a mound in the water table beneath the Richland city system of recharge basins. The Richland city recharge basins are used primarily as a backup system between January and March each year when the filtration plant is closed for maintenance, and during the summer months to augment the city's river water supply. The water level also rose from December 1990 and December 1991 in the area of the Lamb Weston Potato Processing Plant, which uses large amounts of water and, except for plant maintenance during July, operates year-round. The water table in the 1100 Area also seems to reflect irrigation cycles connected with agriculture (Liikala et al. 1994).

The geologic history and hydrogeologic setting of the Hanford Site is described in the annual *Hanford Site Groundwater Report* (Hartman and Dresel 1998). Summaries of site-wide hydrogeologic conditions are also available in Newcomb et al. (1972), Law et al. (1996), and Wurstner et al. (1995). Studies focused on the unconfined aquifer system in the vicinity of the 200 Areas are provided in Graham et al. (1981), Lindsey et al. (1991, 1992), and Connelly et al. (1992a, 1992b). Confined aquifers within the Columbia River Basalts were extensively studied from 1977 to 1987 as part of the Basalt Waste Isolation Project. Detailed descriptions of these studies are available in DOE (1988a).

G.1.3.2.6 Modeling. A three-dimensional groundwater flow and transport model has been developed over the past 10 years for the Hanford Groundwater Project. This model uses the Coupled, Fluid, Energy, and Solute Transport (CFEST) code (Gupta et al. 1997). Initial

Figure G-55. Influence of 200-ZP-1 Remedial Action Pump and Treat Upon Water Table Elevations.



development of the model is described in Wurstner et al. (1995). The model was recently used to simulate future site-wide transport of selected contaminant plumes in the unconfined aquifer system (Cole et al. 1997) and to support the Composite Analysis (Kincaid et al. 1998) with simulation of transport from all radionuclide sources on the Hanford Site. A recent multi-year modeling effort conducted to support development of the *Hanford Sitewide Groundwater Remediation Strategy* (DOE-RL 1995c) was completed during fiscal year (FY) 1996 and was described in Chiaramonte et al. (1996).

Other models have been used recently to simulate groundwater flow conditions for specific projects at a local scale. A model was applied to assess the interaction between the unconfined aquifer and the Columbia River in the vicinity of the 100-N Area. The objective of this model was to better understand the release of ^{90}Sr from the aquifer into the Columbia River. Other models were used in the design and evaluation of pump-and-treat activities aimed at remediation of contaminated groundwater in the 200 West Area. These models were used to delineate capture and injection zones for the extraction and injection wells, respectively, and to estimate the area affected by the pump-and-treat operations at different times.

G.1.4 Columbia River

Technical scope associated with the Columbia River ecosystem extends from reference locations upstream of the Hanford Site to downstream locations appropriate for specific aspects of the system assessment. Environments of interest include the riparian zone, near-river groundwater, the hyporheic zone, and the Columbia River water column. Within each, a wide variety of information is needed to define physical, chemical, and biological characteristics.

The scope of this technical element starts with the zone in which groundwater from the Hanford Site meets the Columbia River. Key topics in this zone include mixing, geochemical conditions, preferential pathways, and biological activity. Credible conceptual and numerical models for processes occurring in this zone are crucial to (1) identify impacts to the river's ecosystem, and (2) quantify risks to aquatic and human receptors. This zone encompasses near-river groundwater and infiltrated river water (bank storage), and the hyporheos (sediment pore water and biota immediately beneath the free-flowing stream).

Once in the Columbia River, Hanford Site groundwater and any entrained contamination co-mingle with river water and disperse to a wide array of potential receptors. The scope of this technical element relates to information needs associated with the fate and transport of contamination within this river environment. These include the contaminant characteristics (type, nature, concentration, decay/attenuation qualities), physical movement in the dynamic flow of the river, and bioavailability. Interaction with the suspended load of the river, and with biological systems, is key to anticipating the fate of contaminants. Erosion and deposition patterns for the river are major topics for understanding where potential contaminant sinks are located, and where sensitive species and humans are at greatest potential threat of exposure. Understanding how the channel morphology and its distribution of sediments evolve (with time) is key to anticipating future conditions.

The Columbia River technical element scope includes the capability to provide information necessary to accurately and credibly assess of risk posed by Hanford Site contaminants to aquatic, terrestrial, and human receptors in the river environment. Key information needs include identifying (1) locations where contaminants enter a pathway to receptors; (2) various habitats in the river environment; (3) contaminant-sensitive receptors; and (4) exposure pathways to habitats and receptors.

An understanding of contaminant bioavailability is crucial for assessing potential impacts and risk, and contaminant-transfer coefficients and bioaccumulation rates are needed for contaminant/species combinations of interest. The capability to differentiate Hanford-derived contamination from other sources is a part of this effort, as is analysis of the potential cultural consequences that may result from impacts to the natural resources of the river environment. The assessment of risk considers near-term conditions, as well as conditions extending far into the future.

G.1.4.1 Current state of knowledge. To understand the current status of the Columbia River environment and the impacts of Hanford Site operations on this environment, one must have a general understanding of the environmental setting and historical environmental assessment activities conducted at the Hanford Site during the past 54 years. Brief discussions are provided below to provide this information. In addition, the current environmental conditions of the Columbia River are summarized.

G.1.4.1.1 Environmental setting. The Columbia River is the primary surface-water feature associated with the Hanford Site. Other surface water bodies bordering or onsite include springs, streams, West Lake, and a number of artificial ponds and ditches. Onsite sources of recharge to these surface water bodies include precipitation, overland flow, groundwater, and direct discharge of water from Hanford Site facilities (Neitzel 1997; Dirkes and Hanf 1996; Cushing 1995; Becker 1990).

Columbia River

The Columbia River is the second largest river (measuring total flow) in the continental United States and is the dominant surface water body on the Hanford Site. Originating in the mountains of eastern British Columbia, Canada, the Columbia River flows south through a gap in the Saddle Mountains, then turns east near Priest Rapids Dam and flows into the northern portion of the Hanford Site. The Hanford Reach of the Columbia River extends from Priest Rapids Dam to the head of Lake Wallula (created by McNary Dam), near the City of Richland, and is currently under consideration for designation as a National Wild and Scenic River. No tributaries enter the Columbia in the Hanford Reach. The bank along the eastern shore of the Hanford Reach in places rises over 150 m above the surface of the Columbia River, forming the White Bluffs. In total, the water level of the Columbia River drops about 20 m along its path through the Hanford Site.

The flow of water in the Columbia River is regulated by 11 dams within the United States, 7 upstream and 4 downstream of the Hanford Site. Priest Rapids Dam is the nearest dam upstream of the Hanford Site, and McNary Dam is the nearest downstream. Flows through the

Hanford Reach fluctuate significantly and are controlled primarily by operations at Priest Rapids Dam. Annual flows below Priest Rapids Dam over the last 77 years have averaged nearly 3,360 m^3/sec (Wiggins et al. 1995). Daily average flows ranged from 1,152 to 7,787 m^3/sec. Monthly mean flows typically peak from April through June during spring runoff from melting snow in the upriver watershed. River flow is lowest from September through October.

As a result of fluctuations in discharges, the depth of the Columbia River varies significantly over time. River stage may change along the Hanford Reach by up to 3 m within a few hours (Dresel et al. 1995). Seasonal changes of about the same magnitude are also observed. River-stage fluctuations measured at the 300 Area are only about half the magnitude of those measured near the 100 Areas because of the effect of the pool behind McNary Dam (Campbell et al. 1993). The width of the Columbia River varies from approximately 300 m to 1,000 m within the Hanford Site. Major floods on the Columbia River are typically the result of rapid melting of the winter snowpack over a wide area augmented by above-normal precipitation. Large Columbia River floods have occurred in the past (DOE 1987), but the likelihood of large-scale flooding recurring in the Hanford Reach has been reduced by the presence of dams upstream of the Hanford Site.

Three tributaries join the Columbia River between the Hanford Site and McNary Dam: the Yakima River at river mile 335, the Snake River at river mile 324, and the Walla Walla River at river mile 315. The mean annual discharge of the Yakima River a few miles upstream of the confluence with the Columbia River at Kiona, Washington, was approximately 70 m^3/sec from 1990 to 1994 (Wiggins et al. 1995). The Snake River mean annual discharge as measured at Ice Harbor Dam, just upstream of the confluence with the Columbia River, is approximately 1,600 m^3/sec. The mean annual discharge of the Walla Walla River, measured before entering the Columbia River, is approximately 15 m^3/sec.

Since McNary Dam was completed in 1953, a significant part of the Columbia River's sediment load has been trapped behind the dam (Robertson et al. 1973). However, as is true of the other Columbia River dams, some of the trapped sediment is resuspended and transported downstream by seasonal high discharges. As expected, much of this material is redeposited behind dams located further downstream. The primary contributor of suspended sediment to the Columbia River is the Snake River (Whetten et al. 1969), but the Yakima and Walla Walla Rivers are also significant sources. Sediment contributions from these sources are highly seasonal. Sedimentation rates at certain sites behind McNary Dam have been assumed to be as high as 30 cm/yr (Robertson et al. 1973). Subsequent studies by Beasley et al. (1986) reported sedimentation rates above McNary Dam to average 7 ($\pm$3) cm/yr along the Oregon shore, 4 ($\pm$2) cm/yr at midchannel, and 2 ($\pm$1) cm/yr near the Washington shore.

Sediment accumulates faster on the Oregon shore than the Washington shore because sediment input from the Snake and Walla Walla Rivers is constrained to the near shore (Oregon side). Based on visual observations from past sediment-monitoring samples taken for the Hanford Sitewide Surface Environmental Surveillance Project (SESP), the top 1 to 5 cm of the bed sediment at Priest Rapids Dam is dominated by coarse-to-fine sands and silts. By contrast, cobble, coarse, and fine sand bed sediment was found at sampling locations along the Hanford

Site, and silt and clay sediment was observed at the McNary Dam sampling site (Blanton et al. 1995).

Water from the Columbia River, both upstream and downstream from the Hanford Site, is used extensively for crop irrigation. River water is a source of onsite drinking water and industrial cooling water for facilities, and is also used by communities downstream from the Hanford Site. In addition, the Hanford Reach is used for a variety of recreational activities, including hunting, fishing, boating, water-skiing, and swimming.

Columbia River Seeps

Seepage of groundwater into the Columbia River has been known to occur for many years. Riverbank springs, defined as groundwater discharge zones located above the water level of the Columbia River, were documented along the Hanford Reach long before Hanford Site operations began (Jenkins 1922). McCormack and Carlisle (1984) walked the 66-km stretch of the Hanford Reach shoreline of the Columbia River in 1983 and identified 115 springs. They reported that the predominant areas of groundwater discharge at that time were near the 100-N Area, the old Hanford Townsite, and the 300 Area. The predominance of springs in the 100-N Area is no longer valid because of declining water-table elevations in response to a decrease in liquid waste discharges to the ground (Dirkes and Hanf 1996). Select springs in the 100-B, 100-D, 100-H, 100-K, and 100-N Areas, the old Hanford Townsite, and the 300 Area have been sampled routinely since 1984.

The presence of springs along the shoreline depends on the height of the water level of the Columbia River. Dresel et al. (1994) reported that groundwater levels in the 100 and 300 Areas were heavily influenced by fluctuations in river stage from operations at Priest Rapids Dam. Water flows into the aquifer (that is, bank storage) as the river stage rises, and water flows from the aquifer as the river stage falls. Following an extended period of low river discharge, groundwater discharge zones located above the water level of the Columbia River may cease to exist once the level of the groundwater comes into equilibrium with the level of the river. Thus, springs are most readily identified immediately following a decline in river stage.

Bank storage of river water also affects the concentration of contaminants in the spring water. When river stage is high, river water flows into the aquifer and overlays or mixes with groundwater. Typically, this inland flow of river water is restricted to within several hundred feet of the shoreline (McMahon and Peterson 1992). Spring discharge that immediately follows a river stage decline generally consists of river water or a river water and groundwater mix. The percent contribution of groundwater to spring discharge increases over time. Because of the effect of bank storage on groundwater discharge and contaminant concentration, it is difficult to estimate the volume of contaminated groundwater (and therefore flux of contaminant) that is discharged to the Columbia River within the Hanford Reach.

Ecology

The Columbia River and its Hanford Reach are the dominant aquatic ecosystem on the Hanford Site. The Columbia River is a complex ecosystem because of its size, number of alterations

(e.g., dams), biotic diversity, and size and diversity of its drainage basin. The Hanford Reach comprises the last unimpounded portion of the Columbia River in the United States above Bonneville Dam. The Hanford Reach supports diverse plant, fish, and wildlife species that are locally abundant. The ecology of the aquatic and riparian systems within the study area has been studied extensively in the last 50 years, largely because of concerns about hydropower and reactor construction and operation.

Several habitats on the Hanford Site could be considered wetlands, but the largest and most important is the riparian zone bordering the Columbia River. Riparian areas include sloughs, backwaters, shorelines, islands, and palustrine areas associated with the Columbia River flood plain. The extent of this zone in the Hanford Reach varies, but includes extensive stands of willows, grasses, various aquatic macrophytes, and other plants. Fitzner and Gray (1991) listed 39 species of mammals known to occur on the Hanford Site. Brandt et al. (1993) identified 24 as occurring within the riparian zone of the Columbia River. Weiss and Mitchell (1992) identified 103 bird species associated with the riparian community of the Hanford Reach. These include species that use the area only during winter (e.g., American widgeon, bald eagle), only during summer (e.g., cliff swallow, Forster's tern,), or year-round (e.g., barn owl, mallard). Principal herbivorous species include Canada geese and mallards. Amphibians and reptiles are also known to exist in the riparian zone of the Hanford Reach.

Aquatic vegetation is composed of three general groups: phytoplankton, periphyton, and macrophytes. Diatoms dominate the Columbia River algae. Periphyton develops on suitable substrate where light is sufficient for photosynthesis. Diatoms also predominate among this group. Macrophytes are sparse outside of McNary Pool and slackwater areas because they require relatively low flow and a sediment substrate in which to root. Zooplankton is generally sparse in the study area. Benthic invertebrates (invertebrate species associated with the substrate rather than the water column) include all major fresh-water benthic taxonomic groups (Brandt et al. 1993). The invertebrate fauna is dominated by insect larvae. A total of 44 species of fish are known to occur in the Hanford Reach (Cushing 1995; Gray and Dauble 1977). Chinook, coho, sockeye salmon, and steelhead trout use the Hanford Reach as a migration corridor to and from upstream spawning areas (Dauble and Watson 1990). The Hanford Reach supports the only major spawning habitat for the upriver bright race of fall chinook salmon within the main stem of the Columbia River. No plants or mammals on the federal list of threatened and endangered wildlife and plant species are known to occur on the Hanford Site. However, three bird species on the federal list have been recorded on the Hanford Site. Table G-4 shows threatened and endangered species on federal and state lists that have been recorded on the Hanford Site and thereby occur within that portion of the study area.

The bald eagle is one of six threatened or endangered birds at the Hanford Site. The bald eagle is a regular winter resident and forages on dead salmon and waterfowl, but has not yet been observed to nest successfully on the Hanford Reach. Access controls are in place along the river at certain times of the year to prevent the disturbance of eagles. The Washington State Bald Eagle Protection Rules were issued in 1986, and DOE prepared a site management plan to mitigate eagle disturbance (Fitzner and Weiss 1994). The American white pelican and ferruginous hawk are listed by the State of Washington as endangered and threatened,

Table G-4. Threatened (T) and Endangered (E) Species Occurring or Possibly Occurring within the Hanford Site.

Common Name	Federal	State
Plants		
Columbia milkvetch		T
Columbia yellowcress		E
Dwarf evening primrose		T
Hoover's desert parsley		T
Birds		
Aleutian Canada goose[a]	T	E
American white pelican		E
Bald eagle	T	T
Ferruginous hawk		T
Peregrine falcon[a]	E	E
Sandhill crane[a]		E

[a] Incidental occurrence.

respectively. In addition, the Aleutian Canada goose, peregrine falcon, and sandhill crane occur, incidentally, at the Hanford Site, and are listed as threatened or endangered.

Eight species of plants listed as threatened or endangered by the State of Washington are found on the Hanford Site. Only Columbia milkvetch and Columbia yellowcress are associated with the Columbia River. Milkvetch occurs on dry-land benches along the Columbia River near Priest Rapids Dam, Midway, and Vernita. Yellowcress occurs in the wetted zone of the water's edge along the Hanford Reach. Northern wormwood is another plant listed by the state as an endangered species and is known to occur near the town of Beverly, upstream of Priest Rapids Dam. The shoreline of the Columbia River, across from the 100 Areas, could provide a suitable habitat for northern wormwood, but it has not been observed in the area.

Steelhead trout (upper Columbia River ESU) are listed as endangered and are known to be present in the Hanford Reach of the Columbia River.

G.1.4.1.2 Current environmental conditions. Currently, there are several different Hanford-related programs and projects working on various aspects of the river evaluation defined in the previous section. In addition, several agencies outside of the Hanford Site domain are conducting related studies. These agencies include Ecology and the Washington State Department of Health (DOH), U.S. Army Corps of Engineers, U.S. Geologic Survey, Federal and State Fish and Wildlife Service, U.S. Environmental Protection Agency (EPA), and the Bonneville Power Administration. The activities performed by the various entities are defined by organization and project-specific objectives. Efforts have been made to coordinate the activities of these organizations.

Columbia River Environment

The Columbia River near the Hanford Site is monitored primarily through the SESP, according to the *Environmental Monitoring Plan (EMP) U.S. Department of Energy, Richland Operations Office* (DOE-RL 1997b). Additional Columbia River monitoring is conducted by the Hanford Site Near-Facility Environmental Monitoring Program, which collects riverbank spring water samples and measures external radiation at the 100-N Area shoreline (Perkins et al. 1997).

The current environmental status of the Columbia River is evaluated and documented on a yearly basis through the Hanford Site Environmental Report (PNL-7930; Woodruff and Hanf 1992; PNL-8682; PNL-9823; PNL-10574; PNNL-11139; PNNL-11472). The *Columbia River Comprehensive Impact Assessment* study (DOE-RL 1998b), non-DOE agency reports (WA 1993; Paris 1994; Wells 1994; Danielson and Jaquish 1996; Wiggins et al. 1996), and other Hanford Site contractor reports (Dirkes 1990; Dirkes 1993; Poston 1994; Poston and Cooper 1994; Hope and Peterson 1996a; Hope and Peterson 1996b) provide valuable information on the status of the Columbia River.

Columbia River Water. The Columbia River was one of the primary environmental exposure pathways to the public from 1990 through 1996. Radiological and chemical contaminants entered the river along the Hanford Reach primarily through seepage of contaminated groundwater. Environmental samples were collected from the river at various locations during this period to determine compliance with applicable standards. Water sampling locations used in 1997 are illustrated in Figure G-56.

Although radionuclides associated with Hanford Site operations continue to be identified routinely in Columbia River water during this time period, concentrations remained extremely low at all locations and were well below standards. The concentrations of tritium (Figure G-57), ^{129}I (Figure G-58) and, for some years, uranium (Figure G-59) were significantly higher (5% significance level) at the Richland water supply pumphouse (downstream from the Hanford Site) than at Priest Rapids Dam (upstream from the Hanford Site), indicating contributions from the Hanford Site. Transect sampling (concentration profiles across the river) revealed elevated tritium concentrations along the Benton County shoreline near the 100-N Area, old Hanford Townsite, 300 Area, and the Richland pumphouse (Figure G-59). Total uranium concentrations were elevated along the Benton and Franklin County shorelines near the 300 Area and Richland pumphouse (Figure G-60). The highest total uranium concentration was measured near the Franklin County shoreline of the Richland pumphouse transect and likely resulted from groundwater seepage and irrigation return canals east of the river.

Several metals and anions were detected upstream and downstream of the Hanford Site. Nitrate concentrations were elevated along the Franklin County shoreline of the old Hanford Townsite, the 300 Area, and Richland pumphouse transects, and likely resulted from groundwater seepage associated with extensive irrigation north and east of the Columbia River. Most metal and anion concentrations measured in Columbia River water collected during this time period were less than Washington State ambient surface water quality criteria levels for acute toxicity, except for

Figure G-56. Water and Sediment Sampling Locations for the Columbia River Used in 1997.

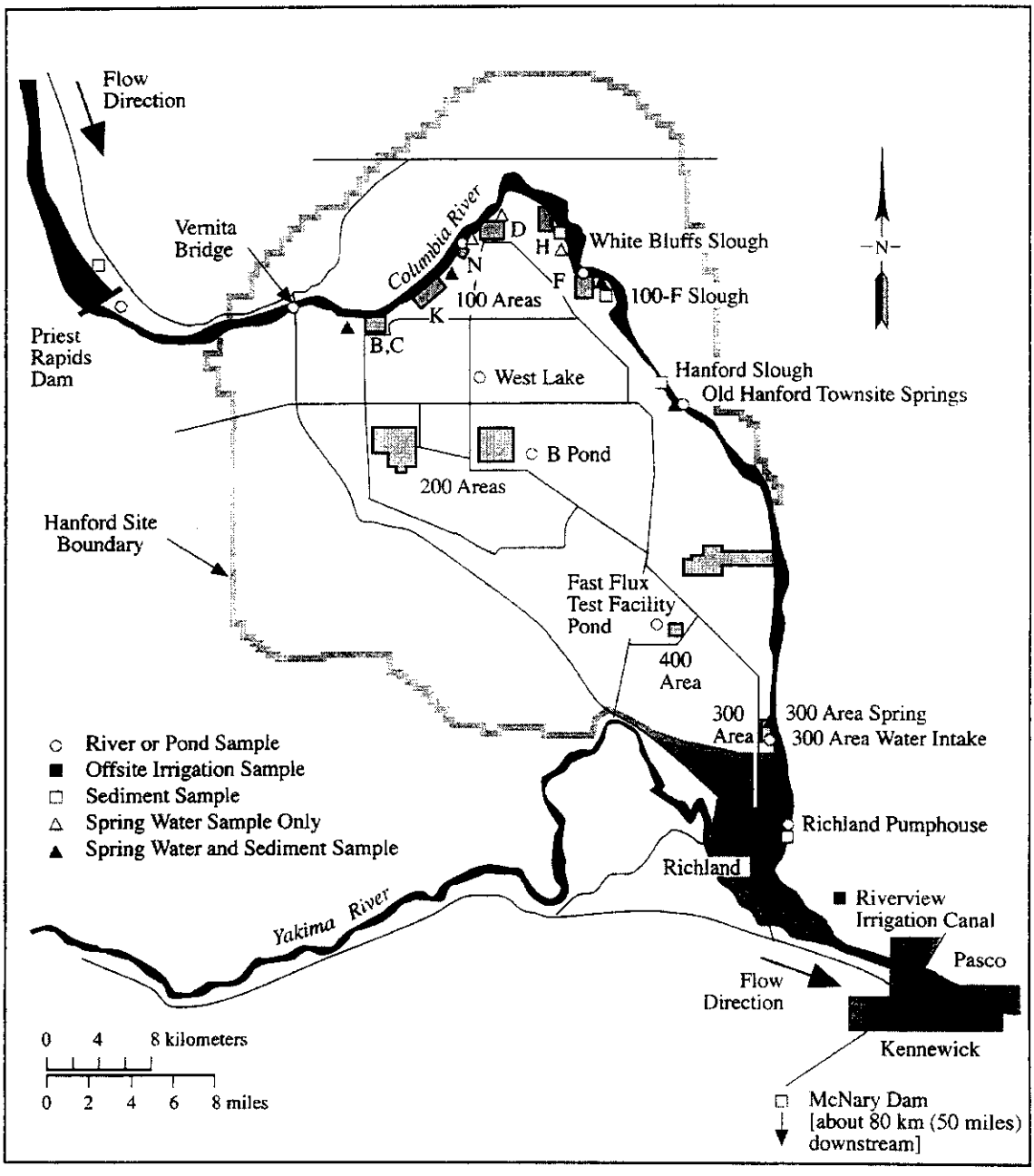


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Figure G-57. Annual Average Tritium Concentrations (±2 Standard Error of the Mean) in Columbia River Water, 1992 Through 1997.

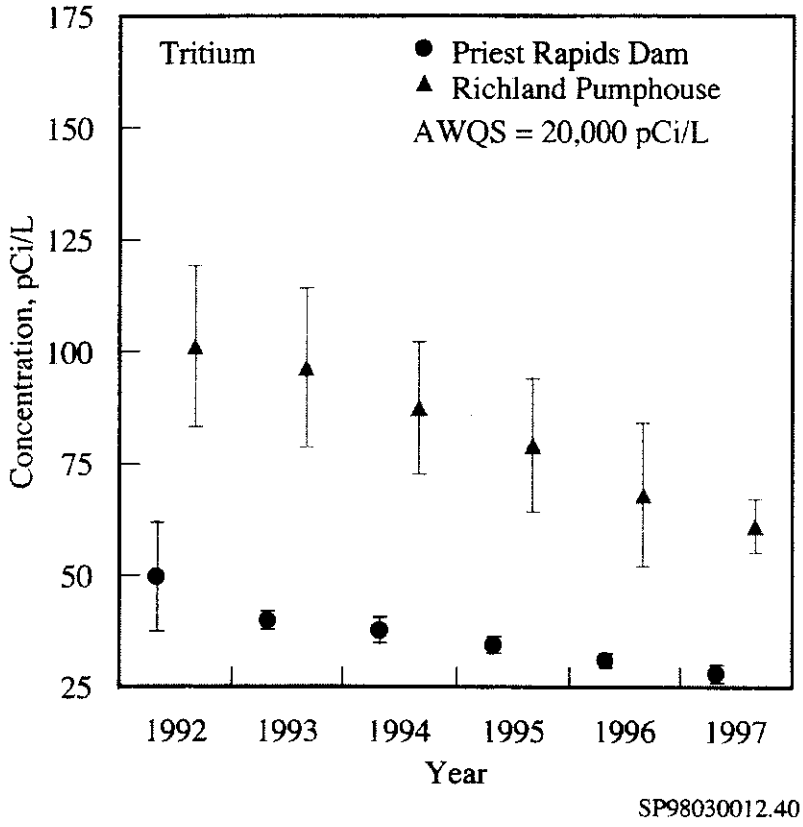


Figure G-58. Annual Average I-129 Concentrations (±2 Standard Error of the Mean) in Columbia River Water, 1992 Through 1997.

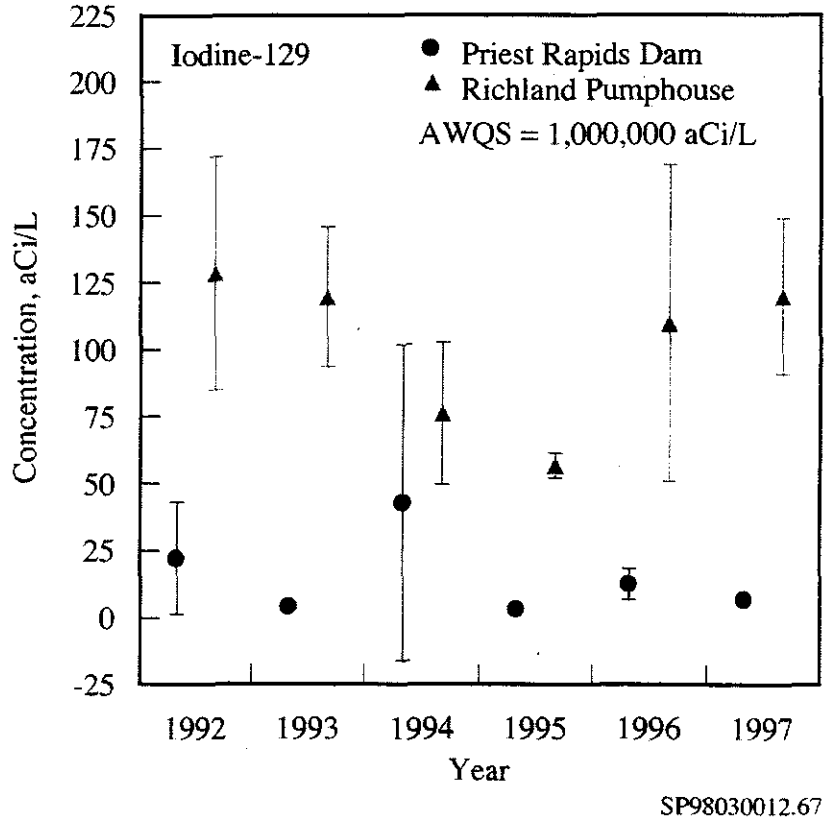


Figure G-59. Annual Average Uranium Concentrations (±2 Standard Error of the Mean) in Columbia River Water, 1992 Through 1997.

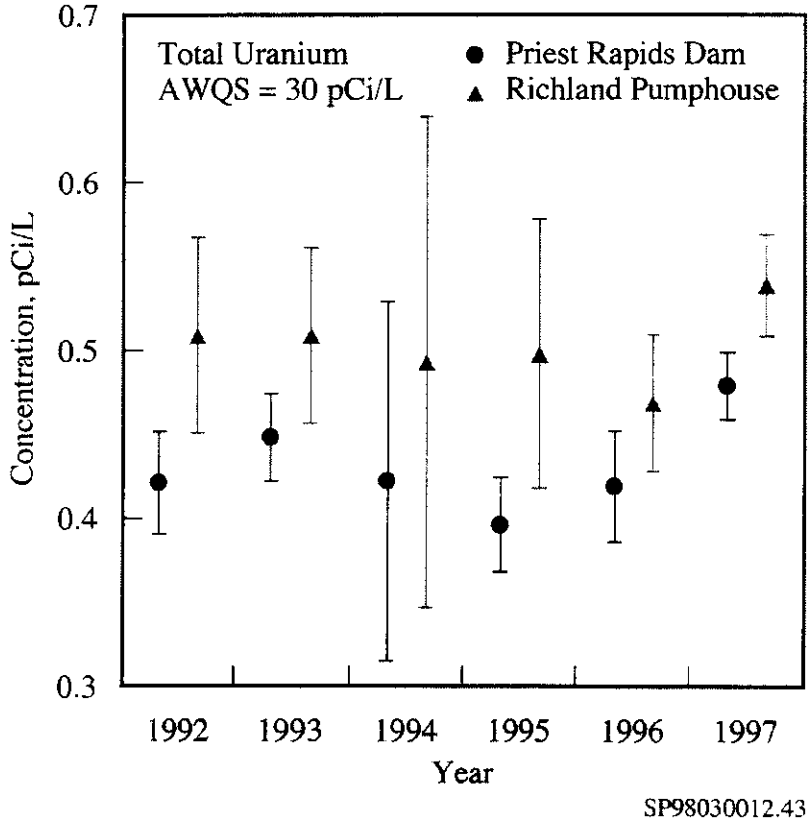
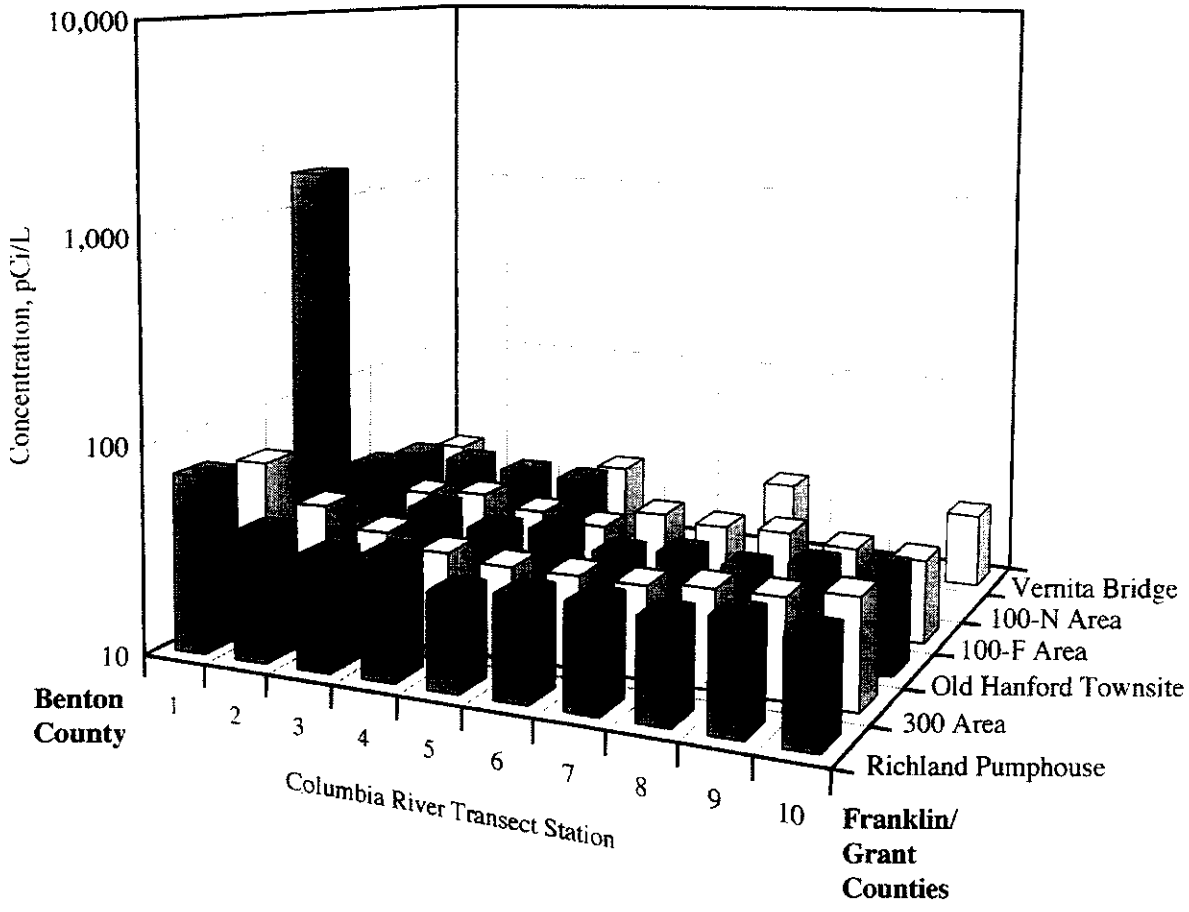


Figure G-60. Tritium Concentrations in Water Samples from Columbia River Transects, August 1997.



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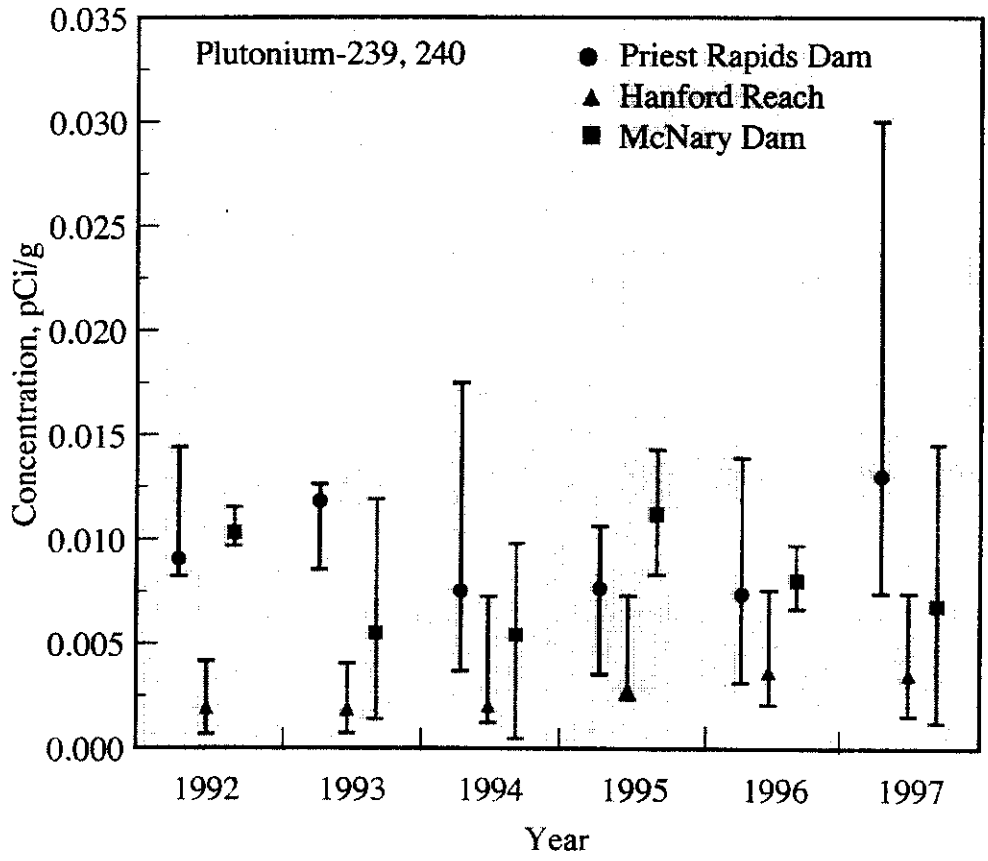
silver and cadmium that exceeded the standards for a few samples. In September 1996, transect samples at Vernita Bridge, 100-F Area, and the Richland pumphouse for ultra-trace levels of mercury were all below 1 part per trillion (Bisping 1997b). The chronic toxicity levels for lead and selenium were occasionally exceeded in Columbia River transect samples. Volatile organic compounds (trichloroethylene, chloroform, and toluene) were occasionally detected in Columbia River water samples.

Since 1986, under the National Stream Quality Accounting Network program, the U.S. Geological Survey has collected water samples along transects of the Columbia River at the Vernita Bridge and the Richland pumphouse. Physical measurements and chemical analyses are performed on the samples. Results are reported annually by the U.S. Geological Survey (Wiggins et al. 1996). Applicable standards for a Washington State Class A-designated surface-water body were reached. From 1990 through 1996, there was no indication of any deterioration of water quality resulting from Hanford Site operations.

Columbia River and Riverbank Spring Sediment. Sediment in the Columbia River contains low levels of radionuclides and nonradioactive metals of Hanford Site origin, as well as radionuclides from worldwide fallout (Woodruff et al. 1992; Beasley et al. 1981; Robertson and Fix 1977). Results of sediment investigations indicate that the predominance of radionuclides in river sediments downstream of Hanford result from worldwide fallout and do not generally result from past or present Hanford Site operations (Beasley et al. 1981, Beasley 1984). Samples of Columbia River surface sediments were collected from permanently flooded monitoring sites above McNary Dam (downstream of the Hanford Site), Priest Rapids Dam (upstream of the Hanford Site), and along the Hanford Reach (Dirkes and Hanf 1997) (Figure G-61). Strontium-90 was the only radionuclide to exhibit consistently higher median concentrations at McNary Dam compared to the other location. The median concentration of ^{60}Co was highest in sediment collected along the Hanford Reach. Sediment samples were also collected from riverbank springs. The concentrations of radionuclides in sediment collected from riverbank springs were similar at all locations and were comparable to sediment collected behind Priest Rapids Dam. Detectable concentrations of most metals were found in all Columbia River sediment samples, except silver, which was below the detection limit for all samples. Median concentrations of most metals were highest in McNary Dam sediments. The highest median concentration of chromium was found in riverbank spring sediment.

Columbia River Shoreline Springs. Currently, reasonably comprehensive coverage of contaminant conditions along the south (or "right") shoreline of the Columbia River is available. Data from near-river monitoring wells at the reactor areas have accumulated for many years, including from as far back as the reactor operating years. Samples of riverbank seepage have been routinely collected and analyzed since the mid-1980s. Some data also exist in reports of specialized sampling conducted during the operating years, although these data are not readily available to analysts, and they must be retrieved from the old reports. Current data sets and interpretations provide a reasonably accurate and comprehensive picture array of opportunities to obtain observational data.

Figure G-61. Minimum, Median, and Maximum Concentrations of Selected Radionuclides Measured in Columbia River Sediments, 1992 Through 1997.



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All radiological contaminant concentrations measured in riverbank spring water were less than DOE Derived Concentration Guides. However, tritium concentrations in the 100-B Area and old Hanford Townsite riverbank springs exceeded the Washington State ambient surface water quality criteria levels. There are currently no ambient surface water quality criteria levels directly applicable to uranium. However, total uranium exceeded the Hanford Site-specific proposed EPA drinking water standard in the 300 Area riverbank spring. All other radionuclides were below the Washington State ambient surface water criteria.

Nonradiological contaminants measured in riverbank springs were below Washington State ambient surface water acute toxicity levels, except copper in the 100-F Area and 300 Area springs; cadmium in the 100-F Area spring; and chromium (IV) in 100-B Area, 100-D Area, and 100-F Area springs. The Washington State ambient surface water chronic toxicity level of cadmium, chromium, zinc, and selenium were exceeded at some locations. Nitrate concentrations were the highest in the 100-D Area and the old Hanford Townsite springs. Concentrations of volatile organic compounds were similar to previous years with most compounds below the detection limits. Chloroform (100-B and 100-D Areas), trichloroethylene (100-B), and tetrahydrofuran (100-B) were occasionally detected (Peterson and Johnson 1992, Peterson et al. 1998).

Irrigation Water. Irrigation water from the Riverview canal was sampled to determine radionuclide concentrations. Radionuclide concentrations in offsite irrigation water were below DOE Derived Concentration Guides and ambient surface water quality criteria levels, and were similar to those observed in the Columbia River.

Aquatic Biota. For fish samples collected from 1990 through 1996, ^{90}Sr was detected in Columbia River bass and carp at concentrations slightly exceeding those found in fish collected upstream of the Hanford Site in the Priest Rapids reservoir. Cesium-137 has occasionally been detected in bass from the Hanford Reach. Results for aquatic biota sampling for 1997 are summarized in Dikes and Hanf (1998). The concentrations of radionuclides measured in Hanford Site fish indicate accumulation of small amounts of radionuclides; however, it is likely that these radionuclides were from atmospheric fallout, as well as the Hanford Site.

Shoreline Vegetation. Shoreline vegetation was sampled from 1990 to 1992 along areas of the Hanford Reach where contaminated groundwater plumes intersect the river and at an upriver control location (Antonio et al. 1993). The 100-N Area, old Hanford Townsite, and the 300 Area had elevated levels of radionuclides. Tritium concentrations were elevated compared to background at all locations. Cobalt-60 and ^{90}Sr were elevated at the 100-N Area, and ^{99}Tc was detected at the old Hanford Townsite. There was some indication of elevated uranium concentrations in milfoil and onions collected at the 300 Area. The concentrations of ^{137}Cs, plutonium, and uranium were slightly higher than background at the 100-N Area, old Hanford Townsite, and 300 Area; and again, are likely attributable to both fallout and the Hanford Site (Poston 1994).

External Radiation. Shoreline surveys conducted in 1979 indicated that measurable radioactive contamination resulting from past generations was present along the Columbia River shoreline (Sula 1980). In 1994, the DOH conducted a study of the health effects of artificial radioactivity

in Columbia River sediment (Wells 1994). This study, which did not address "skyshine" from facilities near the river, shoreline "seeps," or effluent pipes, concluded that the doses resulting from artificial radioactivity in Columbia River sediment were very low, less than 1% of natural background.

Radiological dose rates are measured at selected locations along the Columbia River using thermoluminescent dosimeters (Dirkes and Hanf 1997). Locations are selected based on past aerial and ground radiological surveys that identified areas of elevated exposure rates. As such, average shoreline dose rates in 1996 (89 mrem/yr) were slightly higher than observed background dose rates measured at distant communities (71 mrem/yr). The 1996 average dose rate along the 100-N Area shoreline (129 mrem/yr) was approximately 50% higher than the typical shoreline dose rate (82 mrem/yr). The elevated exposure rate is attributable to skyshine resulting from waste management facilities located near the river at the 100-N Area.

G.1.5 Risk Assessment

The Risk Assessment technical element involves (1) developing several location-specific dependency webs according to where and when the antecedent transport modules predict that contamination will or could occur (onsite and down river). This is followed by (2) estimating exposures, risks, and impacts to (a) humans, (b) the environment, (c) specific cultures and quality of life, and (d) selected economies from radioactive and chemical contaminants at those locations. These calculations may be made for current contaminant distributions, as defined by monitoring data and information on historical operations, and for potential future conditions. The objectives are to evaluate the effects of various remediation options and land uses.

The first step in the risk assessment process is to develop several location-specific dependency webs before defining impacts and performing the more quantitative exposure, dose, and risk calculations. A variety of tools are needed to conduct these risk assessments because of the relatively large geographic area influenced by the Hanford Site, the complexity of sources and characteristics of contamination, and the migration of contaminants through a variety of environmental media. These tools address the release of contaminants, geochemistry, and transport through several media (e.g., vadose and saturated zones, river, air, soil), exposures to humans and the ecosystem; human health; ecological, cultural, and economic impacts; and risks from the exposure.

Human health risk assessment involves generally accepted exposure pathways and scenarios originally developed and documented by the EPA. Recently, there has been increased interest (e.g., Columbia River Comprehensive Impact Assessment [CRCIA] and Hanford Remedial Action Environmental Impact Statement [HRA-EIS]) in the assessment of "lifestyle" scenarios that may involve exposure patterns associated with specific groups, such as Native Americans and others whose lifestyles are closely tied to the Columbia River.

Ecological risk assessment is not as easily outlined as human health risk assessment because of the larger number of potential receptors and pathways, which often result in the need for a very location specific analysis. Of particular interest for assessing ecological risk are locations where sensitive habitat and contaminants coexist, and where the potential uptake of contaminants is

most likely. A critical location is one where the entry of contaminants into an exposure pathway and/or the food chain is likely to occur. The pathways or mechanisms by which receptors of interest are potentially exposed to contaminants are characterized as an integral part of a risk assessment. Some of the receptors of interest will be identified through identification of the food webs.

The process of estimating risks to cultures and economies uses the same contaminant location, duration, and concentration information as used by the human and ecological risk estimation process. Several models are being developed to address cultural impacts for tribal cultures and communities. These methods are sufficiently well developed, with published proof-of-principle reports, that they can be used by the Integration Project. It is essential, however, that Tribal Nation technical staff be involved in, or actually perform, the evaluation of risks to tribes, their cultures, their economies, and the determination of potentially disproportionate impacts to tribal communities. A standard economic impact analysis will be appropriate for nontribal economies.

The last step in the risk and impact analyses is to assess cumulative risks and impacts for specific locations and populations. These risks or impacts will be placed into perspective with the other, non-Hanford impacts to the environment.

G.1.5.1 Current state of knowledge. Relatively small amounts of radioactive and nonradioactive compounds are released to the atmosphere from Hanford Site sources. These emissions are a potential source of human exposure. Therefore, air samples are collected at locations near potential sources, at the site perimeter, and at offsite locations. A description and results of Hanford Site air monitoring are provided in Dirkes and Hanf (1997).

Transport of airborne emissions is controlled by weather patterns, the source location, and the nature of the emission. Past airborne emissions, which were released from chemical separation processes during the early years of Hanford's defense mission, resulted in offsite exposures. However, airborne emissions from remaining wastes have been shown to have minimal impact when analyzed as a part of the performance assessment for various facilities (Kincaid et al. 1997).

Contaminants from the Hanford Reach human and wildlife receptors through liquid effluents that have been discharged directly to the Columbia River, groundwater seeping into the river, and gaseous effluents released to the atmosphere. Assuming that people are not exposed directly to contaminated groundwater on the Hanford Site and that transport of contaminants through the atmospheric pathway is negligible, the Columbia River is the primary interface between human receptors and Hanford Site contaminants. Wildlife may also be exposed to surface contaminants on the Hanford Site.

Where possible, impact to receptors is evaluated based on the results of environmental sampling and direct measurements of radiation. However, the concentrations of most radioactive materials released to the environment from the Hanford Site are too small to be measured directly once they are dispersed in the environment, or it is difficult to identify contributions from the Hanford Site in the presence of worldwide fallout and naturally occurring radionuclides. Therefore, environmental pathway modeling is conducted to determine the impact of these releases.

Modeling is also used to determine the potential impact of future releases. The dose to the maximally exposed individual in 1997 was 0.0152 mrem/yr (Dirkes and Hanf 1998).

In addition to effects on humans, effects on the ecosystem are also of concern. One example is the potential effect of contaminants on salmon spawning beds located in the Columbia River adjacent to the 100 Areas.

G.1.6 Monitoring

G.1.6.1 Scope. The Monitoring technical element includes the spatial and temporal measurement of chemical concentrations and associated transport parameters in the vadose zone, groundwater, and Columbia River. These measurements are evaluated against a baseline or trend to determine if changes have occurred and to judge if and how contaminants move from source terms, through the vadose zone and groundwater, and into the Columbia River system.

The primary goals of the Monitoring technical element are to detect new sources of contamination and track the movement of existing contamination from source term to the Columbia River downstream of the Hanford Site. Contaminant plumes emanating from existing sources must be monitored to provide data for hazards assessment, developing remedial measures, and judging the success of applied remedial actions. The need for monitoring any portion of the transport pathway between a source and the Columbia River begins with a perceived hazard. Depending on results of a risk assessment or a decision to apply remedial measures, the decision to monitor will be made. Not all sites can be characterized at the same time, making it necessary to prioritize the order in which sites are evaluated. In addition to these requirements, some monitoring is required to comply with environmental regulations (i.e., *Resource Conservation and Recovery Act of 1976* [RCRA], CERCLA, or the *Atomic Energy Act of 1954* [AEA]).

The environmental transport pathways that are subject to monitoring are leaching of contaminants through the vadose zone into the groundwater, advective transport of contaminants through the groundwater system to the Columbia River, and the advective transport of contaminants downstream from the Hanford Site in the Columbia River. The contaminants monitored, monitoring locations, and monitoring frequency depend on the proximity of the plume to its source and the transport behavior of the contaminant considered.

Monitoring methods include collecting discrete samples of water and soil, and in situ monitoring using pressure transducers for water level measurements, specific ion probes for water quality data, and moisture-sensing instruments. Geophysical tools lowered into boreholes are used for radiological monitoring. Monitoring locations include vadose zone boreholes (dry wells), groundwater wells, riverbank seepage sites, aquifer sampling tubes near the river shoreline, porewater sampling tubes in the riverbed sediments, riverbed sediment, and the river water column.

A primary task of monitoring is detecting (1) new sources of contamination; (2) changes in the movement of existing contamination; and (3) changes in the characteristics of contamination. An equally important task is supplying data to evaluate the performance of remedial actions.

The geographic scope varies, depending on the requirements defined by other technical elements, but may extend from contaminant source areas on the Hanford Site to locations in the Columbia River downstream of the Hanford Site.

G.1.6.2 Current state of knowledge. This section documents the current status of environmental monitoring related to the Groundwater/Vadose Zone/Columbia River project. The emphasis is on the monitoring that is performed, not the contamination status of each media type monitored. Refer to the vadose zone, groundwater, and Columbia River technical elements for discussions of the current conditions in each of the media types.

Regulatory Requirements for Environmental Monitoring

Environmental monitoring at the Hanford Site is based on a wide range of legislation, promulgated regulations, and regulatory agreements. This section summarizes the regulatory framework on which the monitoring is based.

The four major legislative drivers for environmental monitoring are the AEA, RCRA, CERCLA, and the *Superfund Amendments and Reauthorization Act of 1986* (SARA). From these major pieces of legislation, federal regulations and Washington State Codes were promulgated and DOE orders were enacted. These overlapping regulations govern all aspects of environmental monitoring, remedial investigations, and remediation. The integration of these activities is summarized in the *Environmental Monitoring Plan United States Department of Energy Richland Operations Office* (DOE 1997e). The monitoring requirements specified focus on groundwater and Columbia River monitoring. No regulations specifically address vadose monitoring except as pertaining to leak detection associated with underground storage tanks. CERCLA and RCRA address vadose zone characterization, but not monitoring.

Vadose zone monitoring is currently being performed in and around tank farms and liquid waste disposal sites. Tank farm monitoring is at the stage where a baseline is being established by performing the first systematic monitoring of all SSTs in which high-level radioactive wastes are stored (DOE 1995a). The baseline is established by applying borehole spectral gamma logging, which will be repeated in subsequent years. This baseline is scheduled for completion in mid-FY99. Field logging is scheduled for completion in October 1998, with final reports issued in April 1999.

Leak detection monitoring is planned to take place during retrieval activities associated with SSTs. Primary COCs have been identified as the long-lived mobile radionuclides (i.e., ^{99}Tc, ^{79}Se, and uranium isotopes). Potential other analytes include moisture content/change and temperature. Monitoring activities within the tank farm vadose zone will likely be concentrated on tanks that contain drainable liquid components or those that are undergoing retrieval activities. Primary tank monitoring is performed inside the tanks. Leak detection monitoring systems that are ex situ will be designed and implemented on either tank- or tank farm-specific bases. Active monitoring of the TWRS vadose zone will be initiated during investigation of or following designation of a tank as an assumed leaker. Minimal monitoring of SSTs is planned; this monitoring will take place immediately before a tank is retrieved and following completion of retrieval. Leak detection monitoring is envisaged as monitoring moisture content changes in a

real-time mode, allowing corrections to be made in a timely fashion. Boreholes will be installed predominantly for vadose zone characterization and, possibly, for leak detection. Pending the successful demonstration of cone penetrometer deployed sensors, these tools may be substituted for selected boreholes. Directional drilling (horizontal to subhorizontal) boreholes are being considered for placing leak detection sensors and for characterization sampling. Boreholes that present direct pathways through the vadose zone to the groundwater will require abandonment.

Other vadose zone monitoring within the Groundwater Program is at an early stage. A draft of the first high-level monitoring plan is currently being prepared, and a few selected sites have been monitored using spectral gamma logging. In the past, wells around many of the tank farms and liquid disposal sites were routinely logged using gross gamma logging techniques (Additon et al. 1978a; 1978b; Fecht et al. 1977).

Current Status of Hanford Groundwater Monitoring

Contaminant monitoring is conducted at those CERCLA OUs with known groundwater contaminants that cannot or will not be remediated, but that require plume monitoring to ensure natural attenuation and for plume tracking purposes. Assessment monitoring at OUs is conducted to ascertain and monitor the effectiveness of groundwater remediation activities (i.e., contaminant plume pump-and-treat projects).

The *Groundwater Remediation Strategy* (DOE-RL 1995c) establishes that the overall goal of groundwater remediation on the Hanford Site is to restore groundwater to its beneficial uses in terms of protecting human health and the environment and its use as a natural resource. In recognition of the Hanford Future Site Uses Working Group (Drummond 1992) and public values, the strategy establishes that the site-wide approach to groundwater cleanup is to remediate the major plumes found in the reactor areas and to contain the spread and reduce the mass of the major plumes found in the 200 Areas.

The extent, frequency, and type of groundwater monitoring are determined using the EPA's DQO process. This process leads to collecting new environmental data that support decisions associated with remediation alternatives. By following the DQO process, new data are obtained in an effective and cost-efficient manner.

Records of Decision (RODs) between regulators and principal responsible parties (e.g., DOE) are published that describe the agreed-upon remediation alternative. Where active groundwater remediation is pursued, a monitoring plan is developed to (1) evaluate the performance of the activities relative to stated objectives, and/or (2) demonstrate that ROD requirements are being met at compliance locations.

Some RODs may stipulate no remediation activities other than natural attenuation. Monitoring will usually be required to demonstrate that groundwater conditions remain as anticipated by the remedial investigation. This monitoring is intended to ensure the public that the contamination problem is not becoming worse with time.

The following provides a brief status of each groundwater OU, with respect to groundwater monitoring:

- **100-BC-5**. No interim action groundwater remediation activities. Operable unit environmental monitoring is conducted under a *Tri-Party Agreement* Change Control Form (M-15-96-07, dated July 31, 1996). There are no RCRA treatment, storage, and/or disposal (TSD) facilities or operating facilities in the OU. Remediation of surface waste sites is under way and includes large-scale excavations.

- **100-KR-4**. An interim action pump-and-treat system is addressing chromium contamination between the 116-K-2 "mile long trench" and the river. Performance environmental monitoring is conducted under DOE-RL 1997d. Additional OU monitoring is conducted under a *Tri-Party Agreement* NPL Agreement/Change Control Form (Control No. 108, dated November 20, 1996). Operational monitoring associated with the 100-K Area Fuel Storage Basins is conducted under Johnson and Chou (1995). There are no RCRA TSD facilities in the OU. Remediation involving large-scale excavations of surface waste sites has not yet started.

- **100-NR-2**. An interim action pump-and-treat system is addressing the movement of ^{90}Sr-contaminated groundwater toward the Columbia River. Extracting groundwater reduces the water table gradient that controls the rate of flow to the river. A minor amount of ^{90}Sr is also removed from the aquifer. Environmental monitoring is conducted as a requirement in an Action Memorandum from Ecology (Butler and Smith 1994, as interpreted in 100 NPL Agreement/Change Control Form, Control No. 113, dated March 25, 1997). Other OU monitoring is conducted under a *Tri-Party Agreement* Change Control Form (M-15-96-08, dated October 9, 1996). The previous monitoring activities are summarized in an update to the remediation system performance monitoring plan (Peterson 1998). RCRA TSD monitoring is also conducted for several TSD facilities and is described in a monitoring plan (Hartman 1993a). Large-scale excavations to remediate surface waste sites have not started.

- **100-HR-3**. An interim action pump-and-treat system addresses chromium contamination in groundwater that discharges to the river in areas of sensitive benthic habitat. Groundwater is extracted from well networks in the 100-D/DR and 100-H Areas, and chromium is removed. Performance monitoring is described in a plan (DOE-RL 1997d). Other OU monitoring is conducted under a *Tri-Party Agreement* NPL Agreement/Change Control Form (Control No. 107, dated November 20, 1996). RCRA postclosure monitoring for the 183-H TSD facility in the 100-H Area is described in a monitoring plan (Hartman 1997). Large-scale excavations to remediate surface waste sites is in progress at the 100-D/DR Area, but has not yet started in the 100-H Area.

- **100-FR-3**. There are no interim action groundwater remediation activities under way in the 100-F Area. Operable unit monitoring is conducted under a *Tri-Party Agreement* Change Control Form (M-15-96-06, dated July 31, 1996). There are no RCRA TSD facilities or operating facilities in the OU. Remediation of surface waste sites involving large-scale excavations has not begun.

- **200-UP-1**. An interim action pump-and-treat system is operating to remove uranium and technetium from the high-concentration area of the groundwater plume in the 200 West Area. The extracted water is piped to the 200 Areas ETF for treatment, and sent to the State-Approved Land-Disposal Site north of the 200 West Area for disposal. The Interim Remedial Measure (IRM) ROD was issued in February 1997 (Ecology et al. 1997). Performance monitoring is described in DOE-RL 1997a.

- **200-ZP-1**. An interim action pump-and-treat system is operating to remove carbon tetrachloride from the high-concentration area of the groundwater plume in the 200 West Area. Carbon tetrachloride is removed from the extracted water at an onsite treatment facility, and the resulting clean water is reinjected into the aquifer. The IRM ROD was issued in June 1995 (EPA 1995b). Performance monitoring is described in the *200-ZP-1 IRM Phase II and Phase III Remedial Design Report* (DOE-RL 1996b), and in the *200-ZP-1 Groundwater Sampling and Analysis Plan* (BHI 1995b).

- **200-ZP-2**. An interim action soil vapor extraction system is operating to remove carbon tetrachloride from the vadose zone in the 200 West Area to minimize additional contamination of the underlying groundwater. Authorization to conduct the interim action was provided in an Action Memorandum from EPA and Ecology (EPA 1992). Soil vapor monitoring of carbon tetrachloride concentrations throughout the vadose zone is conducted using wells and soil vapor probes. The monitoring plans are modified periodically and approved by EPA and RL at Unit Manager Meetings.

- **200-BP-5**. Groundwater within the 200-BP-5 OU in the 200 East Area contains a $^{90}Sr/^{137}Cs/^{239,240}Pu$ plume and a $^{60}Co/^{99}Tc$/cyanide/nitrate plume. Treatability tests (using pump-and-treat systems) were conducted in FY95. Following these treatability tests, it was determined that no further action at either plume was required. Annual groundwater monitoring for the 200-BP-5 OU is performed.

- **200-PO-1**. The 200-PO-1 OU contains tritium, ^{129}I, and nitrate groundwater plumes, which cover broad areas within and southeast of the 200 East Area. The preferred corrective action proposed in the RCRA permit modification is natural attenuation coupled with groundwater monitoring (DOE-RL 1996a). Groundwater monitoring of the 200-PO-1 OU is currently included in the site-wide groundwater monitoring strategy (DOE-RL 1995c, BHI 1996). Groundwater monitoring plans for the nine RCRA TSD units within 200-PO-1 also specify monitoring requirements.

- **300-FF-5**. Groundwater within the 300-FF-5 OU contains primarily uranium and two chlorinated hydrocarbon contaminants. The remedial action specified in the ROD is natural attenuation coupled with groundwater monitoring (Ecology et al. 1996b). Groundwater monitoring requirements are specified in the operations and maintenance plan (DOE-RL 1995d).

- **1100-EM-1**. The 1100-EM-1 OU contains the Horn Rapids Landfill. The remedial action specified in the ROD is monitored natural attenuation, with institutional controls on drilling of new water-supply wells (Ecology et al. 1993). The 1100-EM-1 OU was removed from the

National Priorities List in September 1996. A compliance network of groundwater wells adjacent to the Horn Rapids Landfill is monitored for volatile organic compounds, chromium, and nitrate (DOE-RL 1995a).

There are 25 RCRA facilities and units (or waste management areas) that require groundwater. Samples were collected from approximately 239 RCRA wells site wide in 1997. Groundwater samples were analyzed for a variety of dangerous waste constituents and site-specific constituents, including selected radionuclides. The constituent lists meet the minimum RCRA regulatory requirements and are integrated with other groundwater project (e.g., environmental surveillance to meet DOE orders, and CERCLA) requirements at the Hanford Site. During FY97, no new RCRA wells were installed, but 11 new wells will be added to the groundwater network during FY98. Of these 11 wells, 8 will be installed to replace RCRA network wells going dry due to declining groundwater conditions in the 200 West Area, one well is for RCRA assessment at the SST waste management area B-BX-BY, and one is to enhance the detection program at SST waste management area U. In addition to these existing network additions, one borehole is being added to characterize and monitor a proposed new RCRA facility, the ILAW Disposal Complex, located in the 200 East Area.

As of June 1998, 16 waste management areas were monitored under detection programs and did not adversely affect groundwater quality. The other nine waste management areas were monitored under assessment or compliance programs to determine the impacts (source, rate, and extent) of contamination detected in groundwater. Highlights of 1997 RCRA monitoring activities are summarized below.

Four of the seven SST waste management areas were monitored under assessment programs in 1997, primarily to determine the source of contamination detected in downgradient and surrounding wells. The groundwater quality assessment results for these waste management areas, T, TX-TY, S-SX, and B-BX-BY, were released in early calendar year 1998 (Hodges 1998; Johnson and Chou 1998; and Narbutovskih 1998). These reports conclude that the tank farms cannot be ruled out as a potential source of groundwater contamination. The report findings require groundwater monitoring at the T, TX-TY, S-SX, and B-BX-BY Tank Farms to continue under a new phase (II) of assessment, which will be planned and initiated in 1998.

The groundwater quality assessment results for the 216-U-12 Crib were reported during 1997 (Williams 1998), and concluded that the crib is the source of nitrate and ^{99}Tc contamination in the groundwater. RCRA regulations require the site to remain in assessment monitoring. The objectives of the assessment program are to (1) determine if the flux of constituents out of the vadose zone into the groundwater is increasing or decreasing; (2) monitor the known contaminants until a near-term interim corrective action is defined; and (3) monitoring under interim status assessment until a final-status monitoring plan is implemented during closure of the facility.

The groundwater quality assessment results for the 216-B-3 Pond were reported during 1997 (Barnett 1998), and concluded that the pond has contributed no definable hazardous waste contamination to groundwater, despite erratic elevated total organic halides. The site reverted to an indicator evaluation program in October 1997.

The 183-H solar evaporator basins were monitored under final-status regulations during 1997. The basins have contaminated the groundwater with ^{99}Tc, uranium, nitrate, and chromium at levels that exceed applicable concentration limits. Corrective action will be addressed under the CERCLA program; an interim remedial action (pump-and-treat system) for chromium began operation in 1997. Groundwater monitoring to meet RCRA requirements will continue during the remediation.

The 316-5 process trenches changed from an interim-status assessment program to a final-status compliance-monitoring program in December 1996. The site was immediately triggered into a corrective action program because the concentration limits for some constituents were exceeded. A RCRA corrective action groundwater monitoring plan was submitted to Ecology, and is expected to be implemented in 1998. Contaminant concentrations at the site will be allowed to attenuate naturally as approved under the CERCLA ROD.

RCRA groundwater monitoring programs for the 216-A-10, 216-A-36B, and 216-A-37-1 Cribs were combined into a single assessment program in 1997. Specific conductance is elevated downgradient of the cribs and has a direct correlation with nitrate and tritium contaminant plumes in the area.

Current Status of Hanford Reach Columbia River Monitoring

The Columbia River near the Hanford Site is primarily monitored according to the Environmental Monitoring Plan (EMP) (DOE-RL 1997b). Additional Columbia River monitoring is to collect riverbank spring water samples and measure external radiation at the 100-N shoreline (Perkins et al. 1997).

The design of the surface water monitoring program is based on the DOE guide for environmental surveillance (DOE 1991). The sampling plan is published annually (Bisping 1997a), and includes the media, locations, sample types, frequency, and analytes. All samples are collected according to documented procedures (PNL-MA-580). Selected duplicate samples are collected with the DOH (Dirkes and Hanf 1997). Sampling locations and analytes are determined using a pathway analysis process.

River Water. Contaminants are known to have entered the Columbia River from operations at the Hanford Site. Consumption of water or biota from the Columbia River or irrigated foodstuffs, and direct exposure from recreational uses can expose the public to these contaminants.

Background samples are collected at the Priest Rapids Dam and Vernita Bridge. Continuous samples are collected at Priest Rapids Dam and the Richland pumphouse to assess any changes in contaminant concentrations entering the river through the Hanford Reach. The Richland pumphouse is the first public water supply downstream of the Hanford Site. River transect samples are collected to determine the cross-river concentrations and to determine localized zones of influence near contaminated groundwater discharges. Cross-river transects are collected periodically from locations at the Vernita Bridge (background), the 100-N Area, the 100-F Area, old Hanford Townsite, the 300 Area, and the Richland pumphouse. Contaminants

of concern include gross alpha, gross beta, gamma-emitting radionuclides, ^{3}H, ^{90}Sr, ^{99}Tc, ^{129}I, uranium, plutonium, metals, volatile organic compounds, anions, and water quality parameters. In addition to the SESP monitoring, the U.S. Geological Survey conducts environmental monitoring on the Columbia River in conjunction with the National Stream Quality Accounting Network (NASQAN).

Periodic monitoring of contaminant concentrations in select aquifer tubes is required to monitor the extent of contaminated groundwater plumes, particularly in locations with limited access to riverbank springs, and to monitor the flux of contaminant to the river during high river stage. Aquifer tube sampling is required to monitor the spatial extent of underwater upwelling. This work should include bottom-contacting conductivity and gamma measurement probes to determine the spatial extent of upwelling.

Riverbank Springs. Riverbank springs discharge contaminated groundwater at select locations along the Hanford Reach. Seasonal monitoring of riverbank springs and sediments associated with these springs is required to determine changes in the extent of the contaminated groundwater plumes. In addition, riverbank spring sampling is needed to monitor the effect of river stage on contaminant concentrations. This monitoring also confirms findings of the Groundwater Monitoring Project on the extent of contaminated groundwater plumes. Riverbank springs are sampled at 100-B, 100-K, 100-N, 100-D, 100-H, 100-F, old Hanford Townsite, and the 300 Area. Contaminants of concern include ^{3}H, ^{60}Co, ^{90}Sr, ^{99}Tc, ^{129}I, uranium, metals (primarily Cr), volatile organics, and anions.

Columbia River Sediment. Sediments along the Hanford Reach are known to contain elevated concentrations of radionuclides and produce higher than background levels of external radiation. Contaminants in sediments may lead to public exposure through the ingestion of aquatic species, through sediment resuspension into drinking water systems, and as an external radiation source. Sampling of the upper layer of the sediments (i.e., most recent sediment deposits) is conducted annually at Priest Rapids Dam (background), sediment accumulation areas in the Hanford Reach, and at McNary Dam. Sampling is conducted after the spring high-water period to provide consistent measurements and a more easily interpreted information base. Core samples may need to be collected periodically to determine the fate and buildup of sediment material over time or for any future river activity that may disturb the sediments. Contaminants of concern in sediments include gamma-emitting radionuclides, ^{90}Sr, uranium, plutonium, and metals.

Periodic sediment core sampling may be required in the larger sediment deposits, particularly if sediment resuspension is possible. A bottom-contacting gamma probe should be developed to screen sediment deposition zones for contaminants. A sampling methodology using sediment traps should be developed to monitor the movement of contaminated sediment.

External Radiation. Monitoring of external radiation levels near the Hanford Reach shoreline is conducted on a continuous basis using thermoluminescent dosimeters, and on a periodic basis using survey equipment. The 100-N Area shoreline is an area of special interest because of elevated radiation levels at the shoreline from the waste effluent cribs.

Columbia River Aquatic and Riparian Biota. Monitoring of contaminant concentrations in Hanford Reach biota is conducted on a seasonal basis to verify that ecological exposures and human consumption dose remains low. Contaminants of concern include gamma-emitting radionuclides, ^{90}Sr, uranium, and metals.

Offsite Irrigation Water. Periodic monitoring of irrigation water withdrawn downstream from Hanford facilities is conducted to evaluate this pathway. Contaminants of concern include gross alpha, gross beta, gamma emitters, ^{3}H, ^{90}Sr, and uranium.

Onsite Surface Water. While not accessible to the public, West Lake and the Fast Flux Test Facility process water pond/drainfield are used by wildlife that can move off site. The water bodies are monitored periodically to determine the potential exposure to the public through this pathway. Contaminants of concern include gross alpha, gross beta, gamma-emitting radionuclides, ^{3}H, ^{90}Sr, and ^{99}Tc.

Monitoring Strategy

Decisions regarding application of remedial measures and end states will be based on data collected during a characterization phase. After remedial measures have been applied, future site risks will depend on the end states and resulting transport behavior of remaining contamination. Monitoring of key contaminants or conditions on which their transport behavior is based will be decided at that time. Some sites may have to be monitored before characterization and remedial actions due to priority decisions and budget constraints that result in delays in characterization for years in the future. During this interim, an appropriate monitoring system for each source term must be determined from a holistic consideration of all of the transport pathways associated with the source and a strategy for minimizing environmental degradation. The key is to monitor the constituent producing the risk, if possible; monitor surrogate constituents, if necessary and possible; and/or monitor indicators of changing transport conditions, if warranted. These data would then be evaluated in light of change from an established baseline and predetermined action/notification criteria. The elements of a monitoring project include specific plume data needs such as COCs, surrogate constituents, site properties such as moisture content, monitoring technologies, monitoring location in space and time, and delineation of critical parameter values against which monitoring data are compared.

G.1.7 Regulatory Path

G.1.7.1 Scope. The scope of the regulatory path forward activity is (1) developing a site-wide approach to vadose zone, groundwater, and Columbia River assessment that is integrated, consistent, and practical, and (2) ensuring that all applicable regulatory requirements and drivers are fully integrated into and across the technical activities associated with the assessment. The scope would include the following elements:

Regulatory Authority. Define the regulatory authority(ies) applicable to the assessment activities. The lead regulatory authority and secondary authorities will define the process and requirements for regulatory compliance.

Land Use. In concert with the stakeholders, clearly establish land use and exposure scenarios for the Hanford Site and the relationship between land use and remediation under RCRA[1], CERCLA, the *Model Toxics Control Act* (MTCA), and the AEA. The exposure scenarios will be a key element in performing the impact assessment and will be used to define end states for environmental media. Land-use decisions must be in place for the Hanford Site to move forward on a unified and cost-effective assessment.

Constituents of Concern. Identify the full range of RCRA hazardous constituents and CERCLA hazardous substances and ensure that they are considered in planning data collection and impact assessment activities.

Specific Requirements. Identify the specific regulatory requirements applicable to individual activities, and ensure consistency of application across projects. Regulatory requirements and constraints should be considered early in planning specific projects and with an attention equal to that given to the technical requirements and constraints.

G.1.7.2 Current state of knowledge

Regulatory Authority. Both CERCLA and RCRA authorities apply at the Hanford Site. Assessment and management of releases to the vadose zone, the underlying groundwater, the Columbia River, and the accessible environment are the focal points of these regulatory programs and complementary regulatory programs implemented by DOE under authority of the AEA.

Two key documents govern implementation of CERCLA and RCRA at the Hanford Site and the response to releases. The *Tri-Party Agreement* (Ecology et al. 1996a) provides a regulatory framework and schedule for evaluating and remediating releases to the environment. The *Tri-Party Agreement* divides all source sites into one of three categories: CERCLA past-practice, RCRA past-practice, and dangerous waste management units. Although the *Tri-Party Agreement* encourages integration of RCRA and CERCLA, it does not detail the integration process, and actual integration has been slow. The current emphasis is focusing on the similarities in the programs (e.g., MTCA standards are used to establish cleanup levels under both programs) rather than differences in terminology. Ideally, one regulatory authority would be identified as the lead for purposes of terminology, but the process would incorporate requirements of both authorities. The draft *200 Area Implementation Plan* is a good example (DOE-RL 1998a). The *Tri-Party Agreement* also establishes a series of milestones that determine the sequence of remediation activities that are to occur. The Hanford Facility RCRA Permit also governs response actions for dangerous waste management units and RCRA past-practice units (Ecology 1994).

To date, there have been several waste site evaluations leading to CERCLA RODs that require specific remedial action (see Remediation technical element). The exposure scenarios forming the basis for cleanup levels in these RODs have included rural-residential (100 Areas) and

[1] Although the term "RCRA" is used throughout this technical element, it is implicit that many elements of the federal RCRA program have been delegated to the State of Washington and are implemented via the state Dangerous Waste Program.

industrial (300 Areas) (EPA 1995a, 1996). Some of these CERCLA RODs have also addressed remediation at RCRA past-practice units (EPA 1997). There have been no RCRA past-practice units added to the RCRA Permit, in part because the process for governing RCRA past-practice units is still under development by Ecology.

Of the many dangerous waste management units at the Hanford Site, only a fraction has been placed in the RCRA Permit. The closure plans to date for these units have typically been based on clean closure (unrestricted future use), although the Permit allows for modified and landfill closure under specific conditions. Due to the age and constructions of many of Hanford's other units (e.g., single-shell and double-shell tanks), the units are not fully compliant with all applicable RCRA regulations, and instead have RCRA "interim status" to operate until they can be brought into compliance or safely closed.

Land Use. Land use was the subject of a stakeholder working group in 1992 (Drummond 1992), and future land use at the Hanford Site is the subject of the draft *Hanford Remedial Action EIS and Comprehensive Land Use Plan*, soon to be released for public review (DOE 1996a). The EIS evaluates impacts of land-use alternatives for the various areas at the Hanford Site. The EIS does not evaluate impacts associated with remediation; rather, it states that land-use decisions made via the EIS can provide a basis to DOE and the regulatory agencies for making remediation decisions.

Constituents of Concern. Data collection and evaluation activities at the Hanford Site currently are conducted under multiple programs (e.g., RCRA, CERCLA, and DOE orders). There have been efforts to coordinate these activities to address the regulatory requirements of the multiple programs, but further effort is needed. In particular, whether it is to close a RCRA site or remove a CERCLA site from the National Priorities List, there must have been comprehensive consideration of RCRA hazardous constituents and CERCLA hazardous substances. This consideration can be through detailed process knowledge or actual data. There are currently gaps in that analysis for many waste sites.

G.1.8 Remediation Options

G.1.8.1 Scope. The ultimate goal of Hanford Site mitigation and remediation is to (1) prevent further degradation and (2) reduce the impact of existing contamination on human health and the environment. Various options currently are being implemented or considered to attain this goal. Objectives that guide selection of remedial actions include the following:

- Reduce or prevent contamination of the Columbia River.
- Remediate areas of soil contamination consistent with land-use goals.
- Control and/or stabilize sources of contamination.
- Contain and/or remove solid waste stored in landfills.
- Remediate and/or contain groundwater contamination.

Interim actions. Interim remediation is undertaken to mitigate a contamination problem before sufficient information is obtained to make a final closure or remediation decision. These actions include expedited response actions (ERAs) and IRMs. The activities are intended to accelerate

cleanup to control further spread of contamination at inactive facilities. Surveillance and monitoring activities at inactive facilities and waste sites are used to verify that an acceptable condition exists until full-scale remedial actions are initiated.

Remediation alternatives. Selecting an alternative for near-term remediation involves evaluating the available options in light of site conditions and types of contamination. Remediation alternatives that have been successfully implemented on the Hanford Site, or that are considered to have potential application, include the following: no action, institutional controls, engineered surface barriers, removal and disposal, and pump and treat.

No action is required to be evaluated as a baseline for comparison with other remedial alternatives. For the no-action alternative to be selected, a site (in its current condition) must pose no unacceptable threat to human health and the environment.

Institutional controls involve the use of physical barriers (fences) and deed restrictions on access to reduce or eliminate exposure to contamination. Institutional controls are often coupled with groundwater, vadose, surface soil, biotic and/or air monitoring to ensure that exposures are limited by the imposed controls. Many access and land-use restrictions are currently in place at the Hanford Site, and will remain in place during remedial work.

Engineered surface barriers (i.e., caps) function as hydraulic barriers to control the amount of water infiltrating into contaminated media, thus, reducing potential leaching of contamination to groundwater. In addition to their hydraulic performance, barriers also function as a physical limit to direct human and biotic interaction with contamination. Barriers are engineered to limit wind and water erosion and, if needed, can control the release of accumulated gases or attenuate radiation.

Removal and disposal involves the excavation of contaminated material and ultimate disposal in a landfill or other environmentally safe configuration. Depending on the nature (e.g., radioactivity levels, hazardous waste classification) of the waste removed, ex situ treatment may be performed before disposal.

Removal and disposal are effective because contaminated materials are physically removed, there are no long-term requirements for monitoring and maintenance of the site, and there is greater flexibility in future land use. These methods are easily implemented at sites with shallow contamination. Requirements for safety, monitoring, and sampling are generally well understood. Radioactive waste require special handling protocols, and may require remotely controlled equipment if radiation levels are high to preclude the use of standard construction equipment.

Groundwater pump and treat involves the extraction and ex situ treatment of contaminated groundwater, and can be effective for a variety of contaminants. This alternative can also be used to hydraulically control the movement of contaminants in groundwater, to remove contaminant mass, and/or reduce contaminant concentrations. A variety of ex situ treatment processes, such as ion exchange, carbon absorption, and air stripping, are available to address a wide range of contaminants. Pump and treat is a well-developed, commonly used technology

that can be easily implemented. Pump-and-treat systems have been applied at the Hanford Site to remove contaminant mass and/or control contaminant plume movement. The effectiveness of a pump-and-treat system to remove contaminants diminishes as contaminant levels decrease and, depending on cleanup goals, a shift to an alternative remediation technology (such as in situ treatment) may be needed.

Other Technologies. In situ treatment technologies include a broad range of processes in which waste, contaminated soil, or groundwater is treated or immobilized in place or removed by transport through permeable reactive bermes. This feature is advantageous when exposure or worker safety concerns are significant, such as during excavation or where deep vadose zone contamination exists and excavation or placement of surface barriers is impractical or ineffective. Examples of in situ treatments include in situ vitrification, in situ stabilization, soil vapor extraction, in situ redox manipulation, and in situ biotreatment. In situ vapor extraction currently is being used to remediate carbon tetrachloride-contaminated soil at the 200-ZP-2 OU. Examples of in situ groundwater treatments include air sparging and reactive walls.

Monitored Natural Attenuation. Natural attenuation is a passive rather than active treatment. It encompasses natural processes to reduce contaminant toxicity, mobility, or volume. Natural attenuation processes include radioactive decay, biodegradation, biological stabilization, volatilization, dispersion, dilution, chemical or biological stabilization, transformation or destruction, adsorption and desorption, and mineral precipitation.

G.1.9 System Assessment

The system assessment technical element quantifies the environmental consequences of past, present, and future Hanford Site activities on the vadose zone, groundwater, and the Columbia River. Assessment capabilities evaluate the effects of residual contamination from past activities, as well as potential future contamination. The scope of the system assessment technical element includes designing, developing, and applying assessment methods that meet the objectives of the Integration Project. This technical element also provides a vehicle to integrate activities and information generated by the other technical elements, so that coherent and consistent information is available for making major cleanup decisions. The iterative aspect of (1) defining requirements and objectives; (2) obtaining required information and data; (3) interpreting and using the new information; and (4) evaluating the new information in terms of the original requirements is part of this technical element.

The scope and results of assessments made for specific projects, which may be at physical and temporal scales that are more highly resolved than those for an overall system assessment, are coordinated within the system assessment technical element. This integration ensures that the system analysis is reasonably complete and adequate, and that it is internally consistent.

The system assessment scope is oriented toward site-wide and broader scales that consider the significant components of the natural system and waste management issues when evaluating environmental and human health consequences. As a result, system assessments tend to be directed at the longer term consequences of contaminants in the environment. However, because

of the need to evaluate mitigation and remediation alternatives, and impacts from past discharges to the environment, system assessment capabilities must also include near-term durations.

To ensure the coordination and overall consistency of analyses contributing to the system assessment, the system assessment technical element establishes common requirements for shared databases and consensus interpretations of the environmental setting. This technical element is responsible for data-sharing structures. The data-sharing structure recognizes the multiple temporal and spatial scales of observations and required assessments, and ensures that consistent methods are employed for scales ranging from an individual pore or mineral-grain surface to the regional aquifer and the Columbia River.

Once system requirements and standards are agreed upon, they are imposed for all technical elements and scales of analysis. This process ensures completeness and consistency of analyses conducted for other technical elements (e.g., the vadose zone and the groundwater technical elements). In turn, this ensures the applicability of results at a system-assessment scale.

The system assessment technical element is responsible for reconciling technical differences at interfaces between technical elements. For example, the vadose zone technical element provides estimates of past and future releases of contaminants from the vadose zone to the uppermost aquifer. Similarly, the groundwater technical element provides estimates of current and future contaminants within the uppermost aquifer. If the estimate of past releases of vadose zone contaminants to the aquifer fails to agree with the estimate of contaminants in the aquifer, the system assessment technical element, which uses results of both the vadose zone technical element and the groundwater technical element, must satisfactorily resolve the difference.

G.1.9.1 Current state of knowledge. Many project-specific analyses have been made for single contaminated sites or singular aspects of waste migration at the Hanford Site. However, no system-wide assessments of the overall radiological and chemical effects of waste storage and disposal on water resources have been completed. The environmental impact statements issued in 1975 (ERDA 1975) and 1987 (DOE 1987) compiled the data available at those times. The ERDA EIS contains a wealth of information on past Hanford Site operations, but little information on assessed impacts. DOE (1987) contains data and analyses, but it reported only on the alternatives for final disposition of high-level and TRU wastes, and omitted low-level and hazardous chemical wastes.

In the late 1980s, the DOE reached agreement with regulatory agencies on the applicability of RCRA to active facilities and CERCLA to retired facilities, and issued guidance on disposal of radioactive waste (DOE Order 5820.2a). Since then, numerous analyses have supported remediation decisions and continued disposal of low-level radioactive waste. Among the most prominent are the performance assessments for solid waste burial grounds in the 200 West Area (Wood et al. 1995) and 200 East Area (Wood et al. 1996), for the ILAW from the high-level underground waste tanks (Mann et al. 1998), and the TWRS Retrieval Performance Evaluation of the AX Tank Farm for waste retrieval and closure (Jacobs 1998). Another prominent study is the RI/FS for the ERDF (DOE-RL 1994b). Each study examined the environmental impact a single waste form (e.g., solid low-level radioactive waste) or facility (e.g., the ERDF trench), and

forecast contaminant release and subsequent migration through the vadose zone and uppermost aquifer to the Columbia River.

During the late 1980s and early 1990s, estimates were made of the radiation that individuals may have received from radionuclide emissions at the Hanford Site since 1944. A major objective of the study was to estimate doses from exposure to airborne releases of ^{131}I. That regional-scale study was conducted by the Center for Disease Control under the guidance of an independent technical steering panel. Exposure pathways of most interest in this study were the atmosphere (Farris et al. 1994) and the Columbia River (Walters et al. 1994).

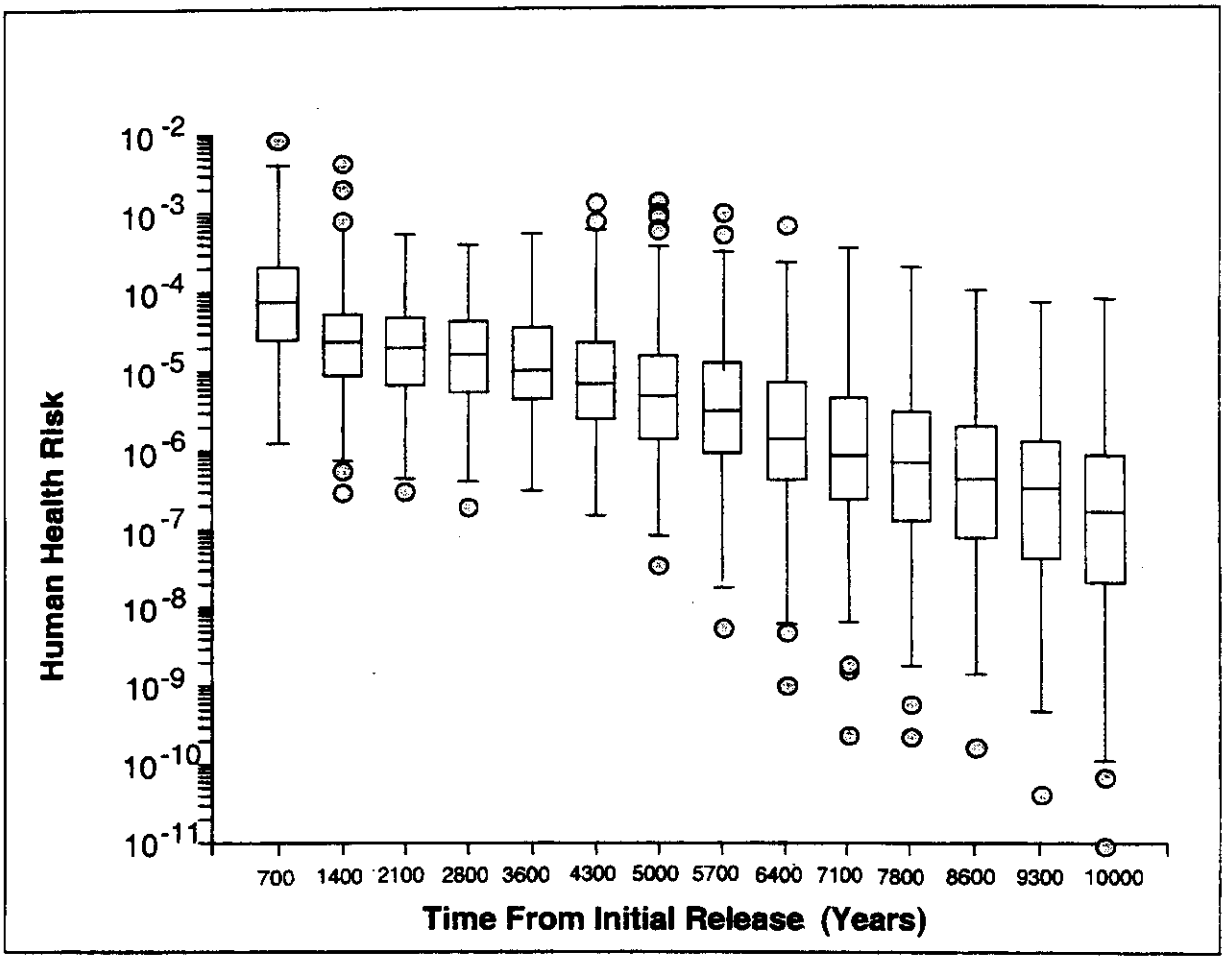
In response to Defense Nuclear Facility Safety Board (DNFSB) Recommendation 94-2, DOE-Headquarters issued guidance to the DOE complex to prepare Composite Analyses to supplement existing analyses of specific waste types or waste disposal sites. This supplemental analysis was to assess the potential for multiple waste forms and contaminated sites to release contamination in ways that superimpose contaminants in time and space, thus potentially exceeding regulatory standards. The first iteration of this Composite Analysis of a post-closure Hanford site (Kincaid et al. 1998) was restricted to planned radioactive waste disposal in the 200 Area Central Plateau. This analysis was further restricted to consider only the most mobile radionuclides with long half-lives, (i.e., ^{14}C, ^{36}Cl, ^{79}Se ^{99}Tc, ^{129}I, and uranium isotopes and their daughter products). Its scope was limited to developing inventory information; simulating contaminant movement in vadose zone, groundwater, and atmospheric pathways; and simulating doses arising from exposure scenarios defined by the *Hanford Site Risk Assessment Methodology* (DOE-RL 1995b).

The CRCIA (Pacific Northwest National Laboratory and CRCIA Management Team Representatives 1998) provided two products. Part 1 of that report is a screening assessment evaluating the potential impact to the Columbia River from current levels of Hanford-derived contaminants. Part 2 of the report provides a suite of guiding principles for an acceptably comprehensive river impact assessment.

The Retrieval Performance Evaluation (Jacobs 1998), scheduled for public release in October 1998, includes a system assessment of the AX Tank Farm. The analysis addressed source term, vadose zone, and groundwater transport, and human health risks; it provides a deterministic calculation for a variety of strategies (Figure G-62) and an uncertainty and sensitivity analysis of the baseline retrieval and closure strategy. The analysis concludes that there are substantial uncertainties associated with long-term risk calculations (4 to 7 orders of magnitude as shown in Figure G-63), and the parameters that dominate uncertainty are associated with the receptor and source terms followed by contaminant transport properties (Tables G-5 and G-6).

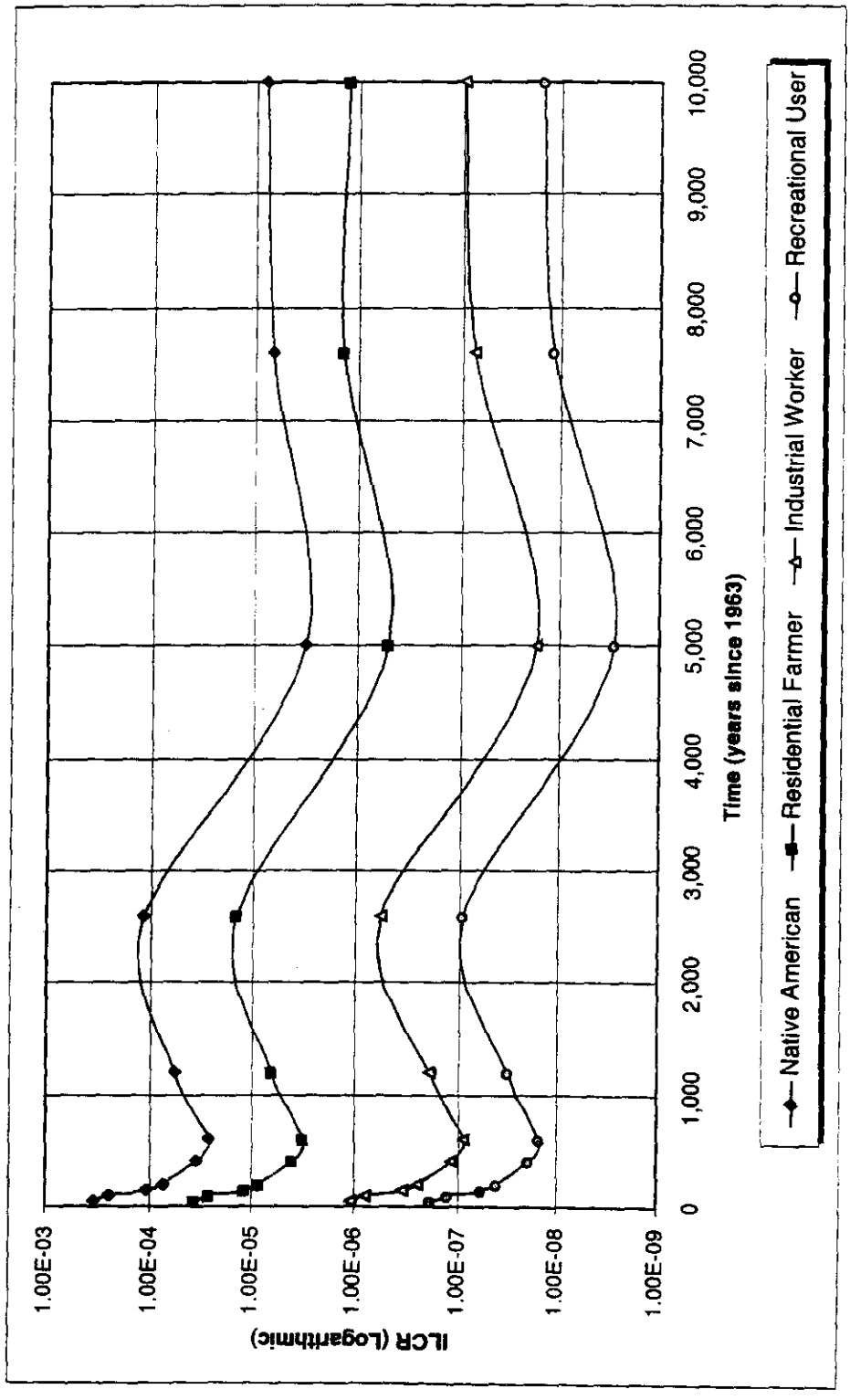
Each of these modeling activities as well as other efforts at the Hanford Site have generated a suite of models (codes and data) that can be used to support the system assessment, if they are appropriate. To evaluate the appropriateness of existing models and establish the need for model development, a team of project scientists, regulators, and stakeholders is evaluating the requirements established for CRCIA. From this activity, requirements will be set to guide development of the system assessment capability.

Figure G-62. Uncertainty Analysis Results for Total Human Health Risk for the AX Tank Farm.



Jacobs 1998

Figure G-63. Long-Term Risk Variations Between Exposure Scenarios, Composite Source Term Nominal Retrieval Losses (1a) AX Tank Farm.



Jacobs 1998

Table G-5. AX Tank Farm Sensitivity Analysis Results with Fixed Exposure Parameters.

Constituent	Variable	Partial
Tc-99	Milk consumption	0.1553
	Retrieval leak volume	0.0901
	Exposure duration	0.0486
	Retrieval leak concentration	0.0274
	Darcy velocity in the groundwater	0.0281
	Past leak concentration	0.0260
	Groundwater thickness	0.0122
	Concentration of Tc-99 in residual waste	0.0112
	Model R^2	0.3988
I-129	Milk consumption	0.2169
	Past leak volume	0.1195
	Exposure duration	0.1352
	Retrieval leak volume	0.0446
	Retrieval leak concentration	0.0323
	Retrieval leak liquid flux (volume/area)	0.0159
	Leafy vegetable consumption	0.0158
	Hydraulic conductivity in vadose zone layer #6	0.0101
	Model R^2	0.5902
U-238	Retrieval leak water volume	0.2300
	Retrieval leak concentration	0.0682
	Exposure duration	0.0658
	Leafy vegetable consumption	0.0201
	Retrieval leak liquid flux (volume/area)	0.0164
	Meat consumption	0.0152
	Past leak volume	0.0141
	Infiltration rate following surface barrier degradation (>500 years)	0.0131
	Total porosity in vadose zone Layer #5	0.0103
	Hydraulic conductivity in vadose zone Layer #5	0.0110
	Field capacity in vadose zone Layer #5 (see Note 2)	0.0099
	Field capacity in vadose zone Layer #8 (see Note 2)	0.0085
	Model R^2	0.4825

Jacobs 1998

Table G-6. AX Tank Farm Sensitivity Analysis Results.

Constituent	Variable	Partial
Tc-99	Retrieval leak volume	0.2228
	Darcy velocity in groundwater	0.0823
	Past leak concentration	0.0733
	Retrieval leak concentration	0.0762
	Groundwater thickness	0.0338
	Past leak infiltration rate (volume/area)	0.0213
	Total porosity in saturated zone	0.0082
	Past leak volume	0.0085
	Model R^2	0.5263
I-129	Past leak concentration	0.6088
	Retrieval leak volume	0.1139
	Retrieval leak concentration	0.0204
	Darcy velocity in groundwater	0.0223
	Groundwater thickness	0.0094
	Past leak volume	0.0074
	Kd in layer 3	0.0050
	Kd in layer 7	0.0036
	Model R^2	0.7908
U-238	Retrieval leak volume	0.3799
	Retrieval leak concentration	0.0654
	Past leak concentration	0.0244
	Total porosity in saturated zone	0.0188
	Groundwater thickness	0.0152
	Kd in layer 3	0.0141
	Residual waste solubility	0.0098
	Model R^2	0.5276

Jacobs 1998

G.2 COMPOSITE ANALYSIS INVENTORY SUMMARY

A small group of mobile radionuclides and chemicals are known to be of primary interest relative to long-term groundwater contamination because they have already contaminated the unconfined aquifer and are known to be chemically mobile. Radionuclides include ^{99}Tc, ^{129}I, uranium, and tritium. Chemicals include carbon tetrachloride, trichloroethylene, nitrite, nitrate, cyanide, and chromium. Other radionuclides that are likely to be less mobile but present in groundwater due to direct injection are ^{139}Cs, ^{90}Sr, and plutonium.

G.2.1 Active or Planned Disposal Facilities

The four active or planned LLW disposal facilities at the Hanford Site are as follows:

- Post-1988 solid waste burial ground in the 200 West Area
- Post-1988 solid waste burial ground in the 200 East Area
- Environmental Restoration Disposal Facility
- Disposal facility for ILAW.

Each of these disposal sites is located on the central or 200 Area Plateau of the Hanford Site. Figures G-5 and G-6 show the position of these LLW disposal sites on the 200 Area Plateau.

In accordance with DOE Order 5820.2A (DOE 1988b), performance assessments have been completed for the solid waste burial grounds located in the 200 West and 200 East Areas. These burial grounds have received solid waste since DOE Order 5820.2A went into effect (September 26, 1988). Burial grounds in the 200 West and 200 East Areas were treated separately in performance assessments by Wood et al. (1995) and Wood et al. (1996). Under the CERCLA program, an RI/FS was completed for the ERDF (DOE-RL 1994b). RL submitted a performance assessment[(2)] for the ILAW from Hanford Site tanks to DOE-Headquarters. Pending review and approval by DOE-Headquarters, the ILAW will be disposed of in a combination of four existing vaults and new facilities that are now in the conceptual design stage.

G.2.2 Other Sources of Radioactive Contamination

As is apparent from the description of Hanford Site operations, other radioactive sources are present or will be placed on the 200 Area Plateau of the Hanford Site. These sources may create contaminant plumes in the unconfined aquifer at the same time and in the immediate vicinity of plumes generated by the four LLW disposal facility sources described above. These sources are the responsibility of the DOE and include the following list:

(2) Mann, F. M., R. P., Puigh II, C. R. Eiholzer, Y. Chen, N. W. Kline, A. H. Lu, B. P. McGrail, and P. D. Rittman. Publication March 1998. *Hanford Immobilized Low-Activity Tank Waste Performance Assessment.* DOE/RL-97-69, Rev. 0. U.S. Department of Energy, Richland Operations Office, Richland, Washington.

- 149 SSTs arrayed in 12 tank farms (i.e., T, TX, TY, U, S, SX, B, BX, BY, C, A, and AX).
- 28 double-shell tanks arrayed in six tank farms (i.e., SY, AP, AN, AZ, AY, and AW).
- Past-practice (pre-1988) solid waste burial grounds.
- Past-practice (pre-1988) liquid discharges to cribs, ditches, french drains, trenches, and ponds.
- Graphite cores from nine surplus production reactors.
- Canyon buildings and related structures (e.g., B Plant, PUREX, T Plant, U Plant, REDOX, Z Plant [PFP], and the PUREX tunnels).

In addition, a commercial low-level radioactive waste disposal facility operated by Ecology is located immediately southwest of the 200 East Area, and was included in this analysis because of its proximity to DOE operations on the plateau. The treatment of each of these facilities was addressed in the analysis.

G.2.3 Solid Waste Burial Grounds

Low-level waste has been disposed in the 200 West and 200 East Area solid waste burial grounds since nuclear materials production and processing began at the Hanford Site. The initial generators of the majority of disposed waste were the chemical separations plants in each area: T Plant, U Plant, REDOX, and PFP, and tank farm operations in the 200 West Area; and PUREX, B Plant, and tank farm operations in 200 East Area. Disposals to the 200 West Area LLW facility support both onsite and offsite generators. The U.S. Navy is the only offsite generator contributing to waste disposal in the 200 East Area.

Solid waste disposals have occurred for several decades, and as one burial ground filled up, another burial ground was opened. The current method of disposal for LLW is to place waste in an unlined trench about 6 to 7 m deep and of variable length up to about 500 m. Slopes of trenches are angled at about 45 degrees. Waste packages are stacked to within about 2.5 m of the surface, and soil is placed over the packages to grade. Some surfaces have been vegetated with grasses to stabilize the cover. In the future, efforts may be made to stabilize the waste in situ to prevent subsidence and to reduce recharge through the waste deposit.

Active burial grounds are defined as those that have received waste since September 26, 1988. Active disposal trenches are found in burial grounds 218-W-3A, 218-W-3AE, 218-W-4C, and 218-W-5 in the 200 West Area; and in burial grounds 218-E-10 and 218-E-12B in the 200 East Area. Since September 26, 1988, when DOE Order 5820.2A went into effect, 23 trenches have been open and receiving waste in the 200 West Area burial grounds, and 6 trenches have been open and receiving waste in the 200 East Area burial grounds. One additional trench in

218-E-12B, Trench 94, is dedicated to the disposal of defueled ship reactor compartments generated by the U.S. Navy. The performance assessments for the active 200 West and active 200 East solid waste burial grounds stipulate an expected 30 years of operation from the September 1988 start date.

In the past, wastes from the chemical separations plants were a function of plant operation. Today the wastes disposed in solid waste burial grounds at the Hanford Site are from facility deactivation projects. Whatever the source, those wastes containing sufficient inventories of waste that could migrate through the environment and result in potential radiation dose (e.g., ^{99}Tc and uranium) are stabilized in various grout formulations or disposed in high-integrity containers, or both.

Radionuclides remaining after the screening process for the 200 East Area burial grounds were long-lived and mobile (Wood et al. 1996). A list of all radionuclides considered in the dose analysis for the 200 East Area burial grounds appears in Wood et al. (1996). The screening process eliminated all moderately to strongly sorbed radionuclides because they were predicted to have no significant ability to contaminate groundwater in the next 1,000 years. Radionuclides passing the screen were tritium, ^{14}C, ^{36}Cl, ^{79}Se, ^{99}Tc, ^{129}I, 187^{Re}, and the uranium isotopes. Because of their unique inventory and waste form degradation characteristics, the U.S. Navy ship reactor compartments were treated as a special case. In this special case, the list of radionuclides potentially able to contaminate groundwater is a subset of the above list: ^{14}C, ^{36}Cl, ^{79}Se, ^{99}Tc, and ^{129}I.

One isotope, ^{187}Re, that passed the screen was eliminated from further consideration. The screen criteria included potential mobility and decay half-life; however, ^{187}Re is not present at the Hanford Site in sufficient quantity to present a health threat. Rhenium-187 is an activation product of tungsten, and its existence in significant quantities in the DOE radioactive waste would indicate that a significant quantity of tungsten had been employed in the fuel or its cladding. This was not the case. Schmittroth et al. (1995) estimated the total production of ^{187}Re at 8.6 x 10^{-6} Ci using the Oak Ridge Isotope Generation and Depletion (ORIGEN2) code (Croff 1980). Based on its potential contribution to drinking water dose, this quantity will not significantly contribute to dose.

Shallow land burial of solid waste has occurred at the Hanford Site since the mid-1940s. Burial grounds closed prior to September 26, 1988, are considered among the other sources of radioactive contamination. Prior to 1970, no distinction was made between TRU waste and LLW. In 1970, the Atomic Energy Commission required that TRU waste be retrievably stored. In the early 1980s, low-level liquid organic waste was segregated from LLW and placed in retrievable storage underground. Low-level waste was further categorized in 1987 when mixed waste (i.e., waste containing both radioactive and hazardous chemicals) disposal in unlined trenches was discontinued. Contact-handled mixed waste is currently stored in aboveground buildings in the Central Waste Complex. Post-1988 LLW in burial grounds exhibits much lower inventories compared to the inventories of pre-1988 burial grounds. The pre-1988 solid waste burial grounds are designated past-practice units, and their remediation, final closure, and end state will be negotiated through the CERCLA process.

The SWITS database (Clark 1995) accounts for all waste disposed in the LLBGs and is kept current as waste is disposed. Inventories for both inactive and active burial grounds are recorded. Both radionuclides and hazardous chemicals are tracked in SWITS. The completeness of the records decreases for earlier disposed wastes. Radionuclide estimates are provided for all disposed waste, but chemical inventories are generally unavailable for waste disposed prior to 1980 and marginally available between 1980 and 1987.

Inventories of key mobile radionuclides disposed in each of the 200 East and 200 West Area solid waste burial grounds were estimated for pre-September 1988 and post-September 1988 amounts using an aged-fuel-ratio methodology and the record of cesium, uranium, or plutonium disposal. These inventories of the key mobile radionuclides were estimated using radionuclide inventory information from the SWITS database (Clark 1995). In addition, the ORIGEN2 code (Croff 1980) was used to estimate the abundance of key mobile radionuclides potentially present but not reported in the SWITS database.

Activities of ^{137}Cs and masses of uranium and plutonium disposed were obtained directly from the SWITS database. Two types of SWITS database reports were generated for two periods. The types of reports summarized unsegregated waste and post-1970 non-TRU segregated wastes. These reports were generated for startup through September 1988 and startup through December 1996. The inventories of uranium, plutonium, and ^{137}Cs disposed were totaled between the unsegregated disposal inventory and the segregated non-TRU inventory. This excluded the TRU waste, which was not expected to remain onsite. By subtracting the September 1988 inventory from the December 1996 inventory, an estimate of the post-September 1988 inventory disposed was obtained.

G.2.3.1 Suspect transuranic waste and pre-1988 inventory. Before 1970, TRU waste at the Hanford Site was not segregated prior to disposal (Wood et al. 1995). After 1970, TRU waste, defined as >10 nCi/g, was segregated prior to disposal so that it could be retrieved and eventually be disposed offsite. In 1984, the definition of TRU waste was changed from >10 nCi/g to >100 nCi/g. Therefore, a portion of segregated TRU waste disposed between 1970 and 1984 may be reclassified as LLW and be disposed on the Hanford Site. The plans for dealing with this type of waste are being developed. The estimated inventory of pre-September 1988 waste was incremented by the estimated suspect TRU waste inventory that will be reclassified as LLW.

G.2.3.2 Future disposal inventories. Future disposal inventories are uncertain. In past analyses the inventory disposed between September 1988 and December 1996 was extrapolated for the planned 30 years of disposal assuming a constant rate of disposal. The inventory values were compared to projections made in the performance assessments for the 200 East and 200 West Area solid waste burial grounds (Wood et al. 1995; 1996). Table G-6 includes the future inventory of key radionuclides for the post-1988 period of disposal in the solid waste burial grounds. Although key radionuclides in Table G-6 are listed in association with disposal areas, future waste disposal may not occur in the same locations.

Table G-6. Inventory of Key Radionuclides for the Solid Waste Burial Grounds.

Site Name	Radionuclide Inventories[a] in Curies[b]					
	C-14	Cl-36	I-129	Se-79	Tc-99	U-238
218-EC-9(a)[c]	2.29E-03	1.51E-04	1.23E-05	1.84E-04	6.22E-03	0.00E+00
218-EC-9(b)[d]	2.79E-05	1.83E-06	1.49E-07	2.24E-06	7.57E-05	0.00E+00
218-E-1(b)	1.39E-04	9.15E-06	7.45E-07	1.12E-05	3.77E-04	1.35E-01
218-E-10(b)	7.73E+01	5.08E+00	4.14E-01	6.19E+00	2.10E+02	2.69E-01
218-E-10(a)	1.15E-01	7.58E-03	6.17E-04	9.23E-03	3.13E-01	0.00E+00
218-E-12A(b)	1.24E-03	8.14E-05	6.63E-06	9.92E-05	3.36E-03	3.33E-01
218-E-12B(b)	2.03E+00	1.34E-01	1.09E-02	1.63E-01	5.51E+00	6.57E-02
218-E-12B(a)	1.73E-02	1.14E-03	4.14E-02	1.38E-03	4.69E-02	6.68E-02
218-E-2(b)	3.48E-02	2.29E-03	1.86E-04	2.79E-03	9.44E-02	1.01E-01
218-E-4(b)	1.39E-05	9.15E-07	7.45E-08	1.12E-06	3.77E-05	3.36E-04
218-E-5(b)	1.04E-02	6.86E-04	5.59E-05	8.36E-04	2.83E-02	4.04E-02
218-E-5A(b)	2.30E-02	1.51E-03	1.23E-04	1.84E-03	6.23E-02	4.04E-02
218-E-8(b)	1.39E-05	9.15E-07	7.45E-08	1.12E-06	3.77E-05	6.73E-04
218-W-1(b)	2.78E-04	1.83E-05	1.49E-06	2.23E-05	7.55E-04	2.35E-01
218-W-11(b)	1.39E-07	9.15E-09	7.45E-10	1.12E-08	3.77E-07	0.00E+00
218-W-1A(b)	6.68E-02	4.40E-03	3.58E-04	5.36E-03	1.81E-01	3.03E-01
218-W-2(b)	6.96E-04	4.58E-05	3.72E-06	5.58E-05	1.89E-03	4.71E-01
218-W-2A(b)	3.63E-01	2.39E-02	1.94E-03	2.91E-02	9.84E-01	9.05E-01
218-W-3(b)	1.25E-03	8.24E-05	6.70E-06	1.00E-04	3.40E-03	2.35E+01
218-W-3A(b)	1.99E+01	1.31E+00	1.06E-01	1.59E+00	5.39E+01	1.99E+01
218-W-3A(a)	6.62E-01	4.36E-02	3.68E-03	5.31E-02	2.89E+00	4.23E-01
218-W-3AE(b)	8.15E-01	5.36E-02	4.36E-03	6.53E-02	2.21E+00	8.93E+00
218-W-3AE(a)	1.10E+01	7.25E-01	5.47E-02	8.83E-01	3.58E+01	1.87E+02
218-W-4A(b)	4.61E-03	3.03E-04	2.47E-05	3.70E-04	1.25E-02	1.33E+02
218-W-4B-c(b)	2.35E-01	1.55E-02	1.26E-03	1.88E-02	6.37E-01	1.00E-01
218-W-4B-n(b)	5.13E-01	3.37E-02	5.00E-01	4.11E-02	1.39E+00	0.00E+00
218-W-4B-c(a)	5.68E-02	3.74E-03	3.04E-04	4.55E-03	1.54E-01	0.00E+00
218-W-4C(a)	4.10E+00	9.42E-03	1.13E-02	6.24E-02	9.88E+00	1.39E+02
218-W-4C(b)	2.90E+00	1.25E-02	1.02E-03	1.61E-02	6.07E-01	7.90E-01
218-W-5(b)	4.09E+00	2.73E-03	3.00E-03	3.33E-03	1.13E-01	3.99E+00
218-W-5(a)	1.51E+00	5.09E-02	1.40E-01	6.20E-02	2.77E+00	1.98E+01
218-W-7(b)	5.61E-03	3.69E-04	3.00E-05	4.49E-04	1.52E-02	2.35E-04
218-W-8(b)	1.07E-03	7.05E-05	5.73E-06	8.58E-05	2.91E-03	1.01E-04
218-W-9(b)	1.39E-07	9.15E-09	7.45E-10	1.12E-08	3.77E-07	0.00E+00

a See Appendix A for greater detail in the development of solid waste burial ground inventories.
b Inventories are decayed to a common date of 2050.
c (a) refers to waste disposed after September 30, 1988.
d (b) refers to waste disposed before September 30, 1988.

G.2.3.3 Estimation of Non-Reported Radionuclides. While uranium, plutonium, and ^{137}Cs are relatively well reported within the SWITS database (Clark 1995), a number of radionuclides may also be present but are not consistently reported. Some of these radionuclides are potentially important to performance assessment calculations, (e.g., ^{14}C, ^{36}Cl, ^{79}Se, ^{99}Tc, and ^{129}I). In an effort to estimate inventories of these radionuclides, Version 2.1 of the ORIGEN2 code was used to estimate the relative abundance of other radionuclides that are important but not consistently reported, compared to the major radionuclides that were reported. This method was applied to develop inventory for solid waste burial grounds (see Table G-6) and those liquid discharge sites that did not receive tank waste (see Section 3.4.5 on CERCLA Sources).

ORIGEN2 calculations were made for single-pass reactor and N Reactor irradiation to determine radionuclide concentrations in spent fuel and cladding. Impurities in the fuel and cladding were included in the model. The quantities are based on Bergsman (1993). A weighted average between the single-pass and N Reactor nuclide concentrations was used to estimate the overall average nuclide composition. About 90% of the fuels processed at the Hanford Site were irradiated in the single-pass reactors.

Inventories of omitted fission products in solid waste were estimated by multiplying the undecayed ^{137}Cs inventory from SWITS by the ratio of the Ci/kg concentration of the radionuclide of interest to that of ^{137}Cs from the ORIGEN2 calculation. The ratios were developed for a fuel age of 10 years after discharge from the reactor. Estimates based on fuel decayed for 1 year are more conservative for radionuclides with decay half-lives less than that of ^{137}Cs (~30 years). The key radionuclides have longer decay half-lives. Estimates based on 10 years of decay prior to disposal were more conservative for radionuclides with longer half-lives. Where the activity of a fission product increased over time beyond 1 year, the maximum activity between 1 and 3,000 years was used to calculate the ratio to ^{137}Cs at 10 years.

The SWITS database reports provide both a mass of uranium disposed, which is not identified by isotope, and quantities of uranium isotopes that are specifically identified. The ORIGEN2 results were used to divide the uranium that was not identified by isotope among the uranium isotopes, and to estimate the quantity of other actinides (except plutonium) that may be present. This was accomplished by multiplying the uranium mass reported in SWITS by the ratio of activity of actinide (or daughter) to uranium mass in discharged fuel. Similar to the fission product case, estimates were provided for fuel with 10 years of decay. As in the case of fission products, the maximum activity between 1 and 3,000 years in the ORIGEN2 calculation was used to calculate the ratio to uranium mass. Plutonium reported without isotopic distribution was divided into isotopes based on the relative abundance indicated in the ORIGEN2 results. Quantities of plutonium reported in SWITS as specific isotopes were then added to arrive at total plutonium isotopic values.

G.2.4 Environmental Restoration Disposal Facility

In the summer of 1996, disposal of wastes generated during excavation and remediation of CERCLA past-practice sites at the Hanford Site began. These wastes are disposed in the ERDF trench. Inventory estimates for CERCLA sites have been developed from process knowledge and sampling and analyses of site materials. CERCLA sites include cribs, ponds, and ditches in the

100, 200, and 300 Areas; decommissioned buildings (reactors, processing plants, auxiliary structures); and inactive solid waste burial grounds. Minimal radionuclide and chemical inventory data exist for many sites, and the process of collecting more detailed inventory information at specific sites is dependent on the remediation schedule.

This trench is a belowgrade excavation that is lined to collect leachate. The excavated material is mounded abovegrade to create a trench of greater disposal volume or capacity. When filled with remediation waste, the trench will be closed with a protective surface barrier. Only remediation wastes originating at Hanford will be disposed in the ERDF. The waste is expected to consist of dangerous and hazardous waste, polychlorinated biphenyl (PCB) and asbestos waste, low-level radioactive waste, and low-level mixed waste containing both dangerous and radioactive waste. The ERDF trench is being developed in stages. Currently it consists of two disposal cells, and approval is now being sought for additional cells. Based on need, it is anticipated the ERDF will be expanded to receive all remediation wastes from Hanford's CERCLA past-practice sites.

At present, the remediation efforts for CERCLA sites are focused on those nearest the Columbia River, i.e., those in the 300 Area and 100 Areas (Hartman and Dresel 1997). In the 300 Area, the effort is focused on past-practice solid waste disposal sites and liquid discharge sites associated with research conducted in the facilities and fuel fabrication efforts. In the 100 Areas, the effort is focused on similar burial ground and liquid discharge sites associated with reactor operation and with the demolition of structures other than of the reactor buildings themselves.

Remediation plans for 200 Area past-practice sites are being developed. These plans require the joint agreement of the DOE, Ecology, and EPA. Facility decommissioning wastes will be disposed in the ERDF trench and not the solid waste burial grounds. The final dispositions of past-practice burial grounds, liquid discharge sites, and canyon facilities are unknown.

In the review of the inventory for the ERDF trench, ^{40}K was identified as a potential isotope of concern; however, it was also identified as a radionuclide considered to be derived completely from natural background. Wood et al. (1995) noted that an average background value of ~15 pCi/g supports this hypothesis. Wood et al. (1995) also noted that ^{40}K is not a known fission product, and consequently, its activity was not considered when calculating the potential dose from DOE wastes such as those in the ERDF. Accordingly, for the purposes of the Composite Analysis, ^{40}K was omitted from the calculation of composite dose from either DOE sites or the commercial LLW disposal facility.

A variety of burial grounds and liquid discharge sites in the 300 Area and 100 Areas are undergoing cleanup efforts. The goals are to excavate contaminated soils and clean sites up so that they may support unlimited or unrestricted industrial (300 Area) and residential (100 Areas) use, to control sources of groundwater contamination to protect the Columbia River, and to control future groundwater cleanup costs (DOE-RL 1996c). Wastes from these sites are being disposed in the ERDF trench. The objectives and methods of remediation for 200 Area sites have not yet been negotiated between DOE, Ecology, and the EPA. However, only wastes from CERCLA cleanup activities will be disposed in the ERDF trench.

Two documents describe the environmental consequences of the ERDF disposal facility: the RI/FS report (DOE-RL 1994b) and a performance assessment (Wood et al. 1995). As a result of decisions made by DOE regarding the applicability of DOE Order 5820.2a (DOE 1988b) to the disposal of cleanup wastes from CERCLA sites, the final performance assessment (Wood et al. 1995) was not peer reviewed but was published as a record of work completed and analyses conducted. Based on the RI/FS (DOE-RL 1994b), a record of decision (ROD 1995) was issued January 1995 that authorized the construction and operation of two disposal cells with an expected capacity of 920,000 m^3 (1,200,000 yd^3).

The RI/FS lists the maximum detected concentrations of radionuclides for soils in the waste sites of the 100, 200 and 300 Areas. Overall maximum contaminant concentrations (pCi/g) for soils in all three areas are listed in the RI/FS (DOE-RL 1994b, Table 3.8). Based on the RI/FS, these concentrations of radionuclides were assumed to be disposed in the ERDF. Consequently, these maximum concentrations were assumed to exist in all wastes disposed at the ERDF.

While the ROD describes the initial construction and operation of two cells, planning is currently underway for the disposal of 3.59 x 10^6 m^3 (4.7 x 10^6 yd^3) in up to six cells. If approved, extending the disposal pit excavation to the east will create the additional four cells. The volume for a six-cell facility is the current projected waste volume for the cleanup and removal of wastes from all 100 and 300 Area CERCLA sites. The density of these wastes upon delivery to the ERDF is an assumed loose density of 1.66 x 10^6 g/m^3 (1.4 $tons/yd^3$). The in-place density compacted to 90% is 2.02 x 10^6 g/m^3 (1.7 $tons/yd^3$). Therefore, the in-place compacted volume of the disposal will be 2.96 x 10^6 m^3 (3.87 x 10^6 yd^3). Location details (e.g., Washington State Plane coordinates for the disposal cell corners, bottom elevation of the disposal) for the ERDF were taken from the subgrade survey control drawing,[3] and the eastward projection of the construction was based on personal communications with contractor staff.[4]

The maximum contaminant concentrations from the RI/FS (DOE-RL 1994b, Table 3.8) were applied to the estimated 3.59 x 10^6 m^3 (4.7 x 10^6 yd^3) of loose waste to be delivered to the ERDF to produce the total curies of each radionuclide disposed. This assumption is conservative and likely results in an overestimate of the inventory. The key radionuclide inventory of the ERDF is shown in Table G-7.

Table G-7. Inventory of Key Radionuclides for ERDF.

Site Name	Radionuclide Inventories[a] in Curies[b]					
	C-14	Cl-36	I-129	Se-79	Tc-99	U-238
ERDF	3.80E+03				6.57E+00	5.43E+04

a Total inventory was calculated using waste volumes for a full six-cell ERDF trench and maximum concentrations reported in the ERDF RI/FS (DOE-RL 1994b). Chlorine, iodine, and selenium values were not reported.

b Inventories are decayed to a common date of 2050.

(3) U.S. Department of Energy, Drawing No. 0600X-DD-C0033, Rev. 1. Date: 11/18/96. Record number H-6-14624 SHT 1.

(4) Information received by C. T. Kincaid, PNNL, during a meeting on February 4, 1997 with F. V. Roeck and M. A. Casbon, Bechtel Hanford Inc., ERC. The meeting topic was "Composite Analysis/ERC."

G.2.5 CERCLA Sources

The CERCLA source term includes past-practice waste sites that are being addressed under the CERCLA process and inactive sites that are being addressed under RCRA. The Environmental Restoration Contractor (ERC) is responsible for evaluation and remediation of these sites. For administrative purposes, the waste sites have been grouped into operable units (OUs), and are designated as either CERCLA past-practice units or RCRA past-practice units. The CERCLA source term does not include past-practice waste sites that are under the jurisdiction of tank farm operations or decontamination and decommissioning.

G.2.5.1 Description of CERCLA sources. A total of 190 separate CERCLA waste sites have some level of inventory developed for them. The CERCLA source term includes liquid discharge sites such as cribs, trenches, and ponds. It also includes a few solid waste sites (landfills) and storage tanks.

In addition to the 190 CERCLA sites, 151 waste sites and more than 200 "unplanned releases" in the 200 Area Plateau that do not have any documented inventory estimates were identified. These were classified as CERCLA sites. Most of these waste sites and unplanned releases have very low radionuclide inventories, have already been remediated, or have been included in another source inventory.

G.2.5.2 CERCLA radionuclide inventories. There are two primary sources of inventory information for CERCLA site radionuclides, *Waste Site Groupings for 200 Areas Soils Investigations* (DOE-RL 1997e, Table A.1), and *Tank Wastes Discharged Directly to the Soil at the Hanford Site* (Waite 1991).

In DOE-RL (1997e, Table A.1), there are 23 waste categories based on the type and concentration of both radioactive and chemical contaminants that are likely to be present in the waste. The report lists 662 waste sites located in central plateau area that are under the jurisdiction of the ERC. Of these, 36 are nonradioactive waste burial grounds, 55 are septic tanks or drain fields that are not suspected of having received any radioactive contaminants, and 30 are burial grounds that are already covered under the LLBG source term. Of the remaining 541 potential sources, partial inventory information was listed for 184 sites. However, radionuclides reported were limited to ^{137}Cs, ^{90}Sr, total uranium, total plutonium, and ^{241}Am. A secondary data source was a spreadsheet provided by the ERC. This spreadsheet contained inventories for additional radionuclides at many of the 184 sites, and at 6 additional sites, which brought the total number of sites with inventory information to 190.

The radionuclides most significantly affecting the analyses results are mobile in the subsurface and have relatively long half-lives. Inventory data for most of these radionuclides are not available for most of the waste sites because they were not commonly measured in waste streams. A strategy based on the use of radionuclide ratios in aged fuel is used to estimate the absent inventories of key mobile nuclides. Thus, the estimated inventories of fission products and actinides are based on inventories of ^{137}Cs, total uranium, and total plutonium, which are usually reported. Some sites were missing the inventory of ^{137}Cs, total uranium, and total plutonium. To calculate the mobile radionuclide inventory, the missing ^{137}Cs, total uranium, and

total plutonium inventories were first estimated. This estimate was based on the average ratios of total uranium to ^{137}Cs, total plutonium to ^{137}Cs, or total plutonium to total uranium for other waste sites in the same waste site group defined in DOE-RL (1997e). The average ratios of these species for each waste site group are listed in Table G-8. The spreadsheet provided by the ERC contained reported inventory data for some specific radionuclides in addition to ^{137}Cs, total uranium, and total plutonium for some of the waste sites.

Waite (1991) reported the type, quantity, and characteristics of wastes associated with the single-shell storage tanks and discharged intentionally to the subsurface at the Hanford Site. Wodrich (1991) also described these wastes and their inventories in a presentation, including those wastes discharged from the SSTs directly to ground through cascade overflow and by pumping wastes to cribs or specific retention trenches. Being limited to facilities that received different forms of tank waste, these estimates of liquid waste volumes and inventories were generated for relatively few of the CERCLA liquid discharge sites. However, these discharges contain potentially significant radionuclide inventories, e.g., 930 Ci of ^{99}Tc and 1.8 Ci of ^{129}I. Based on the Track Radioactive Components (TRAC) model (Jungfleisch 1980, 1983), inventories were assigned to individual cribs and specific retention trenches (see Table G-9).[5] For those sites that received tank waste discharges, the inventories estimated by Coony[6] are applied because they are higher than inventories reported in the Waste Site Groupings report published by the Environmental Restoration program. Inventories of key nuclides for the CERCLA sites are listed in Table G-10.

G.2.6 Tank Waste Remediation System Waste

Since 1944, high-level wastes from the chemical separation plants have been stored in and transferred between large single-shell and double-shell tanks. They include waste streams from the dissolution of cladding materials and irradiated fuel slugs, the original bismuth-phosphate precipitation process, the solvent extraction processes used to recover plutonium and uranium, and the evaporators used to concentrate the waste in the tank farms.

(5) Inventories were developed by F. M. Coony of Waste Management Federal Services of Hanford. Information was received in two electronic mail messages with attached files sent by Coony to C. T. Kincaid: 1) Subject, "Questions on Crib Releases in the 200 Areas," dated November 5, 1997; 2) Subject, "Tc-99 (and I-129)," dated October 29, 1997.

(6) F. M. Coony is the individual responsible for the SWITS database and Hanford input to the complex-wide integrated database.

Table G-8. Ratios of Cesium-137, Uranium (Total), and Plutonium (Total) for Waste Site Groups.

Waste Site Groups[a]	U/Pu	U/Cs-137 (g/Ci)	Pu/Cs-137 (g/Ci)	Notes
Group 2	4604	2773		
Groups 3 & 4	5.18		7.19	
Group 5				U, Pu, and Cs-137 reported for all sites
Group 6			0.371	
Group 7		348	9.89	
Group 8		970	31.8	
Group 9	400	101		
Group 10			4.07	
Group 11				U, Pu, and Cs-137 reported for all sites
Groups 12-16		46,200	54.7	
Group 17		66,300		
Group 18			138	
Group 19	1,000			Assumed
Groups 21 and 23		21,000	6.08	

a Groups 2 through 23 refer to waste site groups defined in DOE (1997b).

Table G-9. Inventories of Uranium-238, Technetium-99, and Iodine-129 for Liquid Discharge (216) Sites from the SWITS Database. (5 Pages)

Site Name	Radionuclide Inventories in Curies[a]		
	U-238[b]	Tc-99[c]	I-129[d]
216-A-1	5.12E-02		
216-A-10	8.09E-02		
216-A-18	4.69E-01		
216-A-19	1.30E+01		
216-A-2	2.60E-02		
216-A-20	1.35E-01		
216-A-21	6.49E-02		
216-A-24	1.66E-02		
216-A-25	4.24E+00		
216-A-27	2.26E-02		
216-A-28	2.11E-01		
216-A-3	5.59E-01		
216-A-30	9.98E-02		
216-A-31	6.99E-03		
216-A-36A	4.83E-02		
216-A-36B	3.99E-02		
216-A-37	1.10E-02		
216-A-37-2	1.73E-02		
216-A-39	0.00E+00		
216-A-4	1.33E-01		
216-A-40	0.00E+00		
216-A-45	2.33E-03		
216-A-5	8.75E-02		
216-A-6	5.49E-02		
216-A-7	2.33E-03		
216-A-8	1.23E-01		
216-A-9	0.00E+00		
216-B-10	3.00E-03		
216-B-10B	0.00E+00		
216-B-11	4.66E-03		
216-B-12	6.96E+00		
216-B-14	7.25E-02	6.44E+00	2.24E-02
216-B-15	3.49E-02	5.20E+00	1.81E-02
216-B-16	1.07E-01	1.67E+01	5.83E-02
216-B-17	1.18E-01	5.65E+00	1.97E-02
216-B-18	7.85E-02	6.44E+00	2.24E-02
216-B-22	1.39E-01	1.19E+00	1.88E-03
216-B-23	5.19E-02	2.88E+00	4.56E-03
216-B-24	8.19E-02	3.33E+00	5.28E-03
216-B-25	5.09E-02	1.47E+00	2.33E-03

Table G-9. Inventories of Uranium-238, Technetium-99, and Iodine-129 for Liquid Discharge (216) Sites from the SWITS Database. (5 Pages)

Site Name	Radionuclide Inventories in Curies[a]		
	U-238[b]	Tc-99[c]	I-129[d]
216-B-26	1.96E-01	2.48E+01	3.92E-02
216-B-27	1.14E-01	9.04E-01	1.43E-03
216-B-28	9.98E-02	6.22E-01	9.84E-04
216-B-29	1.15E-01	1.53E+00	2.42E-03
216-B-3	2.10E+00		
216-B-30	2.93E-02	8.87E+01	1.40E-01
216-B-31	4.06E-02	7.35E-01	1.16E-03
216-B-32	3.66E-03	3.33E+00	5.28E-03
216-B-33	6.66E-03	7.18E+00	1.14E-02
216-B-34	2.83E-02	4.52E-01	7.16E-04
216-B-35	5.66E-03	1.05E+01	1.66E-02
216-B-36	5.32E-03	1.90E+01	3.01E-02
216-B-37	1.33E-03	7.63E+01	1.21E-01
216-B-38	1.40E-02	1.25E+01	1.98E-02
216-B-39	2.00E-03	1.09E+01	1.72E-02
216-B-40	1.16E-02	8.65E+00	1.37E-02
216-B-41	2.66E-03	2.18E+01	3.45E-02
216-B-42	2.27E-01	2.43E+00	3.85E-03
216-B-43	4.66E-03	7.35E+00	2.56E-02
216-B-44	6.66E-04	1.75E+01	6.08E-02
216-B-45	2.33E-03	3.76E+01	1.31E-01
216-B-46	6.36E-02	5.03E+00	1.75E-02
216-B-47	2.33E-03	3.79E+00	1.32E-02
216-B-48	6.66E-04	1.13E+01	3.94E-02
216-B-49	1.06E-01	1.03E+01	3.58E-02
216-B-5	0.00E+00		
216-B-50	0.00E+00		
216-B-52	9.98E-03	9.04E+00	1.43E-02
216-B-55	2.66E-02		
216-B-57	3.33E-04		
216-B-58	3.00E-03		
216-B-59	0.00E+00		
216-B-60	2.39E-01		
216-B-62	9.98E-03		
216-B-63	1.50E-01		
216-B-7	6.06E-02	2.43E+00	8.47E-03
216-B-8	1.50E-02	1.13E+00	3.94E-03
216-B-9	1.50E-02		
216-C-1	9.82E-02		
216-C-10	0.00E+00		
216-C-3	1.50E-02		

Table G-9. Inventories of Uranium-238, Technetium-99, and Iodine-129 for Liquid Discharge (216) Sites from the SWITS Database. (5 Pages)

Site Name	Radionuclide Inventories in Curies[a]		
	U-238[b]	Tc-99[c]	I-129[d]
216-C-4	9.98E-04		
216-C-5	1.80E-02		
216-C-6	0.00E+00		
216-C-7	0.00E+00		
216-C-9	3.33E-04		
216-N-2	0.00E+00		
216-N-3	0.00E+00		
216-N-4	1.66E-03		
216-N-5	0.00E+00		
216-N-6	1.66E-03		
216-N-7	0.00E+00		
216-S-1&2	7.55E-01		
216-S-10	6.72E-02		
216-S-11	6.99E-03		
216-S-12	1.66E-03		
216-S-13	3.03E-02		
216-S-16	1.05E+00		
216-S-17	4.53E-02		
216-S-19	5.19E-02		
216-S-20	1.26E-02		
216-S-21	1.33E-03		
216-S-3	0.00E+00		
216-S-5	9.05E-02		
216-S-6	9.05E-02		
216-S-7	8.62E-01		
216-S-8	6.49E-02		
216-S-9	1.13E-02		
216-T-1	1.66E-03		
216-T-12	1.50E-02		
216-T-14	9.98E-03	1.15E+01	1.83E-02
216-T-15	8.99E-03	2.54E+01	4.03E-02
216-T-16	7.32E-03	1.28E+01	2.03E-02
216-T-17	6.66E-03	9.15E+00	1.45E-02
216-T-18	8.99E-03	1.36E+00	4.73E-03
216-T-19	3.33E-03	9.89E+00	3.45E-02
216-T-20	1.66E-03		
216-T-21	3.33E-04	9.83E+00	1.56E-02
216-T-22	6.66E-04	4.54E+01	7.19E-02
216-T-23	3.33E-04	3.26E+01	5.16E-02
216-T-24	2.66E-03	3.49E+01	5.52E-02

Table G-9. Inventories of Uranium-238, Technetium-99, and Iodine-129 for Liquid Discharge (216) Sites from the SWITS Database. (5 Pages)

Site Name	Radionuclide Inventories in Curies[a]		
	U-238[b]	Tc-99[c]	I-129[d]
216-T-25	3.33E-04	2.18E+02	3.45E-01
216-T-26	4.99E-02	4.29E+00	1.50E-02
216-T-27	2.33E-03		
216-T-28	1.30E-01	1.09E+01	3.80E-02
216-T-3	0.00E+00		
216-T-30	1.66E-03		
216-T-32	7.56E-01	5.65E-01	1.97E-03
216-T-33	1.66E-03		
216-T-34	1.33E-03		
216-T-35	1.63E-02		
216-T-36	3.33E-04		
216-T-4	2.32E-01		
216-T-5	1.66E-03	1.75E+00	2.77E-03
216-T-6	7.65E-03		
216-U-10	1.88E+00		
216-U-12	6.77E-01		
216-U-13	0.00E+00		
216-U-15	6.66E-04		
216-U-16	5.99E-03		
216-U-17	3.33E-04		
216-U-3	5.99E-03		
216-U-4A	3.00E-03		
216-U-4B	0.00E+00		
216-U-5	1.21E-01		
216-U-6	1.21E-01		
216-U-8	8.00E+00		
216-W-LWC	6.66E-04		
216-Z-1&2	2.70E-02		
216-Z-10	0.00E+00		
216-Z-12	0.00E+00		
216-Z-16	0.00E+00		
216-Z-17	0.00E+00		
216-Z-18	0.00E+00		
216-Z-1A	0.00E+00		
216-Z-1A A	0.00E+00		
216-Z-1A B	0.00E+00		
216-Z-1A C	0.00E+00		
216-Z-20	0.00E+00		
216-Z-3	0.00E+00		
216-Z-4	0.00E+00		
216-Z-5	0.00E+00		
216-Z-6	0.00E+00		

Table G-9. Inventories of Uranium-238, Technetium-99, and Iodine-129 for Liquid Discharge (216) Sites from the SWITS Database. (5 Pages)

Site Name	Radionuclide Inventories in Curies[a]		
	U-238[b]	Tc-99[c]	I-129[d]
216-Z-7	1.66E-03		
216-Z-8	0.00E+00		
216-Z-9	0.00E+00		

a Inventories decayed to a common date of 2050.

b Inventory was developed by F. M. Coony. From an electronic mail message with attached files regarding "Questions on Crib Releases in the 200 Areas." Sent by F. M. Coony of Waste Management Federal Services of Hanford to C. T. Kincaid on November 5, 1997.

c Inventories were developed by F. M. Coony. From an electronic mail message with attached files regarding Tc-99 (and I-129). Sent by F. M. Coony of Waste Management Federal Services of Hanford to C. T. Kincaid on October 29, 1997.

Table G-10. Inventories of Key Radionuclides for CERCLA Sites. (5 Pages)

Site Name	Radionuclide Inventories[a] in Curies[b]					
	C-14	Cl-36	I-129	Se-79	Tc-99	U-238
207-U	6.38E-05	4.2E-06	3.42E-07	5.11E-06	1.73E-04	1.51E-02
216-A-1	2.91E-06	1.91E-07	1.56E-08	2.33E-07	7.89E-06	5.12E-02
216-A-10	5.27E-03	3.47E-04	1.07E-01	4.23E-04	1.43E-02	8.09E-02
216-A-18	2.91E-06	1.91E-07	1.56E-08	2.33E-07	7.89E-06	4.69E-01
216-A-19	2.91E-06	1.91E-07	1.56E-08	2.33E-07	7.89E-06	1.30E+01
216-A-2	9.5E-05	6.25E-06	5.08E-07	7.61E-06	2.58E-04	2.60E-02
216-A-20	2.91E-06	1.91E-07	1.56E-08	2.33E-07	7.89E-06	1.35E-01
216-A-21	5.14E-03	3.38E-04	2.75E-05	4.12E-04	1.40E-02	6.49E-02
216-A-24	1.76E-02	1.15E-03	9.4E-05	1.41E-03	4.76E-02	1.66E-02
216-A-25	1.34E-02	8.79E-04	7.15E-05	1.07E-03	3.63E-02	4.24E+00
216-A-27	2.12E-03	1.40E-04	1.14E-05	1.70E-04	5.76E-03	2.26E-02
216-A-28	1.48E-02	9.75E-04	7.93E-05	1.19E-03	4.02E-02	2.11E-01
216-A-3	2.98E-06	1.96E-07	1.6E-08	2.39E-07	8.09E-06	5.59E-01
216-A-30	7.66E-03	5.04E-04	4.1E-05	6.14E-04	2.08E-02	9.98E-02
216-A-31	5.37E-03	3.53E-04	2.88E-05	4.31E-04	1.46E-02	6.99E-03
216-A-36A/B	7.84E-02	5.16E-03	4.20E-04	6.28E-03	2.13E-01	8.82E-02
216-A-37-1	6.2E-06	4.08E-07	4.26E-03	4.97E-07	1.68E-05	1.10E-02
216-A-37-2	1.34E-05	8.79E-07	7.15E-08	1.07E-06	3.63E-05	1.73E-02
216-A-4	4.54E-04	2.99E-05	2.43E-06	3.64E-05	1.23E-03	1.33E-01
216-A-45	6.35E-07	4.18E-08	1.10E-02	5.09E-08	1.72E-06	2.33E-03
216-A-5	7.93E-04	5.21E-05	4.24E-06	6.35E-05	2.15E-03	8.75E-02
216-A-6	6.88E-03	4.52E-04	3.68E-05	5.51E-04	1.87E-02	5.49E-02
216-A-7	1.51E-04	9.95E-06	8.1E-07	1.21E-05	4.11E-04	2.33E-03
216-A-8	3.42E-02	2.25E-03	1.83E-04	2.74E-03	9.28E-02	1.23E-01
216-A-9	3.05E-04	2E-05	1.63E-06	2.44E-05	8.26E-04	8E-05
216-B-10A	2.63E-05	1.73E-06	1.41E-07	2.11E-06	7.13E-05	3.00E-03
216-B-10B	6.55E-09	4.31E-10	3.51E-11	5.25E-10	1.78E-08	2.23E-06
216-B-11A&B	1.40E-03	9.18E-05	7.47E-06	1.12E-04	3.79E-03	4.66E-03
216-B-12	4.69E-02	3.09E-03	2.51E-04	3.76E-03	1.27E-01	6.96E+00
216-B-14	7.47E-03	4.91E-04	2.24E-02	5.99E-04	6.44E+00	7.25E-02
216-B-15	6.05E-03	3.98E-04	1.81E-02	4.85E-04	5.20E+00	3.49E-02
216-B-16	1.94E-02	1.28E-03	5.83E-02	1.55E-03	1.67E+01	1.07E-01
216-B-17	6.55E-03	4.31E-04	1.97E-02	5.25E-04	5.65E+00	1.18E-01
216-B-18	7.47E-03	4.91E-04	2.24E-02	5.99E-04	6.44E+00	7.85E-02
216-B-19	8.25E-03	5.43E-04	2.48E-02	6.62E-04	7.12E+00	6.06E-02
216-B-20	4.48E-02	2.95E-03	6.12E-02	3.59E-03	3.86E+01	1.17E-01
216-B-21	1.11E-02	7.28E-04	1.51E-02	8.87E-04	9.55E+00	2.25E-01
216-B-2-1	6.13E-03	4.03E-04	3.28E-05	4.91E-04	1.66E-02	1.45E+00
216-B-2-2	2.06E-05	1.35E-06	1.1E-07	1.65E-06	5.58E-05	4.88E-03
216-B-23	3.33E-03	2.19E-04	4.56E-03	2.67E-04	2.881494	5.19E-02
216-B-2-3	2.06E-05	1.35E-06	1.1E-07	1.65E-06	5.58E-05	4.88E-03

Table G-10. Inventories of Key Radionuclides for CERCLA Sites. (5 Pages)

Site Name	Radionuclide Inventories[a] in Curies[b]					
	C-14	Cl-36	I-129	Se-79	Tc-99	U-238
216-B-24	3.84E-03	2.53E-04	5.28E-03	3.08E-04	3.33E+00	8.19E-02
216-B-25	1.67E-03	1.10E-04	2.33E-03	1.34E-04	1.47E+00	5.09E-02
216-B-26	2.87E-02	1.89E-03	3.92E-02	2.30E-03	2.47E+01	1.96E-01
216-B-27	1.04E-03	6.81E-05	1.43E-03	8.3E-05	9.04E-01	1.14E-01
216-B-28	7.01E-04	4.61E-05	9.84E-04	5.62E-05	6.21E-01	9.98E-02
216-B-29	1.80E-03	1.18E-04	2.42E-03	1.44E-04	1.53E+00	1.15E-01
216-B-3	6.13E-03	4.03E-04	3.28E-05	4.91E-04	1.66E-02	2.10E+00
216-B-30	1.03E-01	6.77E-03	1.40E-01	8.24E-03	8.87E+01	2.93E-02
216-B-31	7.80E-02	5.13E-03	1.16E-03	6.25E-03	7.34E-01	4.06E-02
216-B-32	3.84E-03	2.53E-04	5.28E-03	3.08E-04	3.33E+00	3.66E-03
216-B-33	8.32E-03	5.47E-04	1.14E-02	6.67E-04	7.18E+00	6.66E-03
216-B-34	5.18E-04	3.41E-05	7.16E-04	4.15E-05	4.52E-01	2.83E-02
216-B-35	1.21E-02	7.97E-04	1.66E-02	9.71E-04	1.05E+01	5.66E-03
216-B-36	2.20E-02	1.45E-03	3.01E-02	1.76E-03	1.90E+01	5.32E-03
216-B-37	8.84E-02	5.82E-03	1.21E-01	7.09E-03	7.63E+01	1.33E-03
216-B-38	1.45E-02	9.52E-04	1.98E-02	1.16E-03	1.25E+01	1.40E-02
216-B-39	1.26E-02	8.27E-04	1.72E-02	1.01E-03	1.08E+01	2.00E-03
216-B-40	1.00E-02	6.59E-04	1.37E-02	8.03E-04	8.64E+00	1.16E-02
216-B-41	2.53E-02	1.66E-03	3.45E-02	2.03E-03	2.18E+01	2.66E-03
216-B-42	2.80E-03	1.84E-04	3.85E-03	2.24E-04	2.43E+00	2.27E-01
216-B-43	8.52E-03	5.60E-04	2.56E-02	6.83E-04	7.34E+00	4.66E-03
216-B-44	2.02E-02	1.33E-03	6.08E-02	1.62E-03	1.75E+01	6.66E-04
216-B-45	4.36E-02	2.87E-03	1.31E-01	3.50E-03	3.76E+01	2.33E-03
216-B-46	5.82E-03	3.83E-04	1.75E-02	4.67E-04	5.03E+00	6.36E-02
216-B-47	4.36E-03	2.87E-04	1.32E-02	3.50E-04	3.79E+00	2.33E-03
216-B-48	1.31E-02	8.62E-04	3.94E-02	1.05E-03	1.13E+01	6.66E-04
216-B-49	1.19E-02	7.84E-04	3.58E-02	9.56E-04	1.03E+01	1.06E-01
216-B-5	1.91E-03	1.26E-04	1.02E-05	1.53E-04	5.19E-03	9.52E-03
216-B-50	3.35E-03	2.21E-04	1.8E-05	2.69E-04	9.10E-03	1E-04
216-B-52	1.05E-02	6.89E-04	1.43E-02	8.40E-04	9.04E+00	9.98E-03
216-B-53A	3.66E-06	2.41E-07	1.96E-08	2.94E-07	9.93E-06	7.65E-03
216-B-53B	2.42E-04	1.59E-05	1.3E-06	1.94E-05	6.58E-04	3.00E-03
216-B-54	3.58E-06	2.36E-07	1.92E-08	2.87E-07	9.72E-06	3.00E-03
216-B-55	8.98E-04	5.9E-05	4.8E-06	7.19E-05	2.43E-03	2.66E-02
216-B-57	1.48E-02	9.74E-04	7.92E-05	1.19E-03	4.02E-02	3.33E-04
216-B-58	2.88E-04	1.9E-05	1.54E-06	2.31E-05	7.82E-04	3.00E-03
216-B-59	7.86E-07	5.17E-08	4.21E-09	6.3E-08	2.13E-06	1.86E-04
216-B-60	1.70E-02	1.12E-03	9.1E-05	1.36E-03	4.61E-02	2.39E-01
216-B-62	8.84E-03	5.82E-04	4.73E-05	7.09E-04	2.40E-02	9.98E-03
216-B-63	4.09E-05	2.69E-06	2.19E-07	3.28E-06	1.11E-04	1.50E-01
216-B-7A&B	2.83E-03	1.86E-04	8.47E-03	2.27E-04	2.43E+00	6.06E-02
216-B-8	1.30E-03	8.53E-05	3.94E-03	1.04E-04	1.13E+00	1.50E-02

Table G-10. Inventories of Key Radionuclides for CERCLA Sites. (5 Pages)

Site Name	Radionuclide Inventories[a] in Curies[b]					
	C-14	Cl-36	I-129	Se-79	Tc-99	U-238
216-B-9	2.57E-04	1.69E-05	1.37E-06	2.06E-05	6.97E-04	1.50E-02
216-C-1	2.98E-06	1.96E-07	1.6E-08	2.39E-07	8.09E-06	9.82E-02
216-C-10	5.6E-06	3.68E-07	3E-08	4.49E-07	1.52E-05	1.68E-05
216-C-3	2.78E-06	1.83E-07	1.49E-08	2.23E-07	7.53E-06	1.50E-02
216-C-4	2.84E-06	1.87E-07	1.52E-08	2.27E-07	7.69E-06	9.98E-04
216-C-5	2.91E-06	1.91E-07	1.56E-08	2.33E-07	7.89E-06	1.80E-02
216-C-6	3.05E-06	2E-07	1.63E-08	2.44E-07	8.26E-06	1E-04
216-C-7	3.5E-06	2.3E-07	1.87E-08	2.8E-07	9.49E-06	3.36E-06
216-C-9	4.61E-05	3.03E-06	2.46E-07	3.69E-06	1.25E-04	3.33E-04
216-N-2	5.14E-06	3.38E-07	2.75E-08	4.12E-07	1.4E-05	1.22E-03
216-N-3	5.77E-06	3.8E-07	3.09E-08	4.63E-07	1.57E-05	1.37E-03
216-N-4	5.33E-06	3.5E-07	2.85E-08	4.27E-07	1.44E-05	1.66E-03
216-N-5	5.77E-06	3.8E-07	3.09E-08	4.63E-07	1.57E-05	1.37E-03
216-N-6	5.33E-06	3.5E-07	2.85E-08	4.27E-07	1.44E-05	1.66E-03
216-N-7	5.77E-06	3.8E-07	3.09E-08	4.63E-07	1.57E-05	1.37E-03
216-S-1&2	7.21E-02	4.74E-03	3.86E-04	5.78E-03	1.95E-01	7.55E-01
216-S-10D	8.12E-05	5.34E-06	4.35E-07	6.51E-06	2.20E-04	6.72E-02
216-S-11	5.37E-05	3.53E-06	2.88E-07	4.31E-06	1.46E-04	6.99E-03
216-S-12	2.84E-05	1.87E-06	1.52E-07	2.28E-06	7.71E-05	1.66E-03
216-S-13	1.81E-04	1.19E-05	9.71E-07	1.45E-05	4.92E-04	3.03E-02
216-S-16P	1.97E-03	1.29E-04	1.05E-05	1.58E-04	5.33E-03	1.05E+00
216-S-17	8.32E-04	5.47E-05	4.45E-06	6.67E-05	2.26E-03	4.53E-02
216-S-19	8.45E-05	5.56E-06	4.52E-07	6.77E-06	2.29E-04	5.19E-02
216-S-20	3.70E-03	2.43E-04	1.98E-05	2.97E-04	1.00E-02	1.26E-02
216-S-21	5.77E-03	3.79E-04	3.09E-05	4.62E-04	1.56E-02	1.33E-03
216-S-22	3.13E-05	2.06E-06	1.68E-07	2.51E-06	8.49E-05	1.68E-05
216-S-23	2.27E-04	1.5E-05	1.22E-06	1.82E-05	6.17E-04	9.75E-05
216-S-25	4.24E-06	2.79E-07	2.27E-08	3.4E-07	1.15E-05	5.56E-02
216-S-26	2.02E-07	1.33E-08	1.08E-09	1.62E-08	5.49E-07	6.89E-05
216-S-3	1.43E-03	9.44E-05	7.68E-06	1.15E-04	3.89E-03	9.75E-05
216-S-5	1.73E-03	1.14E-04	9.26E-06	1.39E-04	4.69E-03	9.05E-02
216-S-6	7.53E-03	4.96E-04	4.03E-05	6.04E-04	2.04E-02	9.05E-02
216-S-7	4.61E-02	3.03E-03	2.46E-04	3.69E-03	1.25E-01	8.62E-01
216-S-8	3.22E-04	2.12E-05	1.73E-06	2.58E-05	8.74E-04	6.49E-02
216-S-9	1.90E-02	1.25E-03	1.02E-04	1.52E-03	5.15E-02	1.13E-02
216-T-1	2.54E-06	1.67E-07	1.36E-08	2.03E-07	6.88E-06	1.66E-03
216-T-12	2.84E-04	1.87E-05	1.52E-06	2.28E-05	7.71E-04	1.50E-02
216-T-14	1.34E-02	8.79E-04	1.83E-02	1.07E-03	1.15E+01	9.98E-03
216-T-15	2.95E-02	1.94E-03	4.03E-02	2.36E-03	2.54E+01	8.99E-03
216-T-16	1.49E-02	9.78E-04	2.03E-02	1.19E-03	1.28E+01	7.32E-03
216-T-17	1.06E-02	6.98E-04	1.45E-02	8.51E-04	9.15E+00	6.66E-03
216-T-18	1.59E-03	1.04E-04	4.73E-03	1.27E-04	1.36E+00	8.99E-03

Table G-10. Inventories of Key Radionuclides for CERCLA Sites. (5 Pages)

Site Name	Radionuclide Inventories[a] in Curies[b]					
	C-14	Cl-36	I-129	Se-79	Tc-99	U-238
216-T-19	1.15E-03	7.54E-05	3.45E-02	9.19E-05	9.89E+00	3.33E-03
216-T-20	2.88E-05	1.9E-06	1.54E-07	2.31E-06	7.82E-05	1.66E-03
216-T-21	1.14E-02	7.50E-04	0.01557	9.14E-04	9.83E+00	3.33E-04
216-T-22	5.26E-02	3.46E-03	7.19E-02	4.22E-03	4.54E+01	6.66E-04
216-T-23	3.78E-02	2.49E-03	5.16E-02	3.03E-03	3.26E+01	3.33E-04
216-T-24	4.04E-02	2.66E-03	5.52E-02	3.24E-03	3.49E+01	2.66E-03
216-T-25	2.53E-01	1.66E-02	3.45E-01	2.03E-02	2.18E+02	3.33E-04
216-T-26	4.95E-03	3.26E-04	1.50E-02	3.97E-04	4.29E+00	4.99E-02
216-T-27	3.66E-03	2.41E-04	1.96E-05	2.94E-04	9.93E-03	2.33E-03
216-T-28	1.26E-02	8.32E-04	3.80E-02	1.01E-03	1.09E+01	1.30E-01
216-T-3	1.40E-03	9.18E-05	7.47E-06	1.12E-04	3.79E-03	6.95E-03
216-T-32	6.36E-04	4.18E-05	1.97E-03	5.1E-05	5.65E-01	7.56E-01
216-T-33	1.75E-05	1.15E-06	9.36E-08	1.4E-06	4.74E-05	1.66E-03
216-T-34	1.03E-02	6.77E-04	5.5E-05	8.24E-04	2.79E-02	1.33E-03
216-T-35	7.66E-04	5.04E-05	4.1E-06	6.14E-05	2.08E-03	1.63E-02
216-T-36	2.48E-04	1.63E-05	1.33E-06	1.99E-05	6.74E-04	3.33E-04
216-T-4B	4.08E-04	2.68E-05	2.18E-06	3.27E-05	1.11E-03	2.32E-01
216-T-5	2.04E-03	1.34E-04	2.77E-03	1.63E-04	1.75E+00	1.66E-03
216-T-6	7.21E-03	4.74E-04	3.86E-05	5.78E-04	1.95E-02	7.65E-03
216-T-7	1.39E-03	9.14E-05	4.14E-03	1.11E-04	1.19E+00	3.00E-03
216-T-8	2.63E-06	1.73E-07	1.41E-08	2.11E-07	7.13E-06	1.66E-03
216-U-1&2	2.86E-04	1.88E-05	1.53E-06	2.29E-05	7.75E-04	7.02E-01
216-U-10	7.21E-04	4.74E-05	3.86E-06	5.78E-05	1.95E-03	1.88E+00
216-U-12	3.71E-06	2.44E-07	1.98E-08	2.97E-07	1.01E-05	6.77E-01
216-U-13	2.91E-06	1.91E-07	1.56E-08	2.33E-07	7.89E-06	1.20E-04
216-U-15	3.05E-06	2E-07	1.63E-08	2.44E-07	8.26E-06	6.66E-04
216-U-16	1.08E-06	7.11E-08	5.79E-09	8.66E-08	2.93E-06	5.99E-03
216-U-17	2.67E-04	1.76E-05	1.43E-06	2.14E-05	7.24E-04	3.33E-04
216-U-3	2.84E-05	1.87E-06	1.52E-07	2.28E-06	7.71E-05	5.99E-03
216-U-4A	1.21E-05	7.97E-07	6.49E-08	9.71E-07	3.29E-05	3.00E-03
216-U-4B	1.29E-05	8.49E-07	6.91E-08	1.03E-06	3.5E-05	4.39E-03
216-U-5	8.57E-03	5.64E-04	4.59E-05	6.87E-04	2.32E-02	1.21E-01
216-U-6	8.57E-03	5.64E-04	4.59E-05	6.87E-04	2.32E-02	1.21E-01
216-U-7	4.37E-04	2.87E-05	2.34E-06	3.5E-05	1.18E-03	4.71E-02
216-U-8	2.98E-06	1.96E-07	1.6E-08	2.39E-07	8.09E-06	8.00E+00
216-Z-1&2	2.62E-06	1.72E-07	1.4E-08	2.1E-07	7.11E-06	2.70E-02
216-Z-10	4.55E-04	2.99E-05	2.44E-06	3.65E-05	1.24E-03	8.71E-05
216-Z-12	3.47E-06	2.28E-07	1.86E-08	2.78E-07	9.42E-06	1.7E-05
216-Z-16	3.42E-05	2.25E-06	1.83E-07	2.74E-06	9.27E-05	1.16E-02
216-Z-17	2.37E-05	1.56E-06	1.27E-07	1.9E-06	6.44E-05	5E-05
216-Z-18	2.09E-01	1.38E-02	1.12E-03	1.68E-02	5.68E-01	4.01E-02
216-Z-1A	1.05E-05	6.89E-07	5.61E-08	8.4E-07	2.84E-05	0.00E+00

Table G-10. Inventories of Key Radionuclides for CERCLA Sites. (5 Pages)

Site Name	Radionuclide Inventories[a] in Curies[b]					
	C-14	Cl-36	I-129	Se-79	Tc-99	U-238
216-Z-20	5.66E-06	3.72E-07	3.03E-08	4.54E-07	1.54E-05	1.34E-03
216-Z-3	3.14E-06	2.07E-07	1.68E-08	2.52E-07	8.53E-06	1.7E-05
216-Z-4	2.29E-06	1.51E-07	1.23E-08	1.84E-07	6.22E-06	1.7E-05
216-Z-5	2.36E-04	1.55E-05	1.26E-06	1.89E-05	6.40E-04	1.7E-05
216-Z-6	2.29E-06	1.51E-07	1.23E-08	1.84E-07	6.22E-06	1.7E-05
216-Z-7	1.31E-02	8.62E-04	7.01E-05	1.05E-03	3.55E-02	1.66E-03
216-Z-8	1.82E-05	1.2E-06	9.75E-08	1.46E-06	4.94E-05	3.48E-06
216-Z-9	3.41E-06	2.24E-07	1.82E-08	2.73E-07	9.24E-06	1.7E-05

a Refer to Sections 3.4.5 for a detailed discussion of the development of CERCLA radionuclide inventories.

b Inventories decayed to a common date of 2050.

As processes used to capture plutonium and uranium from solutions changed, the characteristics of wastes changed. These tank wastes are characterized as concentrated complexed waste, dilute complexed waste, double-shell slurry and double-shell slurry feed, aging waste, and noncomplexed waste (Hanlon 1997). Because carbon steel tanks were used at the Hanford Site, wastes stored in the tanks were neutralized and often have pH values between 12 and 14. Wastes containing complexants were segregated from those that do not.

Sixty-seven of 149 SSTs have leaked or are suspected to have leaked a portion of their inventory into the environment (Hanlon 1997). If sluicing is the method adopted for removal of tank wastes, it is anticipated that some of the SSTs will lose more liquid tank waste to the vadose zone. The TWRS program is evaluating retrieval technologies using low volumes of liquids, which would result in much lower levels of retrieval loss than possible using sluicing. The TWRS program and private contractors will recover the tank waste, separate it into high-level and LLW fractions, and immobilize each. The TWRS program has begun the process to have the LLW fraction that will be disposed onsite declared incident waste, i.e., not high-level waste[7]. The U.S. Nuclear Regulatory Commission (NRC) has confirmed that based on current information, the ILAW can be disposed of as incidental waste. This low-activity waste fraction from the tanks will become ILAW and will be disposed of at the Hanford Site. Over 200,000 m^3 of ILAW LLW will be disposed. The high-level waste will be stored until it can be transferred to a national high-level waste repository. The formal process to declare past tank leaks, future losses, and tank waste residuals incident waste has not begun; however, the TWRS program has conducted evaluations to consider the issues regarding resolution prior to approval by the NRC.

The activation products, actinides, and fission products generated in the reactors at the Hanford Site are anticipated components of the low-activity radioactive stream coming from Hanford single- and double-shell tanks. The complete list of these isotopes can be found in Schmittroth et al. (1995) and Watrous and Wooten (1997).

The screen applied by Schmittroth et al. (1995) to identify those radionuclides that could be potentially significant contributors to dose in groundwater pathway scenarios yielded 12 potentially important isotopes. In order of their contribution to drinking water dose, a major component to all-pathways dose, the 12 isotopes were ^{99}Tc, ^{79}Se, ^{233}U, ^{234}U, ^{238}U, ^{228}Ra, ^{93m}Nb, ^{129}I, ^{226}Ra, ^{236}U, ^{245}Cm, and ^{235}U. To arrive at this list, Schmittroth et al. (1995) used a simple retardation model, and where K_d data were absent, made the conservative assumption of no sorption. After reviewing the Kds, the following values were assigned to several of the elements (Kaplan and Serne 1995; Kaplan et al. 1996): technetium and selenium, 0 mL/g; uranium, 0.6 mL/g; radium, 15 mL/g; niobium, 40 mL/g; iodine, 3 mL/g; and curium, 100 mL/g. The radionuclides that were assigned nonzero K_d values in the study by Schmittroth et al. (1995) failed the screen as significant contributors to dose via the groundwater pathway. Consequently, those elements (i.e., radium, niobium, and curium) assigned the higher values after the initial screen were also eliminated. Accordingly, only the top eight isotopes contributing to drinking

(7) From a letter, dated June 1997, sent by C. J. Papiello, Director of the Office of Nuclear Material Safety and Safeguards, of the U.S. Nuclear Regulatory Commission, to J. Kinzer, Assistant Manager, Office of Tank Waste Remediation System, DOE, "Classification of Hanford Low-Activity Waste Fraction." This letter may be found in Mann et al. (1997).

water dose were identified as potential key radionuclides for the Composite Analysis: ^{99}Tc; ^{79}Se; ^{129}I; and $^{233,-234,-235,-236,-238}U$, and their daughters.

The recovery of wastes from both single- and double-shell tanks will not be perfect. The interim retrieval goal in Milestone M-45 of the *Tri-Party Agreement* (Ecology et al. 1989a) is to leave no more than 10 m^3 (360 ft^3) of waste in each 100-series SST, and no more than 0.8 m^3 (30 ft^3) of waste in each 200-series SST. This corresponds to 1% of the current SST waste inventory of 36 million gallons, allocated equally to each of the 149 SSTs in proportion to the cross-sectional area of the tanks. Thus, an estimated 1% of the waste volume will remain in each tank following completion of recovery operations. For SSTs, the waste source types include leaks, losses during recovery operations, and a residual in the tanks after recovery. In addition to tank waste source types listed above, the TWRS program, specifically the privatization contractors, will produce secondary waste streams during their separations and immobilization steps. These wastes will be returned to DOE for final disposal.

In addition to the disposal of ILAW, releases to the environment originating from the SSTs must also be considered. Sixty-seven SSTs are known or assumed to have leaked. The *Tri-Party Agreement* (Ecology et al. 1989b) calls for approximately 99% of the waste volume in each of the 149 tanks to be removed. At present, sluicing is the method of choice for the removal of these wastes. It is believed that some contaminated liquid could be lost from each SST during recovery operations. Finally, each of the single- and double-shell tanks will contain some residual after wastes are recovered, separated, and solidified. These residuals will also release radioactive contamination to the surrounding environment in the future.

Some waste currently stored in tanks at the Hanford Site will remain at Hanford after closure in one of four forms (DOE and Ecology 1996). The majority will be an ILAW created from the incidental waste fraction recovered from tanks. Some will be in the form of a residual left in the tanks after waste recovery operations. These source inventories, ILAW from tanks, leaks and slurry losses from SSTs, residuals in SSTs, and residuals in double-shell tanks, are described in the following four sections.

The TWRS program has established standard inventories for chemicals and radionuclides in the tank wastes (Kupfer et al. 1997). The Kupfer et al. (1997) inventory is a best-basis global inventory. A best basis tank-by-tank estimate was also produced.[8] The fourth revision of the HDW model (Agnew et al. 1997) was also issued. Agnew et al. (1997) is a supporting document to the more recently published best-basis or standard inventory (Kupfer et al. 1997).

([8]) From letter FDH-9757750 dated August 29, 1997 from D. J. Washenfelder (Fluor Daniel Hanford) to J. K. McClusky (DOE), "Contract Number DE-AC06-96RL 13200; Completion of Milestone T24-97-158, Contractor Letter to Department of Energy, Richland Operations Office, Reporting Completion of Standard Inventory Estimates for All Tanks."

G.2.8 Immobilized Low-Activity Waste from Tanks

The source inventory for the incident waste fraction of waste currently stored in single- and double-shell tanks is reported in the interim performance assessment for low-level tank waste (Mann et al. 1997, Table 3.1). Following recovery from the tanks, waste will be separated into high-level waste and incident waste fractions. The incident waste fraction will be immobilized and returned to the DOE for disposal as ILAW. The high-level fraction is to be returned to DOE for storage until it also is immobilized. After immobilization, it will be stored until the national high-level waste repository is opened, and then it will be shipped to the repository and disposed.

The inventory that appears in the interim performance assessment is fully documented (Schmittroth et al. 1995) as one among many data packages (Mann 1995) developed in support of the interim performance assessment. Plans call for these wastes to be disposed in two locations in four existing vaults and several new disposal vaults. The inventory of ILAW to be disposed in existing facilities is based on the fraction of the waste volume they can contain, and the total inventory reported by Mann et al. (1997). Table G-11 shows the key radionuclide inventory assumed for each disposal location.

Table G-11. Inventory of Key Radionuclides for TWRS Low-Activity Waste.

Site Name	Radionuclide Inventories[a] in Curies[b]					
	C-14	Cl-36	I-129	Se-79	Tc-99	U-238
TWRS glass grout vault	4.54E-01		3.91E-01	6.07E+01	1.32E+03	1.05E+00
TWRS glass new site	7.24E+00		6.23E+00	9.69E+02	2.10E+04	1.67E+01

a The waste inventory in each site is based on the fraction of waste volume in each site and the total inventory.
b Inventories are decayed to a common date of 2050.

G.2.8 Single-Shell Tank Farms – Tank Leaks and Slurry Losses

There are 12 SST farms containing 149 tanks on the 200 Area Plateau. Six tank farms (S, SX, T, TX, TY, and U) containing 83 tanks are located in the 200 West Area. Six tank farms (A, AX, B, BX, BY, and C) containing 66 tanks are located in the 200 East Area.

The TWRS program has published the initial retrieval sequence and blending strategy (Penwell et al. 1996). The retrieval operation is projected to occur over a 15-year period beginning in 2004 and ending in 2019. Penwell et al. (1996) provided detail on the retrieval sequence of each tank and each tank farm. The TWRS program is committed to revise annually the SST retrieval sequence, (Kirkbride et al. 1997). Using currently available leak detection and mitigation technologies, a tank leak could not be detected before 4,000 gal (15 m^3) has been released, and not stopped for most tanks before approximately 8,000 gal (30 m^3) had been released (WHC 1996). Consequently, the TWRS program assumed an average release volume per SST of 8,000 gal (30 m^3). This is a more current estimate than the 4,000 gal (15 m^3) per tank value assumed in the TWRS EIS (DOE and Ecology 1996). Conservative assumptions to establish an upper bound on the amount of leakage from SST 241-C-106, and its potential impact resulted in a calculated leak volume of 40,000 gal (150 m^3) because of hydraulic sluicing of that tank (Lowe 1993).

While an average loss volume of 8,000 gal (30 m^3) has been assumed, there are reasons to expect a lower average. For example, some tanks will have better leak detection and mitigation capabilities than others, and tanks that are confirmed leakers (~50 SSTs) are candidates for alternate cleanout technologies that use robotic arms or low-volume liquid methodologies or both being considered under the Hanford Tanks Initiative (HTI) project. Additionally, some of the tanks are known to have leaked from headers and not along the base of the tank. These tanks may be able to be sluiced with low risk for leakage to soils.

The mobile contaminate inventories for the SST farms are shown in Table G-12.

Table G-12. Inventory of Key Radionuclides for TWRS Single-Shell Tanks. (2 Pages)

Site Name	Radionuclide Inventories in Curies[a]					
	C-14	Cl-36	I-129	Se-79	Tc-99	U-238
TK-A-S[b]	9.43E-02	0.00E+00	2.81E-02	1.68E-02	3.31E+01	7.36E-04
TK-A-L[c]	1.10E+00	0.00E+00	1.83E-01	1.96E-01	1.25E+02	8.57E-03
TK-A-R[d]	2.11E+00		1.71E-03	8.33E-02	1.15E+00	1.52E-01
TK-AX-S-1[e]	8.00E-02	0.00E+00	0.00E+00	0.00E+00	1.68E+00	0.00E+00
TK-AX-S-2	3.14E-02	0.00E+00	9.38E-03	5.60E-03	1.10E+01	2.45E-04
TK-AX-L-1	1.50E-02	0.00E+00	0.00E+00	0.00E+00	0.3156146	0.00E+00
TK-AX-L-2	3.14E-02	0.00E+00	5.14E-03	5.60E-03	3.43E+00	2.45E-04
TK-AX-R-1	2.75E-02		3.90E-05	1.95E-03	2.68E-02	2.13E-03
TK-AX-R-2	1.37E-01		1.95E-04	9.74E-03	1.34E-01	1.07E-02
TK-B-S	5.03E-01	0.00E+00	8.23E-02	8.96E-02	5.48E+01	3.92E-03
TK-B-L	2.12E-01	0.00E+00	3.46E-02	3.77E-02	2.31E+01	1.65E-03
TK-B-R	4.98E+00		2.02E-02	1.01E+00	1.39E+01	3.41E-01
TK-BX-S	3.77E-01	0.00E+00	6.17E-02	6.72E-02	4.11E+01	2.94E-03
TK-BX-L	3.79E-01	0.00E+00	6.20E-02	6.75E-02	4.13E+01	2.96E-03
TK-BX-R	9.18E+00		4.78E-02	2.39E+00	3.28E+01	4.87E-01
TK-BY-S	3.77E-01	0.00E+00	6.17E-02	6.72E-02	4.11E+01	2.94E-03
TK-BY-L	1.61E-01	0.00E+00	2.64E-02	2.88E-02	1.76E+01	1.26E-03
TK-BY-R	2.18E+00		1.76E-02	8.83E-01	1.22E+01	7.93E-01
TK-C-S-1	5.80E-02	0.00E+00	2.16E-03	5.60E-03	3.27E+00	2.35E-04
TK-C-S-2	3.46E-01	0.00E+00	5.66E-02	6.16E-02	3.77E+01	2.70E-03
TK-C-L-1	1.50E-03	0.00E+00	1.80E-04	4.67E-04	2.02E-01	1.96E-05
TK-C-L-2	1.07E-01	0.00E+00	1.75E-02	1.91E-02	1.17E+01	8.35E-04
TK-C-R-1	9.49E-01		3.53E-03	1.68E-01	2.32E+00	3.05E-01
TK-C-R-2	8.79E-01		3.27E-03	1.55E-01	2.15E+00	2.83E-01
TK-S-S	3.14E-01	0.00E+00	5.99E-02	5.60E-02	4.95E+01	2.45E-03
TK-S-L	9.43E-02	0.00E+00	1.54E-02	1.68E-02	1.03E+01	7.36E-04
TK-S-R	3.82E+00		2.38E-02	1.19E+00	1.65E+01	1.82E-01
TK-SX-S-1	5.99E-03	0.00E+00	7.21E-04	1.87E-03	8.08E-01	7.84E-05
TK-SX-S-2	3.46E-01	0.00E+00	6.93E-02	6.16E-02	6.05E+01	2.70E-03
TK-SX-L-2	6.30E-01	0.00E+00	1.06E-01	1.12E-01	7.45E+01	4.92E-03
TK-SX-R-1	1.94E-01		2.17E-03	1.09E-01	1.50E+00	1.69E-02
TK-SX-R-2	1.68E+00		1.88E-02	9.50E-01	1.30E+01	1.47E-01

Table G-12. Inventory of Key Radionuclides for TWRS Single-Shell Tanks. (2 Pages)

Site Name	Radionuclide Inventories in Curies[a]					
	C-14	Cl-36	I-129	Se-79	Tc-99	U-238
TK-T-S	5.03E-01	0.00E+00	8.23E-02	8.96E-02	5.48E+01	3.92E-03
TK-T-L	5.28E-01	0.00E+00	8.65E-02	9.41E-02	5.76E+01	4.12E-03
TK-T-R	1.50E-01		5.09E-04	2.57E-02	3.51E-01	8.05E-02
TK-TX-S	1.89E-01	0.00E+00	3.09E-02	3.36E-02	2.06E+01	1.47E-03
TK-TX-L	2.30E-01	0.00E+00	3.76E-02	4.09E-02	2.51E+01	1.79E-03
TK-TX-R	2.91E+00		1.35E-02	6.76E-01	9.34E+00	1.56E+00
TK-TY-R	4.81E-01		5.34E-03	2.68E-01	3.68E+00	7.78E-02
TK-U-S	4.40E-01	0.00E+00	8.05E-02	7.84E-02	6.32E+01	3.43E-03
TK-U-L	3.99E-01	0.00E+00	6.53E-02	7.11E-02	4.35E+01	3.11E-03
TK-U-R	1.35E-01		1.32E-03	6.52E-02	9.08E-01	3.10E-01

a Inventories are decayed to a common date of 2050.
b "S" refers to sluicing losses during recovery of tank wastes. The inventory is based on an 8,000-gallon-per-tank loss and radionuclide concentrations developed from tank characterization reports.
c "L" refers to past tank leaks as identified in Hanlon (1997). The inventories are based on leak volumes from Hanlon and radionuclide concentrations developed from tank characterization reports.
d "R" refers to residual wastes remaining in tank after tank waste recovery. Inventories are based on 1% of tank farm inventory reported in the TWRS EIS (DOE and Ecology 1996).
e "1" and "2" refer to complexed and non-complexed waste, respectively.

G.2.9 Single-Shell Tank Farm Residuals

Source inventories for the tank wastes were recently compiled and published in the TWRS EIS (DOE and Ecology 1996). The inventory for the no-action alternative of the TWRS EIS (DOE and Ecology 1996, Figure 2.2.2 in Appendix F) was an estimate of the contents of the tanks. Regarding the residuals remaining after the tank wastes are recovered, the TWRS EIS (DOE and Ecology 1996) states:

> "... The amount and type of waste that would remain in the tanks after retrieval is uncertain. The Hanford Federal Facility Agreement and Consent Order (Tri-Party Agreement) (Ecology et al. 1994) set a goal of no more than 1 percent residuals and the ex situ alternatives have been developed to attempt to achieve that goal. However, achieving this level of tank waste retrieval may require extraordinary efforts and cost and it may not be practical to achieve 99 percent retrieval. Conversely, the contaminants that are not recovered are likely to be those that are insoluble in water since substantial quantities of water would be used in an attempt to dissolve or suspend the waste in water during retrieval. Since neither of these issues can be resolved, a conservative assumption was made to bound the impacts of the residual waste. For purposes of this analysis it was assumed that 99 percent recovery would be achieved but that the residual would contain 1 percent of all the contaminants including the water soluble contaminants."

As in the TWRS EIS, the Composite Analysis estimate of residual was assumed to be 1% of the original inventory. One percent of each radionuclide was assumed to remain in the tank farms following completion of waste recovery (Table G-12). In general, radionuclides with long decay half-lives and potentially significant geochemical mobility have been shown to contribute significantly to long-term dose. The 1% residual is believed to overestimate the inventories of these radionuclides (i.e., ^{14}C, ^{79}Se, and ^{99}Tc) that remain in the tanks following Hanford Site closure.

In the release model for tank residuals, leachate concentrations from residual tank wastes were defined as a function of nitrate dissolution (i.e., a maximum nitrate concentration of 360 g/L is maintained) with congruent release of all radionuclides. Thus, the nitrate inventory, water infiltration rate, and solubility of nitrate define the time required for nitrate to be leached from residual wastes. All radionuclides were assumed to linearly release over the same time.

G.2.10 Double-Shell Tank Farm Residuals

There are six double-shell tank farms in the 200 Areas at the Hanford Site. The SY Tank Farm contains three tanks and is located in the 200 West Area. The AN, AP, AW, AY, and AZ Tank Farms contain 25 tanks and are all located on the eastern side of the 200 East Area. The source inventories for the double-shell tank wastes were also recently compiled and published in the TWRS EIS (DOE and Ecology 1996). As for the SSTs, the inventory for the no-action alternative (DOE and Ecology 1995, Table F.2.2.2 in Appendix F) was an estimate of double-shell tank contents and is the basis for estimating residuals to be left in these tanks. As in the case of the SSTs, a 1% residual is assumed in the double-shell tanks upon completion of waste recovery operations. Therefore, the only assumed release from double-shell tanks is the leaching of a 1% residual. The TWRS EIS inventory spreadsheet (DOE and Ecology 1996) contained the necessary tank farm data for ^{14}C and ^{99}Tc, and 1% of the no-action alternative inventory is employed in this release (Table G-13). Chlorine-36, ^{79}Se, and ^{238}U inventories were not included for double-shell tanks in the TWRS EIS. As in the case of the SSTs, the 1% residual is believed to overestimate the inventories of mobile and long-lived radionuclides in the tanks after completion of waste recovery. As in the case of SST residuals, nitrate dissolution and congruent release of radionuclides was assumed to occur after the high-integrity structure and remediation delay release for 500 years.

G.2.11 Liquid Disposal

Since initial processing of irradiated fuels began in 1944, liquid wastes containing radionuclides have been discharged to the subsurface. These large liquid discharges have resulted in water table rises of approximately 24.4 m (80 ft) in the 200 West Area and approximately 9.1 m (30 ft) around the ponds near the 200 East Area (Law et al. 1996). In the past decade this practice has nearly ended; liquid waste discharges continue at only a few sites (e.g., the 200 Area Treated Effluent Disposal Facility [TEDF], the State-Approved Land Disposal Site [SALDS], and the 400 Area discharge ponds). This reduction in liquid disposal will result in the Hanford Site groundwater levels eventually reaching pre-Hanford levels. This will have a significant effect on the routing and movement of contaminants in the aquifer, especially at locations on the Hanford

Table G-13. Inventory of Key Radionuclides for TWRS Double-Shell Tanks.

Site Name	Radionuclide Inventory[a] in Curies[b]					
	C-14	Cl-36	I-129[c]	Se-79	Tc-99	U-238
TK-AN-R-1[d, e]	8.28E+00				5.56E+01	
TK-AN-R-2	1.14E+01				7.64E+01	
TK-AP-R-1	1.00E-03				2.63E-01	
TK-AP-R-2	2.80E-02				7.35E+00	
TK-AW-R	2.31E-02				8.38E+00	
TK-AY-R-1	3.57E-04				2.77E+00	
TK-AY-R-2	3.29E-04				2.55E+00	
TK-AZ-R	3.48E+00				2.10E+01	
TK-SY-R-1	6.03E-03				2.75E+01	
TK-SY-R-2	1.98E-03				9.05E+00	

a Chlorine-36, selenium-79, and uranium-238 were not reported in the TWRS EIS (DOE and Ecology 1996).

b Inventories decayed to a common date of 2050.

c Iodine-129 is reported in the TWRS EIS, but on a tank-farm-group basis, instead of a tank-farm basis. Therefore iodine-129, which has a total inventory of 22.3 Ci (DOE and Ecology 1996) all in double-shell tanks, is not reported here.

d "R" refers to residual wastes remaining in the tank after the tank waste recovery. Inventories are based on 1% of the tank farm inventory reported in the TWRS EIS (DOE and Ecology 1996).

e "1" and "2" refer to complexed and noncomplexed waste, respectively.

Site where the permeability of the Hanford formation currently dominates the total transmissivity of the system. Past discharges occurred to subsurface facilities including cribs, trenches, french drains, and reverse wells. Large volumes of cooling water and steam condensate generated by chemical separations facilities and evaporators were discharged to surface ponds and ditches. Some of the more significant liquid discharges to the subsurface were the intentional discharge of approximately 120 million gallons (4.5×10^8 L) of tank waste in various forms, e.g., first-cycle supernatant, second-cycle supernatant, and scavenged uranium recovery wastes. These sites are designated past-practice units and their remediation, final closure, and end states will be addressed through the CERCLA process.

G.2.12 Reactor Cores

Nine graphite core production reactors were operated at the Hanford Site between 1944 and 1987. Based on the EIS for the eight surplus reactors (DOE 1989), a ROD was issued to follow a safe storage period with one-piece removal of the reactors to the plateau (ROD 1993). Safe storage at their current location along the Columbia River in the 100 Areas would occur for less than 75 years. Then, each reactor block would be transported intact on a tractor-transporter, from its present location to a 200 West Area burial ground for disposal. Since the EIS and ROD were issued, the B Reactor has been declared a national historic monument. Accordingly, it is possible it will be left at its current location along the Columbia River. This reduces the number of reactors affected by the ROD to seven. The N Reactor was not included in the surplus reactor EIS, and it is probable that it will be removed to the 200 West Area burial ground. Thus, eight reactors are assumed disposed on the 200 Area Plateau in this analysis.

Alternatives for decommissioning the Hanford production reactors were evaluated in a draft EIS (DOE 1989), and its final supplement (DOE 1992). The ROD (1993) states the preferred alternative is for the surplus production reactors to be disposed in the 200 West Area. The EIS evaluated eight of the nine production reactors, omitting the N Reactor because it was not shut down when the study was done. The B Reactor was included in the EIS; however, since then, the B Reactor has been declared a national historic monument and may be preserved for future public display at its present location (ROD 1993). Thus, the EIS contains information on seven reactors, C, D, DR, F, H, KE, and KW, that will be moved to the plateau when the ROD is implemented.

The source inventories for the seven production reactors were derived from Appendix A of the surplus production reactor EIS (DOE 1989, 1992). Twenty radionuclides were included, including tritium, ^{14}C, ^{36}Cl, ^{99}Tc, and ^{238}U. Mobile and long-lived radionuclides of interest in other DOE wastes that were not represented in the graphite cores include ^{79}Se and ^{129}I. The ERC provided an inventory for the graphite core of the N Reactor.[9] The N Reactor core was assumed to be disposed concurrently with the other seven reactor cores in the 200 West Area. Inventories for each of the reactors are shown in Table G-14.

Table G-14. Inventory of Key Radionuclides for the Decommissioned Reactor Cores.

Site Name	Radionuclide Inventories[a] in Curies[b]					
	C-14	Cl-36	I-129[c]	Se-79[c]	Tc-99	U-238
C Reactor	4.47E+03	1.20E+01			2.00E-03	4.00E-03
D Reactor	4.27E+03	3.40E+01			2.00E-03	0.00E+00
DR Reactor	3.18E+03	2.60E+01			2.00E-03	0.00E+00
F Reactor	3.68E+03	3.30E+01			2.00E-03	0.00E+00
H Reactor	3.48E+03	1.70E+01			2.00E-03	0.00E+00
KE Reactor	6.95E+03	5.40E+01			3.30E-02	0.00E+00
KW Reactor	6.66E+03	5.20E+01			3.30E-02	0.00E+00
N Reactor	9.49E+03	7.50E+01			3.30E-02	0.00E+00

a Inventories were from Appendix A of the draft EIS *Decommissioning of Eight Surplus Production Reactors at the Hanford Site, Richland, Washington* (DOE 1989) for all reactors except N Reactor. The N Reactor inventory was provided by V. G. Edens (from Interoffice Memorandum #042809; Subject, "105N and 107N Hazardous Assessment [Inventories]"; sent by R. S. Day to V. G. Edens of Hanford Environmental Restoration contractor; February 11, 1997).

b Inventories were decayed to a common date of 2050.

c Neither iodine-129 nor selenium-79 were reported in the inventories for the decommissioned reactor cores.

(9) The N Reactor inventory was provided by V. G. Edens (from Interoffice Memorandum #042809; Subject, "105 N and 107 N Hazardous Assessment [Inventories]"; sent by R. S. Day to V. G. Edens of Hanford Environmental Restoration Contractor; February 11, 1997).

Chemical Separation Canyons or Process Facilities

Facilities in which the chemical separations were conducted are long, monolithic, concrete structures. These are known as the canyon buildings, and are identified as the 221-B or B Plant, 221-T or T Plant, and other facilities. There are also related nearby structures used in additional process steps (e.g., the 224-B and 224-T Buildings) and storage facilities (e.g., the two subsurface tunnels at PUREX). Two canyon buildings are in the 200 East Area: B Plant and PUREX. Four canyon buildings are in the 200 West Area: T Plant, U Plant, REDOX, and Z Plant (PFP). In general, these structures contain inventories of mixed fission products and mixed activation products; however, they are in fixed or immobile settings inside metal vessels and piping and contained inside monolithic concrete cells. The end state of these structures and associated facilities is being defined through negotiations with regulators; however, the current baseline assumes canyon facilities will be demolished to the cover block grade with the remaining structure covered with a surface barrier.

In the case of each canyon building, the major radionuclide sources and waste within the retired plant will be removed, reduced, or stabilized. Radiological contamination within the facility will be removed or fixed in place. The canyon buildings are massive concrete structures, and concrete is an excellent waste form for sorbed radionuclides. Whatever structure is left in place will be stabilized (i.e., filled with soil, gravel, or concrete) and all services (such as water) will be disconnected. Retired filters will be isolated and stabilized to ensure a safe condition. It is likely that these areas and especially any remaining structure will be covered with a protective barrier to further isolate contamination from intrusion and recharge. Final disposals will be dry with minimal driving force to mobilize and transport radionuclides from facilities.

The PUREX storage tunnels (#1 and #2) branch off from the PUREX railroad tunnel and extend southward from the east end of the PUREX plant. The tunnels are used for storage of mixed waste (e.g., spent equipment and tank cars) from the PUREX Plant and from other onsite sources. The radiological contamination in the tunnels consists primarily of uranium, TRUs, and/or mixed fission products. Currently, each storage tunnel is isolated from the railroad tunnel by a water-filled shielding door. Tunnel #1 is constructed of creosote-treated timber covered by roofing material and 2.4 m of earthen fill. Tunnel #2 is constructed of steel and reinforced concrete covered with 2.4 m of earthen fill.

G.2.13 Commercial LLW Disposal Facility

The commercial LLW disposal facility opened in 1965 on 100 acres located southwest of the 200 East Area. The LLW that is packaged and shipped for disposal at the facility comes from medical practices, scientific research, industrial processes, and nuclear power plants. Prior to 1993, LLW came from throughout the United States to this site; but today LLW comes only from Washington, Alaska, Hawaii, Idaho, Montana, Oregon, Utah, Wyoming, Colorado, Nevada, and New Mexico. Naturally occurring radioactive materials can still come from all 50 states. The US Ecology Site is regulated by the DOH and Ecology, and is expected to close by 2063.

The closure plan for the commercial LLW site operated by US Ecology on the Hanford Site (Grant Environmental, Chase Environmental Group, and US Ecology 1996) presents a total

inventory to date and a projection for disposal at the site until its closure in 2063. The inventory was screened according to two criteria, total activity greater than 1 Ci and decay half-life in excess of 100 years. Of the radionuclides identified for further analysis, several have K_ds at or only slightly greater than zero, including ^{14}C, ^{36}Cl, ^{129}I, ^{40}K, ^{99}Tc, and ^{238}U. While all the other radionuclides were identified in prior analyses, ^{40}K was identified as a contaminant of potential concern.

The inventory for the commercial LLW disposal site operated by US Ecology was derived from the recently completed site stabilization and closure plan. The inventory is reported by Grant Environmental, Chase Environmental Group, and US Ecology (1996, in Volume II, Attachment 3 of Attachment D, subsection "Source Term" in section "Pathways Analysis Report"). A detailed accounting of inventory is presented in the same document (page 3.6, Table 3.1, and page 3.12, Table 3.7). The key radionuclides inventory of the commercial disposal site includes inventories for ^{14}C, ^{36}Cl, ^{99}Tc, ^{129}I, and uranium (see Table G-15). Of the more mobile radionuclides thought to be of concern in DOE wastes at Hanford, ^{79}Se was the only one for which no data were available in the detailed inventory.

Table G-15. Inventory of Key Radionuclides for US Ecology.

Site Name	Radionuclide Inventories[a] in Curies[b]					
	C-14	Cl-36	I-129	Se-79[c]	Tc-99	U-238
US Ecology current	3.66E+03	3.44E+01	5.63E+00		6.17E+01	1.08E+04
US Ecology future	1.91E+02	6.00E-02	1.40E-01		3.91E+00	1.21E+02

a Total inventories were taken from the *Site Stabilization and Closure Plan for Low-Level Radioactive Waste Management Facility, US Ecology, Inc., Richland, Washington* (Grant Environmental, Chase Environmental Group, and US Ecology 1996).

b Inventories decayed to a common date of 2050.

c The absence of selenium-79 from the commercial LLW disposal is a result of commercial waste not having a significant source of this radionuclide.

After receiving the site stabilization and closure plan for the commercial LLW disposal site, the DOH decided to complete a *State Environmental Policy Act* (SEPA) EIS for the site. The DOH has developed its own inventory for the commercial disposal site[10]. Minor differences exist between the DOH and Grant Environmental, Chase Environmental Group, and US Ecology (1996) inventories. One similarity is that ^{79}Se is also absent from the DOH inventory. Its absence from the commercial inventory is because it is an inconsequential nuclide in the waste streams accepted at the commercial disposal facility. Where there is a large discrepancy for a key mobile radionuclide (e.g., ^{36}Cl), the inventory from the stabilization and closure plan is conservative. However, in one instance the DOH inventory is larger. For ^{14}C, which is slightly sorbed, it shows an inventory of 4,909 Ci, whereas the stabilization and closure plan inventory shows 3,850 Ci. Although assigning a higher initial inventory, the DOH assumed 55% of the ^{14}C was biodegradable and that the entire inventory was released through the gas phase to the atmosphere.

(10) From two electronic mail messages; Subject, "Comments for Composite Analysis": 1) from A. H. Thatcher (DOH, Olympia, Washington) to R. D. Hildebrand (DOE-RL), dated February 2, 1998; 2) from M. Dunkelman (DOH, Olympia, Washington) to R. D. Hildebrand (DOE-RL), dated January 28, 1998.

G.2.14 Radionuclides Included in the Groundwater Pathway

Groundwater plumes of tritium, ^{90}Sr, ^{99}Tc, and ^{129}I exist in the unconfined aquifer at the Hanford Site. Curie or gram content in groundwater has been estimated in the *Hanford Sitewide Groundwater Remediation Strategy* (DOE-RL 1995c) (Table G-16).

Radionuclides included in the groundwater pathway analysis for future sources are ^{14}C, ^{36}Cl, ^{79}Se, ^{99}Tc, ^{129}I, and $^{233,-234,-235,-236,-238}U$ and their daughters. This list is the result of merging the two lists from the ILAW from tanks and the solid waste burial grounds. In addition, the RI/FS for the ERDF and other environmental impact statements (DOE 1989, 1992 and 1996a; DOE-RL 1994b; DOE and Ecology 1996) were reviewed, and no other radionuclides were identified as potentially
significant contributors to groundwater pathway dose.

Because of its mobility and its disposal to cribs in relatively large volumes of liquid waste, tritium is assumed to be in the aquifer and not significantly retained in the vadose zone. Strontium is highly sorbed in the aquifer and does not pose a threat outside the buffer zone when the source is inside the exclusive waste management area and buffer zone. Strontium-90 will be shown to contribute to dose, but only in the immediate vicinity of these releases.

Table G-16. Contaminant Plume Dimensions and Volumes. (2 Pages)

Project	Target Contaminants	Quantity				Extent of Contamination		
		In Pore Fluid		On Aquifer Solids		Area		Pore Fluid Volume
		(Ci)	(g)	(Ci)	(g)	(m^2)	(mi^2)	(L)
200 West Area								
200-UP-1[a]	Uranium	N/A	1.4E+5	N/A	2.5E+11	5.7E+5	2.2E-1	5.7E+8
	Technetium-99	1.5	9.7E+1	0	0	4.4E+5	1.7E-1	4.2E+8
200-ZP-1[a]	Carbon tetrachloride	N/A	5.3E+6	N/A	-[d]	1.0E+7	3.9	1.1E+10
	Chloroform	N/A	4.3E+4	N/A	-[d]	2.0E+6	7.7E-1	2.0E+9
	Trichloroethylene	N/A	9.7E+3	N/A	-[d]	8.3E+5	3.2E-1	8.3E+8
200 East Area								
B-5Reverse Well[a]	Plutonium-239	1.0E-1	1.6	2.4E+2	4.3E+3	3.1E+2	1.2E-4	7.8E+5
	Cesium-137	8.1E-4	9.3E-6	2.4E-1	9.3E-6	3.1E+2	1.2E-4	7.8E+5
	Strontium-90	4.1E-2	2.9E-4	6.2	4.4E-2	6.6E+4	2.5E-2	1.7E+8
	Technetium-99	18.0	1.0E+3	0	0	2.7E+6	1.0	6.7E+9
	Cobalt-60	3.7E-2	3.3E-5	0	0	9.3E+4	3.6E-2	2.3E+8
Reactor Areas								
100-K Area[b]	Chromium	N/A	2.5E+5	N/A	0	1.3E+6	5.0E-1	1.7E+9
	Strontium-90	2.1E-2	1.5E-4	3.2	2.3E-2	4.0E+5	1.5E-1	5.1E+8
100-D Area[b]	Chromium	N/A	5.9E+5	N/A	0	2.6E+6	1.0	2.9E+9
	Strontium-90	6.6E-4	4.7E-6	9.9E-2	7.0E-4	1.8E+4	6.9E-3	2.2E+7
100-H Area[b]	Chromium	N/A	2.5E+5	N/A	0	2.1E+6	8.1E-1	2.6E+9
	Strontium-90	6.6E-4	4.7E-6	9.9E-2	7.0E-4	1.8E+4	6.9E-3	2.2E+7
100-F Area[b]	Chromium	N/A	0	N/A	0	0	0	0
	Strontium-90	7.5E-3	5.3E-5	1.1	7.9E-3	7.5E+4	2.9E-2	9.4E+7
100-N Area[b]	Chromium	N/A	0	N/A	0	0	0	0
	Strontium-90	8.8E-2	7.4E-3	1.3E+1	1.1E+0	8.2E+5	3.1E-1	6.5E+8
100-B/C Area[b]	Chromium	N/A	0	N/A	0	0	0	0
	Strontium-90	2.6E-2	1.9E-4	3.9E+0	2.8E-2	7.6E+5	2.9E-1	9.5E+8
Sitewide								
Sitewide[c]	Tritium	2.5E+4	1.8E+1	0	0	1.9E+8	7.3E+1	5.3E+11
	Iodine-129	1.2E+0	8.4E+3	0	0	7.5E+7	2.9E+1	3.7E+11
	Nitrate	N/A	4.1E+10	N/A	0	5.5E+7	2.1E+1	1.6E+11

Table G-16. Contaminant Plume Dimensions and Volumes. (2 Pages)

Project	Target Contaminants	Quantity				Extent of Contamination		
		In Pore Fluid		On Aquifer Solids		Area		Pore Fluid Volume
		(Ci)	(g)	(Ci)	(g)	(m^2)	(mi^2)	(L)
Other Areas								
1100	Trichloroethylene	N/A	41.4 E+3	N/A	-[d]	4.8 E+5	2.0 E-1	1.2 E+9
300[b]	Uranium (DOE-RL 1995c)	.04	6.1E+4	0.47	6.7E+5	5.6E+5	2.2E-1	0.8E+9

a Assumes that plumes have an average thickness of 10 m (32 ft).

b Assumes that plumes have an average thickness of 5 m (16 ft).

c Assumes plume thickness as described in Section 4.2.2.

d No estimates available.

Table G-17. Summary Table of Inventories Considered in the Composite Analysis.

Site Name	Radionuclide Inventories in Curies[a]					
	C-14	Cl-36	I-129	Se-79	Tc-99	U-238
Agnew[b] All Tanks	4.78E+03		6.30E+01	7.73E+02	3.26E+04	9.06E+02
Agnew[b] Cribs	1.24E+02		1.64E+00	2.63E+01	8.68E+02	1.31E+03
Agnew[b] Leaks	1.44E+01		2.04E-01	1.85E+00	1.07E+02	4.63E-01
Agnew[b] Total Site	4.91E+03		6.48E+01	8.01E+02	3.35E+04	2.22E+03
Kupfer[c] Global Tank Inventories	4.78E+03		6.61E+01	7.73E+02	3.26E+04	3.22E+02
Schmittroth[d] Total	7.69E+02		6.61E+01	1.03E+03	2.72E+04	2.96E+02
Total[e]	5.00E+04	3.45E+02	1.71E+01	1.05E+03	2.49E+04	6.60E+04
Total minus US Ecology	4.62E+04	3.11E+02	1.13E+01	1.05E+03	2.48E+04	5.50E+04
Total minus (cores + US Ecology)	3.95E+03	7.60E+00	1.13E+01	1.05E+03	2.48E+04	5.50E+04
Total minus (cores + US Ecology + ERDF)	1.50E+02	7.60E+00	1.13E+01	1.05E+03	2.48E+04	8.00E+02
TWRS ILAW	7.69E+00	0.00E+00	6.62E+00	1.03E+03	2.23E+04	1.78E+01
TWRS SST Leaks – cmplx[f]	3.15E-01	0.00E+00	5.99E-02	5.60E-02	5.22E+01	2.45E-03
TWRS SST Leaks – ncmplx[g]	4.11E+00	0.00E+00	6.78E-01	7.32E-01	4.59E+02	3.21E-02
TWRS SST Losses - cmplx	1.44E-01	0.00E+00	2.88E-03	7.47E-03	5.76E+00	3.14E-04
TWRS SST Losses - ncmplx	3.52E+00	0.00E+00	6.23E-01	6.27E-01	4.67E+02	2.75E-02
TWRS SST Residuals - cmplx	1.17E+00	0.00E+00	5.74E-03	2.79E-01	3.84E+00	3.24E-01
TWRS SST Residuals - ncmplx	2.86E+01	0.00E+00	1.54E-01	7.70E+00	1.06E+02	4.42E+00
TWRS DST Residuals - cmplx	8.28E+00	0.00E+00	0.00E+00	0.00E+00	8.62E+01	0.00E+00
TWRS DST Residuals - ncmplx	1.49E+01	0.00E+00	0.00E+00	0.00E+00	1.25E+02	0.00E+00
216[h] liquid discharges + 241[i]	3.65E+00	2.40E-01	1.94E+00	2.93E-01	9.37E+02	1.57E+02
218[j] 200 W[k] pre-1988	2.89E+01	1.45E+00	6.18E-01	1.77E+00	6.01E+01	1.92E+02
218 200 E pre-1988	7.94E+01	5.22E+00	4.25E-01	6.36E+00	2.15E+02	9.85E-01
218 200 W post-1988	1.74E+01	8.33E-01	2.10E-01	1.07E+00	5.15E+01	3.46E+02
218 200 E post-1988	1.35E-01	8.87E-03	4.21E-02	1.08E-02	3.66E-01	6.68E-02
ERDF	3.80E+03	0.00E+00	0.00E+00	0.00E+00	6.57E+00	5.43E+04
Production Reactor Cores	4.22E+04	3.03E+02	0.00E+00	0.00E+00	1.09E-01	4.00E-03
US Ecology	3.85E+03	3.44E+01	5.77E+00	0.00E+00	6.56E+01	1.09E+04

a Inventories have been decayed to a common date of 2050.
b See Agnew et al. (1997).
c See Kupfer et al. (1997).
d See Schmittroth et al. (1995).
e Sum of estimated inventories of sites included in the first iteration of the Composite Analysis.
f cmplx = complexed wastes.
g ncmplx = noncomplexed wastes.
h 216 refers to past-practice liquid disposals.
i 241 refers to tanks associated with reverse wells.
j 218 refers to solid waste burial grounds.
k W and E refer to the 200 West Area and the 200 East Area, respectively.

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APPENDIX H

APPLIED SCIENCE AND TECHNOLOGY PLAN FOR THE INTEGRATED VADOSE ZONE, GROUNDWATER, AND RIVER SYSTEM AT THE HANFORD SITE

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APPLIED SCIENCE AND TECHNOLOGY PLAN FOR THE INTEGRATED VADOSE ZONE, GROUNDWATER, AND RIVER SYSTEM AT THE HANFORD SITE

H.1 INTRODUCTION

The Groundwater/Vadose Zone (GW/VZ) Integration Project (Integration Project) recognizes that there are gaps in the knowledge and data for the vadose zone, groundwater, river, and inventory technical elements that are required to adequately predict the movement of contaminants in the Hanford subsurface. Consequently, the Integration Project asked DOE's national laboratories under PNNL's leadership to provide the scientific perspective on how to best expand the existing base of knowledge and data regarding contaminant migration in the subsurface environment. Teams of experts from Lawrence Berkeley National Laboratory, Lawrence Livermore National Laboratory, Los Alamos National Laboratory, Oak Ridge National Laboratory, PNNL, Sandia National Laboratory, and Savannah River Technology Center met several times with regulators, Tribal Nations, and stakeholders. The focus of the meetings was to understand the state-of-the-knowledge at Hanford; identify the issues, needs, and gaps associated with these four technical elements; and to define applied S&T activities to address the knowledge gaps and provide a defensible basis for sitewide assessments. The results of the meetings have been captured in this S&T plan.

H.1.1 Expected Outcomes

The S&T activities undertaken within each of the technical elements are intended to contribute to upcoming remediation decisions and the system assessment by providing scientifically defensible data, knowledge, and newly developed or expanded use of existing S&T to resolve scientific issues and needs to achieve the project cleanup mission over time. The vadose zone technical element is expected to contribute to upcoming Site decisions about characterization, assessment, and remediation of the 200 Area plateau with regard to near-term corrective actions for tank farms, tank retrieval performance and closure requirements, and closure requirements for cribs and other contaminated soil sites within the 200 Area. The groundwater technical element is expected to contribute to remediation decisions about plumes associated with the 200 Area, to provide a basis for enhanced efficiency and effectiveness of groundwater monitoring, and to contribute the assessment capability by providing regional plume geometry and three-dimensional modeling capability. The river technical element is expected to provide input to the system assessment capability and river monitoring activities, while the inventory technical element is expected to provide a consistent framework for collecting inventory data from individual ongoing projects. (See Figure H-1 for the proposed interactions between the individual projects and the S&T within the four technical elements.)

As a final expected outcome of the S&T activities, having the scientific data, knowledge, and applied S&T needed to make better informed decisions and to deal more effectively with

environmental issues and challenges is expected to improve the credibility of DOE and its contractors in the eyes of stakeholders, regulators, and the public.

H.1.2 Next Steps

The S&T plan represents a first step in defining and implementing an applied S&T program for the Integration Project. The S&T activities described herein will now be aligned with the project priorities and schedules through the Project Specification and Long-Range. Specific S&T products that feed the individual projects and the system assessment are being defined and the corresponding budget developed. The scope, schedule, budget, and products will be documented in the Groundwater/Vadose Zone Project Level S&T Roadmap. These documents comprise the GW/VZ Integration Project Baseline which is developed with and reviewed by the stakeholders. The interrelationship of the S&T and project documents is shown in Figure H-2. The baseline documents will be updated annually to reflect the evolution of project needs and acquisition of new scientific, technical, and field data.

Figure H-1. Proposed Interactions between Individual Projects and S&T within the Integration Project.

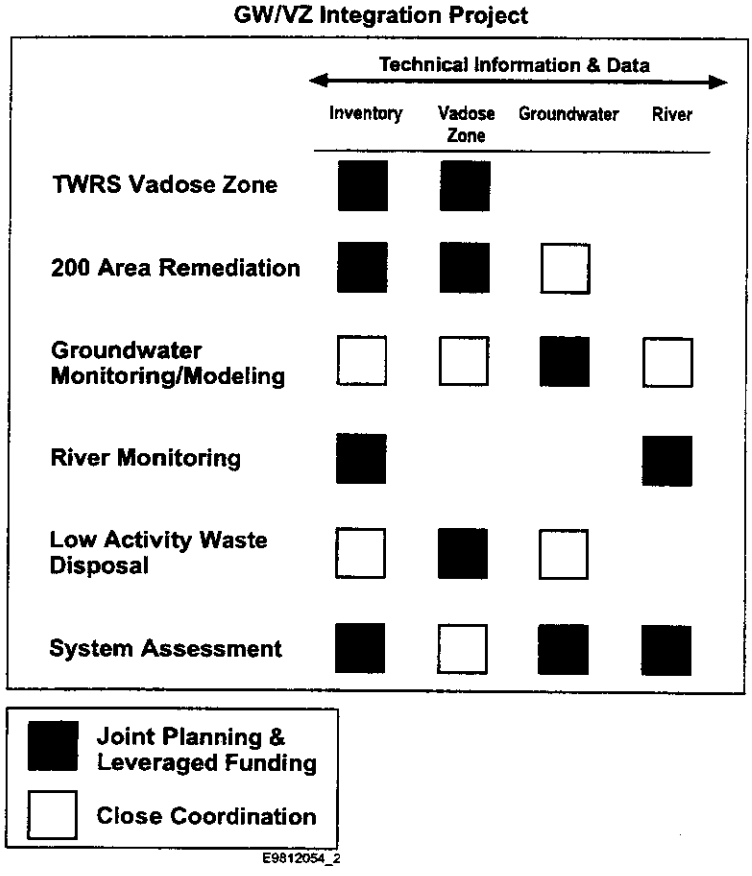
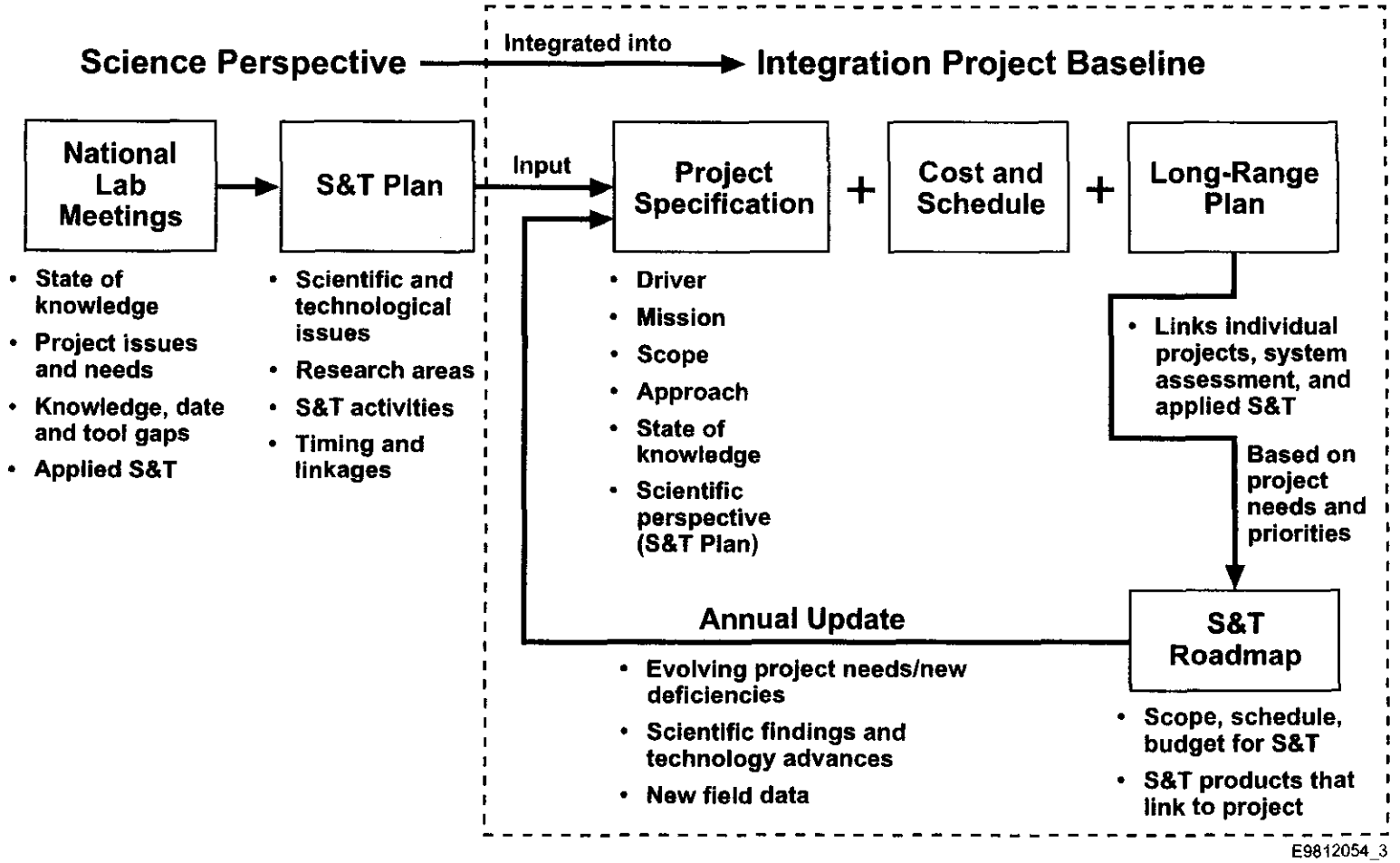


Figure H-2. Integration Process for Planning Applied S&T.



H.1.3 Contents

Sections H.2 through H.5 of this S&T plan document the outcome of the national laboratory meetings. Each chapter describes the scientific and technological issues for the four technical elements that have been addressed thus far followed by a description of the research areas that would address these issues. A general description of the scope, research questions and motivations, proposed S&T activities, and research products and benefits for each of the research areas is also provided. Each chapter closes with expected results of proposed research and a description of the timing of and linkages between the S&T activities within the technical element. Section H.6 summarizes the technical elements and describes their linkages to key decisions at the Hanford Site, to individual projects within the Integration Project, between the technical elements, and to other programs within DOE. It also presents the next steps in the process for defining and implementing applied S&T activities.

H.2 VADOSE ZONE

The vadose zone technical element of the applied science and technology (S&T) plan is intended to address and resolve scientific problems related to the leakage of radioactive and hazardous wastes into Hanford soils and sediments. An applied scientific information base and models will be developed to support short- and long-term technical needs regarding contaminant migration and remediation of the Hanford vadose zone (i.e., region from soil surface to underlying water table). S&T activities proposed for the vadose zone will enhance protection of human health and the environment by providing 1) improved models, measurements, and data to predict contaminant migration and provide warning of potential surface or groundwater contamination before problems arise; 2) scientific rigor to system assessment and performance assessment (PA) models as they are developed, reviewed, and implemented; and 3) scientific support for selection of the most safe, efficient, and effective remedial actions and site closure activities. An implicit goal of this research is to provide scientific and regulatory credibility to DOE's environmental management decision-making process.

Under the vadose zone technical element, the plan includes five major areas of research that were selected to maximize its positive impact on Hanford Site cleanup and closure operations. The activities include the following investigative efforts, which will provide input data and information to risk analysis and risk end points and other applications:

- Field studies of representative contaminated sites to develop improved conceptual models of waste interaction and water/contaminant flow-and-transport processes.

- Directed laboratory research to fill data gaps for understanding chemical and physical processes not previously accounted for in estimating contaminant migration at the Hanford Site.

- Field studies that will provide in situ hydrologic and chemical parameters needed to improve estimates of vadose zone transport.

- Development of credible reactive transport models that address scaling, heterogeneity, multi-component and multiphase reactions, and uncertainty propagation.

- Development of advanced methods and tools needed for improved vadose zone characterization.

The applied S&T plan set forth here both recognizes and builds upon the extensive data and knowledge base that already exists for the Hanford Site. The knowledge base includes conceptual models of both geochemical and hydrologic processes that control waste migration and contaminant retardation (Figures H-3 and H-4) that have been developed through field characterization activities and laboratory measurements. The proposed research plan targets pragmatic S&T needs by 1) capturing relevant knowledge, information, and models developed by other DOE programs or existing in the scientific community; and 2) performing carefully rationalized, product-oriented laboratory and field experimentation and model development to provide Hanford-specific information and/or technology that are not available elsewhere.

H.2.1 Scientific and Technological Issues

The vadose zone will continue to be a dynamic region for solute migration and a source of chemical contaminants to the water table for many years to come. The magnitude of these contaminant fluxes and their spatial and temporal distribution cannot be established or credibly estimated with current characterization data, knowledge, or models. Only with a better estimate of contaminant inventory, and an improved understanding of flow paths through the vadose zone, coupled with a clearer knowledge of contaminant interactions, can proper assessments be made of the risks involved with vadose zone contamination. The following are major scientific deficiencies that require resolution:

- The inventory (e.g., mass), release rates and time history, spatial and depth distribution, phase association, chemical speciation of in-ground contaminants and moderating/facilitating co-contaminants, and major-ion solution chemistry are not adequately known.

- The in situ chemical, physical, and hydrologic properties of subsurface sediments are insufficiently documented.

- The chemical and biologic reactions and colloidal transport processes responsible for contaminant retardation, immobilization, and mobilization are insufficiently understood or lack data on key parameters to allow for defensible predictions of their in-ground rates, extent, magnitude, and effect.

Figure H-3. Vadose Zone Biogeochemistry Conceptual Model.

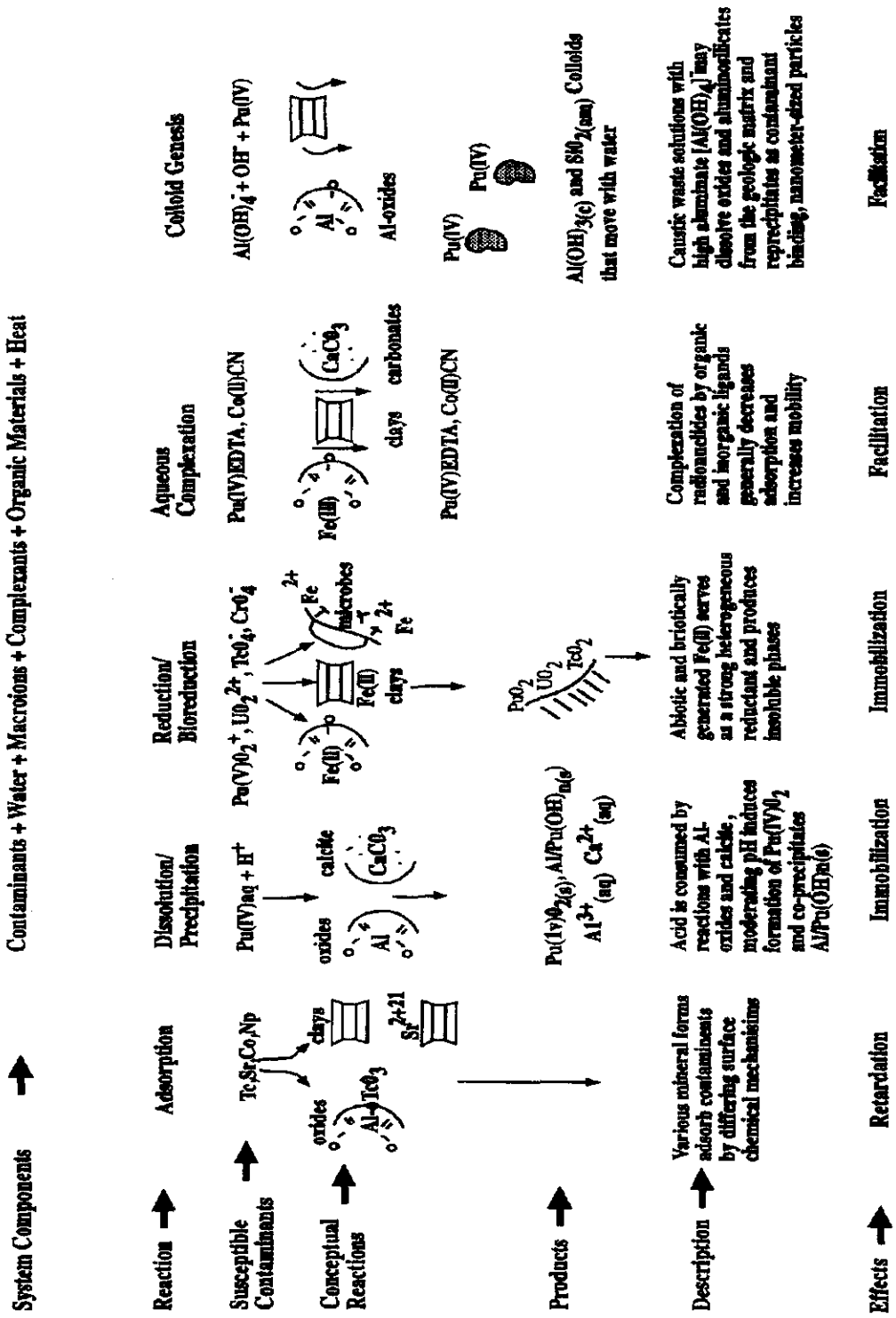
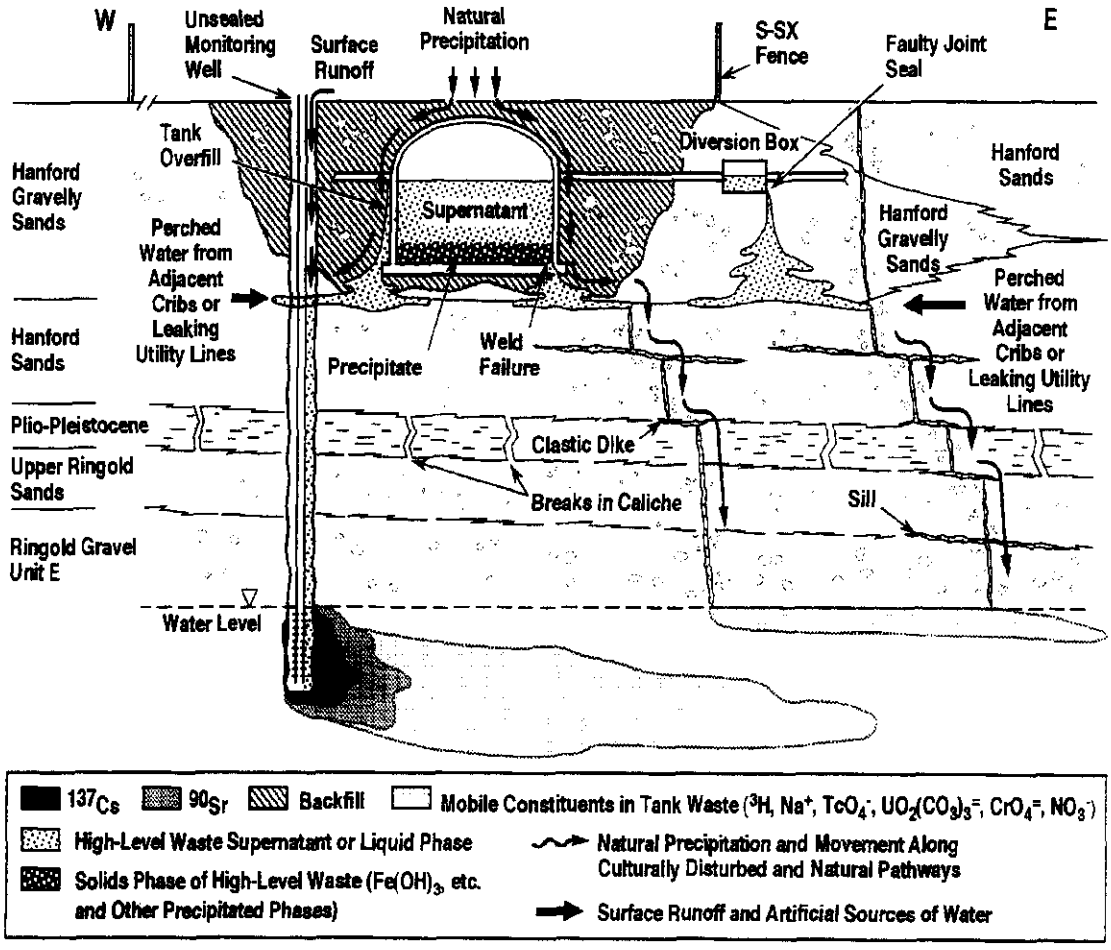


Figure H-4. Conceptual Model of Fluid Flow Beneath Single-Shell Tanks.



- Geo-hydrochemical effects that are known to occur onsite, such as chemical dissolution (of mineral sediments in contact with tank liquor at elevated temperatures), clay dispersion, piping (cavities created by accelerated flow in high sodium environments), colloid transport, precipitation and flocculation, are insufficiently documented and understood.

- The frequency of occurrence of preferred hydrologic pathways is unknown as is their overall impact on contaminant dispersion. These pathways can be created by solutions that have densities much greater than water, by instabilities in wetting fronts in coarse sediments, by funnel flow created by sloping layers from manmade structures (e.g., tanks) and natural sediments (e.g., compacted silts and calcareous sediments), by clastic dikes that may act as vertical conduits for flow, and by unsealed wells penetrating contaminant source areas.

- Credible transport models (and supporting laboratory and field data) that incorporate chemical reaction coupled with transport processes and incorporating representative physical heterogeneities are not available to predict contaminant and water travel times and mass fluxes in the vadose zone.

H.2.2 Approach

Applied S&T activities can resolve or reduce uncertainties and other critical deficiencies that limit risk assessment, stabilization, and cleanup of vadose zone contamination at Hanford by emphasizing two major scientific thrusts:

- Establishment of the existing distribution of chemical and radioactive contaminants and their sources and causes, the chemical/mineralogical/physical state in which they exist, and their future potential for migration.

- Understanding how water and contaminants move through the Hanford vadose zone and the controlling influences of in situ geologic and physical features, and waste attributes such as density, viscosity, temperature, and co-contaminants.

The complexity of the scientific issues associated with the vadose zone, combined with the urgent need for timely technical solutions at Hanford and other sites requires that a joint program of laboratory research, field research, and numerical modeling be established in partnership with ongoing characterization and remediation activities at Hanford. Five research areas are proposed for the vadose zone technical element to accomplish this partnership. These research areas, their primary objectives, and envisioned products are summarized in Table H-1. A more extensive description of the research areas is provided in Section H.2.3.

Table H-1. Objectives and Products of Vadose Zone Research Areas.

Research Area	Objective	Products
1. Field Investigations of Representative Vadose Zone-Groundwater Sites	Couple science with characterization activities at select contaminated sites to identify chemical, physical, biological, and geological causes for contaminant distribution and current physical/ chemical state.	Robust conceptual models of different waste types and source terms, key experimental field investigations and modeling needs.
2. Laboratory Studies of Waste-Sediment Interaction Processes	Fill key data needs for physical, biological, and chemical interaction processes, and receive mobility/speciation issues identified under item 1.	Models of reactions or processes, field relevant reaction and kinetic parameters, information to assess in-ground stability/mobility.
3. Vadose Zone Field Study Sites	Evaluate field-scale migration processes with emphasis on preferred water flow pathways and chemical reactivity within them.	Knowledge of in situ features controlling water flow and retardation, and comprehensive data sets for testing and calibration of models.

Table H-1. Objectives and Products of Vadose Zone Research Areas.

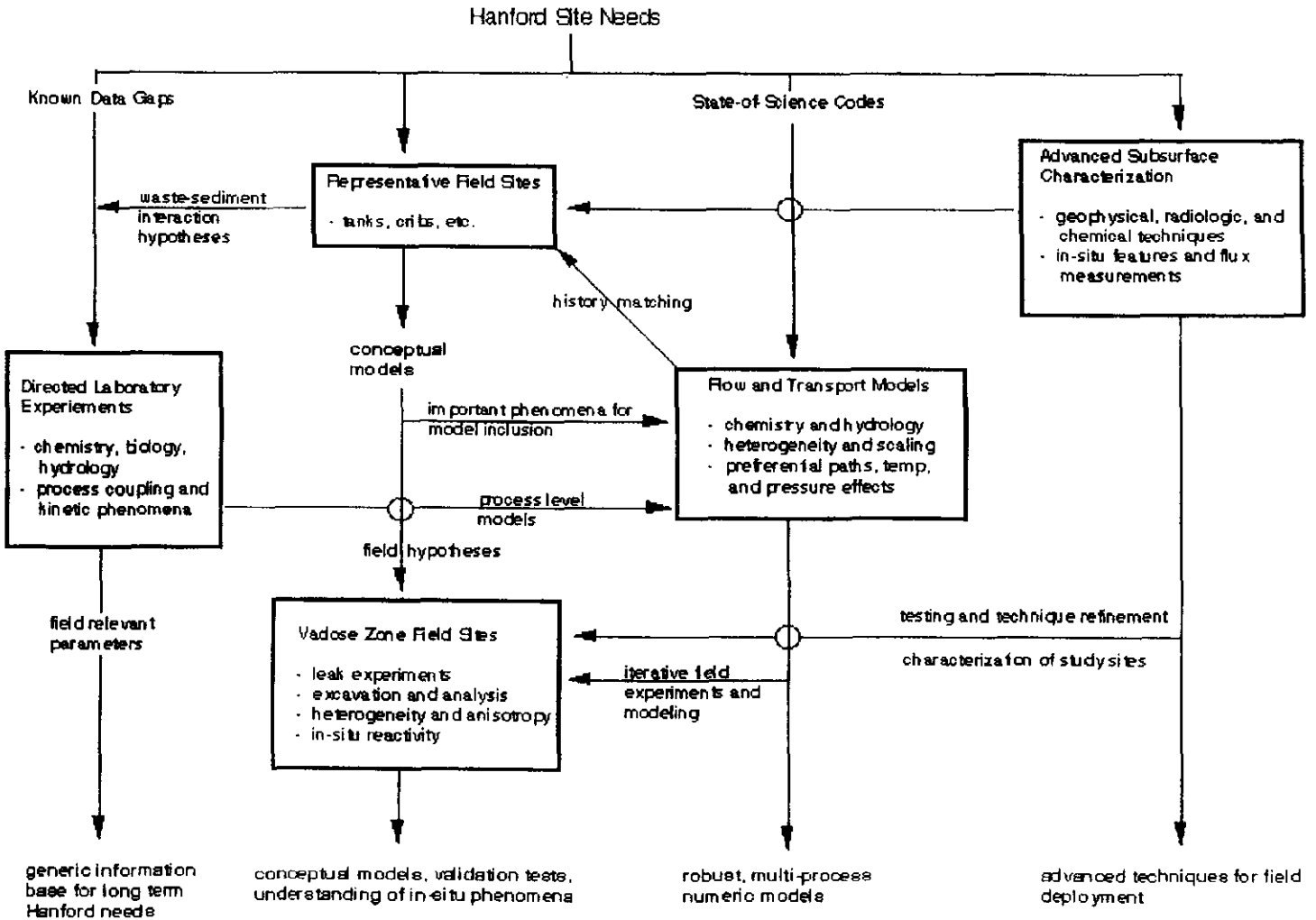
Research Area	Objective	Products
4. Reactive Flow-and-Transport Modeling	Develop credible models to describe and predict contaminant migration in the vadose zone arising from different source term (e.g., cribs, tanks, etc.)	Robust numeric models for application to specific waste sites for long-term mobility and mitigation assessment, and Records of Decision (RODs).
5. Advanced Vadose Zone Characterization	Establish and deploy advanced, nonintrusive methods to determine in situ geophysical properties of vadose zone sediments and to monitor water/ contaminant fluxes and distribution.	Proven geophysical, chemical, radiochemical, or capillary pressure techniques for down-hole or surface monitoring of in situ properties in water/ contaminant fluxes.

The overall scientific approach may be described as follows: we propose to develop conceptual and numerical models of contaminant transport at key, representative waste sites. These models should be supported by necessary physical, chemical, and geologic databases that define properties or parameters and/or their statistical properties. The waste sites should be chosen based on waste stream characteristics, geology, hydrology, recharge rates (artificial and natural), overall significance/relevance to the Hanford cleanup mission, availability of characterization data, and/or planned future characterization activities for the site. Priorities for site selection should be established in association with other research teams (e.g., inventory, groundwater, etc.) that should jointly use these sites as research focal points. The conceptual and numerical models should be allowed to change as more data are obtained from studied sites, as appropriate process understanding emerges from directed laboratory and field studies, and as new insights into the attributes of the vadose zone emerge from various lines of S&T activity both from within and external to the research program. The models should incorporate key chemical, physical, and biological processes that impact contaminant migration in the vadose zone, as well as important geologic features. Models should be coupled with judicious laboratory and field testing to ensure the best possible predictive capability and versatility to different Hanford waste types and sources.

H.2.3 Research Areas

The five applied research areas link and couple in a complex fashion (see Figure H-5). A variety of Hanford Site needs drives applied research. The proposed program targets critical known data and knowledge gaps, and exploits state-of-the-art reactive transport models and new generation in situ characterization methods developed by DOE and other groups and agencies. The proposed S&T activities should collectively yield the following items as major products for the Hanford Site: 1) a generic information base on vadose zone physicochemical processes for long-term Hanford needs; 2) conceptual models of key waste site/source term types, field-scale model validation tests, and understanding of in situ contaminant migration phenomena; 3) robust,

Figure H-5. Linkage and Products of Research Areas.



multi-process numeric models; and 4) advanced techniques for field deployment. Major contributions will also accrue to the system assessment model as described in Section H.2.8.

The scope, research questions and/or motivation, S&T activities, products and their usefulness at Hanford, and the timing and linkage of the activities of the five technical research areas that are summarized in Table H-1 and Figure H-6 are described in the following sections.

H.2.3.1 Field Investigations of Representative Sites

H.2.3.1.1 Scope. Within this research area, we propose to conduct investigations that will evaluate select contaminated sites at Hanford that represent important waste and disposal site types (e.g., cribs, tanks, etc.) and source terms. Conceptual models for reaction and transport of contaminants should be refined and qualified by field sampling and characterization and by solute transport modeling. Deficiencies in critical knowledge of controlling physical and chemical processes should be determined for resolution through laboratory and field studies in other areas of the S&T plan. Pragmatic needs for solute transport models should be established for sites where past histories are not well documented.

H.2.3.1.2 Research Questions and Motivation. Contaminated sites that are considered historical reactive tracer experiments are those where knowledge can be gleaned on the processes controlling long-term contaminant migration, and where knowledge gaps that require resolution can be clearly identified. The study of representative waste sites is motivated by the lack of information on the physical association and chemical form of important contaminants in the vadose zone beneath waste sites of different source terms, ages, and water flow histories (e.g., cribs, tanks, etc.). Little is known about the physical and chemical processes that are most significant over protracted contact times of the wastes with the sediments in the vadose zone. Within this time context, the effects of extreme waste chemistry, unsaturated water conditions, and complex, geologically controlled water flow paths stand out as critical scientific uncertainties.

Three primary questions drive research within this element:

- How is contamination distributed in the vadose zone beneath different types of waste sites with different source chemistries and different release histories?
- What are the relationships between contaminant distribution, moisture content, and the physical, chemical, microbiologic, and geologic characteristics of the subsurface sediments?
- What are the existing physical, chemical, and mineralogical associations of contaminants and co-contaminants and what are the primary processes that have formed these associations?

Secondary questions to be addressed in combination with other research areas concern water flow processes within the vadose zone, particularly those induced by preferential flow paths, high-density waste solutions, and/or other channeling effects. Representative sites that have the broadest possible implications or greatest potential impact to remediation issues at Hanford should be targeted. For example, the program may target a site that received significant inventories of mobile constituents (e.g., technetium-99) yet received only a small volume of

waste liquids. Conceptually, these sites pose the greatest hazard of a delayed release of mobile constituents from the vadose zone to the unconfined aquifer. In contrast, mobile constituents will already have moved to groundwater at high-volume liquid discharge sites. Understanding these transport and release mechanisms, and the factors controlling their timing, is crucial to prediction of the timing, extent, and risk of future releases.

H.2.3.1.3 S&T Activities. Two primary activities are envisioned: 1) reviewing and remodeling the databases for several select, well-characterized waste disposal sites as a basis for assessing future modeling needs and demonstrating the benefit of more accurate predictive tools for remediation decisions; and 2) studying and analyzing core materials from representative contaminated sites to identify controlling hydrochemical processes and enigmatic observations requiring resolution, and to develop conceptual models useful to site cleanup and closure. The research would be performed in close collaboration with site characterization activities and remediation contractor site assessments. Some of the activities identified to date are:

- Collaboration with the TWRS Program in their planned coring of the vadose zone beneath several leaking single-shell waste tanks whose contents exhibit differing waste chemistries.

- Evaluation and supplementation of the existing 200-BP-1 data set for application, performance testing, and validation exercises of more sophisticated reactive transport models.

- Quantification of the variations in recharge rates at existing waste sites (200-BP-1, etc.) of interest and assessment of the impact of these variations on contaminant migration rates.

- Selective, high-impact collaborations with other site characterization efforts at cribs, ponds, and dry waste sites to be investigated as part of 200, 300, and 100 Area ER efforts.

Activities to be conducted range from compilation, review, and evaluation of existing site data to generation of supplementary information. New data or insights should be obtained by re-analyses of inventoried materials, collection of additional samples, and/or geostatistical correlations; performance of new down-hole physical or chemical measurements; collection of soil and/or porewater samples for chemical/mineralogical speciation analyses or process-level laboratory studies; and three-dimensional mapping/visualization of the site.

Forensic studies should be performed on vadose zone core materials from contaminated sites (e.g., as obtained in collaboration with the TWRS Program) to identify attenuation profiles (e.g., transport distances and concentrations) of non-mobile and mobile contaminants, the current physicochemical form in which they exist, isotopic profiles of radioactive contaminants and daughter products, and concentration/speciation of co-contaminants and other waste constituents important to mobility. These measurements are complementary to those performed for site characterization, and would allow for a more rigorous assessment of waste redistribution, reaction, and transport processes than could be accomplished in their absence. Scanning (e.g., tomography) and dissection studies should be used as well as other techniques to assess physical and structural attributes of the Hanford host sediments. Spectroscopy, microscopy, radiochemistry, mass spectrometry, and other techniques should be applied to identify the mineralogical components to which sorbed contaminants are bound, and, where possible, the

chemical forms in which they exist. Such information is critical to establishing primary retardation mechanisms, to evaluating the lability of sorbed contaminants as a basis for assessing the potential for future remobilization, and to proposing remediation and closure strategies.

H.2.3.1.4 Research Products and Benefits. The results of activities under this research area are critical to the overall vadose zone technical element because much of the research in other activities within this technical element is driven by field observations made here, and the degree of success of developed models in matching historical contaminant profiles from these sites. More specific research products would be the refinement and quantification of conceptual models of contaminant migration processes beneath different waste site/source types to guide acquisition of needed new information and model development. Contaminant distribution profiles and chemical/mineralogical speciation measurements would allow for determination of the most important contaminant retardation mechanisms requiring further study (see Sections H.2.4 and H.2.6) and inclusion in flow-and-transport models (see Section H.2.6). Critical unresolved questions about physical transport and chemical reaction mechanisms identified by field sampling or data reanalysis will form the basis for hypothesis-driven laboratory research on waste-interaction processes and field studies at uncontaminated vadose zone sites, and prioritization of other S&T activities within the vadose zone technical element.

Other anticipated research products include the following:

- Identification of key subsurface flow and reaction processes that have controlled or are controlling contaminant distribution in the vadose zone.
- Information on the chemical and mineralogical form of vadose zone contaminants and their potential for future migration or remobilization.
- Important hypotheses on waste-sediment interactions that require resolution through additional laboratory and field studies.
- New/improved data sets for history-matching using reactive transport models.

H.2.3.2 Laboratory Studies of Waste-Sediment Interaction Processes

H.2.3.2.1 Scope. The proposed laboratory research will be performed to fill pressing gaps in data on important physical, chemical, and biologic processes; to develop necessary kinetic and thermodynamic parameters for important reactions; to explain enigmatic field observations at representative sites; and to develop improved process-level models for key processes, waste types, or vadose zone conditions. The research should be constrained to key process-level issues, driven by field observations and needs. Laboratory research should be closely tied to field investigations of representative sites, vadose zone field study sites, and advanced vadose zone characterization.

H.2.3.2.2 Research Questions and Motivation. Directed laboratory research at Hanford is motivated by a lack of predictive knowledge about short- and long-term processes controlling the flux of key risk drivers and inventory elements to the water table. These include biogeochemical

processes (adsorption, mineral precipitation and dissolution, biomineralization) responsible for chemical retardation and immobilization, as well as hydrochemical processes (matrix diffusion, pore plugging, and colloid formation) influencing hydraulic properties and water flow paths. High-priority, laboratory-accessible information gaps related to contaminant mobility are associated with the following questions:

- What is the impact of extreme waste chemical conditions (high acidity, basicity, ionic strength, etc.) on contaminant mobility, the phases with which contaminants associate, hydrologic/geochemical properties and their distribution, and water-flow pathways?

- What is the relationship between contaminant release rates, water-flow rate, and pore space saturation on contaminant reaction and transport for different Hanford waste types?

- Do contaminants become more or less mobile with protracted contact times? What are the directions (e.g., greater or lessor mobility) and physical, chemical, and biologic causes of such changes, and how are they appropriately described (modeled)?

Within the framework of these questions, chemical, physical, and biological processes, and their coupling, need to be sufficiently identified, understood, and parameterized, so that a primary reaction process can be described in the field.

H.2.3.2.3 S&T Activities. Proposed S&T activities will focus on quantifying conceptual model biogeochemical (Figure H-4) and hydrochemical reactions and their coupling to transport processes. Activities aimed at understanding the effects of extreme waste chemistry, unsaturated preferential flow regime, and protracted contact times (as described in the following paragraphs) should be emphasized. Understanding these effects was identified as a crucial need in S&T workshops. Studies should resolve important Hanford-specific geochemical questions for key contaminants such as 1) the potential colloid-facilitated transport of plutonium and the facilitating effects of solvents and complexants, 2) the existence of geochemical reactions (heterogeneous reduction, inter-particle diffusion) potentially responsible for technetium immobilization in the vadose zone, and 3) the extent of in-ground fixation of sorbed cesium-137 and strontium-90.

Extreme Chemical Environments. Waste streams and tank supernates contaminating the vadose zone have been highly alkaline or acidic, with high ionic strength and temperature, and elevated content of organic complexes and solvents. Such waste streams were in gross chemical disequilibrium with the subsurface environment and have promoted a complex network of near- and far-field geochemical phenomena that impact contaminant migration by both chemical and physical means.

Experiments at relevant temperatures with select, representative waste surrogates and representative Hanford sediments should be used to investigate complex multi-species reaction sequences associated with different waste types, contaminants, and their mixtures. These experiments would be used to investigate the reactions responsible for neutralization of high/low pH wastes (dissolution/precipitation) including those leading to formation of new solids such as colloids and gels that may sequester (immobilize) or transport contaminants, or alter sediment permeability. Analytical techniques, such as aqueous and solid-phase spectroscopy combined

with advanced chemically sensitive microscopes would be used to determine contaminant forms both in the waste stream and after waste has interacted with vadose zone materials. These experiments would determine if the contaminants are dissolved in water; sorbed to clay, oxide, or carbonate minerals; or exist as or associated with colloids. Using Hanford vadose zone sediments (pristine and contaminated) with their indigenous microflora, biogeochemical experiments would determine the impact of nutrients in the waste streams on bioreduction of inorganic contaminants, the biodegradation of the organic solvents, or contaminant immobilization via biomineralization.

Vadose Zone Flow Regime. Complex fluid flow pathways have resulted in the current distribution of contaminants in the vadose zone and these pathways are expected to redistribute contaminants in the future. Fluid flow along such pathways ranges from quasi-saturated flow from episodic input of large volumes of radionuclide-bearing fluids (e.g., tank leaks, crib disposals, focused recharge along fast-paths) to redistribution of contaminants under conditions of low water saturation and diffusion from non-focused fluxes of rain water and/or surface run-off. An individual contamination event may have experienced both saturated and unsaturated flow regimes. For example, a tank leak may rapidly infiltrate the vadose zone over a period of days (or less), then slowly react with the sediment over a period of tens of years with infiltrating recharge water. Water flow rate and degree of saturation are important in controlling pore accessibility (reactive surface area) and reaction progress (kinetics and reaction rate).

We propose to conduct laboratory experiments to address the impact of water flow and saturation on the chemical and biological processes that control contaminant mobility (Figure H-4). These would include transport experiments under controlled flow rates using Hanford sediments, key contaminants and mixtures, and variable solution chemistries representative of different waste types to simulate vadose zone hydrology. Critical contaminants, waste mixtures, and transport issues/questions should be targeted as needed to explain field observations at representative contaminated sites or to develop/parameterize/calibrate kinetic reactive transport models. Examples include the multi-component ion exchange behavior of strontium-90, the colloid transport of plutonium oxide, or the fixation of cesium-137.

Episodic, variably saturated flow regimes should be approximated using column and lysimeter experiments. Diffusion cells and unsaturated flow devices (e.g., centrifugal flow apparatuses) should be used in studies of chemical and biological reaction at low moisture content. These and other dynamic transport experiments should provide an opportunity to develop, refine, calibrate, and validate conceptual and numerical reaction models that describe reactive transport. Understanding the relationship between water flow, pore saturation, and chemical and biological reaction rates is a critical step in transferring laboratory-derived information to the field and in the implementation of reactive transport models for predictive purposes.

Waste/Sediment Contact Times. Contaminants have been released to the vadose zone at Hanford since the 1940s. Because contaminant mobility is intimately linked to its chemical form, remediation and performance analysis at Hanford requires knowledge of the changes in contaminant form that may occur as a result of long- and short-term interaction with Site materials. Long-term processes (e.g., inter-particle diffusion, recrystallization) generally proceed at slow rates, but they often act to immobilize sorbed contaminants that may otherwise be exchangeable with the aqueous phase after short contact times. Short-term processes such as

changes in redox state may also lead to immobilization of the affected contaminants. The extent and permanency of this immobilization is a crucial question for the closure of waste sites that have deeply buried contaminants in the vadose zone.

Experiments should be designed to investigate the importance of long-term immobilization or fixation reactions of key vadose zone contaminants. The major focus of these experiments would be the aging of the contaminants as a function of wetting/drying cycles and waste chemistry and under partially saturated conditions to mimic the long-term hydrologic regime in contaminated regions of the vadose zone. These experiments will require sophisticated solid-phase analytical methods (e.g., spectroscopy and microscopy) to define changes in the physical and chemical environments of the sorbed contaminants. Aging experiments may be accelerated by conducting them at elevated temperatures and extrapolating the results to site temperatures. These experiments should provide the rates of geochemical and biogeochemical transformations that will be used in process level and PA models.

H.2.3.2.4 Research Products and Benefits. Research products and benefits should include new insights and descriptive kinetic and thermodynamic information that can be developed based on key biogeochemical and hydrochemical reactions that control unsaturated chemical transport through the vadose zone. These will assist in explaining solute attenuation profiles and chemical/mineralogical speciation at contaminated sites and in developing improved process-level models for important reaction types, including colloid transport, as well as the hydrogeochemical effects on hydraulic properties and fluid flow.

Constitutive relationships should be established and used in reactive transport models for history-matching of contaminant distributions at studied representative sites and in controlled release experiments at vadose zone study sites. Knowledge should be provided to support defensible simplification of complex contaminant reactions for tractable modeling at both waste site and sitewide scales as required for the sitewide PA model.

Although the laboratory research is focused on Hanford-specific issues, the resulting knowledge, concepts, and models may also be applied to vadose zone contamination problems at the Nevada Test Site (NTS), Savannah River Site (SRS), Los Alamos National Laboratory (LANL), and other DOE sites. An additional research product is the scientific understanding needed to dispose of radioactive waste at Yucca Mountain.

H.2.3.3 Vadose Zone Test Facilities

H.2.3.3.1 Scope. Field experiments are proposed at the Hanford Site under controlled conditions at well-characterized, clean sites, to test conceptual and numerical models of flow and transport in heterogeneous systems. The emphasis should be on evaluating fluid phase transport but gaseous phase transport should also be considered. Key geohydrologic, chemical, and biologic processes that control plume migration in the vadose zone would be evaluated. Research would include investigations of the impact of lithological features, such as sediment layering, clastic dikes, and fractures on the flow regime. Investigations will also continue on the documentation of the variability in recharge rates under controlled surface conditions. Field tests, with controlled source terms and boundary conditions, would be conducted to improve

model testing and rigor and provide enhanced understanding of the processes that affect distribution, transport, and attenuation of contaminants in the Hanford vadose zone.

H.2.3.3.2 Research Questions and Motivation. Controlled field experiments are needed at uncontaminated sites to sort out uncertainties in source terms, geohydrologic properties, and chemical interactions that combine to make current modeling of the Hanford vadose zone questionable. The sediments beneath waste sites at Hanford are known to be highly heterogeneous (e.g., interbedded sand, silts and gravels). These heterogeneities, coupled with temporal and spatial variations in net water infiltration (via past liquid discharges, water line leaks, meteoric sources, etc.) and variable chemical interactions complicate description and understanding of contaminant transport, often making an evaluation of transport at contaminated sites ambiguous.

A key issue here is the potential at Hanford for fast flow pathways that could accelerate groundwater contamination. Accelerated transport may occur via preferred flow pathways created by geologic features, by waste-sediment interactions (e.g., dissolution), or unstable wetting fronts. Fast flow paths may be tortuous and of limited horizontal extent so that locating them with widely spaced vertical boreholes will be difficult if not impossible. Temporal variations in vadose zone fluxes are also expected as a result of variations in surface-controlled net water infiltration, spatially distributed preferential flow paths, and temporally/spatially discrete waste-water discharges. Such temporal fluxes are important and are assumed to cause the observed transient peaks in groundwater contaminant levels.

The following scientific questions motivate the need for field experiments at uncontaminated vadose zone field sites:

- How significant is the variability of the surface and its control on net water infiltration? What impact does vegetation dynamics (resulting from disturbances, fires, drought) have on the local and regional recharge rates that ultimately control contaminant migration?

- How frequent are preferred flow paths in Hanford vadose zone sediments? With what geologic and lithologic features do the flow paths associate and under what moisture conditions do they function as conduits? Over what length of scales are preferred flow paths encountered?

- Which waste chemistries are conducive to preferred flow path formation and which are not? What hydrochemical reactions are most important in the field, and to what extent do these control in situ flow velocities and direction?

- To what extent are laboratory-derived reaction parameters descriptive of geochemical phenomena occurring in preferred flow paths? If differences are observed, what in situ features cause the differences?

- What are the best field-scale values and statistics for hydraulic and geochemical parameters? How are these best derived and transferred to other locations at the Hanford Site and depths in the vadose zone?

- How can surface areas of reacting solids be characterized in the field? To what extent are mineral surfaces hydrologically accessible?

H.2.3.3.3 S&T Activities. The proposed vadose zone test facilities will provide sites where heterogeneities in hydrologic, chemical, and biologic properties can be described and model testing, including issues related to field-scale applications, can be performed. Parameters, properties, and statistics derived at each vadose zone test facility can be extended to other sites at Hanford, supplying necessary information for scientifically defensible decisions and supporting a system-level model of Hanford. The vadose zone test facilities involve two site types: 1) controlled sites where detailed transport experiments can be performed, and 2) sites of opportunity that arise during remediation activities and that afford unique scientific possibilities.

Controlled Sites. One site should be selected as the primary vadose zone test facility where concepts, techniques, and tools developed under the other research elements may be evaluated and field-scale hypothesis derived from the activities described in Section H.2.3.1 may be tested on contaminant flow and transport. The advantages of using a controlled site are that: 1) access to the site will be easier, cheaper, and safer than at a contaminated site; 2) baseline information can be obtained related to hydrological, chemical, and biological properties that cannot be obtained at a contaminated site; 3) tests to evaluate key transport processes can be conducted in Hanford sediments under realistic conditions; and 4) issues related to scaling from laboratory processes to field observations can be addressed in a systematic way. Additional facilities should be developed as needed.

The study site should be on the scale of a tank, crib, or other waste disposal facility, and will be characterized by peripheral excavation and non-invasive techniques. Geologic mapping; laboratory and field measurement of hydrologic, chemical, and biologic properties and parameters; and geophysical measurements would be applied along with other methods for characterization. Geophysical measurements and inverse modeling as described in Section H.2.3.5 (Advanced Vadose Zone Characterization) would be applied to establish in situ hydrogeologic parameters. Instrumentation and samplers to measure water content and tracer concentrations would be installed in the experimental area. A three-dimensional (3D) representation (physical model) of the geohydrologic properties of the study site and correlative, scale-dependent functions for key hydraulic properties would be established as a basis for experiment planning and interpretation. Subject to appropriate state permits, controlled release experiments would be performed to mimic waste site releases in terms timing, rate, and volume, and chemical conditions and temperature.

Model predictions of transport (of water and tracer) under controlled test conditions should be made using appropriate geohydrologic input, before actual testing is initiated in collaboration with activities described in Section H.2.3.4 (Flow-and-Transport Modeling). Experiments should be conducted over a range of net infiltration rates to estimate the impact of recharge variation on contaminant transport. Experiments should be conducted to evaluate the potential for finger flow development, funneled flow, vapor-enhanced flow, and other accelerated flow processes. A suite of tracers, including those to track different transport and reaction processes, should be applied and measured, and results of the field test should be compared with the modeling results. Iteration between the field observations, further laboratory experiments described in Section H.2.3.2, and additional model development described in Section H.2.3.4

would ultimately yield an improved vadose zone modeling capability for the Hanford Site. Geophysical techniques should be used in conjunction with tracer application to provide additional data at different scale resolutions to test model results. The controlled site should be reusable so that more experiments can be performed at different flux rates or with different tracers. Also, the test site can serve as a demonstration site for regulators, Tribal Nations, and stakeholders, where it is possible to show them water movement and tracer transport occurring in the geologic materials at Hanford.

Opportunity Sites. Uncontaminated sites should become available during remediation activities at Hanford, such as the Environmental Restoration Disposal Facility (ERDF), where unique opportunities exist to study deeper regions of the vadose zone. These sites offer distinct advantages: 1) excavation costs are avoided, 2) both the horizontal and vertical variability of hydraulic properties can be determined over significant distance, and 3) the effects of features such as clastic dikes on flow and transport can be tested. Use of natural tracers (chloride, oxygen-deuterium, etc.) should be employed to assess the initial state of water flux occurring at the site prior to infiltration testing. Noninvasive geophysical techniques such as ground-penetrating radar (radar imaging and holography methods) or electromagnetic induction (EMI) should be used for initial characterization and determination of site suitability. Then field measurements of hydrologic properties would be performed using a disk infiltrometer or a similar type of instrument. Tests with water and dye tracers would illuminate the rapid flow pathways (as potentially caused by clastic dikes) and plume transport. During further excavation, the dye movement can be observed and recorded and results correlated with known lithology for the site.

H.2.3.3.4 Research Products and Benefit. Comprehensive data sets with clear boundary conditions and known source functions should be established for model testing and validation. Field experiments should decisively illuminate mechanisms that control fast-flow processes under Hanford Site conditions, and the extent to which they may be important. Procedures for upscaling laboratory-derived parameters (e.g., chemical reaction parameters, hydraulic properties, etc.) for improved predictions of contaminant migration should be established in concert with other S&T activities (see Sections H.2.3.2, H.2.3.4, and H.2.3.5). Data, models, and field demonstrations derived from these studies should support remediation decisions by providing realistic assessments of plume migration rates in heterogeneous vadose zone sediments at Hanford.

H.2.3.4 Flow-and-Transport Modeling

H.2.3.4.1 Scope. Within this research area, improved reactive transport models, including important chemical, physical, and biologic processes, as well as heterogeneity and uncertainty propagation, should be established for the Hanford Site. The modeling capability would be adapted from existing state-of-science codes, influenced by laboratory and field observations of controlling processes and geologic features made as part of this technical element (see Sections H.2.3.1 and H.2.3.2), and it would be tested by application to data from controlled release experiments at uncontaminated, vadose zone study sites (see Section H.2.3.3). Such newly developed models would be used for history-matching activities at contaminated field sites to document process, parameter and source term approximation procedures needed for

poorly constrained problems, and ultimately, for improved remediation decision-making at Hanford waste sites.

H.2.3.4.2 Research Questions and Motivation. Previously employed approaches for modeling vadose zone transport may not be sufficient to capture the essential processes that affect contaminant migration at Hanford. For example, although radionuclide/ contaminant transport through the vadose zone may involve fully coupled thermal-hydrological-mechanical-chemical processes, a decoupled approach has been used in previous modeling studies of Hanford. The effects of chemical coupling (through fluid density modification and mineral/precipitation dissolution) on fluid flow and radionuclide transport have also been ignored in previous Hanford studies. This simplified approach, and other simplifications that have been used, may introduce unacceptable errors to long-term assessment of radionuclide transport. Preferential flow in particular is considered to be an important contaminant transport mechanism in the vadose zone of the Hanford Site. Hypothetical pathways include clastic dikes, unsealed monitoring wells, fractures, and other geologic features, that, in concert with waste chemistry, promote highly directed flow. Preliminary numerical studies show that the large density difference between the tank leak fluids and vadose zone water can also result in fast transport through fingering in the vadose zone.

Specific research questions include the following:

- What are the effects of high ionic strength aqueous solutions under varying redox and pH conditions present in some of the leaking storage tanks on the rate of metal/radionuclide migration?

- Do fast radionuclide migration pathways through the vadose zone exist and if so what is their origin? Could preferential flow paths be produced through chemical interaction of dense, high-pH fluids with the host sediments by enhancing dissolution of minerals and selectively plugging pores spaces with secondary mineral products?

- What are the important (key) processes needed to model contaminant transport adequately?

- Can reasonably accurate predictions be made of contaminant plume migration through the heterogeneous unsaturated sediments at Hanford? Or will the role of reactive transport models be more qualitative being aimed mainly at understanding the processes responsible for plume migration, rather than as a detailed predictive tool?

- What sensitivity and uncertainty analyses are needed to provide the basis for acceptable risk assessment and systems models?

H.2.3.4.3 S&T Activities. Proposed S&T activities will focus on scaling, spatial heterogeneity, improved multiphase-multicomponent reactive transport models, uncertainties in model input parameters and output, and integration of activities, as described below.

Scaling. Conceptual and numerical methods are needed to determine whether we can extend laboratory-scale properties to the field scale at which continuum mass transport equations apply. A key unknown in attempting to use laboratory-determined sorption properties and mineral

kinetic rate constants in the analysis of field-scale reactive transport problems is the "hydrologically accessible" reactive surface area. Low permeability zones, fracture-matrix interaction, and coating or armoring of mineral surfaces can lead to inaccessible surface area. Activities here should be conducted in conjunction with laboratory experiments where the issue of reactive surface area under unsaturated water conditions will be investigated.

Spatial Heterogeneity. Spatial heterogeneities have been observed to have an important effect on contaminant plume migration at the Hanford Site. In order to interpret comparisons of model predictions with field observations, spatial variability of physical and chemical properties of the host rock will need to be taken into account. Reactive transport models may be applied qualitatively to understand fast pathways as suggested by the extent of contaminant migration observed in the field at several of the leaking tanks. Fast pathways may be due to physical and/or chemical heterogeneities in the flow system, or they could be a consequence of the reaction of the highly caustic waste solution (pH 14) with the host sediments producing preferential flow paths.

Improved Multiphase-Multicomponent Reactive Transport Models. To adequately describe contaminant migration at the Hanford Site, reactive transport models must incorporate a wide range of processes. These include nonisothermal, multiphase-multicomponent flow and transport for aqueous and nonaqueous fluids in variably saturated media, in one, two, or three dimensions (1D, 2D, or 3D). Single and multiple continuum models of porous media are required to capture matrix and fracture flow and transport. These models require a full range of chemical reactions, including homogeneous aqueous reactions, gaseous reactions, mineral precipitation/dissolution, microbial reactions, ion exchange, and surface complexation, and coupling chemistry with fluid flow. In addition, the capability must exist to account for high ionic strength fluids.

Some existing numerical models incorporate some of these processes but not all of them. Chemical interactions are generally limited to relatively low ionic strength fluids within the range of the extended Debye-Huckel activity coefficient approximation. Development of a high ionic strength activity coefficient model would require extensions of existing thermodynamic databases for Pitzer, Bromley-Zemaitis ion-pair interaction, and other models to include species relevant to the Hanford Site.

Models that need to be developed consist of a site-scale model for PA applications and a group of specialized submodels depending on waste chemistry and other features. The submodels should include geochemical and hydrologic processes that are deemed essential for a particular waste site problem, such as the near-field environment of a leaking tank (high pH and ionic strength) and/or small-scale physical heterogeneities (fast path flow or small-scale structural and mineralogical heterogeneities). The site-scale model would include approximations of the geochemical processes and physical heterogeneities as needed to describe the large-scale hydrologic behavior of the vadose zone, overall fluxes to the groundwater, and the large-scale migration of contaminants in the vadose zone and to the groundwater (far-field behavior).

Uncertainties in Model Input Parameters and Output. Databases of physical and chemical properties of the vadose and saturated zone need to be constructed for use in reactive transport modeling. This would include available mineral abundances, amount of solid organic carbon,

solid solution composition, mineral surface area, sorption parameters, porosity, permeability, characteristic curves for saturation and relative permeability, and aqueous solution composition. An important research issue is the scaling from laboratory measurements of hydraulic properties to field-scale parameters. In addition, databases for recharge rates, their spatial and temporal variability, and characterization of waste sources, including time history, rate of discharge, and chemical composition, will be needed.

Model predictions should be evaluated with onsite field observations at representative sites that can be well characterized. This may be difficult because of the heterogeneous nature of the Hanford Site and uncertainty in source term history. Statistical approaches (multiple realizations, Monte Carlo, etc.) may be required to compare statistically averaged quantities related with contaminant plume migration, rather than point comparisons, which may have little meaning.

Integration Activities. S&T activities in reactive transport modeling will need to be coordinated with other S&T activities such as source term characterization, representative site selection and observation, and field and laboratory studies.

H.2.3.4.4 Research Products and Benefits. The reactive flow-and-transport modeling effort are expected to develop and apply numerical models to aid in understanding the cause, extent, and future effects of subsurface contaminant migration and will serve as input to risk analysis at the Hanford Site. The specific products should include technical reports and new software that are scientifically defensible predictive tools for evaluating remedial actions and otherwise aiding the decision-making process for cleanup of the Hanford Site. Numerical models should then be used to predict contaminant migration through the vadose and saturated zones and help identify processes responsible for fast pathways for radionuclide migration. Detailed process-level reactive transport models are intended to be used to provide the foundation for site-scale models that ultimately are incorporated into sitewide models.

H.2.3.5 Advanced Vadose Zone Characterization

H.2.3.5.1 Scope. The proposed activities within this research area will develop and apply soil, geophysical, geochemical, and hydrological methods to resolve subsurface heterogeneities; characterize geohydrologic properties; and map contaminant distributions at different scales in the vadose zone. The activities should be accomplished with an iterative approach, combining measurements ranging from pore-scale to field-scale and geostatistical techniques. The overall goal is to provide information that will be used to predict flow and transport in the vadose zone beneath Hanford tanks and other waste sites. The vadose zone test facility (Section H.2.3.3) and representative contaminated sites (Section H.2.3.1) should be used to explore and evaluate the various subsurface characterization methodologies.

H.2.3.5.2 Research Questions and Motivation. The prediction of groundwater recharge, contaminant distribution, and future migration requires knowledge and predictive models encompassing scales of 100 meters (300 feet) or more. Heterogeneity in physical and chemical properties, at a variety of spatial scales, has remained the primary conceptual and measurement obstacle to the development of predictive models of flow and transport in the vadose zone.

Improved field methods to characterize heterogeneities, in situ hydrogeologic properties, and contaminant distribution are needed to understand subsurface transport processes and to develop descriptive data at different scales to drive both model validation and forward predictions.

Three main questions pertaining to characterization of subsurface heterogeneities and properties evaluation at the macroscopic scale will drive activities within this research area:

- How should we extrapolate the classical measurements of geohydrologic and transport properties made on small, homogeneous soil cores and in small near-surface experiments to the pertinent field scale at which soil parameters exhibit complex natural heterogeneity?

- What is the distribution of subsurface heterogeneities (natural and those created by waste interaction with the porous medium) that may influence the distribution of soil water and contaminants?

- Which geophysical methods have the sensitivity to characterize subsurface geohydrologic and geochemical properties with sufficient accuracy to permit prediction of contaminant fate and transport?

H.2.3.5.3 S&T Activities. The proposed research will establish better characterization procedures to define the in situ physical and chemical aspects of the vadose zone, and average field-scale properties describing fluid flow and reaction. The procedures should be both direct (e.g., down-hole geophysical) and indirect (inverse modeling) and should be established and/or developed and tested in concert with field activities undertaken within both the representative site (Section H.2.3.1) and vadose zone field site (Section H.2.3.3) activities of the program. Three primary areas should be emphasized: hydrologic properties determination, geophysical measurements, and water/contaminant flux measurement.

Hydrologic Properties. Characterization of porous media at the pore and core scale is a first required step for understanding and modeling fluid flow and coupled geochemical reactions. Information from core-scale studies, including reaction rates, accessible surface area, and hydraulic conductivity is the primary data set that is scaled to the field for behavior description, and may provide the basis for formal scaling procedures. Thus, it is crucial that information on core-scale geohydrologic and geochemical properties be obtained on materials representative of major Hanford vadose zone lithologies. Such information should provide a basis for interpretation of laboratory reactive transport experiments (Section H.2.3.2) and for developing advanced techniques of parameter estimation for Hanford sediments that may exhibit different properties from those studied. Parameters that warrant measurement include, but are not limited to. geohydrologic properties (e.g., porosity, pore size distribution, unsaturated hydraulic conductivity, distributions of water content, matric potential, sorptivity, dispersivity, heat transfer parameters), geophysical properties (apparent resistivity, apparent permittivity) and geochemical properties (e.g., clay mineral and aluminum/iron/manganese oxide content and distribution).

Field-scale transport models generally require knowledge of the core-scale information described above, except at much larger scales. Direct measurement at the pertinent scale is time consuming, expensive, and of limited accuracy. An alternative is to use pedotransfer functions,

which assume a conceptual model and estimate geohydrologic properties based on their correlation with more easily measured physi-cal properties. Recently, neural networks, which require no a priori model, have been used to predict water retention and saturated hydraulic conductivity. Research should be conducted into the use of neural networks to assess uncertainties in pedotransfer functions to determine which basic soil properties are the most relevant for predicting field-scale geohydrologic and geochemical properties. With these parameters, sensitivity studies using both forward and inverse modeling can be done to determine scales of resolution and accuracy of different approaches.

Inverse methods are extremely flexible and can be applied to nearly any combination of water flow, contaminant transport, heat transport, and geophysical data to yield simultaneously estimated hydraulic and solute transport parameters. A major programmatic emphasis of this activity should be on combining techniques and data sets from different investigators and research elements in the Vadose Zone Research Program (e.g., representative sites [Section H.2.3.1], vadose zone study sites [Section H.2.3.4]) to derive well-constrained predictions of flow-and-transport parameters that can be used in contaminant transport for history-matching at contaminated sites and forward prediction of controlled release experiments.

Geophysical Methods. Research should evaluate a number of promising geophysical methods to gain information on the vadose zone. These include established techniques such as: seismic methods (to map paleo-channels, fractures, voids, bedrock and landfill boundaries); cross-well methods (to characterize fractures and contaminant plumes); electromagnetic methods (to monitor contaminant plumes, saline plumes, buried objects, landfills); ground penetrating radar (to map water tables, water content, and contaminant migration); neutron probe (for water content, chlorinated solvents); and new techniques under development: shallow reflection seismology, cross-well tomographic methods, high-frequency electromagnetic, and nuclear magnetic resonance. Research should emphasize the testing and refinement of existing methods for Hanford-specific application, rather than the development of new techniques.

Specific targets of geophysical characterization are as follows: 1) determine the degree of continuity/ thickness of lithologic units in the vadose zone (Hanford sands, plio-pleistocene caliche, upper Ringold sands, Ringold gravels, etc.), 2) establish the location and distribution of heterogeneities within the lithology (sills, clastic dikes, fractures/faults, fracture orientation/density, etc.), 3) identify matrix and fracture properties of units (porosity, grain size distribution, moisture distribution, soil water potential, mineral composition, etc.), 4) locate the extent of contaminant plumes with anomalous chemical or physical signature (precipitation/alteration products, secondary deposition, etc.), and 5) establish the spatial distribution of the location of preferential flow paths affecting transport.

Water and Contaminant Distribution and Flux. The proposed research will focus on the design and deployment of advanced tensiometers for depths greater than several meters to measure soil water potential, potential gradients, and in situ unsaturated hydraulic conductivity. Advanced tensiometry could also lead to reliable measurements of vadose zone water flux and recharge, which at present are difficult to quantify, and to improved estimates of lateral and transverse components of hydraulic conductivity and dispersivity. Improved water flux meters are proposed to be designed and tested to document spatial and temporal variability in mobile fluxes.

Measuring the in-ground distribution of contaminants (particularly radionuclides) has and continues to remain a great challenge. Down-hole spectral gamma analysis has been used with great success to monitor depth distributions of constituents such as cesium-137 and cobalt-60, but is limited to gamma emitters, leaving alpha and beta emitters undetected. Recent developments in the medical field have shown laser-based thermoluminescent dosimetry (TLD) to be useful for measuring alpha, beta, and gamma radiation over a wide dynamic dose range. Research should be conducted into the use of TLD for in situ measurement of currently undetectable, high-risk alpha and beta-emitting contaminants.

Field deployment of new or modified technologies will require some developments in drilling/ installation techniques such as direct push technologies (e.g., cone penetrometer) and side-wall instrumentation to permit the use of existing wells wherever possible. Such advances would allow for the deployment of deep borehole tensiometers, water content sensors like time domain reflectometry (TDR) and capacitance probes, and flux meters to permit measurement of important parameters directly in waste zones. Inverted liner technology would also be tested for applicability in the Hanford vadose zone.

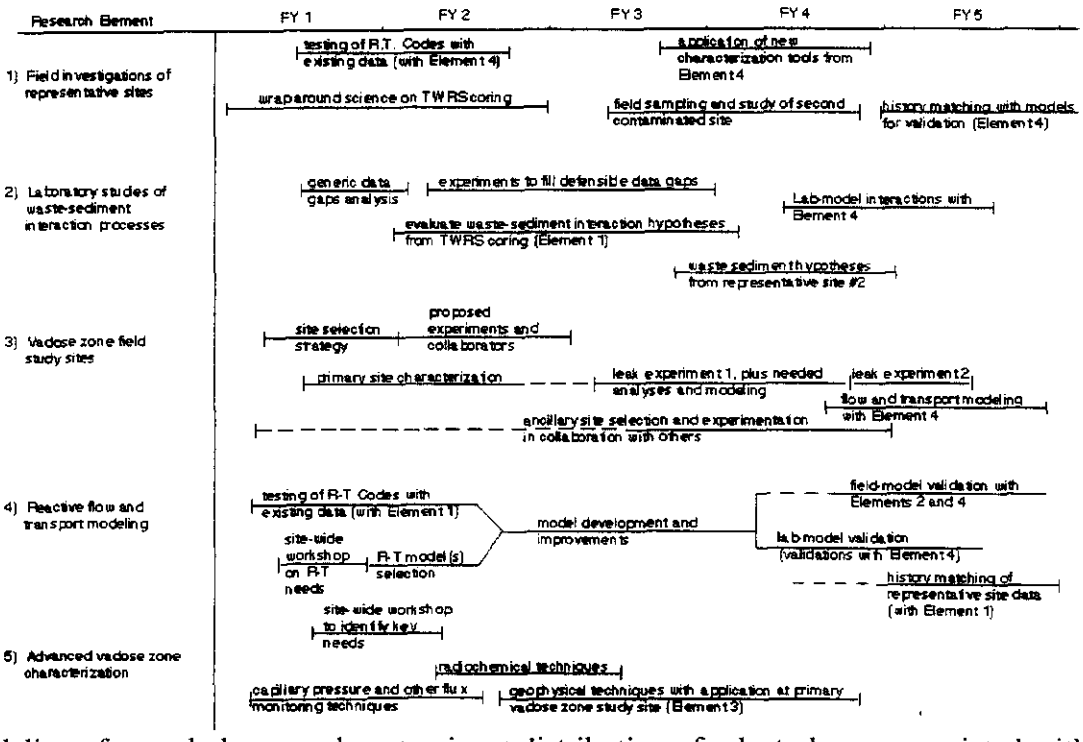
H.2.3.5.4 Research Products and Benefits. The primary product of the vadose zone characterization element will be improved down-hole and modeling methods for determination of the physical and chemical properties/parameters of the vadose zone as well as water and contaminant distribution and flux. Method application and testing should be integrated with other vadose zone S&T activities, such as the characterization of both contaminated representative field sites (Section H.2.3.1) and controlled vadose zone study sites (Section H.2.3.4), as well as the monitoring of controlled release experiments (Section H.2.3.3). Measurements from the pore scale to the field scale, in combination with laboratory and field transport studies (Sections H.2.3.2 and H.2.3.4) should facilitate the development of an improved mechanistic understanding of the critical processes controlling flow and transport at the pertinent spatial and temporal scales. An improved understanding of the processes should lead to a more realistic conceptual model(s)—a requirement for the execution of well-constrained predictions of flow and transport in the vadose zone.

H.2.4 Timing/Linkage of Activities

The five areas of research are not intended to be completed sequentially. Each element contains multiple lines of activity; some build upon each other and link between elements, while others stand, to a large degree, alone. There is a logical sequencing of initial activities that was identified in the planning workshops (Figure H-6). The first proposed activities are as follows:

- Collaborative studies (with TWRS) of contaminant distribution and chemical/mineralogic speciation in vadose zone sediments beneath, representative, leaked single-shell tanks (Section H.2.3.1).

Figure H-6. Linkage and Products of Vadose Zone Research Areas.



- Modeling of mass balance and contaminant distribution of select plumes associated with well-characterized waste sites (e.g., BP-1 Operable Unit) as a basis for assessing long-term modeling needs (Sections H.2.3.1 and H.2.3.4).

- Selection and initial characterization of the primary vadose zone study site (Section H.2.3.3). The specific content of other research elements (Sections H.2.3.2 and H.2.3.5) is less certain, and initial activities in each of these will consist of a workshop whose objective is to develop firmer plans and focus. Longer-term plans and activity sequencing as needed to accomplish Integration Project goals and complete products are also identified in Figure H-6.

Reactive transport models and associated databases should be a primary repository for both laboratory- and field-derived information and process-level understanding developed under this technical element. Because model development takes time and models can be continually improved, it is important to begin the modeling activities early and to carry through with model development and improvement for the lifetime of the S&T program. As models are developed, they can be used in interim form to predict the outcomes of characterization activities and various field experiments as they occur. Such early application will provide important tests of the models that can be used to further improve them. Models can also be useful for making certain that relevant data are collected during characterization activities. As new characterization data are obtained, they can be incorporated into the models; and as numerical and field experiments are carried out to evaluate the importance of specific processes, the models can be adapted to more accurately represent the most important processes. Accurate model results can best be achieved via a long-term iterative process.

S&T activities under this technical element are closely linked with others in this plan and to the Hanford sitewide assessment process. Contaminants, waste compositions, and representative study sites should be selected in close collaboration with and based on input from the inventory technical element. Information on the chemical speciation and composition of influent waste streams should also be provided by the inventory activity as needed for history-matching of attenuation profiles at contaminated sites with reactive transport models. Insights on and data describing primary physical, chemical, and biologic processes in the vadose zone, and models derived from this information should allow for improved estimates of contaminant travel times and flux to the water table—information required by both the groundwater technical element and the site PAs. Research performed herein should provide the scientific basis for the vadose zone module of the sitewide system assessment. Important contributions to the sitewide model are envisioned to be

- Identification of a first-order process and phenomena that must be included in the vadose zone technical element.
- Simplified, but correct descriptions of first-order processes that are appropriate to regional-scale modeling.
- Appropriate descriptors/parameters to drive simplified, first-order process models for different waste types and disposal environments.
- Insights on uncertainty propagation for modeled processes.

H.3 GROUNDWATER

The groundwater technical element of the applied science and technology (S&T) plan will develop the research scope needed to address scientific issues related to understanding the role of groundwater in the overall migration of contaminants from the Hanford Site. Detection of contaminants in groundwater monitoring wells underlying tanks, cribs, landfills, and other sources has often been the first indication of releases and migration. Understanding the flux and dynamics of vadose-capillary fringe-groundwater contaminant transfer and plume migration in three dimensions is critical to reconstructing vadose zone transport. On a larger scale, transport processes in groundwater control migration to extraction wells or surface water bodies (e.g., the Columbia River), define future risk scenarios, and affect the potential for optimized cleanup. An implicit goal of this research is to provide scientifically defensible knowledge and data and identify existing and new science and technology that will serve as input to DOE's decision-making process for Hanford cleanup.

S&T activities proposed for the groundwater technical element are intended to enhance protection of the Columbia River and its environs by 1) determining the existing distributions of contaminants with particular emphasis on three-dimensional (3D) distribution especially at the interfaces with the vadose zone and the river and 2) enhancing the understanding of geological, chemical, geochemical, and hydrologic controls for future movement of contaminants. The plan includes six major areas of research to maximize positive impact on Hanford Site cleanup using a sitewide system perspective. The research areas include:

- Vadose zone-groundwater interface study
- Biogeochemical reactive transport
- Hydrogeological characterization science
- Regional plume geometry
- Multiscale 3D model development
- Groundwater-river discharge study.

To frame the technical objectives of the groundwater technical element that led to these research areas, a conceptual model relating contaminant introduction, movement, and transformation in the saturated zone was developed. Contaminants released to the subsurface reached the groundwater via downward migration through the vadose zone or by direct injection. Contaminants can be components of either aqueous mixtures or non-aqueous phase liquids (NAPLs). Subsurface structure/stratigraphy, geochemistry, and hydrology determine the rate and character of contaminant movement, both above and below the water table. Reactions with soil and sediment minerals may serve to retard chemical migration. Dispersion processes tend to reduce concentration along flow pathways, while microbially facilitated reactions may transform or destroy contaminants in situ. Increased rates of aquifer recharge or pumping and other geochemical phenomena (e.g., colloids, pH/salt perturbations, complexing reactions, increased density, etc.) can promote faster migration of specific contaminant species. The hydrogeological considerations that influence the conceptual model are documented in Figure H-7.

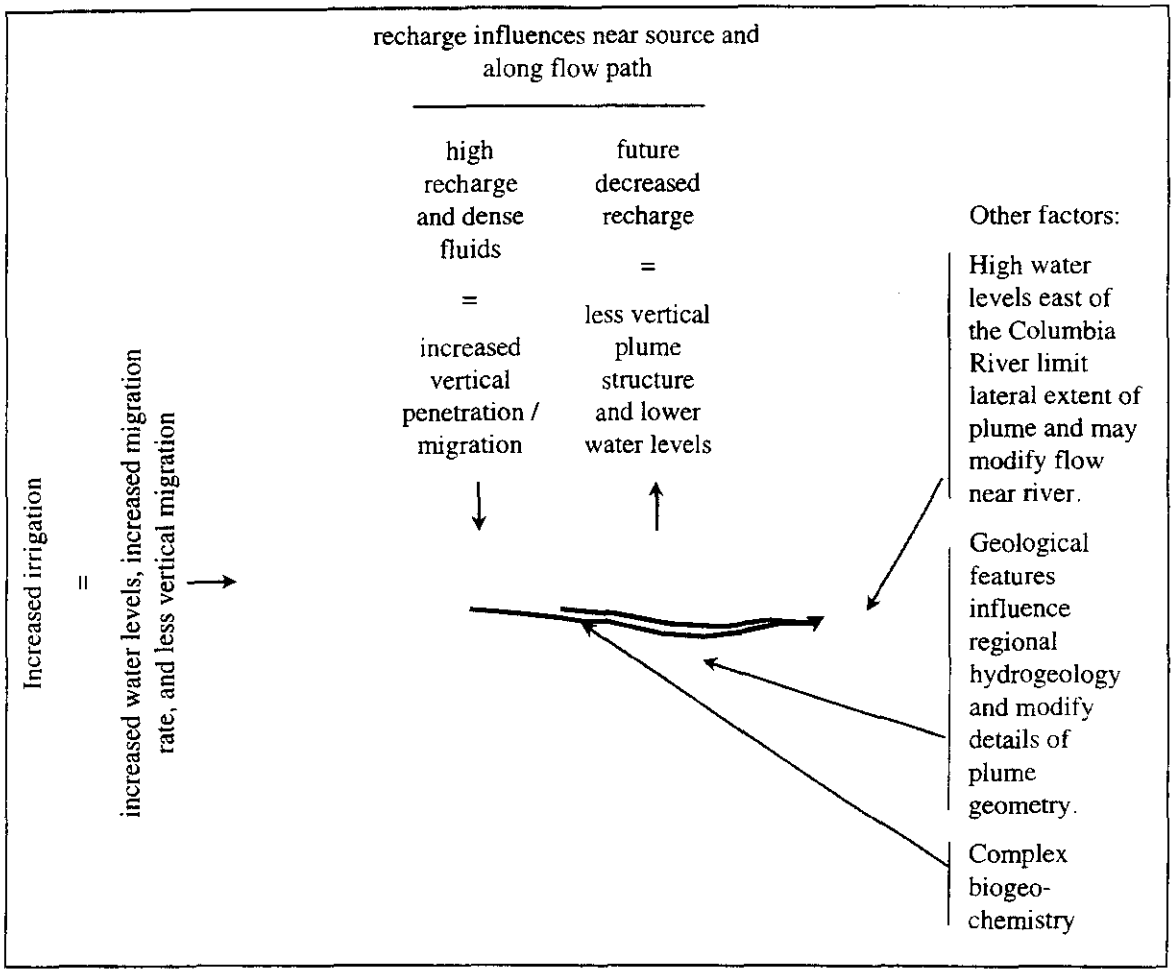
Important features of the conceptual model include the following:

- The vadose zone-groundwater boundary and the groundwater-surface water boundary are important interfaces.

- NAPL bodies (and in particular, high-density dense non-aqueous phase liquids [DNAPLs]) that move into saturated regimes and later take on 'static' configurations along low permeability features can represent long-term sources of aqueous contaminants in the saturated regime as a result of slow and limited dissolution into groundwater.

- Temporal issues (e.g., declining water levels following discontinuance of high-volume waste discharges) will significantly impact plume shape and location. This may be particularly important in areas where the water table is currently in the Hanford formation. Plume behavior will be highly variable over space/time, especially from high-volume sources whose volumes, concentrations, densities, etc., changed radically during disposal history. Technical activities to assist in addressing temporal issues and uncertainties over 10s, 100s, and 1000s of years or longer are required. The validity of longer projections (e.g., > 10^4 years) also requires evaluation given climate change/cycles and other phenomena.

Figure H-7. Conceptual Diagram of Three-Dimensional Nature of Groundwater Flow Superimposed on Diagram of Hanford Hydrology.



Note that plumes tend to migrate downward near sources due to recharge. Near the discharge boundaries (e.g., Columbia River) the plumes migrate upward. Note also that plumes from different source areas tend to generate vertically distinct plumes unless density or other modifiers dominate penetration. Geology and other factors that influence vertical movement of the plume and contaminant penetration are noted.

- Three-dimensional flow, influenced by recharge and discharge boundaries and subsurface heterogeneity controls the horizontal and vertical position of migrating contaminant plumes. Plumes can be thin and vertically discrete (especially near low-volume sources). Results from partially penetrating monitoring wells with long screens can be confusing if not interpreted in this light.

- Some parts of the system have little characterization (or are not included in current conceptual models (e.g., fractured basalt and lower confined aquifers, and the Franklin County side of the Columbia River).

- Properly formulated groundwater concepts are needed at the different scales of observation. Two examples were discussed: 1) regional flow with improved understanding of recharge, hydraulic conductivity, field and mud zone structure, and the resulting 3D flow structure, and 2) local models with an improved focus on reactive transport in heterogeneous geologic environments.

- Various scenarios of vadose zone-groundwater contaminant transfer are found at Hanford and are determined by volume (high or low), contaminant class (inorganic or organic), and key waste characteristics (high/low pH, high/low specific conductance, DNAPL, etc.). These typical scenarios may serve as the basis for careful study of analog sites. Importantly, some waste characteristics significantly alter plume behavior and geometry. For instance, dense fluids result in thicker and deeper plume development.

The groundwater represents an important portion of the potential exposure path and is the link between the source/vadose system and the receptor at the river or a well. During the development of this plan, the task team found substantive gaps in groundwater-related data at Hanford. These data gaps result from both S&T needs and from institutional and practical considerations (e.g., depth to groundwater, drilling costs, programmatic complexity, budgetary constraints). In the cases where the data gaps are S&T-related, descriptions of programs to supply the needed information and technologies have been developed. The following were repeatedly observed during development of this plan:

- Emphasis on the effective use of historical groundwater, geohydrology, and geochemical data to calibrate source estimates and as "tracer tests of opportunity" is critical to improve/calibrate/bound transport processes. Despite the data gaps mentioned above, Hanford has a rich and informative history of relevant data. Maximum use of the historical information and the cumulative best conceptual model are critical at a "data rich" site such as the Hanford Site.

- Much more emphasis and interpretation of the 3D structure of the existing contaminant plumes are needed.

- S&T needs are influenced not only by the development of a systems assessment capability (SAC), but also by overall goals for remediation. Integration of science activities outlined in this plan with approaches already identified by the Columbia River Comprehensive Impact Assessment (CRCIA), Tank Waste Remediation System (TWRS), and Environmental Restoration (ER) Program will result in more consistent, better, and more defensible results. The priority of scientific activities should be based on the significance of the issue and reduction of uncertainties in allocating effort.

Emphasis on leveraging planned drilling (e.g., by extending boreholes or completing wells in a way that allows expanded geophysics) is needed. A scenario-based concept (e.g., identifying typical [or "analog"] scenarios/sites) is envisioned to facilitate efficient and cost-effective work.

H.3.1 Scientific And Technological Issues

Scientific and technological issues relate to source definition, plume geometry, hydrogeology, recharge/discharge boundaries, biogeochemistry, and drilling and sampling. These issues are summarized below.

Source Definition. More detail and documentation on contaminant sources and delivery from the vadose zone and groundwater are needed (this is a cross-cutting need that is coordinated with other technical elements and is captured within the scope of the inventory technical element). Hanford needs an improved understanding of how contaminants are entering aquifer. Attention should be focused on the type of contaminant release—aqueous mixtures, NAPLs, or volatile vapors and condensates.

Plume Geometry. Three-dimensional groundwater flow, influenced by recharge and discharge boundaries, subsurface heterogeneity, and waste characteristics and volumes, controls the horizontal and vertical position of migrating contaminant plumes. Additional considerations arise with NAPL bodies and their movement and dissolution over time. Plumes are horizontally and vertically discrete. Hanford needs an improved understanding of how contaminants are moving through the aquifer.

Hydrogeology. Adequate description of the variability of subsurface structure and its influence on water flow both above and below the water table is needed. The task team recognized approximately 50 years of studies with interesting recent work, including recent 3D modeling and conversion of two-dimensional (2D) transmissivities to 3D parameters. Maximum use of the historical information and the cumulative best conceptual model is critical at a "data rich" site such as this one. Hanford needs an improved understanding of controlling geological conditions.

Recharge and Hydrologic Boundaries. Transient changes in recharge as a result of waste disposal, leaks in domestic and process water, discharges from confined basalt aquifers, and regional agricultural practices influence the flux of contaminants from the vadose zone, as well as the direction/rate of groundwater migration. Hanford needs an improved understanding of controlling hydrologic boundaries.

Biogeochemistry. Hanford needs an improved understanding of the nature of contaminant transport—primarily for contaminants with limited mobility and NAPLs. This is a joint effort with the vadose zone task team. Hanford also needs an improved understanding of controlling biological and chemical processes that influence contaminant behavior in the groundwater. Additional transport mechanisms should be considered, such as diffusion into soil grains, or into clumps of soil grains (super particles) that may be otherwise hydrologically isolated. If colloidal transport is found to occur, then characterization of the colloidal material is needed, such as size distribution, charge, sorptive properties, residence times, type of material (e.g., clay, iron hydroxides, microbes, etc.).

Uncertainty. It is impossible to have complete knowledge of the hydrogeologic system, past and future water flow, or past and future contaminant movement. Regardless of the data collected, there will always be uncertainty in our understanding and prediction of the situation. Incorporation of uncertainty in our analyses will allow us to better predict and describe present

and future scenarios. Research is needed into how to incorporate uncertainty in a large regional model such as that for the groundwater at Hanford.

Drilling and Sampling Methods. Hanford needs 1) improved access to the subsurface system to reduce costs and increase data density; and 2) an improved ability to access and sample the groundwater.

More detailed discussions of proposed activities that address these technical issues and specific recommendations are provided in the descriptions of the technical research areas (Section H.3.3).

H.3.2 Approach

The contributors to the groundwater technical element recognized that understanding of the Hanford groundwater system is somewhat more mature than other technical elements within the S&T plan. Thus, the proposed activities were carefully selected to address specific remaining gaps and needs that were identified, consistent with the conceptual model described in Figure H-7, field observations to date, and the scientific issues just presented. A combination of field measurements in existing wells with new devices, field observations from new wells or extended wells, focused laboratory studies, and updated modeling are proposed to fill these gaps.

The research represents a logical progression following contaminant migration from the source to the potential receptor. Such an organization facilitates prioritizing, managing, and funding, and roughly aligns S&T activities with the existing project organizational infrastructure at the Hanford Site. This alignment assists S&T infusion into the projects.

H.3.3 Research Areas

Based on the needs and scientific issues, the six areas of research were developed to address the various issues in a logical progression. The interrelationships between these areas of research are shown graphically in Figure H-8. In this diagram, circles represent interactions with other technical elements, and the rectangles represent themes recommended for the groundwater technical element. Each of the research areas is described in more detail in subsequent sections.

The research areas typically are structured to minimize potential institutional barriers (e.g., by consolidating work in any particular area). Nevertheless, the proposed scope of each theme was developed in an integrated manner and all of the scientific issues discussed above are addressed in some fashion within each theme.

The proposed scope leads to development of a robust and defensible program that establishes a credible estimate of risk and optimizes (reduced cost and protective) environmental remediation. The research areas as presented represent a minimal proposal and a notation of relative significance is provided for each research area. The following sections discuss scope, research questions or motivation, S&T activities, research products and benefits, and timing and linkage to other activities, as appropriate, and Table H-2 summarizes the objectives and products of the related S&T activities.

Figure H-8. Proposed Groundwater Science and Technology Activities and Linkages.

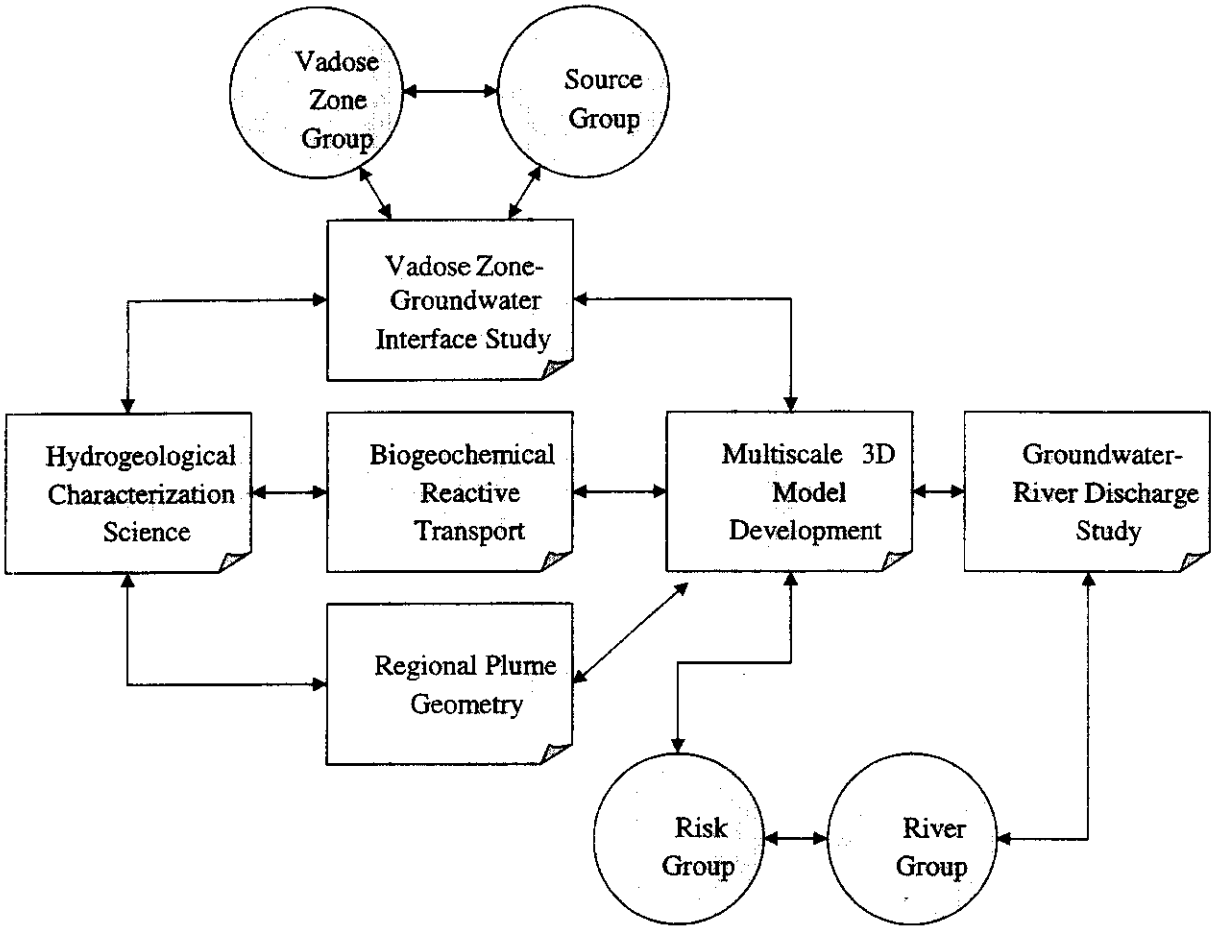


Table H-2. Objectives and Products of Groundwater Science and Technology Research Areas

Research Area	Objective	Product
1. Vadose Zone-Groundwater Interface Study	Collect detailed depth-discrete contaminant concentrations and biogeochemistry data to elucidate near-source plume structure and character.	Critical information related to source character and inventory and corroboration of the vadose zone transport and delivery processes. Data may also distinguish between closely spaced sources in key areas (e.g., cribs versus tanks).
2. Biogeochemical Reactive Transport	Evaluate biogeochemical processes using detailed characterization of shallow groundwater near extreme chemistry sources–particularly, DNAPL/ transuranic interactions, radionuclides near former reverse wells, and chlorinated solvent transport/ transformation.	Confirmation and quantification of poorly understood contaminant migration mechanisms (e.g., DNAPL as a vector for transuranic penetration). Documentation of continued influence of extreme chemistry beyond the vadose zone to the groundwater pathway.
3. Hydrological Characterization Science	Integrate existing data and future characterization using innovative methods over a hierarchy of spatial scales. Synthesize results using imaging and geostatistics for incorporation into multiscale modeling.	Document and implement the scientific basis for collecting and representing geologic and hydrogeologic data over a variety of scales. Assist in use of state-of-the-art methods for linking models to the data.
4. Regional Plume Geometry	Delineate the 3D structure of the regional contaminant plume and collect data on the controlling hydrogeologic features in a cross section from the source plateau across the Columbia River.	Confirm inventory estimates for relatively mobile contaminants. Document the position of the plume and generate visualizations of the plume structures to support decision-making. Provide better estimate of plume structures to support groundwater-contaminant discharge estimates.
5. Multiscale 3D Model Development	Document approaches for consistent modeling and parameter estimation/assignment across a hierarchy of scales (e.g., local scale to regional scale).	Improved model consistency and technical defensibility.
6. Groundwater-River Discharge Study	Delineate the horizontal and vertical location of the distal portion of the plume of contaminants approaching the river based on multilevel sampling and monitoring.	Better estimates of groundwater-surface water flux based on samples that are less susceptible to temporal effects of riverbank storage. Improved prediction of the location of potential high concentration seeps.

H.3.3.1 Vadose Zone-Groundwater Interface Study

H.3.3.1.1 Scope. The research proposed within this area will address the near-source contaminant distribution for a limited number of sites selected in collaboration with the inventory and vadose zone technical elements. The research should address source definition, plume geometry, recharge boundaries, biogeochemistry, and drilling/sampling at the vadose zone-groundwater interface. While the results should be diagnostic for reconciling inventories, vadose delivery processes, and local groundwater behaviors for a wide range of contaminants, the data are especially critical for contaminants of low to moderate mobility. This work allows for field measurements and observations of plumes in areas where concentrations are sufficient for more assured interpretation. Further, the results should be directly usable for the systems assessment capability activities for the subject sites, and can be used to assist in analysis of similar waste/disposal scenarios as needed.

H.3.3.1.2 Research Questions and Motivation. Specific research questions are:

- What is the rate and nature of contaminant delivery from the vadose zone to the groundwater underlying Hanford sources? What does assessment of the 3D plume below the discharge area infer about transport through the vadose zone?

- What is the flux of contaminants? Can depth-discrete soil core data and depth-discrete near-source groundwater data refine these processes and improve models?

- Are current inventory estimates associated with groundwater plumes consistent with field measurements of inventory? If not, why not?

H.3.3.1.3 S&T Activities. A limited set of S&T activities performed near the source areas are intended to provide critical information to support interpretation and prediction of contaminant transfer from the vadose zone to the saturated system. These activities include detailed depth-discrete sampling of contaminants and "near source" plumes to determine the nature and rate of vadose contaminant influx and the behavior of contaminants in the capillary fringe. Specific near-source activities include detailed depth-discrete sampling of soil through the lower vadose zone, capillary fringe, and upper aquifer in conjunction with planned characterizations. This activity should be performed by supplementing sampling and analysis costs and extending boreholes as needed through the Integration Project to obtain these data.

An additional task that sets up monitoring of the development of the tritium plume from the recently opened C018H Facility is proposed to document the 3D development of a Hanford groundwater plume from near its onset. Importantly, the pattern of contamination and arrival of this plume at the groundwater should assist in calibrating the vadose moisture movement portions of fate/transport/risk models and the subsequent development of the groundwater plume as it extends downgradient.

Detailed Soil/Groundwater Depth-Discrete Sampling. This task includes the following specific activities:

- Take depth-discrete samples and related samples in existing wells. We recommend analysis of water from low-volume downhole samplers such as the Kabis (or similar), a SEAMIST™ sampler deployed in existing wells, or diffusion samplers. Other recommendations include high-resolution video surveys and other direct observation/profiling tools. Use of downhole sensors is possible but may be expensive relative to resulting data.

- Do depth-discrete sampling during additional borehole/well installations at selected sites. We recommend measuring physical and chemical data from continuous core and we encourage extension of boreholes (especially in light of high drilling costs) while avoiding drag down, to collect data from the lower portion of the unconfined aquifer and to depths greater than the projected post-Hanford water table elevation. Casing should be chosen to facilitate geophysics (i.e., modify current installation plans to include using nonconductive casing to permit induction and related logging as well as seismic/ gamma-logging, or to alternate conductive and nonconductive casing to allow all of the above and electrical resistance tomography.

- Develop and routinely use a robust suite of borehole geophysical logs. These should include stratigraphic and chemical logs (e.g., spectral gamma logging as appropriate).

- Perform additional interpretation of historical data, if possible, accounting for vertical positions and lengths of screens.

- Evaluate temporal issues and relate them to seasonal or source issues. Specific suggestions include plotting time history for concentration and water level in all significant wells and determining if any trends are evident that are informative about near-source plume geometry/position.

C018H Plume Development Study. This task involves increased 3D monitoring of the C018H Facility to identify the early development of a tritium plume. Specific activities should include the installation of multilevel samplers (TimCo, Canadian, WestBay and others are possible) to supplement standard groundwater monitoring wells.

H.3.3.1.4 Research Products and Benefits. The vertical plume geometries near-source areas need careful assessment to help with source identification and description. The concentration, position, and thickness of the plumes near the sources and immediately downgradient relates directly to waste volumes and character. For example, thin plumes at the water table surface imply low-volume sources. Plumes from higher-volume sources and dense wastes (e.g., DNAPLs and dense aqueous phase liquids [DAPLs]) may be thicker because they are located deeper in the aquifer. This assessment should determine if existing data provide adequate sampling and data for estimating inventory.

The proposed work is intended to integrate the groundwater plume inventory estimates with source estimates on a large scale. The estimates should assist in reconciliation of the data and

help determine areas where the data suggest that additional source evaluations are needed. The work would supplement the data set used in a past system assessment. Several discrepancies related to mass/activity and location were identified in that effort, which should be documented and addressed based on significance/risk. The data from this S&T activity would provide better (more 3D) interpretation of plumes—including data from the lower portion of the unconfined aquifer. Geostatistics, uncertainty analysis, and 3D imaging techniques should be used as appropriate.

H.3.3.2 Biogeochemical Reactive Transport

H.3.3.2.1 Scope. The proposed research within this area is intended to address critical geochemical issues that appear to be modifying contaminant distribution and transport at Hanford. The research should address the plume geometry, and biogeochemistry scientific issues identified in Section H.3.1. The work is proposed for a limited number of sites selected in collaboration with the vadose zone technical element task team, guided by the SAC, and in cooperation with responsible Site organizations (e.g., TWRS and ER). The results are intended to be usable by the Hanford groundwater modelers and the systems assessment efforts.

H.3.3.2.2 Research Questions and Motivation. The fundamental research questions that will be addressed within this area of research are as follows:

- What is the mobility of transuranic (TRU) radionuclides (especially neptunium-237) that may enter (or already have entered) the unconfined aquifer via preferential pathways or intentional disposal?

- Is there any evidence of colloid formation and or complexation of TRU radionuclides in Hanford groundwater?

- What is the fate of TRU radionuclides in DNAPL that reach groundwater?

- What is the rate and extent of natural biodegradation of dissolved carbon tetrachloride in the unconfined aquifer under both oxic and anoxic (deep) conditions?

H.3.3.2.3 S&T Activities. Biogeochemical reactions may result in either enhanced contaminant mobility, degradation (natural attenuation), or fixation in the unconfined aquifer. An understanding of these fundamental processes is needed to predict the long-term behavior of contaminants as they enter the unconfined aquifer and during transport along the groundwater flow path to the river. Biogeochemical processes are also a major focus area in the vadose technical element. The groundwater biogeochemical sub-element is intended to supplement the vadose geochemical process investigation by addressing conditions that may be unique to the saturated zone. The groundwater task team has selected near-term opportunities to elucidate important biogeochemical phenomena that will link to future vadose zone technical element activities. The primary constituents targeted for early evaluation are carbon tetrachloride and TRU radionuclides. A two-year effort involving both laboratory and field observations at key disposal sites is proposed to account for information gaps relevant to the groundwater flow path. A start date of fiscal year (FY) 1999 is proposed for the TRU portion of the proposed work

because of its critical relevance to ongoing remedial action activities and related near-term Records of Decision (RODs).

The basic approach is to employ both laboratory studies and field study sites (analog waste disposal sites) to address the research questions noted above. The proposed S&T activities to test hypotheses associated with the research questions identified are described separately below. For TRU radionuclides, two study sites are proposed for mobility investigations, a DNAPL-TRU liquid waste disposal site and an injection well that received both fission products and TRU radionuclides from one of the three major chemical separations processes used at Hanford. The intent is to determine the impact of co-contaminants on the flux of TRU radionuclides through the groundwater.

DNAPL-Transuranic Site. Transuranic radionuclides dissolved in DNAPL (tributyl phosphate [TBP]-carbon tetrachloride) may have migrated through the vadose zone and into the unconfined aquifer beneath the PFP liquid waste disposal sites. Approximately 20,000 Ci of TRU radionuclides were discharged to the ground in the PFP cribs, the largest soil column TRU source at Hanford. The DNAPL-TRU-TBP mixture may move through the vadose zone with minor modification or at least incomplete degradation of the mixture. Dissolved carbonate (as HCO_3 in groundwater) forms a stronger complex with TRU radionuclides than does TBP. Thus the TRU that hypothetically reaches groundwater in the DNAPL (co-contaminant mixture) could be resolubilized as an aqueous ion complex. Depending on the affinity of the specific TRU radionuclide for sediment surfaces, the resolubilized TRU radionuclide could either become tightly bound by the mineral phases, mobilized as the anionic or non-charged carbonate complex species, or it could form a mobile colloidal phase. Of the TRU radionuclides of concern—plutonium, americium, and neptunium—the latter is the most likely to exhibit carbonate complex formation and thus exhibit the greatest long-term mobility in groundwater.

Multiphase modeling of the Z-9 trench site, which received the largest amounts of carbon tetrachloride and TRU radionuclides, suggests that the DNAPL will drain slowly through the vadose zone to groundwater for a long time into the future (50 + years). Thus, this vector represents a unique transport mechanism and potential long-term TRU source in groundwater. If the hypothesized pathway from the vadose zone source to groundwater is correct, neptunium-237 in an anionic or non-charged chemical state (or plutonium-americium as colloidal phases) should be detectable near the major source areas where high concentrations of dissolved carbon tetrachloride occur in groundwater. To test this hypothesis, groundwater samples can be collected from an existing production well adjacent to the Z-9 trench where the highest carbon tetrachloride concentrations in groundwater currently exist. The existing production well (60 gpm) provides an opportunity to interrogate the area around and beneath the major TRU/carbon tetrachloride source in the Plutonium Finishing Plant (PFP) complex. If the hypothesized transport process is correct, the expected TRU concentrations (mobile species) should be approximately proportional to the ratio of TRU to carbon tetrachloride discharged to the disposal sites. For example, if neptunium-237 is mobile (Kd <1) as a result of carbonate-complex formation, there should be about 0.01 to 0.1 pCi of neptunium-237 per µg of carbon tetrachloride dissolved in groundwater, based on the inventory estimates discharged to the cribs. At current dissolved carbon tetrachloride concentrations of 8000 µg/L adjacent to the Z-9 trench, the

neptunium-237 should be easily detected if this pathway is viable (only one or two attempts to measure neptunium-237 in groundwater at Hanford have been made). If initial sampling based on unfiltered samples (total) indicate the presence of neptunium-237, the follow-up work should include fractionation of the water sample using a multi-pore size membrane filtration apparatus and the Battelle large-volume sampling device to differentiate anionic, cationic, non-charged, and colloidal size fractions. The absence of detectable TRU radionuclides associated with the highly dissolved carbon tetrachloride would suggest that the DNAPL co-contaminant mixture may have been biodegraded in the vadose zone, or that the TRU radionuclides were removed from the organic phase by sorption on mineral phases (e.g., calcium carbonate) in the vadose zone. Thus, this activity is closely linked to vadose zone investigation of the chemical status of TRU radionuclides retained in the soil column.

Advanced (ultra-sensitive) analytical methods may be needed for this work in order to quantify the relative distribution of TRU radionuclides among various potential physical and chemical fractions. For this purpose, TIMS (thermal ionization mass spectrometry), low-level counting, and radiochemical separations to remove interferences (especially for neptuium-237) are needed.

TRU Radionuclides at an Injection Well Site. The B-5 reverse well or injection well received significant amounts of TRU radionuclides and fission products associated with the bismuth phosphate chemical separations process. Some of this waste was injected directly into the aquifer in 1947. Several wells were installed around this site to investigate radionuclide movement away from the point of injection. More recently, a pump-and-treat campaign was conducted to determine if retrieval was a feasible remedial action approach. Recovery was very limited and the pump-and-treat campaign was terminated. The injection well site represents an opportunity (a "natural laboratory") to study the behavior of TRU radionuclides injected into the groundwater from one of the major chemical processes used at Hanford. The same field approach as described above can be used to assess the physical and chemical state of TRU occurrence in groundwater at this site. The results should provide an indication of the fate of tank waste containing TRU radionuclides that may reach the groundwater directly (e.g., via preferential pathways).

Carbon Tetrachloride Biogeochemistry. Biodegradation of carbon tetrachloride can be assessed using laboratory studies and field observations (degradation products in groundwater samples). A significant amount of work has already been done on this issue for the Arid Site Demonstration Project (ASDP). Thus, additional work should build on the findings from the ASDP site studies. Most of the work to date has been under oxic conditions. However, there is indirect evidence that carbon tetrachloride as a DNAPL may have migrated to the bottom of the unconfined aquifer beneath where anoxic or near-anoxic conditions prevail. Thus, anaerobic biodegradation processes need additional attention in order to predict the long-term fate of deeply distributed carbon tetrachloride.

The rate of carbon tetrachloride degradation as a function of major physical and chemical variables should be used to 1) predict the amount of natural attenuation due to biodegradation that will occur during average projected travel times from the 200-West Area to the Columbia River, 2) contribute to prediction through modeling of the long-term fate of more deeply distributed DNAPL, and 3) assist in locating the deeply distributed DNAPL.

H.3.3.2.4 Research Products and Benefits. This work is intended to link to future vadose zone geochemical activities. For example, if no evidence is found for TRU radionculides in groundwater at the PFP crib sites, then additional vadose zone characterization to understand the mechanism of retention in the soil column should be emphasized. Thus the groundwater investigation should precede vadose zone characterization of the PFP crib sites. Also, knowledge of TRU radionculide status beneath the Z cribs is needed at an early date to support a decision to either close these crib sites (because removal of carbon tetrachloride has reached the point of diminishing returns) or to leave them open for further characterization and or remediation of contaminated soil (excavation, stabilization in place). Closure could involve placement of the Hanford barrier over the surface. However, to close this site it must be decided if the deeply distributed TRU radionuclides can be left in place or if at least the near-surface contamination should be removed or fixed in place. Thus knowledge of the mobility (or fixation) status of TRU radionuclides is needed at an early date to guide subsequent characterization and closure decisions.

Biodegradation studies of carbon tetrachloride and studies at the "natural" TRU laboratory site can be started at later dates because this information will support long-term or closure decisions.

H.3.3.3 Hydrogeological Characterization Science

H.3.3.3.1 Scope. The proposed research conducted within this area is intended to address the geologic controls that affect groundwater flow and the distribution of contaminants within the system. The research should address the plume geometry, recharge and hydrogeologic boundaries, hydrogeology, biogeochemistry, and drilling/sampling scientific issues identified in Section H.3.1. With limited exception, all work within this research area should be leveraged with existing characterization activities by responsible site organizations (e.g., TWRS and ER). This effort should also be coordinated with the inventory, vadose zone, and river technical elements. The results should be usable for the SAC activities for the subject sites and they can be used to assist in analysis of similar waste/disposal scenarios as needed.

H.3.3.3.2 Research Questions and Motivations. Specific research questions are as follows:

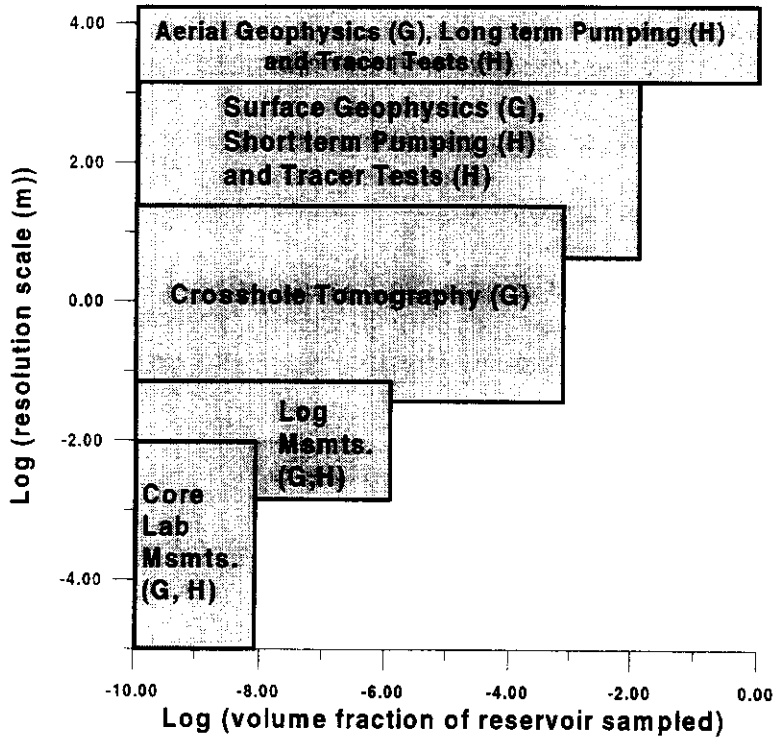
- How does the physical/hydrological heterogeneity influence flow and transport in the saturated zone?
- What scale(s) of physical/hydrological heterogeneity definition is necessary to understand and predict flow and transport at the Hanford Site?
- How do we relate hydraulic measurements acquired with different support scales or different volumes of investigation?

H.3.3.3.3 S&T Activities. The proposed S&T activities to be conducted to answer these questions will include 1) a thorough review of past hydrogeological characterization work; 2) an integrated characterization effort over a hierarchy of spatial scales; and 3) data interpretation, synthesis, visualization, and integration with numeric modeling efforts. The foundations of the

conceptual and numerical models will be the existing database, which should be enhanced by new data from the multiscale characterization effort as defined in the task description.

The characterization should include an iterative approach to be performed in conjunction with development of a monitoring system and numerical model. The evaluation of characterization methods should include determining the capability of various measurement techniques at the Hanford Site to provide value-added information and insight into the distribution of subsurface properties such that the results can be implemented with emerging computer visualization, interpretation, parameter estimation, and numerical modeling efforts. Selected promising physical and hydrological characterization methods should be identified from a suite of possible techniques to study critical properties at the appropriate scales of interest. An example of scale-based investigation methods is geophysical techniques; the scales of investigation and resolution of some of the geophysical and hydrological measurement techniques are shown in Figure H-9.

Figure H-9. Resolution and Fraction of Subsurface Sampled Using Hydrological (H) and Geophysical (G) Characterization Tools.



Multiscale Characterization. This proposed activity involves performing innovative characterization over a hierarchy of scales: Hanford Site scale, intermediate scale, and core/laboratory scale.

The goal of the **Hanford Site scale** (~ kms x kms) effort is to define geometry (structure, stratigraphy, model boundaries) and effective hydraulic properties that control flow and transport at the field scale.

S&T activities under this task should include the following:

- Collect hydraulic property measurements using field-scale techniques (well interference tests, river pump tests) as well as indirectly from lithological logs, depositional information, and other database information.
- Refine existing hydrostratigraphic unit definition based on hydraulic measurements.
- Refine, document, and justify correlations currently used to relate physical well-logs to hydraulic properties.
- Map key interfaces using borehole data, well test information, and surface geophysical data.
- Collect additional information on the structure of the May Junction Fault.
- Provide input to the existing sitewide model.

The goal of the **intermediate scale** (~30m x 30m) effort is to study the physical/hydrological/ geophysical properties at log- to meter-plus scale to identify preferential flow features or barriers, and to enable high-resolution estimation of hydrogeological properties that control flow and transport.

S&T activities under this task should include the following:

- Forward modeling to evaluate the feasibility of using high-resolution geophysical tomographic techniques.
- Collect borehole hydrological/geophysical/physical data and cores and high-resolution 2D geophysical tomographic data as deemed appropriate from the modeling study. Possible methods include tomographic seismic, electrical resistance, electromagnetic, and radar.
- Use site-specific relationships developed at the borehole or core scale to relate 1) hydrological properties (such as porosity and permeability); 2) physical properties (such as grain size distribution, consolidation, mineralogy, and facies type); and 3) geophysical properties available from tomography data (such as seismic velocity, seismic attenuation, dielectric constant, and electrical resistivity).

- Transform geophysical attribute tomographic profiles into high-resolution, 2D estimates of hydrological properties.

- Using high-resolution hydraulic property estimates from tomographic data 1) investigate the location of preferential flow zones or barriers and 2) characterize hydrological properties at detailed scale including and develop uncertainty estimates and estimates of variability and spatial correlation.

Two locations for the intermediate scale study are suggested. First, the Gable Gap area is recommended because the water table is shallow (which will result in cheaper boreholes for geophysical tomographic work and suitable conditions for surface geophysical work). It is also an area of concern for future contaminant transport due to potential northerly groundwater flow through the gap rather than easterly flow to the river. Secondly, the saturated zone beneath a tank farm is recommended, because this area would have a more typical (thicker) vadose zone section and more suitable leveraging with the Office of Waste Management (EM-30) activities and planned representative site research under the vadose zone technical element.

The goal of the **core/laboratory-scale** characterization task is to understand the relationship between physical, hydrological, and geophysical properties at a single scale of investigation.

S&T activities under this effort should include the following:

- If data are not currently available, from each important hydrostratigraphic unit, collect several intact cores and define or measure the following for each core: 1) grain size distribution; 2) porosity; 3) saturated hydraulic conductivity; 4) grain density; 5) lithology; 6) interpreted hydrostratigraphic facies; 7) seismic velocity and attenuation; 8) electrical resistivity; and 9) dielectric constant.

- Define core-scale relationships between physical, hydrological, and geophysical properties.

- Use relationships to aid in interpretation of geophysical data acquired in the intermediate-scale effort and Hanford-scale effort.

Data Interpretation, Synthesis, Visualization, and Integration with Numerical Modeling Efforts. This proposed research effort will be undertaken to:

- Refine (based on additional characterization), the existing field- and detailed-scale geological and hydrological maps and cross sections of the Hanford Site that will be used to build 3D computer visualization of the subsurface and as input to the numerical model.

- Provide estimates of small-scale hydrological property variability and spatial correlation to numerical modeling effort that can be used with a stochastic modeling approach.

- Investigate scale dependence of hydraulic measurements by comparing measurements collected at the large scale (well tests, river pump tests), intermediate scale (tomographic estimates), and log/core scale.

- Iterate with the modeling effort and historical transport data to investigate the scale(s) of physical and hydrological heterogeneity characterization that are important for understanding flow and transport at the Hanford Site.

- Use iterative characterization efforts as guidelines for numerical model building, groundwater monitoring, and further physical, geophysical, hydrological, and geochemical sampling campaigns.

- Develop a suite of tools and techniques that are appropriate and cost-effective for Hanford saturated subsurface characterization.

H.3.3.3.4 Research Products and Benefits. The expected result of the enhanced characterization efforts will include an improved understanding of contaminant transport as effected by physical and hydrological heterogeneity. This information should guide the conceptual and numerical model development to aid in contaminant transport prediction and remediation design strategies.

H.3.3.4 Regional Plume Geometry

H.3.3.4.1 Scope. The proposed research within this area is intended to address the large-scale controls and plume structure at Hanford. The research should address the source definition, plume geometry, recharge and hydrogeologic boundaries, hydrogeology, and drilling/sampling scientific issues identified in Section H.3.1. All work within this area should be leveraged with activities by responsible site organizations (e.g., TWRS and ER) and with the Hanford SAC and groundwater modeling activities. This effort should also be coordinated with the inventory and Columbia River technical elements.

H.3.3.4.2 Research Questions. The following research questions have been developed for understanding the role of regional plume geometry in the distribution of mobile and nonconservative contaminants and tracers:

- What is the structure of the regional groundwater plume(s) for the mobile (e.g., tritium) and moderately mobile contaminants (e.g., technetium, strontium, etc.)?

- What is the role of poorly understood groundwater conditions (e.g., high water levels to the east of the Columbia River) in controlling the subsurface distribution of contaminants?

The structure and development of the regional groundwater plumes is critical to the integrated evaluation and calculation of risks. This plume structure also provides information about controlling hydrogeology and is critical to calibrating and documenting the quality/performance of numerical models.

H.3.3.4.3 S&T Activities. This effort is focused primarily on field measurement and 3D imaging of the regional plumes. A transect from the 200-West Area plateau toward the Columbia River should be defined and installed (including a well to the east of the river). A minimum of five wells are needed for this effort. Each well would include depth-discrete

sampling and rapid (field screening or nearby support lab) analysis of contaminant concentrations throughout the water table and semi-confined aquifer system. A well would be installed in the highest concentration lens at each location. If the plume exhibits multiple lenses, permanent depth-discrete monitoring (2 to 3 zones) would be installed using a 4-inch diameter StrataSampler or similar system. Analyses for contaminants, geochemical and microbial parameters, geological parameters, and isotope geochemistry markers (e.g., tritium age-dating and helium ratios) would be collected along the proposed transect.

H.3.3.4.4 Research Products and Benefits. This work will provide the necessary information to clarify the transport path of contaminant plumes to the receptor and the influence of high water levels outside of Hanford boundaries on the flow system and plume structure.

H.3.3.5 Multiscale 3D Model Development

H.3.3.5.1 Scope. The research within this area is intended to address the large-scale controls and Plume structure at Hanford. The research should address the source definition, plume geometry, recharge and hydrogeologic boundaries, and hydrogeology scientific issues identified in Section H.3.1. With limited exception, all work within this area should be leveraged with existing characterization activities by responsible site organizations (e.g., TWRS and ER). This effort should also be coordinated with the inventory and Columbia River technical elements. Finally, the proposed S&T activities should support and supplement current efforts by Hanford and PNNL (e.g., updating model calibration data, moving from a 2D to 3D model, and evaluating long-term water level changes). The results should be diagnostic for reconciling groundwater behaviors for relatively mobile contaminants; the data should be especially critical for contaminants of low to moderate mobility. The results should be directly usable for the SAC activities, and can be used to assist in analysis of similar waste/disposal scenarios as needed.

H.3.3.5.2 Research Questions and Motivations. The ultimate objective of an improved multiscale model is to facilitate consistent approaches to evaluating contaminant transport and risk. The modeling approach must be robust and address near-field, intermediate scale, and Hanford Site-scale issues and the variety of modeling goals/outputs to support Hanford decision-making. The approach must accommodate the following necessary elements:

- Geological, chemical, and biological conceptual models
- Vadose zone inputs
- River discharge
- 3D plume geometry/variability
- Regional geologic structure (faults, basement topography, folds)
- Fast/interconnected pathways
- Multiphase conditions
- Roles of low-permeability materials.

The following research questions arise:

- How can improved multiscale 3D models be used to attain consistency between interpretations and observations at different scales?
- What approaches can be taken to incorporate geological, geochemical, and biological heterogeneity into multiscale 3D models?
- What numerical and analytical schemes can be used to incorporate coupled geochemical and microbiological reactions into multiscale 3D models?
- How can multiscale 3D models be used to identify and target new phenomena for field observation?

H.3.3.5.3 S&T Activities. S&T activities proposed to respond to these research questions include efforts to 1) define multiscale modeling objectives and 2) develop and implement a multiscale modeling approach.

Define Multiscale Modeling Objectives. At Hanford, the modeling approach selected should be consistent and must address a variety of issues on a variety of scales. This task represents the initial coordination and collaboration between the existing modeling and SAC activities and the proposed S&T effort to reduce overlap and facilitate the transfer and use of the science.

Specific scale and related issues to be considered in developing a balanced approach include the following:

- Proper representation of continuum physics and chemistry across scale boundaries (e.g., pore, site, regional).
- Localized geohydrologic and biogoechemical environments (at facies or smaller scales).
- Multicomponent speciation and mineral phase interaction (migration rates) and decay and transformation rates.
- Transient flow behavior, including climate change, large recharge mounds, and seasonal and river effects.
- Land-use issues (agriculture, industrial/residential use, local Hanford operations).
- NAPL behaviors, NAPL effects, and co-contaminant transport vectors.

Develop and Implement a Multiscale Modeling Approach. Consistent with the objectives developed under the previous task, models need to be implemented based on the approach to support integrated vadose zone/groundwater/river needs. The activities under this task include implementation of a fully 3D regional model and select implementation of models for specific sites, as described here.

- Boundary/initial conditions (natural and artificial fluxes, river).
- Improved representation of geologic structure and incorporation of historical and recent characterization data.
- The need to address transient issues such as climate change, recharge mounds and future changes to more natural conditions, seasonal and river effects, land-use issues (agriculture, industrial/residential use, local Hanford operations), and NAPL effects.

Site-specific scale models should be implemented for the carbon tetrachloride plume, example tank leaks, and crib disposal sites selected in cooperation with other groundwater and vadose science activities and leveraging characterization by EM-30 and the Office of Environmental Restoration (EM-40). Sites should be selected to be broadly representative of the disposal and waste character diversity at Hanford. Representative (analog) sites that would be expected to be similar to the modeled sites should be identified as a part of the modeling effort. For each specific site the following actions should be completed:

- Identify relevant flow/transport/reaction processes; parameterize and incorporate them into a model.
- Address facies-scale heterogeneity in this process.
- Establish flow boundary conditions.
- Identify initial conditions for chemical contaminant distribution(s).
- Pose historical or risk/remediation scenarios for evaluation.
- Implement 3-D numerical flow and reactive transport models.
- Evaluate results and compare them with available data/measurements.

H.3.3.5.4 Research Products and Benefits. The S&T activities undertaken above are expected to:

- Improve confidence and refinement of conceptual models, including validation and cross validation of assumptions and improved consistency with observations.
- Provide inputs to other technical elements, including past, present, and future hydraulic and chemical fluxes to groundwater-river discharge, which is of interest to the river technical

element task team; realistic contaminant distribution and fate to the effects technical element; and changes in water table for vadose zone technical element.

- Provide a specific report on future water level changes and the ramifications as the water table decreases from Hanford formation into the Ringold Formation in critical plume areas.

- Provide a framework for future work, including prioritization of site activities, refinement of characterization/remediation approaches, provision of boundary conditions for Site-specific models, and accommodation of different input scenarios from vadose zone studies.

- Improve scientific defensibility of contaminant fate and risk predictions.

H.3.3.6 Groundwater Discharge Study

H.3.3.6.1 Scope. The research under this area is intended to focus on quantifying the discharge of contaminated water to the river and anticipating (or measuring, where appropriate) the amount of inflow and the flow path of the groundwater at that boundary. The research should address the plume geometry, recharge and hydrogeologic boundaries, and hydrogeology scientific issues identified in Section H.3.1. With limited exception, all work conducted under this theme should be leveraged with existing characterization and surveillance activities by responsible Site organizations. This effort should also be coordinated with the Columbia River technical element, and the results should be directly usable for the SAC activities.

H.3.3.6.2 Research Questions and Motivations. The focus of this research area should be to answer the following question:

- What is the horizontal location and vertical structure and location of the groundwater contamination as it approaches and enters the Columbia River?

The river boundary condition represents a critical point of exposure and it is the link from the groundwater studies to the river studies. As such, this region is called out as a specific task.

H.3.3.6.3 S&T Activities. This effort emphasizes the necessary groundwater studies and supplements the detailed river water, flux chamber, ecological, and related research proposed under the river technical element. The specific goal of this work is to collect information in an area that is near the river but where concentrations and estimated fluxes are robust to river stage and seasonal influences. This work should be designed based on the shallow groundwater monitoring points recently installed by Hanford/PNNL. This is a low-cost, but important activity that includes the installation of multilevel samplers and collection of water level/stage data (logged), and chemistry, relating results to overall flux, seasonal flux, and hydraulic properties.

This activity should focus on determining how contaminants discharge into the river—along the shoreline, in the bed of the river, and how far out into the river—and determine how these discharges are affected by daily and seasonal variations of river stage.

H.3.3.6.4 Research Products and Benefits. This work should provide the necessary information to document the near-river transport path of contaminant plumes to the receptor. These data will be critical in providing flux data to river risk assessors because it will be less variable throughout the year as river bank storage effects are seen nearer the river. The data will also help estimate the detailed location of outcrop to assist in determining local impacts to specific organisms/spawning areas.

H.3.4 Timing and Linkage of Activities

All of the proposed research areas rely on coordination and collaboration with and among existing site organizations and operations. In particular, work near source areas (vadose zone-groundwater interface study, and biogeochemical reactive transport) should be performed in cooperation with the TWRS, ER, or other appropriate organizations. Selection of representative sites should be performed in collaboration with the other technical elements. As discussed above, many of the activities proposed under the groundwater technical element are extensions of work that is already planned as part of characterization, monitoring, or environmental surveillance efforts at the Hanford Site. We propose leveraging the planned work by adding selected and limited activities that will provide the necessary improvement in S&T understanding for the least additional investment. This leveraging is an assumption in this planning, and the resources needed to address the problem if the leveraging is not possible would be increased significantly. A proposed schedule of activities is provided in Figure H-10. This figure also notes relative prioritization by the groundwater task team to assist in planning.

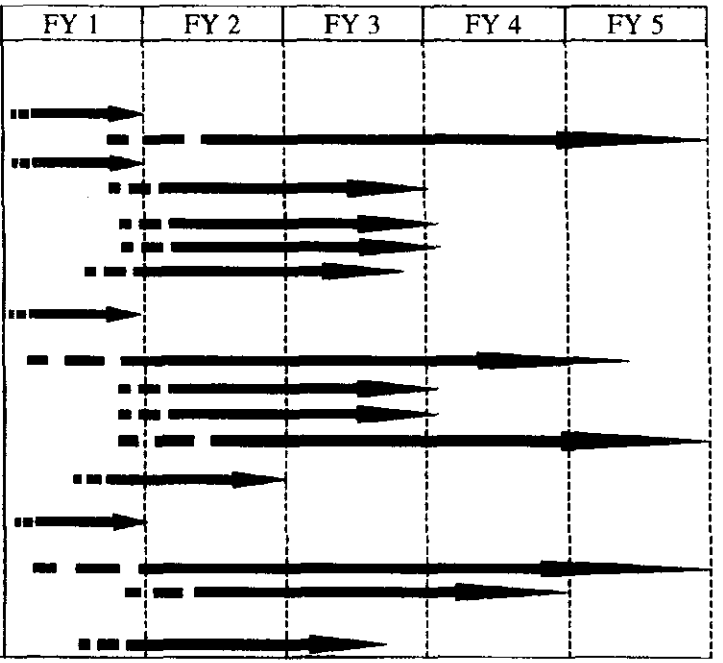
In summary, the information on near-source plume geometry and biogeochemistry should provide critical S&T information to support reconciliation of inventory and to document the vadose zone contaminant delivery processes—especially for contaminants of moderate mobility or for complex transport modes. The regional plume geometry information, improved hydrological characterization, and river discharge work should directly support reconciliation of inventories for mobile contaminants, the Hanford SAC and groundwater modeling efforts, and ultimately improve the defensibility of human and ecological risk assessments. The integration of the S&T is graphically depicted in Figure H-8.

H.4 COLUMBIA RIVER

The Columbia River technical element is intended to support and provide information necessary for an assessment of the effects of Hanford-derived materials and contaminants on the Columbia River environment, river-dependent life, and users of river resources. The river technical element consists of a combination of data management, field measurement, and modeling capability. The objectives of the river technical element are to provide relevant and meaningful information to support remedial decisions and subsequent risk and system assessments, to guide ongoing and subsequent environmental surveillance programs, and to focus future iterations of the cumulative river assessment. Meeting the objectives will enhance protection of human health and the environment by providing scientifically defensible knowledge and data and identifying

Figure H-10. Sequencing of Major Activities Under the Groundwater Technical Element.

	codes
Vadose groundwater interface study	
Detailed soil/groundwater depth discrete sampling	
Depth discrete samples in existing groundwater wells	QS$
Leveraged depth discrete sampling during additional drilling	HL$$
Additional interpretation of historical data and temporal analysis of data	QS$
C018 Plume Development Study	MI$$
Biogeochemical Reactive Transport	
DNAPL – Transuranic Site	HI$$
Transuranics at an Injection Well Site	HI$$
Carbon Tetrachloride Biogeochemistry	MI$$
Hydrogeological Characterization Science	
Review Past Hydrogeologic Characterization	QS$
Integrated Characterization Over a Hierarchy of Scales	
Hanford Site Scale (assumes leverage with plume geometry etc.)	HL$$$
Intermediate Scale	HI$$$
Core/Laboratory Scale	MI$
Synthesis-Visualization-and Integration	HL$
Regional Plume Geometry	
Install, interpret and image data from a transect of wells	QS$$
Multiscale 3D Model Development	
Define Multiscale Modeling Objectives	QS$
Develop and Implement Multiscale Modeling Approach	
Regional Model	HL$$
Site Specific Model	HI$$
Groundwater Discharge Study	
Install, interpret and image data from an array of multilevel samplers	QS$$



Priority Codes

Q = quick win; H = high; M = medium (no low priority activities were included)

Length of Study Codes

S = Short term (<2FY); I = intermediate (2-3 FY); L = longer term (>3 FY) or ongoing

Resource Codes (rough assessment that assumes leveraging of EM30 and EM 40 activities and coordination of science and technology activities)

$ = low cost and/or highly leveraged w/ planned work, $$ = intermediate; $$$ = high

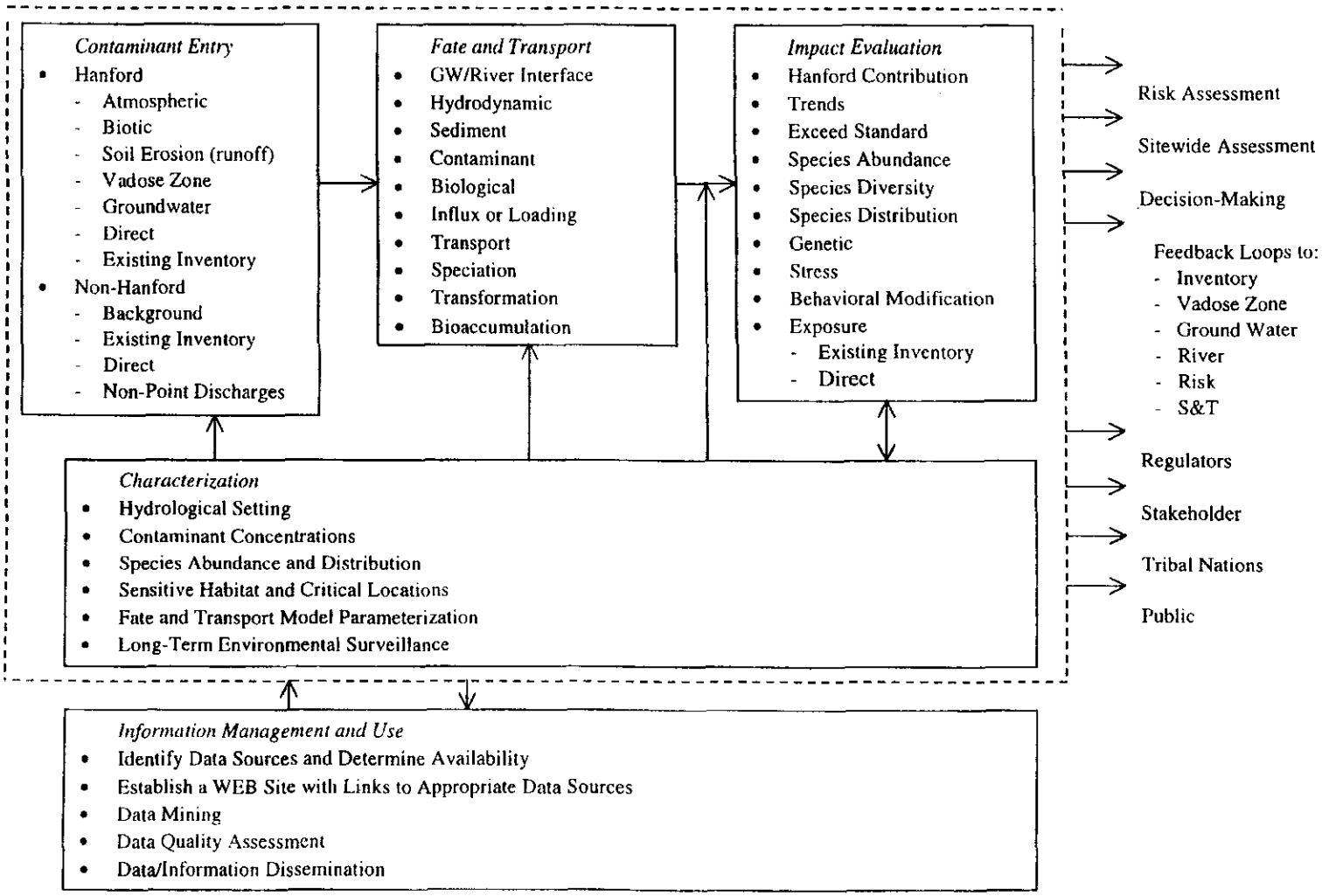
existing and new science and technology that will serve as input to DOE's decision-making process for Hanford cleanup. This applied science and technology (S&T) plan for the Columbia River builds upon a conceptual model of contaminant mobility throughout the physical system.

This S&T plan identifies six major research areas under the Columbia River technical element to maximize positive impact on Hanford Site cleanup and closure while protecting the region. The activities include the following:

- Development of a detailed conceptual model of the Columbia River and its environs to help focus efforts in information management and data collection that ensure proper emphasis on key issues.
- Management of the available and future information to ensure its availability to multiple projects onsite as well as to other interested agencies interested in the protection of the Columbia River.
- Characterization of the river environment to fill current data gaps that are important to system assessment and site decision-making.
- Enhanced understanding of the groundwater-to-river discharge to ensure meaningful assessment of affected biota and to confirm fate-and-transport assumptions within the river system.
- Modeling of fate and transport based on the conceptual model, available information, and new characterization data to collect the knowledge in a meaningful way for system assessment.
- Evaluation of the impacts of contaminants on the people, cultures, and ecology of the region.

A simplified set of components for the conceptual model of the river technical element is shown in Figure H-11. Five upper-level components have been identified: contaminant entry (which is a key interface with the groundwater technical element and includes the groundwater/river interface), fate and transport, characterization, impact evaluation, and information management and use. Within each component there are numerous critical areas that must be addressed to ensure that the understanding of the river system is adequate for credible decision-making. This decision-making is driven by several regulatory requirements. In some cases, these critical areas have been identified as S&T needs and are discussed in more detail in Section H.4.1. As such, detailed conceptual models for each major component must be linked internally into an overall detailed conceptual model of the river technical element. This detailed model then must be linked with the overall project conceptual model and objectives.

Figure H-11. Components of the Conceptual Model for the River Technical Element.



H.4.1 Scientific And Technological Issues

Key scientific and technological issues are topical areas or technical concerns that are relevant to an assessment of the Columbia River, Waste Management (WM), or Environmental Restoration (ER) decision-making and/or future stewardship of the Hanford Site. Key issues highlight information that must be available to perform the assessment in an acceptable manner and provide the public with technically defensible WM and ER Program decisions. A common objective links the scientific issues (or S&T needs) of the river technical element: an increasingly thorough understanding of the characteristics of the river and the contaminant problem. The most significant scientific issues center around the following kinds of questions:

- What is the nature and extent of contaminants entering the Columbia River from the groundwater pathway? What range of contaminant concentrations are observed? Where along the river are the most contaminants being introduced?
- What mixtures of contaminants are observed? How do contaminant concentrations change with time?
- What is the distribution of contaminants in the river and how do those distributions vary with time?
- What populations of biota are exposed to either single contaminants or mixtures of contaminants? What is the toxicity of the contaminant mixtures?
- How are the contaminants bioaccumulated? What mechanisms of biomagnification occur? Do bioaccumulation and biomagnification of low concentrations of contaminants constitute an increased and previously unperceived risk?
- What is the environmental impact of the contaminants? What is the extent of contaminant migration within the food web?
- Can we predict the future contamination of the river and its impacts?

These key issues underscore the complexity of the problem of assessing impacts. These specific technical issues provide the basis for defining the S&T needs within the river technical element.

H.4.2 Approach

The approach proposed to address S&T needs includes the development of a complete, integrated assessment plan and detailed conceptual models focusing on the six specific research areas with sufficient detail to define specific activities within each area. These research areas, their primary objectives, and anticipated products are summarized in Table H-3. A more detailed description of each research area is provided in Section H.4.3.

There is a significant need to enhance existing capabilities and expand the existing level of understanding of the river environment in order to use new S&T. In some cases, the need for

this "enabling" supportive information or capability may take precedence over S&T needs (either needed before or more important than S&T).

A combination of field observations, laboratory experimentation, numerical modeling, and long-term monitoring is recommended to address the information and S&T needs of the river technical element. Additional field observations should be obtained to fill known gaps in the characterization of the riverine environment and in defining parameters for numerical models. Numerical modeling and field/laboratory experimentation should be used to help meet information needs, particularly in circumstances where observational data cannot be obtained and in estimating future environmental conditions. Long-term monitoring should provide 1) a means for model verification/validation to the extent practical; 2) a continual assessment of the condition of the river environment over time; and 3) assurance that remedial decisions and subsequent waste cleanup activities have not negatively impacted the quality of the Columbia River environs.

We propose to evaluate existing site information relative to the purposes and objectives of the systems assessment capability (SAC) and the applied S&T plan for the river and use them as appropriate to minimize unnecessary duplication of effort. The further definition of the river technical element activities depends on the needs identified by establishing the SAC and risk assessment plans. Early activities involve interfaces with the vadose zone, groundwater, and the inventory technical elements. In addition, the roles and responsibilities of the various projects involved with Columbia River assessment activities should be defined and coordinated to 1) maximize efficiency in the conduct of the work; 2) use the experience and expertise available within the various organizations; and 3) minimize duplication of capabilities and effort.

Efficiency can be further increased by focusing collection of new field data by rigorous application of the U.S. Environmental Protection Agency's (EPA's) data quality objectives (DQO) process, i.e., identify decisions to be made with the new data and devise appropriate collection strategy. Subsequent activities are intended to focus on addressing key issues and should be prioritized across the river technical element and the overall assessment so that essential information is available in a timely manner.

H.4.3 Research Areas

The river technical element provides the information, capabilities, and understanding necessary to perform an effective assessment of the impacts of Hanford operations on the Columbia River and its associated ecosystems and river users. This technical element consists of a combination of data management, field measurement, laboratory experimentation, and modeling capabilities. The technical element must provide an accurate understanding of current conditions over time and the ability to assess potential future conditions, near- and long-term. In addition, the evaluation must allow for the differentiation between contaminant contributions from Hanford and other sources (natural and/or anthropogenic).

Table H-3. Objectives and Products of River Technical Element Research Areas.

Research Area	Objective	Product
1. Detailed Conceptual Model	Provide a thorough understanding of the Columbia River environment, including all the physical, chemical, and biological processes that are intricately linked throughout the system. In addition, provide the structure through which the river technical element activities will be conducted.	A detailed conceptual model of the river system that includes the critical processes and components necessary to conduct an acceptable assessment, identifies the links between activities across the project, provides a basis for prioritizing and coordinating related activities, and enables S&T development and application in a meaningful manner.
2. Information Management and Use System/Procedure	Define and implement the procedures and establish the system that will be necessary to gather, screen, manage, and disperse the data/information generated both inside and outside the Hanford domain that is considered in the river assessment.	A functional information management and use system/procedure enabling a river assessment and the initiation of S&T development and application.
3. Characterization of Columbia River Environment	Define the hydrologic setting, current contaminant levels, species abundance and diversity, sensitive habitats, and critical locations in the Columbia River environment, including the groundwater/river interface. In addition, define and verify input parameters for, and provide data for the verification/validation of fate-and-transport models to be used in the river assessment.	A thorough understanding of the river environment and comprehensive data sets to be used in assessing the impacts of Hanford operations on the river and in developing, parameterizing, testing and validating fate-and-transport models.
4. Groundwater/River Interface	Fill key data needs relative to physical, chemical, and biological processes influencing contaminants flowing from the groundwater into the Columbia River.	Model of the groundwater/river interactions linking temporal and spatial scales of the groundwater model outputs with those necessary in ecological assessments and providing the contaminant flux into the river.
5. Fate-and-Transport Modeling	Develop credible models (hydrodynamic, sediment, contaminant, and biological) to describe and predict contaminant migration and fate in the river environment.	Robust numerical models for application to specific contaminants for long term river impacts assessment.
6. Impact Evaluation	Define impacts in terms of water quality, species abundance, species diversity, genetic alterations, stress, behavioral modifications, toxicology, exposure, socioeconomic conditions, and/or cultural endpoints.	Knowledge of the state of the river in terms of impact endpoints useful in system assessment, risk assessment, remedial action and waste management decision-making processes, regulatory analysis, and stakeholder, Tribal, and public evaluations.

The river technical element includes the entry of contaminants into the river environment, the transport and fate of contaminants within and through the river ecosystem, and the evaluation of impacts to receptors of interest. The study area includes the Columbia River environment from upstream of Hanford (establishing a background, or reference, segment) to a point downstream of Hanford as determined appropriate by the assessment process. The Columbia River environment to be considered in the river technical element includes the riparian zone and associated biota along the river, the groundwater/river interface (bank storage, hyporheic zone, etc), the river water column, the river bottom and associated sediments, aquatic biota, and users of the river environment.

The scope of the six areas of research, related research questions and/or motivation, S&T activities, products and benefits, and timing and linkage with other activities are discussed, in the following sections.

H.4.3.1 Detailed Conceptual Model

H.4.3.1.1 Scope. A more thorough understanding of the Columbia River environment is essential to the success of the river technical element and to the implementation of an SAC that addresses impact on the region. This understanding will include all the physical, chemical, and biological processes that are intricately linked throughout the system and will be demonstrated through a detailed and complete conceptual model of the river system under this research area. This model should include the critical processes and components necessary to conduct an acceptable assessment, identify the links between activities across the project, provide a basis for prioritizing and coordinating related activities, and enable S&T development and application in a meaningful manner.

H.4.3.1.2 Research Questions and Motivation. The Columbia River at the Hanford Reach is a complex ecosystem that contains many receptors, both human and environmental. The groundwater/river interface, included in the river technical element, encompasses not only the challenges of the vadose zone and groundwater technical elements, but a combination of these together with the complex river dynamics. All of these must be considered at an adequate level in the conceptual model as guided by the SAC, which is currently being developed.

For example, the Columbia River basin receives inputs from various upstream surface water runoffs including agriculture, riparian zones, sewage, storm water, mine drainage, industrial drainage, as well as the Hanford Site itself. The basin receives groundwater input from Hanford and the length of the river basin due to a variety of seeps and springs with recharge zones that may be miles from the river itself. The potential contamination sources in these recharge areas are numerous. In addition, dust from surfaces for hundreds of miles around the river can be carried into the river by the wind. Birds, fish, reptiles, insects, etc., can bring material to the river and transport it away. Migratory birds and fish can become significantly contaminated via bioaccumulation and represent an exposure pathway at great distances from the river and Hanford. Burrowing aquatic insects (e.g., mayflies) may bioaccumulate contaminants and fly away from the river during their hatch, or become a significant prey source for some birds and animals around the river.

In addition to a large number of different biological, chemical, and physical processes that control contaminant mobilization, immobilization, biodegradation, biotransformation, and transport in the groundwater/sediment/river interface there are still more in the river system such as sloughs, the riparian zone, reservoirs, and neustonic areas of the river. The pathways and processes that lead to and affect significant toxicological receptors are many and varied and could have a profound effect on the relative risk that contaminants represent to man and the environment.

Water management along the river, including dams upstream and downstream from the Hanford Reach, and water management policy will also significantly impact the future risk associated with contaminants reaching the river. Indeed, global climate changes in temperature of only a degree or two could affect the rate of water use, spring melts, etc. In addition, the management of land around the river both upstream and down could also have a profound effect on the characteristics of the river through the Hanford Reach. These changes also may influence the life of the dams up and downstream, which would also impact the river for future water management in the basin. Future socioeconomic and cultural pressures could also have profound effects on water quality in the Columbia River and hence on the impact of Hanford contaminants, in previously unimagined ways. There are many issues associated with time and scale that must be addressed as well.

H.4.3.1.3 S&T Activities. A careful study of the Columbia River and documentation of the conceptual model should be undertaken by a multidisciplinary team of toxicologists, hydrologists, geologists, ecologists, fisheries and wildlife experts, meteorologists, water management experts, sociologists, economists, Tribal representatives, atmospheric scientists, and perhaps oceanographers depending on the downstream extent of the study area.

H.4.3.1.4 Research Products and Benefits. This S&T activity is intended to result in a detailed conceptual model of the river system that 1) includes the critical processes and components necessary to conduct an acceptable assessment; 2) identifies the links between activities across the project; 3) provides a basis for prioritizing and coordinating related activities; and 4) enables the development and application of S&T in a meaningful manner. The objective of the conceptual model is to provide a thorough understanding of the Columbia River environment, including all of the physical, chemical, and biological processes that are intricately linked throughout the system. In addition, we intend to provide the structure within which the river technical element activities will be conducted.

The detailed conceptual model will be used extensively in the planning and conduct of the River technical element fate and transport research area and river impacts evaluation research area, risk technical element, system assessment capability (SAC), monitoring technical element, and River Monitoring core technical project. While conceptual models of the river system exist at various degrees of detail within the current work structure at Hanford, this conceptualization expands upon these and takes the river system to the regional/watershed level. The conceptual model will also provide the basis from which the SAC documents the holistic starting point in performing the site-wide assessment.

H.4.3.2 Information Management and Use

H.4.3.2.1 Scope. The focus of this proposed research area is to develop the necessary functional information management and use system or process to enable the conduct of a river assessment and the initiation of S&T development and application. As discussed above, several organizations within the Hanford domain and outside of Hanford are currently studying the Columbia River environs. A tremendous amount of information has been generated that may be useful in the river assessment. In addition, a wealth of useful information has been generated in the past by similar organizations. Although in the context of this plan this component is strictly not S&T development, it is a crucial support activity to define and implement processes and a system that will be necessary to gather, screen, manage, and disperse the data/information considered in the river assessment.

H.4.3.2.2 Research Questions and Motivation. To develop the information management system, the following specific questions must be addressed:

- What and where are potentially useful data?
- Are the data useable for this assessment?
- How can all the available data be brought together in a useable manner?
- What data mining techniques are appropriate?
- What mechanism is needed to screen and ultimately reject/accept data for inclusion in the river assessment?
- Who are the potential users?
- Once the assessment is complete, what is the best way to disseminate the information so that it is available and useful to all potential users?

H.4.3.2.3 S&T Activities. Using the detailed conceptual model, researchers intend to identify potential sources (Hanford and non-Hanford) of information/data relative to the river assessment and determine the availability of this material. The feasibility of establishing a WEB site with links to existing databases would be evaluated. Potentially useful data/information would be screened through some process, perhaps a DQO approach, to determine its usefulness in the assessment. Depending on the source and availability of the data/information, data mining techniques may be developed and employed to gather the useful material on the assessment data management system. A WEB site may be the most efficient mechanism through which the information used and generated in the river assessment can be made available to the potential users. The data management system must be dynamic so that the database can be updated as additional data/information is generated.

H.4.3.2.4 Research Products and Benefits. A functional information management and use system/process necessary to enable the conduct of a river assessment and the initiation of S&T

development and application is intended to be provided by this research area. The objective of this effort is to define and implement the processes and establish the system that will be necessary to gather, screen, manage, and disseminate the data/information generated both inside and outside the Hanford domain that is to be considered in the river assessment.

The benefit of this effort lies in the capability to pull from and use existing databases, thereby avoiding unnecessary duplication of effort in generating and disseminating relevant information. The product must be compatible, if not one and the same, with the information management and control system used in the SAC. Secondary users may include the existing River Monitoring Core Technical Project. Clearly, capabilities existing within existing programs or projects should be considered in the development and operation of this product.

H.4.3.3 Characterization

H.4.3.3.1 Scope. Additional characterization of the river environment is described within this research area. Characterization is required to completely evaluate future potential impacts of Hanford contaminants on the Columbia River. Appropriate characterization activities should include the Columbia River environment from upstream of Hanford (establishing a background or reference segment) to a point downstream of Hanford as determined appropriate by the assessment process. The Columbia River environment to be considered in the river module includes the riparian zone and associated biota along the river, the near-river groundwater (bank storage), the hyporheic zone, the river water column, the river bottom and associated sediments, aquatic biota, and users of the river environment. In addition to providing a thorough understanding of the river conditions, the results of the characterization effort should provide the information to define parameters for and verify/validate various fate-and-transport models. Characterization should also provide extensive information necessary to identify and provide direction for development and application of the necessary S&T.

H.4.3.3.2 Research Questions and Motivation. Research will be undertaken to determine the following:

- Composition and extent of contamination in all components of the river environment.
- Rates for the movement of contamination through the ecosystem.
- Spatial and temporal trends in contaminant characteristics.
- Pathways for contaminant movement through and export from the river environment.
- Attenuation or fixation of contaminants within the various components of the river system.
- Long-term changes to the natural system that may influence the levels and distribution of contaminants in the river, such as river discharge levels and erosion/deposition patterns.
- Species abundance and spatial distributions.

- Sensitive habitat and critical locations.

H.4.3.3.3 S&T Activities. Contaminant concentrations need to be determined in a number of river media at a sufficient scale to fill gaps and reduce uncertainties in our current understanding. Because most of the Hanford contaminants are present in background samples, a detailed characterization of the upriver input and non-Hanford inputs within the study area must be considered. In addition to current inputs, an inventory of past Hanford contaminants currently in the river needs to be conducted. This activity within the research area should be coordinated with the inventory technical element and the SAC.

The hydrological setting should be described at a watershed level to the extent necessary to fully understand the relationships between Hanford and non-Hanford inputs into the system and the resultant potential impacts. River bathymetry should be characterized and maps developed in support of fate-and-transport models, as needed based on the requirements established in the first quarter of FY99 under the SAC.

Species abundance and distributions should be defined and mapped for use in exposure pathway evaluations. Much is known about the species within the Hanford Reach, including occurrences, food relationships, and spatial distributions during certain life stages. The greatest focus has been on game species such as salmon, geese, and mule deer. Bald eagles are also well characterized. The potential distributions of these and other key species remain to be understood both within the Reach and in the McNary Pool. The present and future distributions may be affected by real or predicted contaminant levels. Consequently, we need to understand the species-habitat relationships for all key species between Priest Rapids and McNary Dams to match plumes and exposures with actual effects likely to be found in the field. The first areas of emphasis should be identified in the first quarter of FY99 with the development of a risk assessment plan.

The identification and mapping of sensitive habitats and critical locations within and along the river, identification of potential receptors, and the definition of potential exposure pathways to these receptors are essential elements of the characterization effort. Critical locations include areas of contaminant accumulation or potential exposure to receptors such as drinking water intakes and recreational areas.

Input parameters for the fate-and-transport models used to evaluate the river system need to be determined and verified on a site-specific basis. These parameters include hydrodynamic, sediment, contaminant, and biological fate-and-transport models. In addition, characterization data will be used in verifying/validating the models. This research area should identify the characterization needed to obtain the data for these parameters.

H.4.3.3.4 Research Products and Benefits. The products of this research area include a thorough understanding of the river environment and comprehensive data sets to be used in assessing the impacts of Hanford operations on the river and in developing, parameterizing, testing, and validating fate and transport models. The objective of this research area is to define the hydrologic setting, current contaminant levels, species abundance and diversity, sensitive habitats, and critical locations in the Columbia River environment, including the

groundwater/river interface. In addition, this effort is intended to define and verify input parameters for, and provide data for the verification/validation of fate and transport models to be used in the river assessment.

The information generated through this research area is intended to be used extensively in support of the river technical element's conceptual model development research area, groundwater/river interface research area, fate-and-transport modeling research area, river impacts evaluation research area, and the Columbia River surveillance core technical project. In addition, the SAC and risk technical elements rely heavily on the information generated through the characterization activity.

H.4.3.4 Groundwater/River Interface

This area of research is associated with the entry of contaminated groundwater from the Hanford Site into the Columbia River and covers the characteristics, dynamics, and temporal changes in contamination. Characteristics include composition, concentration, mobility, toxicity, and attenuation processes. Locations and plume boundaries are also characteristics. Dynamics involve the direction, rates, and preferential pathways associated with discharge from the aquifer into the free stream of the river. Processes occurring in the zone of interaction between groundwater and river water that cause changes in contaminant concentrations need to be characterized and quantified. Temporal changes involve natural attenuation processes, such as dispersal, decay, chemical transformation, and biological processes, and also changes induced by remediation activities and changes in the natural system (e.g., near-river excavations; increased river levels).

H.4.3.4.1 Research Questions and Motivation. Within this research area, research should be undertaken to determine the

- Composition and extent of contamination along the Hanford (right bank) shoreline.
- Rates for the movement of contamination from the aquifer into the river.
- Spatial and temporal trends in contaminant characteristics.
- Pathways for groundwater discharge into the river.
- Attenuation or fixation of contaminants within the interface zone.
- Potential for changes in contamination near the river because of natural or human activities.
- Long-term changes to the natural system that influence the discharge of groundwater from the aquifer into the river, such as river discharge levels and erosion/deposition patterns.
- Rate at which contaminant plumes from inland areas on the Hanford Site approach the river.

- Future land use associated with the near-river areas.

H.4.3.4.2 S&T Activities. S&T activities should focus on S&T needs for addressing the characteristics, dynamics, and temporal changes in the groundwater/river contaminants, as described in Table H-4. There will likely be linkages to the inventory technical element as groundwater/river interface characteristics are determined, and there will likely be linkages of the groundwater technical element to characteristics, dynamics, and temporal changes. Hence, S&T scope and results should be coordinated with the other technical elements.

H.4.3.4.3 Research Products and Benefits. This research area is intended to provide the model of the groundwater/river interactions, linking spatial scales of the groundwater model outputs with those necessary in ecological assessments and providing the contaminant flux into the river. The objective is to fill key data needs relative to physical, chemical, and biological processes influencing contaminants flowing from the groundwater into the Columbia River. In addition, this effort intends to develop the capability to estimate the flux of Hanford contaminants into the Columbia River.

This product serves as the source term input for the subsequent river fate and transport modeling activity. This product will be used extensively in the fate-and-transport research area, SAC, and risk technical element. In addition, information generated will be used in planning river monitoring activities within the Columbia River monitoring core technical project.

Table H-4. Groundwater/River Interface Research Summary.

Research Area	Science and Technology Need
Characteristics	Improved capability for sampling water and biota from within the zone of groundwater/river interaction. Discrete sample acquisition methods, aerial survey methods, and in situ measurements are all desirable improvements to existing capabilities. Improved methods for storing, manipulating, and presenting data, including graphical products, such as distribution maps and trend charts. More data on the characteristics of contamination in the vadose zone near the river, especially at the liquid waste disposal trenches associated with each reactor.
Dynamics	Improved estimates for the movement of contaminants via groundwater flow through the aquifer/river channel interface. Better information on the geometry of the interface and the distribution of contaminants will provide for more accurate calculations of the flux of contaminants into the river. Improved resolution of the movement characteristics of contamination in the zone of interaction. The fluctuating river stage sets up complex motions that include complete reversal of direction, and a downstream component of motion. Numerical simulation of movement in the zone will provide insight for a variety of decision-making objectives. More comprehensive information on preferential pathways for contaminated groundwater to leave the site. Preferential pathways include natural features as well as manmade features, such as buried pipelines and underground structures. More data on the geochemical environment in the zone of interaction—to better understand the changes in contaminant mobility that may occur.
Temporal Changes/Trends	Improved understanding of the fate of contaminants in the zone of interaction, including responses to a changing chemical environment (e.g., speciation, precipitation). Improved understanding of biological activity in the hyporheos zone. Identification of species (especially bacteria) that are indicative of various contaminants at levels below typical water quality analyses detection levels. Enhanced groundwater monitoring at remediation sites involving large-scale excavations. Increased use of low-cost drive-point sampling technology and in situ sensors with data-logging equipment are examples of enhancements.

H.4.3.5 Contaminant Fate and Transport

The S&T needs anticipated in the assessment of the transport and fate of contaminants in the Columbia River system can be identified by considering the physical-chemical-biological processes listed in Table H-5.

Table H-5. Physical-Chemical-Biological Processes.

Process	Description/Details
Influx or Loading	• Point and nonpoint surface water/groundwater/ vadose zone discharges to the river, atmospheric deposition
Transport	• Hydrodynamic advection and dispersion • Sediment transport, deposition, and resuspension • Volatilization
Speciation	• Sorption to sediments • Ionic state • Reduction-oxidation
Transformation	• Hydrolysis • Photolysis • Biodegradation
Ecological	• Bioavailability • Bioconcentration • Biomagnification • Biota transport • Synergistic effects

H.4.3.5.1 Scope. Hydrodynamic advection and dispersion can be simulated using 1D, 2D, and 3D models. Key information needs will be refined river bathymetry and calibration/verification data. An existing 1D model is currently available for the Hanford Reach. This model simulates cross-sectional averaged quantities and thus will not be useful for investigating contaminant mixing in the river. However. it is useful as a means to provide time-varying water surface elevation boundary conditions at the river that can be used in the vadose zone/groundwater models. A 2D model exists for the area of the Columbia River from Kennewick to Portland. This model could be extended upstream to Priest Rapids Dam and would enable simulations of lateral distributions of velocities, sediments, and contaminants. Note that a 2D model averages quantities over the depth of the water column. In limited areas of great concern a 3D model can be applied. Items to be addressed include the following:

- Bathymetry data
- Calibration/verification data
- 2D/3D model application.

Transport and fate of contaminants that sorb to sediments will require the application of sediment transport models that will be coupled to the hydrodynamic and contaminant transport models. Key needs in this area are the existing sediment size distribution in the channel bottom and influx of sediments from tributaries to the Columbia River. Also needed is the porosity of the channel bed and amount of sediment available for transport. Calibration and verification data include measurements of suspended sediment load, bed load, and deposition rates in McNary Reservoir. Grain-size specific transport parameters such as critical shear stress for erosion and deposition will also need to be measured. Items to be addressed include the following:

- Sediment size distribution
- Transport parameters
- Calibration/verification data.

The transport and fate of dissolved, sediment-sorbed, and bioaccumulated contaminants will need information to define influx rates, existing channel bed inventory, sorption, transformation, and bioaccumulation. Key information that is needed will be the grain-size specific sorption parameters (Kd), speciation, and rates of bioaccumulation. These will be needed to apply and parameterize a 2D and/or a 3D numerical model. Items to be addressed include the following:

- Influx rates
- Existing channel bed inventory
- Chemical reactions
- Bioaccumulation
- Calibration/verification data.

Biota constitute both an endpoint for determining cleanup standards and impacts as well as a transport medium for groundwater-derived contaminants in the Columbia River system. Many of the contaminants in the Hanford inventory are also biological nutrients or their chemical analogs. Transport parameters for these components within the biota are highly uncertain (up to 4 orders of magnitude) due to poor understanding of underlying nonlinear processes. Items to be addressed in the biological transport model include the following:

- Bioavailability
- Bioconcentration
- Biomagnification
- Biotic transport.

H.4.3.5.2 Research Questions and Motivation. The fate-and-transport component of the river technical element is intended to describe/predict 1) what happens to specific contaminants once they enter the river environment and 2) where the contaminants finally end up in the environment.

H.4.3.5.3 S&T Activities. Tools and information will be needed for each of the process categories identified above in order to support the SAC. The tools should include the application of mass and momentum conservation principles to the system and can range from analytical solutions to fully coupled, three-dimensional hydrodynamic, sediment transport, biotic transport, and contaminant transport numerical models. Information required to apply these tools will typically be (but not limited to) existing contaminant concentrations and influx rates, chemical characteristics, and sediment characteristics.

In most cases the knowledge exists to develop these tools without the need for new S&T. However, biota constitute both an endpoint for determining cleanup standards and impacts as well as a transport medium for groundwater-derived contaminants in the Columbia River system. Many of the contaminants in the Hanford inventory are also biological nutrients or their chemical analogs. Transport parameters for these components within the biota are highly uncertain (up to four orders of magnitude) due to poor understanding of underlying nonlinear processes. This issue needs to be addressed to provide the basis for cleanup decisions and to complete an analysis of Columbia River impacts.

H.4.3.5.4 Research Products and Benefits. The fate-and-transport research area intends to develop credible numerical transport models (hydrodynamic, sediment, contaminant, and biological) to describe and predict contaminant migration and fate in the river environment.

The fate-and-transport modeling capabilities defined in this research area are critical to performing a predictive assessment of potential risks of Hanford operations and remedial action alternatives to the river. The primary users of the fate-and-transport models are expected to be the river technical element, risk technical element, SAC, and the Columbia River monitoring core technical project.

H.4.3.6 Impact Evaluation

H.4.3.6.1 Scope. The impact evaluation research area of the river technical element relates to the conditions imposed on the Columbia River system as a result of past, present, and future operations at Hanford. The impacts, or in the case of predictive modeling, the potential impacts, can be defined in many ways. Impacts may be defined in terms of water quality, species abundance, species diversity, genetic alterations, stress, behavioral modifications, toxicology, exposure, or risk. In addition, impacts may be realized on socioeconomic and/or cultural scales.

H.4.3.6.2 Research Questions and Motivation. The overriding questions relative to the river impacts are what are they, how are they incurred, and are they irreversible? In many cases, the answers to these questions are straightforward and the information needed to determine whether or not there is an impact is available. In other cases the variables and unknowns surrounding our understanding of the system make accurate determinations of impacts difficult at best. In the cases where our information base is limited or nonexistent there is potential for S&T development.

One of these potential areas for development is the area of toxicological and radiological impacts. These are currently not well understood for the river system as a whole. The effects of some contaminants on some receptors have been established, but a system-wide understanding of the toxic and radiological effects of all single contaminants and combinations of multiple contaminants is lacking. Related to the toxicological and radiological impacts are the standards with which water quality measurements or exposures will be compared in order to identify potential adverse effects on receptors. In many instances, standards do not exist for the specific contaminant/media combinations of interest at Hanford.

Data on the magnitude of genetic changes due to contaminant exposures are lacking for the Columbia River system and many other ecosystems of the world, but there is interest in pursuing this topic as an indicator of environmental exposure.

S&T Activities. Metrics upon which impacts can be measured must be defined. In some cases, these are available while in other cases additional S&T are needed. The toxicity of various individual contaminants and mixtures of contaminants must be determined. Drinking water standards and sediment standards that exist will need to be modified to be applicable at Hanford, and exposure standards for some contaminants need to be established. The understanding of genetic changes and the use of biomarkers and bioindicators in evaluating river impacts must be developed to a level that renders this a viable means by which to monitor the quality of the river environment. A means of determining socioeconomic and cultural impacts and a way of relating them to other impact metrics are needed.

Research Products and Benefits. The fate-and-transport research area intends to develop credible numerical transport models (hydrodynamic, sediment, contaminant, and biological) to describe and predict contaminant migration and fate in the river environment.

The fate-and-transport modeling capabilities defined in this research area are critical to performing a predictive assessment of potential risks of Hanford operations and remedial action alternatives to the river. The primary users of the fate-and-transport models are expected to be the river technical element, risk technical element, SAC, and the Columbia River monitoring core technical project.

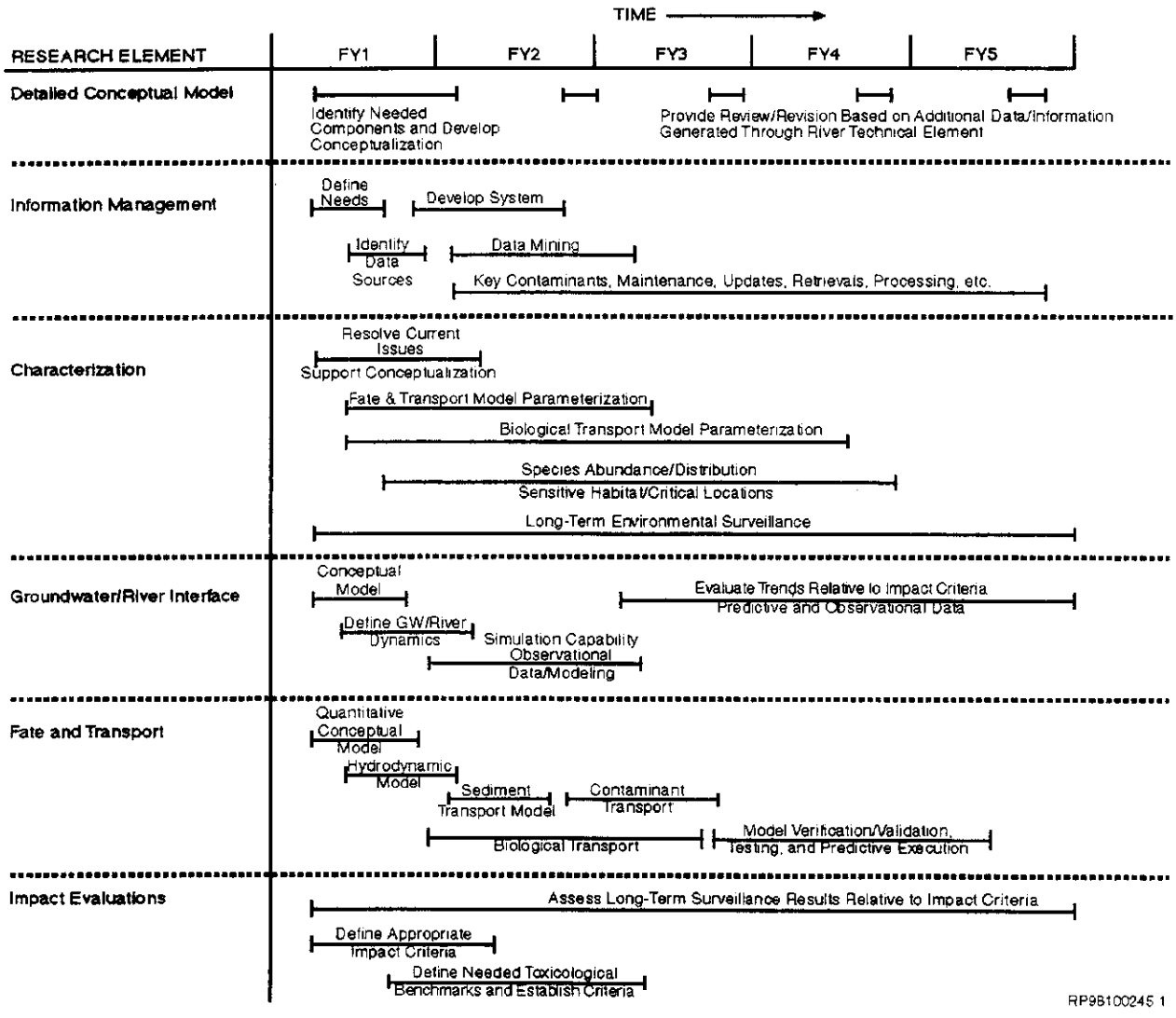
H.4.4 Timing and Linkage of Activities

The river technical element must interface successfully with several other GW/VZ Integration Project technical elements. Direct links exist between the groundwater, vadose zone, inventory, and the river technical element (inputs). Likewise, a direct link exists between the river and the risk assessment technical elements (output). In addition, the river technical element provides the basis for and directs the river component of the monitoring technical element. Finally, the river technical element is an integral part of and must be consistent with the SAC. Linkages, external and internal to the river technical element, are illustrated in Figure H-11.

It is anticipated that activities will be conducted interactively, both internal to the river technical element and externally across the other project technical elements identified above. The need for careful coordination throughout this process cannot be overemphasized. In addition, the assessment should be performed in an iterative fashion, with feedback to and from the other technical elements determining to a certain extent those activities warranting attention.

Figure H-12 provides an upper-level sequencing of major activities included in the river technical element. This is a first-cut, rough approximation provided to stimulate thought and input from river technical element task team members. This draft schedule must not be considered representative of actual schedules, which will be included in the Project-Level S&T Roadmap document, consistent with the S&T plan development.

Figure H-12. Sequencing of Major Activities under the River Technical Element .



A well-thought-out and researched conceptual model of the Columbia River has to be one of the top priorities for the river module. The other research needs for the river hinge on a good conceptual model of the river. As such, the development of a detailed conceptual model clearly is an enabling support activity that must be completed early in the system assessment process in order to provide meaningful input and direction to other river technical element activities.

The development of the information management and use capability clearly must be initiated early in the assessment process. This activity is interrelated with all other components of the river technical element. Establishment of a functional system is mandatory in defining and providing direction to subsequent characterization activities and S&T development and application. Once established, level-of-effort activities will be performed to maintain, update, and use the system.

Characterization activities will be performed throughout the period of the river assessment and long-term monitoring of the river will continue as long as Hanford exists. A thorough understanding of the river environment based on field measurements is necessary to identify, provide direction to, and prioritize S&T needs. Several questions and issues have been raised and data gaps identified during recent river assessments. For example, there are immediate needs in the areas of model parameterization that must be addressed to enable the development and application of the fate and transport and receptor exposure models. As such, there is a significant need to initiate the characterization effort early in the assessment process. As the river assessment matures and additional data needs are identified further characterization activities will be defined and performed.

The influx of contaminants into the river environment is one of the initial and key components of any fate-and-transport type assessment. As such the groundwater/river interface component of the river technical element must be completed early in the assessment process, prior to the execution of subsequent hydrodynamic, sediment, biological, and contaminant transport models.

The development of fate-and-transport models must be initiated early in the conduct of the river technical element research. Parameterization of the models must be coordinated with the corresponding characterization activities. Once developed, testing and verification/validation activities will be performed.

H.5 INVENTORY

The inventory technical element of the applied science and technology (S&T) plan is designed to address the need for estimates of radionuclide and chemical contaminants that have been or are expected to be released to Hanford's soil column. Such an inventory would represent the total amount of selected radionuclide and chemical constituents at the Hanford Site and their distribution among facilities, waste disposal sites, vadose zone, groundwater, and Columbia River. Activities proposed for the inventory technical element will enhance protection of human health and environment by providing estimates of the location, amounts, concentrations, chemical form, and mobilization/release mechanisms of key inventory components, which provides the necessary input to sitewide subsurface system assessments. An implicit goal of this

research is to provide scientifically defensible knowledge and data and identify existing and new science and technology that will serve as input to DOE's decision-making process for Hanford cleanup.

The objectives of the inventory technical element are largely twofold. First, a consistent approach and set of assumptions for providing information on waste site inventories across the Hanford Site will be established to ensure that a sitewide inventory data set is available for system-wide and project-specific impact assessments. Second, key chemical and radiological contaminants and soil sites will be identified, and estimates of the amount of these key contaminants in different waste forms and storage/disposal areas (e.g., tanks, solid waste burial grounds, other) will be validated. The proposed plan will meet these objectives by addressing the following six research areas for further study and development:

- Soil column release volumes, timing, and uncertainties.
- Specialized models for selected species such as tritium, iodine-129, and technetium-99 in tank wastes.
- Prioritization and compositing of soil sources.
- Development of criteria for prioritizing critical chemical and radionuclide contaminants into a 'short list' of key species.
- Inventory process conceptual model.
- Inventory release modes to soil.

The plan builds on the information about the amount and nature of the Hanford inventory, including soil contamination, that already exists in different forms. Systems that track inventories include the Tank Waste Information Network System (TWINS, http://www.proxy.rl.gov1050), the Waste Information Data System (WIDS), and the Solid Waste Information Tracking System (SWITS) (Clark 1995). However, there are many gaps in inventory data, including a lack of information on the amount of the inventory previously released to soil sites. The nature and extent of contamination of many waste sites is poorly known. Even when sites have information on many constituents, they often lack crucial data on particular species, e.g., iodine-129, technetium-99, and chemical species. Furthermore, there are aspects of certain radionuclide distributions that are not yet thoroughly understood. For example, the partitioning of iodine-129 is quite complicated because of its volatility during fuel reprocessing. Knowing exactly how much iodine-129 is captured in either scrubber liquids or scrubber solids, how much escapes to air, and how much remains in the process waste and is placed into tanks is important for sitewide system assessments.

In addition to inventory estimates, mechanisms that result in release of inventory from facilities and stored wastes into the vadose zone, groundwater, or the Columbia River must be identified. Because the long-term configuration of the waste inventory depends on future remediation and

land-use decisions, a baseline estimate of end-state inventory must be defined for system assessment.

H.5.1 Scientific and Technological Issues

A good understanding of inventory is key to a system assessment, because the potential groundwater and river contamination is proportional to the amount of radionuclides and chemicals that are disposed on Hanford Site and capable of migrating off the Site. Technical information needed to determine inventory include 1) locations, amounts, and concentrations; 2) characteristics of the radionuclide or chemical compound; 3) mobilization and release mechanisms and rates; and 4) the change in inventory because of natural processes (e.g., decay), remediation activities, and Hanford Site operations.

A consistent approach and set of assumptions used to quantify site inventory is central to the scope of the inventory technical element. To date, inventory estimates that have been developed under specific projects have tended to be conservatively high. No comprehensive analysis has been performed that compares and reconciles the estimates for each facility with the estimate of the total Hanford Site inventory. Comprehensive integrated analysis will help ensure that estimates of key contaminants are sufficiently accurate and credible to support a sitewide assessment of environmental impacts and risks. The following are the major scientific issues that require resolution:

- **Information management.** There are a large number of contaminants and contaminated soil sites that need to be considered in a sitewide system assessment. The evaluation of existing data to determine their adequacy along with management of new and existing data pose a challenge. Thus a very important issue will be how to effectively manage and communicate inventory information.

- **Short-list of key contaminants.** For purposes of a system assessment, there is likely to be only a selected set of contaminants that are of greatest concern. The selection of these contaminants is important to many parties, including regulators, stakeholders, scientists, and the U.S. Department of Energy (DOE). There must be an effective way to prioritize contaminants to meet multiple expectations while generating as short a list as practical. A prioritization process and criteria need to be developed to be acceptable to interested parties.

- **Prioritization of source terms (e.g., reactor vs. plateau).** Because there is a large number of source terms and all source terms may not be equally important with respect to system impact, a process for focusing efforts on key soil site sources is needed. Like the key contaminants, the soil sources will be prioritized. Ideally, the same criteria and process used to prioritize the key contaminant will be applied to the soil source terms.

- **Scale issue and how it affects each task.** There are very large differences between the scale of observations of cesium-137 contamination around Tank SX-108 and the tritium plume over the entire Site. Furthermore, the time scale in integrated dose scenarios and chemical

exposure can vary from several years to tens of thousands of years. These different scales result in very different contaminant and soil site priorities and dramatically impact the complexity of the modeling.

- **Waste/soil interface.** The release of contaminants into the environment begins at the waste/soil interface. The rate of release depends critically on the properties of the waste material and its interaction with soil and soil moisture.

- **Inventory estimates and their uncertainties.** Past inventory estimates for specific projects have tended to be conservative. This approach is not adequate for a sitewide system assessment because the cumulative uncertainty is too great and skewed unrealistically. Therefore, an approach is needed that focuses on quality estimates for key contaminants and sites. There is an iterative and continuing process with the prioritization process and addressing inventory uncertainty because prioritization criteria depend on contaminant amounts, and yet the quality of the contaminant estimate depends on how high of a priority the contaminant has received.

H.5.2 Approach

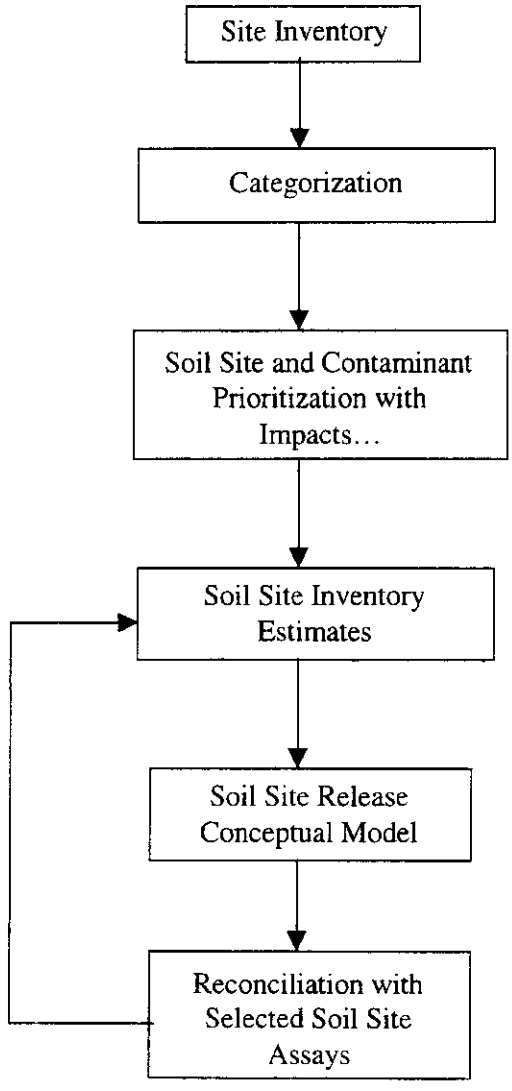
The technical approach involves first the categorization and prioritization of soil sites and contaminants and will in effect parallel the programmatic work now underway under the individual projects within the Integration Project. This effort emphasizes the similarity among soil sites for cooling water discharges, for example, and therefore the placement of these sources in one group. The approach prioritizes key contaminants with a focus on their sitewide distributions among soil sites. The way in which this approach is implemented is described in detail in the following section using iodine-129 partitioning among all of the site soil source terms, as an example.

The development of inventories will proceed for prioritized sites and contaminants and will largely involve adaptation of existing historical process models such as the Hanford-Defined Wastes (HDW) model (Agnew et al. 1997). However, we anticipate that certain radionuclides, such as tritium, technetium-99, and iodine-129, and chemicals will require some new model development. Figure H-13 shows the overall flow of this approach for the inventory technical element.

H.5.3 Research Areas

Six research areas have been identified for investigation under the inventory technical element. Each of these research areas supports the S&T needs noted previously. Each research area is described in the following sections, which address the associated scope, research questions and/or motivation, S&T activities, and expected research products and benefits.

Figure H-13. Overall Flow of Tasks within the Inventory Technical Element.



H.5.3.1 Soil Column Release Volumes, Timing, Contaminants, and Uncertainties

H.5.3.1.1 Scope. Within this research area, currently available models should be used to derive radionuclide and chemical inventories of contaminated soil sites that have been grouped based on the process streams that are discharged to them. Where model development is needed to establish a baseline current inventory, new models should be used as they are developed for individual contaminants (see Section H.5.3.2).

H.5.3.1.2 Research Questions or Motivation. There are over 2500 sites where releases of wastes of one sort or another occurred at Hanford and most of these releases resulted in

contaminated soil sites. Unfortunately, there is often very little information about the nature of these releases and what information is available is often incomplete, causing data gaps or uncertainty in inventory estimates. One of the primary objectives of the inventory technical element should be to produce reasonable inventory estimates for particular contaminants for these sites.

H.5.3.1.3 S&T Activities. The approach of grouping sites should consider similar characteristics such as source of waste received or hydrogeologic setting. A recent grouping of 1,200 sites in the 200 Area has produced 23 soil waste groups (DOE 1997). This grouping strategy was based on the needs of that particular effort and it is possible to further reduce the number of soil waste groups for purposes of inventory estimation. For example, the inventory technical element would undoubtedly combine soil sites with a common operation, such as process cooling water cribs, into a single group. Within this research area, extension of this concept to a site categorization of sites is proposed.

The following list provides a preliminary grouping that is consistent with the existing process historical information. This grouping has combined cooling water cribs but separated major plant operations such as the PUREX and Redox processes into their own soil waste groups. This grouping should facilitate the use of existing model information, such as the HDW model (Agnew et al. 1997), for the soil inventory estimates.

1. FeCN, scavenged wastes supernatants (technetium-99, cobalt-60, cesium-137, strontium-90)

2. Z Plant
   Organic (plutonium/americium)
   Nonorganic (plutonium/americium)

3. Plant Cooling Water
   U/Z Plants
   PUREX/B Plant
   200 N Facility
   Redox Facility
   T Plant

4. Lab
5. PUREX/B/Semi
   Plant condensates
   Organic compounds
   Uranium and associated technetium-99
   Steam condensates
   Other sewer sources
   Ammonia scrubber with associated iodine-129
   Chemical sewers

6. Redox/U/T Plants
   Plant condensates
   Organic compounds
   Uranium with associated technetium-99
   Steam condensates
   Other sewers
   Ammonia scrubber with associated iodine-129
   Chemical sewer including chromium

7. 1C/2C/224 supernatants(technetium-99, cobalt-60, cesium-137, strontium-90)

8. Tank condensates

9. Radioactive landfill (pre-1970 transuranic [TRU] radionuclides)

10. Non-radioactive landfill

11. Sanitary

12. MUST (miscellaneous underground storage tanks)

13. Unplanned releases (e.g., leaks, spills, other)

14. Fuel storage basins (tritium, cesium-137, strontium-99)

15. Reactor cooling water (chromium, cobalt-60)

16. Tank residuals (after tank closure)
17. Interim low-activity waste (ILAW) – technetium-99, iodine-129

18. Plant residuals (after closure).

Explicitly included are subgroups for further delineation of contaminant sources where appropriate. Although there are some similarities between this grouping and the 23 soil site groups in the 200 Area Waste Site Grouping report (DOE 1997), that set is reduced here to 14 with an additional 4 soil sites for completeness to represent all of the soil sites at the Hanford Site. The primary difference in the previous site categories and the lumping of sites described here is the approach of grouping by major operation. For example, the previous site groupings considered organic-rich processes across both Redox and PUREX plants together. However, the fact that the Redox process had highly volatile organic solvent while PUREX process had low volatile solvents means that organic compounds from the Redox process will not be present while the organic compounds from the PUREX process will be present in cribs. We believe that the historical estimates of soil sites should necessarily use process information that is specific to one set of plants and facilities. For background information on these soil sites see the descriptions in that report (DOE 1997).

Although the list of groups identified here is preliminary, it represents a useful starting point for discussion. For example, Group 1 (scavenged wastes) represents the waste supernatants that were sent to cribs and trenches in the mid- to late-1950s as part of uranium recovery operations. This waste group constitutes perhaps the largest single source of technetium-99 (1,000 Ci) and cobalt-60 in the ground at Hanford. In fact, much of the technetium-99 already in the groundwater is attributed to these sites. However, the scavenging waste that was disposed to the BC crib area southeast of 200-East Area has not yet contributed any contaminants to the groundwater. The question is whether the technetium-99 in this crib will contribute to groundwater contamination at some time in the future.

Unplanned releases (UPRs) are made up largely of the leaks and spills that have occurred at the Hanford Site. Although there are volume estimates for many of these events, compositions have not yet been associated with many of them. Furthermore, the timing and volumes of some of the reported leaks often conflict with the volume history of associated tanks. In particular, some leaks are reported for tanks at a time when those tanks' liquids had already been removed. It should be part of this effort to resolve such discrepancies and correspondingly use uncertainties to represent any information that may be lacking.

A key part of this task should be reconciliation of historical process-based estimates with soil sample assay data from selected sites. This reconciliation would be useful in many different ways, not the least of which is to provide some validation for historical information. Furthermore, soil sites may have been misidentified and therefore are now associated with incorrect groups. Finally, sites with completely unknown waste origin may be placed into an appropriate group by means of limited soil assays.

H.5.3.1.4 Research Products and Benefits. The inventory estimates for categories of waste sites is expected to provide physical properties, timing, volumes, and uncertainties for these estimates. This information will be important for many varied programmatic needs, such as Data Quality Objectives (DQOs) for soil site assays and future sequencing of actions for the Resource Conservation and Recovery Act (RCRA), Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), environmental impact statements (EISs), and performance assessments (PAs).

H.5.3.2 Models for Selected Species to Estimate Inventory

The inventory estimates described in Section H.5.3.1 often require models of individual species to describe distribution between process streams. For example, better estimates of total technetium-99 in a soil site may be dependent on assumptions about speciation as pertechnetate or non-pertechnetate. Similarly, assumptions about the behavior of volatile organic compounds (VOCs) in processes impact distribution in process streams that lead to assumptions about volumes actually released to the soil site.

H.5.3.2.1 Scope. Although existing models are adequate for many of the contaminants, past modeling experience at Hanford has already pointed out the need for more specialized modeling of technetium-99, iodine-129, and tritium. The activities proposed within this research area will

provide this modeling. Moreover, other species may be identified in future system assessments that require specialized modeling; these too will be developed through this research area.

H.5.3.2.2 Research Questions and Motivation. Many of the radionuclide and chemical inventories should be derived by adapting existing models for waste process estimates. The HDW model (Agnew 1997) provides a historical basis for tank waste estimates that could be used for soil estimates as well. Other information sources will also be important to this effort (Watrous 1997; Kupfer et al. 1998). For the three radionuclides already identified, however, we expect that specialized models will be needed to address their complexities or uniqueness, and associated uncertainties.

H.5.3.2.3 S&T Activities. S&T activities should address the need to develop specialized models for technetium-99, iodine-129, and tritium, each of which is complicated by its behavior in the process from which they were generated. For example, technetium-99 is complicated because of its tendency to follow the uranium in the solvent extraction process. Consequently, in-tank inventories of technetium-99 should be reduced by some as yet undetermined fraction. Likewise, uranium-laden wastes disposed directly to the soil column require that technetium-99 should be accounted for in those soil sites as well.

Iodine-129 is complicated in that the scrubber systems that were meant to remove iodine from the off-gas from fuel dissolution were by some accounts, extremely effective. However, the percent volatility of iodine during fuel dissolution has always been somewhat uncertain. This issue has been further complicated by the occasional addition of iodine "getters" such as mercury to the fuel element dissolution process. Mercury additions were used especially when very green fuel was processed in anticipation of the increased amount of the short-lived iodine-131 isotope.

Thus, while the total amount of iodine produced is fairly certain, its location is subject to some dispute. As a result, a past system assessment for the 200 Area was unable to account for the total amount of iodine-129 in the soils. Certainly a large fraction of iodine-129 will have been disposed of along with scrubber waste from fuel element dissolution. Some iodine-129 remains with the silver saddles used in the scrubbers and some iodine-129 will reside in waste tanks. Each of these different sources represents different and not previously addressed challenges for any iodine-129 soil inventory estimate.

Finally, tritium is unique because it is tied up as water and is the most frequently measured and observed radionuclide in groundwater monitoring. Nearly all of the tritium produced at Hanford comes from the fuel elements and was released to the process stream as tritiated water. This tritiated water largely followed the high-level waste fraction of the waste stream eventually ending up in a waste tank. Once in the waste tank, volume reduction by evaporation of tank supernatants partitioned a large fraction of tritium to the soil column as condensate, probably in excess of two-thirds of the site inventory of tritium. Hence, the tritium model will require a partitioning of these condensates among site sources for such wastes.

H.5.3.2.4 Research Products and Benefits. Because large Hanford Site project drivers are associated with each of these radionuclides, we anticipate that the development of particular inventory models will be a fairly high priority for the Integration Project. In any event, these

three radionuclide inventory estimates for many key soil sites will be strongly dependent on the special radionuclide models.

H.5.3.3 Prioritization and Compositing of Soil Sources

Given the large number of contaminated soil sites and their often highly uncertain inventories distributed across Hanford, and given the limited resources available to the inventory technical element, it is imperative that criteria be developed to prioritize this effort in an effective manner. The grouping strategy described in Section H.5.3.1 is intended to guide the prioritization of soil source terms.

H.5.3.3.1 Scope. Activities conducted within this research area are intended to derive criteria for environmental impacts that can be used to prioritize soil source decontamination efforts. The criteria can then be applied to prioritize the soil source terms for follow-up remediation work.

H.5.3.3.2 Research Questions and Motivation. Eighteen classes of soil contamination that encompass the varied soil source terms for the Hanford Site have been tentatively identified (Section H.5.3.1.3). However, it will not be possible nor even desirable to define each source term to the same level of detail. It becomes important to prioritize work in each of the 18 classes and apportion effort according to expected environmental impacts of each class.

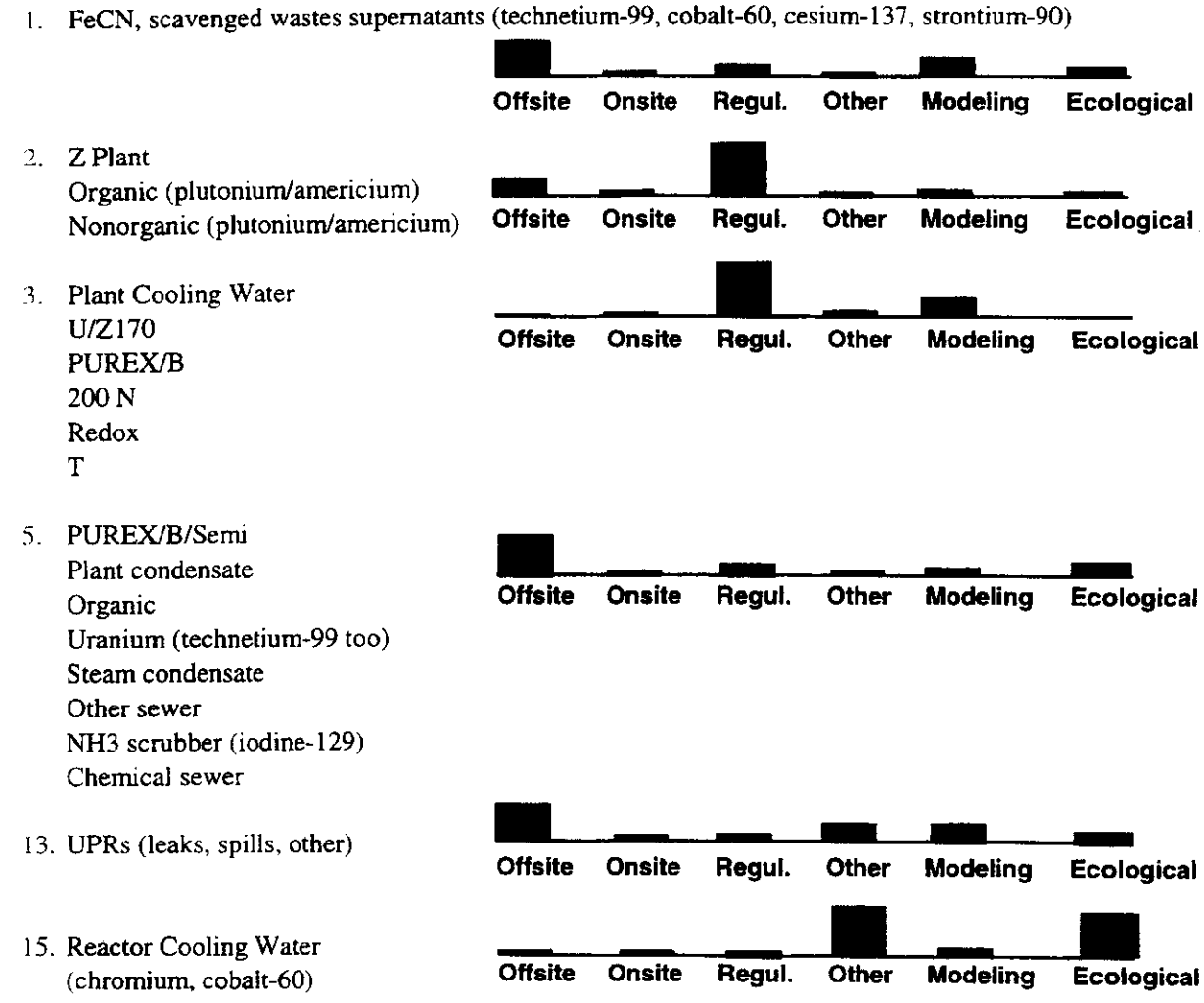
H.5.3.3.3 S&T Activities. There are a variety of Hanford Site project drivers for current efforts within the Integration Project at Hanford. To effectively prioritize the work in support of the Hanford Site drivers, we have established a preliminary set of criteria by which to rank soil sites for priority action based on source terms at the contaminated soil sites, which are grouped into one of 18 classes of soil contamination by waste source and type. The criteria represent the overarching issues that must be agreed upon by DOE, the Tribal Nations, regulators, and stakeholders who are framing the requirements for a system assessment. The candidate criteria are listed below along with the possible ratings, which must be defined by these same contributors. Note that the last three criteria take into account a broader set of considerations for identifying sites on which to focus additional inventory effort—more so than has been done traditionally.

- Offsite dose and chemical hazard risk (negligible, acceptable, tolerable, unacceptable).
- Onsite worker safety and health (negligible, acceptable, tolerable, unacceptable).
- Regulatory drivers (Tri-Party Agreement [TPA], U.S. Environmental Protection Agency [EPA], Ecology, and DOE) (none, indirect, direct).
- Other stakeholder concern (low, moderate, high).
- Modeling needs (no use, useful, critical).
- Ecological risk (negligible, acceptable, tolerable, unacceptable).

The soil site ranking scheme (Figure H-14) shows an example of how selected soil waste groups could be ranked with the previously listed criteria by means of bar charts for the six candidate criteria. The bar height above each impact qualitatively indicates a judgment of the importance of that impact for that soil site. This approach provides a relative ranking that allows for the prioritization or scoring of each of the soil waste groups with respect to the criteria, which are distillations of Hanford Site drivers. These rankings are very preliminary and are only meant to illustrate the methodology.

Figure H-14. Illustration of Possible Resulting Bar Charts for Selected Soil Sites Representing Relative Importance of Each of Six Impact Categories.

Note: This is an example only; actual development of bar charts would be conducted with DOE, regulators, and stakeholders.



H.5.3.3.4 Research Products and Benefits. A prioritization scheme for these waste groups is needed to permit effective allocation of limited resources. Furthermore, we anticipate that only a limited number of soil waste groups (e.g., 6 out of these 18 soil waste groups) will be dealt with during the first years of the Integration Project because of the limited resources that are likely to be available. Therefore, it is imperative that resources be focused on the highest priority soil waste groups.

We must account for each of these criteria to properly prioritize the work. Each soil site is ranked by its relative importance for each of these criteria and the criteria allow for further prioritization of overall Site needs.

H.5.3.4 Development of Criteria for Key Radionuclides and Chemicals

Hanford operations have at various times involved hundreds of different radionuclides and chemicals, some in relatively large quantities. The materials present in the largest quantities, although significant from an operational handling point of view, may not necessarily be those of greatest concern from a long-term risk perspective.

It is not feasible to accurately reconstruct the inventories of all materials used or created at Hanford and determine their present locations and concentrations. Historical monitoring and record-keeping have investigated either gross radioactivity, prominent tracers, or bulk mass, without detailed assays of individual constituents. However, it is necessary to determine which of the radionuclides and chemicals have the potential to impact the environment.

A number of factors, including release amounts, short radiological half-lives, biogeochemical degradation, and geochemical interactions with Hanford soils, govern whether or not radionuclides and chemicals have an impact on the environment. Therefore, it will be necessary to select a minimum number of radionuclides and chemicals to evaluate in detail those that are most likely to result in environmental injury in the future. This reduction of a large number of possible contaminants to a few important ones is called screening.

Screening criteria are influenced by model assumptions and parameter values as well as by the conservatism implicit in those assumptions and values. These criteria are useful for identifying important sources, model elements, and exposure pathways and not wasting valuable resources on less important aspects. If screening criteria show that particular radionuclides and chemicals lead to exposures that are substantially below levels of concern, those contaminants may be excluded ("screened out") from further in-depth analysis. This process requires that the screening criteria capture the main essence of the larger projected assessment while still being simple enough to function on a very large number of potential contaminants.

To best develop the screening criteria, it is necessary to have an idea of the endpoints or outcomes for which an assessment will be conducted. If human exposure scenarios include direct intrusion into waste disposal units in the distant future, the pathways of exposure are different than if only offsite migration is considered. Contaminants may have different impacts on humans than on ecosystems, so the ecological impacts must also be defined.

Another key factor is the projected time span of the assessment. For even a moderate period, contaminants with half-lives of less than a few years will have decayed and for even longer times, only very long-lived radionuclides and stable chemicals are important. The end-states of each soil site must be considered as well because key contaminants left near the Columbia River may be of more concern than those same species on the Hanford 200 Area plateau.

It is necessary to define levels of risk below which contaminants, pathways, or mechanisms can be neglected. This must be coordinated with the risk assessment technical element and the Tribal Nations, stakeholder, and regulatory groups. It is important that the stakeholders and public have input to the parameter selection so that their concerns are addressed through inclusion in the parameter definition process.

H.5.3.4.1 Scope. Similar to the soil site prioritization, activities within this research area are intended to develop and apply criteria for prioritization of contaminants and physical properties.

H.5.3.4.2 Research Questions and Motivation. Like the soil source terms, the key contaminants must be prioritized and managed in order to most effectively apportion sampling and historical analyses efforts. We suggest that the same six criteria described in Section H.5.3.3.3 can be used to effectively drive and prioritize the key contaminants and that each key contaminant can be ranked according to its contribution to each impact category represented by the criteria. Currently, a possible short list includes the following key contaminants (Table H-6) based on information gleaned thus far in discussions and meetings. This list is not intended to be inclusive or final, but rather illustrative. The actual list would be developed with input from regulators, stakeholders, Tribal Nations, and DOE, as well as technical experts. An example of a resulting prioritization is shown in Figure H-15 for illustrative purposes only.

Table H-6. Example of Possible Short List of Key Contaminants.

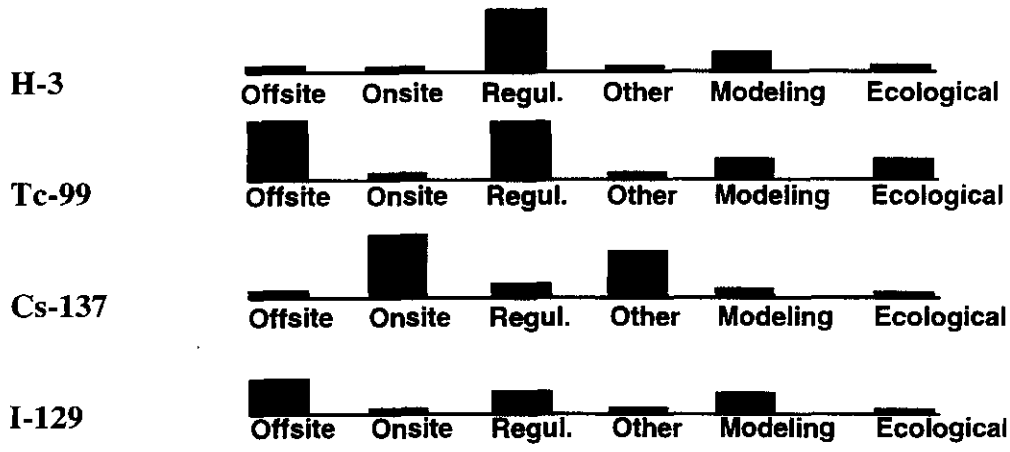
Radionuclides	Chemicals	Physical Properties
H-3, Tc-99, Sr-90, Cs-137, I-129, Pu, Am, U, Np-237, Co-60	Cr, CCl4, Na, complexants, nitrate, Al, hydroxide	pH, density, ionic strength, heat, wt% water, water vapor pressure, Redox state

Note: The actual list will be determined by broad group input.

H.5.3.4.3 S&T Activities. Within this research area, a short list of key contaminants should be established for more in-depth determination of inventory and the prioritization reasoning should be documented. It will then be necessary to periodically revisit or manage the list in a documented way as conditions at the Site change and emphases shift due to new information and programmatic shifts or both.

Figure H-15. Illustration of Possible Resulting Bar Charts Showing Relative Importance of Each of Six Impacts for Tritium, Technetium-99, Cesium-137, and Iodine-129.

Note: Example only; actual bar charts would be developed with DOE, regulators, and stakeholders.)



H.5.3.4.4 Research Products and Benefits. The use of short lists of radionuclide and chemical inventories is a very common practice and many of the programmatic needs now being pursued necessarily include such short lists. What this task should do in conjunction with the SAC is provide some sitewide uniformity to the criteria that are used to define and refine these short lists and then to document the reasons for any future changes to the list.

H.5.3.5 Inventory Process Conceptual Model

H.5.3.5.1 Scope. Within this research area, we propose to construct the conceptual model for the overall inventory process. This conceptual model should link major plants and processes with soil sites as well as providing the slice of the overall model that pertains to each contaminant.

H.5.3.5.2 Research Questions and Motivation. Given the 18 soil waste groups noted previously, a conceptual model for relating each group to a set of historical processes is needed. Such conceptual models endeavor to capture in appropriate detail the more salient pieces of the overall effort while at the same time providing a means to emphasize the more critical aspects of the overall problem.

Once again, the six impact categories (represented by the six criteria as modified by the public process) should be used to rank the conceptual model components. For example, the offsite dose risk for iodine-129 drives the model components for iodine-129 material flow in the conceptual model. For cesium-137 material flow, on the other hand, onsite worker safety, stakeholder concerns, and modeling needs provide the impetus.

H.5.3.5.3 S&T Activities. To be developed.

H.5.3.5.4 Research Products and Benefits. To be developed.

H.5.3.6 Inventory Release Modes to Soil

Another key issue is the interface between the inventory and the vadose zone technical elements. For many years there have been questions about the amount of inventory located within the vadose zone. The Tank Waste Remediation System (TWRS) program compiles current data on leaks from waste tanks to the soil column every month (Hanlon 1998) and has conducted dry-well gamma-logging operations for baseline characterization (Brodeur et al. 1998). Bechtel Hanford, Inc. (BHI), the environmental restoration (ER) contractor, has been vigorously pursuing a better understanding of contaminated soil sites with the Waste Information Data System (WIDS 1998). Past reports have noted the amounts of various contaminants released to the soil (Waite 1991; Wodrich 1991; Williams 1996). However, there are significant gaps in our knowledge about the nature and extent of contamination by certain key radionuclides and chemicals. The distribution of the 65 Ci of iodine-129 on the Site appears to have a critical impact on the long-term risk for offsite dose, yet there is significant uncertainty about the nature and extent of iodine-129 contamination in many key contaminated soil sites. Another long-term offsite dose driver is technetium-99. Hanford has produced about 32,000 Ci of technetium-99 throughout its history. Estimates for the amount in the soil range widely from 500 to 1,500 Ci, while the total amount in groundwater plumes is only estimated to be on the order of 5-10 Ci.

The Hanford Tank Initiative (HTI) Project has reported that technetium-99 in Tank AX-104 is the predominant in-tank radionuclide contributor to long-term risk. To add to concern, initial sampling of waste sludges in Tank AX-104 yielded technetium-99 concentrations over an order of magnitude higher than previous best-basis estimates. Research proposed for the inventory technical element is aimed at resolving these kinds of uncertainties.

The HTI Project has also suggested that contaminant mobilities are very sensitive to inventory leak volumes. It is difficult to accurately estimate the volumes of leaks from tanks. For SX tanks, there are order of magnitude differences in leak volume estimates by Hanlon versus Agnew (Agnew 1998 [SX Leak Report]).

Another parameter influencing contaminant mobility is the areal extent of tank leaks. The TWRS Vadose Zone Program Plan (DOE-RL 1998c) notes more generically that source release rates are important inputs to performance and risk assessments, both for immobilized low-activity wastes (ILAW) and tank wastes.

The TWRS Vadose Zone Program Plan assumes that waste chemistry is important to contaminant mobility because of its potential effects on soil hydraulics as well as interactions between contaminants and soil. For single-shell tanks, two particular waste chemistry factors are "believed to be among the most important discriminating factors affecting movement of contaminants during leak events" (DOE-RL 1998c). These are aluminate in leaked waste and organic complexants. Ionic strength and pH are also acknowledged to affect contaminant

mobility. These issues should be investigated under the vadose zone technical element as described in Section H.2.

H.5.3.6.1 Scope. The activities within this research area are intended to derive release modes for contaminants from various soil sites. These modes should be improved as new knowledge emerges from the S&T efforts in the vadose zone.

H.5.3.6.2 Research Questions and Motivation. Given a particular waste form, such as low-activity glass, the release of its contaminants over time will be a very important driver for the determination of offsite dose risk. Such inventory release rates will be important to allow for projection of future risk. Likewise, plant and tank closure criteria will need to include release rates for residues to the soil column.

In contrast to tank and plant closure, release rates for other solid waste sites have not received much attention. We need to better understand the release rates for soil sites that have significant impacts. In particular, we suggest that the iodine-129 release from iodine scrubber hardware to the soil column will comprise an area of need because large risk drivers are associated with this radionuclide for long-term offsite dose risk.

For leaks and spills that have entered the soil column, we expect that high caustic waste has significantly altered the chemical and physical properties of the soil with which they came into initial contact. The materials so formed will exhibit unique and as yet undetermined release characteristics and this determination will fall under the scope of the vadose zone technical element (Section H.2.4). Also considered part of the vadose zone technical element is any facilitated transport of key contaminants by organic or inorganic complexing agents (Sections H.2.4 and H.2.6).

Any system assessment of Hanford Site wastes requires a model for release from each waste form into environmental pathways. Some wastes have an atmospheric or air phase component, while all have a vadose zone-to-groundwater pathway component. Performance assessments, environmental impact statements, and remedial investigation and feasibility studies have all shown that the groundwater pathway is the primary pathway of concern. Therefore, the release modes of contaminants into the vadose zone sediments surrounding waste deposits are fundamentally important as the link between the waste source and the groundwater.

At the time of Hanford Site closure, the Site will have a variety of wastes in the shallow subsurface or vadose zone. Past-practice burial grounds contain a combination of low-level and transuranic (TRU) wastes. Past-practice liquid discharge sites spread contamination in the vadose zone beneath cribs, trenches, and reverse wells to the water table of the unconfined aquifer. Past tank leaks and losses that occurred during tank cleanout operations will also leave tank waste in the vadose zone. Tanks, canyon buildings, and virtually all other facilities will contain residual radionuclide and hazardous chemical wastes in their end-state at the time of Site closure. Current and future disposals of solid waste, CERCLA cleanup waste, and low-activity waste from the tanks will be the best known and characterized wastes.

H.5.3.6.3 S&T Activities. To simulate the near- and long-term release of all of these wastes, one of two problems must be simulated. Either a boundary value problem that begins with a clean environment and simulates all historical discharges and disposals or an initial value problem in which the location and magnitude of all wastes are known or assumed to be known at a single moment in time, (e.g., either today or the time of Site closure) must be solved. To solve either problem, the ability to model the near- and long-term release of contamination is required.

Thus, for the variety of radionuclides and hazardous chemicals contained in the variety of waste forms, we need to know how the constituents release into environmental pathways, especially the surrounding soils and sediments. These waste forms include solid waste; liquid discharges to cribs, trenches, and reverse wells; tank residuals; tank leaks and losses; canyon buildings; low-activity waste forms; and wastes on railroad flatcars in underground tunnels.

Research is needed to better understand and quantify the present state and future release of contaminants in solid waste burial grounds and in the vadose zone beneath cribs, trenches, and tank farms (e.g., tank leaks and future losses). Certainly, better understanding and simulation capabilities are needed for residual wastes in tanks (e.g., hard heel), in canyon buildings, and in the PUREX tunnels. Finally, in the context of performing system assessment, the models and data applied to the host of contaminants and waste forms need to be studied in terms of their applicability to the assessment of uncertainty. Literally hundreds of waste sites exist and require analysis at Hanford. Characterization of existing contamination and environmental pathways is and will remain incomplete. Thus, simulations of release, migration, and fate should be posed, solved, and presented as uncertain. Hence, the S&T activities should be directed at updating the timing and volume of inventory release rates based on 1) improved understanding of vadose zone issues through S&T; 2) additional data obtained from field sampling that provide insight to past releases; and 3) release rates calculated for future waste forms such as low-activity waste.

Research is underway to better understand future releases from cement-based waste forms (waste management—solid waste burial grounds) and from glass (TWRS ILAW). Research to better understand and quantify the position and mobility of tank waste in the vadose zone is an objective of TWRS Vadose Zone Program. Our ability to simulate release will be highly related to our ability to simulate the migration and fate of contaminants in the vadose zone.

Efforts to characterize the inventory and release modes for canyon buildings are beginning as decontamination and decommissioning (D&D) programs for those facilities get underway. The ER Program recently grouped waste sites according to the wastes they received. The program has begun to prioritize sites in the 200 Areas for characterization and remediation; however, waste sites located near the Columbia River have been the focal point of recent ER activities.

H.5.4 Interfaces and Linkages

There are three levels of interface that must be addressed. First, each research area must be linked to programmatic needs and commitments at Hanford. For example, if the ILAW PA depends critically on the amount of technetium-99, there will be a corresponding emphasis on technetium-99 in the inventory technical element. Consideration of ILAW technetium-99

migration without an adequate knowledge of existing soil technetium sources could lead to an incorrect incremental risk for offsite dose. Second, the inventory technical element must be linked with corresponding technical elements from the vadose zone, groundwater, and Columbia River technical elements. Third, there are linkages between and among the research areas of the inventory technical element.

H.5.5 Expected Results

The results of the research proposed under the inventory technical element include the following:

- A consistent approach for establishing an inventory for sitewide use in both the SAC and individual waste site performance assessment.
- A documented process for focusing on key soil sites and contaminants that meets the needs of DOE, regulators, stakeholders, Tribal Nations, projects, and researchers. This process also allows for tracking of changes to soil site groupings or list(s) of key contaminants, which helps clarify inventory assumptions made for the Hanford system.
- A series of special contaminant process models that guide data collection from the field to confirm assumptions about the inventory of key contaminants that drive performance and system assessments.
- An approach for establishing a best-basis inventory for soil sites by linking process models, historical records, and field data.
- An approach for describing and quantifying release rates from key waste disposal sites to the soil. There are two release sites of immediate interest that will be a focus for the inventory technical element: tank leak estimates and crib inventory.

H.5.5.1 Leak Estimates

Past leak estimates have been most reliable when there was a clear unaccounted-for volume lost from a tank. However, it was discovered very early that significant ground contamination occurred for many tanks where there are inherent uncertainties and variabilities associated with tank inventory. Many secondary leak detection systems were implemented, many on an after-the-fact basis. These secondary systems amounted to the placement of vertical dry-wells proximal to each waste tank, as well as horizontal or lateral wells placed spoke-like under many tanks from 2 meter (6-foot) diameter caissons within the tank farms.

Without an accounting of inventory loss, the presence of soil contamination only provides a very rough estimate of leaked inventory. Complicating the use of dry-well gamma-logging for leak inventories is the extreme chemistry of the leaked wastes, which are highly alkaline and highly ionic. The reactions of waste with soil significantly alter the soil characteristics, thereby making any assumptions about local porosity and ion retention problematic.

Fundamental soil-wetting arguments that have been used for one waste type may not be valid for a tank leak involving another waste type. Therefore it is important to group leaks into categories of waste and leak type where analogous arguments can be made comparing leak inventories within a leak group. Furthermore, bounding leak estimates are more defensible when there is a firm technical basis for their analogies to other better determined tank leaks.

One strategy for grouping leaking tanks is as follows:

- Self-concentrating waste receivers: S, SX, A, AX, U-110
- In-tank heaters in BY Farm
- Surface spills: BY-101, 2 ,3 92 kgal overfill, March 1951
- Sudden structural failures (T-106)
- Complexant waste leaks including slurry growth
- Non-complexant waste leaks
- Losses following salt-well stabilization
- Long-term evaporative losses
- Rainwater and other intrusions.

An expected benefit of the inventory technical element will be the improved estimate of past tank leaks by using the proposed approach.

H.5.5.2 Crib Inventories

The inventories of various crib sources fall into several distinct classifications, which have already been delineated (DOE-RL 1997). Primary for consideration are the scavenged waste supernatants, often termed ferrocyanide waste supernatants. Other important tank waste sources are 2C and 224 (early plutonium finishing) overflow wastes. These sources are within the tank wastes category.

Next highest on the list are chemical sewer and Z Plant organic process wastes. In fact, the Z Plant cribs with high organic constituents are currently undergoing remediation by vapor well extraction, where the organic specie that dominates these cribs is carbon tetrachloride. Then there are five different cooling water groups: Gable Mountain/B Pond, S Pond, 200 North Pond, and T Pond. These groups are on TPA-driven milestones.

These site activities, coupled with the approach on inventory estimates proposed under this technical element, are expected to result in better estimates of amount of contaminants in crib sites.

H.6 LINKAGES AND EXPECTED OUTCOME

The research areas and activities identified under each of the four technical elements included in this applied science and technology (S&T) plan are intended to provide the knowledge, data, tools, and understanding that can be used by the Hanford Site for 1) making defensible decisions regarding Site cleanup and closure and 2) protecting the Columbia River and associated water

resources during and after Site cleanup. Furthermore, the research areas support the Integration Project approach of expanding the use of existing Site knowledge and developing new knowledge that allows for a system assessment of contaminant impacts. In so doing, the Site can assess whether the cumulative endpoints for each of the individual projects will result in an acceptable end-state for the Hanford Site. Such an assessment could result in a revision of the requirements for individual projects to ensure that an acceptable end-state is achieved.

To fill these knowledge, tool, and data gaps, the research areas and the S&T activities within each area as described in this plan can be characterized in one of two ways. Some of the research areas support integrated sitewide characterization and analysis and are envisioned as a framework for characterization and analysis conducted under individual projects. This framework would result in the use of common approaches and assumptions that meet both sitewide system assessment and individual project assessments that are site-specific. Other activities are directed at developing and conducting applied S&T activities to fill knowledge and data deficiencies that can be used by both individual projects and the sitewide system assessment. The relationship between the project vision and mission and the research areas for each technical element is described in Figures H-16 through H-19.

The decisions for which the results of the S&T activities are intended to be used are also identified in Figures H-16 through H-19. The exact timing and definition of the S&T products required to support the key decisions identified in these figures is presented in the GW/VZ Project-Level S&T Roadmap in Appendix I of the *Project Specification.* The vadose zone technical element is intended to contribute to many upcoming Site decisions associated with characterization, assessment, and remediation of the 200 Area plateau. These decisions include near-term corrective measures for tank farms, tank retrieval performance and tank closure requirements, as well as closure requirements for cribs, trenches, and other contaminated soil sites within the 200 Area. To support these decisions, the S&T activities within the vadose zone technical element should be jointly planned in some cases and closely coordinated in other cases with the corresponding individual projects that are being integrated through the Integration Project.

The groundwater technical element is intended to contribute to upcoming remediation decisions for plumes associated with the 200 Area and provide a basis for enhanced efficiency and effectiveness of groundwater monitoring as shown in Figure H-1. Furthermore, this technical element will contribute directly to the system assessment by providing regional plume geometry and three-dimensional modeling capability where needed. The river technical element is intended to provide input to the system assessment capability and the river monitoring activities as shown in Figure H-1. The inventory technical element is intended to draw upon data being generated by the individual projects as shown in Figure H-1 and to provide a consistent framework for collecting inventory data from each of these projects. Subsequently, the resulting waste inventory and waste release mechanisms will become input to the system assessment capability.

Figure H-16. Relationship between Research Areas for the Vadose Zone Technical Element of the Hanford Vadose Zone/Groundwater/River System and the Integration Project Vision and Mission.

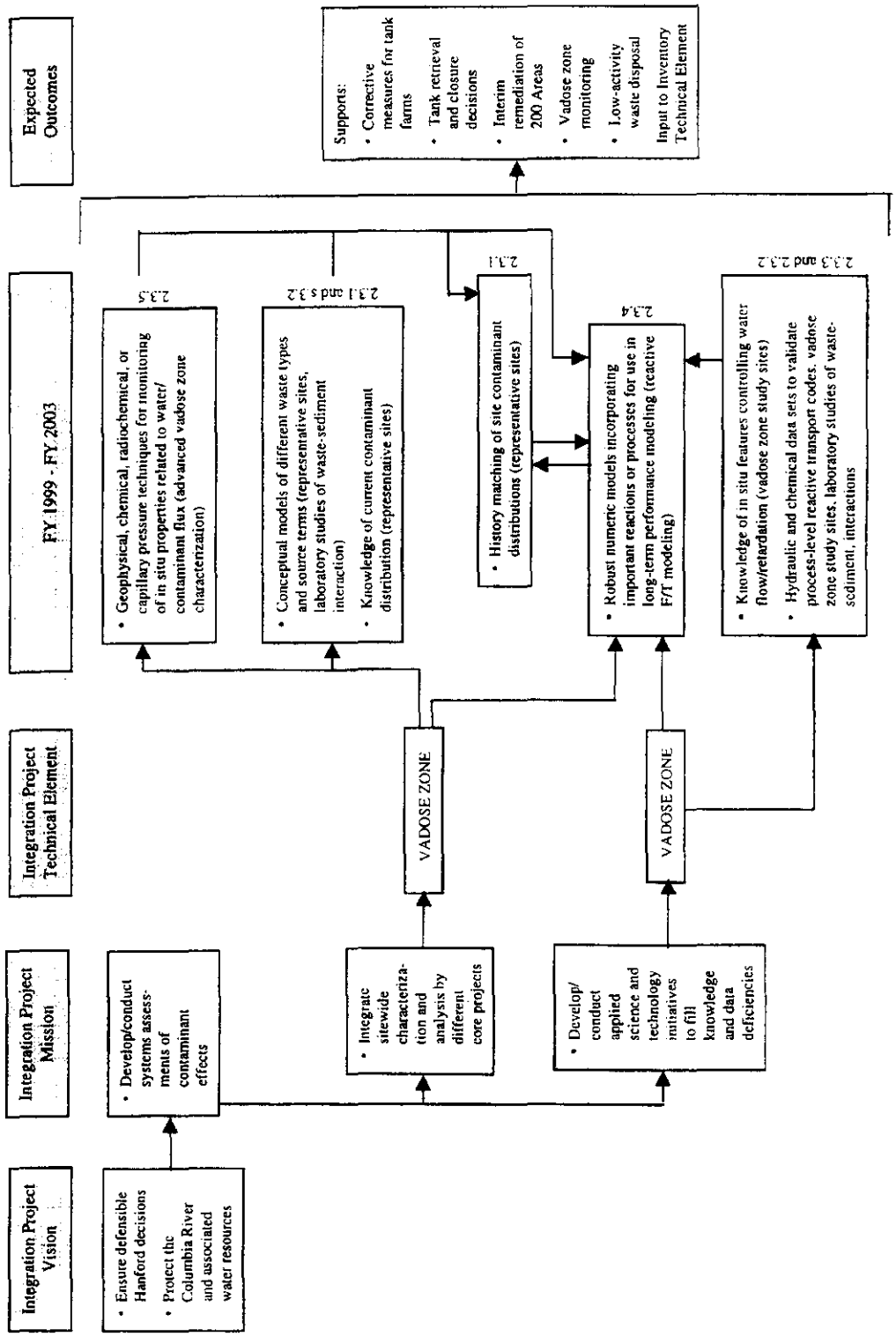


Figure H-17. Relationship between Research Areas for the Groundwater Technical Element of the Hanford Vadose Zone/Groundwater/River System and the Integration Project Vision and Mission.

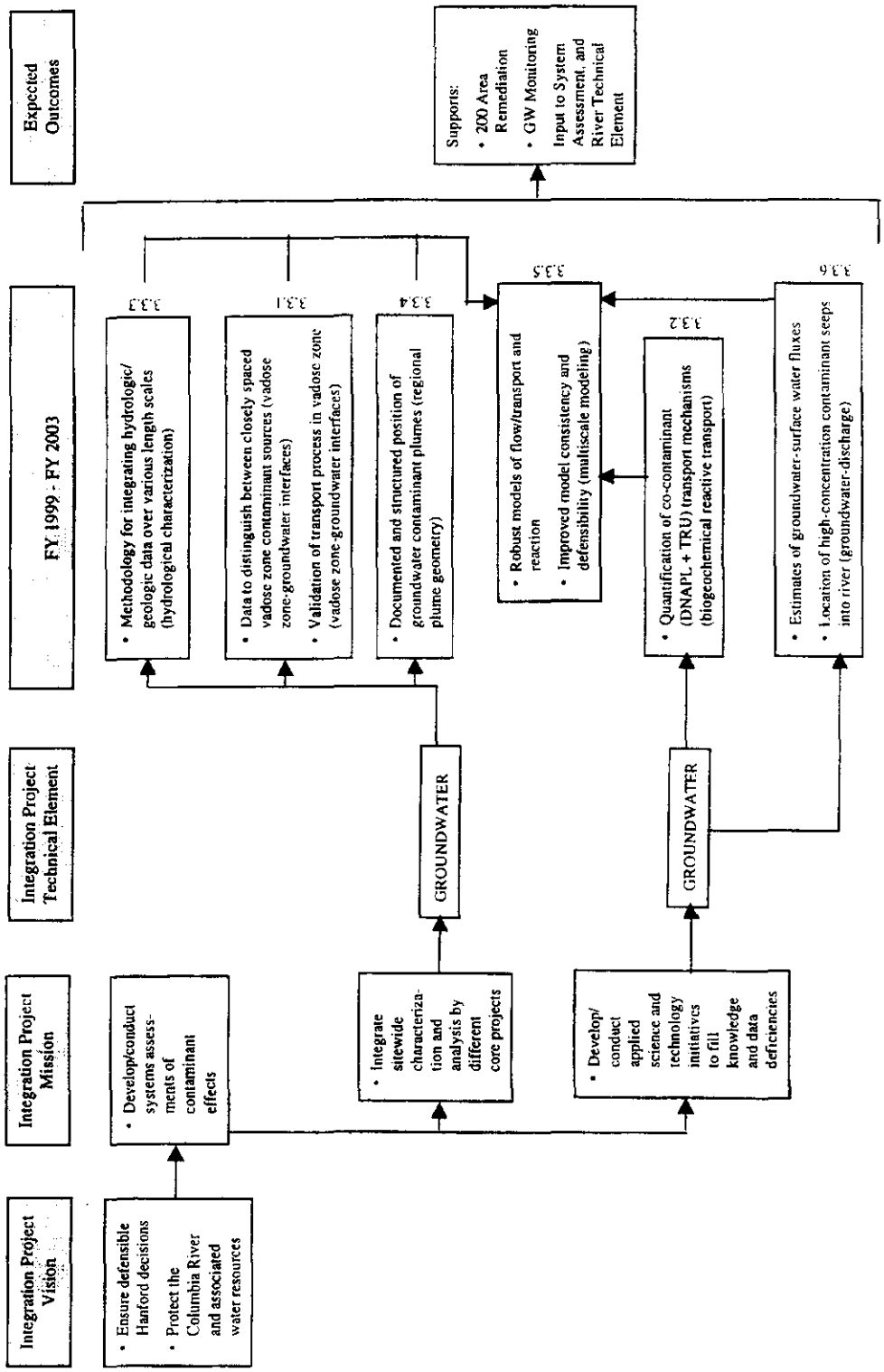


Figure H-19. Relationship between Research Areas for the Inventory Technical Element of the Hanford Vadose Zone/Groundwater/River System and the Integration Project Vision and Mission.

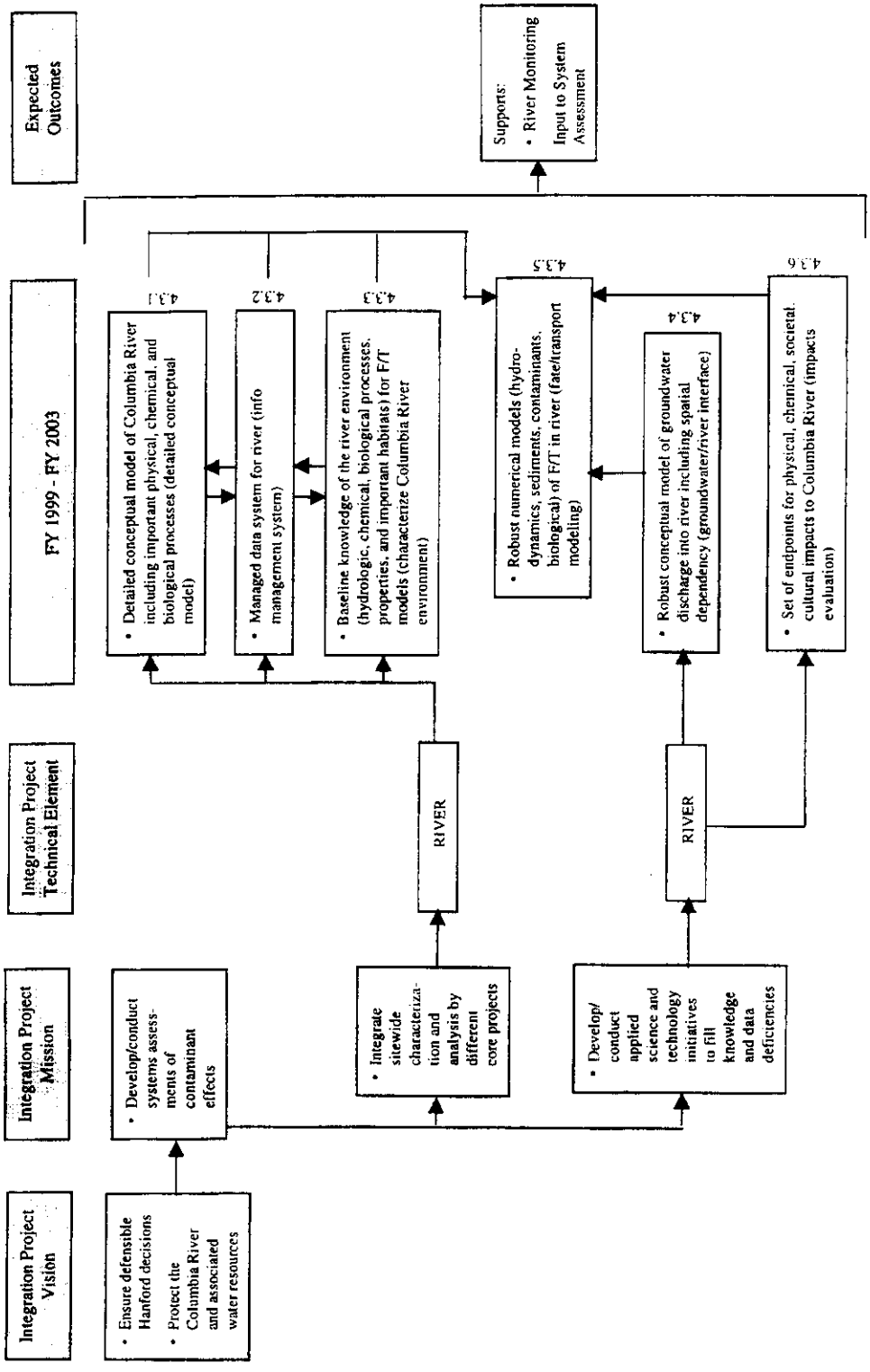
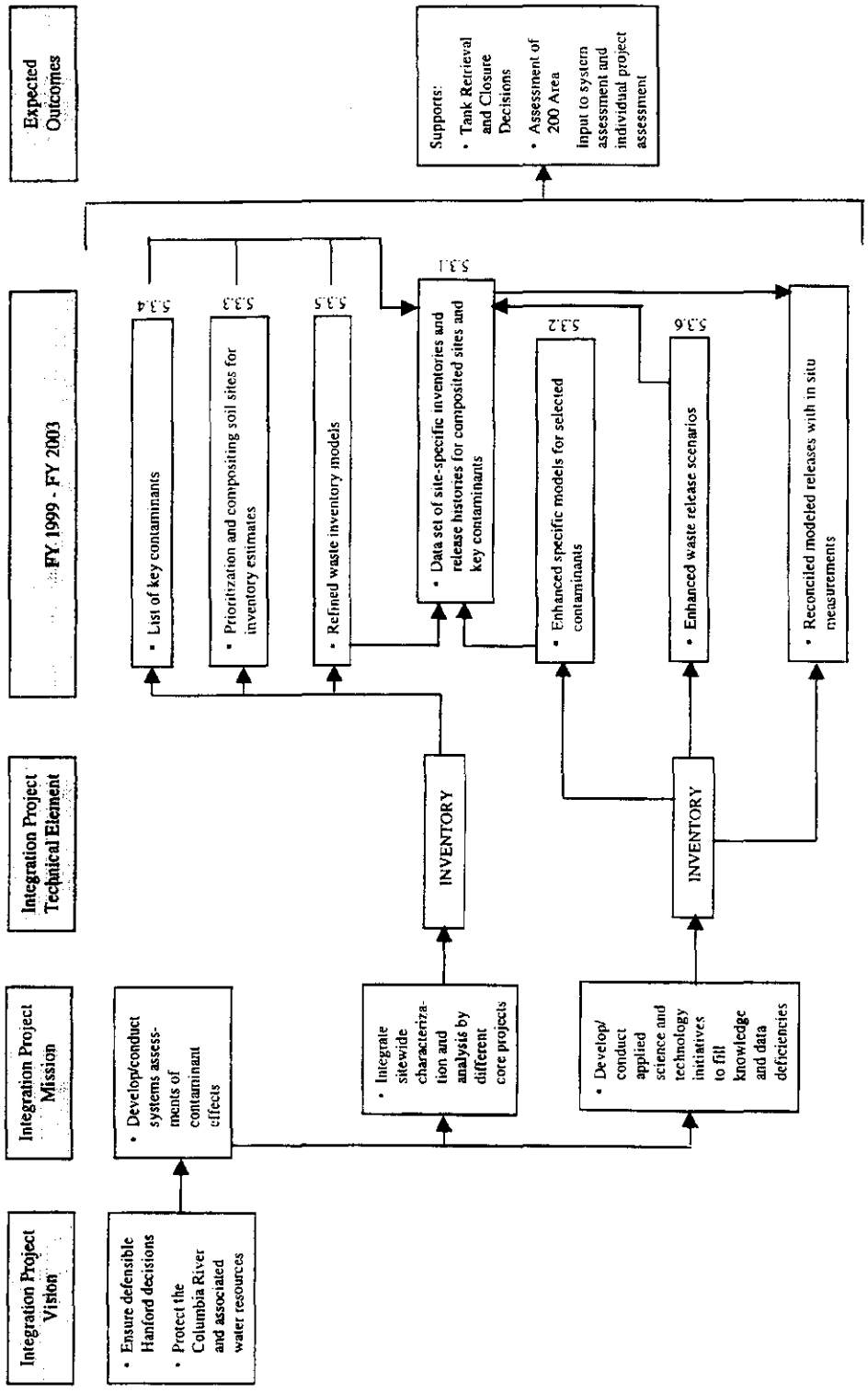


Figure H-20. Relationship between Research Areas for the River Technical Element of the Hanford Vadose Zone/Groundwater/River System and the Integration Project Vision and Mission.



There are also key linkages between the technical elements as identified in Figures H-16 through H-19. For example, the vadose technical element will identify key waste release mechanisms that will be used in the inventory technical element. The groundwater element is closely linked to the river technical element through the estimation of groundwater-surface water fluxes and the location of high-concentration contamination. The river technical element will be guided by the risk assessment technical element which is currently being developed and not included in this draft of the S&T plan. The inventory technical element crosscuts the vadose zone, groundwater, and river technical elements in the sense that new data developed through the other technical elements can be incorporated into the waste inventory research area and new knowledge developed through the other technical elements can be incorporated into the waste release mechanism research area. The full set of linkages between the technical elements are found in the GW/VZ Project-Level S&T Roadmap (Appendix I of the *Project Specification*).

H.6.1 Linkages with Other Ongoing DOE Programs

An important aspect of the applied S&T plan proposed here is the linkage and leverage of related ongoing research and technology development efforts conducted elsewhere within DOE. The Office of Biological and Environmental Research's (OBER's) NABIR (Natural and Accelerated Bioremediation Program) and the EMSP (Environmental Management Science Program) are developing information, technology, and models that are relevant to parts of the Hanford vadose zone/groundwater/river physical system. The research portfolio and future plans of these programs must be carefully considered during the initiation of this program so that expected contributions of NABIR and EMSP can be both anticipated and built upon, rather than replicated by new activities described herein. A coordination workshop at Hanford with EMSP researchers whose projects focus on vadose zone issues and NABIR Science Team Leaders would be a first step in initiating dialog to foster interprogram linkages and collaboration.

Teaming and collaboration between the programs would be synergistic and to the long- term benefit of DOE. For example, some EMSP researchers, especially those from the academic community, seek field sites from which to obtain samples or upon which to focus their own research. Offering the contaminated, representative field sites or the uncontaminated vadose zone study sites described as part of the vadose zone technical element of the program for multi-program collaborative use would stimulate the development of the largest possible Hanford-specific knowledge and information base. Similarly, the OBER/NABIR program intends to establish one or more field research centers (FRC) on DOE lands to study field-scale issues associated with bioremediation. The establishment of a NABIR FRC at Hanford would clearly benefit both programs, and would provide much needed insights on bioremediation that could be applied to different waste sites at both Hanford and the broader DOE complex.

For the river technical element, a large portion of the scope of work described above is contained within existing programs. While efforts have been made to coordinate the activities of these organizations, improvements can be made. Activities identified and conducted under the river technical element will be coordinated with other site environmental surveillance programs to maximize efficiencies and take advantage of existing expertise, experience, and capabilities while avoiding duplication of effort to the extent possible. Currently, there are several different

Hanford-related programs and projects working on various aspects of the river evaluation defined above. The primary Hanford programs include:

- Hanford Sitewide Surface Environmental Surveillance Project (SESP) conducted by the Pacific Northwest National Laboratory.
- Ecosystem Monitoring Project conducted by the Pacific Northwest National Laboratory.
- Cultural Resource Management Project conducted by the Pacific Northwest National Laboratory.
- Groundwater Project, managed by BHI and performed by CH2M Hill Hanford, Inc., part of the Environmental Restoration Contract Team led by BHI.
- Effluent and Environmental Monitoring Program, specifically the Near-Facility Environmental Monitoring Program, managed by Waste Management Federal Services of Hanford, Inc. and performed by Waste Management Federal Services Inc., Northwest Operations, part of the Project Hanford Management Contract Team led by Flour Daniel Hanford, Inc.

Several agencies outside of the Hanford domain are also conducting various studies of the Columbia River environs. These include the Washington State Department of Ecology, Washington State Department of Health, U.S. Army Corp of Engineers, U.S. Geologic Survey, Federal and State Fish and Wildlife Service, EPA, Bonneville Power Administration, and local communities. Coordination with outside agencies conducting river-related studies along the Hanford Reach will also be pursued to the extent practical.

The Yucca Mountain Project and the Waste Isolation Pilot Project (WIPP) can provide valuable lessons learned to the Integration Project and provide an opportunity for potential collaborations. For example, WIPP is using a process for focusing S&T activities and for ensuring that system data are being developed to support decisions. The Integration Project would benefit from taking a similar approach to ensure that S&T and field data collection are focused. There is also the possibility for model intercomparisons and model validation exercises that could benefit both parties.

Review and mapping of research and data resulting from other programs to the key problems identified in the S&T Plan and S&T Roadmap is part of the implementation of the S&T Roadmap function.

H.6.2 Expected Outcomes

The resulting S&T activities are expected to provide data and information on hydrologic, chemical, and microbiologic process controlling the field-scale behavior of DOE contaminants to meet both short-term regulatory and environmental technology needs at Hanford and to resolve long-term evolving scientific issues and needs that meet the project mission. The results of the S&T with and between the different technical elements should provide the information,

capabilities, and understanding necessary to perform effective assessments (current conditions and predictive) of the impacts of Hanford operations to and through the Columbia River. The combination of field observations, laboratory experiments, numerical simulations, and long-term monitoring is intended to provide relevant and meaningful information to be used in support of the waste management, environmental restoration, and future Site land use decision-making processes.

The intent of the applied S&T activities is to enhance the scientific data and information that the DOE and its contractors need to make informed decisions and to deal effectively with environmental issues and challenges. The credibility of DOE in the eyes of stakeholders, regulators, and the tax-paying public at large will be improved in part if cleanup and closure plans are based on knowledge and a scientific understanding of underlying natural processes and phenomena.

In addition, this information provides the capability to continue to assess the quality of the Hanford environs; evaluate impacts attributable to Hanford operations; focus future river monitoring activities; identify and address environmental concerns; and provide assurance to the stakeholders, Tribal Nations, and public that neither their livelihood or the Hanford environs are being compromised.

The success of the applied S&T activities will be gauged by the impact of the results and models on cleanup and closure activities at Hanford, and the use in resolving known and unforeseen future issues. The following are criteria by which the success of the program may be evaluated:

- Confidence in proposed conceptual models for different waste site types (e.g., solid waste burial grounds, past-practice liquid-discharge sites, leaked single-shell tanks, low-activity waste disposal [ILAW], etc.).
- Timely development of scientific information in support of critical site decision milestones (e.g., leak-loss limits).
- Use of science knowledge base and developed models in support of preferred mitigation, remediation, and waste management actions; and Records of Decision.
- Acceptance of program research results and models by peer reviewers, the Hanford Advisory Board, regulatory agencies, Native American Tribes, and stakeholders.
- Ability to simulate and history match contaminant migration profiles at different representative waste sites using developed models, data bases, and measurements.
- Measurable positive impact on environmental management decision-making at the Hanford Site.
- Remedial action cost savings and confidence boosting.

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APPENDIX I

APPLIED SCIENCE AND TECHNOLOGY ROADMAP FOR INTEGRATED VADOSE ZONE, GROUNDWATER, AND RIVER SYSTEM AT THE HANFORD SITE

(This appendix has been prepared as a stand-alone document.)

APPENDIX I

Applied Science and Technology Roadmap For the Integrated Vadose Zone, Groundwater, and River System at the Hanford Site

I.1 INTRODUCTION

In late 1997, the DOE established the Integration Project to ensure protection of the Columbia River environment, river-dependent life, and users of the river resources. The Integration Project now serves as the single entity accountable for the integrated management of all vadose zone, groundwater, and Columbia River activities at the Hanford Site. This integrated management role involves the following responsibilities:

- Integrating existing projects to avoid technical and regulatory fragmentation.
- Developing a credible SAC to support site decisions that are based on a site-wide perspective in addition to a site-specific perspective.
- Implementing an applied S&T program that provides technical input to assessment and remediation decisions.

This roadmap describes the S&T program and its relationship to the SAC and individual projects within the Integration Project. A description of the SAC is provided in section I.2. An overview of the S&T program to support Hanford assessments is provided in section I.2.1. The S&T activities will be integrated into or coordinated with individual projects during the implementation of the S&T program. The opportunities for integration and coordination of S&T activities that support Hanford assessments are detailed in Section I.2.2 and the opportunities for integrating S&T activities that support Hanford remediation are described in section I.2.3. The schedule, the S&T products, and the customer for those products (e.g., SAC or an individual project) is described in section I.3. The budget for these S&T activities are summarized in section I.4 and the S&T priorities are listed in section I.5.

To define the S&T program, a series national laboratory meetings were held in FY98. In these meetings, scientific experts in subsurface assessment and remediation met with the DOE, site remediation contractors, and local stakeholders. Many of these scientists had developed assessment capabilities for other DOE programs (such as Yucca Mountain). This diverse set of experience and capability was used to identify the scientific and technical challenges facing the Hanford Site, and to subsequently define an applied S&T program to address these challenges.

The resulting S&T scope, schedule, budget, and products for the next five years are presented in this roadmap. The S&T products will be delivered to the SAC and individual projects that are supporting two key decisions during this initial five-year period:

- 200 Area remediation assessment (in FY02).
- Single-shell tank (SST) retrieval (in FY04).

In addition, this roadmap includes S&T products that provide new knowledge, data, and tools for decisions on tank farm closure, remediation of soil sites, and the tank farms in the following five years.

I.2 APPROACH

The critical path activity for the Integration Project is the SAC. The SAC is a collection of the conceptual models, databases, analytical and predictive tools used to conduct site-wide system assessments. These assessments support key decisions regarding remediation of the vadose zone, and groundwater, in order to protect the Columbia River. The knowledge collected through the SAC will also form the basis for site-specific assessments, thereby ensuring that the best scientific knowledge is used for all Hanford Site vadose zone/groundwater assessments. To be fully functional, the SAC will require data acquired through field sampling and from S&T activities. Hence, the SAC can be used to help guide data collection from the field, define monitoring requirements, and guide future S&T investments. The SAC approach is illustrated in Figure I-1.

Figure I-1. System Assessment Capability.

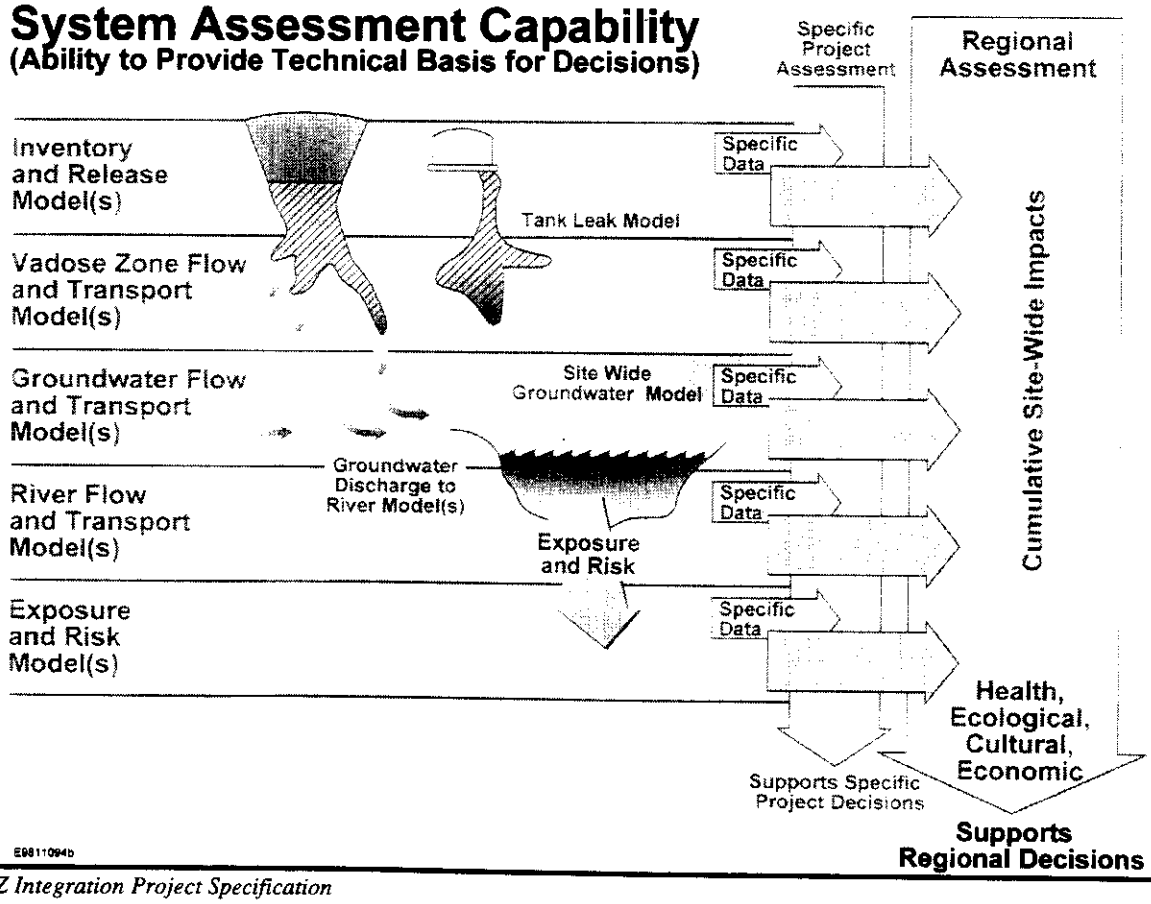
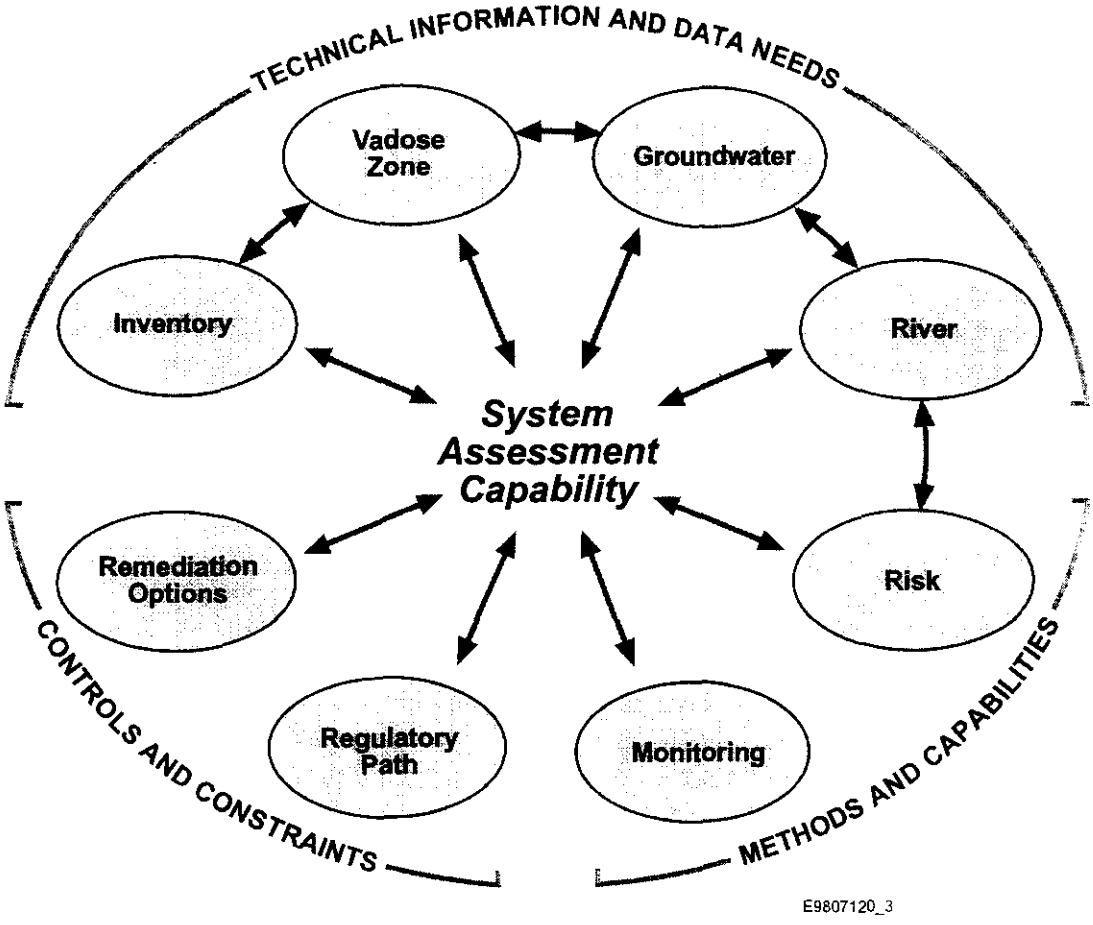


Figure I-2. Integration Project Technical Elements.



The SAC and the S&T program are organized along technical lines referred to as technical elements. The technical elements and the interrelationships between technical elements and the SAC are shown in Figure I-2. The inventory, vadose zone, groundwater, and river technical elements are intended to provide the technical information and data that characterize various features and key processes that are essential to the development of conceptual models that attempt to describe how the natural system works. The risk assessment and monitoring technical elements identify the methods and capabilities required for site-wide system assessments. The regulatory and remedial options technical elements identify the controls and constraints on the system-wide assessment.

This first version of the S&T roadmap includes the inventory, vadose zone, groundwater, and river technical elements. A placeholder for the risk assessment technical element, which is being developed by the Center of Risk Excellence in early FY99, is identified in the roadmap. Current S&T activities identified for the remedial options technical element are also included. These latter needs (remedial options) were not developed through the national laboratory meetings;

they were identified through the Hanford Site Technology Coordination Group (STCG)[*] with support from the Mixed Waste, Tanks, and Subsurface Contaminants subcommittees. The monitoring technical element is not included in this version of the S&T roadmap. It will be developed in FY00 and incorporated in a future revision. The regulatory path technical element will not have S&T associated with it.

I.2.1 Summary of the S&T Needs and S&T Activities

A brief summary of the needs associated with the inventory, vadose zone, groundwater, and river technical elements, and the proposed S&T activities to address those needs, is described in this subsection. A more detailed description of each of these S&T activities (and their links to the SAC and individual projects) is presented in the next two subsections. (A detailed discussion of the scientific and technical issues, and the corresponding S&T activities for the inventory, vadose zone, groundwater, and river technical elements, can be found in Appendix H of this *Project Specification.*)

Inventory Technical Element:

Need: An approach is needed to provide a realistic inventory of contaminants in soil sites that can be used by the SAC and individual projects. Based on past assessments at the Hanford Site, four problems have been identified: 1) there is a huge number of sites and contaminants; 2) inventory data that meet data quality requirements are not available for all of the sites and contaminants; 3) characterization to obtain these missing inventory data is expensive and time consuming; and 4) current approaches for inventory estimates introduce large uncertainty into a system assessment.

Solution: To respond to this need, the S&T program will provide models that:

- Describe partitioning of wastes in process streams that were discharged to the soils.
- Describe behavior of specific contaminants for which reconciliation of inventory is important, but has not been achieved in past efforts.
- Group and prioritize waste sites to improve inventory estimates for site-wide assessments.
- Describe release mechanisms and rates from the source term to the soils.

[*] The STCG is a group of users and stakeholders at the Hanford Site. This group identifies technology needs that are submitted to the Office of Science and Technology (OST) annually. OST through its national research programs considers these needs in the development of their technology programs. The science and technology needs are documented in DOE-RL, 1998, Hanford Science and Technology Needs Statements, DOE/RL-98-0, Rev 1, U.S. Dep of Energy, Richland, Washington. These needs can also be accessed through the web page at http://www.hanford.gov.

Vadose Zone Technical Element:

Need: The flux of contaminants through the vadose zone to the groundwater under varying geologic, hydrologic, and chemical conditions is key to making technically credible and sound decisions regarding soil site remediation, SST retrieval (where operational or tank leaks may occur), and tank farm closure. Past knowledge has not always been sufficient to forecast the quantity, location, and movement of contaminants in the vadose zone. The cost has been high and the characterization tools have not been available for collecting some types of field data. Hence, there is a need to improve the conceptual and numerical models that describe the location of contaminants today, and provide the basis for forecasting future movement of contaminants on both site-specific and site-wide scales. There is also a need for new and improved tools to characterize the vadose zone.

Solution: In response to this need, the S&T program will conduct field studies to improve conceptual and numerical models of contaminant behavior in the 200 Area vadose zone. These field studies will include evaluation of water and contaminant movement at representative, contaminated, and uncontaminated field sites. Results from the field studies will be used to focus 1) laboratory experiments on waste-sediment interactions and chemical transport; and 2) the development of relevant and applicable transport models. The field sites also provide an opportunity to deploy and test advanced characterization tools and methodologies, to clearly identify mechanisms and processes that control the depth and extent of contaminant plumes in the Hanford vadose zone, and to calibrate and refine predictive reactive transport models.

Groundwater Technical Element:

Need: Although the understanding of the groundwater technical element is somewhat more mature than the understanding of other technical elements, there are still some areas of deficiencies--particularly as site-wide system assessments are conducted. For example, the 3-dimensional (3D) plume at the interface between the vadose zone and groundwater, across the region, and at the interface between the groundwater and river are not known. Moreover, characterization, 3D modeling, and parameter estimation across a hierarchy of spatial scales will be needed for some site-specific assessments (as well as site-wide assessments). Finally, groundwater in the 200 Area is contaminated with dense non-aqueous phase liquids (DNAPLs) and transuranic (TRU) wastes such as plutonium, cerium, and neptunium. This combination of contaminants can be both an assessment and a remediation challenge.

Solution: The S&T program proposes that the following activities be conducted:

- Depth-discreet sampling at key locations to better describe distribution of contaminants in 3 dimensions at the vadose zone/groundwater interface.
- Biogeochemical reactive transport studies for extreme chemical environments that will be assessment and remediation challenges.
- Hydrological characterization that uses innovative methods over a hierarchy of scales.

- Field scale evaluation of the regional plume geometry.
- Multi-scale 3D modeling based on objectives to be determined in concert with the SAC requirements and individual project needs.
- Groundwater-river discharge studies to determine the location of contaminant releases and the estimation of contaminant flux to the river.

River Technical Element:

Need: Potential impacts and consequences of contaminant migration from the Hanford Site are manifested in the river environment. To conduct the site-wide system assessment of the potential impacts of alternative remedial actions on the Columbia River, an enhanced conceptual model of the river is needed. The conceptual model needs to account for multiple contaminant input to the river from all sources (not just Hanford sources); the transport and fate of those contaminants in the riverine environment (physical, chemical, and biological systems); and the potential impacts of those contaminants.

Solution: The S&T program will address this need in the following ways:

- Develop a conceptual model of the river and make use of existing monitoring data from multiple agencies.
- Characterize the river to develop transfer factors and input parameters for transport and fate models.
- Enhance the understanding of the potential impacts of groundwater discharge to the river on affected biota, as well as confirming transport and fate predictions in the river.
- Evaluate the impact of contaminants on the public, cultures, and ecology of the region.

I.2.2 Integrated S&T Activities to Support Assessment

The two key decisions that are the focus of the Integration Project activities in the next five years are 1) the determination of the readiness to proceed with remediation of the 200 Area soil sites in FY02; and 2) the decision to proceed with single-shell tank (SST) retrieval in FY04. The first decision is a milestone in the *Hanford Federal Facility Agreement and Consent Order* (*Tri-Party Agreement*). The S&T activities that support these assessment decisions are directly integrated with the following Hanford projects within the Integration Project:

- System Assessment Capability
- 200 Area Remediation Assessment
- Tank Waste Remediation System (TWRS) Vadose Zone.

In addition, the S&T activities will coordinate with the following Hanford projects to gain additional opportunities to developed data and models that will be needed in this effort.

- Immobilized Low-Activity Waste (ILAW)
- Groundwater Monitoring/Modeling
- River Monitoring.

In section I.2.1, a summary description of the S&T activities by technical element was given. In this section, a more detailed description of each of these S&T activities is described and linked to the projects with which they are either to be integrated (SAC, 200 Area Remediation Assessment, and TWRS Vadose Zone) or coordinated (ILAW, Groundwater Monitoring/Modeling, and River Monitoring). The technical element and the identification numbers (Id. No.) for the S&T products will be identified for each description of the S&T activity to aid the reader in crosswalking to Table 1 in Section I.3 for more information on scope and schedule.

System Assessment Capability: S&T activities linked to the SAC provide conceptual models, analytical and numerical models, data, and model parameters that directly support the 200 Area Remediation Assessment and SST Retrieval decisions.

The system assessment capability (SAC) is intended to be the key integrating tool used by the Integration Project management team. It is being developed in FY99 and is envisioned to provide a hierarchical suite of models and parameter data-bases that can be used by 1) individual projects to conduct site-specific assessments; and 2) the Integration Project to conduct site-wide system assessments (See Figure I-1). The results of these assessments can be used to make project and site decisions regarding operations (e.g., tank retrieval) or remediation at the Hanford Site. In the next one to two years, the SAC will define requirements for the analyses conducted at higher resolutions (space and time) on site-specific and S&T research scales. The SAC will work with S&T project and individual project staff to define the scale effects of models developed and applied at differing scales, and the linkages between and among SAC technical elements. The first revision of the SAC (FY02) may be used to support the 200 Area Remediation Assessment decision in FY02. The second revision of SAC (FY03) will be used to support the SST retrieval decision in FY04.

Consequently, the SAC is an important end-user of S&T products that provide parameters and models for use at the Hanford Site. Within the next five years, the SAC will require input from the inventory, vadose zone, groundwater, river, and risk assessment technical elements in the S&T roadmap (as listed below).

- Develop models that provide a holistic accounting of contaminant quantity, volume, and timing of releases, with uncertainty boundaries including estimates of containment failure and contaminant release for waste disposal in engineered or man-made systems (inventory technical element; Id. No. Inv-interim report, Inv -final reports, Inv – 8 through Inv-12).

- Develop models and parameters for fate and transport through the 200 Area vadose zone that allow adequate flux predictions of contaminants from vadose zone to groundwater (vadose zone technical element; Id. No.VZ-interim report, VZ-final report, VZ-2,VZ-5, VZ-6, VZ-17, VZ-20, and VZ-21).

- Develop models and parameters for fate and transport of contaminants through the groundwater that allow adequate flux predictions from groundwater to river (groundwater technical element; Id. No. GW-5, GW-7, GW-9, GW-11, GW-12, GW-13, GW-16, GW-18, and GW-19).

- Define the conceptual model of the groundwater/river interface and river; manage and utilize existing information from multiple agencies (as appropriate); adequately characterize the river environment to support impact evaluation and risk assessment activities; and define parameters required for determining the fate and transport of contaminants within and through the Columbia River (river technical element; Id. No. R-1, R-2, R-3, R-4, R-9, R-21, R-23, R-24, and R-25).

- Evaluate potential impact of contaminants on the river system (river and risk assessment technical elements; Id. No. R-27 through R-30).

- Define the approach for assessing hazards and consequences of contaminants that reach receptors (risk assessment technical element; products not yet defined).

200 Area Remediation Assessment (RA): S&T activities linked to the 200 Area RA provide conceptual models, analytical and numerical models, data, and model parameters that directly support the 200 Area Remediation Assessment decisions.

Characterization of the 200 Area waste site groupings is scheduled to begin in FY99 and continue through early FY04. Analysis of field characterization results will lead to an assessment of the readiness to proceed with remediation in FY02, which is one of the key decision points for the Integration Project. The S&T activities described in this roadmap support this project and the key decision point through the following activities:

- Develop the models to estimate quantity, volume, and timing of releases to the soil sites receiving plant cooling water, chemical sewer, scavenging waste, and surface spills (inventory technical element; Id. No. Inv-4 through Inv-7).

- Assess existing reactive transport models using existing characterization data for the 200-BP-1 crib complex to determine whether advanced modeling provides improved information for decisions or system assessment (vadose zone technical element; Id. No. VZ-7).

- Document the benefit of new and advanced vadose zone characterization tools that may be transferred to 200 Area characterization activities (vadose zone technical element; Id. No. VZ-22, VZ-24, and VZ-25).

- Conduct biogeochemical studies on sites receiving transuranic (TRU) and organic (e.g., DNAPLs) wastes such as those received by the Z-9 trench (groundwater technical element; Id. No. GW-6 and GW-7).

- Conduct biogeochemical studies for the TRU at injection well sites (e.g., B-5 reverse well); (groundwater technical element; Id. No. GW-8 and GW-9).

- Re-evaluate existing data from groundwater monitoring activities and conduct depth-discreet sampling in existing wells to collect additional data that describes the 3-dimensional plume in the groundwater near the vadose zone discharge (groundwater technical element; Id. No. GW-2 and GW-4).

TWRS Vadose Zone: S&T activities linked to the TWRS Vadose Zone Project provide conceptual models, analytical and numerical models, data, and model parameters that support the SST Retrieval decisions.

The TWRS Vadose Zone Project is collecting field data to better assess the need for corrective measures in the tank farms to mitigate further migration of contaminants released from tanks or ancillary facilities. A date for the decisions for corrective actions is currently being negotiated with the state, but is anticipated to occur early within the five-year time horizon covered by this roadmap. Concurrently, data will be collected that will be useful to future decisions such as single-shell tank (SST) retrieval, which has a decision point in FY04, and SST closure (which is addressed through the NEPA process that begins in FY04). The S&T activities described in this roadmap support this project and the key decision point through the following activities:

- Provide chemistry models for the tanks; better thermal models to establish leaks lost; and better techniques to estimate contamination (particularly non-gamma emitters) already in vadose zone (inventory technical element; Id. No. VZ-1, VZ-2, VZ-3).

- Conduct wrap-around science[†] at representative field sites to collect samples that provide data for focused lab studies on waste-sediment interaction and numerical modeling of reactive transport to understand the contaminant migration process near leaked tanks and to predict future migration resulting from recharge or tank retrieval losses (vadose zone technical element; Id. No. VZ-1 through VZ-6).

- As part of the wrap-around science effort, carry out vadose zone hydrology tests at uncontaminated sites that allow reconciliation of conceptual and numerical models describing hydrogeologic flow through different Hanford Site vadose zone geologies (vadose zone technical element; Id. No. VZ-16 through VZ-21).

[†] Wrap-around science refers to additional activities (such as sampling and analysis) that are conducted in conjunction with the site-specific project field activities that support scientific investigations beyond the project-specific objectives but still pertinent to system assessment needs.

- Deploy advanced vadose zone characterization for measurement of water and solute transport at representative field sites, and at the vadose zone hydrology test site (vadose zone technical element; Id. No. VZ-22 through VZ-26).

- Re-evaluate existing data from groundwater monitoring activities and conduct depth-discreet sampling in existing wells to collect additional data that describe the 3-dimensional plume in the groundwater near the near-source discharge from the vadose zone (groundwater technical element; Id. No. GW-1, GW-3).

- Evaluate the impact of tank farm species reaching the Columbia River, even in dilute concentrations (river and risk assessment technical elements; R-27 through R-30).

Immobilized Low-Activity Waste (ILAW): A selected set of S&T activities may be conducted in conjunction with the field activities conducted for the ILAW to obtain key data or test models that will support the 200 Area Remediation Assessment and SST Retrieval decisions.

The ILAW facilities, which will be located in the 200 East Area, will receive the low activity waste form generated from the treated and immobilized tank waste. The construction decision for this facility is due in FY03. Hence, current field and S&T activities carried out through the project are directed at gathering the information needed to conduct performance assessments that support this decision. The S&T and field activities currently planned within the project include gathering of data on geology, recharge rates, near-field and far-field hydraulic information, near-field and far-field geochemical information, establishing contaminant transport codes, and definition of a conceptual model. Interaction with the S&T activities within the Integration Project are identified for each of these activities to provide the technical basis for integration between this project and other projects.

- Conduct wrap-around science as appropriate to obtain geology, near- and far-field hydrology, and near- and far-field geochemistry that can be used in conceptual and numerical modeling to the mutual benefit of the ILAW project, the SAC, and the S&T activities (vadose zone technical element; Id. No. to be determined).

- Coordinate activities on reactive transport modeling to ensure mutual benefit of the ILAW project, the SAC, and the S&T activities (vadose zone technical element; Id. No. to be determined).

- Maximize relevant data collection from future boreholes (vadose zone and groundwater technical elements; Id. No. GW-12).

Groundwater Monitoring/Modeling: A selected set of S&T activities may be coordinated with or conducted through the Groundwater Monitoring/Modeling Project to obtain key data or test models that will support the 200 Area Remediation Assessment and SST Retrieval decisions.

Groundwater monitoring is conducted to meet regulatory requirements and to support individual projects in obtaining important data to meet project specific objectives. To meet these goals,

data quality objectives with input from all interested site projects are established annually for new wells. Coordination of S&T tasks with planning for groundwater monitoring provide an opportunity to obtain key field data for both the vadose zone and groundwater technical elements. In addition to monitoring, this project also conducts groundwater modeling that will be important to both the S&T activities and the SAC. The following S&T activities have been identified for coordination with the groundwater monitoring/modeling project.

- Coordination of the re-evaluation of existing data; depth-discreet sampling; and observation of a developing tritium plume from the C018H facility needed to support the TWRS Vadose Zone and 200 Area Remediation Assessment Projects (groundwater technical element; Id. No. Gw-1 through GW-5).

- Definition of the objectives and implementation of 3-dimensional modeling as needed to support the SAC and selected S&T investigations (groundwater technical element; Id. No. GW-17 through GW-23).

- Deployment of advanced characterization and monitoring tools for vadose zone and groundwater (vadose zone technical element; Id. No. VZ-23 and VZ-26).

In FY00, the S&T activities specific to the monitoring technical element will be defined. At that time, S&T will be directly integrated with the Groundwater Monitoring/Modeling Project to provide 1) technical support in the area of advanced monitoring technologies associated with sampling and analysis (e.g., advanced sensors); 2) development and application of technology based monitoring strategies (e.g., use of stable isotope geochemistry, waste specific fingerprints); and 3) application of predictive modeling to support monitoring network design.

River Monitoring: S&T activities will be coordinated with the River Monitoring Project to ensure data and models needed for the river technical element within the SAC are developed and used to support the 200 Area Remediation Assessment and SST Retrieval decisions.

The river monitoring project currently samples the river and the related environment to meet regulatory drivers. Results of the river monitoring activities are used to determine compliance with applicable environmental standards and evaluate the current impacts of Hanford Site operations on the river. Because the river is the key technical element within the SAC that leads to the evaluation of potential impacts and consequences of migrating contaminants, as well as the assessment of potential risk, S&T activities will be coordinated with the river monitoring project to obtain the needed data, parameters, and models. The specific S&T activities are identified below:

- Develop a detailed conceptual model of the river system that includes the critical processes and components necessary to conduct an acceptable assessment; identifies the links between activities across the technical elements; provides a basis for prioritizing and coordinating related activities; and enables S&T development and application for the river technical element in a meaningful manner. Expand the current river conceptual model to meet SAC

requirements; identify existing data strengths and weaknesses; and define contaminant transfer factor requirements/needs (river technical element; Id. No. R-1 through R-4).

- Develop a functional information management and use system/process necessary to enable the conduct of a river assessment and the initiation of S&T development and application. Identify, evaluate, consolidate, and utilize appropriate available information from multiple agencies to support use of the expanded conceptual model in planning S&T activities; determine the fate and transport of contaminants within and through the river system; evaluate potential impacts; and better define future river characterization needs (river technical element; Id. No. R-5 through R-8).

- Define the hydrologic setting, current contaminant levels, species abundance and diversity, sensitive habitats, and critical locations in the Columbia River environment, including the groundwater/river interface. In addition, define and verify input parameters, and provide data for the verification/validation of fate and transport models to be used in the river assessment (river technical element; Id. No. R-9 through R-12).

- Develop a model(s) of the groundwater/river interactions, linking spatial scales of the groundwater model outputs with that necessary in ecological assessments and providing the contaminant flux into the river (groundwater and river technical elements; Id. No. GW-24 and R-13 through R-18).

- Develop numerical biological fate and transport model for application to specific contaminants and specific species of interest for long-term river impacts assessment (river technical element; Id. No. R-21).

- Develop credible models (hydrodynamic, sediment, and contaminant) to describe and predict contaminant migration and fate in the river environment (river technical element; Id. No. R-19, R-20, R-22 through R-25).

- Define impact endpoints or metrics useful in system assessment, risk assessment, remedial action and waste management decision making processes, regulatory analysis, and stakeholder, Tribal Nations, and public evaluations. Define impacts in terms of water quality, species abundance, species diversity, genetic alterations, stress, behavioral modifications, toxicology, exposure, socioeconomic conditions, and/or cultural endpoints (river and risk technical elements; Id. No. R-26 through 30).

I.2.3 Integrated S&T to Support Remediation

The S&T activities that support planned remediations are linked to the following Hanford projects that comprise the GW/VZ Integration Project:

- Groundwater Remediation
- 100/300 Area Waste Sites

- TWRS Vadose Zone (Corrective Measures)
- 200 Area Waste Site Remediation.

Groundwater Remediation and Hanford Burial Grounds/Waste Sites: Pump and treat methods for groundwater remediation are currently being used to remediate the river (e.g., 100 H and 100 K Areas) and plateau sites (e.g., 200 UP and 200 ZP Areas) at the Hanford Site. Alternative groundwater treatment is being considered for 100H, 100K, and 200 ZP through field scale feasibility studies. Additionally, various soil and burial ground remedial activities are underway or planned within the next five years (100/200/300 Areas). Decisions for alternative treatment are scheduled (as shown below). The planned S&T activities for these feasibility studies include the following:

- **Burial Ground Remediation (100 Area)** - Currently, 45 burial grounds are scheduled for excavation. Final design for the excavations will specify technologies for excavation, characterization, segregation, and treatment where necessary. Insertion Point Milestone: FY01.

- **Soils and Burial Ground Remediation (200 Area)** - Planning is underway for the 200 Area soils and burial grounds. Assessment of potential remedial action alternatives will consider technologies for excavation, capping, characterization, segregation, and treatment where necessary. Insertion Point Milestone: FY01.

- **300-FF-2 Remediation (300 Area)** - Planning is underway for the 300-FF-2 Operable Unit soils and burial grounds. Assessment of potential remedial action alternatives will consider technologies for excavation, capping, characterization, segregation, and treatment where necessary. Insertion Point Milestone: FY06.

- **Chromium Remediation (100 Area Groundwater)** - The current interim response measure (IRM) for the chromium plumes is pump-and-treat, to contain the plume such that chromium does not migrate into the Columbia River. Enhanced treatment through application of in situ remediation techniques or improved pump-and-treat approaches are being considered. The current approach is expensive and an alternative approach for a permanent, final remediation for the all the chromium plumes will be considered. Insertion Point Milestone: FY03.

- **Carbon Tetrachloride Remediation (200 Area Groundwater)** - The current interim response measure (IRM) for the carbon tetrachloride plume is pump-and-treat, to contain the plume within the 2000-to-3000 ug/L contour boundaries. The current approach would need to be expanded significantly and continued for several years to treat the entire plume. Enhanced treatment through application of in situ remediation techniques or improved pump-and-treat approaches are being considered as ways to speed remediation and reduce costs. Insertion Point Milestone: FY03.

- **Strontium Remediation (100 Area Groundwater)** - The current remedial action for the strontium plume is pump-and-treat to contain the plume such that strontium does not migrate into the Columbia River. Enhanced treatment through application of in situ remediation

techniques or improved pump-and-treat approaches are being considered. The current approach is expensive and an alternative approach for a permanent, final remediation for the strontium plume will be considered. Insertion Point Milestone: FY08.

I.3 SCHEDULE OF S&T ACTIVITIES AND PRODUCTS

The S&T schedule is a subset of the Integration Project's *Long-Range Plan* that can be found in the baseline documents. Figure I-3 presents that portion of the *Long-Range Plan* describing the S&T activities by technical element at the next lower level of detail. In this figure, the S&T products, the schedule logic, and the linkages of the S&T products to other S&T activities, the SAC, and individual project are shown. The S&T products that link to other S&T activities are depicted by circles with orange lines drawn between the products. The S&T products linked to the SAC are depicted by down arrows. The S&T products linked to individual projects are depicted by up arrows with black lines linking the specific S&T product to the specific individual project. The products are also colored to indicate project lead. Red coloration refers to an S&T activity that will be carried out through a project. An example would be wrap around science which is jointly planned by the project and the S&T lead(s), but the field work is executed through the project. Blue coloration refers to an S&T lead where planning and execution are predominantly conducted by the scientists. Green coloration indicates that there is a mixture of project and S&T leadership.

More detail about Figure 3 is provided in Table I-1. In this table, the identification number for the S&T product used in Figure I-3 guides the reader to the following information:

- Technical element
- S&T activity within the technical element
- Descriptive (and unique) title for each S&T product shown in Figure I-3
- Brief description of scope and outcome for each S&T product shown in Figure I-3
- Identification of the projects or other S&T activities for which integration or coordination is needed to conduct the S&T activity and generate the desired product
- Identification of the recipient (or customer) for the S&T product
- Date that startup is needed for the overall S&T activity within each technical element to meet "compliance case" project schedules (most activities are proposed for startup in FY99, with some activities starting in FY00)
- S&T product delivery date assuming startup date met and budget shown in Table I-2 is provided per schedule

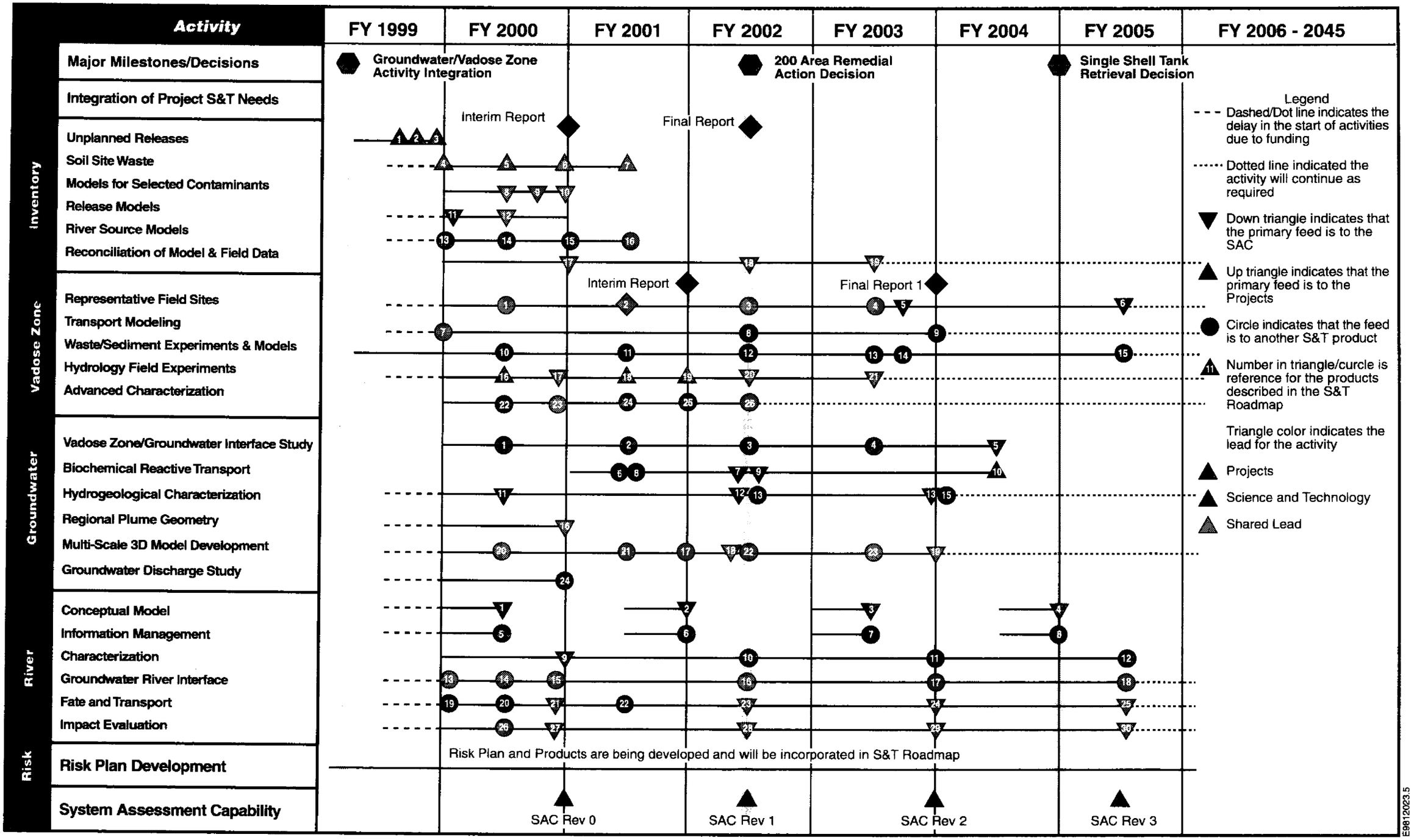


Figure I-3. Applied Science and Technology Schedule, Logic, and Linkages.

Table I-1. S&T Schedule and Products for Inventory, Vadose Zone, Groundwater, and River Technical Elements

Inventory Technical Element							
Inv-final report	Soil Site Waste Inventory	Soil Site Waste Inventory	Develops disposal timeline and waste inventory for waste site groupings	SAC to define waste site groupings, establish priorities for groupings and key contaminants	SAC Rev 1	Mar 99	Mar 02
Inv-interim report	Soil Site Waste Inventory	Intermediate Inventory	Develops disposal timeline for waste site groupings and derives inventory on a contaminant basis	SAC to define waste site groupings, establish priorities for groupings and key contaminants	SAC Rev0	Mar 99	Sept 00
Inv-1	Unplanned Releases	Boiling Waste Tanks (S, SX, A, AX)	Estimate of UPR volumes and waste composition that defines basis for release to soil	TWRS Vadose Zone Project	TWRS Vadose Zone Project, input to Vadose Zone Product # VZ-1 and Inv-interim report	Jan 99	Jun 99
Inv-2	Unplanned Releases	Dilute Waste Leaks (B, BX, T, TY, C)	Estimate of UPR volumes and waste composition that defines basis for soil release	TWRS Vadose Zone Project	TWRS Vadose Zone Project, input to Vadose Zone Product # VZ-1 and Inv-interim report	Jan 99	Aug 99
Inv-3	Unplanned Releases	Concentrated Tank Leaks (BY, U, TX)	Estimate of UPR volumes and waste composition that defines basis for soil release	TWRS Vadose Zone Project	TWRS Vadose Zone Project, input to Vadose Zone Product # VZ-1 and Inv-interim report	Jan 99	Sept 99

Table I-1. S&T Schedule and Products for Inventory, Vadose Zone, Groundwater, and River Technical Elements

Inv-4	Soil Site Waste Inventory	Plant Cooling Water Model	Contaminant inventories and physical properties of soil site group with uncertainty value for volume and quantity.	200 Area Remediation Assessment Project	200 Area Remediation Assessment Project and Inv-interim report	Mar 99	Sept 99
Inv-5	Soil Site Waste Inventory	Chemical Sewer Model	Contaminant inventories and physical properties of soil site group with uncertainty value for volume and quantity.	200 Area Remediation Assessment Project	200 Area Remediation Assessment Project and Inv-interim report	Mar 99	Mar 00
Inv-6	Soil Site Waste Inventory	Scavenging Waste Model	Contaminant inventories and physical properties of soil site group with uncertainty value for volume and quantity.	200 Area Remediation Assessment Project	200 Area Remediation Assessment Project and Inv-interim report	Mar 99	Sept 00
Inv-7	Soil Site Waste Inventory	Surface Spill Model	Contaminant inventories and physical properties of soil site group with uncertainty value for volume and quantity.	200 Area Remediation Assessment Project	200 Area Remediation Assessment Project and Inv-final report	Mar 99	Mar 01
Inv-8	Models for Selected Contami-nants	Tc-99 Model	Model to describe distribution of Tc-99 as input to waste type models	SAC	SAC – Rev 0	Oct 99	Mar 00
Inv-9	Models for Selected Contami-nants	Tritium Model	Model to describe distribution of tritium as input to waste type models	SAC	SAC – Rev 0	Oct 99	Jun 00

Table I-1. S&T Schedule and Products for Inventory, Vadose Zone, Groundwater, and River Technical Elements

Inv-10	Models for Selected Contami-nants	I-129 Model	Model to describe distribution of I-129 as input to waste type models	SAC	SAC – Rev 0	Oct 99	Sept 00
Inv-11	Release Models	Solid Waste Site Release Model	Release model for solid waste	SAC	SAC – Rev 0	Mar 99	Sept 99
Inv-12	Release Models	I-129 Saddles	Release model from saddles used to capture I-129 from offgas	SAC	SAC – Rev 0	Mar 99	Mar 00
Inv-13	River Source Term	Cr Sources	Determines quantity of released chromium to river	SAC & River Monitoring Project	Input to River Product # R-1	Mar 99	Sept 99
Inv-14	River Source Term	Sr-90 @ N Springs	Determines quantity of released strontium-90 to river	SAC & River Monitoring Project	Input to River Product # R-1	Mar 99	Mar 00
Inv-15	River Source Term	Co-60	Determines quantity of released cobalt-60 to river	SAC & River Monitoring Project	Input to River Product # R-2	Mar 99	Sept 00
Inv-16	River Source Term	Tritium	Determines quantity of released tritium to river	SAC & River Monitoring Project	Input to River Product # R-2	Mar 99	Mar 01
Inv -17	Reconcilia-tion of Model and Field Data	Reconcile Inventory – Rev 0	Reconcile inventory from field data collection and S&T activities	Vadose Zone, Groundwater,& River Technical Elements and 200 Area Remediation Assessment and TWRS Vadose Zone Projects	SAC – Rev 0	Oct 99	Sept 00
Inv -18	Reconcilia-tion of Model and Field Data	Reconcile Inventory – Rev 1	Reconcile inventory from field data collection and S&T activities	Vadose Zone, Groundwater,& River Technical Elements and 200 Area Remediation Assessment and TWRS Vadose Zone Projects	SAC – Rev 1	Oct 99	Mar 02

Table I-1. S&T Schedule and Products for Inventory, Vadose Zone, Groundwater, and River Technical Elements

Inv -19	Reconciliation of Model and Field Data	Reconcile Inventory – Rev 2	Reconcile inventory from field data collection and S&T activities	Vadose Zone, Groundwater,& River Technical Elements and 200 Area Remediation Assessment and TWRS Vadose Zone Projects	SAC – Rev 2	Oct 99	Mar 03
Vadose Zone Technical Element							
VZ-interim report	Field Investigations of Representa-tive Sites	Interim input to SAC for 200 Area RA Decision	Interim conceptual and numerical models to SAC for 200 Area Remediation Assessment	SAC and 200 Area Remediation Assessment Project	SAC – Rev 1	Mar 99	Sept 01
VZ-final report 1	Field Investigations of Representa-tive Sites	Tank farm assessment tools to support SST Retrieval Decision	A suite of conceptual and numeric models, associated data bases, and advanced characterization techniques will be assembled to provide a scientifically defensible capability to simulate water and contaminant migration (immobilization, remobilization, etc.) in the tank farms.	SAC and TWRS Vadose Zone Project	SAC Rev 2, TWRS Vadose Zone Project (SST Program)	Mar 99	Sep 03
VZ-final report 2	Field Investigations of Representa-tive Sites	Models for 200 Area waste sites including tank closure and soil remediation	A suite of conceptual and numeric models, associated data bases, and advanced characterization techniques will be assembled to provide a scientifically defensible capability to simulate water and contaminant migration (immobilization, remobilization, etc.) in waste cribs and retention basins in the Hanford 200 Areas.	SAC and 200 Area Remediation Assessments Project	200 Area Remediation Assessments Project	Mar 99	FY08

Table I-1. S&T Schedule and Products for Inventory, Vadose Zone, Groundwater, and River Technical Elements

VZ-1	Field Investiga-tions of Representa -tive Sites	Preliminary conceptual models – Site 1	A preliminary depiction of the chemical and hydrologic phenomena that control contaminant distribution beneath tank farms (candidates S/SX, B/BX, BY/TX /Tank Farms)	TWRS Vadose Zone Project and Inventory Technical Element	Input to Product # VZ – Interim Report and useful to TWRS Vadose Zone Project	Mar 99	Mar 00
VZ-2	Field Investiga-tions of Representa -tive Sites	Preliminary conceptual models – Site 2	A preliminary depiction of the chemical and hydrologic phenomena that control contaminant distribution at a soil site	200 Area Remediation Assessments Project and Inventory Technical Element	Input to SAC – Rev 1, Product # VZ- Interim Report, and useful to 200 Area Remediation Assessment Project	Mar 99	Mar 01
VZ-3	Field Investiga-tions of Representa -tive Sites	Preliminary conceptual models – Site 3	A preliminary depiction of the chemical and hydrologic phenomena that control contaminant distribution beneath tank farms (candidates S/SX, B/BX, BY/TX /Tank Farms)	TWRS Vadose Zone Project and Inventory Technical Element	Input to Product # VZ – Final Report 1 and useful to TWRS Vadose Zone Project	Mar 99	Mar 02
VZ-4	Field Investiga-tions of Representa -tive Sites	Preliminary conceptual models – Site 4	A preliminary depiction of the chemical and hydrologic phenomena that control contaminant distribution at a soil site	200 Area Remediation Assessments Project and Inventory Technical Element	Input to SAC – Rev 1, Product # VZ-final Report 1, and useful to 200 Area Remediation Assessment Project	Mar 99	Mar 03

Table I-1. S&T Schedule and Products for Inventory, Vadose Zone, Groundwater, and River Technical Elements

VZ-5	Field Investiga-tions of Representa -tive Sites	Conceptual models for Input to SAC Rev 2	A comprehensive understanding of subsurface processes controlling contaminant distribution beneath leaked SSTs containing different waste types in different geologic zones	SAC	SAC – Rev 2	Mar 99	Jul 03
VZ-6	Field Investiga-tions of Representa -tive Sites	Conceptual models for Input to SAC Rev 3	A comprehensive understanding of subsurface processes controlling contaminant distribution beneath leaked SSTs containing different waste types in different geologic zones	SAC	SAC – Rev 3	Mar 99	Mar 05
VZ-7	Transport Modeling	Best existing transport codes	A literature evaluation and history matching exercise using characterization data from a Hanford waste site to identify the best available transport code(s) for Hanford applications.	Representative Sites and Waste-Sediment Lab Studies tasks of Vadose Zone Technical Element	Input to Product # VZ-1 within Vadose ZoneTechnical Element	Mar 99	Sept 99
VZ-8	Transport Modeling	Interim codes for corrective action	The best available transport code will be modified as appropriate for SST application integrating i.) preliminary conceptual models and data from waste site sampling and leak simulation experiments and ii.) interim data from laboratory experiments.	Representative Sites and Waste-Sediment Lab Studies tasks of Vadose Zone Technical Element	Input to Product # VZ-3 within Vadose ZoneTechnical Element	Mar 99	Mar 02
VZ-9	Transport Modeling	Complete transport code (s)	A suite of codes and needed data bases will be produced that integrate process-level geochemical and hydrologic models that have been calibrated against field and laboratory experiments and tested at selected sampled waste sites.	Representative Sites and Waste-Sediment Lab Studies tasks of Vadose Zone Technical Element	Input to Product # VZ-final report 1	Mar 99	Sept 03

Table I-1. S&T Schedule and Products for Inventory, Vadose Zone, Groundwater, and River Technical Elements

VZ-10	Waste-Sediment Lab Expts & Process Models	Interim data – Site 1	Laboratory kinetic and thermodynamic data on selected contaminants and first order chemical and hydrochemical reactions and processes directed at tank site (e.g., representative site 1 in VZ-1)	Representative Sites and Transport Modeling tasks of Vadose Zone Technical Element	Input to Product # VZ-1	Oct 98 (Some tasks ongoing through EMSP)	Mar 00
VZ-11	Waste-Sediment Lab Expts & Process Models	Interim data – Site 2	Laboratory kinetic and thermodynamic data on selected contaminants and first order chemical and hydrochemical reactions and processes directed at soil site (e.g., representative site 2 in VZ-2)	Representative Sites and Transport Modeling tasks of Vadose Zone Technical Element	Input to Product # VZ - 2	Oct 98 (Some tasks ongoing through EMSP)	Mar 01
VZ-12	Waste-Sediment Lab Expts & Process Models	Interim data – Site 3	Laboratory kinetic and thermodynamic data on first order chemical and hydrochemical reactions for selected contaminants directed at second tank site (e.g., representative site 3 in VZ-3)	Representative Sites and Transport Modeling tasks of Vadose Zone Technical Element	Input to Product # VZ - 3	Oct 98 (Some tasks ongoing through EMSP)	Mar 02
VZ-13	Waste-Sediment Lab Expts & Process Models	Interim data – Site 4	Laboratory kinetic and thermodynamic data on selected contaminants and first order chemical and hydrochemical reactions and processes directed at soil site (e.g., representative site 4 in VZ-4)	Representative Sites and Transport Modeling tasks of Vadose Zone Technical Element	Input to Product # VZ - 4	Oct 98 (Some tasks ongoing through EMSP)	Mar 03

Table I-1. S&T Schedule and Products for Inventory, Vadose Zone, Groundwater, and River Technical Elements

VZ-14	Waste-Sediment Lab Expts & Process Models	Process models and data – tank sites	Numerical models of first order hydrochemical processes, descriptive thermodynamic and kinetic data, 1-D model/data verification using unsaturated flow columns representative of selected tank sites.	Representative Sites and Transport Modeling tasks of Vadose Zone Technical Element	Input to Product # VZ - 5	Oct 98 (Some tasks ongoing through EMSP)	Jul 03
VZ-15	Waste-Sediment Lab Expts & Process Models	Process models and data – soil sites	Numerical models of first order hydrochemical processes, descriptive thermodynamic and kinetic data, 1-D model/data verification using unsaturated flow columns representative of 200 Area soil sites.	Representative Sites and Transport Modeling tasks of Vadose Zone Technical Element	Input to Product # VZ - 6	Oct 98 (Some tasks ongoing through EMSP)	Mar 05
VZ-16	Vadose Zone Transport Field Studies	Leak simulation experiments Tank Farm 1	Field experiments demonstrating water migration pathways in different vadose zone geologies beneath simulated single shell waste tanks for S, SX, A, or AX.	TWRS Vadose Zone Project	TWRS Vadose Zone Project	Mar 99	Mar 00
VZ-17	Vadose Zone Transport Field Studies	Field scale verification – site 1	Integrated field scale infiltration/tracer experiments and transport modeling that demonstrates an improved capability to describe water and solute migration through the vadose zone to integrate with Site 1 (e.g., VZ-1)	SAC , 200 Area Remediation Assessment Project, and TWRS Vadose Zone Project	SAC – Rev 0	Mar 99	Aug 00
VZ-18	Vadose Zone Transport Field Studies	Leak simulation experiments – Tank Farm 2	Field experiments demonstrating water migration pathways in different vadose zone geologies beneath simulated single shell waste tanks for B, BX, T, or TY.	TWRS Vadose Zone Project	TWRS Vadose Zone Project	Mar 99	Mar 01

Table I-1. S&T Schedule and Products for Inventory, Vadose Zone, Groundwater, and River Technical Elements

VZ-19	Vadose Zone Transport Field Studies	Leak simulation experiments – Tank Farm 3	Field experiments demonstrating water migration pathways in different vadose zone geologies beneath simulated single shell waste tanks for BY, U, or TX.	TWRS Vadose Zone Project	TWRS Vadose Zone Project	Mar 99	Sept 01
VZ-20	Vadose Zone Transport Field Studies	Field scale verification - soils site for 200 Area	Integrated field scale infiltration/tracer experiments and transport modeling that demonstrates an improved capability to describe water and solute migration through the vadose zone to support 200 Remediation Assessment decision.	SAC , 200 Area Remediation Assessment Project, and TWRS Vadose Zone Project	SAC – Rev 1	Mar 99	Mar 02
VZ-21	Vadose Zone Transport Field Studies	Field scale verification – tank farms	Integrated field scale infiltration/tracer experiments and transport modeling that demonstrates an improved capability to describe water and solute migration through the vadose zone to support SST retrieval and tank farm closure decisions.	SAC , 200 Area Remediation Assessment Project, and TWRS Vadose Zone Project	SAC – Rev 2	Mar 99	Mar 03
VZ-22	Advanced Vadose Zone Characteri-zation	Enhanced methods application at leak test 1	Apply pedotransfer function methods to estimate hydraulic variability and ERT or similar tomographic methods to measure shape and distribution of contaminant plumes at first tank farm leak test.	Vadose Zone Hydrology Test in Vadose Zone Technical Element, Groundwater Monitoring/Modeling Project, and TWRS Vadose Zone Project (SST Retrieval)	Input to Product # VZ-16	Mar 99	Mar 00

Table I-1. S&T Schedule and Products for Inventory, Vadose Zone, Groundwater, and River Technical Elements

VZ-23	Advanced Vadose Zone Characteri-zation	Enhanced methods application at field verification site 1	Apply pedotransfer function methods to estimate hydraulic variability and ERT or similar tomographic methods to measure shape and distribution of contaminant plumes at first field scale verification.	Vadose Zone Hydrology Test in Vadose Zone Technical Element, Groundwater Monitoring/Modeling Project, and TWRS Vadose Zone Project (SST Retrieval)	Input to Product # VZ-17	Mar 99	Aug 00
VZ-24	Advanced Vadose Zone Characteri-zation	Enhanced methods application at leak test 2	Apply pedotransfer function methods to estimate hydraulic variability and ERT or similar tomographic methods to measure shape and distribution of contaminant plumes at second tank farm leak test.	Vadose Zone Hydrology Test in Vadose Zone Technical Element, Groundwater Monitoring/Modeling Project, and TWRS Vadose Zone Project (SST Retrieval)	Input to Product # VZ-18	Mar 99	Mar 01
VZ-25	Advanced Vadose Zone Characteri-zation	Enhanced tool deployment at leak site 3	Deploy improved tomography, advanced tensiometers, flux meters and tracers to document flow and transport at clean site surrogates of tank farm for leak test 3.	Vadose Zone Hydrology Test in Vadose Zone Technical Element, Groundwater Monitoring/Modeling Project, and TWRS Vadose Zone Project (SST Retrieval)	Input to Product # VZ-19	Mar 99	Sept 01
VZ-26	Advanced Vadose Zone Characteri-zation	Enhanced tool deployment at verification site 2	Deploy improved tomography, advanced tensiometers, flux meters and tracers to document flow and transport at clean site surrogates for field verification 2	Vadose Zone Hydrology Test in Vadose Zone Technical Element, Groundwater Monitoring/Modeling Project, and TWRS Vadose Zone Project (SST Retrieval)	Input to Product # VZ-20	Mar 99	Mar 02

Table I-1. S&T Schedule and Products for Inventory, Vadose Zone, Groundwater, and River Technical Elements

Groundwater Technical Element							
GW-1	Vadose Zone-Ground-water Interface Study	Depth-Discrete Sampling at Vadose Zone Discharge – Representative Site 1	Spatial and temporal interpretation of historical GW data to better evaluate 3-dimension plume at discharge point. Augment with additional depth-discrete in existing wells.	TWRS Vadose Zone Project, Groundwater Monitoring/Modeling Project, and Representative Sites in Vadose Zone Technical Element	Input to Vadose Zone Product # VZ-1 and Inventory Product # Inv -17	Oct 99	Mar 00
GW-2	Vadose Zone-Ground-water Interface Study	Depth-Discrete Sampling at Vadose Zone Discharge – Representative Site 2	Spatial and temporal interpretation of historical GW data to better evaluate 3-dimension plume at discharge point. Augment with additional depth-discrete in existing wells.	200 Area Remediation Assessment Project, Groundwater Monitoring/Modeling Project, and Representative Sites in Vadose Zone Technical Element	Input to Vadose Zone Product # VZ-2 and Inventory Product # Inv -18	Oct 99	Mar 01
GW-3	Vadose Zone-Ground-water Interface Study	Depth-Discrete Sampling at Vadose Zone Discharge – Representative Site 3	Spatial and temporal interpretation of historical GW data to better evaluate 3-dimension plume at discharge point. Augment with additional depth-discrete in existing and new wells.	TWRS Vadose Zone Project, Groundwater Monitoring/Modeling Project, and Representative Sites in Vadose Zone Technical Element	Input to Vadose Zone Product # VZ-3 and Inventory Product # Inv -18	Oct 99	Mar 02
GW-4	Vadose Zone-Ground-water Interface Study	Depth-Discrete Sampling at Vadose Zone Discharge – Site 4	Spatial and temporal interpretation of historical GW data to better evaluate 3-dimension plume at discharge point. Augment with additional depth-discrete in existing and new wells.	200 Area Remediation Assessment Project, Groundwater Monitoring/Modeling Project, and Representative Sites in Vadose Zone Technical Element	Input to Vadose Zone Product # VZ-4 and Inventory Product # Inv -19	Oct 99	Mar 03

Table I-1. S&T Schedule and Products for Inventory, Vadose Zone, Groundwater, and River Technical Elements

GW-5	Vadose Zone-Ground-water Interface Study	Tritium Plume Development	Document development of a new tritium plume from the C018H facility to better define 3-D flow.	SAC	SAC – Rev 3	Oct 99	Mar 04
GW-6	Biogeo-chemical Reactive Transport	Biogeochemical Transport of TRU in DNAPL - Interim	Preliminary determination of the fate of plutonium, americium, and neptunium in DNAPL as mixture reaches groundwater.	SAC and 200 Area Remediation Assessment Project	Input to Vadose Zone Product # VZ-2	Oct 99	Mar 01
GW-7	Biogeo-chemical Reactive Transport	Biogeochemical Transport of TRU in DNAPL - Final	Final determination of the fate of plutonium, americium, and neptunium in DNAPL as mixture reaches groundwater.	SAC and 200 Area Remediation Assessment Project	SAC Rev 1	Oct 99	Mar 02
GW-8	Biogeo-chemical Reactive Transport	Biogeochemical Transport of TRU Discharged to Reverse Wells - Interim	Preliminary determination of mobility of TRU (especially neptunium) associated with bismuth phosphate process as it enters unconfined aquifer.	SAC and 200 Area Remediation Assessment Project	Input to Vadose Zone Product # VZ-2	Oct 99	Mar 01
GW-9	Biogeo-chemical Reactive Transport	Biogeochemical Transport of TRU Discharged to Reverse Wells - Final	Final determination of mobility of TRU (especially neptunium) associated with bismuth phosphate process as it enters unconfined aquifer.	SAC and 200 Area Remediation Assessment Project	SAC Rev 1	Oct 99	Mar 02
GW-10	Biogeo-chemical Reactive Transport	CCl4 Biochemistry	Determine feasibility of biodegradation of CCl4 under anoxic conditions	SAC and 200 Area Remediation Assessment Project	Alternative Treatment for 200 ZP	Oct 99	Mar 04
GW-11	Hydrogeo-logical Characteri-zation Study	Historical Groundwater Data Review	Review and interpret historical data with the objective of addressing hierarchy of scales for hydrogeochemcial characterization	SAC and Groundwater Monitoring/Modeling Project	SAC – Rev 0	Mar 99	Mar 00

Table I-1. S&T Schedule and Products for Inventory, Vadose Zone, Groundwater, and River Technical Elements

GW-12	Hydrogeo-logical Characteri-zation Study	Multi-scale Study – Soil Site	Conduct multiple-scale studies at a clean site such as ILAW or 200 Area Remediation Assessment site	SAC, ILAW, 200 Area Remediation Assessment Project, Groundwater Monitoring/Modeling Project	SAC – Rev 1	Mar 99	Mar 02
GW-13	Hydrogeo-logical Characteri-zation Study	Multi-scale Study – Tank Site	Conduct multiple-scale studies at selected vadose representative tank site	SAC, TWRS Vadose Zone Project, Groundwater Monitoring/Modeling Project, and Representative Sites in Vadose Zone Technical Element	SAC – Rev 2	Mar 99	Sept 03
GW-14	Hydrogeo-logical Characteri-zation Study	Synthesis & Visualization of Hydrogeology – Soil Site	Refine existing field- and detailed-scale geological and hydrological maps to be used to build 3D computer visualization and input to numerical models, provide estimates of small-scale hydrological property variability and spatial correlation to numerical modeling, investigate scale dependence of hydraulic measurements, investigate important scales of physical and hydrological heterogeneity characterization, provide guidelines for modeling and monitoring, and develop suite of tools	Hydrogeochemical Characterization multi-scale studies, Groundwater Monitoring/Modeling Project	Input to Groundwater Product # GW-12	Mar 99	Mar 02

Table I-1. S&T Schedule and Products for Inventory, Vadose Zone, Groundwater, and River Technical Elements

GW-15	Hydrogeo-logical Characteri-zation Study	Synthesis & Visualization of Hydrogeology – Tank Site	Refine existing field- and detailed-scale geological and hydrological maps to be used to build 3D computer visualization and input to numerical models, provide estimates of small-scale hydrological property variability and spatial correlation to numerical modeling, investigate scale dependence of hydraulic measurements, investigate important scales of physical and hydrological heterogeneity characterization, provide guidelines for modeling and monitoring, and develop suite of tools	Hydrogeochemical Characterization multi-scale studies, Groundwater Monitoring/Modeling Project	Input to Groundwater Product # GW-13	Mar 99	Sept 03
GW-16	Regional Plume Geometry	3D Imaging of Regional Plumes	Define transect, install wells, and collect depth-discreet sampling of groundwater extending from 200 Area West to river.	SAC and Groundwater Monitoring/Modeling Project	SAC – Rev 0	Mar 99	Sept 00
GW-17	Multi-scale 3D Model Develop-ment	Define 3D Modeling Objectives	Establish requirements for representation of continuum physics and chemistry across scale boundaries,; balance localized geohydrological and biogeochemical environments at facies or smaller scales; and consider multicomponent speciation and mineral phase interaction and decay and transformation rates.	SAC and Groundwater Monitoring/Modeling Project	Input to Groundwater Product # GW-18	Mar 99	Aug 01

Table I-1. S&T Schedule and Products for Inventory, Vadose Zone, Groundwater, and River Technical Elements

GW-18	Multi-scale 3D Model Develop-ment	Multi-Scale Model Approach for Region - Interim	Develop and implement an approach for multi-scale modeling over a regional area with a focus on soil site issues	SAC, Hydrogeological Characterization Science in Groundwater Technical Element, and Groundwater Monitoring/Modeling Project	SAC – Rev 1	Mar 99	Mar 02
GW-19	Multi-scale 3D Model Develop-ment	Multi-Scale Model Approach for Region - Final	Develop and implement an approach for multi-scale modeling over a regional area with a focus on tank site issues	SAC, Hydrogeological Characterization Science in Groundwater Technical Element, and Groundwater Monitoring/Modeling Project	SAC Rev 2	Mar 99	Sept 03
GW-20	Multi-scale 3D Model Develop-ment	Site–Specific Multi-Scale 3-D Model Development – Representative Site 1	Develop and implement an approach for multi-scale modeling for a specific site selected through the vadose zone technical element	SAC, Groundwater Monitoring/Modeling Project, and Representative Sites in Vadose Zone Technical Element	Input to Vadose Zone Product # VZ-1	Mar 99	Mar 00
GW-21	Multi-scale 3D Model Develop-ment	Site–Specific Multi-Scale 3-D Model Development – Representative Site 2	Develop and implement an approach for multi-scale modeling for a specific site selected through the vadose zone technical element	SAC, Groundwater Monitoring/Modeling Project, and Representative Sites in Vadose Zone Technical Element	Input to Vadose Zone Product # VZ-2	Mar 99	Mar 01
GW-22	Multi-scale 3D Model Develop-ment	Site–Specific Multi-Scale 3-D Model Development – Representative Site 3	Develop and implement an approach for multi-scale modeling for a specific site selected through the vadose zone technical element	SAC, Groundwater Monitoring/Modeling Project, and Representative Sites in Vadose Zone Technical Element	Input to Vadose Zone Product # VZ-3	Mar 99	Mar 02

Table I-1. S&T Schedule and Products for Inventory, Vadose Zone, Groundwater, and River Technical Elements

GW-23	Multi-scale 3D Model Develop-ment	Site–Specific Multi-Scale 3-D Model Development – Representative Site 4	Develop and implement an approach for multi-scale modeling for a specific site selected through the vadose zone technical element	SAC, Groundwater Monitoring/Modeling Project, and Representative Sites in Vadose Zone Technical Element	Input to Vadose Zone Product # VZ-4	Mar 99	Mar 03
GW-24	Ground-water Discharge Study	GW Discharge Study	Install, interpret and image data from an array of multi-level samplers near river, but not in bank storage area.	River Technical Element and Groundwater Monitoring/Modeling Project	Input to River Product # R-15	Mar 99	Mar 00
River Technical Element							
R-1	Detailed Conceptual Model	Rev 0 Conceptual Model of River	Detailed conceptual model of the river system. Includes critical processes and components necessary to conduct acceptable river assessment. Identifies links between activities across project. Provides basis for prioritizing and coordinating related activi-ties. Enables S&T development and application in a meaningful manner.	SAC and River Monitoring Project	SAC - Rev 0	Mar 99	Mar 00
R-2	Detailed Conceptual Model	Rev 1 Conceptual Model of River	Update river conceptual model based on additional field data and an update of requirements from SAC Rev 0.	SAC and River Monitoring Project	SAC – Rev 1	Mar 01	Sep 01
R-3	Detailed Conceptual Model	Rev 2 Conceptual Model of River	Update river conceptual model based on additional field data and an update of requirements from SAC Rev 1.	SAC and River Monitoring Project	SAC – Rev 2	Sep 02	Mar 03

Table I-1. S&T Schedule and Products for Inventory, Vadose Zone, Groundwater, and River Technical Elements

R-4	Detailed Conceptual Model	Rev 3 Conceptual Model of River	Update river conceptual model based on additional field data and an update of requirements from SAC Rev 2.	SAC and River Monitoring Project	SAC – Rev 3	Mar 04	Sept 04
R-5	Information Management	Processes and Systems for river data management	Develop functional information management and use system/process. Define and implement the processes and establish the system necessary to gather, screen, manage, and disperse the data/information generated both inside and outside the Hanford domain that is considered in the river assessment.	Conceptual Model within River Technical Element and River Source Term from Inventory Technical Element	Input to River Product # R-1	Mar 99	Mar 00
R-6	Information Management	Data Mining	Review available data from multiple agencies and include those data that support review and update of the conceptual model into the information system.	Conceptual Model within River Technical Element and River Source Term from Inventory Technical Element	Input to River Product # R-2	Mar 01	Sep 01
R-7	Information Management	Update information system - Rev 2 of River Conceptual Model	Maintain and update functional information management and use system/process.	Conceptual Model within River Technical Element and River Source Term from Inventory Technical Element	Input to River Product # R-3	Sep 02	Mar 03
R-8	Information Management	Update information system - Rev 3 of River Conceptual Model	Maintain and update functional information management and use system/process.	Conceptual Model within River Technical Element and River Source Term from Inventory Technical Element	Input to River Product # R-4	Mar 04	Sep 04

Table I-1. S&T Schedule and Products for Inventory, Vadose Zone, Groundwater, and River Technical Elements

R-9	Characteri-zation	Fate and Transport Model Parameterization	Determine critical data gaps. Determine biological transfer factors for contaminant/species combinations of interest. To be used in development of biological transport model.	SAC, River Monitoring, and Fate and Transport S&T Activity within River Technical Element	SAC- Rev 0	Oct 99	Sept 00
R-10	Characteri-zation	Species Abundance Data Collection – Transport and Fate for SAC Rev 1	Identify sensitive habitats and critical locations. Define species abundance and distribution within study domain. Basis for conceptual, fate and transport, and contaminant exposure models.	Impact Evaluation within River Technical Element and Ecology within Risk Technical Element	Input to river Product # R-28	Oct 99	Mar 02
R-11	Characteri-zation	Species Abundance Data Collection - Transport and Fate for Sac Rev 2	Update sensitive habitat and critical locations maps as needed for SAC. Update species abundance and distribution information.	Impact Evaluation within River Technical Element and Ecology within Risk Technical Element	Input to river Product # R-29	Oct 99	Sep 03
R-12	Characteri-zation	Species Abundance Data Collection - Transport and Fate for Sac Rev 3	Update sensitive habitat and critical locations maps as needed for SAC. Update species abundance and distribution information.	Impact Evaluation within River Technical Element and Ecology within Risk Technical Element	Input to river Product # R-30	Oct 99	Mar 05
R-13	Ground-water – River Interface Study	Define groundwater dynamics and simulation	Develop site specific conceptual model(s) consistent with SAC and River Technical Element conceptual model.	River Monitoring Project and Groundwater Monitoring/Modeling Project	Input to River Product # R-14	Mar 99	Oct 99

Table I-1. S&T Schedule and Products for Inventory, Vadose Zone, Groundwater, and River Technical Elements

R-14	Ground-water – River Interface Study	Trend Evaluation of Discharges	Define dynamics such as direction, attenuation, decay, chemical transformation, biological processes, transport rates, and preferential pathways associated with contaminant discharge from aquifer into the river. Fill key data needs relative to physical, chemical, and biological processes influencing contaminants flowing from groundwater into the Columbia River.	River Monitoring Project and Groundwater Monitoring/Modeling Project	Input to River Product # R-15	Mar 99	Mar 00
R-15	Ground-water – River Interface Study	Numerical Models for Groundwater Discharge to River	Develop numerical model of the groundwater/river interactions linking spatial scales of the groundwater model outputs with those necessary in ecological assessments and providing contaminant flux into the river.	River Monitoring Project, Groundwater Monitoring/Modeling Project, and Fate and Transport within River Technical Element	Input to River Product # R-21	Mar 99	Aug 00
R-16	Ground-water – River Interface Study	Evaluate Predictive and Observational Data – Rev 1	Evaluate predictive and observational data against impact criteria. Verify/validate numerical model predictions. Evaluate trends in predictive and observational data indicative of changing conditions in GW/River interface.	River Monitoring Project, Groundwater Monitoring/Modeling Project, and Fate and Transport within River Technical Element	Input to River Product # R-23	Mar 99	Mar 02

Table I-1. S&T Schedule and Products for Inventory, Vadose Zone, Groundwater, and River Technical Elements

R-17	Ground-water – River Interface Study	Evaluate Predictive and Observational Data – Rev 2	Evaluate predictive and observational data against impact criteria. Verify/validate numerical model predictions. Evaluate trends in predictive and observational data indicative of changing conditions in GW/River interface.	River Monitoring Project, Groundwater Monitoring/Modeling Project, and Fate and Transport within River Technical Element	Input to River Product # R-24	Mar 99	Sep 03
R-18	Ground-water – River Interface Study	Evaluate Predictive and Observational Data – Rev 3	Evaluate predictive and observational data against impact criteria. Verify/validate numerical model predictions. Evaluate trends in predictive and observational data indicative of changing conditions in GW/River interface.	River Monitoring Project, Groundwater Monitoring/Modeling Project, and Fate and Transport within River Technical Element	Input to River Product # R-25	Mar 99	Mar 05
R-19	Fate and Transport	Analytical Models for River Transport and Fate	Develop a detailed quantitative conceptual model of the river system based on analytical models, existing data or conservative projections, and limited application of numerical models.	River Monitoring Project	Input to River Product # R-20	Mar 99	Oct 99
R-20	Fate and Transport	Hydrodynamic Model for River System	Develop credible hydrodynamic model to describe and predict contaminant migration and fate in the river environment.	River Monitoring Project	Input to River Product # R-21	Mar 99	Mar 00
R-21	Fate and Transport	Sediment and Biological Transport Models for River	Develop credible sediment and biological transport models to describe and predict contaminant migration and fate in the river environment.	SAC and River Monitoring Project	SAC Rev 0	Mar 99	Aug 00

Table I-1. S&T Schedule and Products for Inventory, Vadose Zone, Groundwater, and River Technical Elements

R-22	Fate and Transport	Contaminant Transport Model for River	Develop credible contaminant transport model to describe and predict contaminant migration and fate in the river environment.	SAC and River Monitoring Project	Input to River Product #23	Mar 99	Mar 01
R-23	Fate and Transport	Model Application for SAC – Rev 1	Verify/validate numerical hydrodynamic, sediment, biological, and contaminant transport models. Execute numerical models as warranted for Risk Technical Element and/or SAC.	SAC and River Monitoring Project	SAC Rev 1	Mar 99	Mar 02
R-24	Fate and Transport	Model Application for SAC – Rev 2	Verify/validate numerical hydrodynamic, sediment, biological, and contaminant transport models. Execute numerical models as warranted for Risk Technical Element and/or SAC.	SAC and River Monitoring Project	SAC Rev 2	Mar 99	Sep 03
R-25	Fate and Transport	Model Application for SAC – Rev 3	Verify/validate numerical hydrodynamic, sediment, biological, and contaminant transport models. Execute numerical models as warranted for Risk Technical Element and/or SAC.	SAC and River Monitoring Project	SAC Rev 3	Mar 99	Mar 05
R-26	Impact Evaluation	Impact Evaluation Criteria for River	Develop criteria to evaluate impacts in terms of water quality, species abundance, species diversity, genetic alterations, stress, behavioral modifications, toxicology, and exposure.	SAC and Risk Assessment Technical Element	Input to River Product #R-27	Mar 99	Mar 00

Table I-1. S&T Schedule and Products for Inventory, Vadose Zone, Groundwater, and River Technical Elements

R-27	Impact Evaluation	Toxicological Benchmarks	Identify needed toxicological benchmarks based on gaps in available information relative to species/contaminant combinations of interest. (in conjunction with Risk Technical Element)	SAC and Risk Assessment Technical Element	SAC Rev 0	Mar 99	Aug 00
R-28	Impact Evaluation	Model Prediction Assessment for SAC Rev 1	Evaluate environmental surveillance results against impact criteria and numerical model predictions. Identify trends in contaminant concentrations and potential environmental quality concerns.	SAC and Risk Assessment Technical Element	SAC Rev 1	Mar 99	Mar 02
R-29	Impact Evaluation	Model Prediction Assessment for SAC Rev 2	Evaluate environmental surveillance results against impact criteria and numerical model predictions. Identify trends in contaminant concentrations and potential environmental quality concerns.	SAC and Risk Assessment Technical Element	SAC Rev 2	Mar 99	Sep 03
R-30	Impact Evaluation	Model Prediction Assessment for SAC Rev 3	Evaluate environmental surveillance results against impact criteria and numerical model predictions. Identify trends in contaminant concentrations and potential environmental quality concerns.	SAC and Risk Assessment Technical Element	SAC Rev 3	Mar 99	Mar 05

I.4 BUDGET SUMMARY

The budget for the S&T activities proposed for the next five years is provided in Table I-2. The S&T activity for each technical element in the table corresponds to the S&T activity listed in the second column of Table I-1. All S&T products listed in Table I-1 are included in the budget provided in Table I-2. The potential FY99 funding program has also been identified. Some of the S&T activities are very project specific and must be executed through the projects; these S&T activities would most likely be funded through Hanford site budgets. All other S&T activities are candidates for funding from the Office of Science and Technology (EM-50) or a combination of EM-50 and the Hanford site.

Table I-2. Five-Year Budget Summary by S&T Activity.

Inventory							
	Unplanned Releases	Hanford	200				
	Soil Site Waste Inv	Hanford	470	260	260		
	Models for Sel. Cont.	Hanford		130			
	Release Models	Hanford	65	65			
	River Source Term	Hanford	65	65	65		
	Reconciliation of Model to Field Data	Hanford		130	130	130	130
Inventory Total			**800**	**650**	**455**	**130**	**130**
Vadose Zone							
	Field Investigations of Representative Sites	Hanford and EM-50[a]	2400	3500	4000	4000	3500
	Transport Modeling	EM-50[a]	1200	2000	2500	2500	2500
	Waste-Sediment Lab Expts & Process Models	EM-50[a]	850	2500	3000	3000	3000
	Vadose Zone Transport Field Studies	Hanford and EM-50[a]	1650	3500	4000	4000	4000
	Advanced Vadose Zone Characterization	Hanford and EM-50[a]	1100	2500	2500	2500	2500
Vadose Zone Total			**7200**	**14000**	**16000**	**16000**	**15500**
Groundwater							
	Vadose Zone/Groundwater Interface Study	Hanford and EM-50[a]		650	300	300	300
	Vadose Zone/Groundwater Interface Study – C018H	Hanford				750	750

Table I-2. Five-Year Budget Summary by S&T Activity.

Groundwater (cont.)							
	Biogeochemical Reactive Transport - DNAPL/TRU	EM-50[a]		1500	1500		
	Biogeochemical Reactive Transport – Reverse Wells	EM-50[a]		1500	1500		
	Biogeochemical Reactive Transport – CCl4	EM-50[a]				600	600
	Hydrogeological Characterization - Scale Hierarchy	EM-50[a]	550	1000	1000	1000	1000
	Hydrogeological Characterization – Synthesis/Visualization	EM-50[a]		150	150	150	150
	Regional Plume Study	Hanford	700	1400			
	Multi-scale 3-D Model Development - Regional	Hanford	150	250	250	250	250
	Multi-scale 3-D Model Development – Site-Specific	Hanford	150	250	250	250	250
	Groundwater Discharge Study	Hanford	375	375			
Groundwater Total			**1925**	**7075**	**4950**	**3300**	**3300**
River							
	Detailed Conceptual Model	Hanford	125	125	50	0	50
	Information Mgmt	Hanford	75	175	150	0	50
	Characterization	Hanford		1185	835	835	500
	Groundwater/River Interface Study	Hanford and EM-50[a]	250	750	500	250	250
	Fate and Transport	Hanford and EM-50[a]	500	1000	500	100	100
	Impact Evaluation	Hanford and EM-50[a]	1000	1000	500	500	500
River Total			**1950**	**4235**	**2535**	**1685**	**1450**
Grand Total			**11875**	**25960**	**23940**	**21115**	**20380**

Table I-2. Five-Year Budget Summary by S&T Activity.

Remedial Options							
	Burial Ground Remediation (100 Area[b]						
	Soils and Burial Ground Remediation (200 Area) [b]						
	300-FF-2 Remediation (300 Area) [b]						
	Chromium Remediation (100 Area Groundwater[b]						
	Carbon Tetrachloride Remediation (200 Area Groundwater) [b]						
	Strontium Remediation (100 Area Groundwater) [(b]						

[a] Funding to be requested/negotiated with the Office of Science and Technology (EM-50)
[b] Funding data are not available at this printing.

I.5 S&T PRIORITIES FOR FY99

The objective of prioritizing project activities is to ensure that investments are made in activities that have the greatest potential for improving site decisions. A project activity therefore derives its basic priority from two fundamental considerations: 1) the relative importance of the decisions it is intended to affect; and 2) the anticipated impact it will have on those decisions. Science and technology activities derive their priority from their ability to improve the technical basis for key decisions identified as a priority by the Integration Project. Scheduling, cost, and budget characteristics further determine whether and how an activity is supported in a given year.

In the near term, the project is establishing priorities based on their value for addressing uncertainties inherent in the site's ability to perform defensible assessments of the cumulative effects of its wastes. This approach is based on an assumption that a site-wide SAC lies on the site's critical path for effectively closing the 200 Area remediation assessment and SST retrieval decisions. Therefore, all other things being equal, activities that most effectively support the development and implementation of that assessment capability have highest priority for project funding under a constrained budget.

Using this logic, initial priorities have been established among the candidate S&T activities identified in the S&T roadmap. Those priorities reflect the expected value of information associated with each S&T activity for making credible assessments. The project relied on insights drawn from the CRCIA, guidance about priorities provided by the national laboratory leads, and on the site's experience with the *Retrieval Performance Evaluation* (in draft), the *Composite Analysis* (Kincaid, et al), and other site assessments to formulate the initial "value of information" judgments underlying S&T priorities. Those judgments were based on three fundamental considerations:

1. The magnitude of the uncertainty (or gap in knowledge) associated with each of the major technical elements comprising the assessment capability (inventory, vadose zone, groundwater, and river).
2. The ability of the candidate S&T activities to significantly and effectively reduce the uncertainty or fill the gap.
3. The need to initiate the activity immediately in order to realize its benefit on time to support the first two revisions of the SAC (supporting the site's 200 Area Remediation and SST Tank Retrieval decisions, respectively).

The results of the prioritization are presented in Table I-3. For this iteration of the roadmap, the prioritization was conducted for the inventory, vadose zone, groundwater, and river technical elements. Along with the priorities of the S&T activities within these four technical elements, the cumulative budget totals for the next five years have been provided. No funding line has been determined at the time of this printing. In the next revision (later in FY99), S&T associated with the risk technical element will be included. Hence, the prioritization will be repeated to integrate the risk S&T activities.

Table I-3. Priorities Across the Inventory, Vadose Zone, Groundwater, and River Technical Elements.

Priority	Technical Element	S&T Activity	Cummulative ($K)				
			FY99	FY00	FY01	FY02	FY03
High	Inventory	Soil Site Waste Inventory	470	260	260	0	0
	Inventory	Models for Selected Contaminants	470	390	260	0	0
	Inventory	Release Models	535	455	260	0	0
	Vadose Zone	Field Investigations of Representative Sites	2935	3955	4260	4000	3500
	Vadose Zone	Transport Modeling	4135	5955	6760	6500	6000
	Vadose Zone	Waste/Sediment Lab Experiments and Process Models	4985	8455	9760	9500	9000
	Vadose Zone	Vadose Zone Transport Field Studies	6635	11955	13760	13500	13000
	River	Fate and Transport	7135	12995	14260	13600	13100
	River	Impact Evaluation	8135	13955	14760	14100	13600
	Inventory	Reconciliation of Models to Field Data	8135	14085	14890	14230	13730
	Inventory	Unplanned Releases	8335	14085	14890	14230	13730
Medium	River	Characterization	8335	15270	15725	15065	14230
	River	Groundwater/River Interface Studies	8585	16020	16225	15315	14480
	Vadose Zone	Advanced Vadose Zone Characterization	9685	18520	18725	17815	16980
	Groundwater	Biogeochemical Reactive Transport	9685	21520	21725	18415	17580
	Groundwater	Hydrogeochemical Characterization	10235	22670	22875	19565	18730
	Groundwater	Regional Plume Geometry	10935	24070	22875	19565	18730
	Inventory	River Source Term	11000	24135	22940	19565	18730
	Groundwater	Groundwater Discharge Study	11375	24510	22940	19565	18730
	River	Detailed Conceptual Model	11500	24635	22990	19565	18780
Low	Groundwater	Vadose Zone/Groundwater Interface Study	11500	25285	23290	20615	19830
	Groundwater	Multi-Scale 3D Model Development	11800	25785	23790	21115	20330
	River	Information Management	11875	25960	23940	21115	20380