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Department of Energy

Richland Operations Office
P.O. Box 550
Richland, Washington 99352

SEP 29 1999

Ms. M. L. Blazek
Department of Consumer and Business Services
Oregon Office of Energy
625 Marion Street N.E., Suite 100
Salem, Oregon 97301-3742

Dear Ms. Blazek:

OREGON OFFICE OF ENERGY REQUEST FOR DOCUMENTS: "RISK/IMPACT TECHNICAL REPORT FOR THE HANFORD GROUNDWATER/VADOSE ZONE INTEGRATION PROJECT," FINAL DRAFT JULY 1999, AND "RECOMMENDATIONS FOR SELECTION OF A SITE-WIDE GROUNDWATER MODEL AT THE HANFORD SITE," AUGUST 1999

Per your request both documents are enclosed for your review.

51929

The document "Risk/Impact Technical Report for the Hanford Groundwater/Vadose Zone Integration Project," Final Draft, July 27, 1999, prepared for the U.S. Department of Energy (DOE), Center for Risk Excellence (CRE) and DOE, Richland Operations Office (RL) by Argonne National Laboratory with input from the CRE team has been revised based on received comments and issued for review and comment. Distribution has been made two ways: some individuals on distribution have received hard copies of the document; and all other individuals are receiving notice of electronic access through the Internet. The URL for the document is <http://riskcenter.doe.gov/docs/cre/gwvz/gwvz.cfm>}

The purpose of this technical report is to describe methods for evaluating different kinds of risks and other impacts that could result from multiple contamination sources at the Hanford Site. The overall goal is to strengthen the scientific foundation of environmental decisions to be made, and to help the groundwater/vadose zone component of the environmental management program move forward through the assessment and implementation phase with the best knowledge available.

The CRE and RL would welcome all comments on this final draft. Comments received prior to October 14, 1999, will be accepted for possible incorporation as appropriate. Comments may be sent to me at the above address Mail Stop HO-12, or by fax at (509)376-4360.

The document "Recommendations for Selection of a Site-Wide Groundwater Model at the Hanford Site," August 1999, has been revised based on received comments and issued for distribution. Distribution has been made two ways: some individuals on distribution have received hard copies of the document; and all other individuals are receiving notice of electronic access through the Internet. The URL for the document is http://etd.pnl.gov:2080/gwmodeling//reports/index.html. Please contact me by phone to receive the user name and password.

This draft report provides a current summary of the overall recommendations for consolidation of the site-wide groundwater modeling at the site. These recommendations include descriptions of: (1) the overall approach being used to achieve the objectives of the model consolidation process, (2) past and present uses of groundwater models at the Hanford Site, (3) future groundwater modeling activities, (4) requirements for the consolidation site-wide model, (5) technical issues and concerns on proposed needs and requirements for the consolidated site-wide groundwater model, and (6) an approach to address technical issues and concerns.

Comments are requested by October 9, 1999; or 30 days from when this letter is issued.

If you want to discuss this matter further or require additional information, please contact me at (509)373-9626.

Sincerely,

K. Michael for

R. Douglas Hildebrand, Project Manager
Groundwater Project

GWP:RDH

Enclosures

cc w/encls:
D. Dunning, OOE
S. Sautter, OOE

DOE/RL-99-xxx

Recommendations for Selection of a Site-Wide Groundwater Model at the Hanford Site

August 1999

United States
Department of Energy
P. O. Box 550
Richland, Washington 99352

ABSTRACT

The U.S. Department of Energy, Richland Operations Office (RL) has initiated a project to consolidate multiple groundwater models at the Hanford Site into a single consolidated site-wide groundwater model. This report documents the overall recommendations being made by RL for selection of the site-wide groundwater model in the initial phase of the consolidation process. Included in this report are descriptions of

- the overall approach being used by RL to achieve the objectives of the site-wide groundwater model consolidation process
- the needs and requirements for a site-wide groundwater model that were developed in the initial phase of the site-wide groundwater model consolidation process
- an overview of the consolidated site-wide groundwater model proposed by RL as the starting point for external review
- a summary of technical concerns and issues raised by external reviewers on the consolidated site-wide groundwater model, including input received from the U.S. Environmental Protection Agency (EPA), Washington State Department of Ecology (Ecology), Tribal Nations, and other stakeholders
- refinements and modifications to the consolidated site-wide groundwater model recommended by RL in response to external review comments.

The two most recently used site-wide groundwater modeling efforts conducted for the Hanford Groundwater Project (HGWP) and for the development of the Hanford Site-Wide Groundwater Remediation Strategy (GWRS) were considered in the evaluation. In general, the evaluation of the GWRS and HGWP models showed that both models are capable of meeting many of the requirements for a consolidated site-wide groundwater model. However, RL concluded that the model developed by the HGWP provides broader capabilities to meet the anticipated needs of the site. For this reason, RL selected the HGWP model as the preferred alternative for the initial phase of the site-wide groundwater model-consolidation process.

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EXECUTIVE SUMMARY

Until recently, the Hanford Site has had multiple versions of site-wide groundwater flow and contaminant transport models. In response to both internal and external recommendations, the U.S. Department of Energy - Richland Operations Office (DOE/RL, referred to hereafter as RL) initiated a process to consolidate the site-wide groundwater models into a single model during fiscal year (FY) 1998 to eliminate redundancies and promote consistency in groundwater modeling analyses at the Hanford Site. As an initial step in this process, RL developed a recommendation for a site-wide groundwater model based on the most current hydrogeologic conceptual model of the aquifer system at Hanford.

This report provides a summary of this overall recommendation and describes the basis for the selection. Included in the report as background information for the selection are descriptions of

- the overall approach being used by RL to achieve the objectives of the site-wide groundwater model consolidation process

- the needs and requirements for a site-wide groundwater model that were developed in the initial phase of the site-wide groundwater model consolidation process

- an overview of the consolidated site-wide groundwater model proposed by RL as the starting point for external review.

- a summary of technical concerns and issues raised by external reviewers on the consolidated site-wide groundwater model, including input received from the U.S. Environmental Protection Agency (EPA), Washington State Department of Ecology (Ecology), Tribal Nations, other stakeholders, and the Site-wide Groundwater Model External Peer Review Panel.

The specific needs and requirements and the anticipated future uses of the site-wide groundwater model developed in the initial phase of the site-wide groundwater model consolidation were based, in part, on a review of current and future groundwater modeling activities conducted within the Hanford Site Environmental Restoration, Waste Management, and River Protection programs. The needs and requirements also reflect input collected from external stakeholders, EPA, Ecology, the Hanford Advisory Board, and two Tribal Nations (the Nez Perce Tribe and the Yakama Indian Nation). Representatives of the Confederated Tribes of the Umatilla Indian Reservation were also consulted and asked to participate in the site-wide groundwater model consolidation process.

Based on input received from Hanford Site contractors, Tribal Nations, and stakeholders, the consolidated site-wide groundwater model needs to be capable of being used to meet a variety of Hanford Site project objectives, including:

- site-specific performance assessments of proposed waste-disposal facilities

- assessment of environmental impacts involving the prediction of contaminant transport and dose modeling

- design and evaluation of groundwater remediation strategies including natural attenuation, hydraulic control/containment, and contaminant removal/cleanup
- design and evaluation of groundwater-monitoring networks
- risk assessments.

The key future anticipated uses of this model over the next five years include modeling support to

- the Hanford Groundwater Project (HGWP)
- future iterations of the Composite Analysis of waste sites located in the 200-Area plateau
- the River Protection Program
- performance assessment of the facilities being considered for disposal of immobilized low-activity tank waste and solid waste disposal
- the System Assessment Capability (SAC) being developed as part of the Hanford Site Groundwater/Vadose Zone Integrated Project.

Groundwater modeling analysis may also be needed to support

- the Canyon Disposition Initiative
- the 200 Area Soils Characterization and Remediation project
- maintenance of performance assessments of solid low-level waste burial grounds
- permitting analyses for liquid discharge facilities
- the potential reevaluation and update of the Hanford site-wide groundwater remediation strategy
- the development of final records of decisions for contamination currently being managed by interim remedial measures (e.g., pump-and-treat remediation) in 100 and 200 Areas.

A technical evaluation of site-wide conceptual and numerical models and preliminary recommendations for the consolidated site-wide groundwater model was conducted in a series of internal workshops attended by representatives of Hanford contractors involved in groundwater modeling. Two most recently used site-wide groundwater modeling efforts conducted for the HGWP and for the development of the Hanford Site-Wide Groundwater Remediation Strategy (GWRS) were considered.

In general, the evaluation of the GWRS and HGWP models showed that both models are capable of meeting many of the needs and requirements for a consolidated site-wide groundwater model. However, RL concluded that the model developed by the HGWP will have the broader capabilities to meet the anticipated needs of the site, and, as such, RL selected the HGWP model as the preferred alternative for the initial phase of the site-wide groundwater model-consolidation process. The discriminating factors that caused the HGWP model to be the preferred alternative are as follows:

- **model resolution** - The HGWP model reflects the most recent site-wide groundwater-model development effort and contains a higher level of resolution in its representation of the Ringold Formation than used in the GWRS model. The capabilities offered in this framework can be more easily used to evaluate and investigate the anticipated importance of hydrostratigraphic complexity in the Ringold Formation in influencing future flow and contaminant transport.

- **extent of models** - The areal extent of the HGWP model already includes the city of Richland north of the Yakima River and west of the Columbia River. Including this area in the model thus provides the needed capability to address the potential impact of onsite contaminant plumes on the city of Richland drinking water supply derived from the North Richland well field. The GWRS model extends just south of the 300-Area and does not include the North Richland well field area

- **natural recharge** - The HGWP model incorporates the effect of natural recharge as an upper hydrologic boundary condition. This capability will facilitate evaluating the importance of natural recharge in controlling future flow conditions and contaminant transport as the effect of artificial recharge on water table conditions dissipate. The GWRS model does not account for natural recharge in its implementation.

RL also initiated an evaluation of computer codes for implementation with the consolidated site-wide groundwater model. Only two computer codes were reviewed in this initial phase of the model-consolidation process: 1) the VAM3D-CG code developed by Hydrogeologic, Inc., in Herndon, Virginia, and 2) the CFEST-96 code developed by the CFEST Co. in Irvine, California. The GWRS model is implemented based on the VAM3D-CG code. The HGWP model is based on the CFEST-96 code. In a qualitative comparison of the two computer codes, both VAM3D-CG and CFEST-96 were found to be technically acceptable because they

- were included in the list of accepted groundwater flow and transport codes identified in Milestone M-29-01 (DOE/RL 1991)

- met the technical capabilities and administrative requirements outlined in the original Milestone M-29-01 document, and they generally met the technical capabilities and administrative requirement in this report.

In the interest of minimizing initial cost and potential schedule impacts, RL selected the CFEST-96 code as an interim code for implementing the consolidated site-wide groundwater model. RL deferred decisions on final selection of the code until the external peer review of the consolidated site-wide groundwater model and the resulting final refinements and modifications have been completed. When this first phase of the model consolidation process is completed, RL may consider more in-depth testing and benchmarking of the CFEST-96, VAM3D-0CG, and other applicable codes using the refined and modified site-wide groundwater model before reaching a final decision on selection of a code.

An external peer review of the consolidated Hanford site-wide groundwater model was conducted in the autumn of 1998. The three-member review panel was asked to comment on three specific issues: 1) adequacy of the conceptual model and its technical capabilities to meet the anticipated uses and needs, 2) possible improvements to the modeling framework / implementation, and 3) immediate new data needs. The most notable recommendations from the panel concerned adoption of uncertainty techniques in the site-wide groundwater model, treatment of contaminants that require reactive transport modeling to adequately characterize, and improved justification or re-examination of several model parameters and boundary conditions. The review comments will be used by RL to identify model refinements and modifications or alternative conceptual models that should be investigated to further improve the ability of the consolidated site-wide groundwater model to meet the anticipated Hanford Site needs, requirements, and uses.

ACKNOWLEDGMENTS

RL wishes to express their thanks and acknowledge the support provided by a number of representatives of major RL programs and contractor representatives who provided technical input, key technical documents, and planning information used to assemble this report. RL and contractor representatives and cognizant programs involved in support of this effort include

Environmental Restoration Program

Department of Energy, Richland Operations Office representatives

Tom Ferns, Hanford Remedial Action (HRA)/Land Use Environmental Impact Statement (EIS)

Bryan Foley, 200 Area Soils Characterization Program

Jim Goodenough, Canyon Disposition Initiative

Doug Hildebrand, Site Wide Model Consolidation, Hanford Groundwater Project, ERC Site-Wide Groundwater Modeling, Composite Analysis

Dave Olsen, 100-N Area Remedial Investigation/Feasibility Study (RI/FS) and Interim Remediation Measures (IRM) [now with DOE Office of River Protection]

Arlene Tortosa, 100 Areas RI/FS and IRM

Donna Wanek, 200 Areas RI/FS and IRM

Site Contractor Representatives

Marcel Bergeron, Pacific Northwest National Laboratory (PNNL), Hanford Site-wide Groundwater Model Consolidation and Consolidated Site-Wide Groundwater Modeling Activities

Charlie Cole, PNNL, Hanford Groundwater Project Consolidated Site-wide Groundwater Modeling Activities

Mike Connelly, CH2M-Hill Hanford, Inc., Environmental Restoration Contractor (ERC) Groundwater Modeling Activities [now with HydroGeoLogic, Inc.]

Mike Fayer, PNNL, Hanford Groundwater Project Consolidated Site-wide Groundwater Modeling Activities

Karl Fecht, Bechtel Hanford Inc. (BHI), ERC Site-wide Groundwater Activities

Charlie Kincaid, PNNL, Composite Analysis and Groundwater/Vadose Zone Integrated Project

Tony Knepp, BHI, ERC Site-Wide Groundwater Activities and Groundwater/Vadose Zone Integrated Project [now with Lockheed Martin Company]

Philip Meyer, PNNL, Hanford Site-wide Groundwater Model Consolidation

Greg Mitchem, BHI, 200 Area Soils Characterization Program

William Nichols, PNNL, Hanford Groundwater Project Consolidated Site-wide Groundwater Modeling Activities

Paul Thorne, PNNL, Hanford Groundwater Project Site-wide Modeling Activities

Signe Wurstner, PNNL, Hanford Groundwater Project Consolidated Site-wide Groundwater Modeling Activities

Waste Management Program

Department of Energy, Richland Operations Office Representatives

Greg Sinton, Effluent Treatment Facility and Permitting of State Approved Liquid Disposal Site (SALDS)

Allison Wright, Performance Assessment of Solid Waste Burial Grounds in the 200 Areas, Solid Waste EIS

Alex Teimouri, Liquid Effluents Program

Site Contractor Representatives

Brent Barnett, PNNL, Effluent Treatment Facility and permitting of SALDS

Pat Mohondro, WMH, Permitting of SALDS

Marc Wood, Waste Management Hanford (WMH), Performance Assessment of Solid Waste Burial Grounds in the 200 Areas, Environmental Restoration Disposal Facility (ERDF)

River Protection Program (formerly the Tank Waste Remediation System Program [TWRS])

Department of Energy, Richland Operations Office Representatives

Phil Lamont, River Protection Program (formerly TWRS) Immobilized Low Activity Waste (ILAW) Disposal Facility

Robert Lober, River Protection Program (formerly the TWRS), EIS and Hanford Tank Initiative

David Shafer, River Protection Program (formerly TWRS) Vadose Zone Program [now with Desert Research Institute, Las Vegas, Nevada]

Site Contractor Representatives

Jerry Davis, Numatec Hanford Corporation (NHC), Groundwater/Vadose Zone Integrated Project

Fred Mann, Fluor Daniel Northwest, Inc. (FDNW), Performance Assessment of the River Protection Program (formerly TWRS), ILAW Disposal Facility

Phil Rogers, Jacobs Engineering Group, Inc. (JEGI), River Protection Program (formerly TWRS) EIS and Hanford Tank Initiative

RL also wishes to acknowledge input provided by several individuals involved in staff consultations of this effort with U.S. Environmental Protection Agency, the Washington State Department of Ecology, the Nez Perce Tribe, the Yakama Indian Nation, the Confederated Tribes of the Umatilla Indian Reservation, and the Hanford Advisory Board. Representatives of these organizations are as follows:

U.S. Environmental Protection Agency

Brian Drost, Water Resources Division, U.S. Geological Survey (USGS), Tacoma District Office

Larry Gadbois

Doug Sherwood

Washington State Department of Ecology

Dib Goswami

Shri Mohan

Nez Perce Tribe

Stan Sobcyzk

Yakama Indian Nation

Lino Niccoli

Wade Riggsbee

Confederated Tribes of the Umatilla Indian Reservation

Stuart Harris

The Hanford Advisory Board

Environmental Restoration Subcommittee chaired by Madeline Brown

Finally, RL acknowledges input provided by the members of the Site-wide Groundwater Model External Peer Review Panel:

The External Peer Review Panel

Charles Andrews, S.S. Papadopulos and Associates, Inc.

Steven Gorelick (Panel Chair), Stanford University

James Mercer, HSI GeoTrans, Inc.

Glossary of Acronyms

BHI	Bechtel Hanford Inc.
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act of 1980
CTUIR	Confederated Tribes of the Umatilla Indian Reservation
DNFSB	Defense Nuclear Facilities Safety Board
DOE	U.S. Department of Energy
DWS	drinking water standards
Ecology	Washington State Department of Ecology
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
ERC	Environmental Restoration Contractor
ERDF	Environmental Restoration Disposal Facility
ETF	Effluent Treatment Facility
FDNW	Fluor Daniel Northwest
FFTF	Fast Flux Test Facility
FY	fiscal year
GIS	Geographic Information System
GWRS	Groundwater Remediation Strategy
HEIS	Hanford Environmental Information System
HGWP	Hanford Groundwater Project
HRA	Hanford Remedial Action
HTI	Hanford Tanks Initiative
ILAW	Immobilized Low Activity Waste
IRM	interim remedial measure
JEGI	Jacobs Engineering Group, Inc.
LAW	low activity waste
LFRG	Low Level Waste Federal Review Group
LLW	low level waste
NEPA	National Environmental Policy Act
NHC	Numatec Hanford Corporation
NPT	Nez Perce Tribe
ONWI	Office of Nuclear Waste Isolation
PA	performance assessment
PHMC	Project Hanford Management Contractor
PNNL	Pacific Northwest National Laboratory
RCRA	Resource Conservation and Recovery Act
RI/FS	Remedial Investigation/Feasibility Study
RL	U.S. Department of Energy/Richland Operations Office
ROD	record of decision
RPE	Retrieval Performance Evaluation
SAC	System Assessment Capability
SALDS	State-Approved Land Disposal Site
SMB	RL Site Management Board
TWRS	Tank Waste Remediation System
USGS	U.S. Geological Survey
WAC	Washington [State] Administrative Code
WMH	Waste Management Hanford
WM PEIS	Waste Management Programmatic Environmental Impact Statement
YIN	Yakama Indian Nation

Contents

Figures

Tables

1.0 Introduction

Until recently, the Hanford Site has had multiple versions of site-wide groundwater flow and contaminant transport models. In response to both internal and external recommendations, the U.S. Department of Energy - Richland Operations Office (DOE/RL, referred to hereafter as RL) initiated a site-wide groundwater model-consolidation process, which included the participation of all affected Hanford programs. This process will eliminate redundancies and promote consistency in groundwater analyses produced for Hanford programs. The RL Site Management Board (SMB) directed the Environmental Restoration Program to lead the effort. On September 5, 1996, John Wagoner issued an RL Letter of Instruction to affected RL programs, and site contractors that said "... with RL and contractor customers, tribal and stakeholder participation, Pacific Northwest National Laboratory (PNNL) will develop and maintain a predictive Hanford standard groundwater model...." In a letter to regulators and stakeholders dated July 28, 1997, RL also made a commitment to initiate the model-consolidation process in fiscal year (FY) 1998.

At Hanford, several groundwater-modeling programs have developed among different contractors since the Hanford mission changed from producing special nuclear materials to environmental restoration. The Project Hanford Management Contractor (PHMC) has maintained a vadose zone and groundwater modeling capability in support of active and planned disposals in the 200 Areas and operational issues at the site. The Environmental Restoration Contractor (ERC), Bechtel Hanford, Inc. (BHI), has implemented a site-wide groundwater model in support of past-practice operable unit investigations and cleanup activities. PNNL maintains groundwater-modeling capabilities for the site to support of the site-wide groundwater monitoring program and vadose-zone modeling capabilities for a variety of site and national programs.

The purpose of the model consolidation is to establish a site-wide groundwater modeling process to foster 1) consistency in assumptions and applications across programs, 2) model enhancements based on new data/information and improved technical capabilities, and 3) model flexibility to meet and support new program needs and decisions. As an initial step in FY 1998, the consolidation process was to provide a consolidated site-wide groundwater model of the site based on the most current hydrogeologic conceptual model of the aquifer system at Hanford.

In FY 1998, the scope of the model-consolidation process was to 1) establish the needs and requirements of a Hanford site-wide groundwater model, 2) evaluate current site-wide groundwater models and codes, 3) make recommendations for a consolidated site-wide groundwater model, and 4) initiate external review of the recommendations for the consolidated site-wide groundwater model. In FY 1999-2000, the model consolidation effort will 1) complete the external peer review of the consolidated site-wide groundwater model, 2) document the external peer review recommendations for refinement and modifications to the consolidated site-wide groundwater model, 3) complete suggested refinements and modifications of the model, and 4) document the refined site-wide groundwater model. Current plans also call for development of a multi-year (FY 2000-2005) program plan in FY 1999, and to make the site-wide groundwater model available for use by internal Hanford programs in FY 2000.

1.1 Purpose and Scope of Report

The purpose of this report is to document the overall recommendations being made by RL for selection of a site-wide groundwater model. Included in this report are descriptions of

- the overall approach being used by RL to achieve the objectives of the model-consolidation process
- the needs and requirements for a site-wide groundwater model that were developed in the initial phase of the model-consolidation process
- an overview of the consolidated site-wide groundwater model proposed by RL as the starting point for external review
- a summary of technical concerns and issues raised by external reviewers on the consolidated site-wide groundwater model, including input received from the U.S. Environmental Protection Agency (EPA), Washington State Department of Ecology (Ecology), Tribal Nations, and other stakeholders
- specific refinements and modifications to the consolidated site-wide groundwater model recommended by RL in response to external review comments.

The specific needs and requirements and the anticipated future uses of the site-wide groundwater model developed in the initial phase of the model consolidation process were based, in part, on a review of current and future groundwater modeling activities being conducted by the Hanford Site Environmental Restoration, Waste Management, and the River Protection (formerly Tank Waste Remediation System) Programs. The needs and requirement also reflect input collected from external stakeholders including EPA, Ecology, the Hanford Advisory Board, and two Tribal Nations (the Nez Perce Tribe [NPT] and the Yakama Indian Nation [YIN]). Representatives of the Confederated Tribes of the Umatilla Indian Reservation (CTUIR) were also consulted and asked to participate in the model-consolidation process.

This report is separated into ten sections:

- Section 1.0 is the Introduction.
- Section 2.0 provides an overview of the approach being used in the site-wide groundwater model consolidation process.
- Section 3.0 provides a summary of the past and present uses of a site-wide groundwater model.
- Section 4.0 summarizes anticipated future uses of the site-wide groundwater model.
- Section 5.0 provides summary of the site-wide conceptual model and descriptions of the needs and requirements for the site-wide groundwater model.

- Section 0 provides a discussion of the acceptability of current models and codes relative to the anticipated uses, needs, requirements, and recommendations for selecting a site-wide groundwater model and computer code.

- Section 7.0 provides a description of the consolidated site-wide groundwater model, including the rationale for its selection and a summary discussion of its conceptual model and numerical implementation.

- Section 8.0 provides a summary of technical issues and concerns raised by review of the consolidated site-wide groundwater model by regulators, Tribal Nations, other stakeholder groups, and the external peer review panel.

- Section 9.0 characterizes the approach for addressing the technical issues and concerns summarized in Section 7.

- Section 10.0 provides a list of cited references.

The main body of the report is also supplemented by information included in five appendixes. Appendix A provides summaries of recent groundwater modeling activities of major program areas at the Hanford Site, including the Environmental Restoration, Waste Management, River Protection Programs. Appendixes B, C, and D provide a summary of technical issues and comments provided by regulators, Tribal Nations, and other stakeholders on the consolidated site-wide groundwater model at three workshops. Appendix E provides a copy of the final report of the external peer review panel.

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2.0 Approach for Site-Wide Groundwater-Model Consolidation

On October 27, 1997, RL initiated the site-wide groundwater-model-consolidation process with representatives of affected RL programs and contractor personnel. An overview of the model consolidation process, which is schematically presented in Figure 1, included descriptions of the four major tasks:

- development of site-wide groundwater modeling needs and requirements, including anticipated model uses and technical and administrative requirements for the selected computer code
- technical evaluation of site-wide conceptual and numerical models
- external peer review of the proposed consolidated site-wide groundwater model
- develop, review, and publish the recommendations for a consolidated site-wide conceptual and numerical model and computer code to implement the consolidated numerical model
- implementation of the recommendations.

In the context of this evaluation, the site-wide groundwater model refers to the numerical representation of the conceptual model of the aquifer system at Hanford based on a set of site-specific hydrogeologic and hydraulic data and information as implemented with a specific groundwater flow and transport computer code. The groundwater flow and transport computer code refers to computer software (i.e., a set of instructions written in a programming language acted on by a computer) used to represent the physics of groundwater flow and transport. The conceptual model of the aquifer system refers to the general understanding of the system being studied.

To facilitate the development of the needs and requirements summarized in this report, representatives of Hanford Site programs were asked to provide an overview of current and planned model activities, including identification of supporting planning and technical documents. The documents identified provide the basis for summaries of current and planned groundwater-modeling activities described in the next section of this report. RL also consulted with representatives of the EPA, Ecology, the Hanford Advisory Board, and Tribal Nations that included the NPT, the YIN, and CTUIR about the model-consolidation process.

A technical evaluation of site-wide conceptual and numerical models and preliminary recommendations for a consolidated site-wide conceptual and numerical model and computer code was conducted in a series of internal workshops attended by representatives of Hanford contractors involved in groundwater modeling. These meetings were held between March 12 and March 31, 1998, and were attended by representatives of key internal site programs within the Environmental Restoration, Waste Management, and Tank Waste Remediation Programs. In these meetings, the two most recently used site-wide modeling efforts supporting the Hanford Groundwater Project (HGWP) (Wurstner et al. 1995; Cole et al. 1997; Kincaid et al. 1998) and the development of the Hanford Site-wide Groundwater Remediation Strategy (GWRS) (Law et al. 1997; Chiaramonte et al. 1997) were considered. In these internal meetings, the basic similarities among and differences between these two recent models were discussed and

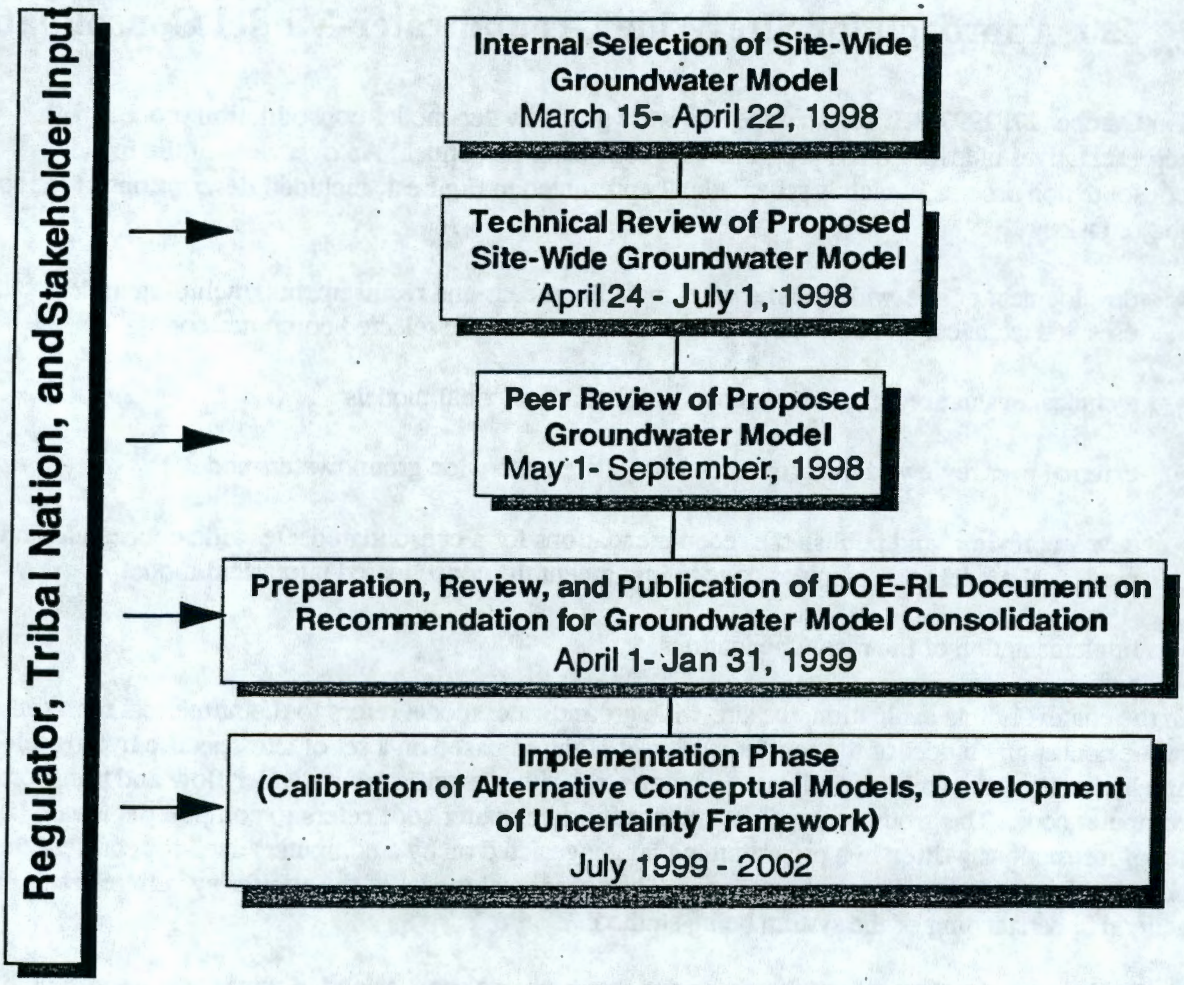

Figure 1. An Overview of the Model Consolidation Process

evaluated. This internal process resulted in selecting the site-wide conceptual groundwater model developed by the HGWP as the consolidated site-wide groundwater model for external peer review. Results of this qualitative evaluation are summarized in Section 5.0 of this report.

Following the internal evaluation and selection process, a technical workshop was convened on April 24, 1998, with representatives for EPA, Ecology, Tribal Nations (YIN, NPT, and CTUIR), and other Hanford contractors. The purpose of the workshop was 1) to discuss a proposed process for achieving the groundwater-model-consolidation objectives, 2) to review the anticipated uses, needs, and requirements of the site-wide groundwater model, 3) to evaluate how current model and codes meet the needs and requirements, and 4) to discuss the basis for selecting the HGWP model as the consolidated site-wide groundwater model for Hanford. The workshop provided an overview of the consolidated site-wide groundwater model to aid the attendees in their subsequent review of the technical documents that more fully document the conceptual model and the interpretations that support it, the model's numerical implementation, and the predictive results from the model.

As a follow up to the workshop, representatives of the regulatory agencies and Tribal Nations were asked to review the background information related to the consolidated site-wide groundwater model and to identify technical issues or concerns regarding the conceptual model and numerical implementation. A summary of the key technical issues and concerns identified by regulators, Tribal Nations, and other stakeholders during the original workshop and in written communications to RL are provided in Appendix B and summarized in Section 7 of this report.

The recommendations for a consolidated site-wide groundwater model documented in this report were presented for review by an external peer panel in the autumn of 1998. Comments and suggestions solicited during the review are being evaluated and to the extent possible will be incorporated into a final draft of this report that will be published in July 1999. The specific scope of the external review was to address the following questions:

- Are the conceptual model and technical capabilities embodied in the numerical implementation of the consolidated site-wide groundwater model adequate to meet the anticipated needs, requirements, and uses for modeling at the Hanford Site?

- What model refinements/modifications or alternative conceptual models should be investigated to further improve the conceptual model and its numerical implementation to meet the anticipated Hanford Site needs, requirements, and uses?

- Are there major conceptual model, parameters, and data uncertainties that can and should be resolved by collecting additional data and information to enhance the consolidated groundwater model to meet the anticipated Hanford Site needs, requirements, and uses?

Following peer review of the recommendations for model consolidation, RL will initiate the implementation phase designed to refine and modify the consolidated site-wide groundwater model before its use by internal Hanford applications. The implementation phase will include the following elements:

- Alternative conceptual models: Continue implementation of the site-wide groundwater model consolidation activities related to refinement and calibration of alternative conceptual models as suggested by external peer review. Document the results of these activities and their implications of site-wide groundwater model predictions of flow and contaminant transport and their uncertainty. Within this activities, staff will work closely with the Systems Characterization activity within the Integrated GW/VZ project to develop and implement an consistent approach for development of management of Alternative conceptual and the use of the Features, Events, and Processes approach to management of technical issues and concerns. Deliverable: technical reports documenting inverse recalibration of current conceptual model and inverse calibration of one alternative conceptual model (due September 30, 2000). Other alternative conceptual models would be calibrated and documented as part of out year activities (fiscal years 2001-2002).

- Uncertainty Framework: Develop and implement an analysis framework that can be used to assess uncertainty in results produced by the range of alternative site-wide groundwater conceptual and numerical models. Deliverable: technical report on uncertainty framework approach and strategy (due June 1, 2000). The recommended uncertainty framework would be implemented during fiscal years 2000 through 2002.

- External Peer Review: The current external peer review panel assembled to review the site-wide groundwater flow and transport will be retained for periodic review of the modeling task activities. Specifically, they will provide independent technical review of the alternative conceptual models selected for inverse calibration and the overall technical approach and strategy being used to address uncertainty in site-wide groundwater flow and transport results using the alternative conceptual models. This task includes the peer review panel's activities as well as PNNL interaction with the panel.

3.0 Past and Present Uses of Groundwater Models at the Hanford Site

This section of the report provides an overview of recent and continuing groundwater modeling uses at the Hanford Site.

3.1 Overview of Groundwater Modeling Uses at Hanford

Site-wide groundwater modeling is a critical component of system assessment capability at the Hanford Site that is being done to quantify the environmental consequences of past, present, and future DOE activities at impacted compliance boundaries and receptor points at the site and within the region. The specific methods and models used must consider the key elements of the site-wide aquifer system and the spatial and temporal scale of the system impacted. The spatial scales of specific analyses and assessments that will rely on this capability are defined by the diverse locations of waste at the site in the 100 Area, 200 Area, 300 Area, and a number of miscellaneous waste sites in the 600 Area (Figure 2). Several hundred individual waste sites within the exclusive waste management area and buffer zone, depicted in Figure 3 and Figure 4, may need to be analyzed using the system-assessment capability. The methodology must be able to evaluate the potential impacts of past practices of discharging large volumes of liquid wastes to the subsurface, and past and future accidental and unplanned leaks and releases over the past 50 to 55 years that have already impacted the unconfined aquifer system and may be seen for decades to come. The methodology must also be able to evaluate the potential impacts from past disposal of solid low-level radioactive wastes (LLW) and transuranic (TRU) radioactive and mixed wastes and future disposal of solid LLW radioactive and mixed wastes that may impact the groundwater system for several hundred to thousands of years.

The selected site-wide groundwater model must be able to assess current and future impacts of the groundwater transport of a broad variety of radioactive and chemical contaminants of varying environmental mobility. The migration of long-lived radionuclides and chemical contaminants, in particular, presents long-term threats to the environment and to human health and safety.

Because of the long-term nature of some assessments, the selected site-wide groundwater model needs to have the ability to evaluate the anticipated future transient behavior of the groundwater system. The planned cessation of past practices of discharging dilute waste liquids to the subsurface will result in future water table decline of the unconfined aquifer and long-term changes in future flow patterns. These flow patterns may also be impacted by future land uses and water-resources impacts both on and outside of the Hanford Site. Changes in onsite land uses may result as lands outside of the exclusive waste management and buffer areas are remediated and released to the general public for alternative land uses.

A critical aspect of the site-wide groundwater model in the context of a system-assessment methodology is its ability to interact with other components and modules in the methodology. The typical linkages are with modules that assess flow and/or contaminant transport in the overlying unsaturated or vadose zone, flow

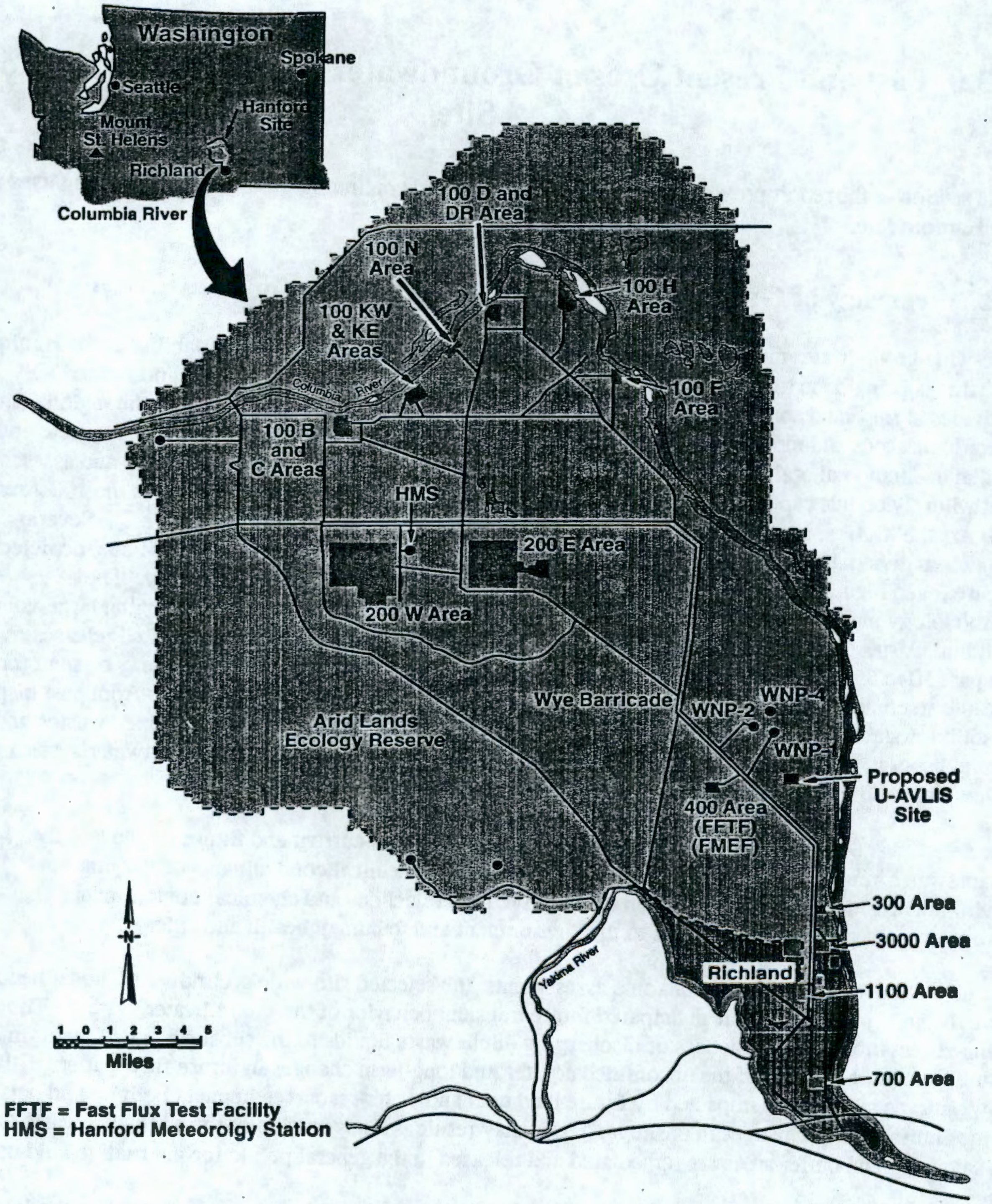

Figure 2. Location of Operational Areas on the Hanford Site

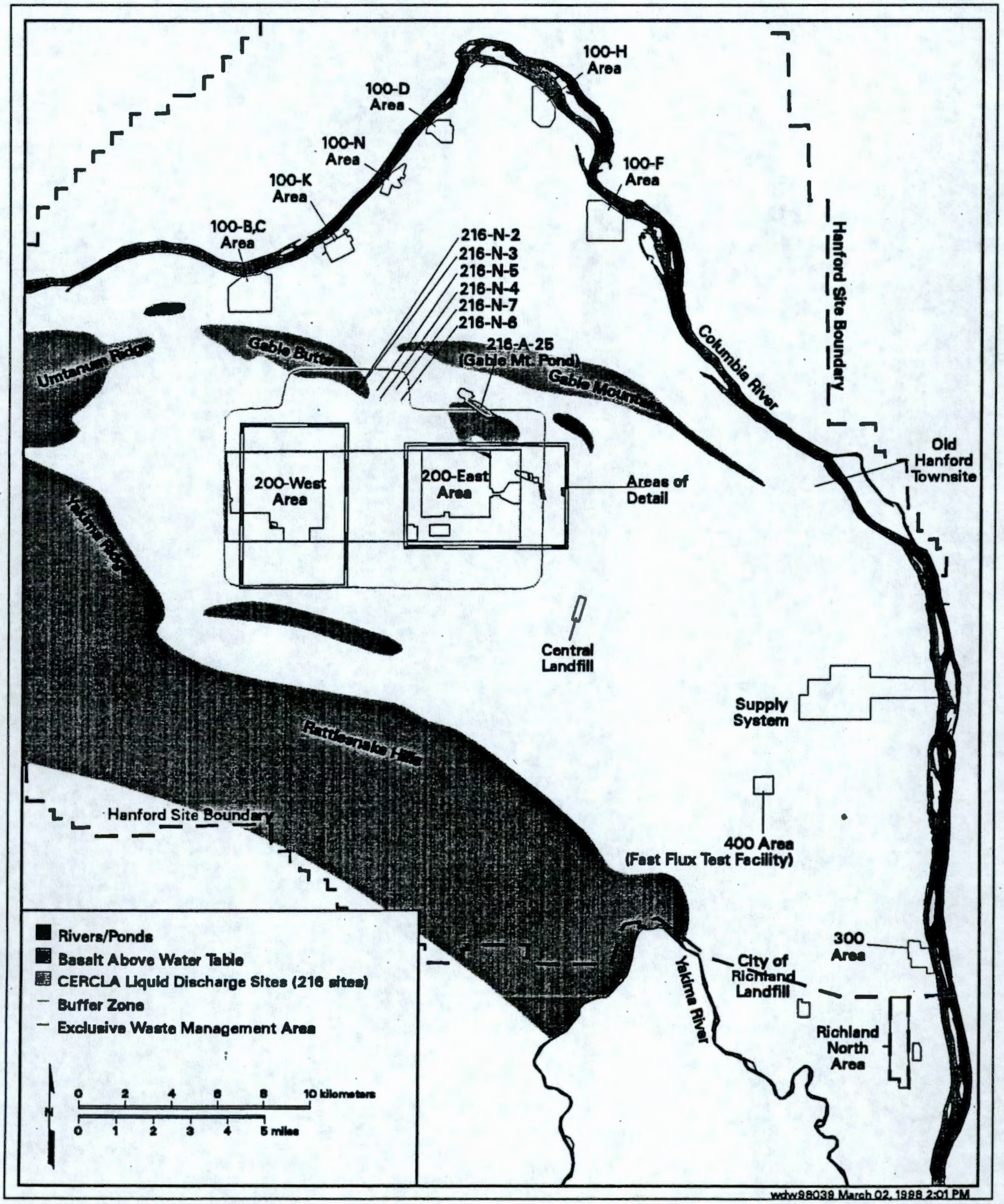

Figure 3. The Exclusive Waste Management Area and Buffer Zone of the 200-Area Plateau at the Hanford Site

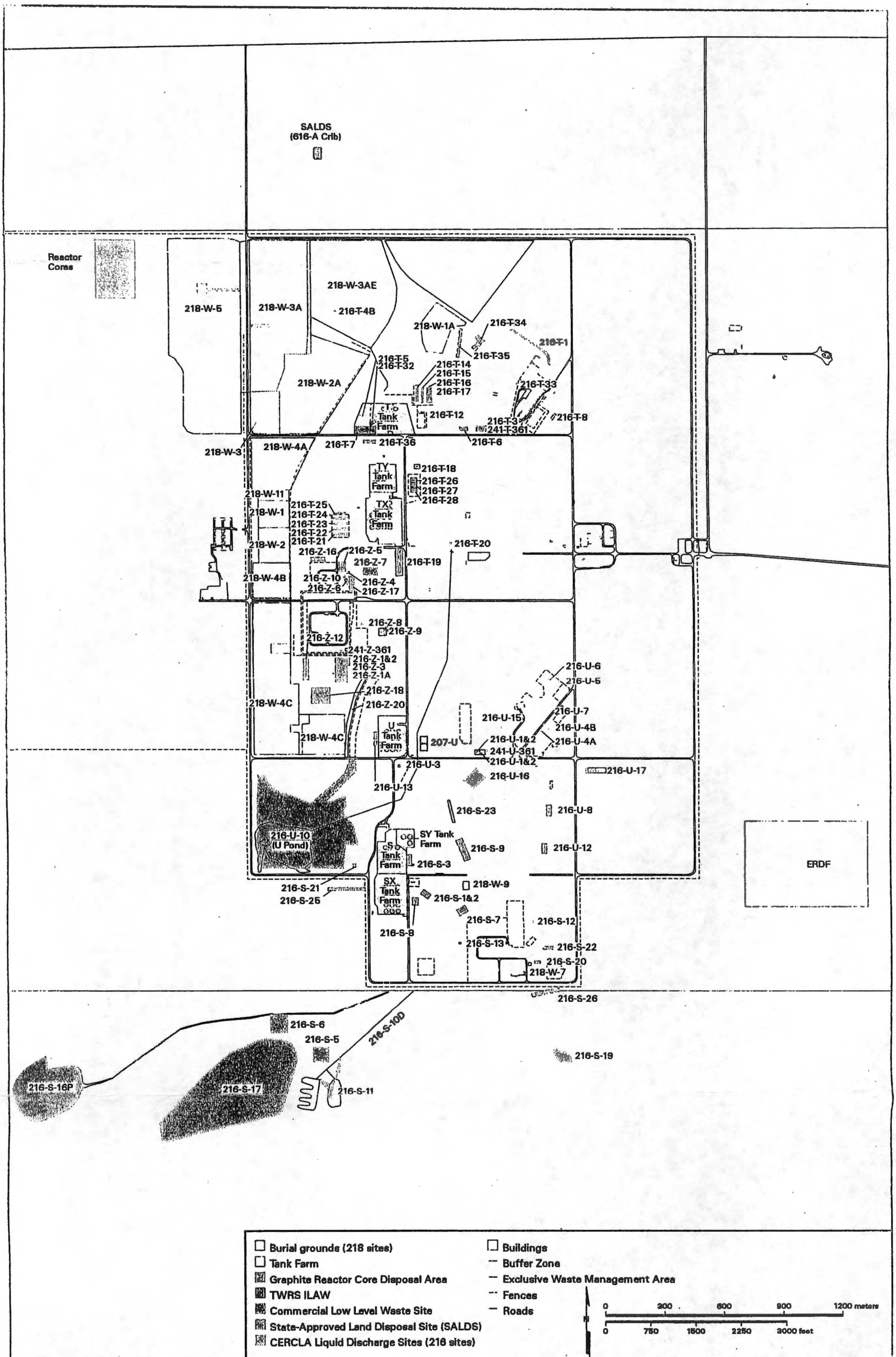

Figure 4. Waste Sites in the 200-West and 200-East Area of the Hanford Site

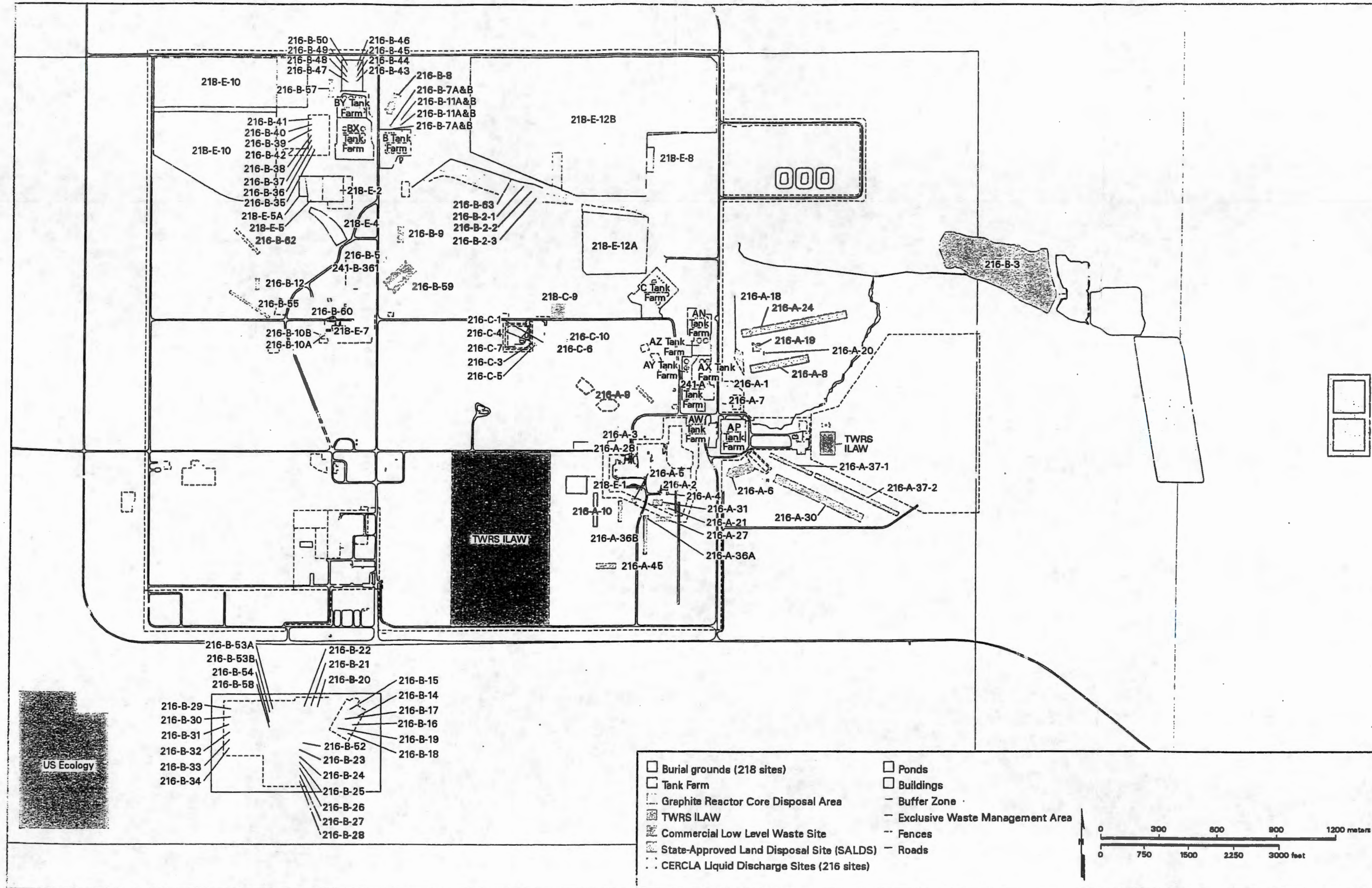

Figure 4. (contd)

and transport in the Columbia River, and human health and ecosystem exposures and risk at compliance and/or potential receptor points.

3.2 Recent Groundwater Modeling Activities

A review of recent and ongoing groundwater-modeling applications on the Hanford Site was completed to help identify the specific needs and requirements essential for a site-wide groundwater model. The requirements of a model are determined primarily by the objectives of the modeling and by the characteristics of the groundwater system being modeled. For example, if one of the objectives is to compare predicted groundwater-contaminant concentrations from a waste disposal facility to a regulatory concentration standard, the model developed must be sufficiently precise to resolve concentrations as low as the standard. Similarly, if an unconfined aquifer is being modeled, the code selected for the modeling must provide the capability to represent unconfined conditions.

This section summarizes the modeling objectives and model characteristics used in the applications reviewed. The applications considered included key projects and activities related to the Environmental Restoration, Waste Management, and River Protection Programs. A description of each key project reviewed can be found in Appendix A. A high level summary of the specific applications reviewed and their important modeling characteristics and references are provided in Table 1 and Table 2.

The modeling applications reviewed supported five broad categories of analyses carried out at the Hanford Site, which are listed below. Under each category, several examples of modeling objectives identified in the review are listed:

- Site performance assessments of proposed waste disposal facilities - Objectives include
  - comparing predicted groundwater contaminant concentrations at the facility boundary to background levels or risk-based concentration limits
  - evaluating the effect of facility design on predicted groundwater concentrations
  - using predicted groundwater concentrations to establish requirements on the design or inventory of a waste disposal facility
- Assessment of environmental impacts involving the prediction of contaminant transport and dose modeling - Objectives of this category include
  - estimating contaminant concentrations in the soil, groundwater, surface water, and air to which a human or ecological receptor might be exposed
  - evaluating the potential impacts on groundwater quality of land use alternatives
- estimating the effect of operational facilities on future water quality

Table 1. Model Attributes of Key Projects in the Environmental Restoration Program

Model Attributes	Hanford Site-Wide Remediation Strategy	Environmental Restoration Disposal Facility	Hanford Remedial Action/Land Use EIS	Hanford Groundwater Project: Future Water Level Assessment	Hanford Groundwater Project: Impacts to Drinking Water Systems and GW Use	Composite Analysis	System Assessment Capability
Current Status							
Work Completed							
No future work needed							
Future revisions needed	X	X	X	X	X	X	X
Work Initiated							
Work Planned and in Baseline							X
Work Planned and not in Baseline							
Drivers							
CERCLA	X	X					
RCRA Compliance					X		
NEPA			X				X
DOE Guidance						CA Guidance	X
DOE Orders					X		X
Facility Permitting					X		
Emergency Response							
DNFSB						94-2	94-2
Public Interest							X
Purpose or Objective of Analysis							
Site Performance Assessment		X				X	X
Design & Evaluation of Remediation Strategy	X	X					X
Assessment of Environmental Impacts		X	X		X	X	X
Evaluation & Design of Monitoring Networks				X	X		
Risk Assessment		X	X				X

Note: n/a not applicable; VZ vadose zone; GW groundwater

Table 1. (contd)

Model Attributes	Hanford Site-Wide Remediation Strategy	Environmental Restoration Disposal Facility	Hanford Remedial Action/Land Use EIS	Hanford Groundwater Project		Composite Analysis	System Assessment Capability
				Future Water Level Assessment	Impacts to Drinking Water Systems and GW Use		
Scope of Analysis							
Dimensionality							
Model Orientation	3-D	1-D	2-D	2-D	3-D	3-D	2-D or 3-D
Flow Analysis							
Vadose Zone Flow		Steady-state	Steady-state			Transient	Transient
Groundwater Flow	Transient	Steady-state	Transient	SS, Transient	SS, Transient	SS, Transient	SS, Transient
Transport Analysis				n/a			
Vadose Zone Transport		Steady-state	Transient			Transient	Transient
Groundwater Transport	Transient	Steady-state	Transient		Transient	Transient	SS, Transient
Geochemical Capabilities Used/Required							
Sorption	X	X	X		X	X	X
Radioactive Decay w/o chain decay	X	X	X		X	X	X
Radioactive Decay with chain decay						X	X
Scale of Analysis							
Spatial Scale	Site-wide	Local	Site-wide	Site-wide	Site-wide	Site-wide	Site-wide
Temporal Scale	< 200 yrs	< 10,000 yrs	< 10,000 yrs	< 50 yrs	< 200 yrs	< 1000 yrs	1000, 10,000, 1,000,000 yr
Codes Used							
VAM3DCG	GW						To Be Decided
PORFLOW							
STOMP						VZ	
MEPAS			VZ/GW				
CFEST-SC or CFEST-96			GW	GW	GW	GW	
MICROFEM							
MODFLOW							
MT3D							
Spreadsheet Analysis		VZ/GW					
RESRAD							

Note: n/a not applicable; VZ vadose zone; GW groundwater

Table 1. (contd)

Model Attributes	Hanford Site-Wide Remediation Strategy	Environmental Restoration Disposal Facility	Hanford Remedial Action/Land Use EIS	Hanford Groundwater Project: Future Water Level Assessment	Hanford Groundwater Project: Impacts to Drinking Water Systems and GW Use	Composite Analysis	System Assessment Capability
Boundary Conditions							
Basalt Outcrops		n/a					
No Flow	X		X	X	X	X	
Rattlesnake Hills Spring Discharge			X	X	X	X	
Cold Creek Valley		n/a					
Specified Head			Steady-State	Steady-State			
Specified Flux	Steady-State				Steady-State	Steady-State	
Dry Creek Valley		n/a	n/a				
Specified Head							
Specified Flux	Steady-State			Steady-State	Steady-State	Steady-State	
Yakima River		n/a			n/a	n/a	
Specified Head	Steady-State		Steady-State	Steady-State			To Be Decided
Specified Flux							
Columbia River		n/a					
Specified Head	Steady-State		Steady-State	Steady-State	Steady-State	Steady-State	
Specified Flux							
Local-scale Boundaries	n/a	n/a	n/a	n/a	n/a	n/a	
Natural Recharge		X					
Base of Model		n/a					
5 m below Water Table							
Hanford/Ringold Contact							
Top of Lower Ringold Mud Unit	X				X	X	
Top of Columbia River Basalts	X		X	X	X	X	

Note: n/a not applicable; VZ vadose zone; GW groundwater

Table 1. (contd)

Model Attributes	Hanford Site-Wide Remediation Strategy	Environmental Restoration Disposal Facility	Hanford Remedial Action/Land Use EIS	Hanford Groundwater Project: Future Water Level Assessment	Hanford Groundwater Project: Impacts to Drinking Water Systems and GW Use	Composite Analysis	System Assessment Capability
Hydrostratigraphic Units							
Number of hydrostratigraphic units	2	1	1	1	10	10	To Be Decided
Hanford Formation	X				X	X	
Ringold Formation (as single unit)	X	X					
Combined Hanford and Ringold Formation			X	X			
Palouse Soil					X	X	
Plio-Pliestocene Unit					X	X	
Upper Ringold (Unit 4)					X	X	
Middle Ringold (Unit 5)					X	X	
Middle Ringold (Unit 6)					X	X	
Middle Ringold (Unit 7)					X	X	
Lower Ringold (Unit 8)					X	X	
Basal Ringold (Unit 9)					X	X	
Columbia River Basalt					X	X	
Contaminants Considered							
Radionuclides	X	X	X		X	X	X
Chemicals	X	X	X				X
Key References							
Key References	Law et al. (1997), Chiaramonte et al. (1997)	DOE/RL (1994)	DOE (1996a)	Wurstner and Freshley (1994)	Cole et al. (1997)	Kincaid et al. (1998)	*Under Development*

Note: n/a not applicable; VZ vadose zone; GW groundwater

Table 1. (contd)

Model Attributes	100-N Area Modeling		Interim Remedial Action Design Analyses					Focused Feasibility Studies	
	LWDF's	Bank Storage	N Springs	100-H Area	100-D Area	200 UP-1	200 ZP-1	100-H Area	100-D Area
Current Status									
Work Completed									
No future work needed									
Future revisions needed	X	X	X	X	X	X	X	X	X
Work Initiated									
Work Planned and in Baseline									
Work Planned and not in Baseline									
Drivers									
CERCLA	X	X	X	X	X	X	X	X	X
RCRA Compliance									
NEPA									
DOE Guidance									
DOE Orders									
Facility Permitting									
Emergency Response									
DNFSB									
Public Interest									
Purpose or Objective of Analysis									
Site Performance Assessment									
Design & Evaluation of Remediation Strategy		X	X	X	X	X	X	X	X
Assessment of Environmental Impacts	X								
Evaluation & Design of Monitoring Networks									
Risk Assessment									

Note: n/a not applicable; VZ vadose zone; GW groundwater

Table 1. (contd)

Model Attributes	100-N Area Modeling: LWDF's	100-N Area Modeling: Bank Storage	Interim Remedial Action Design Analyses: N Springs	Interim Remedial Action Design Analyses: 100-H Area	Interim Remedial Action Design Analyses: 100-D Area	Interim Remedial Action Design Analyses: 200 UP-1	Interim Remedial Action Design Analyses: 200 ZP-1	Focused Feasibility Studies: 100-H Area	Focused Feasibility Studies: 100-D Area
Scope of Analysis									
Dimensionality	2-D/3-D	2-D	2-D	2-D	2-D	3-D	3-D	3-D	3-D
Model Orientation		Cross-section	Areal/X-Section	Areal	Areal				
Flow Analysis									
Vadose Zone Flow	Transient	Transient							
Groundwater Flow	Transient	Transient	Steady-state	Transient	Steady-state	Transient	Transient	Steady-state	Steady-state
Transport Analysis									
Vadose Zone Transport	Transient								
Groundwater Transport	Transient		Transient					Transient	Transient
Geochemical Capabilities Used/Required									
Sorption	X		X					X	X
Radioactive Decay w/o chain decay	X		X						
Radioactive Decay with chain decay									
Scale of Analysis									
Spatial Scale	Local	Local	Local	Local	Local	Local	Local	Local	Local
Temporal Scale	< 50 yrs	< 1 yrs	< 300 yrs	< 50 yrs	< 50 yrs	< 50 yrs	< 50 yrs	< 50 yrs	< 50 yrs
Codes Used									
VAM3DCG	VZ/GW					GW	GW		
PORFLOW	VZ/GW		GW						
STOMP		VZ/GW							
MEPAS									
CFEST-SC or CFEST-96									
MICROFEM				GW	GW				
MODFLOW								GW	GW
MT3D								GW	GW
Spreadsheet Analysis									
FLOWPATH			GW						

Note: n/a not applicable; VZ vadose zone; GW groundwater

Table 1. (contd)

Model Attributes	100-N Area Modeling		Interim Remedial Action Design Analyses					Focused Feasibility Studies	
	LWDF's	Bank Storage	N Springs	100-H Area	100-D Area	200 UP-1	200 ZP-1	100-H Area	100-D Area
Boundary Conditions									
Basalt Outcrops	n/a	n/a	n/a	n/a	n/a	No flow	No flow	n/a	n/a
No Flow	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Rattlesnake Hills Spring Discharge	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Cold Creek Valley	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Dry Creek Valley	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Yakima River	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Columbia River						n/a	n/a		
Specified Head	Transient	Transient	Steady-state	Steady-state	Steady-state				
Specified Flux								Steady-state	Steady-state
Local-scale Boundaries									
Specified Head	Steady-state	Transient	Steady-state	Steady-state	Steady-state	Steady-state	Steady-state	Steady-state	Steady-state
Specified Flux					Steady-state				
Natural Recharge	X	X	X					X	X
Base of Model									
5 m below Water Table									
Hanford/Ringold Contact				X					
Top of Lower Ringold Mud Unit	X	X	X[1]		X	X	X	X	X
Top of Columbia River Basalts						X			X

Note: n/a not applicable; VZ vadose zone; GW groundwater

[1] Base of model was 50 feet into the Lower Ringold Mud Unit

Table 1. (contd)

Model Attributes	100-N Area Modeling		Interim Remedial Action Design Analyses					Focused Feasibility Studies	
	LWDF's	Bank Storage	N Springs	100-H Area	100-D Area	200 UP-1	200 ZP-1	100-H Area	100-D Area
Hydrostratigraphic Units									
Number of hydrostratigraphic units	2	2	2	1	1	2	2	2	1
Hanford Formation	X	X		X		X	X	X	X
Ringold Formation (as single unit)	X	X				X	X	X	
Combined Hanford and Ringold Formation					X				
Palouse Soil									
Plio-Pliestocene Unit									
Upper Ringold (Unit 4)									
Middle Ringold (Unit 5)			X						
Middle Ringold (Unit 6)			X						
Middle Ringold (Unit 7)									
Lower Ringold (Unit 8)									
Basal Ringold (Unit 9)									
Columbia River Basalt									
Contaminants Considered									
Radionuclides	Sr^{90}	n/a	Sr^{90}	n/a	n/a	n/a	n/a		
Chemicals		n/a		n/a	n/a	n/a	n/a	Chromium	Chromium
Key References									
Key References	Connelly et al. (1991)	Connelly et al. (1997)	DOE/RL (1995d); see also DOE/RL (1996a)	ERC (1996); DOE/RL (1996b)	WHC (1994)	BHI (1996b)	WHC (1994); BHI (1996a)	DOE/RL (1995a; 1995b; 1995c)	DOE/RL (1995a; 1995b; 1995c)

Note: n/a not applicable; VZ vadose zone; GW groundwater

Table 2. Model Attributes of Key Projects in the Waste Management and Tank Waste Remediation System Programs

Model Attributes	Waste Management				River Protection Program			
	LLW Burial Grounds Performance Assessment		Liquid Effluents Program			Hanford Tank Initiative	RPP Low Activity Waste Disposal Facility	
	200 East Area	200 East Area	ETF	Other Discharges	RPP EIS		Interim PA	Final PA
Current Status								
Work Completed								
No future work needed								
Future revisions needed	X	X	X		X		X	
Work Initiated						X		X
Work Planned and in Baseline				X				
Work Planned and not in Baseline								
PA Maintenance	X	X						X
Drivers								
CERCLA								
RCRA Compliance						X		
NEPA					X	X		
DOE Orders	5820.2A	5820.2A	5400.5				5820.2A	5820.2A
Facility Permitting			X	X				
Emergency Response								
Public Interest								
Purpose or Objective of Analysis								
Site Performance Assessment	X	X					X	X
Design & Evaluation of Remediation Strategy						X		
Assessment of Environmental Impacts			X	X	X	X	X	X
Evaluation & Design of Monitoring Networks			X	X				
Risk Assessment								

Note: n/a not applicable; VZ vadose zone; GW groundwater

Table 2. (contd)

Model Attributes	Waste Management				River Protection Program			
	LLW Burial Grounds Performance Assessment		Liquid Effluents Program			Hanford Tank Initiative	RPP Low Activity Waste Disposal Facility	
	200 East Area	200 East Area	ETF	Other Discharges	RPP EIS		Interim PA	Final PA
Scope of Analysis								
Dimensionality	2-D	2-D	3-D	?	1-D/2-D	2-D	2-D/3-D	2-D/3-D
Model Orientation	Cross-section	Cross-section		?	Areal	Areal/ Cross-section	Areal/Cross-section	Areal/Cross-section
Flow Analysis				?				
Vadose Zone Flow					SS & Transient	Transient	SS & Transient	Steady-state
Groundwater Flow	Steady-state	Steady-state	Transient		Steady-state	Steady-state	SS & Transient	Steady-state
Transport Analysis				?				
Vadose Zone Transport					Transient	Transient	Transient	Transient
Groundwater Transport			Transient		Transient	Transient	Transient	Transient
Geochemical Capabilities Used/Required								
Sorption	X	X			X	X	X	X
Radioactive Decay w/o chain decay	X	X	X		X	X	X	X
Radioactive Decay with chain decay	X	X				X	X	X
Scale of Analysis								
Spatial Scale	Local	Local	Local	?	Site-wide	Local, Site-wide	Local, Site-wide	Local, Site-wide
Temporal Scale	< 10,000 yrs	< 10,000 yrs	< 200 yrs	?	< 10,000 yrs	< 10,000 yrs	> 10,000 yrs	> 10,000 yrs
Codes Used								
VAM2D/VAM3DCG	VZ/GW	VZ/GW		?	VZ/GW		GW	GW
PORFLOW				?		VZ/GW	VZ	VZ
STOMP				?				
MEPAS				?		VZ/GW		
CFEST-SC or CFEST-96			GW	?		GW		
MICROFEM				?				
MODFLOW				?				
MT3D				?				

Note: n/a not applicable; VZ vadose zone; GW groundwater

Table 2. (contd)

Model Attributes	Waste Management: LLW Burial Grounds Performance Assessment: 200 East Area	Waste Management: LLW Burial Grounds Performance Assessment: 200 East Area	Waste Management: Liquid Effluents Program: ETF	Waste Management: Liquid Effluents Program: Other Discharges	River Protection Program: RPP EIS	River Protection Program: Hanford Tank Initiative	River Protection Program: RPP Low Activity Waste Disposal Facility: Interim PA	River Protection Program: RPP Low Activity Waste Disposal Facility: Final PA
Hydrostratigraphic Units								
Number of hydrostratigraphic units	2	2	9	Undecided	2	2	2	2
Hanford Formation	X	X	X		X	X	X	X
Ringold Formation (as single unit)	X	X			X	X	X	X
Combined Hanford and Ringold Formation								
Palouse Soil			X					
Plio-Pliestocene Unit			X					
Upper Ringold (Unit 4)			X					
Middle Ringold (Unit 5)			X					
Middle Ringold (Unit 6)			X					
Middle Ringold (Unit 7)			X					
Lower Ringold (Unit 8)			X					
Basal Ringold (Unit 9)			X					
Columbia River Basalt								
Contaminants Considered								
Radionuclides	X	X	X	Tritium	X	X	X	X
Chemicals					X	X		
Key References								
Key References	Wood et al. (1996)	Wood et al. (1995)	Barnett et al. (1997)	n/a	DOE (1996)	JEGI (1998a; 1998b)	Mann (1995), Lu (1996), Mann et al. (1998)	Mann et al. (1998)

Note: n/a not applicable; VZ vadose zone; GW groundwater

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- Design and evaluation of groundwater remediation strategies including natural attenuation, hydraulic control/containment, and contaminant removal/cleanup - Objectives of this type of analysis include
  - estimating the effectiveness of alternative groundwater cleanup approaches
  - supporting planning and implementation of remediation alternatives
  - evaluating the impact of a declining water table on remediation effectiveness
- Design and evaluation of site monitoring networks - Objectives include
  - determining whether a monitoring network is adequate to detect and monitor changes in a groundwater contaminant plume
  - evaluating the effectiveness of a monitoring network to predict the fate and transport of existing and emerging contaminant plumes under a declining water table
  - assessing the ability of a monitoring network to determine the performance of a groundwater remediation strategy
- Risk assessments - objectives include
  - estimating radiological and chemical human health impacts from predicted contaminant concentrations arising from past and future releases of contaminants
  - identifying the sensitivity of risk predictions to flow and transport parameters
  - evaluating the relative importance of various transport processes.

Many of these types of applications require that a groundwater model be integrated with other models, most commonly with waste or source-term release, vadose zone flow and transport, river flow and transport, and exposure models. In general, this integration does not place any extraordinary requirements on the groundwater model in that the integration of source term release, vadose zone flow and transport, river flow and transport, exposure, and groundwater models is typically accomplished through the use of appropriate boundary conditions.

The characteristics of the Hanford Site groundwater system, important in determining the requirements of a model, will be discussed in detail later in this document. Here we summarize the characteristics of the groundwater models that have been used in the Hanford Site applications. These models exhibited a variety of characteristics, summarized as follows:

- **dimensionality** - One-, two-, and three-dimensional models have been used. Both plan-view and cross-sectional models have been used in applications that considered two-dimensional models.
- **geologic framework** - The hydrogeologic framework of conceptual models generally identified numerous geologic units in the vadose and saturated zones. However, over the range of applications

reviewed, the level of detail used in models to simulate flow and transport in the identified geologic units were highly variable and dependent on specific modeling objectives.

- **spatial variability** - The level of spatial variability in hydraulic properties and other model parameters differed between models. Homogeneity was often assumed, particularly within a given geologic unit. Some model applications have considered spatial variability on the scale of the numerical grid.

- **flow conditions variability** - Assumed flow conditions that provided the hydraulic basis for each analysis were variable. In some cases, steady-state flow conditions were assumed to represent current and/or future flow conditions. The assumed current conditions were based on interpretations of water-level measurements. Assumed future conditions were based on simulated water-table conditions. A small number of modeling assessments have attempted to simulate past and anticipated transient changes in water-table conditions resulting from changes in Hanford Site waste management operations. Assumptions used were dependent on the specific objectives of each modeling analysis.

- **radionuclides** - Transport of numerous radionuclides has been evaluated. Radioactive decay is commonly considered. In a few instances, the in-growth of decay products was evaluated. Approaches that approximate the environmental mobility of radioactive contaminants were limited to examination of the sorption process using an equilibrium adsorption model.

- **chemicals** - The transport of a variety of chemicals has been assessed. Approaches used to approximate the environmental mobility of chemical contaminants were limited to examining the sorption process using an equilibrium adsorption model.

- **spatial scale** - Many of the modeling applications reviewed used models that covered a relatively small portion of the Hanford Site such as an operable unit in the 100 Areas. The greatest degree of spatial and temporal variability and the finest spatial resolution was generally associated with these local-scale models. The spatial scale modeled varied from less than a square kilometer using local-scale models to the entire Hanford Site using a site-wide groundwater model.

- **temporal scale** - Modeling studies have considered a variety of temporal scales. Changes on a time-scale as short as one hour and longer than 10,000 years have been considered.

- **boundary conditions** - A variety of boundary conditions have been used. Because of the scale of interest, some analyses have relied on approximations of regional boundaries of the aquifer system. Both specified head and flux boundary conditions have been used to approximate the effect of assumed steady-state and transient boundaries. Many of the analyses examined, particularly those using local scale models, have relied on arbitrary boundaries to approximate fluxes into or out of the local scale of interest. In a few cases, estimated local-scale boundaries were calculated with the use of larger scale models.

Numerical model grid resolution - The spatial resolution of the numerical models varied considerably and was dependent of the specific objectives of the model analysis. Grid spacing ranged from 8 to 1000 m in the horizontal plane and from 0.1 to 2 m or more in the vertical plane. The number of computational nodes in the models varied widely, exceeding 50,000 nodes in one application.

4.0 Future Groundwater Modeling Activities

A review of future groundwater-modeling applications on the Hanford Site was conducted to identify the anticipated uses of the selected site-wide groundwater model over the next three to five years. These key projects, activities, and assessments are summarized in Table 3. Brief summaries of the planned scope, anticipated groundwater analysis needs, and schedule for these projects, activities, and assessments are provided. Section 4.1 discusses activities in which use of a site-wide groundwater model planned. Section 4.2 discusses other activities that have no specific plans to use a site-wide groundwater model, but have the potential to use a site-wide groundwater model.

4.1 Planned Activities

This section describes activities in which use of a site-wide groundwater model is planned for in the next three to five years. They include

- the Solid Waste Environmental Impact Statement
- modeling support to the HGWP
- the Composite Analysis of the 200-Area plateau
- modeling support to the Hanford Tank Initiative
- the performance assessment of the River Protection Program's Immobilized Low-Activity Tank Waste Disposal Facilities
- the Systems Assessment Capability being developed under the Hanford Groundwater/Vadose Zone Integrated Project.

A brief summary of each activity is provided below.

4.1.1 Solid Waste Environmental Impact Statement

DOE has announced its intent to prepare an environmental impact statement (EIS) for the Solid Waste Program at the Hanford Site. This program manages several types of solid wastes at the Hanford Site, including low-level, mixed low-level, transuranic, mixed transuranic, hazardous wastes, and contaminated equipment. The EIS will evaluate the potential environmental impacts associated with ongoing activities of the Hanford Site Solid Waste Program, the implementation of programmatic decisions resulting from the Final Waste Management Programmatic Environmental Impact Statement (DOE 1997), and reasonably foreseeable treatment, storage, and disposal facilities/activities. The EIS will evaluate alternatives for managing the program's radioactive and hazardous wastes, including waste generated at the Hanford Site or received from offsite generators, during the same 20-year period evaluated by the WM PEIS. This EIS will be used to comprehensively analyze impacts of reasonable alternatives,

Table 3. Summary of Anticipated Groundwater Analyses at the Hanford Site (Present to Fiscal Year 2003)

Modeling Activity/Project	Current Time Frame of Analysis	Brief Statement of Scope
Solid Waste Environmental Impact Statement	July to December 1998	Site-wide groundwater modeling to support development of preliminary draft of EIS
	Fiscal year 1999	Analysis to support development of final EIS
Modeling Support to Hanford Groundwater Project	Present to 2003	General modeling support to address groundwater monitoring issues
Composite Analysis of 200-Area Plateau	Fiscal year 1999	Response to DOE headquarters comments on first iteration
	Fiscal year 1999	Initial evaluation of chemical impacts
System Assessment Capability	Unspecified	Next-generation Composite Analysis
Modeling support to River Protection Program Hanford Tank Initiative	November 1998 January 1999	Report on modeling analysis support for the tank waste retrieval performance evaluation 200 Draft Report - Final Report
	Fiscal year 2000	Modeling support to technology deployment selection
	Fiscal years 1999-2003	Modeling support to develop cleanup standards and tank waste residuals
Performance Assessment of River Protection Program Immobilized Low Activity Waste	January - August 2000 January - August 2002	Groundwater modeling support on performance assessment of: 200 Grout vault disposal - New facility disposal
Groundwater/Vadose Zone Integrated Project	Fiscal year 2000-2001	Use of site-wide groundwater model as a part of the groundwater component of a System Assessment Capability to acceptably quantify the environmental consequences of past, present, and future DOE actions at the Hanford Site
Performance Assessment of 221-U Facility - Canyon Disposition Initiative	Fiscal year 1999-2001	Potential groundwater Modeling support to performance assessment as a part of development of Record of Decision (ROD) for final disposition 221-U facilities
200 Area Soils Characterization and Remediation Project	Fiscal year 2002	Potential groundwater modeling support in quantitative risk assessments to support development of interim RODs of characterized waste groupings sites
Maintenance of Performance Assessments for Solid LLW Burial Grounds	Unspecified	Potential groundwater modeling support to potential five-year cycle PA revisions
Permit support to liquid discharge facilities	Unspecified	Potential groundwater modeling support to reevaluation of permit conditions based on new monitoring data
Reevaluation of Hanford Groundwater Remediation Strategy	Unspecified	Potential groundwater modeling support to future reassessment of site-groundwater remediation strategy

Table 3. (contd)

Modeling Activity/Project	Current Time Frame of Analysis	Brief Statement of Scope
Final ROD's for the 100 and 200 Area Interim Remedial Measures	Unspecified	Potential groundwater modeling support to final ROD development for pump-and-treat systems at the 200-UP-1, 200-ZP-1, and 100-KR-3 operable units and in the 100-N Area.

including potential cumulative impacts of other relevant past, present, and reasonably foreseeable activities.

Specific groundwater modeling requirements and methodologies that will be used to support this project are under development at this time. However, initial planning indicates that a groundwater-analysis capability will be needed to assess the environmental consequences and human health impacts of potential radiological and chemical contaminants from all solid LLW disposal facilities for site groundwater and surface-water resources. Implicit in this need is the potential use of a site-wide groundwater model to provide the necessary spatial and temporal hydraulic and transport framework for transport analysis of key radionuclides and chemicals. The assessment is being initiated in FY 1998, and the initial draft of the EIS will be completed for public review and comment in FY 1999.

4.1.2 Modeling Support to the Hanford Groundwater Project

Groundwater modeling is being actively used to support key objectives of the HGWP. These objectives include identification and quantification of existing, emerging, or potential groundwater quality problems and assessment of the potential for both radiological and chemical contaminants to migrate from the Hanford Site through the groundwater pathway.

Two recent assessments related to the HGWP that made extensive use of groundwater modeling were

- prediction of impacts of future water-level declines on site-wide monitoring wells
- development of a three-dimensional groundwater model and its application to evaluate the impacts of existing contaminant-plume migration on Hanford Site drinking water systems and groundwater use.

In the future, this project will continue to require a three-dimensional model of the unconfined aquifer system to assist in assessing and interpreting the behavior of existing, emerging, or potential groundwater quality problems across the site. A site-wide modeling capability is required to predict impacts of future water-level changes on site-wide monitoring wells and future groundwater flow patterns and to assess the potential for existing contaminant plumes and potential future releases of contaminants contained within waste sites or in the vadose zone to migrate from the Hanford site to onsite and offsite water supplies. End points of the groundwater flow and transport analysis are problem-specific and can range anywhere from locations directly beneath or in close proximity to individual waste sites to locations along or in the Columbia River.

4.1.3 Composite Analysis of the 200-Area Plateau

In response to the Defense Nuclear Facilities Safety Board (DNFSB) Recommendation 94-2, DOE Headquarters has directed field sites to include in site performance assessments, an analysis of the impact of other radioactive sources that could add to the dose from active or planned LLW disposal facilities. In response to this directive, a composite analysis of the Hanford Site was initiated in FY 1996 and completed in FY 1998. This composite analysis focused on the 200-Area central plateau because of the variety of LLW facilities (e.g., 200-West and 200-East burial grounds, LLW from tank wastes, and the Environmental Restoration Disposal Facility [ERDF] trench) impacted by the DNFSB recommendations.

As part of the Composite Analysis, site-wide groundwater modeling was carried out to assess dose impacts for the transport of existing plumes and future releases of contaminants in the 200 Areas. Efforts were made to identify and screen all sources that could potentially interact with contaminants from Hanford LLW disposal facilities. Inventories and projected releases of radionuclides that are expected to contribute to the predicted doses were established for each of these sources.

The initial assessment is summarized in Kincaid et al. (1998), which was reviewed the DOE LLW Federal Review Group. Current plans for the Composite Analysis are to initiate a second iteration in FY 2000. The scope of the second iteration may also be expanded to include the potential impacts of other facilities within and outside of the 200-Area plateau not specifically considered in the first iteration and may evaluate the potential risk impacts of critical chemical contaminants.

4.1.4 Modeling Support to the Hanford Tanks Initiative

Vadose zone and groundwater modeling assessments are being conducted as part of the Hanford Tanks Initiative (HTI) to provide engineering and scientific analysis necessary to evaluate the impact of tank closures. These analyses are being designed to assist RL in

- establishing appropriate retrieval techniques
- determining appropriate release during waste retrieval
- evaluating the need for new tank retrieval technologies
- supporting the identification of the most important field characterization and technologies development area
- supporting future National Environmental Policy Act (NEPA) analyses.

In the initial phases of this work, the effort has focused on performing screening-level sensitivity analyses of the AX and SX tank farms to identify and rank transport parameters and evaluate transport phenomena in the vadose zone as a part of the Retrieval Performance Evaluation Criteria Assessment part of the HTI. These analyses are being used to better focus the development and application of more refined two- and three-dimensional vadose-zone models and to support field-characterization efforts by defining data needs to reduce uncertainties in the risk-assessment process. Results of these initial sensitivity analyses are summarized in two recent reports by Jacobs Engineering Group, Inc. (JEGI) (1998a and 1998b).

Detailed vadose zone models have been developed for the AX and SX tank farms and have been used in conjunction with a site-wide model of the unconfined aquifer to evaluate the environmental and human health impacts of contaminants of concern. The purpose of the detailed modeling was to evaluate alternative remediation and closure options at the AX tank farm. The saturated zone model used in early analyses was a two-dimensional site-wide model involving both groundwater flow and contaminant transport with risk as the endpoint. Parameters and boundary conditions of the numerical model were based on the parameters of the three-dimensional site-wide model of the Hanford Groundwater Project. A two-dimensional model was used in part to reduce the computational requirements of the analysis. PORFLOW was selected initially because it is on the list of approved codes for the Hanford Site, and members of the project team were already using it. However, the project has benchmarked the two-dimensional model based on PORFLOW results to an equivalent site-wide model based on CFEST-96 for use in its final analysis. The Draft Retrieval Performance Evaluation (RPE) Report was completed on October 5, 1998 and was issued for agency, Tribal Nation, and stakeholder review. The final report on the overall RPE assessment was released in April 1999.

Additional analysis that may involve use of a site-wide groundwater model will focus on analysis to support the retrieval technology selection in FY 2000 and the development of cleanup standards and tank waste residuals through FY 2003.

4.1.5 Performance Assessment of Immobilized Low Activity Waste Disposal Facilities

The performance assessment (PA) for the Hanford Immobilized Low-Activity Waste (ILAW) disposal facilities provides an analysis of the long-term environmental and health impacts of the on-site disposal of Hanford immobilized low-activity wastes (LAW) (Mann et al. 1998). RL is currently proceeding with plans to permanently dispose of radioactive and mixed wastes that have accumulated over the last 50 years in single- and double-shell tanks in the 200 Areas of the site. Waste currently stored in single- and double-shell tanks will be retrieved and pretreated to separate the low-activity liquid fraction from the high-level and transuranic wastes. The low-activity fraction will then be immobilized and disposed of onsite in near-surface disposal facilities located in the 200-East Area.

Two sites are being proposed for the River Protection Program ILAW disposal complex. The principal site, which is located in the south-central part of the 200-East Area, will store the bulk of the ILAW generated as wastes are retrieved from single-shell and double-shell tanks for vitrification by private vendors. Another site, which is located at the previously constructed grout disposal facility just east of the 200-East Area, will be modified to receive initial quantities of ILAW from a private vendor while the principal waste disposal facility is being developed.

The first version of the ILAW PA was published in Mann et al. (1998) and submitted for DOE headquarters for review by the LLW Federal Review Group (LFRG). This assessment was preceded by an interim ILAW performance assessment described in Mann et al. (1996) that was prepared to provide an early assessment of the effects of the disposals using available information. The groundwater flow and transport component of the analysis, described in Lu (1996), relied on the site-wide model used to support the GWRS. Much of the data used in the ILAW PA was derived from information obtained in other onsite programs and documented in Mann (1995). The data and information documented include the disposal-site locations, geology, waste inventory, estimates of recharge, disposal package and facility design, release rates from glass waste forms, hydrologic parameters, geochemical parameters, and dosimetry. The transport analysis of contaminants from the disposal facility considered the key physical and chemical processes causing release from the glass waste form and subsequent vertical and lateral transport through the vadose zone to the underlying groundwater. Once in the groundwater, environmental and health impacts were evaluated 100-m downgradient of the facility and at the Columbia River. The methods and technical approaches used to generate the data values are also described.

Several future revisions of the ILAW PA are planned; these will use more site-specific, waste-form specific, and facility-specific data that are planned to be generated over the next two to three years. A series of PAs will be written in order to support the disposal of ILAW at the two disposal facility locations. The first two, currently scheduled to be published in March 2001 and January 2003, will use newly generated site- and waste form-specific information, respond to comments from DOE on the 1998 PA, and investigate the impacts of new disposal-facility designs and concepts. In both cases, the analyses will require a site-wide groundwater flow model to evaluate three-dimensional contaminant transport of key radioactive contaminants and potential human- health impacts from facility releases. These impacts will be assessed at 100 m downgradient from the planned disposal facilities (to meet the requirements of DOE Order 5820.2a for protection of ground water) and at the Columbia River boundary (to meet the requirements in DOE Order 5820.2a for protection of surface water). The current guide for PA maintenance will also require an ongoing annual review and five-year revision cycle that repeats itself during the entire operational period for the ILAW disposal facilities.

4.1.6 System Assessment Capability Development – Hanford Site Groundwater/Vadose Zone Integrated Project

The mission of the Hanford Site Groundwater/Vadose Zone (GW/VZ) Integrated Project, which was initiated in FY 1998, is to develop and conduct defensible assessments of the Site's present and post-closure cumulative effects of radioactive and chemical materials which have accumulated throughout Hanford's history and that continue to be received. These assessments will be conducted 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. As part of its mission, the GW/VZ Project will define those actions necessary to bring into consistency and maintain mutual compatibility among site-wide characterization and analysis tasks that bear on decisions, receptor impacts, and regulatory compliance.

An integral part of the GW/VZ project will entail the design, development, and application of a System Assessment Capability (SAC) to acceptably quantify the environmental consequences of past, present, and future DOE actions at the Hanford Site. The SAC that will be developed will include elements for quantification of 1) onsite radiological and chemical inventories and related contaminant releases to the environment, 2) water flow and contaminant transport in the vadose zone and groundwater systems, 3) water flow and contaminant transport in the Columbia River System, and 4) exposures and risk to humans and the environment from radioactive and chemical contaminants in various environmental media impacted by Hanford operations.

The site-wide groundwater model selected in this model consolidation process is expected to provide the conceptual framework upon which the groundwater component of the SAC will be developed. The overall SAC is currently in the conceptual model development phase but is expected to be developed in a time frame that will allow for its initial application in the next one to two years. Because of the scope of these broad assessments, the framework of the groundwater component of the SAC may use a simplified calculational module that captures the key elements of the site-wide conceptual model for groundwater flow and transport rather than using its full numerical implementation.

4.2 Other Possible Applications

This section describes future activities that currently have no specific plans for use of a site-wide groundwater model but have the potential to make use of a site-wide model. These activities include

- the Canyon Disposition Initiative
- the 200 Area Soils Characterization and Remediation Project
- maintenance of performance assessments of the solid LLW burial grounds
- permit support for liquid discharge facilities
- potential reevaluation of the Hanford Site-Wide GWRS
- development of final records of decision for interim remedial measures in the 100 and 200 Areas.

4.2.1 Canyon Disposition Initiative

The Canyon Disposition Initiative is focused on identifying solutions for the long-term closure of the five main processing facilities in the 200 Area (B-Plant, T-Plant, 221-U Facility, Plutonium Uranium Extraction Facility, and the Reduction Oxidation Plant). The initial phases of the initiative are using the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA) process to evaluate optimum alternatives for final disposition of the first canyon facility to be examined: the 221-U Facility.

In the initial assessment of the 221-U Facility, a long-term PA will be needed to examine the potential environmental impact of contaminants of concern that would be left in place for various alternatives under consideration. A component of this PA will be the evaluation of the impacts of released contaminants on the unconfined aquifer system beneath the 221-U Facility.

Selected methodologies and technical approaches must be able to quantitatively assess the key elements of these conceptual models, including the expected long-term release of critical contaminants from the facilities of concern, the transport of these contaminants in the environment, and the subsequent risk and environmental impact of these contaminants at expected exposure and receptor points. The specific scope and methodology used for the groundwater flow and transport component of the analysis will be developed during the initial phases of the PA process.

Current plans call for starting the first phases of the PA of all alternatives being considered in FY 1999. The current Tri-Party Agreement schedule calls for a record of decision for disposition of the 221-U

Facility to be completed in September 2001. Similar assessments of the other main processing facilities (B-Plant, T-Plant, Plutonium Uranium Extraction Facility, and the Reduction Oxidation Plant) will be initiated after completion of the 221-U Facility analysis.

4.2.2 200 Area Soils Characterization and Remediation Project

The 200 Area Soils Characterization and Remediation program focuses on assessment and remediation of contaminated soil that resulted from discharge of liquids and solids from processing facilities to the ground (e.g., ponds, ditches, cribs, and burial grounds) in the 200 Areas. The central strategy for this effort has been to establish 23 waste-site groupings that integrate the treatment, storage, and disposal and past-practice sites and to build on the common chemical processes and waste-site types (cribs, ponds, ditches) that cross between 32 previously established operable units. Characterization and analysis of data, collected from representative sites associated with each waste-site group, will provide the basis for reaching remedial action approaches and decisions for all sites within each particular waste-site group. This overall strategy and the detailed descriptions of the individual waste-site groups have been developed and summarized in DOE/RL (1996) and in DOE/RL (1997a).

Detailed conceptual models to be used for the assessment of each waste-site group have not developed. However, it is anticipated that part of the analyses will need to evaluate the potential environmental and human health impacts from the underlying groundwater system of important radiological and chemical contaminants from each alternative. The site-wide groundwater model may not be used directly in each individual waste-site grouping assessment but could provide a hydrologic framework or the basis for the calculational methodology used to address the groundwater component of the assessment.

A cumulative risk assessment will be performed once sufficient data has been collected for a comprehensive analysis. Final remedial actions will also need to be defined and end states will need to be established. Any cumulative risk assessment that is required to establish cleanup standards other than those contained in the current regulations is not considered on a waste-site-specific basis but rather must be considered at a site-wide level. This level of analysis will likely involve the use of a site-wide groundwater model to address environmental and human health impacts from the unconfined aquifer system.

Current plans within this project will potentially result in the development of interim records of decisions at several of the waste grouping sites being examined over the next three to five years.

4.2.3 Maintenance of Solid Waste Burial Ground Performance Assessments

Since September 26, 1988, PA analyses have been required by DOE Order 5820.2A to demonstrate that DOE-operated waste-disposal facilities containing DOE LLW can comply with the appropriate performance objectives. Two separate PAs that have included use of groundwater modeling have recently been completely for post-1988 solid LLW disposal facilities located in the 200-East Area and the 200-West Area (Wood et al. 1995, Wood et al. 1996). The following is a brief description of the scope and groundwater-modeling activities carried out to support these analyses.

Current program plans for Hanford LLW burial grounds call for ongoing maintenance of PA analyses. This maintenance plan is designed to perform a routine review of PA-derived controls on waste disposal so those potential problems are identified and managed. Problems could result from new data or information on waste inventory, waste-form release mechanisms, environmental characterization, or monitoring that could have an impact on fundamental assumptions and parameter estimates used to establish the PAs. PA revisions may be required to evaluate conditions or assumptions not originally included in the PA analysis.

The current guide for PA maintenance requires an ongoing annual review and five-year revision cycle that repeats itself during the entire operational period. The first five-year revision period will be in FY 2000. However, because of the technical approach and calculational methodology used in the original PAs, future use of the site-wide groundwater model to support the ongoing maintenance is not anticipated unless the PA review and potential five-year revisions require its use to resolve a particular issue. It is anticipated that if required, the site-wide groundwater model will be used to provide the hydrologic framework or the basis for the calculational methodology used to address the groundwater component of the PA.

4.2.4 Permitting Support for Liquid Discharge Facilities

Under the Hanford Site State Waste Discharge Permit Program, the Hanford Site discharges treated cooling and wastewater to the soil column at several locations in accordance with the Washington State Administrative Code (WAC) 173-216 and DOE Order 5400.5. Individual discharge permits include the following sites:

- ST-4500, 200 Area Effluent Treatment Facility (ETF) managed by Waste Management Hanford (WMH) PHMC
- ST 4501, Fast Flux Test Facility (FFTF) secondary cooling tower water managed by WMH-PHMC
- ST 4502, 200 Area Treated Effluent Disposal Facility managed by WMH-PHMC
- ST 4503, 183-N backwash discharge pond managed by BHI
- ST 4507 100-N sewage lagoon managed by Dyncor-PHMC
- ST 4508, Hydrotest, Maintenance, and Construction Discharges. This is a site-wide permit managed by both BHI and contractor personnel from the PHMC.

Of these facilities, the only facility that has used groundwater modeling is the 200 Area ETF. In 1997, groundwater modeling was performed to support ongoing permitting requirements for the ETF disposal site located just north of the 200-West Area (Barnett et al. 1997). The ETF disposal site, also known as the State-Approved Land Disposal Site (SALDS), receives treated effluent containing tritium which is allowed to infiltrate through the soil column and pass through to the water table (Note: Tritium is allowed in the liquid effluent per exception detailed in DOE Order 5400.5). The facility operating permit, promulgated by WAC 173-216 (Ecology 1986), requires groundwater monitoring for tritium, reporting of monitoring results, and periodic review of the monitoring network.

The ETF began operations in November 1995, and tritium was first detected in groundwater monitoring wells around the facility in July 1996. The SALDS groundwater-monitoring plan requires a re-evaluation of the monitoring-well network and a revision of the predictive groundwater model used in the original permit one year after first detection of tritium in groundwater.

Current permit requirements commit RL to an ongoing reevaluation of the effectiveness of the monitoring network and the appropriateness of past modeling results as new liquid discharge information or monitoring data become available during the entire operational period. Future use of the site-wide groundwater model to support SALDS-specific permit requirements will depend on the consistency of new discharge information or monitoring data with the fundamental assumptions and results simulated with the current site model.

4.2.5 Potential Reevaluation and Update of Hanford Site-Wide Groundwater Remediation Strategy

The Groundwater Remediation Strategy describes the approach to remediate the major groundwater contaminant plumes in the 100 and 200 Areas of the Hanford Site. As part of the strategy, a site-wide groundwater model was developed to be used in estimating the effectiveness of alternative groundwater cleanup approaches, to support planning and implementation of remediation alternatives, to support risk assessments, and to evaluate the impact of changes in the groundwater flow field. The groundwater modeling for the Groundwater Remediation Strategy is summarized in detail in Law et al. (1997) and Chiaramonte et al. (1997). A summary of the key aspects of the groundwater model is provided in Appendix A.

This work and related site-wide groundwater modeling was completed and published in 1996 and republished with revisions in 1997. No plans are being made to revisit the developed strategy in the near future. However, should a reassessment of this strategy be required, the previously predicted groundwater flow and transport modeling results may need to be re-evaluated. This reassessment may also require new analysis of future predictions of water table elevations and vertical and horizontal contaminant transport of several key contaminant plumes that were examined in the original study, including tritium, iodine-129, uranium, technetium-99, nitrate, carbon tetrachloride, trichloroethylene, and chloroform.

4.2.6 Final Records of Decision for Interim Remedial Measures in 100- and 200- Areas

Pump-and-treat systems have been implemented and are being used to reduce and contain contaminant plumes in the 100-N, 100-D, and 100-H areas (DOE/RL 1997b). A pump-and-treat system is being operated in the100-N Area as a small-scale treatability test to evaluate the ability of the system to remove dissolved strontium-90 from the groundwater near N-Springs and to provide hydraulic control of the movement of strontium-90 to the Columbia River. The system is also being used to support an evaluation of an adsorption barrier designed to reduce the flux of strontium-90 to the Columbia River by significantly delaying its transport to the river and allowing radioactive decay to mitigate the problem.

A pump-and-treat system is being operated in the 100-HR-3 Operable Unit area (100-D and 100-H reactor areas) as a treatability test to evaluate the ability of the system to remove chromium from the groundwater near N-Springs. The test is currently being performed in the 100-D Area. While the system has effectively provided hydraulic control of the movement of chromium to the Columbia River, it may not be an effective long-term option for achieving full remediation (DOE/RL 1997b). Final remediation may require further identification and remediation or removal of continuing sources of contamination, if feasible and cost effective.

Two pump-and-treat systems have been implemented as pilot-scale tests and are being used to reduce and contain contaminant plumes at the 200-UP-1 and 200-ZP-1 Operable Units in the 200-West Area (DOE/RL 1997b). The 200-UP-1 pump-and-treat system is being used to minimize the migration of uranium and technetium-99 groundwater plumes in the 200-UP-1 Operable Unit. The 200-ZP-1 pump-and-treat system is being used to minimize the migration of the high-concentration portion of a carbon tetrachloride plume and co-contaminants chloroform and trichloroethylene in the 200-ZP-1 Operable Unit.

As part of the initial remedial design process for pilot-scale pump-and-treat tests, capture-zone analyses of the 200-UP-1 and 200-ZP-1 groundwater operable units were carried out. Modeling associated with the capture-zone analyses is described in WHC (1994) (see also BHI 1996a, BHI 1996b). The stated objectives of these past studies were to evaluate alternative interim remedial actions, to assess refinements or expansions of interim actions, and to help choose a final remedy. Additional objectives were to assess impacts of changes in the water table elevation, to evaluate well configurations for the pump-and-treat, to design and evaluate monitoring networks, to evaluate hydraulic control and containment, and to predict contaminant-transport pathways and travel times.

These pump-and-treat systems are being used as interim remedial measures (IRM) and are being monitored to evaluate their overall effectiveness in containing the 200-UP1 and ZP-1 contaminant plumes and to provide useful data and information on final remediation selection. These approaches may constitute a final action of these plumes if monitoring data can demonstrate that they represent an effective long-term solution for remediating the selected plumes.

Final assessments of the IRMs being undertaken in the 100 and 200 Areas as potential final remedies have not been undertaken at this time but could be evaluated within the next three to five years as additional data and information are collected on their overall effectiveness. This final assessment may require a re-evaluation of previously predicted groundwater modeling results and may also require new analysis of future predictions of water table elevations and contaminant transport of several key contaminant plumes that were examined in the original studies. Previous analyses to support remediation decisions have relied on local-scale modeling. It is not known whether a site-wide groundwater model will be used to support these future studies.

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5.0 Requirements for the Consolidated Site-Wide Groundwater Model

This section of the report provides a summary of requirements for the consolidated site-wide groundwater model. These requirements were based on the review of recently completed and ongoing Hanford Site groundwater modeling applications, as well as consideration of the future applications of the consolidated site-wide groundwater model as documented in the previous section and in Appendix A. Also, review comments and suggestions have been received from representatives of regulatory agencies, Tribal Nations, and other stakeholders who have participated in the model consolidation process.

The requirements for the consolidated site-wide groundwater model address the key elements of the conceptual model of the aquifer system, anticipated future flow conditions, the types of contaminant transport, and the spatial and temporal scales of potential applications.

The requirements for the consolidated site-wide groundwater model were combined with information provided in Simmons and Cole (1985), Kozak et al. (1989), DOE/RL (1991), and Mann and Myers (1998) to develop technical and administrative requirements for selecting a computer code that will be used in the implementation of the consolidated model. A brief discussion of the rationale is provided with each requirement.

The review of future groundwater analyses that will be performed at the Hanford Site revealed that the analyses could cover a range of problems that cannot be all addressed with a consolidated site-wide groundwater flow and transport model. The range of analyses include evaluations of

- current and near-term impacts of operations facilities and proposed waste-disposal facilities
- planning, design, and evaluation of remediation strategies including monitoring, natural attenuation, hydraulic control/containment, and contaminant removal/cleanup
- long-term performance assessment involving risk assessment and management
- assessment of site-wide cumulative environmental impacts.

This section of the report will discusses technical considerations and limitations in the potential application of the consolidated site-wide groundwater model including

- a narrower, and perhaps more pragmatic, list of potential site-wide groundwater model uses that involve less disparate temporal and spatial scales and range of contaminants than may be considered in the potential range of groundwater analyses
- potential use of the site-wide groundwater model to support development of more specialized local-scale models needed for some of the analyses
- linkages of the site-wide groundwater model to other analysis tools being used in these range of assessments and analyses.

- Required configuration control and management to support consistent usage of the site-wide groundwater model.

5.1 Conceptual Model Summary

This section of the report provides a summary of the current conceptual model of the Hanford Site aquifer system. The Hanford site geology and hydrology have been studied extensively for about 50 years. Detailed summaries of these past studies and investigations are described in a number of reports and references including DOE/RL (1988), Delaney et al. (1991), Lindsey et al. (1992), Lindsey (1995), Thorne et al. (1993), Thorne et al. (1994), and Wurstner et al. (1995). Material and information derived from these references are used to provide the following current understanding of the conceptual model of the aquifer system. This summary includes brief descriptions of the regional setting, the major hydrogeologic units, the major hydrologic boundaries, current and future anticipated flow conditions, and existing and potential future radiological and chemical contamination in the aquifer system.

5.1.1 Regional Setting

The Hanford Site lies within the Pasco Basin, a structural depression within which a relatively thick sequence of sediments has accumulated. The Pasco Basin developed through deformation of the underlying Columbia River Basalt Group, a sequence of Miocene-Age continental flood basalt covering more than 160,000 km^2 of Washington, Oregon, and Idaho.

The stratigraphic units underlying the Hanford Site, provided in Figure 5, show that sediments overlying the Columbia River Basalt Group include, in ascending order, the Pliocene-aged Ringold Formation, the Plio-Pleistocene unit (including early Palouse soil), the pre-Missoula gravels, and the informally named unit referred to as the Hanford formation.

The sedimentary interbeds and the basalt intra-flow zones of the Ellensburg formation within the Grande Ronde, Wanapum, and Saddle Mountain basalts of the Columbia River Basalt Group make up a series of confined aquifers that may interact with the unconfined aquifer system to some limited but unknown degree. These aquifers are areally extensive and cover much of the Columbia River plateau in Washington State and Idaho.

The saturated portions of the sedimentary deposits found in the Ringold Formation, the Plio-Pleistocene unit, the pre-Missoula gravels, and the Hanford formation make up an unconfined aquifer system that underlies the Hanford Site. The saturated thickness of the unconfined aquifer system is greater than 60 m in some areas, but pinches out along the flanks of the basalt ridges. Depth to groundwater ranges from less than 1 m near the Columbia River to more than 100 m near the 200-Area plateau.

Groundwater in the unconfined aquifer system generally flows from recharge areas in the west to the Columbia River in the east. The unconfined aquifer system is contained within the Ringold Formation and the Hanford formation within the Pasco Basin. The aquifer system is bounded by basalt ridges, including the Umtanum Ridge, the Yakima Ridge, and the Rattlesnake Hills to the west, Rattlesnake Mountain on the southwest, the Saddle Mountains to the north, and the Palouse Slope on the east. The Columbia River forms a point of regional discharge and an important northern and eastern boundary to

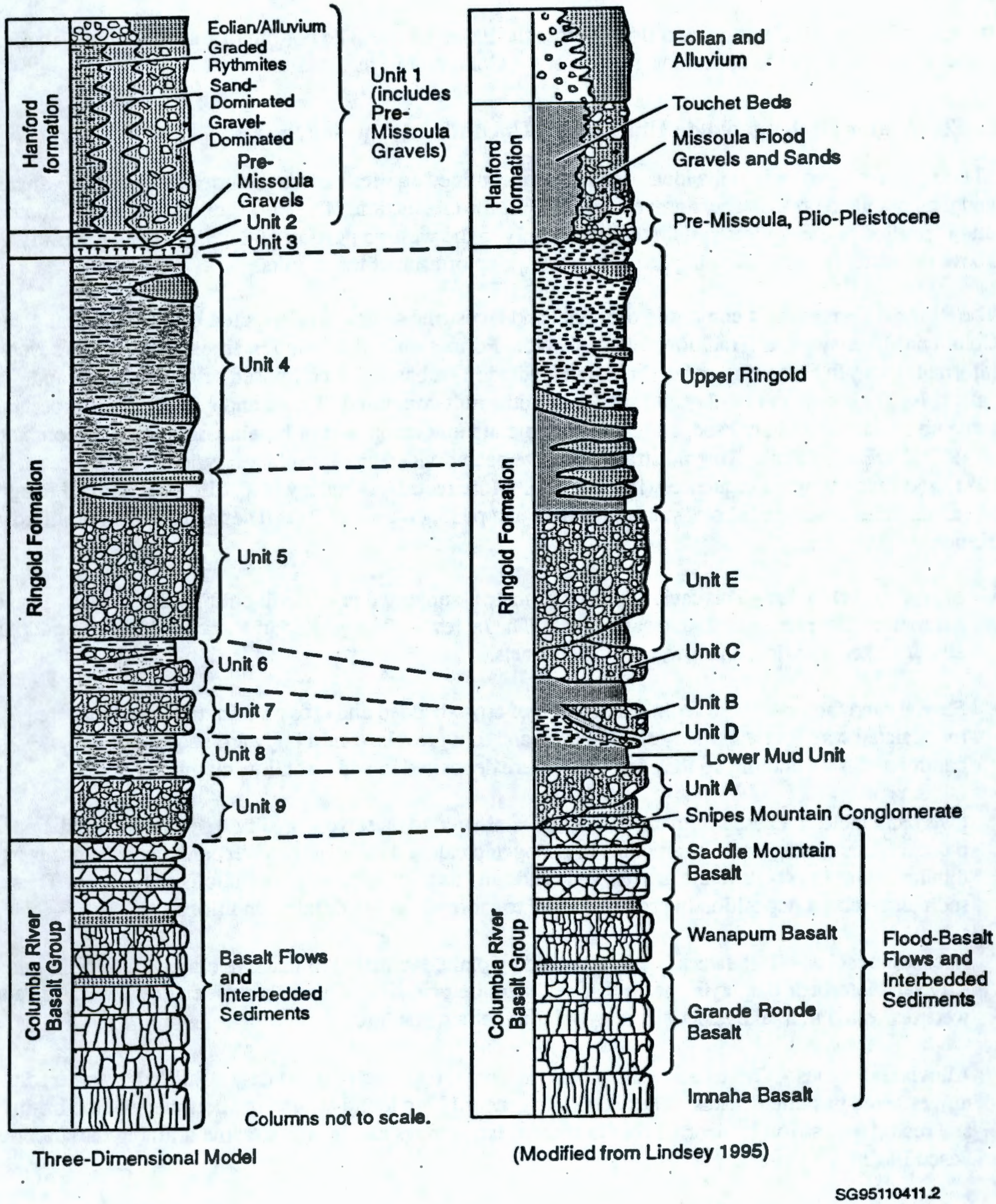

Figure 5. Major Stratigraphic Units Underlying the Hanford Site

the unconfined aquifer system and flows across the Pasco Basin. The bottom of the unconfined aquifer systems is formed by the uppermost surface of the Columbia River Basalt.

5.1.2 Major Hydrogeologic Units of the Unconfined Aquifer System

The major hydrogeologic units identified in the unconfined aquifer system include the Ringold Formation and the combined pre-Missoula gravels and the Hanford formation. The Plio-Pleistocene unit is another unit identified in the aquifer system that exists only in the western portion of the Site and is generally above the water table. Following is a brief description of each of these units.

The Ringold Formation is composed of fluvial and lacustrine sediments deposited by the ancestral Columbia River system. Traditionally, the Ringold Formation in the Pasco Basin is divided into several informal units. In ascending order, these units include 1) a basal unit composed of gravel, sand, and paleosols, 2) a lower unit of clay and silt, 3) a middle unit composed of sand and gravel, 4) an upper unit made up of mud and lesser sand, and 5) a fanglomerate unit composed of basaltic detritus (Newcomb et al. 1972; DOE/RL 1988). Ringold strata also have been divided based on facies types (Tallman et al. 1981) and fining upward sequences (PSPL 1982). More recently, Lindsey et al. (1992) described Ringold sediment facies based on lithology, stratification, and pedogenic alteration. The facies types identified include the following:

- Fluvial gravel facies - This facies consists of matrix-supported granule-to-cobble gravels with a sandy silt matrix and intercalated sands and muds. The facies were deposited in a gravelly fluvial braidplain characterized by wide, shallow, shifting channels.

- Fluvial sand facies - These sediments consist of cross-bedded and cross-laminated sands that are intercalated with lenticular silty sands, clays, and thin gravels. Fining upward sequences are common. Strata making up the association were deposited in wide, shallow channels.

- Overbank facies - These sediments consist of laminated to massive silt, silty fine-grained sand, and paleosols containing variable amounts of pedogenic calcium carbonate. Overbank deposits occur as thin lenticular interbeds in the gravels and sands and as thick, laterally continuous sequences. These sediments record deposition in proximal levee to more distal floodplain conditions.

- Lacustrine facies – This facies is characterized by plane-laminated to massive clay with thin silt and silty sand interbeds displaying some soft-sediment deformation. Deposits coarsen downward. Strata were deposited in a lake under standing water to deltaic conditions.

- Alluvial fan facies - These sediments are characterized by massive to crudely stratified, weathered to unweathered basaltic detritus. These deposits generally are found around the periphery of the basin and record deposition by debris flows in alluvial fan settings and in side streams draining into the Pasco Basin.

As described by Lindsey (1995) and illustrated in Figure 5, the upper part of the Ringold Formation is composed of interbedded fluvial sand and overbank facies, which are overlain by mud-dominated lacustrine facies. The lower part of the Ringold Formation contains five separate stratigraphic intervals dominated by the fluvial gravel facies type. These gravels, designated units A, B, C, D, and E, are separated by intervals containing deposits typical of overbank and lacustrine facies. The lowermost of the fine-grained sequence units, overlying gravel unit A, is designated the lower mud sequence.

The informally named Hanford formation and the similar pre-Missoula gravel deposits, which underlie the Hanford formation gravel deposits in the central part of the Hanford Site, are coarser and less consolidated than the Ringold. They were deposited by a series of catastrophic floods during the Pleistocene. The Hanford formation has been divided into three facies: 1) gravel-dominated, 2) sand-dominated, and 3) silt-dominated. These facies generally correspond to coarse gravels, laminated sands, and graded rhythmites, respectively, described in DOE/RL (1988). Gravel-dominated strata consist of coarse-grained sand and granule-to-boulder gravel. The sand-dominated facies consists of fine- to coarse-grained sand. Small pebbles and pebbly interbeds (<20 cm [8 in.] thick) may be encountered. The silt-dominated facies consists of silt and fine- to coarse-grained sand forming normally graded rhythmites. Plane lamination and ripple cross-lamination is common in outcrop. For the most part, the fine-grained sediments in the Hanford formation are found near the margins of the Pasco Basin and in areas protected from the main flood currents, which deposited the coarse-grained sediments. Capping the Hanford formation in many areas is a thin veneer of eolian sand and recent fluvial deposits.

The fluvial pre-Missoula gravels underlie the Hanford formation gravel deposits in the central part of the Hanford site. The pre-Missoula deposits are difficult to distinguish from the Hanford formation gravels, so they are usually grouped together (Hartman and Dresel 1998).

The Plio-Pleistocene Unit is a buried soil horizon containing caliche and side-stream basaltic gravels and is only recognized in the western part of the site and Pasco basin. The caliche developed on the top of the Ringold sediments and has a low hydraulic conductivity, while the side-stream gravels have a high conductivity.

To support development of the three-dimensional model for the HGWP, Thorne and Chamness (1992), Thorne et al. (1993), and Thorne et al. (1994) used the lithofacies described by Lindsey (1995) and regrouped them 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 designated in the conceptual model are briefly described in Table 4. Lindsey's corresponding units are shown in parentheses. A graphical comparison of the model units with Lindsey's stratigraphic column is shown in Figure 5. 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 were designated as model Unit 1. Units 2 and 3 correspond to the early Palouse soil and Plio-Pleistocene unit, respectively. The other units identified in the sequence make up the key hydrogeologic units within the Ringold Formation. The predominantly mud facies of Lindsey's upper Ringold were designated as 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.

Table 4. Major Hydrogeologic Units used in the Site-wide Three-dimensional Model

Unit Number	Hydrogeologic Unit	Lithologic Description
1	Hanford formation	Fluvial gravels and coarse sands
2	Palouse Soils	Fine-grained sediments and eolian silts
3	Plio-Pleistocene Unit	Buried soil horizon containing caliche and basaltic gravels
4	Upper Ringold Formation	Fine-grained fluvial/lacustrine sediments
5	Middle Ringold (Unit E)	Semi-indurated coarse-grained fluvial sediments
6	Middle Ringold (Unit C)	Fine-grained sediments with some interbedded coarse-grained sediments
7	Middle Ringold (Units B, D)	Coarse-grained sediments
8	Lower Mud Sequence (Lower Ringold and part of Basal Ringold)	Lower blue or green clay or mud sequence
9	Basal Ringold (Unit A)	Fluvial sand and gravel
10	Columbia River Basalt	Basalt

The areal extent and stratigraphic relationships of these major hydrogeologic units are shown in a series of cross sections across the Hanford Site provided in Figure 6 through Figure 10. The data and information used to develop these interpretations are shown in Figures 2.9 through 2.28 in Wurstner et al. (1995). Locations of the cross sections are given in Figure 6. Two west-east cross-sections (A-A' and B-B') are provided in Figure 7 and Figure 8. Two north-south cross-sections are given in Figure 9 and Figure 10. The position of the water table observed in 1997 is provided for reference.

A map view of major hydrogeologic units at the water table during 1997, shown in Figure 11, shows that the water table lies within the Hanford formation over most of the eastern and northern parts of the Hanford Site and within the Ringold Formation over the remainder of the site. The Hanford formation lies entirely above the water table in the western part of the Site and in some other localized areas.

5.1.3 Hydraulic Properties of the Major Hydrogeologic Units

This section provides a description of the hydraulic properties of major hydrogeologic units of the unconfined aquifer system.

The hydraulic properties of the major hydrogeologic units are inferred from hydraulic tests performed in the unconfined aquifer system. Hydraulic and transport properties are documented in DOE/RL (1988), Thorne and Newcomer (1992), Connelly et al. (1992a), Connelly et al. (1992b), Thorne et al. (1993), Thorne et al. (1994), Wurstner et al. (1995), Cole et al. (1997), and other project-specific reports.

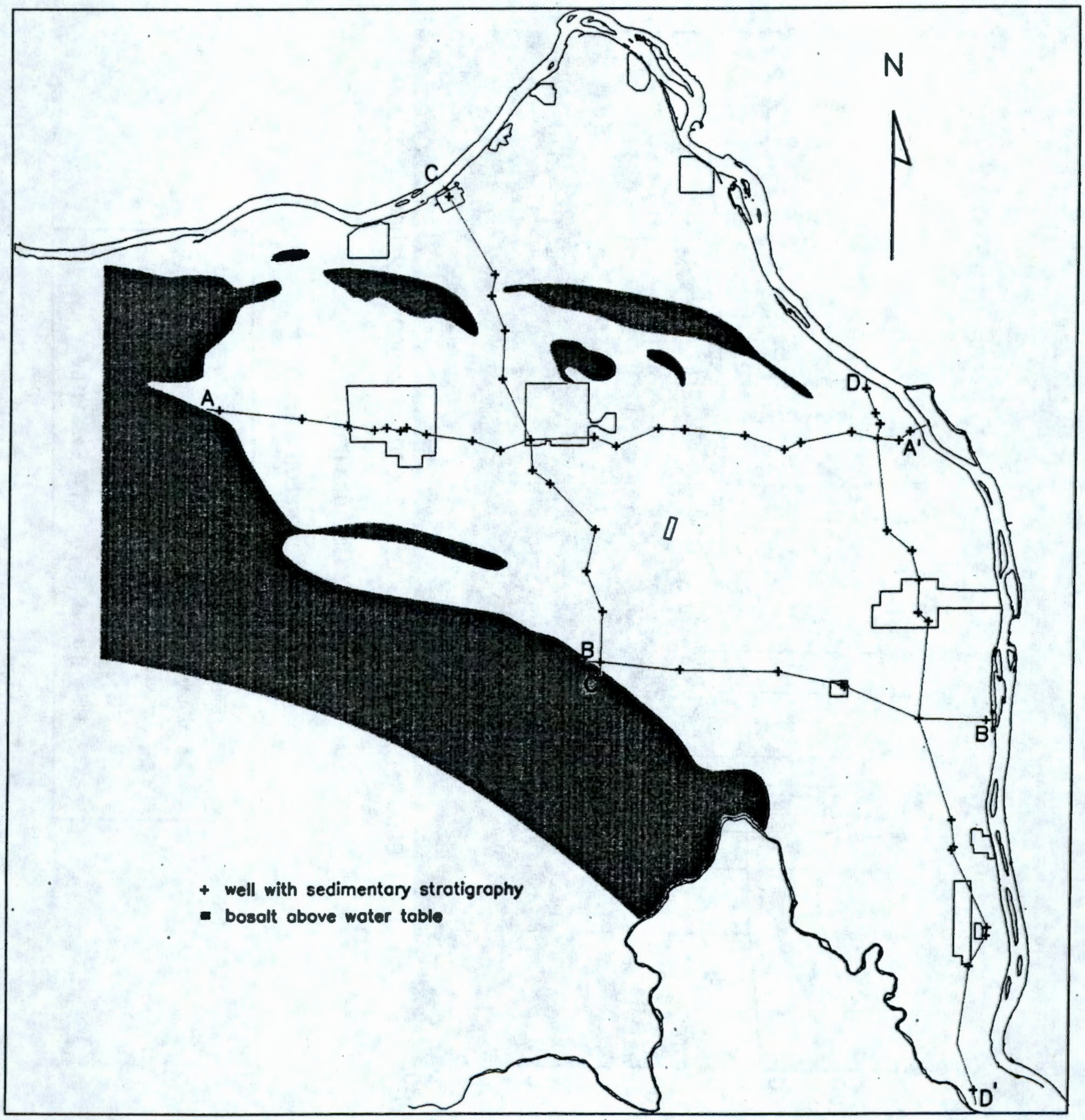

Figure 6. Location of Section Lines for Cross-sections A-A', B-B', C-C', and D-D' across the Hanford Site

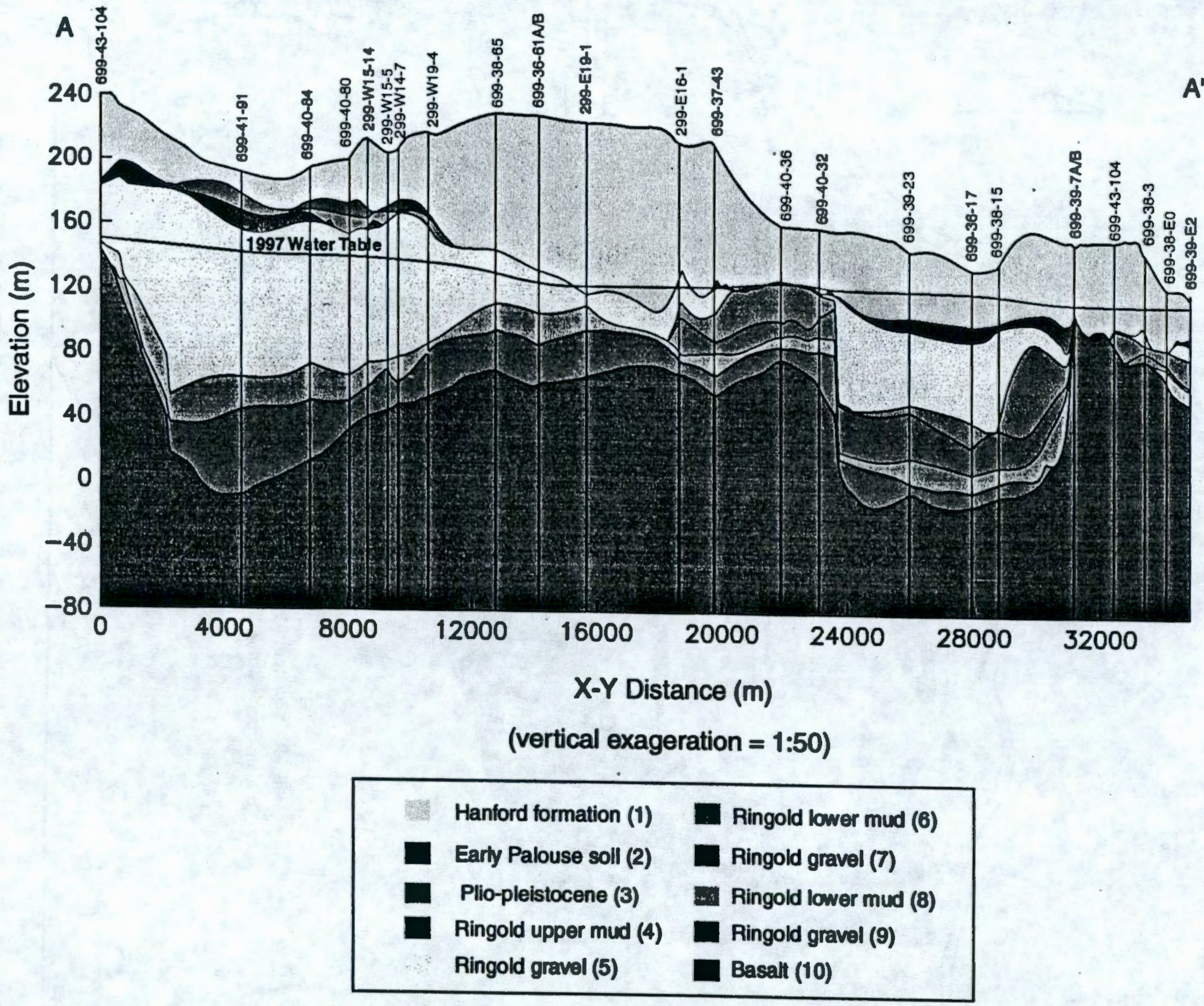

Figure 7. West-East Cross-section A-A', Showing Major Hydrogeologic Units through the Hanford Site

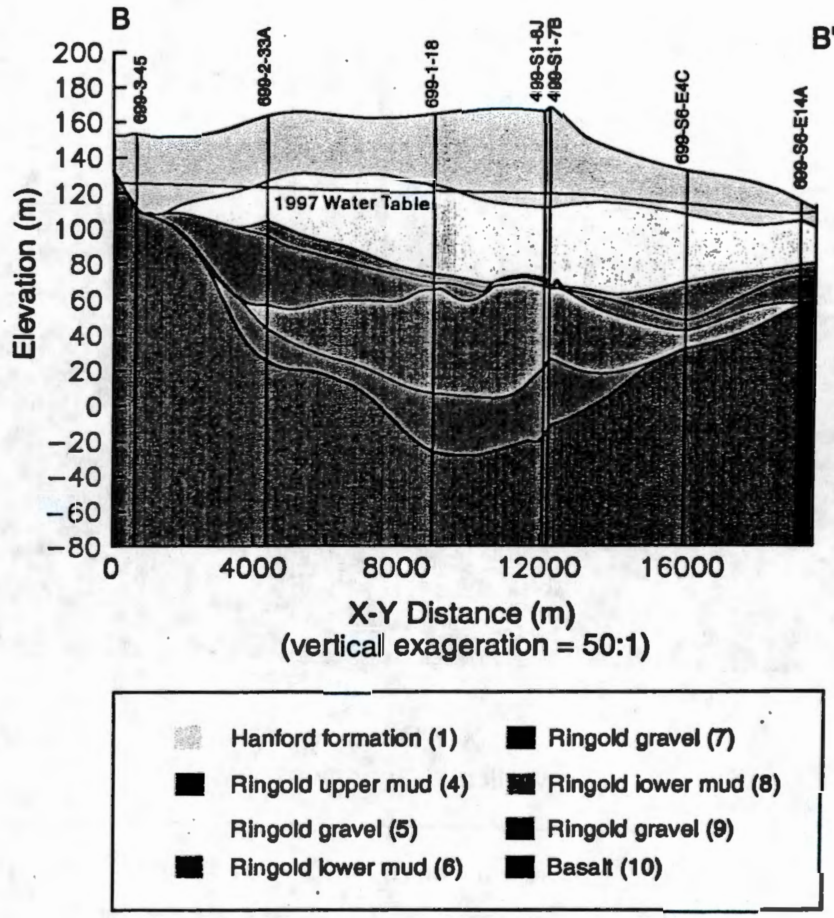

Figure 8. West-East Cross-section B-B', Showing Major Hydrogeologic Units through the Hanford Site

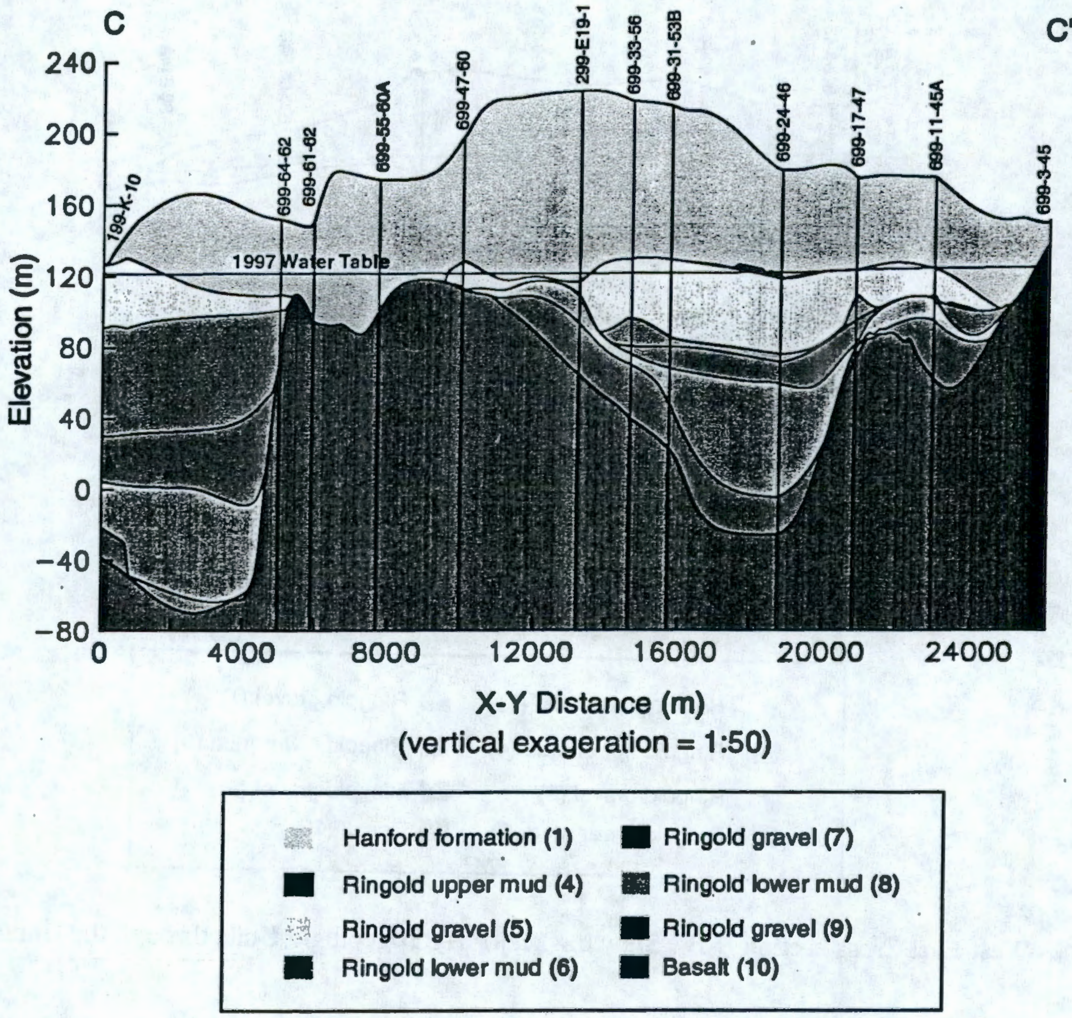

Figure 9. North-South Cross-section C-C', Showing Major Hydrogeologic Units through the Hanford Site

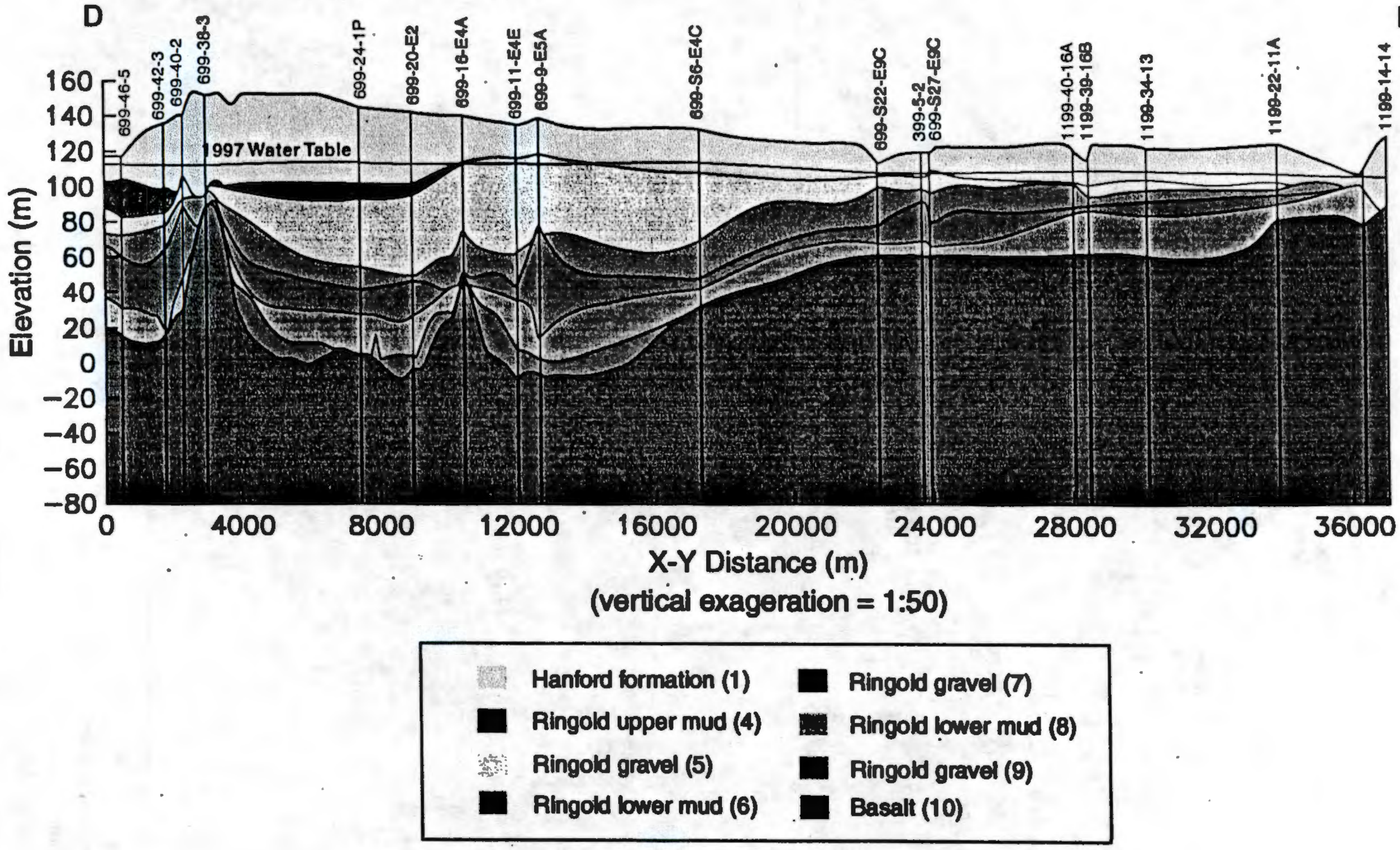

Figure 10. North-South Cross-section D-D', Showing Major Hydrogeologic Units through the Hanford Site

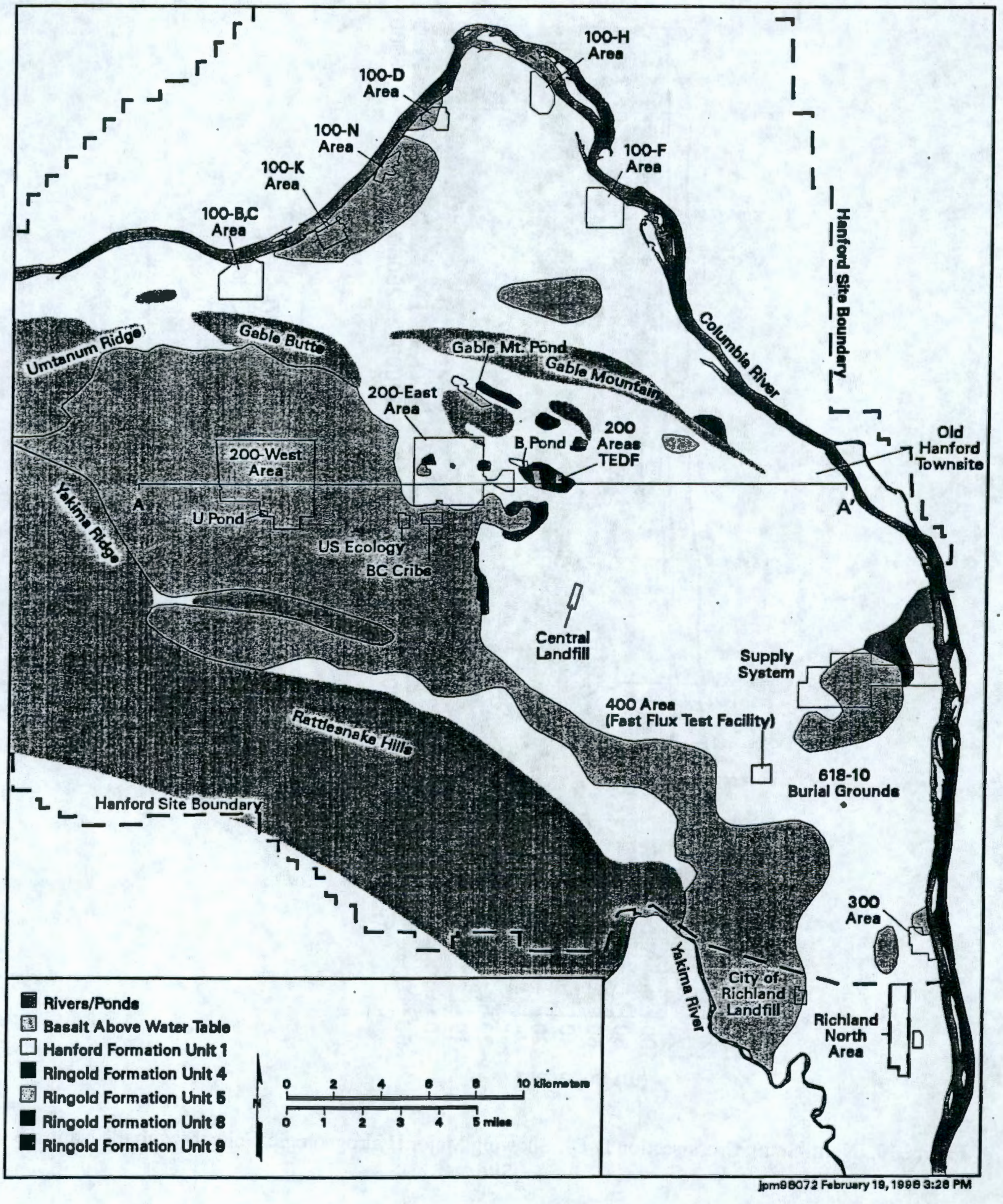

Figure 11. Map View of Hydrogeologic Units Present at the Water Table, June 1997

Transmissivity (the product of hydraulic conductivity and aquifer thickness) and storage information for the unconfined aquifer system have 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 that are determined from aquifer pumping and slug-interference tests (Spane 1993; Spane and Thorne 1995) are considered 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 Site (Section 3.3 in Wurstner et al. [1995]).

The distribution of transmissivity data from aquifer pumping tests and slug-interference tests is illustrated in Figure 12. Aquifer transmissivity is relatively high in the area between Gable Mountain and Gable Butte, and in the central part of the 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.

The range of hydraulic conductivity values calculated from measured transmissivity and aquifer thickness in provided in Figure 13. 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.

The aquifer 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 more permeable than Ringold sediments, they tend 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 non-ideal aquifer conditions and well configuration (Spane 1993) affect these types of tests. Measured aquifer storage properties are documented in Section 2.5.2 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 and from 0.0001 to 0.001 for the Ringold Formation gravels.

5.1.4 Transport Properties of the Major Hydrogeologic Units

This section provides a brief summary of the transport properties of the major hydrogeologic unts that make up the unconfined aquifer system. Simulation of contaminant transport requires estimates of a number of transport properties including estimates of the effective porosity, dispersivity, and retardation factors. Section 2.7 in Wurstner et al. (1995) and Cole et al. (1997) provide information on transport properties used in past modeling studies at the Hanford Site. A brief discussion of each of these parameters is provided below.

Porosity is defined as the volume of void space divided by the total volume of the soil or rock matrix that it is contained within the void space. Effective porosity is a quantity equal to the overall porosity minus the void space that is isolated from groundwater flow and therefore, a quantity that may be smaller than total porosity. Total porosity, derived from laboratory measurements from samples at a few wells, ranged from 0.19 and 0.41 and averaged 0.33 for the Ringold Formation and 0.31 for the Hanford formation in six wells in the 100-H Area. Porosity of the Ringold Formation from five depth intervals in 200-West

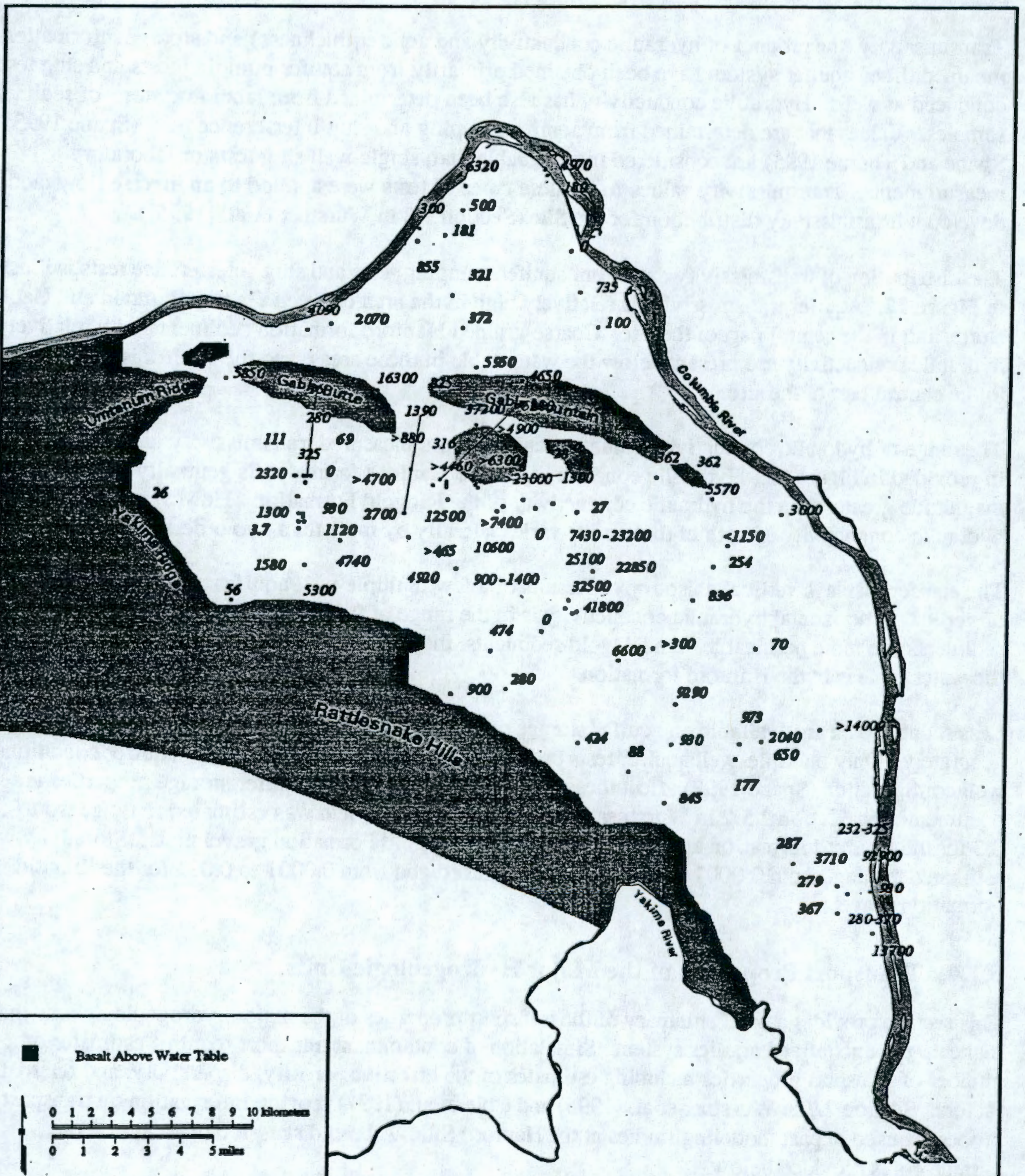

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Figure 12. Distribution of Transmissivity Data from Aquifer Pumping Tests and Slug-Interference Tests at Hanford

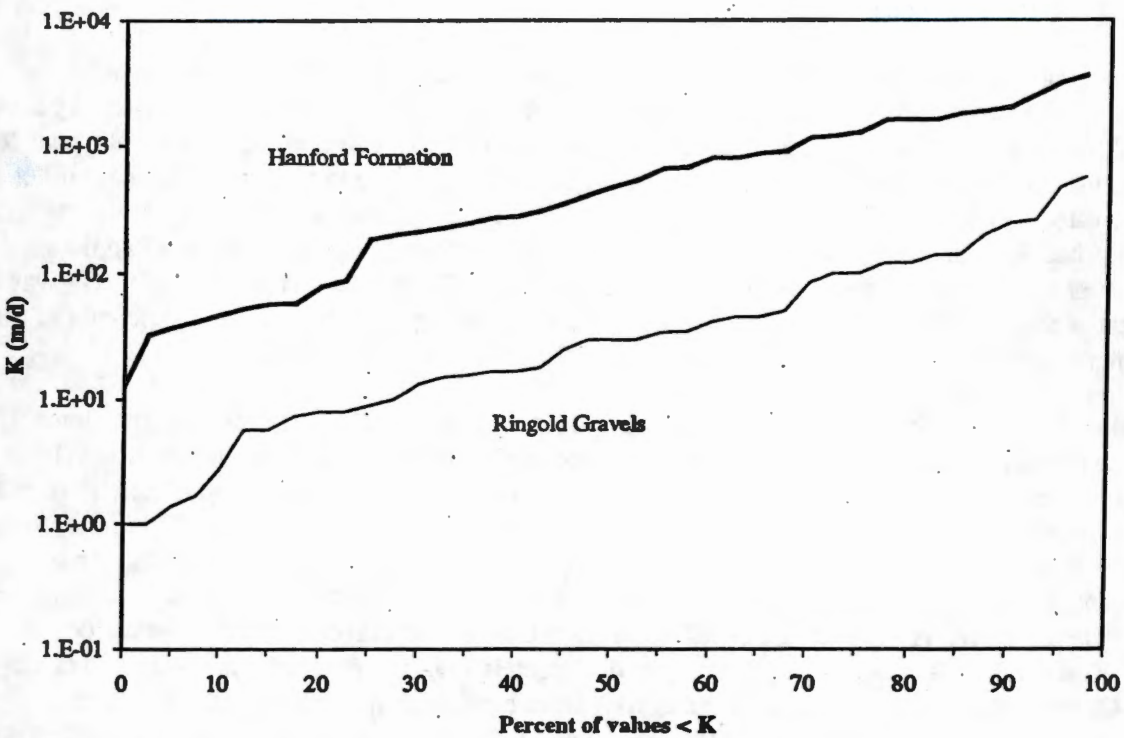

Figure 13. Range of Hydraulic Conductivity Values Calculated from Measured Transmissivity and Aquifer Thickness

Area measured by Newcomer et al. (1995) ranged from 0.21 to 0.33 and averaged 0.27. For Hanford applications, the effective porosity is more closely approximated by the specific yield of the unconfined aquifer as calculated from a few multiple well aquifer tests. Results of a few tests demonstrated the specific yield to range from 0.01 to 0.37. Results of site-wide modeling by Law et al. (1997) used porosity values of 0.1 and 0.25. Recent transport simulations by Cole et al. (1997) use 0.10 and 0.25 to represent the effective porosity in the Ringold Formation and Hanford formations respectively.

As a solute moves through the aquifer, it is dispersed by a combination of mechanical mixing and molecular diffusion. Dispersivity is a transport parameter used in modeling to represent these processes. General studies have indicated that dispersion is a function of both time and transport distance and results from spatial and temporal variations in the groundwater velocity field caused by spatial variations in hydraulic conductivity and spatial and temporal variations in the hydraulic gradient. Dispersivity cannot be directly measured in the field or laboratory. Dispersivity can be determined by inverse modeling of tracer tests breakthrough curves from tests performed at the transport scale of interest and in the hydrogeologic system of interest (Farmer 1986). Freeze and Cherry (1979) indicate that values of longitudinal and transverse dispersivity are significantly larger than values obtained in laboratory-scale experiments on homogeneous materials and materials with simple heterogeneity. No field test has been performed at the Hanford Site to develop a suitable estimate for this parameter at the scale of transport appropriate for the site wide model.

Past contaminant transport simulations at the Hanford Site have used a variety of longitudinal dispersivities (D_l) and transverse dispersivities (D_t). Most recent site-wide modeling analyses by Law et al. (1997) and Chiaramonte et al. (1997) used values of 30.5 m for D_l and 3 m for D_t, which appear to be related to the transport grid spacing of 100-m used in the analysis. Cole et al. (1997) and Kincaid et al. (1998) selected a D_l and D_t of 95 m and 20 m, respectively, for use in the 200-Area plateau Composite Analysis primarily to meet the numerical constraints related to the grid Peclet number. Complete discussion of this justification is provided in Kincaid et al. (1998). In Mann et al. (1998), the D_l was set at 10 percent of the travel length in the direction of flow (30.5 m) and the D_t was set at 1.0 percent of the travel length (3-m) to be consistent with ratios reported in the Gelhar et al. (1992).

Retardation factors are determined from estimates of contaminant specific distribution coefficients, bulk density, and porosity using the standard formulation for retardation factor defined in equation 9.14 in Freeze and Cherry (1979). Bulk densities and porosities used to calculate retardation factors in recent site-wide modeling studies ranged from 1.6 to 1.9 g/cm^3 and 0.1 to 0.25, respectively (Chiaramonte et al. 1997; Cole et al. 1997; Kincaid et al. 1998; Mann 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. A summary of distribution coefficients used in recent model applications at Hanford is provided in Table 5. This summary is discussed in detail in Appendix E in Kincaid et al. (1998). Of the key radioactive constituents that have been evaluated in site wide modeling in Chiaramonte et al (1997), Cole et al. (1997), Mann et al. (1998), and Kincaid et al. (1998), no adsorption has been accounted for in simulation of tritium and technetium-99 plumes. Transport of other radioactive constituents in these same assessments has used distribution coefficients ranging from 0.0 to 1.0 ml/g for iodine-129, 0.0 to 0.5 ml/g for uranium, and 5 ml/g for strontium-90. The reader is referred to the cited reports for distribution coefficients used for other radioactive and chemical constituents evaluated in these studies.

5.1.5 Hydrologic Boundaries of Unconfined Aquifer System

This following section describes the major lateral, upper, and lower hydrologic boundaries of the unconfined aquifer. The Columbia River bounds the aquifer system to the north and east and basalt ridges and the Yakima River to the south and west. The unconfined aquifer system does extend beyond these boundaries, but because contaminant sources are found in the operating areas of the Hanford Site south and west of the Columbia River, the area of concern for site-wide groundwater modeling is primarily focused on this area of the site.

The Columbia River represents a point of regional discharge for the unconfined aquifer and the amount of groundwater discharging to the river is a function of local hydraulic gradient between groundwater elevations alongside and beneath the river. This hydraulic gradient is highly variable because seasonal variations in precipitation and runoff in other regions of the river drainage system affect the river stage. The river stage is also impacted by weekly and daily changes in river flows at numerous dams on the river, as determined by electric power generation needs, fisheries resources management, and other dam operations.

Table 5. Summary of Distribution Coefficients (ml/g) Used in Previous Analyses

Element	Distribution Coefficients Assigned in Previous Studies								
	Surplus Reactors[(a)]	ERDF[(b)]	200 East SWBG[(c)]	TWRS EIS[(d)]	HRA EIS[(e)]	US Ecology[(f)]	TWRS ILAW[(g)]	Low K_d[(h)]	High K_d[(h)]
Group of Highly Mobile Elements Assigned a K_d of 0 ml/g									
H	0	0	0		0				
Cl	0		0		0	0			
Se			0	0	0		0	0	0.78
Tc	0	0	0	0	0	0	0	0	1.3
Group of Somewhat Mobile Elements Assigned a K_d of 0.6 ml/g									
I			-	-	-	-	3	0.04	18
U	0	0	0	0	0 to 250	0	0.6	0.08	79.3
Group of Moderately Immobile Elements Assigned a K_d of 10 ml/g									
Np		2	10	0	0 to 500		15	2.4	29.1
Pa				1	50		6	10	1000
Ra		10	10	10	20	200	15	24	100
Ru				0	0			27	274
Sr	0.64	10	10	10	10	0.64	3	5	173
Group of Highly Immobile Elements Assigned a K_d of 40 ml/g									
Ac				50			40	7	1330
Am	76	100	100	50	50	810	40	67	>1200
Bi				1	100				
Ce							100	100	>2000
Cm				50	50		100	106	1330
Co	100	1	1		12		100	1200	12,500
Cs	26	100	100	50	30		100	540	3180
Eu		10	10	50			100	100	228
K		10	10		0.2	0			
Nb					100	350	40	50	100
Ni	100	100	100	1	12	100	40	50	2350
Pb				10	100		100	13,000	79,000
Po					100				
Pu	71	100	100	10	1 to 200	73	40	80	>1980
Re			0						
Sn				10			100	100	230
Th		100	100	10	50	40	40	40	100
Y				50	100				
Zr	2000			50	50		40	90	>2000
Special Case Elements									
C[(i)]	0	0	0	0	0	0	6	0	4

(a) From DOE (1989).
(b) From DOE/RL (1994).
(c) From Wood et al. (1996).
(d) From DOE and Ecology (1996).
(e) From DOE (1996).
(f) From Grant Environmental, Chase Environmental Group, and US Ecology, Inc. (1996).
(g) From Mann et al. (1997).
(h) From Kaplan and Serne (1995) and Kaplan, Serne, and Piepho (1995).
(i) Recent work by Martin (1996) suggests carbon-14 undergoes attenuation in the environment because of isotopic exchange or dilution through recrystallization of minerals.

The Yakima River's stage elevation is higher than the water table in the adjacent aquifer, so it represents a potential source of recharge in the southern part of the Site. The total volume of recharge from the Yakima River is not well known. However, low permeability sediments adjacent to the river appear to limit leakage into the aquifer. Comparison of Yakima River stage and water levels in an adjacent well showed little correlation (Section 2.2.2 in Wurstner et al. [1995]).

The unconfined aquifer system on the Hanford Site receives groundwater inflow from the Cold Creek and Dry Creek valleys along the western boundary of the site. The aquifer system also is recharged from springs and runoff that infiltrate the aquifer along the northern side of Rattlesnake Hills.

The Columbia River basalts, underlying the unconfined aquifer sediments, are currently considered to represent a lower impermeable boundary to the unconfined aquifer system. However, areas of increased vertical communication have been previously identified in the Gable Mountain and Gable Butte area based on chemistry data (Graham et al. 1984; Jensen 1987). The increased communication in the area results from erosion 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). Recent modeling of post-Hanford conditions suggests that inter-aquifer communication between the unconfined aquifer and the upper basalt confined aquifers may become an important source of additional recharge to the unconfined aquifer. The volume and distribution of water movement between the aquifer systems has not been quantified.

The aquifer system has been significantly impacted by artificial recharge from past and current Hanford Site operations. Under natural conditions, groundwater in the unconfined aquifer generally moves from natural recharge areas along the western boundary of the site eastward and northward toward the Columbia River. Since the start of Hanford operations in the mid-1940s, this flow pattern has been altered locally by the formation of groundwater mounds resulting from large volumes of wastewater discharge from Hanford operations. During this period, artificial recharge from wastewater disposal facilities has been much greater than the estimated recharge from natural sources. This 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. From 1979 to 1996, the estimated annual rate of artificial recharge over the entire site ranged from 1.13 m^3/sec in 1984 to 0.24 m^3/sec (Section 2.3 in Wurstner et al. [1995]). During the past five years, all production activities on the Hanford Site have been curtailed to about 0.04 m^3/sec at two liquid-disposal facilities. The resulting decrease in wastewater disposal has caused decreases in water-table elevations over much of the site. Specific sources and volumes of artificial recharge over the Hanford Site are summarized in Section 2.3.2 in Wurstner et al. (1995) and in Cole et al. (1997).

In addition to the natural recharge that occurs from infiltration of runoff from elevated regions west of the site, the unconfined aquifer system receives natural recharge from direct infiltration of precipitation falling across the Hanford Site. Recharge from precipitation across the 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). Fayer and Walters (1995) developed a natural recharge map based on distributions of soil and vegetation types (see Figure 2.5 in Wurstner et al. [1995]). The average recharge from precipitation across the Site was estimated as 0.27

m^3/s. As the transient effects of past artificial recharge to the unconfined aquifer dissipate, the effect of natural recharge on flow conditions in the aquifer will become more important.

5.1.6 Anticipated Future Flow Conditions

Future flow conditions in the unconfined aquifer will undergo transient changes as artificial wastewater discharges from Hanford Site operations are curtailed, and water-table conditions are more strongly influenced by natural recharge conditions. Past site-wide modeling of future water table conditions following elimination of wastewater discharges to the ground at the Hanford Site by Chiaramonte et al. (1997) and Cole et al. (1997) both suggests the water table will decline significantly over the next 200 to 300 years. These analyses also showed that the water table would return to near pre-Hanford Site conditions that were estimated to exist in 1944 (Kipp and Mudd 1974) over most of the site.

In simulations documented in Section 4.3.2 of Cole et al. (1997), the areas that are different included 1) the area west of the 200 Area where the water-table is higher than pre-1944 conditions because it reflects the effect of higher irrigation in areas west of Hanford, and 2) the area north of Richland, where the model simulates the hydraulic effect of the North Richland well field. The water table has been estimated to drop as much as 11 m beneath the 200-West Area near U Pond and 10 m beneath the 200-East Area near B Pond from 1996 to predicted post-Hanford steady-state flow conditions. Steady-state conditions were reached in many areas by the year 2100 and all areas by 2350.

Simulations from 1995 conditions made by Chiaramonte et al. (1997) (see Figures 3-2 through 3-6 in Chiaramonte et al. [1997]) showed the water table would decline for the first 100 years and stabilize within 200 years. A comparison of the water table at 200 years with the hindcast map of 1994 water table conditions showed a similar pattern of agreement as indicated in results by Cole et al (1997) (see Figures 4.17 and 4.18 in Cole et al. [1997]). Good agreement with 1944 conditions was seen in areas north of the Gable Butte and Gable Mountain and in areas to the east of 200-West Area. Higher water-table conditions were simulated in and west of the 200-West Area. Higher simulated water-table conditions were attributed by Chiaramonte et al. (1997) to a combination of uncertainties in natural recharge, hydraulic conductivity, and porosity estimates used in these areas of the model.

Past flow-modeling results also suggest that the water table in the central areas in the site will decline from its current position in the Hanford formation into the uppermost units of the Ringold Formation. Consequently, future flow conditions and potential contaminant transport in areas east of the 200-Area plateau will be more strongly influenced by the hydraulic characteristics of the sub-units identified in the Ringold. Of particular significance will be the influence of the low-permeability mud units identified in the upper part of the Ringold profile.

Future flow conditions simulated by Chiaramonte et al. (1997) (see Section 3.2 in Chiaramonte et al. [1997]) and Section 4.3.2 in Cole et al. [1997]) have suggested that the water table may decline to near the top of basalt in an area north of 200-East Area. As water levels drop in the vicinity of central areas in the model, the saturated thickness of the unconfined aquifer greatly decreases and may eventually dry out south of Gable Mountain along the south-east extension of the Gable Butte anticline. This could cause the unconfined aquifer to the north and south of this line to become hydrologically separated. As a result, flow paths from the 200-West Area and the northern half of 200-East Area that currently extend through the gap between Gable Butte and Gable Mountain, effectively may be cut off in the future.

More detailed investigations of local geologic and hydrologic conditions within the HGWP has suggested that predictions of flow and potential contaminant transport through this region are uncertain and could be influenced by a number of factors:

- interpretations of the top of basalt. In the region just east of Gable Butte, the top of basalt has been eroded and is difficult to delineate to the resolution needed to accurate model the position of the water table. Current interpretations of the top of basalt in this area are based on information from magnetic surveys.

- interpretations of the areal extent and geometry of low-permeability mud units found in the Ringold Formation just east of 200-East plateau. Patterns of groundwater flow and contaminant transport will be influenced by the lower hydraulic characteristics of these units as the water table drops.

- the potential for upward leakage of water from the uppermost confined basalt aquifers. The region in vicinity of Gable Butte and Gable Mountain is an area where the basalt is significantly deformed and fractured and an area of potential recharge to the unconfined aquifer system from the uppermost confined aquifers. As the unconfined aquifer becomes less influenced by the artificial recharge, upward leakage from the basalt confined aquifer could influence the future position of the water table and future directions of groundwater flow.

- uncertainty in the amount of recharge that comes into the unconfined aquifer system from the Cold Creek and Dry Creek Valleys. Increases or reductions in flow from these boundaries could have a significant influence on the future position of the water table in the aquifer system.

- future offsite and onsite land uses. Future land uses, particularly the potential from large-scale irrigation, could have a significant influence on future water table conditions and resultant groundwater flow.

5.1.7 Existing Radiological and Chemical Contamination and Potential Future Transport

Monitoring of groundwater across the Hanford Site has detected a number of radioactive contaminant plumes (Figure 14) emanating from various operational areas (Hartman and Dresel 1997). The most widespread are from groundwater contamination by tritium and iodine-129. Smaller plumes of strontium-90, technetium-99, and plutonium contain concentration levels exceeding EPA and state of Washington interim drinking water standards (DWS). Uranium concentrations are also found at levels greater than the proposed DWS. In recent years, areas contaminated by cesium-137 and cobalt-60 have also been found at or exceeding the DWS. The extent of major chemical constituents at levels above the primary concentration limits in the unconfined aquifer system, shown in Figure 15, include carbon tetrachloride, chloroform, chromium cis-1, 2-dichloroethane, fluoride, nitrate, and trichloroethylene (Hartman and Dresel 1997).

The unconfined aquifer will be affected by potential future releases of radiological and chemical contaminants to the groundwater that may occur from a variety of waste sources including:

- residual contamination left in the vadose zone from waste-management operations in the past and liquid discharges to cribs, ditches, French drains, trenches, and ponds in the 100, 200, and 300 Areas

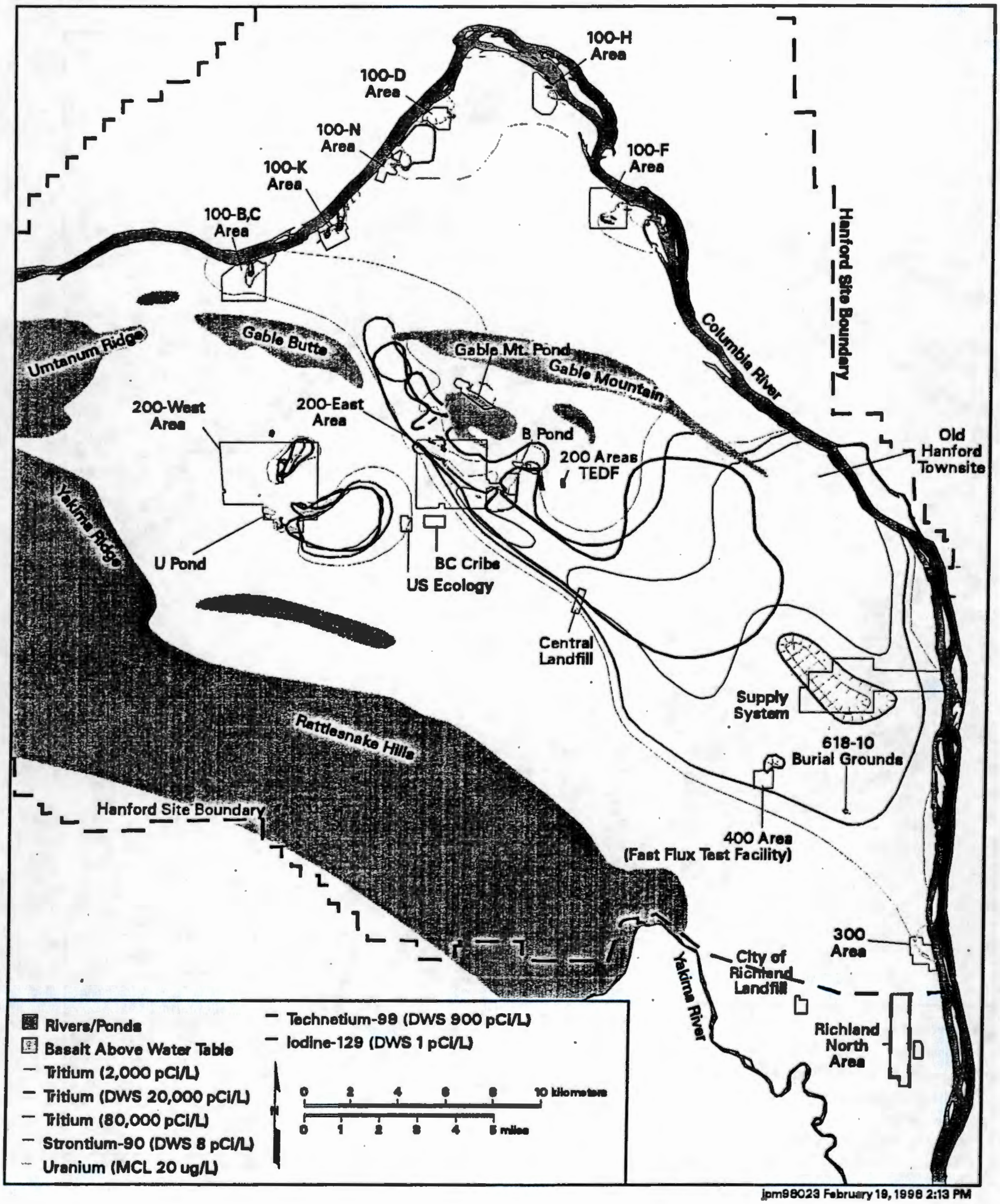

Figure 14. Areal Extent of Major Radioactive Contaminant Plumes in Unconfined Aquifer

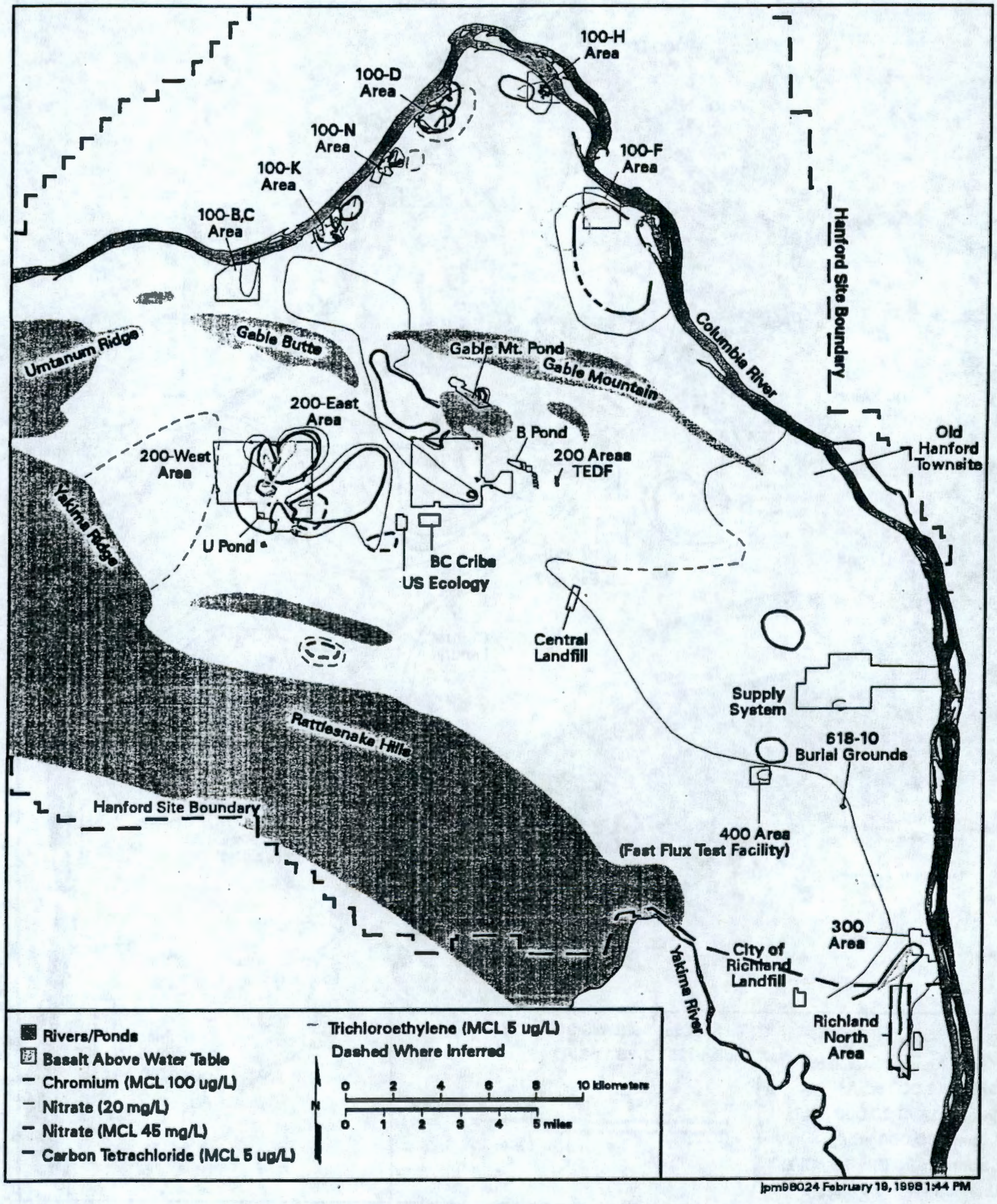

Figure 15. Areal Extent of Major Chemical Contaminant Plumes in Unconfined Aquifer

- past-practice (pre-1988) solid LLW burial grounds in the 200 Areas
- post-1988 solid LLW burial grounds in the 200 Areas
- Environmental Restoration Disposal Facility located between 200-East and 200-West Areas
- 149 single-shell tanks arrayed in 12 tank farms and in the 200 Areas
- 28 double-shell tanks arrayed in six tank farms in the 200 Areas
- immobilized low-activity wastes disposed of in two locations in 200-East Area
- graphic cores from surplus reactors currently located in the 100 Areas
- canyon buildings and related structures located in the 200 Areas.

5.2 Model Requirements

This section of the document outlines the requirements and associated rationale for the consolidated site-wide groundwater model.

5.2.1 Major Hydrogeologic Units of the Unconfined Aquifer System

Requirement: The consolidated site-wide groundwater model needs to represent the major hydrogeologic units identified in the unconfined aquifer system. These include the Ringold Formation and combined pre-Missoula gravels and the Hanford formation. The Plio-Pleistocene unit is another unit identified in the aquifer system that exists only in the western portion of the Site and is generally above the water table. The site-wide groundwater model should also have the capability to represent the major sub-units identified in the Ringold Formation, including the low permeability mud units that will become more important as the water table drops in the unconfined aquifer system

Rationale: Incorporation of the areal extent and thicknesses of the major hydrogeologic units identified in the current conceptual model of aquifer are critical to accurately simulate past, present, and future behavior of the groundwater flow and contaminant transport. As the water table drops, consideration of the areal extent and geometry of the fine-grained sub-units identified in the Ringold Formation will be particularly important to understanding and transport conditions near and downgradient of 200-East Area.

5.2.2 Hydraulic Properties of Major Hydrogeologic Units

Requirement: The consolidated site-wide groundwater model needs to represent the spatial variability in hydraulic properties of the major hydrogeologic units that has been inferred from hydraulic tests performed in the aquifer system.

Rationale: Transmissivity (the product of hydraulic conductivity and aquifer thickness) and storage information for the unconfined aquifer system obtained primarily from aquifer pumping tests and slug tests conducted at wells suggest that hydraulic properties of the major hydrogeologic units are highly variable. Key features of this variability need to be considered to accurately represent past, present, and future groundwater flow and contaminant transport.

5.2.3 Transport Processes

Requirement: The consolidated site-wide groundwater model should have the capabilities to simulate contaminant transport of a variety of radiological and chemical constituents that currently exist and potentially could contaminant the aquifer system in the future. Key processes that are important to simulating radiological and chemical contaminant transport include advection, dispersion, adsorption, and radiological decay. Chemical degradation could potentially be important for some of the chemical plumes that have been detected.

Rationale: The migration of contaminants that eventually reach the underlying groundwater system from the waste sources through the vadose zone can potentially be affected by a variety of chemical processes including precipitation/dissolution, sorption, complexation, and filtration of colloids and suspended particles. Whether a given set of reaction or physical process will have a strong influence on the mobility of contaminants in near or away from individual waste sites is dependent on a number of factors including

- composition of the waste stream in terms of major and minor ions
- pH of the waste and the associated ionic strength
- mineralogical, organic, and surface chemical characteristics of subsurface sediments encountered by the released wastes
- the presence of organic and chemical complexants
- the amounts of contaminant decay or biodegradation
- oxidation-reduction conditions.

A more detailed description of important geochemical controls to contaminant transport in the vadose zone is provided in Appendix G of DOE/RL (1988).

Ideally, all possible chemical reactions and biochemical processes expected to affect the transport of contaminants should be considered in a numerical implementation of the contaminant transport model. In practice, particularly for models developed at a scale and hydrogeologic detail similar to the proposed model developed for the Hanford Site, computational considerations and the limited amount of required geochemical and biochemical data and information at the scale of interest limit the chemical processes considered in transport models. The set of processes considered in the proposed model is limited to sorption process as represented in the linear sorption isotherm (i.e., K_d approach) and first order rate constant to represent decay. Use of this limited set of chemical processes, however, it is consistent with

Table 6. Contaminants, Mobility, and Operational Areas where Regulatory Standards are Exceeded

Contaminants	Normal Mobility	Operational Areas Where Contaminants of Concern Exceed Regulatory Standards											
		100-B, 100-C Area	100-K Area	100-N Area	100-D, -DR Area	100-H Area	100-F Area	200-W Area	200-E Area	400 Area	600 Area	300 Area	Richland North Area
Tritium	High	x	x	x	x			x	x	x	x	x	
Technetium-99	High					x		x	x				
Iodine-129	High							x	x				
Nitrate	High	x	x	x	x	x	x	x	x	x	x	x	x[4]
Chromium	High	x	x	x	x	x	x	x			x		
Uranium	High					x	x	x			x	x	
Carbon Tetrachloride	High							x	x				
Trichloroethylene	High		x	x			x	x				x	x[4]
cis-1,2-Dichloroethylene	High											x	
Sulfate	High			x									
Fluoride	High							x					x[4]
Strontium-90	Moderate	x	x	x	x	x	x		x[2]		x	x	
Carbon-14	Moderate		x										
Manganese	Moderate			x								x	
Iron	Moderate											x	
Cobalt-60	Low								D[3]				
Cesium-137	Low								x[2]				
Americium-241	Low							D[1]					
Plutonium-239/240	Low							D[1]	x[2]				

D[1] Plutonium-239/240 and americium-241 have been detected at low levels at a well near the 216-Z-9 crib. The origin of these contaminants are unclear and may be associated with a poor quality well completion and may be very localized or may represent mobilization by complexants found in the organic liquid phase.

x[2] Elevated concentrations of strontium-90, cesium-137, and plutonium 239/240 are found in wells near the 216-B-5 injection well in northern part of 200 East area where radioactive wastes were directly injected below the water table. The distribution of these contaminants is generally restricted to the immediate vicinity of the injection well by low mobility caused sorption onto Hanford sediments and the extremely low hydraulic gradient in this area.

D[3] Detectable levels of cobalt-60 that have been observed north of 200-East area from discharges at the BY cribs. Cobalt-60, which is otherwise thought to be relatively immobile for Hanford sediments, appears to be mobile in this area because of the presence of a soluble cobalt-cyanide (or ferrocyanide) complex associated with the plume originating from the BY cribs.

x[4] Sources of these contaminants are attributable to local off-site industry and agriculture.

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the dominant processes controlling the transport of most contaminants at Hanford on a site-wide scale (see Table 6).

The transport of most existing site-wide plumes of mobile contaminants (tritium, technetium-99, iodine-129 and uranium) and potentially important future plumes of long-lived constituents that are not significantly impacted by reactive processes on a site-wide scale other than by adsorption. So far, use of the standard advection-dispersion approach for transport combined with a linear equilibrium adsorption isotherm model has provided reasonable approximations to observed plume transport behavior of these particular constituents. Observations in the historical behavior of contaminants mobility suggest that once contaminants originating from the vadose zone reach the unconfined aquifer and begin to migrate over kilometers, the effect of complex chemical interaction apparent at a local scale near some waste sites become less important. At a site-wide scale, sorption tends to be the dominant process affecting contaminant mobility for most contaminants. For the most part, the larger scale contaminant plumes are associated with general mobile contaminants that were discharged to ground with large quantities of waste discharges. Excellent examples of such plumes are the tritium, iodine-129, and nitrate plumes originating from 200-Area plateau that have migrated over several km from their original source locations. Plumes of technetium-99, carbon tetrachloride, chromium, and uranium, although not as widespread as the tritium, iodine-129, and nitrate plumes represent other examples of relatively mobile constituents.

On a local scale, there are some instances of contaminants (e.g. cobalt-60, cesium-137, strontium-90, americium-241, and plutonium-239, plutonium-240) that normally have a low mobility but have been detected at wells located near the originating waste facilities. One example of contaminant migration that has been observed north of 200-East area where the occurrence of detectable levels of cobalt-60 that has been detected north of 200-East area from discharges at the BY cribs. Cobalt-60 appears to be mobile in this area because of the presence of a soluble cobalt-cyanide (or ferrocyanide) complex associated with the plume originating from the BY cribs. Much of the discharged cobalt-60 has now decayed away because of its relatively short half-life of 5.6 years and is not anticipated to represent a long-term groundwater pathway risk. Plutonium-239, plutonium-240 and americium-241 have been detected at low levels at a well near the 216-Z-9 crib. The origin of these contaminants are unclear and may be associated with a poor quality well completion and may be very localized or may represent mobilization by complexants found in the organic liquid phase. Elevated concentrations of strontium-90, cesium-137, and plutonium 239/240 are found in wells near the 216-B-5 injection well in northern part of 200 East area where radioactive wastes were directly injected below the water table. The distribution of these contaminants are generally restricted to the immediate vicinity of the injection well by low mobility resulting from sorption onto Hanford sediments and the extreme low hydraulic gradient in this area.

First-order decay is appropriate to represent radioactive decay, and can be appropriate for representing simple degradation processes of certain contaminants at a site-wide. However, this approximation, is one of several possible capabilities for contaminant decay or degradation, and may not be adequate for some contaminants of concern at a local scale. For certain radionuclides of concern such as uranium, consideration may need to be given to the in-growth of progeny that can result from the radioactive decay. If the mobility of the daughters can be accepted to be equivalent as is assumed for mobility of the parent, then calculation of the in-growth can be easily calculated at the point of concern using the results from calculated transport of the parent.

The use of a linear adsorption isotherm model embodied in a distribution coefficient (K_d) is a common approach used in groundwater models to represent the retardation of contaminants due to sorption processes. Such an approach allows the use of the model for prediction of the behavior of many of contaminants of concern at the Hanford Site. For applications involving the migration of certain contaminants through the aquifer, such as tritium or technetium-99, the chemical processes in the consolidated site-wide groundwater model (first-order decay and no sorption) are adequate. However, for other contaminants, such as carbon tetrachloride, use of first-order rate decay constant and linear sorption may not adequate because predicted concentrations could be significantly affected of other important processes such as volatilization or by the occurrence of non-aqueous phase liquids. In any application of the consolidated site-wide groundwater model, justification of the linear isotherm approach embodied in the consolidated site-wide groundwater model to retard specific contaminants to represent the process of adsorption is needed.

Simulation of past, present, and future contaminant transport for most radiological and chemical constituents of concern at a site-wide scale requires, at a minimum, consideration of the processes of advection, dispersion, adsorption, and radiological decay. The transport of most existing site-wide plumes and potentially important future plumes reflect relatively mobile constituents (tritium, iodine-129, technetium-99, and uranium) that are not significantly impacted by reactive processes other than adsorption. To date, using the standard convective-dispersion approach for transport combined with a linear equilibrium adsorption isotherm model has provided reasonable approximations of observed plume transport.

The consideration of more complex reactive transport processes such as chemical or biological degradation would be desirable for local-scale transport modeling of certain chemical contaminants such as carbon tetrachloride found in 200-West Area. Using more complex reactive transport processes may be a helpful approach to address a number of local-scale contamination issues on the site. Sites that have received wastes with complex chemistry, such as crib and trench sites that have received tank wastes or at sites near suspected tank leaks, can have unique geochemical conditions that can influence contaminant mobility. However, because of the significant computational requirements and the required extensive geochemical data needs, the use of reactive transport models in the context of a site-wide groundwater model is not presently viewed as practical and has not been currently implemented on a site-wide scale.

5.2.4 Hydrologic Boundaries of Unconfined Aquifer System

Requirement: The consolidated site-wide groundwater model needs to consider the near-term and long-term impacts of major lateral, upper, and lower hydrologic boundaries of the unconfined aquifer including the

- Columbia River on the north and east
- basalt ridges and outcrops
- Yakima River on the south and west form peripheral boundaries for the unconfined aquifer system on the Hanford Site

- groundwater inflow to the unconfined aquifer on the Hanford Site from the Cold Creek and Dry Creek valleys

- interaction of the Columbia River basalt underlying the unconfined aquifer sediments and basalt cropping out above the water table within the Hanford Site.

Rationale: Consideration of all major hydrologic boundaries is critical to address near-term and long-term predictions of ground water flow and contaminant transport. The Columbia River represents a point of regional discharge for the unconfined aquifer. The Yakima River's stage elevation is higher than the water table in the adjacent aquifer, so it represents a potential source of recharge in the southern part of the Site. Groundwater inflow to the unconfined aquifer from the Cold Creek and Dry Creek valleys is an important component of the overall water budget to the aquifer system on Site. The Columbia River basalts are currently considered to represent a lower impermeable boundary to the unconfined aquifer system. However, in areas north of Gable Mountain and Gable Butte and in the southeast part of the Hanford Site, the lowermost mud unit within the Ringold Formation effectively isolates upper portions of the unconfined aquifer from the uppermost basalt confined aquifers. The uppermost confined aquifers within the basalts have the potential to provide sources of vertical upward leakage to the unconfined aquifer system in local areas.

5.2.5 Recharge

Requirement: The consolidated site-wide groundwater model needs to consider all sources of significant recharge to the unconfined aquifer system including

- artificial recharge to the unconfined aquifer system from past and current Hanford Site operations

- natural recharge from direct infiltration of precipitation falling across the Hanford Site

- recharge from springs and runoff that infiltrate the aquifer along the northern side of Rattlesnake Hills.

Rationale: Artificial recharge to the unconfined aquifer system from past and current Hanford Site operations has and continues to have significant impact on water table conditions. As the transient effects of past artificial recharge to the unconfined aquifer dissipate, the effect of natural recharge on flow conditions in the aquifer will become more important. In addition to natural recharge from on site infiltration, the aquifer receives recharge from infiltration of runoff and spring discharges originating in elevated regions off site. The spring discharges from Rattlesnake Hills are such an example.

5.2.6 Anticipated Future Flow Conditions

Requirement: The consolidated site-wide groundwater model will need to evaluate transient and steady-state future flow conditions in the unconfined aquifer system.

Rationale: Past site-wide modeling by Chiaramonte et al. (1997) and Cole et al. (1997) of the elimination of wastewater discharges to the ground has suggested that the water table will decline significantly in the next 100 years. Predictions also have indicated that the water table will return to near pre-Hanford Site conditions (Kipp and Mudd 1974) over most of the Site in the next 200 to 400 years.

5.2.7 Existing Radiological and Chemical Contamination and Potential Future Transport

Requirement: The consolidated site-wide groundwater model will need to be able simulate contaminant transport of a variety of radiological and chemical constituents. The consolidated site-wide groundwater model will also need to be able to evaluate potential future releases of radiological and chemical contaminants to the groundwater that may occur from a variety of waste sources

Rationale: Monitoring of groundwater across the Hanford Site (Figure 14) has detected a number of radioactive contaminant plumes emanating from various operational areas (Hartman and Dresel 1997). The most widespread plumes are tritium and iodine-129. Smaller plumes of strontium-90, technetium-99, and plutonium contain concentration levels exceeding EPA and State of Washington interim DWS. Uranium concentrations are also found at levels greater than the proposed DWS. In recent years, areas contaminated by cesium-137 and cobalt-60 have also been found at or exceeding the DWS. The extent of major chemical constituents at levels above the primary concentration limits in the unconfined aquifer system, shown in Figure 15, include carbon tetrachloride, chloroform, chromium cis-1, 2-dichloroethane, fluoride, nitrate, and trichloroethylene (Hartman and Dresel 1997). Past analysis has shown that the aquifer system will likely be impacted by future release of contaminants from a variety of waste sources in the 100, 200, and 300 Areas.

5.2.8 Spatial and Temporal Scales of Analysis

Requirement: The consolidated site-wide groundwater model will need to support a variety of spatial and temporal scales of analysis to adequately meet project specific needs.

Rationale: Review of anticipated future applications of the site-wide groundwater model indicated that the model will need a variety of spatial and temporal scales of analysis to adequately meet project specific needs.

The distribution of hydrogeologic data and the nature of the problem to be solved are both controlling factors in determining the appropriate spatial scale for a groundwater flow and transport model. The consolidated site-wide groundwater model was developed to support the Hanford Groundwater Monitoring Project, which is responsible for monitoring and assessing the movement of contaminants in the Hanford Site aquifer. The hydrogeologic conceptual model was developed at a spatial resolution of 150 meters. Data from approximately 550 wells were used to define the three-dimensional hydrogeologic structure of the unconfined aquifer system. Many of these wells were used to determine the elevation of the top of basalt, and not all have been interpreted over their entire depth. Nine hydrogeologic units were defined based on textural composition. Wells were chosen to represent a site-wide distribution of data, and in areas where the spatial distribution of wells is dense, only a representative portion of the existing wells were used in the interpretation. The well picks were made to define the regionally extensive hydrogeologic units. The finite element flow grid for the current site-wide groundwater model has a resolution of 750 meters. This grid spacing can be refined for smaller scale problems, however, since the conceptual model is based on regionally extensive units, it does not include the level of detail that may be needed for local scale models. These refinements can be included in the model as needed. In areas near the Columbia River, the resolution of the current site-wide groundwater model is not adequate to represent the local transient effects resulting from a fluctuating river boundary.

The vertical grid spacing for the transport model is refined by subdividing the nine hydrostratigraphic units. The basic thickness of these transport layers in the current site-wide groundwater model is 8 m. In the refined simulations for the ETF, the spacing used was 5 m. The transport layers are defined from the water table surface to the basalt to account for the overall declining water table and to adequately represent contaminant concentrations in the three-dimensional model. At every model node, each of the nine hydrostratigraphic units below the water table is represented by at least one transport model layer.

The temporal scale of the consolidated site-wide groundwater model is controlled primarily by the nature of the problem to be solved. Over the past 50 years, the large volume of wastewater discharged to disposal facilities at the Hanford Site has significantly affected the groundwater flow in the unconfined aquifer and caused major groundwater mounds to occur beneath B Pond, Gable Mountain Pond, and U Pond (Dresel et al. 1995). The volume of artificial recharge has decreased significantly during the past 10 years and is continuing to decrease (Barnett et al. 1997; Dresel et al. 1995). This change in surface flux has had a significant effect on the character of the unconfined aquifer. As the water table rises and falls, the unit transporting groundwater and contaminants will transition between the highly transmissive Hanford Formation, and the much less transmissive Ringold formation in areas near the 200-Area plateau. This contact occurs near several contaminant sources. In order to effectively model the movement of the contaminant plumes, the temporal scale used by the model must be small enough to capture the effect of the water table moving from the Hanford to the Ringold formation.

The current site-wide groundwater model is appropriate for long-term analyses that require simulations on the order of hundreds to thousands of years such as the Composite Analysis. These types of analyses consider slow releases to the groundwater accounting for transport through the vadose zone. Evaluating the effects of changes in the natural recharge distribution would also require simulations on the order of tens to hundreds of years. For analyses of remediation technologies, such as pump and treat systems, the temporal scale of the simulations will be on the order of days and weeks. The current site-wide groundwater model is appropriate for all of these problems, but may require the support of a local-scale model to address pump-and-treat situations that involve high flow rates.

The HGWP has largely used groundwater modeling to assess the impact of operational changes at Hanford on groundwater flow conditions and to estimate the future behavior of existing contaminant plumes. For the most part, analyses have been performed on a site-wide scale. However, the monitoring program will likely need to use local-scale models to support Resource Conservation and Recovery Act (RCRA) monitoring at 25 separate facilities and ongoing groundwater assessment and compliance programs evaluating possible contamination at nine facilities. Because the focus of the program is on current and near-term groundwater monitoring, the temporal scale of interest for these analyses has been on changes in groundwater conditions and contaminant transport behavior over a few years to a few decades. Because of the spatial and temporal scales of interest, the consolidated site-wide groundwater model will need the capability to simulate both local and site-wide scales with full sub-modeling capabilities. The model will also need to simulate the transient nature of water-table changes that are expected to occur after cessation of wastewater discharges to ground at the Site.

Groundwater modeling supporting the most recent Composite Analysis of waste sources in the 200-Area plateau (Kincaid et al. 1998) was done at a site-wide scale with the primary focus on model results predicted from outside the buffer zone surrounding the 200-Area plateau to the Columbia River. The temporal scale of the analysis was primarily focused on the first 1000 years after site closure (i.e., from year 2050 to 2150) following Composite Analysis guidance. Future-flow conditions were simulated out 2000 years and transport calculations of existing and future sources of contaminant migration were conducted for a period of 1500 years from current conditions. Because of the spatial and temporal scales of interest, the model selected for the Composite Analysis will need to simulate both local and site-wide scales and the transient nature of water-table changes that are expected to after cessation of wastewater discharges to ground at the Site. The consolidated site-wide groundwater model will also need to simulate steady-state water table conditions for sources that are not expected to release to the unconfined aquifer for several hundred years.

Groundwater modeling analysis being performed to support the HTI will largely focus on predicted impacts to groundwater from tank-sluicing losses immediately downgradient from the tank-farm facilities being evaluated. However, the analysis will also be used to evaluate the potential impacts to groundwater between the facilities and the accessible environment (e.g., at the Columbia River). The temporal scale of the analysis will examine potential impacts at the water table from losses during tank-waste recovery operations over the next several hundred years. The analysis will also examine the potential long-term impacts (up to 10,000 years) of future releases from residual contamination in the vadose zone and releases from residual wastes left in tanks following waste recovery.

The long-term PA of the ILAW disposal facilities will require a site-wide groundwater flow model to evaluate three-dimensional contaminant transport of key radioactive contaminants and potential human health impacts from facility releases. This assessment will be performed at 100 m downgradient from the planned disposal facilities (to meet the requirements of DOE Order 5820.2a for protection of ground water) and at the Columbia River boundary (to meet the requirements in DOE Order 5820.2a for protection of surface water) (DOE 1988). Results of the preliminary PA of the ILAW disposal facilities have shown that potential releases to the water table from ILAW disposal are not expected to reach the unconfined aquifer until well after the aquifer has reached steady-state conditions. Thus, the selected model used in this analysis could rely on a steady-state analysis of future flow conditions and would not need to simulate the transient declines in the water table conditions that are expected to occur in the next 100 to 200 years. The anticipated low-volume nature of the contaminant release would also suggest that the analysis could be completed with the use of a local-scale model that would focus on the impact on groundwater from the immediate vicinity of the disposal facilities to the Columbia River.

The groundwater model used for the ILAW PA will need to have appropriate sub-modeling capabilities to facilitate the transfer of important hydraulic information on boundary conditions used in the local-scale model. In addition, following the requirements outlined in DOE order 5820.2a, the consolidated site-wide groundwater model will need to evaluate long-term release from the ILAW disposal for at least 10,000 years after site closure. The modeling-analysis capability may also need to examine groundwater impacts in excess of 10,000 years to evaluate potential peak releases from postulated source terms. Because of the time frame of the analysis, the location of the disposal facilities, and the low-volume nature of the potential contaminant releases, the consolidated site-wide groundwater model supporting this analysis will focus on a local scale analysis of flow and transport between the disposal facilities and the Columbia River.

5.2.9 Configuration Control

Requirement: The consolidated site-wide groundwater model, including the databases supporting the conceptual model and its numerical implementation, will need to be maintained under configuration control.

Rationale: Because the consolidated site-wide groundwater model will provide the framework for all groundwater modeling analysis performed on the Hanford Site, a common site-wide groundwater model database will be maintained containing all the information necessary to establish the pedigree of the most current version of the model. Such a database will contain

- the basic geologic and hydrologic information that provides the basis for the conceptual model

- the key interpretations of geologic and hydrologic data and information including descriptions of methods and approaches used to make interpretations. The database and data interpretations will be updated, as new data, on both the local and regional scale, become available. The site-wide groundwater modeling database should be stored in a form independent of the computer code used or the assumptions made for a particular modeling study. By storing high resolution, regularly gridded information, it is possible to use the model information at different scales (e.g., in sub-models) or with different groundwater computer codes. This allows for use of the numerical representation and computer code that is most appropriate for simulating the problem being considered.

- model parameter databases based on a consensus interpretation of the available data. Methods and approaches used to develop the parameter estimates should also be included. The database should include all information necessary to develop parameter distributions based on geologic data (e.g., geometry of the main hydrogeologic units), hydraulic property estimates, boundary conditions, initial conditions, locations and volumes of sources and sinks, and natural recharge estimates.

The site-wide groundwater model must be a flexible and evolving platform for analyzing groundwater flow and contaminant transport at Hanford. As more data are collected, it is likely that the conceptual model of the groundwater system will change, and new predictive capabilities will be desired and available. The adopted model framework must be one in which new concepts can be tested and enhancements readily included. The data used in the site-wide groundwater model is stored in a Geographic Information System (GIS), which allows for easy data retrieval, display and update. Collections of raw data (measured data) will be described as databases, and interpretations will be described as information bases.

Results of groundwater sampling and analysis are made accessible in the Hanford Environmental Information System (HEIS) database. Well log information is reported in Hanford Wells. This information is extracted from these databases and stored in Arc/Info[2] coverages at well points. Data from pump tests are also stored at well locations in Arc/Info.

The existing information base of interpreted geologic and hydrologic information was developed to be independent of the model grid. This information is stored as regularly gridded data at the finest resolution

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[2] Arc/Info is a registered trademark of Environmental Software Research Institute, Santa Fe, New Mexico.

permitted by the data. These data are then sampled at node and element locations to generate the numerical model. Modifications to the finite-element grid can be made and the data resampled quite easily. This allows the conceptual model to be maintained while the numerical grid can be designed for specific problems that require special emphasis. This approach also allows for modifications and updates to the conceptual model to be easily implemented into the numerical model.

Strict revision control of the most current version of the site-wide groundwater model should be maintained. Any changes to model versions based on new or updated data and information should be documented and should include clear justification for revisions to the model. Because data continue to be gathered and because newly gathered data do not always fit the existing conceptual model, a continuous effort is required to continually evaluate the data and refine the geologic and hydrogeologic conceptual models.

Any modeling applications that make simplifications to the site-wide conceptual model and modeling database for use in their specific analyses should include adequate documentation to demonstrate the consistency of their modeling assessment with the accepted site-wide conceptual model. Such documentation may include a list of assumptions made, their justification, and comparisons with simulation results based on the most complete and complex conceptual model.

5.2.10 Model Uncertainty

Requirement: The consolidated site-wide groundwater model will provide for explicit acknowledgement and estimation of uncertainty. A more specific requirement will be promulgated after additional evaluation of alternatives and methodologies for addressing uncertainty have been proposed and evaluated.

Rationale: Ultimately, the site-wide groundwater model must embrace uncertainty. Implementation of an uncertainty framework with respect to the databases, model, and code will require a long commitment of resources and model development, and so no specific requirement is established at this time.

5.3 Requirements for the Computer Code

The following section includes a summary of technical and administrative requirements for the computer code that will need to be used to perform numerical calculations with the consolidated site-wide groundwater model.

5.3.1 Technical Requirements

The following section describes technical requirements and rationale for the code used for the consolidated site-wide groundwater model.

5.3.1.1 Fluid Flow

Requirement. The computer code used to support the consolidated site-wide groundwater model must be capable of simulating two- and three-dimensional saturated confined and unconfined flow of constant density groundwater in an isothermal setting for steady state and transient conditions.

Rationale. The focus of most site-wide groundwater modeling investigations will be on flow and transport in the unconfined aquifer systems. Groundwater flow in the unconfined aquifer takes place in three dimensions due to the geometry of the major hydrogeologic units and the boundary conditions of the unconfined aquifer system. Both confined and unconfined aquifers exist and may be important in determining future flow and transport conditions. Flow conditions are anticipated to change significantly over time due to changing site operations and land use. In general, site-wide flow is not likely to be strongly influenced by temperature or density effects. However, for certain modeling applications, such as the simulation of remediation options for the carbon tetrachloride plume in the 200 Areas or the evaluation of innovative *in situ* treatment technologies as are being applied in the 100 Areas, the ability to simulate the effects of variable density may be desirable. These features are not required in a site-wide groundwater model, however, as the remediation options are likely to be modeled on a smaller scale with more specialized codes. These specialized codes will need to be integrated and consistent with the conceptual and numerical model framework of the consolidated site-wide groundwater model.

5.3.1.2 Hydrologic Properties

Requirement. The code must be capable of modeling the three-dimensional geometry and spatial variation of hydraulic parameters (hydraulic conductivity, transmissivity, specific storage, storage coefficient, etc.) of the important hydrogeologic. The code must allow for the use of anisotropy in representing the variability in hydraulic conductivity distributions

Rationale. The conceptual model of the unconfined aquifer system suggests that hydraulic properties of the sediments within the aquifer system are highly variable horizontally and exhibit vertical anisotropy. This spatial variability has a strong influence on groundwater flow and contaminant transport and must be modeled to accurately represent observed and future conditions.

5.3.1.3 Boundary Conditions

Requirement. The code must be capable of incorporating time-dependent and spatially varying Dirichlet (constant head or concentration) and Neumann (fluid or mass flux) boundary conditions. The code must also be able to model time- and space-dependent sources and sinks of water and contaminants. Although use of a head-dependent flux boundary condition may be useful to explore local scale flow conditions in vicinity of the Columbia and Yakima Rivers, this type of boundary condition is not considered a requirement for typical applications of the site-wide groundwater model.

Rationale. The consolidated computer code will need to have the capability to simulate recharge and discharge boundary conditions that vary in time and space to adequately represent the hydrologic boundaries needed in the site-wide groundwater model. Correctly representing these boundaries will be required to obtain accurate estimates of groundwater flow. In addition, the site-wide groundwater model will likely interface with a vadose zone model(s) by assigning appropriate boundary conditions specifying water and contaminant fluxes. Output fluxes from the vadose zone model(s) are likely to vary both in space and in time. Modeling future land use, site operations, and contaminant sources will require capabilities to represent sources and sinks that vary in time and space.

5.3.1.4 Contaminant Transport

Requirement. The code must be capable of simulating two- and three-dimensional contaminant transport resulting from the processes of advection, mechanical dispersion, and molecular diffusion. Code capabilities must be able to simulate transport of both radiological and chemical contaminants. The code formulation must allow for specification of a longitudinal and transverse dispersivity to approximate dispersion in three-dimensions.

Rationale. Advection and hydrodynamic dispersion are the primary mechanisms of solute transport in the groundwater at the Hanford Site. To accurately represent observed conditions, the code must have capabilities to quantify dispersive characteristics of the aquifer system. The code should allow for dispersion to vary in the longitudinal and transverse directions. A desirable feature of the code is to allow dispersivities to vary spatially (i.e., to be a function of the hydrogeologic unit in which transport occurs). Since site-specific data on dispersion is limited, however, this is not a required feature.

5.3.1.5 Contaminant Reactions and Radioactive Decay

Requirement. To support planned site-wide groundwater model transport calculations, the code must, at a minimum, be able to support simulation of geochemical retardation on a contaminant specific basis. Use of the linear equilibrium adsorption model would meet the intent of this requirement. A desirable feature of the code is to allow adsorption to vary not only by contaminant but also spatially (i.e., to be a function of the contaminant and of the hydrogeologic unit in which transport occurs). However, since site-specific data on adsorption are limited, this capability is not a required feature.

Rationale. Adsorption is a major process affecting contaminant transport in groundwater at the Hanford Site. Adsorption is known to vary significantly based on the contaminant and the porous medium in which it occurs.

Reactive transport models have been proposed for use to model more complex contaminant transport behavior in vicinity of certain facility and contaminant release locations. We acknowledge using more complex reactive transport processes may be a helpful approach to address a number of local-scale contamination issues on the site. Sites that have received wastes with complex chemistry, such as crib and trench sites that have received tank wastes or at sites near suspected tank leaks, may have geochemical conditions that can influence the contaminant mobility. However, because of the significant computational requirements and the required extensive geochemical data needs, the use of reactive transport models in the context of a site-wide groundwater model is not presently viewed as practical and has not been currently implemented on a site-wide scale. The transport of most existing site-wide plumes and potentially important future plumes reflect relatively mobile constituents (tritium, iodine-129, technetium-99, and uranium) that are not significantly impacted by reactive processes other than adsorption. To date, using the standard convective-dispersion approach for transport combined with a linear equilibrium adsorption isotherm model has provided reasonable approximations to observed plume transport.

Requirement. The consolidated code must be able at least to simulate the effect of first-order radioactive decay. A desired feature would the ability to calculate the radioactive ingrowth of decay products ("chain decay") in modeling the transport process.

Rationale: The capability to simulate first-order radioactive decay is a requirement for the majority of radioactive constituents of concern in future contaminant-transport calculations. This capability may also be useful in estimating the effect of chemical degradation if the degradation process can be approximated using this type of decay function. This capability is common in most codes used for contaminant transport and is a requirement for convenience.

This type of capability could be easily performed on transport results outside of the code framework. A number of codes designed to perform these types of calculations as well as calculating the amounts of decay product ingrowth are available. There may be a few instances where the capability to calculate the effect of chain decay in transport simulations would be desirable feature, particularly in cases where the decay products are more mobile or have greater toxicity than the parent. However, this feature is not considered important for most of the most of the mobile radioactive constituents being evaluated on a site-wide scale and is not considered a requirement for the code used in the consolidated site-wide groundwater model applications

5.3.1.6 Coupling of Flow and Contaminant Transport

Requirement. The code must be flexible in simulating flow only; contaminant transport based on previously simulated flow conditions, or combined flow and contaminant transport.

Rationale. This capability is required for efficient, non-redundant simulation over the wide range of necessary applications.

5.3.1.7 Particle Tracking Capabilities

Requirement. The code must be capable of efficiently performing streamline (for steady-state conditions) and pathline (for transient conditions) analyses in two- and three-dimensions.

Rationale. Particle tracking is a useful tool in understanding the movement of contaminants without the computational expense of solving the contaminant transport equation.

5.3.1.8 Spatial Scale of Analysis

Requirement. The code must be capable of simulating groundwater flow and contaminant transport at scales ranging from areas in the immediate vicinity of an individual waste site or facility to the entire area of the Hanford Site. The code must also be capable of transferring output from the site-wide flow and contaminant transport model to local-scale (smaller than site-wide) models as appropriate.

Rationale. The primary purpose of the site-wide groundwater model is to be able to model groundwater conditions over the entire Hanford Site. However, the range of potential applications of groundwater flow and transport modeling at the Site suggest that flexibility will be required to support sub-modeling or detailed refinement in grid resolution within the framework of the site-wide groundwater model. The ability to facilitate the transfer of critical information derived from the site-wide groundwater model to higher resolution local-scale models is required. Site-wide groundwater model output that may be required for the local-scale model includes hydraulic head, contaminant concentration, water fluxes, and contaminant fluxes. The local-scale model will require that this output be available from interior nodes of the site-wide groundwater model and that the output be time varying.

Objectives of some groundwater analyses at the Hanford Site will focus on local-scale or specific facility-scale predictions of flow conditions (e.g. capture analysis associated with pump and treat operations) or contaminant concentrations (e.g. compliance analyses associated with RCRA or CERCLA remediation efforts), which may require the development of specialized, local-scale models. Design of such models will require a higher level of resolution and may consider other chemical processes beyond those considered in the consolidated site-wide groundwater model (first-order decay and linear sorption isotherm). Two approaches can be used to develop local-scale models. A local scale problem can be simulated using the full domain with the grid refined in the local scale area only, or the boundary conditions can be derived from the regional flow system and applied to a refined grid sub-model. The current interim code, CFEST-96, allows for the transfer of these boundary conditions from a regional to local scale model with ease. For other codes that could be used in the future, this capability will be an important requirement.

The hydrogeologic conceptual model may need to be revised to incorporate local-scale geologic units that may affect the flow and transport of contaminants. If so, the local scale conceptual model must be consistent with the regional scale conceptual model, and the regional flow field must be established incorporating the local scale conceptual model.

5.3.1.9 Temporal Scale of Analysis

Requirement. The code must have the capability to effectively simulate groundwater flow and contaminant transport on a variety of time-scales ranging from a few years to more than 10,000 years.

Rationale. Site-wide groundwater modeling over a large range of time periods is required for the consolidated model to satisfy all programmatic needs. A number of analyses (groundwater modeling support to the HGWP and the Composite Analysis) will require using a model to simulate flow and transport during expected transient changes to the water as the effect of artificial discharges from Hanford operations on the unconfined aquifer conditions dissipate. For other analysis (groundwater modeling support to HTI and the ILAW disposal-facility PA), the code must also have the flexibility to support simulation of long-term flow conditions and contaminant transport out to 10,000 years and beyond. Long-term assessments of flow and transport may be best served by developing a simplified approach to the required analysis that is based on the computational framework and results derived from the consolidated site-wide groundwater model.

5.3.1.10 Linkage to Other Analysis Modules

Requirement. The selected code for the consolidated site-wide groundwater model must have the capability to link to other analysis modules that will be used in conjunction with the code to meet the objectives of anticipated assessments. Other analysis modules would include vadose zone flow and transport codes

Rationale. For many assessments involving groundwater that will be performed at the Site, the groundwater flow and transport components will be among several computational modules needed to complete the required analysis. The consolidated site-wide groundwater model will be expected to have capabilities to link other analysis tools that would provide needed input for the site-wide groundwater model or would use outputs of simulated groundwater contaminant concentrations and fluxes as input data. The typical linkages for a groundwater are with modules that assess flow and/or contaminant transport in the overlying unsaturated or vadose zone, flow and transport in the Columbia River, and human health and ecosystem exposures and risk at compliance and/or potential receptor points. Following are brief discussions of user considerations in linking the consolidated model to other analysis modules

Vadose Zone Flow and Transport. Vadose zone flow and/or transport models are being used at Hanford to investigate and estimate water movement and contaminant migration from source locations to the water table. The primary mechanism for transport in the vadose zone is from water flow in response to gravitational and capillary forces. Vadose zone models provide input data to the groundwater model resulting from the complex interaction of natural recharge, artificial sources of recharge from planned and/or accidental discharges to the land surface or in the vadose zone, and contaminant releases from waste sites and sources of different characteristics within the hydrogeologic framework of sediments above the water table. These input data are represented as boundary conditions in the groundwater model that vary in time and space. Movement of water into the aquifer system is typically represented in the model as specified volume per unit time. Contaminant flux to the aquifer can be represented in one of two ways: 1) as a flux of fluid (units of volume/unit time) with an associated concentration (units of mass/unit volume) or 2) as a dry mass flux (mass/unit time). Direct use of these calculated flow rates and contaminant fluxes in the groundwater model may require some processing to ensure that the units reflective of the resolution and dimensionality of the vadose zone model are consistent with the resolution and units being used in the groundwater model.

Groundwater/Surface Water Interaction and River Flow and Transport Models. Representation of groundwater-surface water interaction in the consolidated site-wide groundwater model is based on use of a constant head boundary condition that approximates the long-term average river stage. As such, use of this type of boundary condition limits the use of the model in estimating long-term regional groundwater discharges and contaminant loading to the Columbia River. This regional approach to groundwater-surface water interaction is inappropriate to analyses that need to evaluate the shorter-term transient effects of river stage on local-scale flow conditions and contaminant transport into and out of specific locations of the Columbia River. These types of assessments would likely require higher resolution local-scale models that would focus on shorter-term transient processes of daily and seasonal river stage fluctuations and their effect on local aquifer conditions. Boundary conditions required in such a model to represent the regional groundwater flow into the region of interest could be estimated from local-scale measurements of head and hydraulic properties or could be supplied by the regional-scale hydrogeologic framework embodied in the consolidated site-wide groundwater model. The current implementation of the site-wide groundwater model based on the CFEST-96 computer code contains the necessary post-processing utilities to facilitate the generation of appropriate spatial and temporal variations in boundary fluxes to support the latter approach to representing the regional flow component in the local-scale model

The complex level of interaction of the Columbia River with local aquifer conditions may also require consideration of features and characteristics of local-scale hydrogeologic framework that are not resolved on a regional scale of the site-wide groundwater model. Consistency of such local features should they become important on a local scale should be resolved with the regional interpretation of the hydrogeologic framework of the site-wide groundwater model.

Simulated groundwater discharge rates and concentrations of contaminants of concern at selected times and specified points in space as derived from the groundwater model can provide input data and information for use in river flow and transport models. However, it is important to recognize that significant differences exist between the spatial and temporal scales of the groundwater system and the Columbia River. Direct use of these calculated flow rates and contaminant loading rates may require post-processing to ensure that the units reflective of the resolution, dimensionality, and time scales of the groundwater flow and transport model are consistent with the temporal and spatial resolution and units being used in the river flow and transport model. Local-scale models of higher spatial and temporal scales may be required to meet the intended objectives of the river flow and transport models which are typically run on short time scales that used in the site-wide groundwater model.

Exposure and Risk Models. The impacts from groundwater considered in the exposure and risk models are predicted with unit factors that relate concentration of a particular constituent in an environmental medium. Impacts considered include human health impacts such as radiation impacts (dose), cancer risk (cancer incidence), or ecosystem impacts. The unit factors considered are evaluated for each assumed exposure scenario at assumed receptor points. Appropriate outputs from the groundwater model for use in exposure and risk models included estimated concentrations of selected contaminants at selected times and specified points in space.

Input and output formats for the current implementation of the consolidated site-wide groundwater model with CFEST-96 are believed to be sufficiently well documented and flexible that simple computer programs can be developed to provide the linkage with other analysis programs. Development of the consolidated site-wide groundwater model at this stage should be able to accommodate inputs from vadose zone flow and transport models or river flow and transport and to provide for easy access to output of simulated head and contaminant values and fluxes over space and time that can be used as input other analysis modules.

5.3.2 Administrative Requirements

The following section describes administrative requirements and rationale for the code selected for the consolidated site-wide groundwater model.

5.3.2.1 User Interface Issues

Requirement. The code must interface with some form of pre- and post-processing modules that allow users to readily set up problems and understand results.

Rationale. Pre- and post-processing modules reduce the likelihood of errors occurring in model input and improve the interpretation of model output. Graphical interfaces are preferred to text interfaces. The capability to graphically display the numerical grid discretization along with zone identifiers, contaminant and water fluxes across selected boundaries and/or regions in the modeling domain, and contours, spatial cross sections, and time histories of contaminant concentrations is highly desired. Pre- and post-processing modules may be an integral part of the code or a separate package. They may be commercial or public-domain products not developed by those responsible for the computer code.

Requirement. The code must be capable of interfacing with the available site ArcInfo Geographic Information Systems (GIS).

Rationale. Interfaces to site GIS and site-wide groundwater model parameter database(s) allow for the efficient specification of hydraulic properties, boundary and initial conditions, and sources and sinks. The appropriate interfaces will allow the site-wide groundwater model to receive input from the GIS and to produce outputs that can be read by the GIS. These interfaces may be part of the pre- or post-processing software.

5.3.2.2 Code Reliability Issues

Requirement. Code documentation must be published and readily available and must clearly describe the theory, governing equations, assumptions, and solution methods of the code. In addition, a user's guide describing the operation of the code must be available.

Rationale. The documentation provides a reference for those who want to evaluate the code as well as a reference for the actual development and application of a numerical model for a particular problem. The user's guide should include a description of the input required, including the implementation of all execution options and any formatting requirements. A description of the output options should also be included in the user's guide. If graphical user interfaces to assist in the development of input files and the display of output files are distributed with the code, these should be documented in the user's guide. Although graphical user interfaces may be available, the flat files used to contain the input and output should be described, including formatting and the location of parameters.

Requirement. Evidence of code verification must be available.

Rationale. The verification provides evidence that the solution methods used in the code are correctly implemented and should demonstrate the effect of the assumptions and potential errors arising from limitations of the code. The verification evidence should include comparison of the code results for a variety of known or accepted solutions.

Requirement. A body of code applications must exist.

Rationale. Prior applications should demonstrate that the code is well regarded among the user and regulatory community. In particular, the code should be acceptable to the EPA and Ecology for environmental assessments at the Hanford Site.

5.3.2.3 Technical Support

Requirement. Adequate technical support for the code must be available to allow rectification of technical difficulties that arise in its application to Hanford specific applications.

Rationale. Technical difficulties may arise that require modifications to the code. If a public domain code is used, the technical support for the code may reside with one of the Hanford Site DOE contractors. If a proprietary code is used, technical support will likely reside with the code developer. In either case, arrangements must be in place to allow a rapid response to technical needs.

5.3.2.4 Configuration Control

Requirement. The code must be maintained under a software-control program that ensures that all changes to the code are well documented and tested. Differences between versions of a code must be documented.

Rationale. Modifications to the code may affect the results produced by a model. To understand and explain these results, all modifications must be traceable.

5.3.2.5 Contractor Use

Requirement. The code must be available for use by all contractors performing Hanford Site groundwater modeling.

Rationale. To maintain the benefits of a consolidated site-wide groundwater model, it must be available for use by all Hanford Site contractors.

5.3.2.6 Public Availability and Cost

Requirement. The executable code must be available to the public at a reasonable cost.

Rationale. Regulatory agency staff, their contractors, tribal representatives, and other Hanford Site stakeholders require access to the code for the purposes of repeating calculations and confirming results.

5.3.2.7 Proprietary Codes

Requirement. Inspection and verification of the source code by DOE and its contractors must be possible.

Rationale. Inspections and/or verification reviews may be required to assist DOE and its contractors in rectifying problems encountered in applying the code or in working with the code author to develop technical approaches for required code enhancements. For public domain codes, this requirement is satisfied. For proprietary codes, special arrangements with the code's owner will be necessary. Proprietary codes will be considered if they provide an advantage over public-domain codes but only if arrangements for inspection and verification can be made.

5.3.2.8 Portability

Requirement. The code selected for the consolidated site-wide groundwater model should be capable of being run efficiently on a variety of computational workstations and platforms including UNIX-based and Windows-based workstations.

Rationale. Different users may have a variety of computers and operating systems.

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6.0 Acceptability of Current Models

This section provides a summary of the acceptability of two site-wide groundwater models that were evaluated in the first phase of the model consolidation process relative to the model requirements outlined in Section 5.2.

6.1 Hanford Site-Wide GWRS and HGWP Models

The review of models for this initial phase of the model consolidation process was limited to the two Hanford Site models used in the most recent site-wide groundwater modeling assessments. These included site-wide groundwater modeling efforts conducted for the HGWP (Wurstner et al. 1995; Cole et al. 1997; Kincaid et al. 1998) and for development of Groundwater Remediation Strategy (GWRS) (Law et al. 1997; Chiaramonte et al. 1997).

A comparison of the two site-wide groundwater models with the model requirements, provided in Table 7, shows that the models have very similar capabilities. The requirements that both models meet include

- **hydrogeologic units** - Both models simulate the combination of the Hanford formation and the pre-Missoula gravels as a single hydrogeologic unit

- **lateral boundaries** - Both models include inflow boundaries to represent inflow of groundwater into the Hanford Site from Cold Creek Valley and Dry Creek Valley, although the simulation of Dry Creek Valley is handled in a slightly different manner in the two models (some of the Dry Creek Valley is explicitly modeled within the GWRS model, but not in the HGWP model). The Columbia River is represented in both models as a major groundwater discharge boundary, although the details of the implementation are slightly different.

- **lower boundaries** - In general, both models have relied on the uppermost surface of the Columbia River Basalt Group to represent a no-flow lower boundary to the aquifer system. However, in some areas of the models (north of Gable Mountain and Gable Butte and in the southeast area of the Hanford Site), the HGWP model makes use of a mud sequence in the lower part of the Ringold Formation to represent the base of the aquifer model. Both models have the capability to add additional model layers to represent potential interaction and upward leakage from the basalt-confined aquifers to the unconfined aquifer system.

- **anticipated future flow conditions** - Both models have the ability and have been used to simulate anticipated future transient-flow conditions. Both models have also been used to simulate steady-state, post-Hanford flow conditions.

temporal scales of analysis - Both models have the necessary capabilities to simulate the full range of required time scales of analysis. The GWRS model has been used to support transient flow and transport of a variety of radiological and chemical contaminants for a period of 200 years. A steady

Table 7. A Comparison of Hanford Site-Wide Groundwater Remediation and Hanford Groundwater Project Models Capabilities with Technical Model Requirements

Required Model Capabilities	Hanford Site-Wide Groundwater Remediation Strategy Model	Hanford Groundwater Project Model
Elements of Conceptual Model		
	Hydrostratigaphic Units	
Plio-Pleistocene Unit	This unit is not explicitly modeled but is included as part of Hanford formation/pre-Missoula Gravel Unit	This unit is included as a single model unit
Hanford formation/Pre-Missoula Gravels	This unit is included as a single model unit	This unit is included as a single model unit
Ringold Formation	This unit is included as a single model unit	This unit is included and subdivided into six sub-units
Ringold Sub-units	These sub-units were not explicitly modeled	These units are explicitly modeled
Upper Ringold Mud		
Middle Ringold Sand and Gravel		
Middle Ringold Mud		
Middle Ringold Sand and Gravel		
Lower Ringold Mud		
Basal Ringold Sand and Gravel		
Columbia River Basalt	Modeled as lower no-flow boundary. Model has capability to incorporate an explicit basalt unit or to simulate upward leakage from basalt	Modeled as lower no-flow boundary. Model has capability to incorporate an explicit basalt unit or to simulate upward leakage from basalt
	Boundary Conditions	
Basalt Outcrops	All major lateral and internal basalt subgroups included	All major lateral and internal basalt subgroups included
Rattlesnake Hills Spring Discharge	Not explicitly included	Explicitly modeled
Cold Creek Valley	Outlet of valley at western model boundary simulated as an inflow boundary condition (constant head and constant flux)	Outlet of valley at western model boundary simulated as an inflow boundary condition (constant head and constant flux)
Dry Creek Valley	Modeled as an inflow boundary condition (constant head and constant flux). Flow in part of Dry Creek Valley on Hanford Site explicitly modeled	Modeled as an inflow boundary condition (constant head and constant flux) at two valley outlet locations
Yakima River	Short segment of Yakima River modeled in southeast part of the model as a constant head boundary	Lower segment of Yakima River modeled in southeast part of the model as a constant head boundary

Table 7. (contd)

Required Model Capabilities	Hanford Site-Wide Groundwater Remediation Strategy Model	Hanford Groundwater Project Model
Columbia River	Entire reach of the Columbia River on site modeled as a constant head discharge boundary	Entire reach of the Columbia River modeled as a constant head discharge boundary
Natural Recharge	Not explicitly modeled	Explicitly modeled
Spatial Scale		
Site-Wide Scale including North Richland Well Field	Scale of model extends over entire site to just south of the 300 Area. Area in vicinity of North Richland well field is not included	Scale of model extends over entire site and includes the area south of the 300 Area to the area in vicinity of North Richland well field.
Local scale sub-modeling	Capable of supporting local scale modeling	Capable of supporting local scale modeling
Time Scale		
Few Years to 10,000 years	Model has been used to support transient flow and contaminant transport for 200 years	Model has been used to support transient flow and contaminant transport for 1500 years
Anticipated Future Flow		
Expected short-term transient flow conditions	Model has been used to examine transient behavior of aquifer over next 200 years	Model has been used to examine transient behavior of aquifer to steady state
Long-term Steady State Flow	Model has been applied using steady state flow option	Model has been applied using steady state flow option
Contaminants Considered		
Radionuclides	Model used to simulation of existing site-wide tritium, Tc-99, I-129, and uranium plumes	Model used to simulation of existing tritium, Tc-99, I-129, uranium, and Sr-90 plumes and plumes resulting from future release of radiological contaminants from 200-Area plateau
Chemicals	Model used to simulation of existing site-wide nitrate, carbon tetrachloride, chloroform, trichloroethane plumes	Model capable of simulating existing and future chemical plumes
Geochemical Processes		
Linear Adsorption	Model included linear adsorption	Model included linear adsorption
Radioactive Decay	Model included first-order radioactive decay	Model included first-order radioactive decay
Chemical Degradation	Option is not specifically available but if chemical degradation is linear, decay option can be used to approximate degradation	Option is not specifically available but if chemical degradation is linear, decay option can be used to approximate degradation

- state flow field developed with this model has also been used to evaluate performance of the ILAW disposal facilities for 10,000 years. The HGWP model has been used to support transient flow and transport a variety of radiological contaminants for 1500 years. While the HGWP model has not been specifically applied to transport problems spanning 10,000 years, it does have the necessary capabilities to perform these required calculations. For long-term simulations (i.e., over thousands of years), the computational burden associated with the higher resolution HGWP model is likely to be higher than for equivalent simulations made with the GWRS model.

- **radiological and chemical contaminant transport** - Both models have the necessary capabilities to simulate the transport of existing and future radiological and chemical contaminant plumes within the unconfined aquifer. The model used in the development of GWRS has been used to evaluate the transport of existing site-wide tritium, technetium-99, iodine-129, and uranium plumes and the nitrate, carbon tetrachloride, chloroform, and trichloroethylene plumes. The model used to support the HGWP has been used to evaluate transport of existing tritium, technetium-99, iodine-129, uranium, and strontium-90 plumes and plumes resulting from future release of radiological contaminants from 200-Area plateau.

The most notable discriminating differences between the models are as follows:

- **major hydrogeologic units** - The level of resolution used to represent the Ringold Formation in each model is significantly different. The HGWP model identifies three sand and gravel and three mud units (i.e., six hydrogeologic units) to represent the Ringold Formation while the model used for GWRS lumps all units below the Hanford Site into a single Ringold hydrogeologic unit. The mud units are mapped as being areally extensive (e.g., Lindsey 1995; Law et al. 1997; Thorne and Chamness 1992) and therefore may control or influence the flow of groundwater on the Hanford Site. An additional minor difference between the two models is in the way they consider the Plio-Pleistocene unit. In the GWRS model, it is included as part the Pre-Missoula Gravel Hanford Unit. The HGWP model considers it as a separate hydrogeologic unit.

- **recharge** - While both models are capable of including artificial and natural recharge as an upper boundary condition, only the HGWP model includes natural recharge.

- **lateral boundaries** - Both models consider slightly different boundary conditions. The GWRS model does not include as long a segment of the Yakima River as a lateral boundary condition as the HGWP model. In addition, while both models have capabilities to incorporate spring discharge from the Rattlesnake Hills region, these fluxes are only considered in the HGWP model.

- **spatial scales** - Both models have the sub-modeling capabilities that would enable their use to simulate the required multiple spatial scales of interest ranging from local facility to site-wide scales. However, the GWRS model does not include the North Richland well field and could not be used to evaluate the potential impact of offsite contaminant transport to this well field. The HGWP model includes this area in its modeled domain and could be used to assess this potential impact.

While the evaluation of the GWRS and HGWP models showed that both models are capable of meeting many of the requirements for a consolidated site-wide model, RL has selected the HGWP model as the preferred alternative for the initial phase of the model-consolidation process. The discriminating factors that led to the selection of the HGWP as the preferred alternative for this initial phase are as follows:

- **model resolution** - The HGWP model is the most recent site-wide groundwater model development effort and contains a higher level of resolution in its representation of the Ringold formation than used in the GWRS model. The capabilities offered in this framework can be more easily used to evaluate and investigate the anticipated importance of the hydrostratigraphic complexity in the Ringold Formation in influencing future flow and contaminant transport as the water table declines.

- **extent of models** - The areal extent of the HGWP model already includes Richland north of the Yakima River and west of the Columbia River. Including this area in the model provides the needed capability to address the potential impact of onsite contaminant plumes on the City of Richland drinking-water supply derived from the North Richland well field.

- **natural recharge** - The HGWP model incorporates the effect of natural recharge as an upper hydrologic boundary condition. This capability will facilitate evaluating the importance of natural recharge in controlling future flow conditions and contaminant transport as the effect of artificial recharge on water-table conditions dissipates.

6.2 Computer Code Selection for Initial Phase

The review of codes for this initial phase of the model-consolidation process was limited to the two computer codes used in the most recent site-wide groundwater modeling assessments. The codes considered included

- the VAM3D-CG code developed by Hydrogeologic, Inc., in Herndon, Virginia (Huyakorn and Panday 1994) and used in site-wide groundwater modeling for the GWRS

- the CFEST-96 code developed by the CFEST Co. in Irvine, California (Gupta 1997), and used in the site-wide groundwater modeling in support of the HGWP.

In a qualitative comparison of the two computer codes, both VAM3D-CG and CFEST-96 were found to be technically acceptable because

- these codes were included in the list of accepted groundwater flow and transport codes identified in Milestone M-29-01 (DOE/RL 1991). (Note that the current versions of the codes were not specifically mentioned in the original reference. However, these versions of the codes are assumed acceptable because they were originally derived and they do not significantly depart from the original versions of the codes.)

- these codes met the technical capabilities and administrative requirements outlined in the original M-29-01 document (DOE/RL 1991)

- these codes generally met the technical capabilities and administrative requirements outlined in this report - A summary of how both VAM3D-CG and CFEST-96 meet these specific capabilities and requirements is provided in Table 8.

Table 8. A Comparison of VAM3D-CG And CFEST-96 Capabilities with Technical and Administrative Needs and Requirements

Needs and Requirements	VAM3D-CG Capabilities	CFEST-96 Capabilities
TECHNICAL NEEDS AND REQUIREMENTS		
Two- & Three Dimensional Flow	Options available	Options available
Three- Dimensional Hydraulic Properties	Option available	Option available
Steady & Transient States	Options available	Options available
Unconfined & Confined Conditions	Options available	Options available
Two- & Three Dimensional Transport	Options available	Options available
Radioactive Decay	Option available	Option available
Linear Equilibrium Adsorption Model	Option available	Option available
Spatial Scale of Hanford Site	Option available	Option available
Time Scales ranging from a few yr. to 10,000 yr.	Option available	Option available
Streamline & Pathline Analysis	Options not available, but can be implemented with particle tracking code	Options available
Variety of Computational Algorithms and Solvers	Options available	Options available
Coupled Flow and Transport Capabilities	Options available	Options available
Dirichlet (constant head & concentration) Boundary Conditions	Option available	Option available
Neumann (fluid or mass flux) Boundary Conditions	Options available	Option available
Interaction with Sub-models	Option available, but not implemented at Hanford	Option available
ADMINISTRATIVE NEEDS AND REQUIREMENTS		
User Interface with pre- and post-processing	Both codes have code resident utilities for pre- and post-processing capabilities.	
Linkage to GIS	Uses code resident software and TECPLOT for Input and Output Graphics; currently not linked to Arc/Info at Hanford.	Currently uses code resident software, Earth Vision, and Arc/Info; Use of TECPLOT utilities available from developer
Model Reliability		
– Sufficient Documentation	Both codes have acceptable documentation	
– Body of applications	Both codes have history of use at other sites and situations	
– Regulatory Acceptance	Both codes have been used in regulatory arenas and have been accepted at Hanford for use.	
Availability of Technical Support	Hydrogeologic, Inc. Herndon, VA (Dr. Peter Huyakorn)	CFEST Co. Irvine CA (Dr. Sumant Gupta)
Configuration Control	Both codes can be maintained under configuration control	
Public Availability and Costs	Executables for both codes are available for purchase	
Proprietary Codes and Availability of Source	Source for both code available.	
Portability, Computational and User Efficiency	Both codes run on PC and UNIX workstations with efficient solvers.	

During this initial phase of the model consolidation process, DOE has made the decision to use the CFEST-96 code as an interim code during the model refinement and modification phase following the initial peer review because it has been implemented with the consolidated site-wide groundwater model. Little information is currently available to benchmark the VAM3D-CG code and the CFEST-96 code to facilitate the final selection of a code by RL because the current model implementations with these codes are based on different conceptual model complexity. RL deferred decisions on final selection of the code until the external peer review of the consolidated site-wide groundwater model and the resulting final refinements and modifications are completed. Once this first phase of the model consolidation process is completed, RL may consider more in-depth testing and benchmarking of the CFEST-96, VAM3D-CG and other applicable codes using the refined and modified site-wide groundwater model before reaching a final decision on selection of a code.

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7.0 Description of the Consolidated Site-Wide Model

This section of the report describes the consolidated site-wide groundwater model including a synopsis of its historical development and its numerical implementation and application.

7.1 Synopsis of Model Development

Various site-wide flow and transport models has been under continuous development since the early 1960s in the Hanford Site's groundwater-monitoring programs and other site programs. Early flow models were two-dimensional (e.g., the Variable Thickness Transient [VTT] code [Kipp et al. 1972]). Transport modeling used a variety of approaches including an advective type of approach (e.g., the Hanford Pathline Calculation code [Friedrichs et al. 1977]), a quasi-three-dimensional particle tracking type of approach (e.g., the Multi-component Mass Transport [MMT] code [Alhstrom et al. 1977]), or a multiple stream-tube type of approach (e.g., the TRANSS code [Simmons et al. 1986]). Early flow-model calibration was carried out using a stream-tube approach that used available field measurements of transmissivity, river stage, disposal rates to ground, and head in an iterative approach to determine the Hanford Site unconfined aquifer transmissivity distribution (Transmissivity Iterative Calculation Routine [Cearlock et al. 1975]). Freshley and Graham (1988) describe applications of the VTT, MMT, and TRANSS codes at the Hanford Site.

In the mid-1980s, the CFEST code was selected for upgrading of the HGWP's two-dimensional modeling capability from the VTT code. CFEST has been used to model the Hanford Site and a number of other sites in three dimensions (Dove et al. 1982; Cole et al. 1984; Gale et al. 1987; Foley et al. 1995). Evans et al. (1988), in a Hanford Site groundwater monitoring report for 1987, discuss the selection of the CFEST code for application to modeling flow and transport in the Hanford Site's unconfined aquifer.

Initial flow modeling with the CFEST code was two-dimensional, as it had been with the previous VTT code. New data were used to re-calibrate the CFEST two-dimensional groundwater flow model of the Hanford Site unconfined aquifer. A steady-state finite-element-inverse calibration method developed by Neuman and Yakowitz (1979) and modified by Jacobson (1985) was used in this effort. All available information on aquifer hydraulic properties (e.g., transmissivities), hydraulic heads, boundary conditions, and discharges to and withdrawals from the aquifer were included in this inverse calibration. Initial inverse-calibration efforts are described by Evans et al. (1988), final calibration results are described by Jacobson and Freshley (1990), and the calibrated two-dimensional model of the unconfined aquifer is described in Wurstner and Devary (1993).

Two-dimensional flow models used extensively at the Hanford Site before cessation of disposal operations were generally adequate for predicting aquifer head changes and directions of groundwater flow. This is because groundwater levels were somewhat stable through time across the Hanford Site. However, in the early 1990s, it was recognized that a three-dimensional model was needed for accurate calculation of future aquifer head changes, directions of groundwater flow, mass transport, and predictions of contaminant concentrations. The three-dimensional model was needed because there is significant vertical heterogeneity in the unconfined aquifer, and the cessation of large liquid disposals has caused the water table to drop over most of the Hanford Site.

Development of a three-dimensional model began in 1992 (Thorne and Chamness 1992) and was completed in 1995 (Wurstner et al. 1995). In the interpretation of the hydrogeology of the Hanford Site unconfined aquifer, Thorne et al. (1994) suggested that it is composed of alternating series of transmissive units that are separated from each other in most places by less transmissive or mud units. Accounting for this vertical heterogeneity is particularly important for unconfined aquifer predictions at the Hanford Site as the future water table changes and the key hydrogeologic layers are de-watered. The water table is currently near the contact between the Hanford formation and the underlying, and much less permeable, Ringold Formation over a large part of the Hanford Site. Water-level declines caused by decreased discharge at disposal facilities is causing and will continue to cause de-watering of the highly permeable Hanford formation sediments in some areas (Wurstner and Freshley 1994). This may result in aquifer transmissivity changes of an order of magnitude or more that would not be properly accounted for by two-dimensional flow and transport models that average vertical properties at each spatial location. Consequently, a two-dimensional model can not accurately simulate changes in groundwater levels, groundwater-flow direction, and contaminant transport because the three-dimensional routing of groundwater flow and contaminant mass resulting from the vertical heterogeneity can not be properly accounted for. Changes along the migrating front of de-saturating sediments can provide the means for plumes emanating from different places and at different times to interact in time and space. To begin to address such issues, HGWP supported development of the three-dimensional site-wide groundwater model that captured the major hydrogeologic units of the unconfined aquifer that would likely have an influence on site-wide flow and transport.

The initial three-dimensional model of the Hanford Site unconfined aquifer (Section 3.3 in Wurstner et al. [1995]) was calibrated in a two-step process. In the first step, the two-dimensional model was re-calibrated with a steady state, statistical inverse method implemented with the CFEST-INV computer code (Devary 1987). The two-dimensional transmissivity distribution from this inverse modeling was preserved during the calibration of the three-dimensional model as is described in Section 3.3 of Wurstner et al. (1995).

The final improvements and calibration of the consolidated site-wide groundwater model were carried out during FY 1996 and FY 1997 as part of the HGWP. The first application of the three-dimensional model was to examine future groundwater flow conditions and to predict the future transport of already-present contaminant plumes in the unconfined aquifer. This two-dimensional model was re-calibrated again in fiscal year 1997 (Section 4.1 of Cole et al. [1997]) when evaluation of previous calibration results indicated unrealistically high transmissivity values in some parts of the model domain. The re-calibration effort resulted in some adjustments to the aquifer transmissivity distribution in some regions of the model to better reflect the trends in transmissivity developed in previous calibration efforts by Jacobson and Freshley (1990) and Cearlock et al. (1975). Section 4.3.2 of Cole et al. (1997) reports predicted changes in transient-flow conditions in the unconfined aquifer to the year 4000. These future flow conditions provided the hydrologic basis for the simulation of the migration of existing contaminant plumes presented in the Cole et al. (1997) report as well as the simulation of future contaminant plume migration considered in the Composite Analysis of the 200-Area plateau (Kincaid et al. 1998).

In FY 1997, a sub model was developed from the three-dimensional site-wide model to assess the transport of the tritium plume resulting from future operations of the SALDS. Results of this analysis are presented in more detail in Barnett et al. (1997).

7.2 Numerical Implementation of Site-Wide Conceptual Model

The three-dimensional groundwater flow and transport model selected for this initial phase of the model consolidation is implemented numerically using the CFEST code (Gupta et al. 1987; Cole et al. 1988; Gupta 1997). The CFEST code was originally designed to support the radioactive waste repository investigations under DOE's Civilian Radioactive Waste Management Program (Gupta et al. 1987). The chemical-waste-management community for conducting exposure assessments, evaluating remediation alternatives, and designing extraction and control systems for aquifer remediation (Dove et al. 1982; Cole et al. 1984; Gale et al. 1987; Foley et al. 1995) has also effectively used the CFEST code.

Descriptions of the capabilities and approach used in the CFEST code and its selection for the HGWP are included in Evans et al. (1988), Wurstner et al. (1995), and Cole et al. (1997). CFEST is an approved code for working on Hanford Federal Facility Agreement and Consent Order also known as the Tri-Party Agreement (Ecology et al. 1989) milestones related to risk assessment (DOE/RL 1991). The CFEST software library was extensively tested and brought under strict software quality assurance/quality control procedures by the Office of Nuclear Waste Isolation (ONWI) when it was developed by ONWI for DOE's Civilian Radioactive Waste Management Program. The supercomputer version (CFEST-SC), developed to run on all major UNIX workstations (Cole et al. [1988]), was used for all flow and transport modeling before FY 1996. In FY 1997, the refinement of the site-wide three-dimensional model continued with its application to contaminant transport of selected contaminant plumes (Cole et al. 1997). An updated version of the CFEST code called CFEST-96 (Gupta [1997]) was used in this effort and in the Composite Analysis. The recent modeling studied documented in Barnett et al. (1997), Cole et al. (1997), and Kincaid et al. (1998) represented the first application of the CFEST-96 code at Hanford. CFEST-96 is a more computationally efficient version of the original CFEST code that uses iterative solvers with reduced disk storage requirements and is fully operational for both PC and UNIX workstation environments (Gupta 1997).

Results from CFEST are graphically displayed using the Arc/Info GIS. The Arc/Info GIS package is also used to store fundamental hydrogeologic data and information used to represent the three-dimensional conceptual model and to construct the three-dimensional numerical model. The three-dimensional visualization software package, EarthVision[3], is used to process and visualize hydrogeologic data and interpretations originating from the conceptual model. Additional graphical representations of data may be produced using TecPlot[4] or other third-party graphics software.

7.2.1 Translation of the Conceptual Model into a Numerical Model

This section describes the translation of the conceptual model into the numerical implementation of the consolidated site-wide groundwater model.

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[3] EarthVision is a registered trademark of Dynamic Graphics, Inc., Alameda, California.

[4] TecPlot is a registered trademark of Amtec Engineering, Inc., Bellevue, Washington.

7.2.1.1 Major Hydrogeologic Units

Data from 426 wells across the Hanford Site have been used to define the major hydrogeologic units of the unconfined aquifer system, and information from an additional 150 wells have been used to define the top of basalt (Wurstner et al. 1995). The lateral extent and relationships between the nine hydrogeologic units of the Ringold Formation and Hanford were defined by determining geologic contacts between these layers at as many wells as possible. These interpreted distributions and thicknesses were integrated into EarthVision, which was used to construct a database for formulation of the three-dimensional Hanford Site conceptual model. The resulting numerical model contains nine hydrogeologic units above the top of the underlying basalt. The resulting areal distribution and thicknesses of the major units are provided in a series of figures (Figures 2.10 through 2.27) in Wurstner et al. (1995).

The areal extent and stratigraphic relationships of these major hydrogeologic units are shown in a series of cross sections across the Hanford Site as they are represented in the model. Locations of the cross sections through the modeled region are given in Figure 16. Two west-to-east cross-sections (A-A' and B-B') are provided in Figure 17 and Figure 18. Two north-south cross-sections are given in Figure 19 and Figure 20.

7.2.1.2 Aquifer Boundaries

Peripheral boundaries defined for the three-dimensional model are illustrated in Figure 21. The Columbia River bounds the flow-system on the north and east and by the Yakima River and basalt ridges on the south and west. To approximate the long-term effect of the Columbia River on the unconfined aquifer system in the three-dimensional model, the Columbia River was represented as a prescribed-head boundary over the entire thickness of the aquifer. The CHARIMA river-simulation model (Walters et al. 1994) was used to generate average river-stage elevations for the Columbia River based on 1979 conditions. At Cold Creek and Dry Creek Valleys, the unconfined aquifer system extends westward beyond the boundary of the model. To approximate the groundwater flux entering the modeled area from these valleys, both constant-head and constant-flux boundary conditions were defined. A constant-head boundary condition was specified for Cold Creek Valley for the steady-state model calibration runs. Once calibrated, the steady-state model was used to calculate the flux condition that was then used in the transient simulations. The constant-flux boundary was used because it better represents the response of the boundary to a declining water table than a constant-head boundary. Discharges from Dry Creek Valley in the model area, resulting from infiltration of precipitation and spring discharges, are approximated with a prescribed-flux boundary condition. A more complete description of these boundaries is provided in Section 4.2.2 of Cole et al. (1997).

The overall water balance of the consolidated site-wide groundwater model for 1979 conditions is as follows:

- natural recharge, 7.2×10^6 m^3/yr
- Dry Creek, 1.25×10^6 m^3/yr
- Cold Creek, 1.0×10^6 m^3/yr

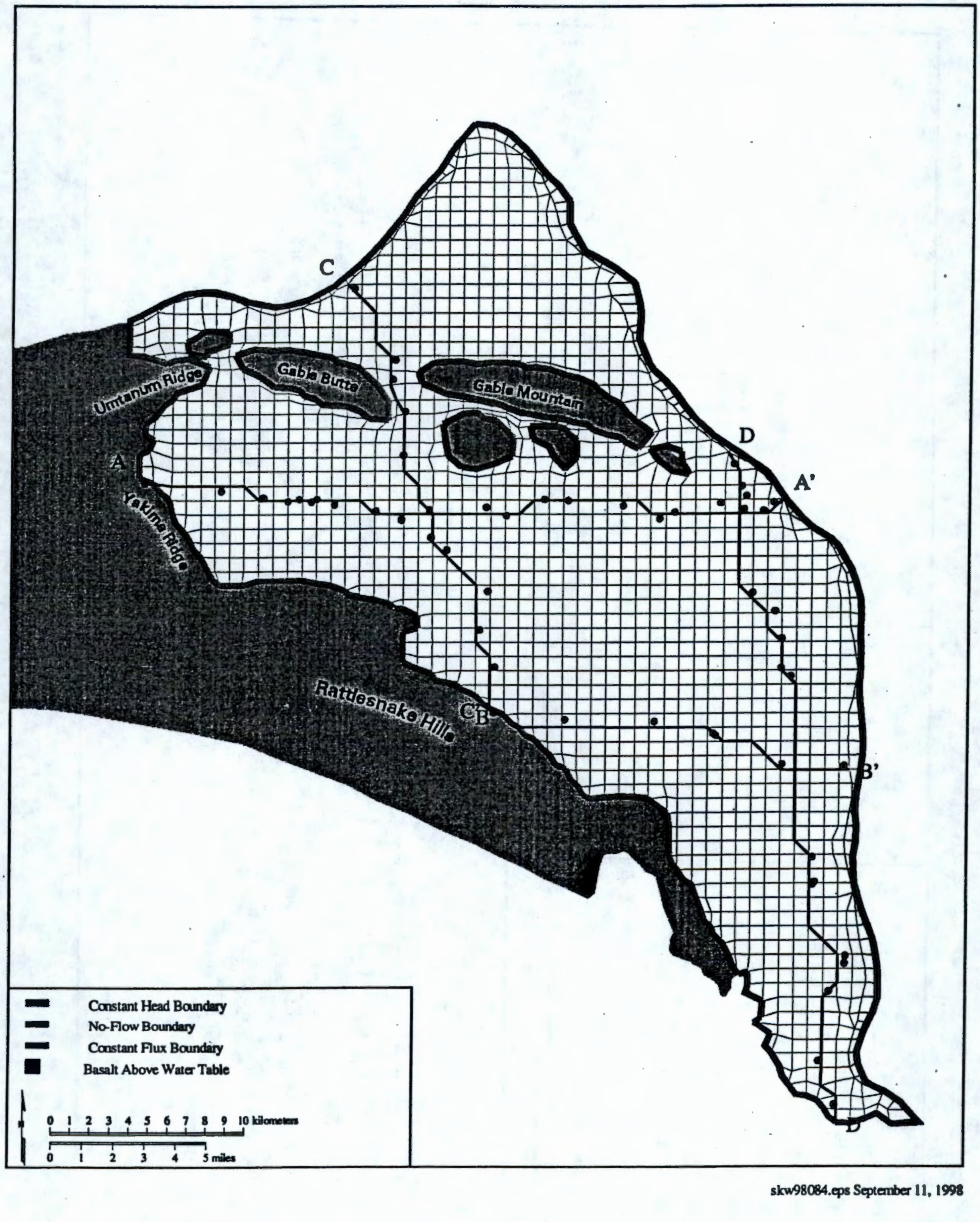

Figure 16. Location of Section Lines for Cross-sections A-A', B-B', C-C', and D-D' across the Hanford Site in the Three-dimensional Model

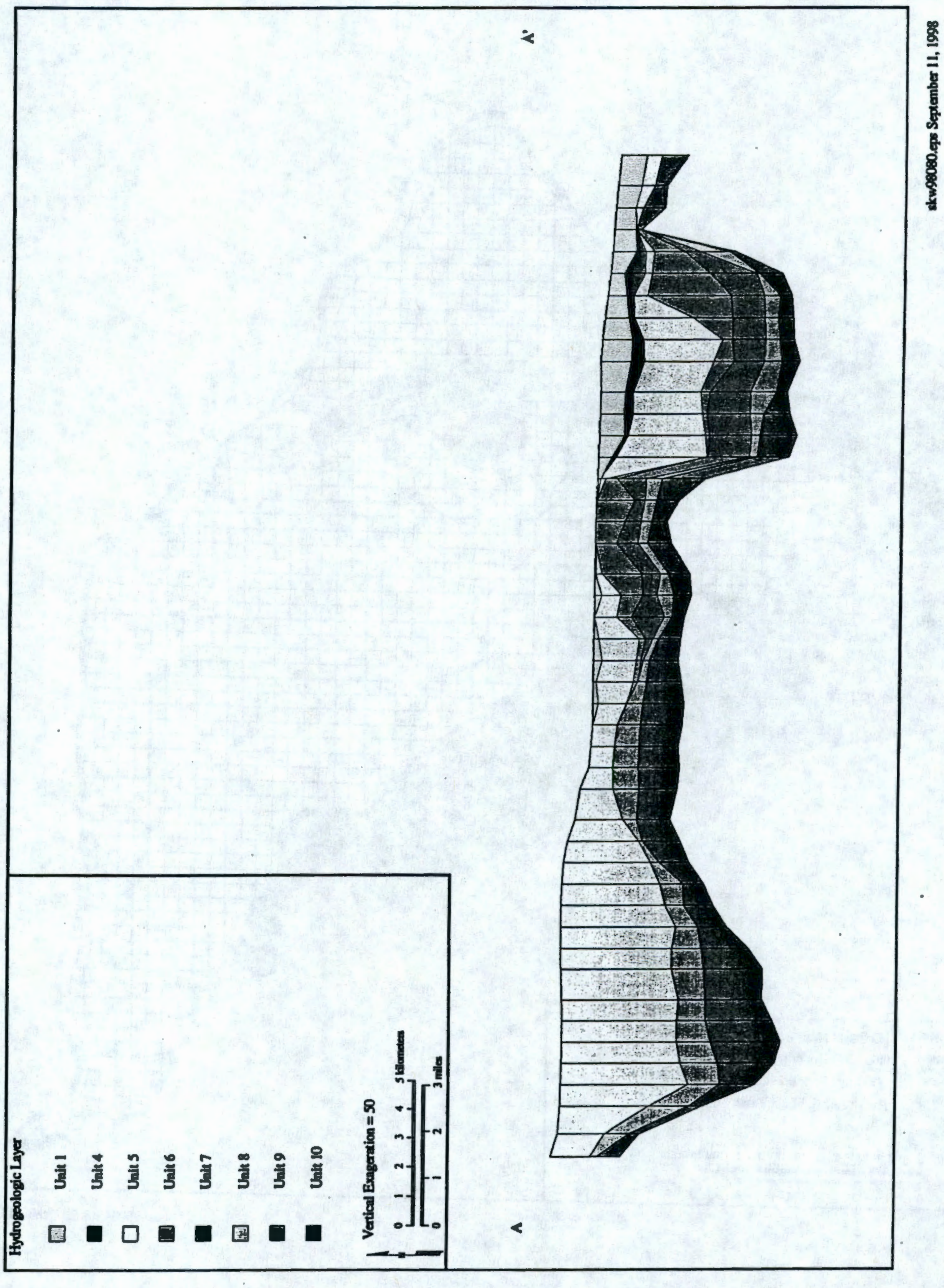

Figure 17. West-East Cross-section A-A', Showing Major Hydrogeologic Units across the Hanford Site in the Three-dimensional Model

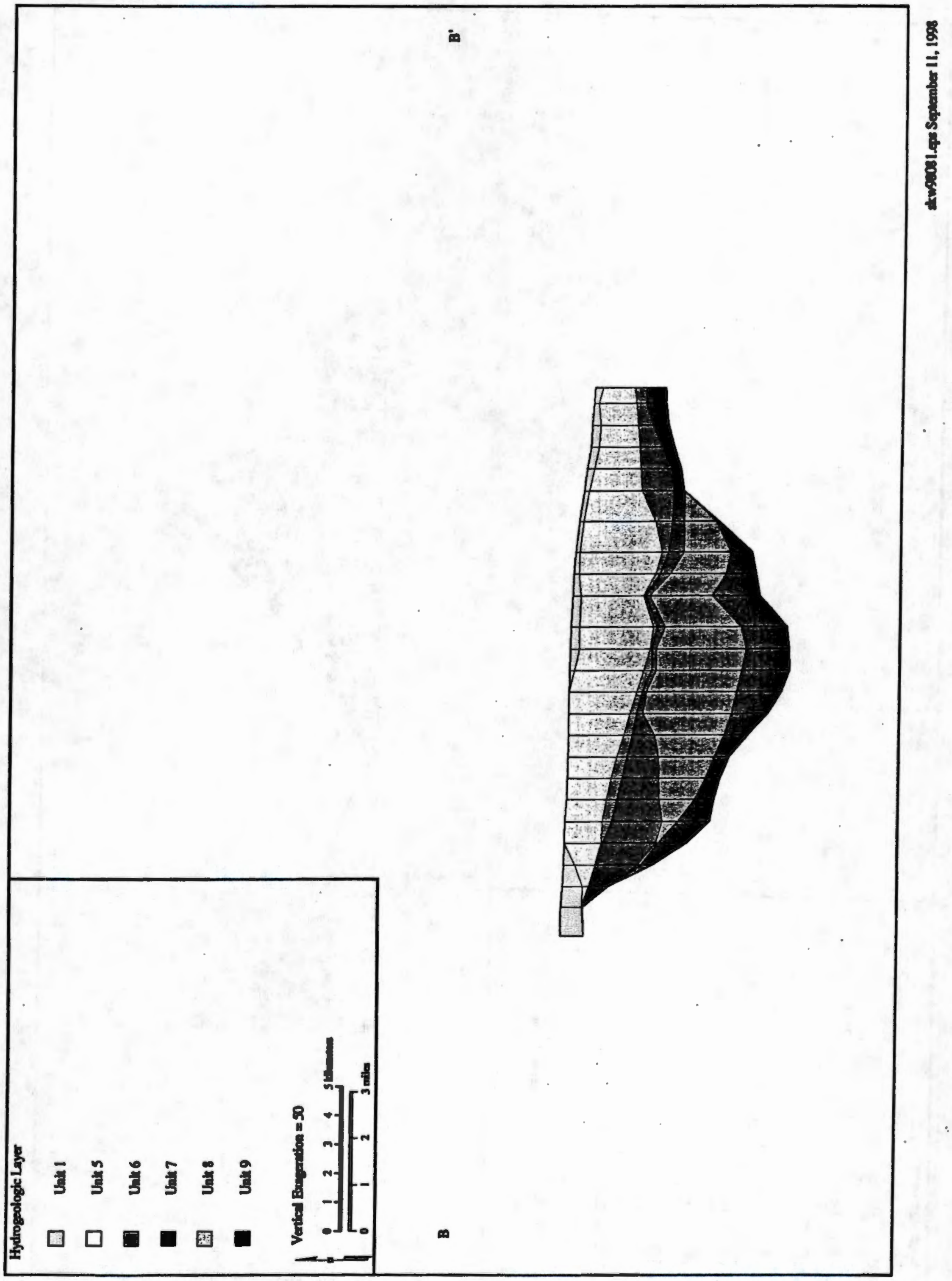

Figure 18. West-East Cross-section B-B', Showing Major Hydrogeologic Units across the Hanford Site in the Three-dimensional Model

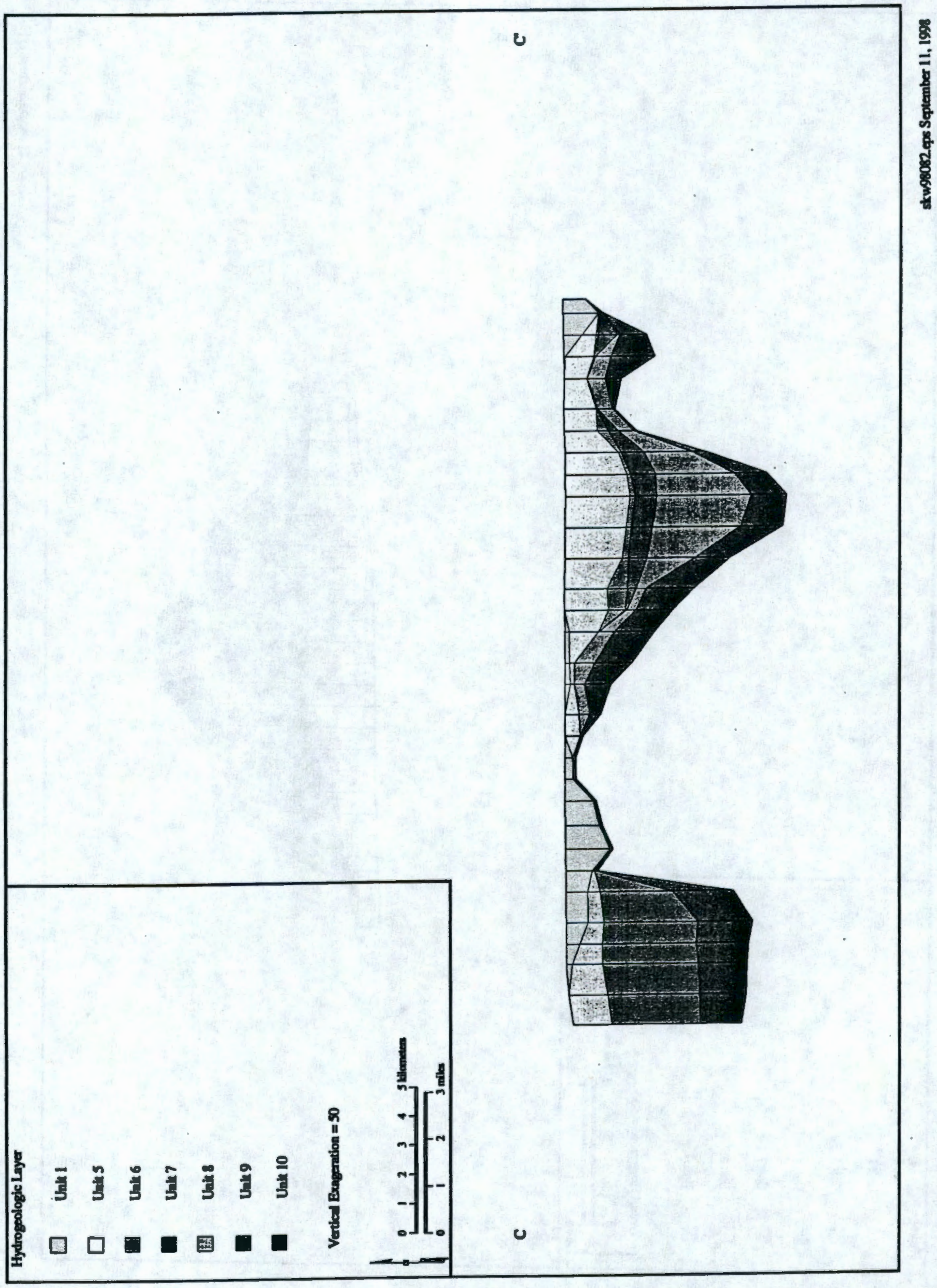

Figure 19. North-South Cross-section C-C', Site Showing Major Hydrogeologic Units across the Hanford in the Three-dimensional Model

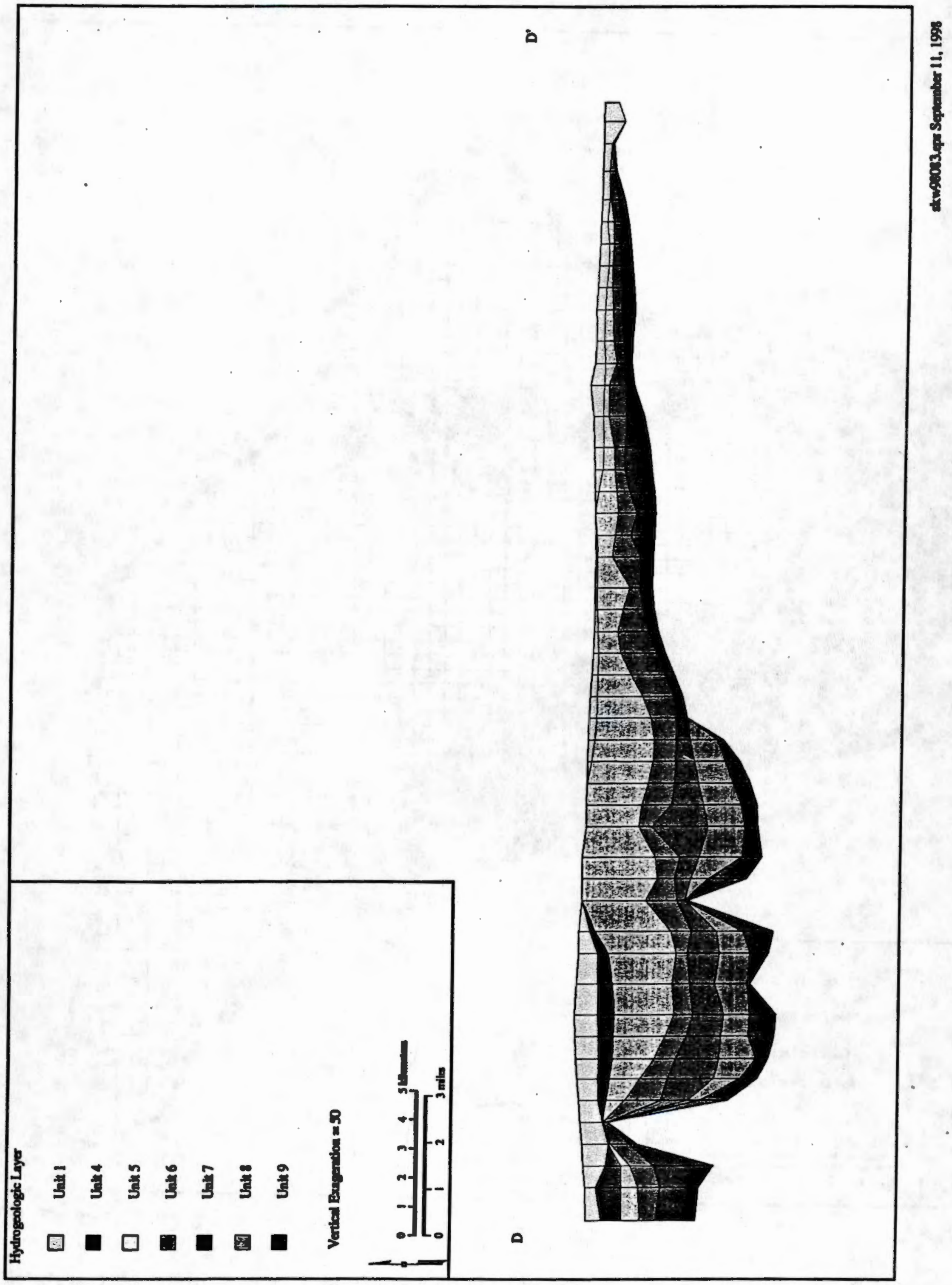

Figure 20. North-South Cross-section D-D', Showing Major Hydrogeologic Units across the Hanford Site in the Three-dimensional Model

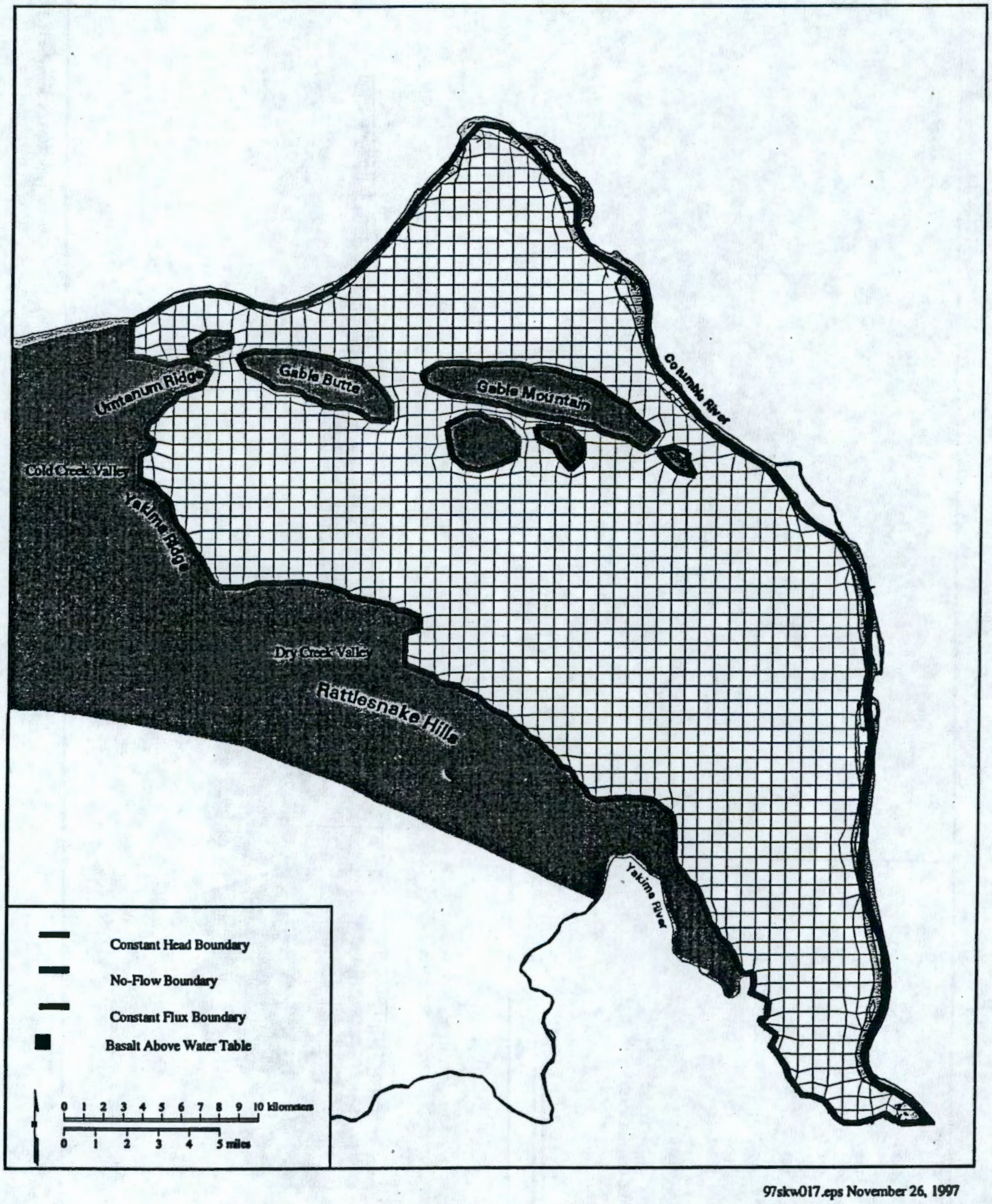

Figure 21. The Surface Finite-element Grid and Boundary Conditions used in the Three-dimensional Flow Model

- Rattlesnake Hills, 1.13×10^6 m^3/yr
- Hanford sources (artificial recharge), 33.5×10^6 m^3/yr
- total (all input fluxes), 44.08×10^6 m^3/yr.

7.2.1.3 Recharge

Both natural and artificial recharge to the aquifer was incorporated in the model. Natural recharge to the unconfined aquifer system occurs from infiltration of 1) runoff from elevated regions along the western boundary of the Hanford Site, 2) spring discharges originating from the basalt-confined aquifer system, and 3) precipitation falling across the site. Some recharge also occurs along the Yakima River in the southern portion of the site. Natural recharge from runoff and irrigation in Cold Creek Valley, upgradient of the site, also provides a source of groundwater inflow. Areal recharge from precipitation on the site is highly variable, both spatially and temporally, and depends on local climate, soil type, and vegetation. The recharge map developed by Fayer and Walters (1995) for 1979, as applied in the model, is provided in Figure 3.1 in Cole et al. (1997).

7.2.1.4 Relationship to Underlying Basalt-Confined Aquifers

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 (Law et al. 1997; Cole et al. 1997; Lu 1996). Therefore, interflow with underlying basalt units was not included in the current three-dimensional model. The basalt was defined in the model as an essentially impermeable unit underlying the sediments. This discussion can be found in Section 2.2.4 of Wurstner et al. (1995) and Section 3.1.1 of Cole et al. (1997).

7.2.2 Model Design and Grid Discretization

An areal depiction of the surface finite-element grid and boundary conditions used in the three-dimensional models of the unconfined aquifer are illustrated in Figure 21. The finite-element grid depicted here is a more regularly spaced grid than has been described in previous reports and used in previous applications. The grid was redesigned to increase the overall effectiveness and efficiency of the three-dimensional model to simulate both flow and transport problems. Most of the interior surface grid spaces are of rectangular shape and are about 750 m on a side. The total number of surface elements used in both the two-dimensional and three-dimensional model is 1606 elements. The three-dimensional model based on this surface grid is made up of 7200 elements (1606 surface and 5594 subsurface elements) and 8465 nodes.

A number of changes have been made to the areal extent of the model, model boundary conditions, and model grid design to reflect the most recent understanding and interpretation of the unconfined aquifer system by the HGWP. The most significant changes incorporated in the current version of the site-wide models were derived from a reinterpretation of the 1979 water-table surface of the unconfined aquifer and the top of the basalt, which led to changes in both internal and lateral boundary conditions, including

- inward movement of the model boundary along Rattlesnake Ridge and the Yakima River to more closely approximate the location where basalt intersects the water-table surface

- changes in the areal extent of the basalt subcrops above the water-table surface in areas south and east of Gable Mountain and northwest of Gable Butte, to more closely approximate the location where basalt intersects the water-table surface.

A more complete discussion of model design and grid discretization can be found in Section 3.0 of Cole et al. (1997).

7.2.3 Flow-Model Development, Calibration, and Results

Before conducting contaminant-transport simulations with the three-dimensional model, the previous steady-state, two-dimensional model of the unconfined aquifer system was calibrated to 1979 water-table conditions with a statistical inverse method implemented in the CFEST-INV computer code Devary (1987). The three-dimensional model was calibrated by preserving the spatial distribution of transmissivity from the two-dimensional inverse modeling. The transmissivity distribution derived from this inverse calibration is shown in Figure 22. A comparison of the calibrated water-table surface using the three-dimensional model and the measured 1979 conditions is provided in Figure 23. A statistical comparison of the difference between the predicted water table and the interpreted water-table surface, summarized on Table 4.2 on p. 4.6 of Cole et al. (1997), provides additional information on the goodness of fit at all 1457 surface-node locations.

Another measure of goodness of fit is a comparison of predicted water-table elevations with those measured in individual wells summarized in Figure 4.7 on p. 4.19 of Cole et al. (1997). The plot for 100 wells shows that predicted water levels were within 1 m of observed water levels at 85 wells and well within 5 m of observed water levels at all wells.

The vertical distribution of hydraulic conductivity at each spatial location was interpreted based on the inverse transmissivity value and the available three-dimensional hydraulic property data that included data on the geologic structure, facies data, and generic property values based on facies descriptions. A complete description of the seven-step process used to distribute the transmissivity distribution derived from the inverse calibration among the major conductive hydrogeologic units is described in Section 4.3 of Cole et al. (1997).

The transient behavior of the three-dimensional flow model was calibrated by adjusting specific yield until transient water-table predictions approximated observed water-table elevations between 1979 and 1996. A comparison of the resulting predicted water table at the end of this period with the observed 1996 conditions is provided in Figure 24. Following the steady state and transient calibrations, the three-dimensional model was applied to predict the future response of the water table to postulated changes in

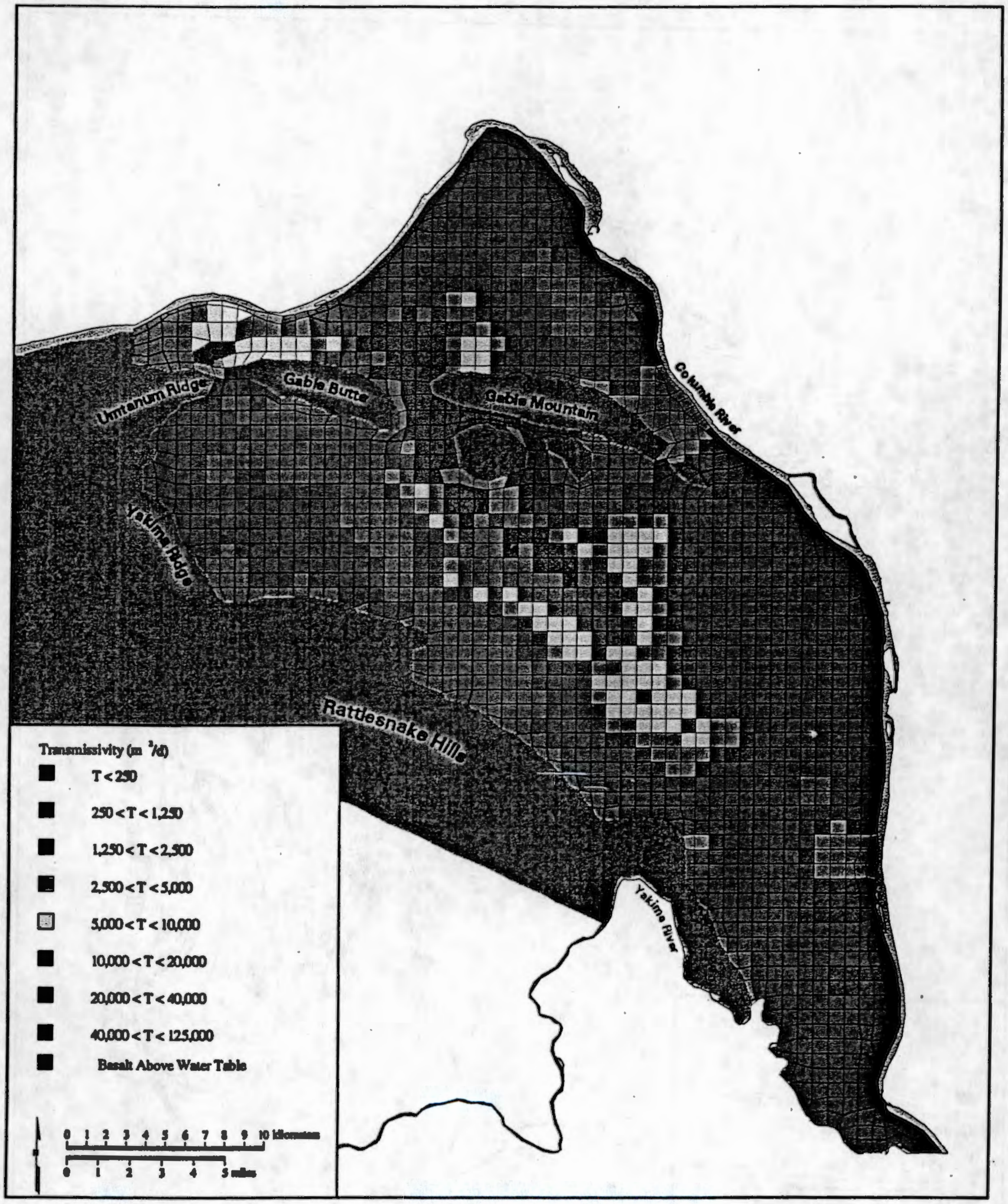

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Figure 22. Transmissivity Distribution Derived from Inverse Calibration of Two-dimensional Model

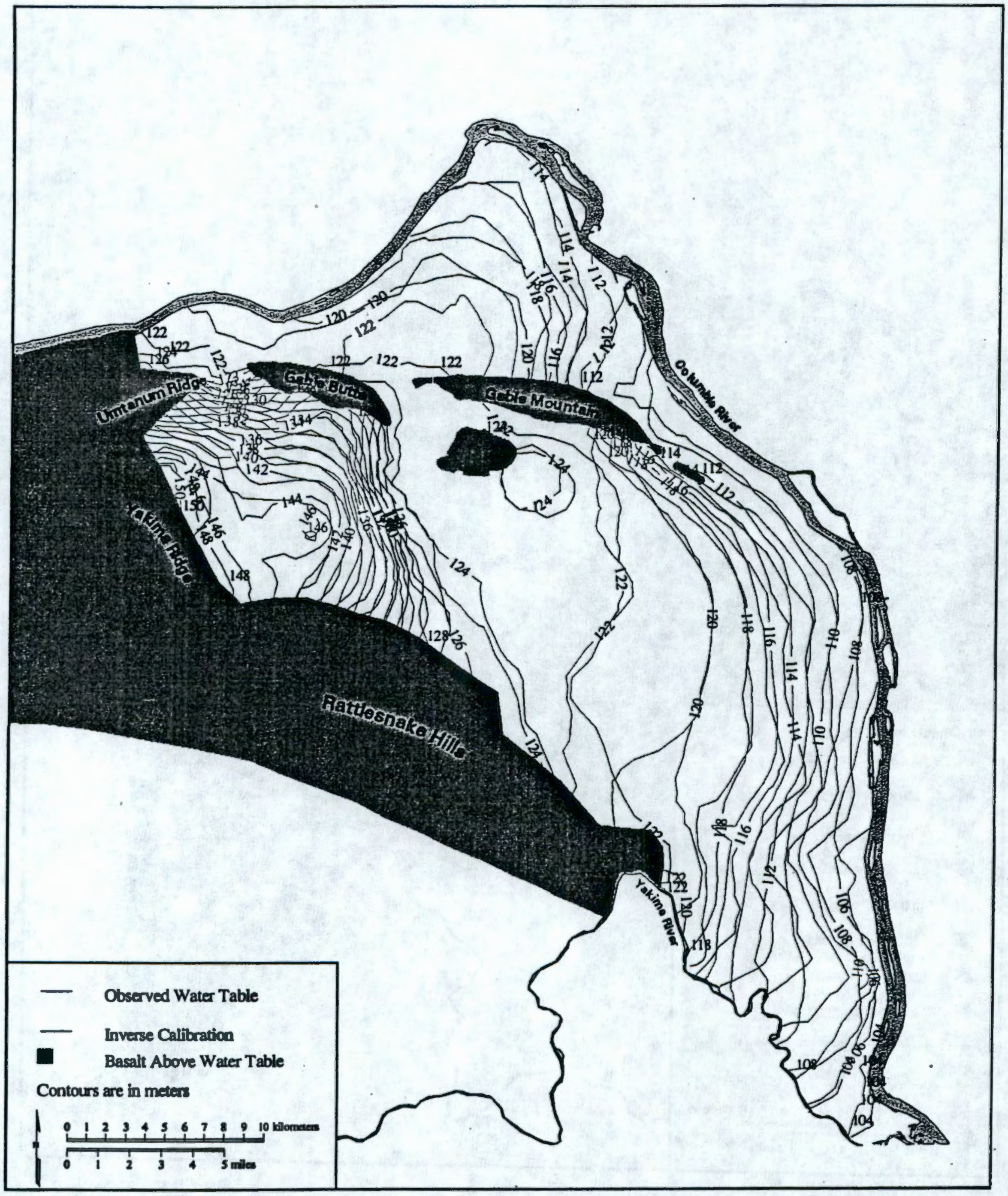

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Figure 23. Comparison of Calibrated Water Table Predicted by Three-dimensional Flow Model and Two-dimensional Model for 1979 Conditions

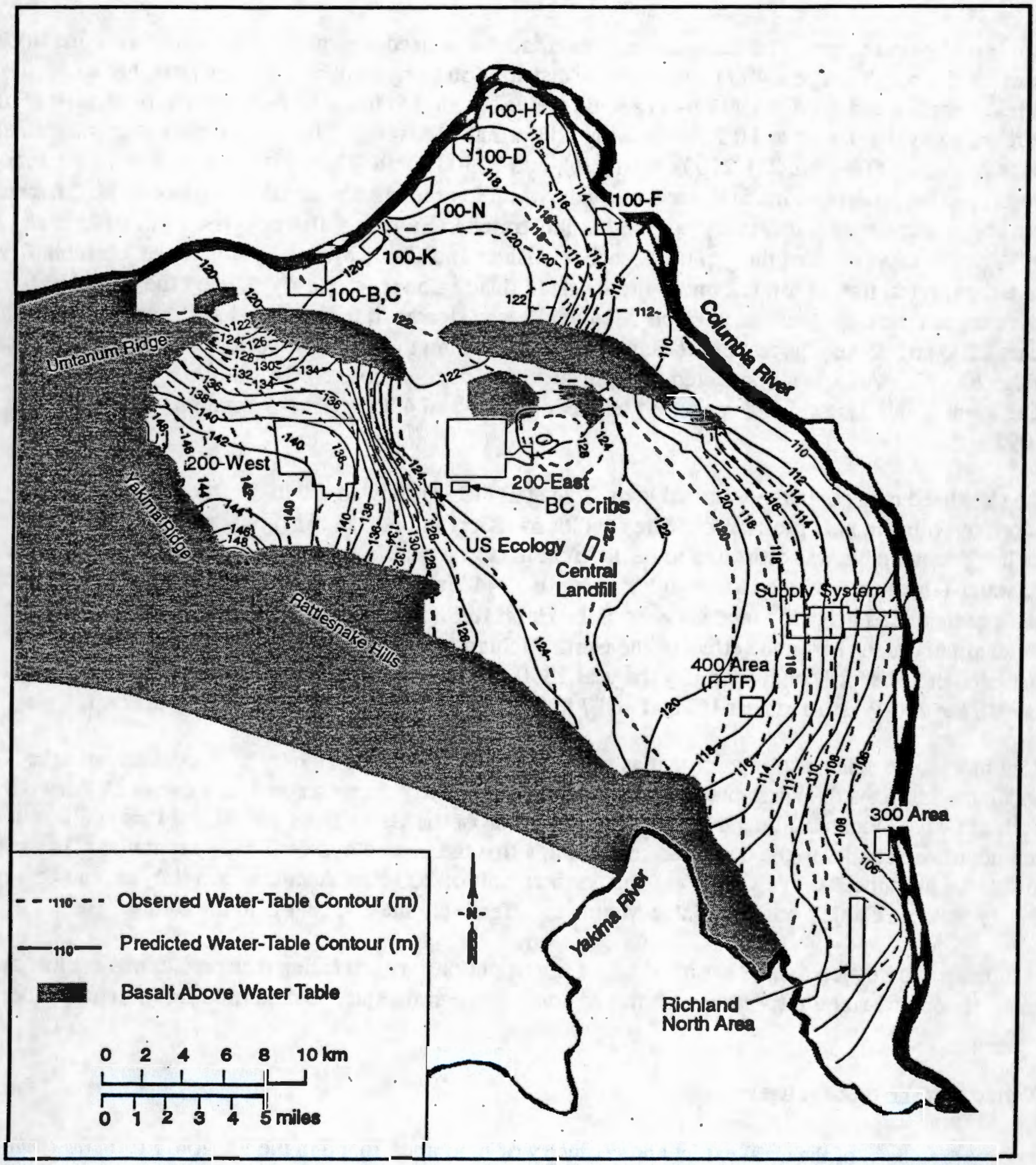

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Figure 24. Comparison of Water Table Predicted by Three-dimensional Flow Model with Observed Conditions for 1996

Hanford Site operations. The three-dimensional model was used to simulate transient-flow conditions from 1996 through the year 4000, based on the distribution of hydraulic conductivity from the steady-state calibration and the distribution of specific yields developed from the transient calibration (0.25 for Hanford formation layers and 0.1 for the Ringold Formation layers). The water table contours estimated for the years 2000 (Figure 25), 2100 (Figure 26), and 2350 (Figure 27) with the three-dimensional model predict an overall decline in the water table and hydraulic gradient across the entire site. The different areas approach steady state at varying rates, as illustrated in Figures 4.10 through 4.14 of Cole et al. (1997). The areas north of the gap between Gable Butte and Gable Mountain along the Columbia River have the shortest time constants, and water levels in this region reach steady state by the year 2100. The area between the Gable Butte and Gable Mountain reach steady-state conditions sometime between the years 2200 and 2300. The rest of the Hanford Site, including the area south of Gable Mountain and east of the 200-West Area, is all predicted to reach steady-state conditions by the year 2350. A complete discussion of this assessment is provided in Section 4.3.1 and 4.3.2 (page 4.9 through 4.12) of Cole et al. (1997).

The simulated changes in the water table by Cole et al (1997) showed it will decline over 200 to 300 years before returning to near pre-Hanford Site conditions (Kipp and Mudd 1974) over most of the site. The predicted water table was estimated to be different in two areas. In the area west of the 200-Area plateau, the water-table was estimated to be higher than pre-1944 Hanford Site conditions because it reflects the effect of increased irrigation in areas west of the Hanford Site. The area north of Richland, where the model simulates the hydraulic effect of the North Richland well field, was also different than the estimated pre-Hanford conditions. By the year 2350, the water table is predicted to drop as much as 11 m beneath the 200-West Area near U Pond and 7 to 8 m beneath the 200-East Area near B Pond.

Flow-modeling results also suggest that as water levels decline in the vicinity of central areas in the model, the saturated thickness of the unconfined aquifer greatly decreases and may eventually dry out south of Gable Mountain along the south-east extension of the Gable Butte anticline. This could cause the unconfined aquifer to the north and south of this line to become hydrologically separated. As a result, flow paths from the 200-West Area and the northern half of 200-East Area that currently extend through the gap between Gable Butte and Gable Mountain, effectively may be cut off in the future.

As indicated in Section 4.1.2, ongoing detailed investigations are indicating that predictions of flow and potential contaminant transport through this region are uncertain and could be influenced by a number of factors:

- interpretations of the top of basalt
- interpretations of the areal extent and geometry of mud units found in the Ringold Formation just east of 200-East Area
- the potential for upward leakage of water from the uppermost confined basalt aquifers
- uncertainty in the amount of recharge that comes into the unconfined aquifer system from the Cold Creek and Dry Creek Valleys
- future offsite and onsite land uses.

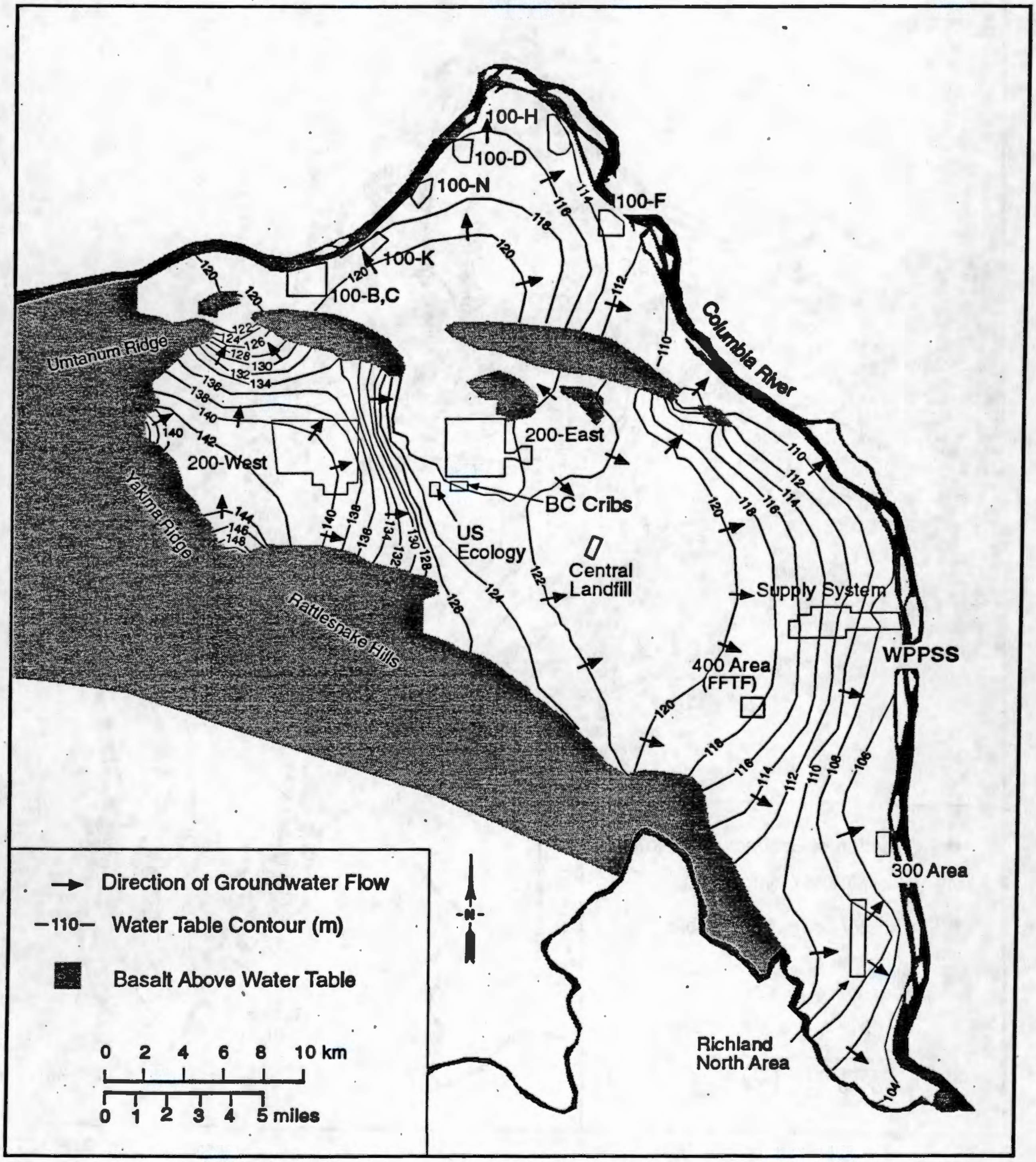

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Figure 25. Water Table Predicted with the Three-dimensional Flow Model in the Year 2000

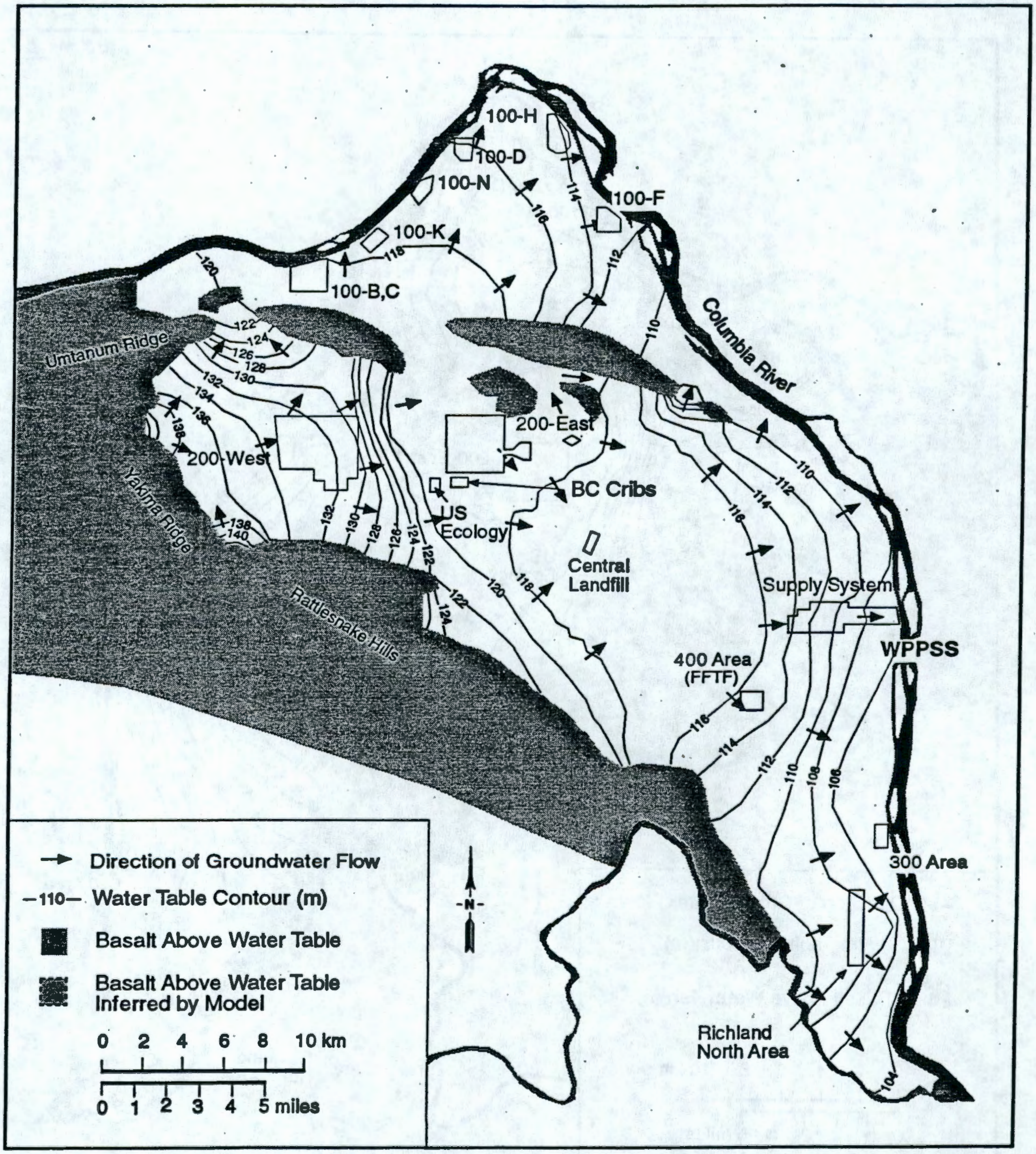

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Figure 26. Water Table Predicted with the Three-dimensional Flow Model in the Year 2100

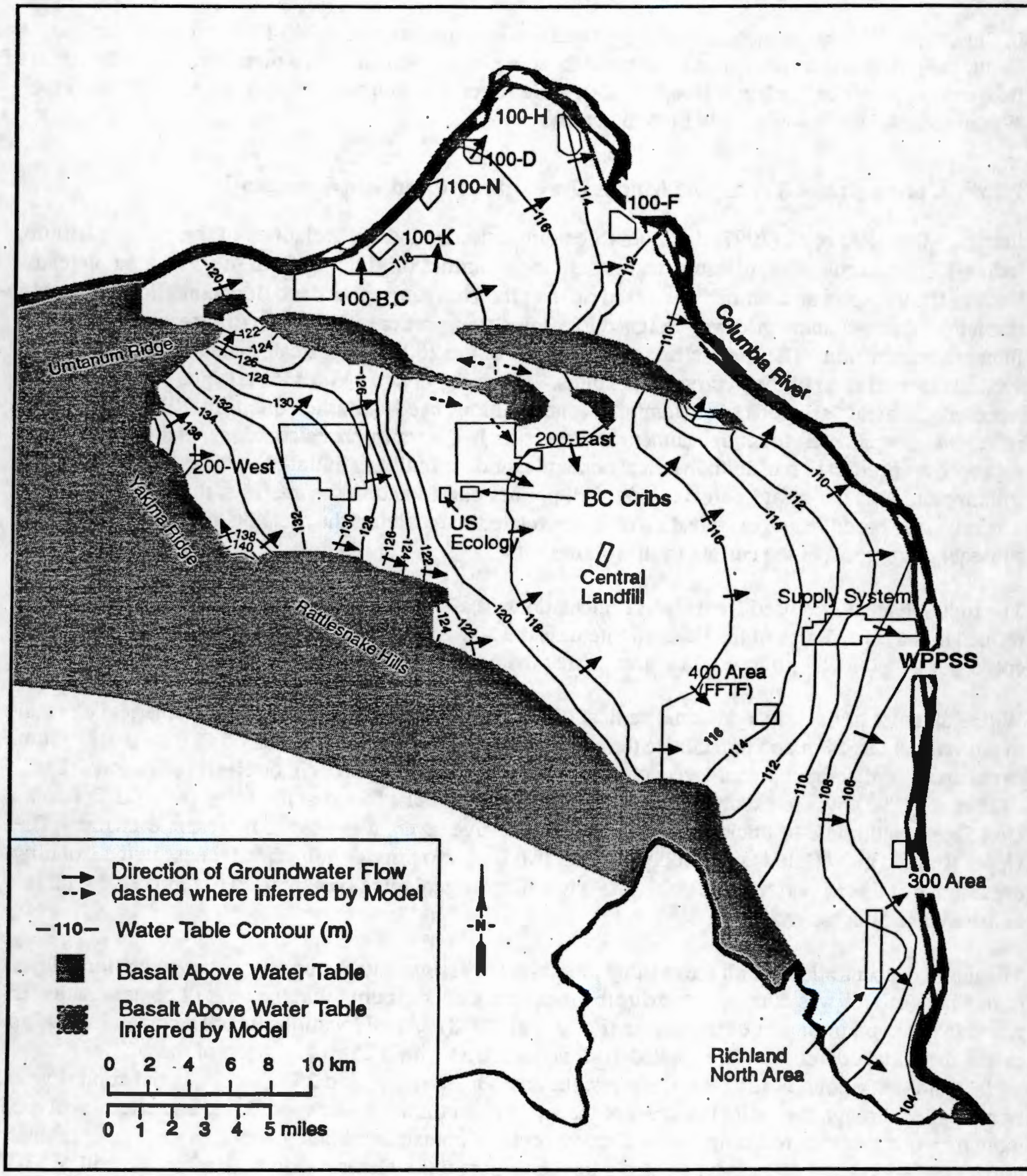

Figure 27. Water Table Predicted with the Three-dimensional Flow Model in the Year 2350

In time, the overall water table, including groundwater mounds near the 200-East Area will decline. As a result, the groundwater movement from the 200-Area plateau will shift to a more west-to-east pattern of flow toward points of discharge along the Columbia River between the old Hanford town site and the Washington Public Power Supply System facility.

7.2.4 Contaminant Transport Model Development and Implementation

Section 5.0 of Cole et al. (1997) describes three-dimensional model simulations of the existing tritium, iodine-129, technetium-99, uranium, and strontium-90 plumes originating from the 200-Area plateau. Each of the transport simulations was based on the predicted future transient-flow conditions and a high-resolution, finite-element grid was designed to resolve transport calculations in the areas of current and future contamination. The finite-element was refined in the 200-Area plateau to add horizontal and vertical discretization of the hydrogeologic units. This was done to 1) provide adequate resolution to represent the areal variations of contaminant concentrations used as initial conditions, 2) more accurately represent flow paths, 3) minimize numerical dispersion in the transport calculations, and 4) allow for appropriate specification of initial vertical contaminant distributions (initial conditions). Because the tritium plume has the greatest areal extent of all plumes considered in the analysis, the grid refinement was primarily based on the examination of issues related to resolving the areal distribution and subsequent transport of the current tritium plume.

The finite-element grid used for transport calculations of all existing plumes (Figure 28) was primarily refined in the central area of the Hanford Site near the 200-Area plateau. In this area, each 750-m grid space was subdivided into four grid spaces so that the final grid resolution was 375 m on a side.

Within all areas of the grid, additional vertical discretization was added to minimize numerical dispersion in the vertical direction and to facilitate the assignment of initial concentrations of all the existing plumes to the uppermost computational layers of the model. The general approach, outlined in Section 5.1 of Cole et al. (1997), was to subdivide the principal hydrologic units found at the water table (Unit 1 and Unit 5) into multiple 8-m-thick layers. A maximum of five layers was used to represent each unit. The Upper Ringold unit (Unit 4) was subdivided into two layers to provide full effectiveness in the isolating capabilities of this important mud unit. The original hydrogeologic layering used to represent all other units remained unchanged.

The initial concentrations of all the existing plumes were assigned to the uppermost computational layers of the model. This was done to approximate the current understanding that the bulk of contamination is found in the uppermost part of the aquifer (Eddy et al. 1978). At all locations where a contaminant plume exists, the initial conditions were applied to all nodes found within 25 m of the top of the aquifer (i.e., initial water-table conditions). In some areas, the aquifer is thinner than 25 m, so the initial conditions were applied through the entire thickness of the aquifer. In finite-element solutions, nodes are involved in more than one element, resulting in the effective depth of contaminant being about 28 m. The combined horizontal and vertical refinement yielded a final transport finite-element grid with a surface grid of 3108 nodes and 2991 elements and a total grid of 23,668 nodes and 23,128 elements.

Transport simulations of both existing plumes and plumes from future sources were based on the previously described three-dimensional flow model. Transient flow conditions were used to provide the basis for all Composite Analysis modeling transport predictions.

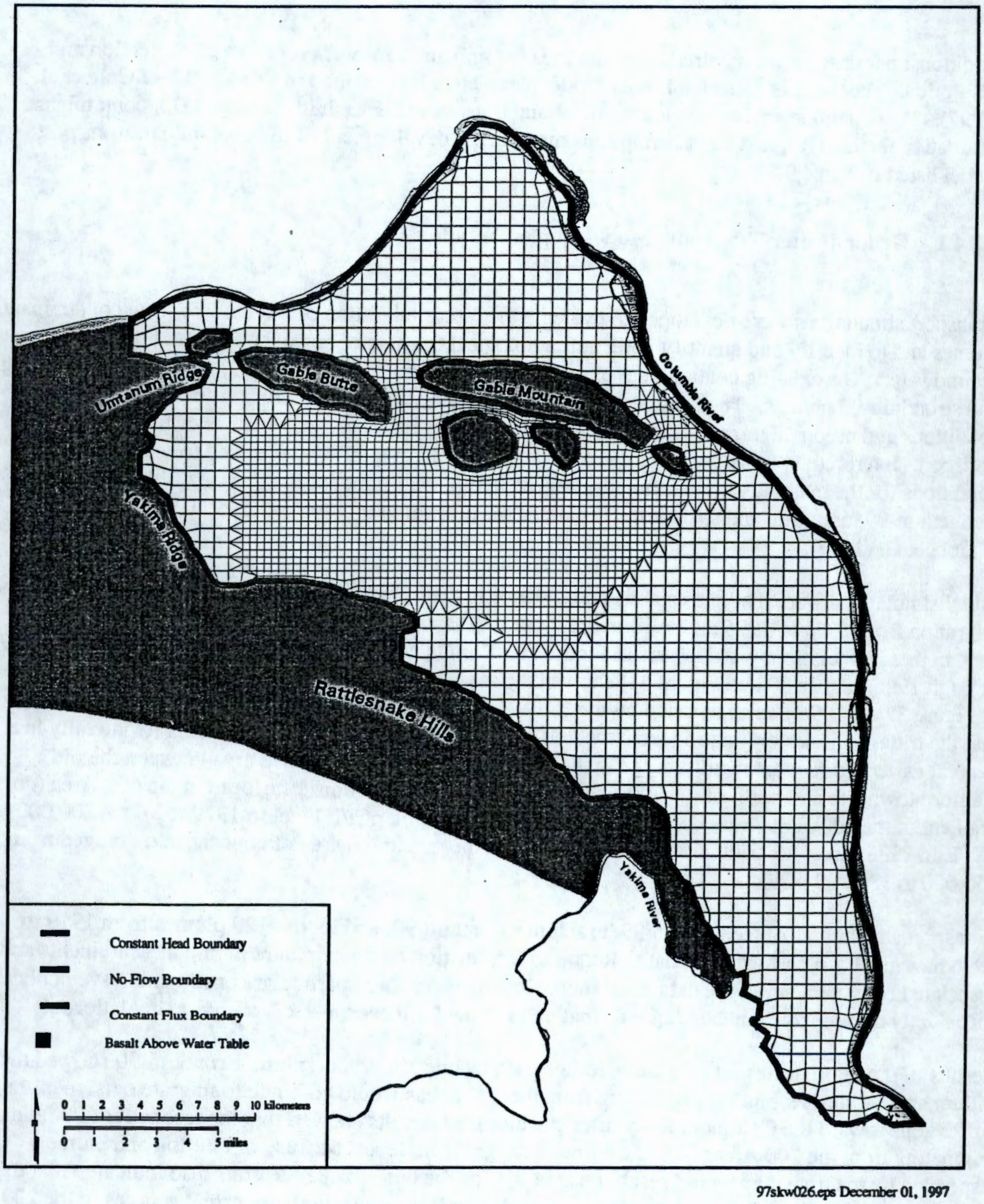

Figure 28. The Surface Finite-element Grid and Boundary Conditions used in the Three-dimensional Transport Model

Additional parameters are required to model the contaminant transport processes of dispersion and adsorption. The basis of these additional model parameters is described in Section 3.2 of Cole et al. (1997). These parameters include longitudinal and transverse dispersivities (D_l and D_t), contaminant retardation factors (R_f), and key assumptions made in the development of the contaminant-transport model listed in Table 9.

7.2.4.1 Groundwater Transport Model Implementation

Transport simulations were developed to evaluate the future migration of selected existing contaminant plumes and to identify and quantify potential radiological impacts of onsite and offsite use of groundwater. The existing contaminant plumes included the tritium, iodine-129, technetium-99, uranium, and strontium-90 plumes. The transport simulations were based on the predicted future transient flow conditions and used a high-resolution finite-element grid designed to resolve areas of future plume transport. Interpreted plume maps for 1996 (Hartman and Dresel 1997) were used to represent initial conditions for the existing plume simulations. The initial conditions for the existing tritium, iodine-129, technetium-99, uranium, and strontium-90 plumes are illustrated in Figures 5.5, 5.10, 5.15, 5.20, and 5.25 of Cole et al. (1997).

Initial simulations were made to establish confidence in the transport model by simulating tritium plume migration from 1979 to 1996 and to compare those results with observed conditions. Initial conditions used in these simulations are depicted in Figure 29. Results of tritium transport for the period from 1979 through 1996 (Figure 30 and Figure 31) showed the same overall trends of contaminant migration shown in Figure 32 for 1996 and as reported by the HGWP (Hartman and Dresel 1997). Model results showed that the tritium plumes originating from the 200-East and 200-West Areas slowly migrate laterally in a general easterly direction and discharge to the Columbia River along a broad area between the old Hanford town site and north of the 300 Area. Maximum concentrations of tritium in the 600 Area (down-gradient of the 200-East Area) declined from over the 2-million pCi/L level in 1979 to above 200,000 pCi/L in 1996. In 1996, tritium levels in wells within the maximum area of concentration ranged from 150,000 to 180,000 pCi/L.

Transport simulations of technetium-99, uranium, strontium-90, and iodine-129 plumes from 1979 to 1996 have not been performed to date. Required information on contaminant plume measurements and associated contaminant release data from source locations for these particular constituents have not been sufficiently developed from existing information to allow for these types of transport simulations.

Results of the future transport of tritium, iodine-129, technetium-99, uranium, strontium-90 showed that tritium and iodine-129 plumes originating from the 200 Areas would continue to migrate outside of the buffer zone toward the Columbia River after site closure. Results showed that the technetium-99 plumes originating from the 200 Areas would decline to insignificant levels because of dilution and plume dispersion by the time they would reach the area outside the buffer zone. Results also indicated that the uranium and strontium-90 plumes would not migrate significantly from their current sources in the 200 Areas because of the process of adsorption. A complete description of these simulations is provided in Section 5.0 of Cole et al. (1997).

Table 9. Key Assumptions Made in the Development of the Contaminant Transport Model

Assumption	Rationale	Impact
The unconfined aquifer system, overlying the basalt, can be adequately represented by nine hydro-stratigraphic units.	Flow of water (and transport of radionuclides) is assumed to occur in three dimensions. Nine hydro-stratigraphic units are considered adequate to represent flow in this unconfined aquifer system over a wide range of conditions. Nine units are supported by available hydrogeologic data and represent all major and areally extensive conductive and nonconductive hydrogeologic units above the basalt.	Additional units would better represent local flow conditions and hydrogeology. However, data are not currently available to improve this interpretation on a site-wide basis and other uncertainties could nullify the effect of this improvement. Additionally, simulation times would be adversely affected.
Natural recharge is variable across the Hanford Site and is included as a surface condition in the flow (and transport) model.	Variability of recharge across the Hanford Site is based on the distribution of surface cover, ranging from natural shrub-steppe vegetation to gravel surfaces in some of the 200 Areas. The differences in recharge based on surface cover have been well documented for the Hanford Site (Fayer and Walters 1995).	The surface recharge affects the flow model calibration by adding water to the system. The result is a distribution of higher hydraulic conductivity than would occur without recharge. Recharge affects the transport model by diluting the contaminant plumes and driving the maximum plume concentrations below the surface nodes.
The Columbia River is treated as a constant head boundary using hydraulic heads for 1979 to represent the long-term average conditions.	Performing simulations with transient river stage boundary conditions would not be appropriate since the inland areas that are the focus of a site-wide analysis are not greatly affected by river stage variations because they damp out before they reach the 200 Areas. Additionally, how the future river stage might vary is not known, and it would be too costly computationally at the Hanford Site-wide scale of the Composite Analysis.	Including the highly variable river stage conditions in the Hanford Site-wide Composite Analysis model would not affect the long-term results.

Table 9. (contd)

Assumption	Rationale	Impact
Post-Hanford conditions do not include large-scale irrigation impacts.	The prospect of large-scale irrigation occurring on the Hanford Site is unlikely for the following reasons: • Public acceptance of food products grown on the Hanford Site, regardless of the actual risk associated with agricultural development is uncertain. • Sufficient water rights within the Columbia Basin for development of crops requiring large-scale irrigation on the Site are unavailable. If agriculture should develop on the Hanford Site, it is likely that the crops to be planted will use the efficient and focused irrigation methods (e.g. drip irrigation) that are used in fruit orchards or vineyards. • New technologies and advanced resource management practices will likely eliminate or significantly curtail over-irrigation of crops.	The impact of this assumption can be significant depending on the scenario that is used. Previous site-wide analyses such as the Hanford Defense Waste Environmental Impact Statement (DOE 1987) included significant agricultural irrigation scenarios, which can alter the overall flow system in the unconfined aquifer and control the direction and rate of groundwater flow and contaminant transport.

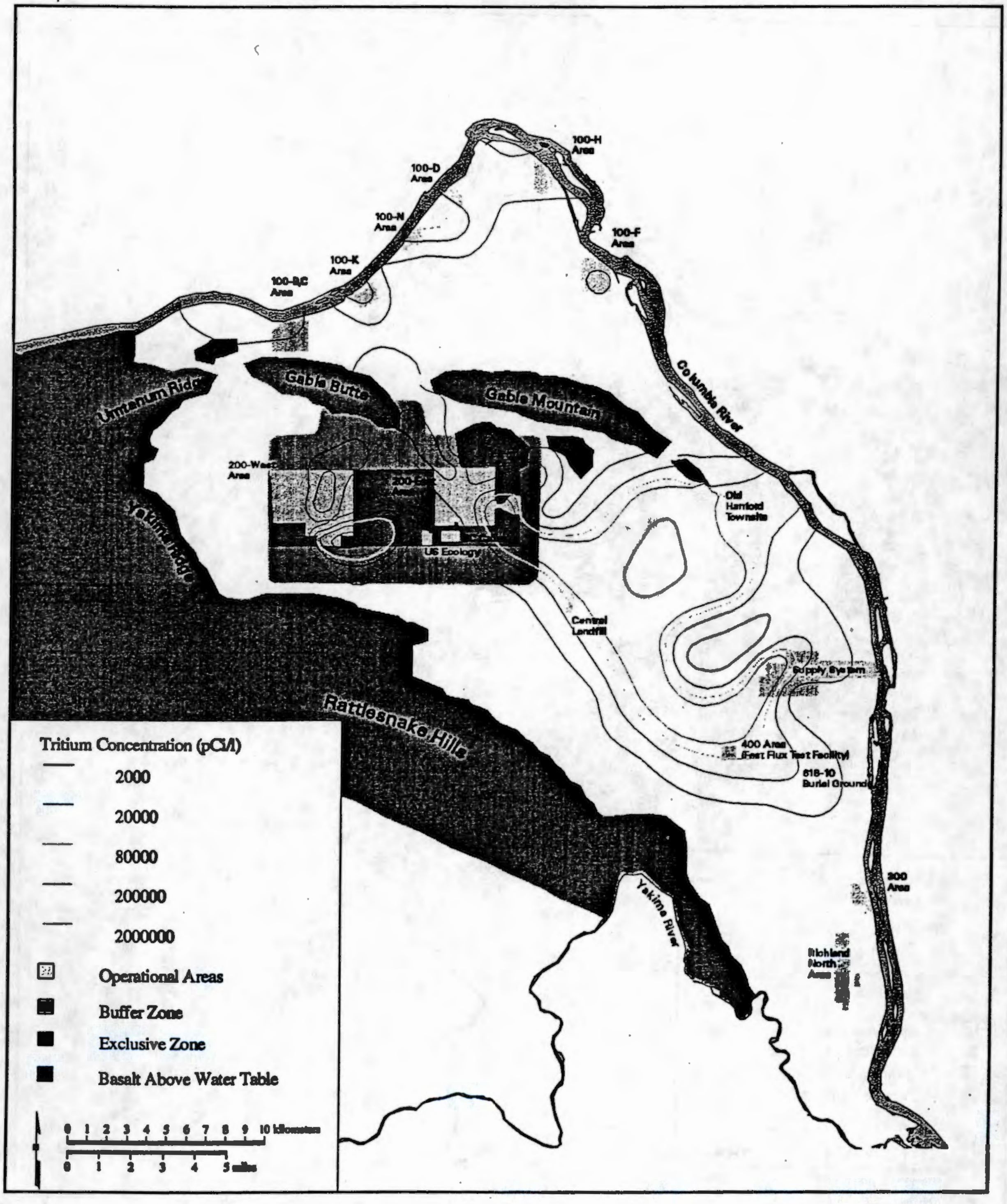

Figure 29. Initial Conditions Used for Tritium Plume Transport to Represent 1979 Conditions

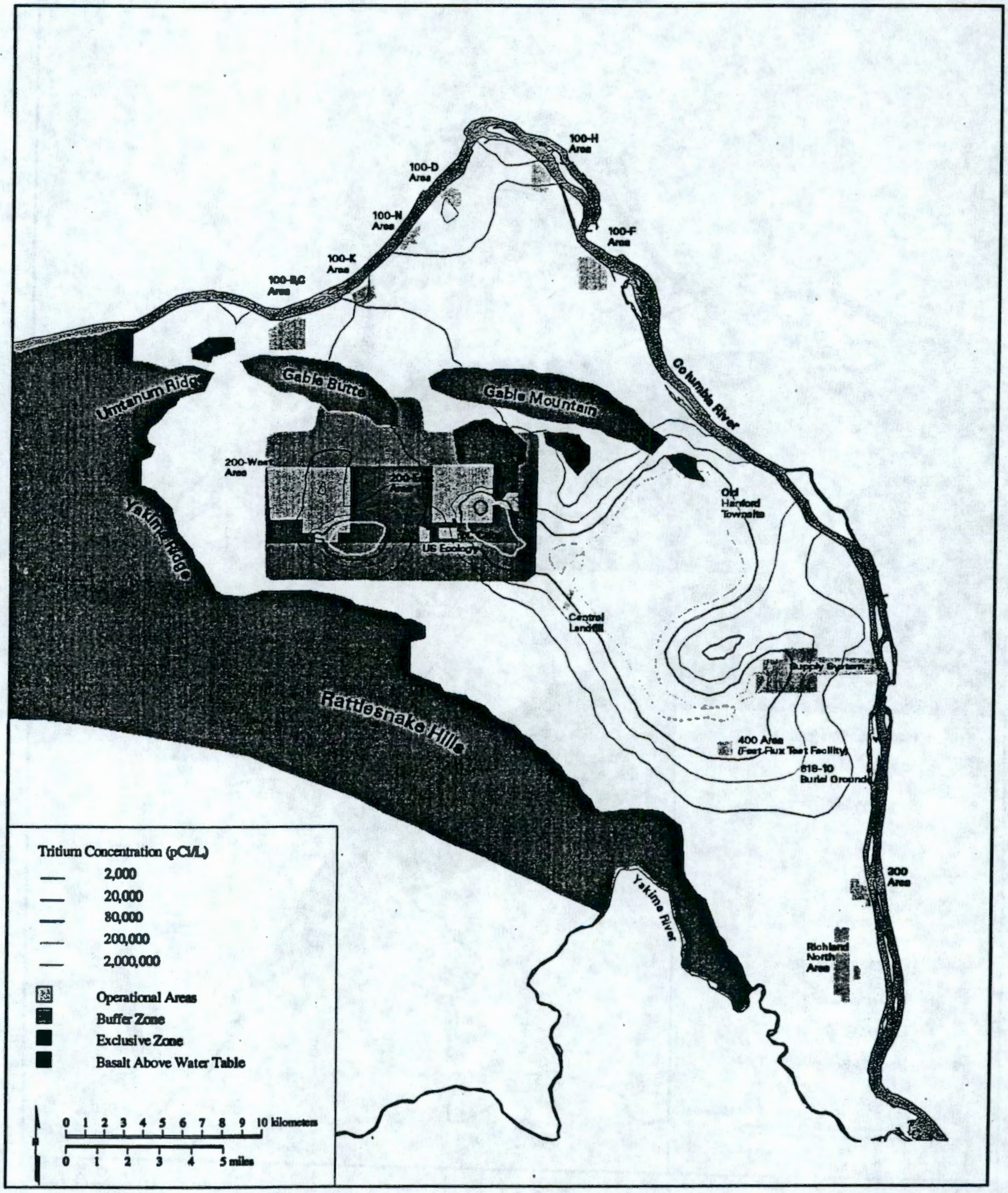

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Figure 30. Tritium Plume Transport Predicted by the Three-dimensional Flow Model for Year 1985

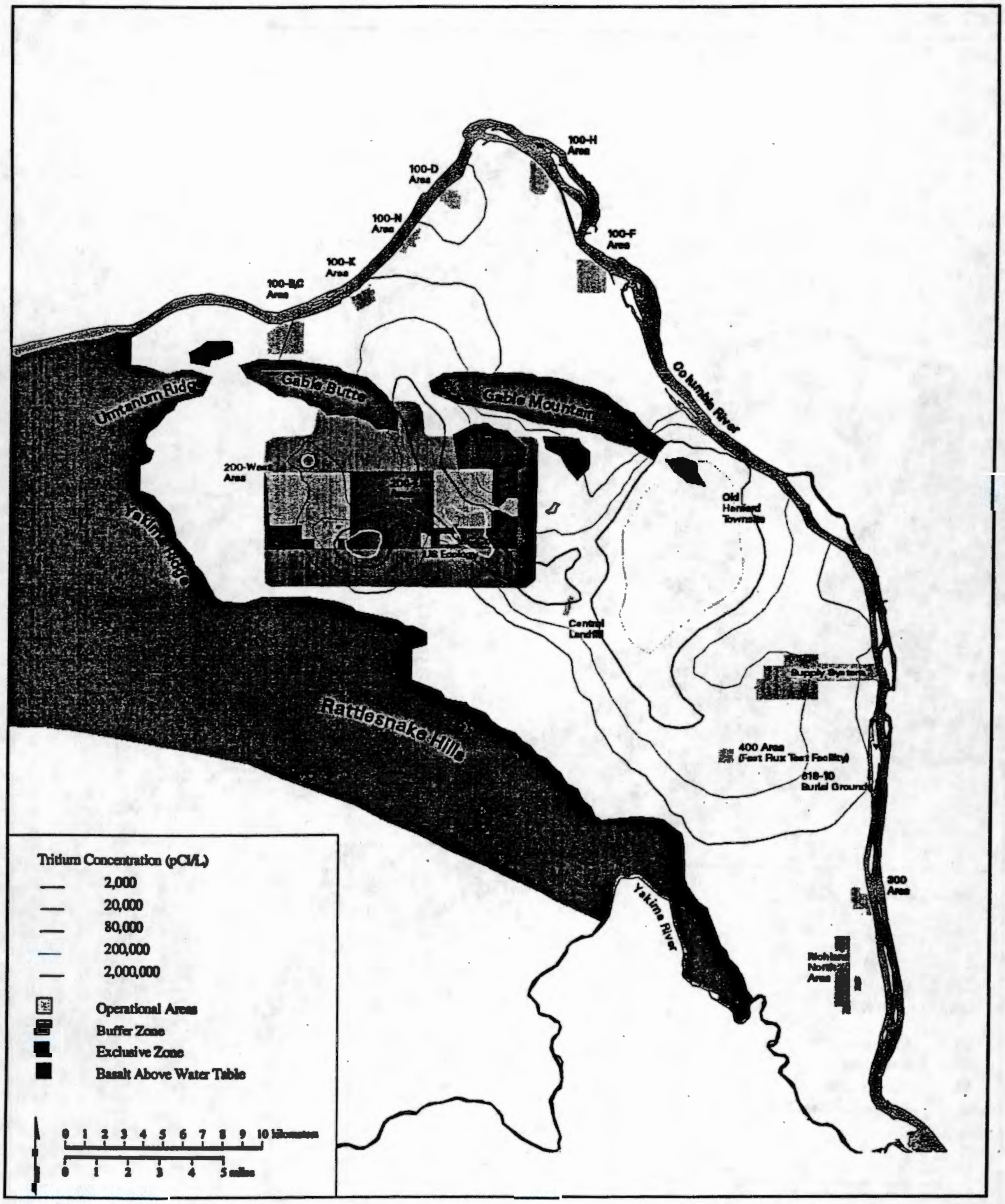

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Figure 31. Tritium Plume Transport Predicted by the Three-dimensional Flow Model for Year 1996

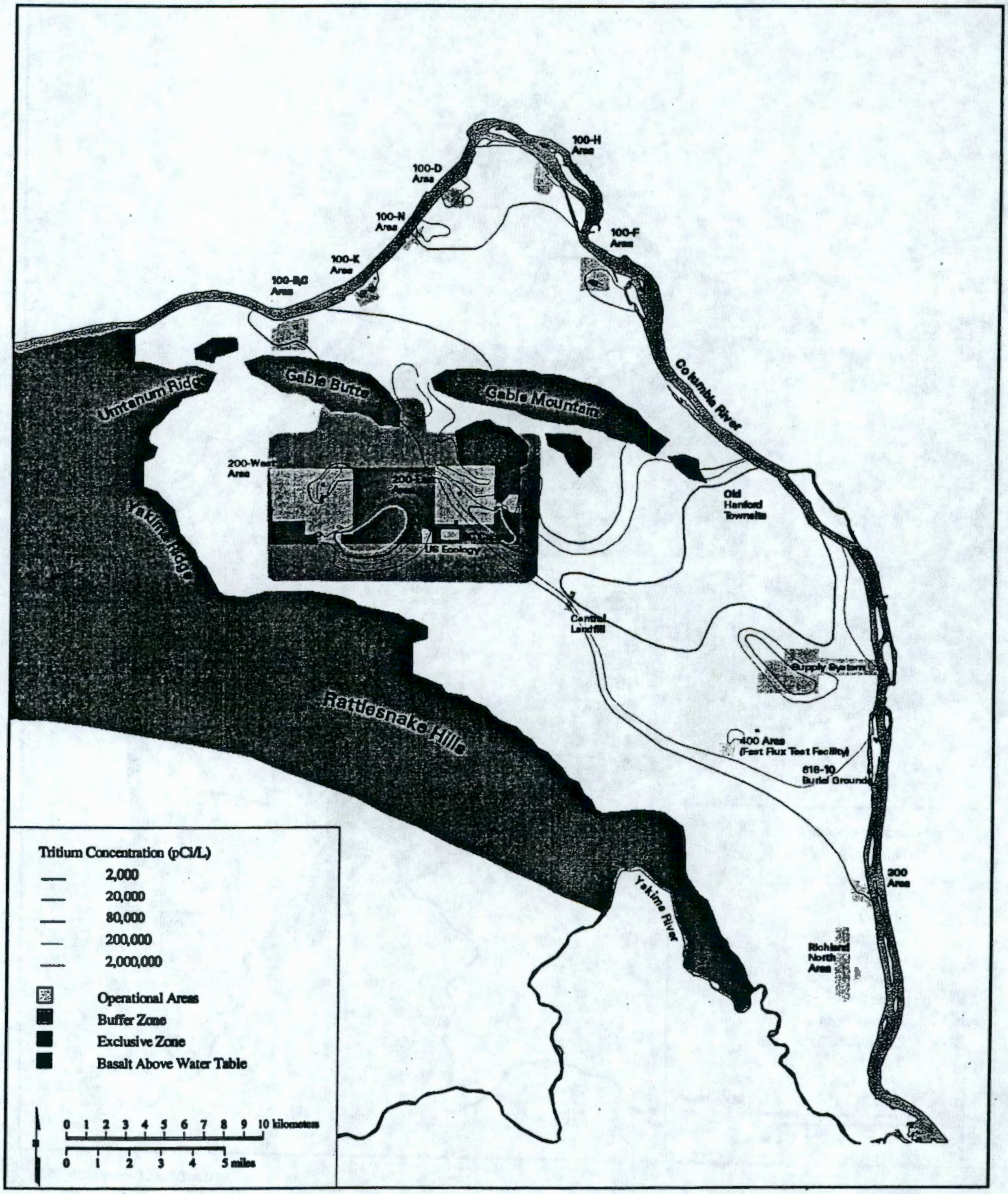

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Figure 32. Observed Tritium Plume in 1996

In general, the results of transport analyses of tritium, iodine-129, technetium-99, and uranium with the three-dimensional model are in agreement with comparable site-wide modeling results obtained by Chiaramonte et al. (1997) (see Figures 4-2 through 4-6; Figures 4-19 through 4-23, and Figures 4-95 through 4-99 in Chiaramonte et al. [1997]). However, transport results by Cole et al. (1997) resulted in higher estimates of peak concentrations at the water table that were predicted in Chiaramonte et al. (1997). These differences are attributable to differing assumptions regarding initial conditions for the plumes and the hydrogeologic framework and the horizontal and vertical discretization used in each model. The differences in assumptions resulting from each modeling approach affected the lateral and vertical distributions of predicted hydraulic heads and contaminants in the unconfined aquifer. To date, a detailed comparison of these two models has not been done.

In the Composite Analysis of the 200-Area plateau documented in Kincaid et al. (1998), the transport of future contaminant releases to the unconfined aquifer for source areas in the exclusive waste management area was evaluated to examine the future movement of contaminant plumes resulting from these releases to areas outside of the buffer zone. Radionuclides evaluated include future releases of technetium-99, iodine-129, carbon-14, chlorine-36, selenium-79, and uranium.

Results of these analyses indicate that the most of radionuclide inventory in past-practice liquid discharge and solid-waste burial sites on the 200-Area plateau will be released in the first several hundred years following Hanford Site closure. The analysis also indicated that a significant fraction of the inventory would be released before closure. The resulting maximum predicted agricultural dose outside of the buffer zone surrounding the exclusive waste-management area (see Figure 3) was less than 6 mrem/yr in the year 2050 and declined thereafter. The largest portion of the dose was attributable to intake of groundwater containing tritium and iodine-129 from existing plumes. The maximum doses estimated for residential, industrial, and recreational scenarios, were 2.2, 0.7, and 0.04 mrem/yr, respectively, at 2050 and also declined in subsequent years. A more complete description of these simulations is provided in Kincaid et al. (1998).

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8.0 Summary of Technical Issues and Concerns on Proposed Needs and Requirements for the Consolidated Site-Wide Groundwater Model

8.1 Overview

This section provides a summary of technical issues and concerns raised by representatives of regulatory agencies (EPA and Ecology), and Tribal Nations (the NPT and the YIN) at a technical representative's workshop on the site-wide groundwater consolidation process and in follow-up discussions. Meeting minutes of the workshop with the agenda, copies of the viewgraph materials and attendee list, and written concerns and issues provided by regulators and Tribal representatives following the workshop are included in Appendix B of this report.

The technical issues and concerns raised by the Peer Review Panel on the consolidated site-wide groundwater model are incorporated into this summary. This external peer review panel was cognizant of the technical issues and concerns provided by the representatives of regulatory agencies and Tribal Nations in preparing their report. The full report of the Peer Review panel is included in Appendix E of this report.

Table 10 briefly lists the primary technical issues and concerns, and indicates specific references within Appendix B and Appendix E where the relevant comments can be found that relates to a specific issue or concern.

8.2 Flow and Transport Processes

Technical issues and concerns related to the treatment of flow and transport processes in the site-wide groundwater model are summarized here. Flow and transport process categories include adsorption, decay, dispersion, diffusive mass transfer, and reactive transport.

8.2.1 Adsorption

Distribution coefficients (K_d) are used to represent the retardation of contaminants due to sorption. The use of a retardation approach precludes use of the model for prediction of the behavior of the majority of contaminants of concern at the Hanford Site. For applications involving the migration of tritium through the aquifer, the chemical processes in the site-wide groundwater model (decay and no sorption) are adequate. For other contaminants, such as carbon tetrachloride, the model may provide reasonable predictions if no volatilization occurs, water quality is nearly constant, and the chemistry can be represented by first-order decay and linear sorption. In any application of the site-wide groundwater model, justification of the engineering approach to retardation is needed.

This issue is also summarized in Section 8.4.5 (Distribution Coefficient).

Table 10. Index to Technical Issues and Concerns.

Technical Issues and Concerns	Regulator / Stakeholder (Appendix B)	Peer Review Panel (Appendix E)
8.2 Flow and Transport Processes		
8.2.1 Adsorption • Use of the retardation approach to transport modeling limits the model to first-order decay and linear sorption cases: other uses would require justification.		*Representation of Contaminant Chemistry* Recommendation, paragraphs 1:2, page 6.
8.2.2 Decay • Incorporate radioactive chain-decay capability	EPA Comments on Preliminary Draft, comment 2.	
8.2.3 Dispersion • Need to explicitly recognize that the concentrations produced by the site-wide groundwater model do not represent local values when using large field-scale dispersivities.		*Dispersivity (and Mixing Versus Spreading)* Recommendation, paragraph 4, pages 7:8.
8.2.4 Diffusive Mass Transfer • Recommend modifying model and code to include diffusive mass transfer between immobile and mobile domain.		*Representing Diffusive Mass-Transfer* Recommendation, page 8.
8.2.5 Reactive Transport • Consideration should be given to adding the capability to model interactions between chemical contaminants.	Summary of Key Technical Comments and Issues, *Comments on Scope, Schedule, Process, Needs, and Requirements,* paragraphs 4:5, page B.5 EPA Comments on Hanford Site-Wide Groundwater Model, *Conceptual Model: Transport Properties,* bullet 2. EPA Comments on Preliminary Draft, comment 2.	*Executive Summary,* point 4, bullet 2, page ES-2.
8.3 Model Domain		
8.3.1 Boundaries • General concern that all boundary conditions need to be re-inspected due to inconsistencies.		*Executive Summary,* point 4, bullet 4, page ES-2.
8.3.1.1 Lateral Boundaries • Lateral extent of the site-wide groundwater model needs to be better justified.		*Executive Summary,* point 4, bullet 3, page ES-2.
8.3.1.1.1 Cold Creek, Dry Creek, and Rattlesnake Springs • Boundary fluxes at Cold Creek, Dry Creek, and Rattlesnake springs based on present-day conditions; these are likely to change in the future. • Concern about the vertical flux distribution and it is applied: some rationale for the distribution is required.	EPA Comments on Hanford Site-Wide Groundwater Model, *Numerical Implementation: Translation of Conceptualization,* bullet 5.	*Boundary Fluxes* Recommendation, paragraph 1, page 6.

Table 10. (contd)

Technical Issues and Concerns	Regulator / Stakeholder (Appendix B)	Peer Review Panel (Appendix E)
8.3.1.1.2 Columbia River • Approach of using the centerline of the Columbia River as a line of symmetry given that the heads in the aquifer are so much greater on the Franklin County side. • Consideration should be given to using head-dependent flux boundaries at the Columbia River rather than the specified-head boundaries. • Use of median river stages may yield much different predictions of flow-system dynamics than would be computed with actual river stages. • Specified head boundary along Columbia River is adequate for large-scale applications, but inadequate for small-scale sites near the river or short-term analyses affected by the river. • If head is specified at the Columbia River boundary, it should be specified only at the upper boundary of the aquifer, not over its entire thickness.	Summary of Key Technical Comments and Issues, *Comments on Numerical Implementation*, paragraph 3, pages B.6:B.7. EPA Comments on Hanford Site-Wide Groundwater Model, *Conceptual Model: Aquifer Boundaries*, bullets 1:2. EPA Comments on Hanford Site-Wide Groundwater Model, *Numerical Implementation: Translation of Conceptualization*, bullets 1:2. EPA Comments on Preliminary Draft, comments 5, 6.	*Boundary Conditions* Recommendation, page 6.
8.3.1.1.3 Yakima River • For some cases, consider using head-dependent flux boundaries at the Yakima River rather than specified-head boundaries.	Summary of Key Technical Comments and Issues, *Comments on Numerical Implementation*, paragraph 3, page B.7. EPA Comments on Hanford Site-Wide Groundwater Model, *Numerical Implementation: Translation of Conceptualization*, bullet 1.	*Boundary Conditions* Recommendation, page 6.
8.3.1.1.4 No-Flow Lateral Boundaries • Significant internal boundary fluxes exist and are not considered. • Stronger rationale required for no-flow boundaries.		*Boundary Fluxes* Recommendation, paragraph 1, pages 6:7.
8.3.1.2 Upper Boundary • Does the vadose zone need to be included in the site-wide groundwater model?	Summary of Key Technical Comments and Issues, *Comments on Scope, Schedule, Process, Needs, and Requirements*, paragraph 8, page B.6.	
8.3.1.2.1 Natural Recharge • Applicability of present-day estimates of recharge in long-term simulations of unconfined aquifer behavior should be justified. • Evapotranspiration from water table near rivers and ponds not included in the conceptual model. • The effect of macropore recharge has not been considered in current estimates of recharge. • Spatial variability of recharge should be treated geostatistically. • PNNL should develop a strategy to represent the spatial distribution of recharge for a range of climatic conditions, consequent vegetation, and antecedent soil-moisture conditions.	EPA Comments on Hanford Site-Wide Groundwater Model, *Conceptual Model: Aquifer Boundaries*, bullet 2. EPA Comments on Hanford Site-Wide Groundwater Model, *Conceptual Model: Recharge*, bullet 2.	*Executive Summary*, point 4, bullet 5, page ES-2. *Recharge* Recommendation, page 7.
8.3.1.2.2 Artificial Recharge • Was evapotranspiration considered in estimating artificial recharge at disposal ponds? • It is unclear how artificial recharge in the Richland area (from infiltration from ponds, agricultural and residential irrigation, and disposal of wastewater at the potato-processing plant) has been represented in the model.	EPA Comments on Hanford Site-Wide Groundwater Model, *Conceptual Model: Recharge*, bullets 1 and 3.	

Table 10. (contd)

Technical Issues and Concerns	Regulator / Stakeholder (Appendix B)	Peer Review Panel (Appendix E)
8.3.1.3 Lower Boundaries • The potential for recharge to unconfined aquifer from the upper basalt confined aquifer should be investigated. • Further justification, beginning with the conceptual model, is required for the treatment of the lower boundary between the basalts and the alluvial material at the base of the model.	Summary of Key Technical Comments and Issues, *Comments on the Conceptual Model*, paragraph 4. EPA Comments on Hanford Site-Wide Groundwater Model, *Conceptual Model: Interaction with Basalt Confined Aquifer*, bullet 1.	*Boundary Fluxes* Recommendation, paragraph 2, pages 6:7.
8.3.2 Hydrogeologic Structures		
8.3.2.1 Major Units (Lithologies) • Large-scale heterogeneity: Only large-scale features and differences in major hydrostratigraphic units are captured. • Data get sparse with depth: how will the model deal with this increasing uncertainty? • Sufficiency of data to support refinement of Ringold into three sand /gravel units and three "mud" units. • Alternative conceptual model of muds (with possibility of sand stringers in muds) needs to be evaluated.	Summary of Key Technical Comments and Issues, *Comments on Conceptual Model*, paragraphs 1:3, page B.6. EPA Comments on Hanford Site-Wide Groundwater Model, *Conceptual Model: Hydrogeological Framework*, bullet 1. EPA Comments on Preliminary Draft, comment 7.	
8.3.2.2 Geologic Structures • Fault north of Gable Mountain and Gable Butte. • May Junction Fault and Cold Creek Fault.	Summary of Key Technical Comments and Issues, *Comments on Numerical Implementation*, paragraphs 1:2, pages B.6:B.7. EPA Comments on Hanford Site-Wide Groundwater Model, *Numerical Implementation: Translation of Conceptualization*, bullet 3.	
8.4 Model Parameters • Uncertainty be acknowledged and embraced: A new modeling framework that is stochastic rather than purely deterministic is needed. • To assess importance of uncertainty in parameter values, stochastic methods can be used.		*Executive Summary*, point 3, bullet 2, page ES-1. *Conceptual Model* Recommendation 2, bullet 2, page 3. *Model Calibration* Recommendation, item 6, page 5.
8.4.1 Hydraulic Conductivity (Transmissivity) • Based on sparse set of data from hydraulic testing: need to express uncertainties associated with these data. • Need sensitivity analysis over range of measured parameter. • Concerns about use of "book value" conductivities. • Assumption of constant ratio of conductivities between units is probably incorrect, and may cause some of the impossibly large conductivity values obtained from the inverse modeling. • Concern about disaggregation of 2D T's to 3D K's; other methods need to be evaluated. • Effect of using transmissivities from wells that are partially screened.	Summary of Key Technical Comments and Issues, *Comments on Numerical Implementation*, Paragraphs 5:7, page B.7. EPA Comments on Hanford Site-Wide Groundwater Model, *Conceptual Model: Hydraulic Properties*, bullet 2. EPA Comments on Hanford Site-Wide Groundwater Model, *Numerical Implementation: Translation of Conceptualization*, bullet 4.	*Model Calibration* Recommendation, reasons 3 and 5, page 5.
8.4.2 Effective Porosity • There is no physical justification for basing effective porosity values on measured specific yield values.		*Effective Porosity Versus Specific Yield* Recommendation, page 8.
8.4.3 Specific Yield • Use of a specific yield of 0.1 for Ringold sediments might be inappropriate.	EPA Comments on Hanford Site-Wide Groundwater Model, *Conceptual Model: Hydraulic Properties*, bullet 1.	

Table 10. (contd)

Technical Issues and Concerns	Regulator / Stakeholder (Appendix B)	Peer Review Panel (Appendix E)
8.4.4 Storage Coefficient • Some predictive errors may be introduced by the use of incorrect storage coefficient values.		*Storage Coefficient Values* Recommendation, page 8.
8.4.5 Distribution Coefficient • Use of the retardation approach to transport modeling limits the model to first-order decay and linear sorption cases: other uses would require justification.		*Representation of Contaminant Chemistry* Recommendation, paragraphs 1:2, page 6.
8.4.6 Dispersivity • The current dispersivity-selection criteria make the model susceptible to mesh size effects: an independent method for selecting dispersivity values is needed. • Vertical transverse and horizontal transverse dispersivities should not be equivalent.	EPA Comments on Hanford Site-Wide Groundwater Model, *Conceptual Model: Transport Properties*, bullet 1. EPA Comments on Preliminary Draft, comment 1.	*Dispersivity (and Mixing Versus Spreading)* Recommendation, paragraphs 1:3, pages 7:8.
8.5 Model Implementation		
8.5.1 Model Discretization • Concerns about the oddly shaped elements used where the transport grid transitions from coarse to fine sediments	Summary of Key Technical Comments and Issues, *Comments on Numerical Implementation*, paragraph 4, page B.7.	
8.5.2 Flow Model Calibration • Because the model is calibrated to heads only (i.e., none of the significant inflows and outflows is measurable), modeling results will always contain significant uncertainty. • Calibration also focused on matching measured water-table elevations. Future work should consider examining vertical head data or information where it is available. • Calibration procedure is not defensible: 1) insufficient justification for use presumed 1979 steady-state conditions, 2) over-parameterization, 3) incompatibility between pumping test results and model aquifer representation, 4) 2D model calibration for a 3D model, 5) use of interpolated head values. • Head data used in inverse model were not in fact head data, but rather were interpolated values at model node locations which carry a bias. • "Mean head difference" is not a good measure of model accuracy: "Mean absolute head difference" or "root-mean-square" would be better. • Comparison of contour maps is not an adequate means to evaluate model predictive value, because interpolations of data are compared, not actual data. Instead, data should be compared on a point-by-point (well-by-well) basis.	EPA Comments on Hanford Site-Wide Groundwater Model, *Numerical Implementation: Flow Model Development and Calibration*, bullets 1 and 2. EPA Comments on Preliminary Draft, comment 8.	*Executive Summary*, point 4, bullet 1, page ES-2. *Model Calibration* Recommendation, reason 4, page 5. *Measured Versus Observed Heads and Concentrations* Recommendation, page 9.
8.5.3 Transport Model Calibration • Data showing the vertical distribution of contaminants in the unconfined aquifer are generally lacking in most areas leading to uncertainty in defining initial conditions. • Vertical discretization of most of the model area may be too coarse to accurately simulate the vertical migration of contaminants. • Data being used to calibrate the transport model may not be sufficient. Although there is adequate information on areal distributions of contaminants in 1985 and 1995, the differences between the distributions are not large. • Transport model (or a particle-tracking model) should be used to check simulated travel or first-arrival times against observed data. • Future simulations of existing plumes have assumed that no new contaminants will reach the aquifer in the future.	EPA Comments on Hanford Site-Wide Groundwater Model, *Conceptual Model: Contaminant Distribution*, bullet 1. EPA Comments on Hanford Site-Wide Groundwater Model, *Numerical Implementation: Transport Model Implementation*, bullets 1:3. EPA Comments on Hanford Site-Wide Groundwater Model, *Numerical Implementation: Transport Model Calibration*, bullets 1:2.	*Initial Conditions in 3D* Recommendation, page 9.

Table 10. (contd)

Technical Issues and Concerns	Regulator / Stakeholder (Appendix B)	Peer Review Panel (Appendix E)
8.6 Model Uncertainty		
8.6.1 Uncertainty • Need to acknowledge uncertainty in model and it's inputs, and the consequent uncertainty in model results.		*Executive Summary,* point 3, bullet 1, page ES-1. *Conceptual Model* Recommendation 1, page 3.
8.6.2 Alternative Conceptual Models • Need to construct a comprehensive list of alternative conceptual model components and assess their potential impacts on predictive uncertainty.		*Executive Summary,* point 3, bullets 3 and 4, page ES-1. *Conceptual Model* Recommendation 2, bullet 1, and Recommendation 3, pages 3:4.
8.7 Model Applications		
8.7.1 Scope of Model Application • Need to specify a narrower, more pragmatic, list of model uses.		*Executive Summary,* point 2, page ES-2.
8.7.2 Sub-Modeling Capability • Support for interface with special, local-scale models. • Maintenance of database. • Subscale spatial variability: need for maintenance of geologic data independent from model database.	Summary of Key Technical Comments and Issues, *Comments on Scope, Schedule, Process, Needs, and Requirements,* paragraphs 6:7, page B.6.	*Sub-Models of the SGM and Specialized Local Models* Recommendation, pages 10:11.
8.8 Code and Model Management		
8.8.1 Source-Code Availability • Source code available for model modification and support.	Summary of Key Technical Comments and Issues, *Comments on Scope, Schedule, Process, Needs, and Requirements,* paragraph 1, page B.5.	*Interfaces and Output Needs: Selected Computer Code* Recommendation, paragraph 1, pages 9:10.
8.8.2 Regulator/Stakeholder Involvement • Continual informal interaction during consolidation process. • Model/code access for regulators, Tribal Nations, others.	Summary of Key Technical Comments and Issues, *Comments on Scope, Schedule, Process, Needs, and Requirements,* paragraphs 2:3, page B.5.	*Interfaces and Output Needs: Selected Computer Code* Recommendation, paragraph 3, pages 9:10.
8.8.3 Database Management and Configuration Control • New data collection campaign would be premature; need to broaden modeling framework to accept uncertainty first. • Maintain *databases* and *information-bases,* separate and distinct from each other and from the model. • Model should be considered a flexible and evolving tool.		*Executive Summary,* point 5, pages 2:3.

8.2.2 Decay

Consideration should be given to including radioactive chain-decay in the transport model to account for creation of daughter products that result from the radioactive decay of some radionuclides.

8.2.3 Dispersion

It must be recognized that the concentrations produced by the site-wide groundwater model do not represent local values when using large field-scale dispersivities. If the site-wide groundwater model is integrated with a multi-species interactive chemical module that relies on accurate prediction of local concentrations, then the issue of predicted concentrations due to local mixing (versus those predicted using a macrodispersion-approach) must be addressed.

8.2.4 Diffusive Mass Transfer

Diffusive mass transfer, involving mass transfer between an immobile and a mobile domain, is important to model in situations where the effective porosity is significantly smaller than the total porosity. It is expected that "tailing" (later mass arrival) of contaminant plumes is likely to be significant at the Hanford Site, and that the site-wide groundwater model will overestimate the rate at which these plumes migrate and dissipate after a source is removed because diffusive mass transfer to and from immobile domains is not considered. See Section 8.4.2 (Effective Porosity) for related comments.

8.2.5 Reactive Transport

The existing site-wide groundwater model is capable of representing transport of individual non-interacting solutes undergoing first-order decay (including radioactive decay) and linear sorption. This is potentially adequate for some of the prevalent contaminants found in Hanford groundwater, but for most contaminants of concern found in the vadose zone, reactive transport needs to be represented. If these contaminants are modeled using the site-wide groundwater model, then reactive transport capabilities (including transport of multiple species, microbial degradation, and perhaps nonlinear feedback to the flow model as aquifer or water properties change) must be incorporated into the model. The alternative is for the site-wide groundwater model to provide hydraulic boundary conditions to specialized local models that address reactive transport.

8.3 Model Domain

Technical issues and concerns related to the model domain, including the treatment of the lateral, top, and bottom boundaries and of hydrogeologic structures, are summarized in this section.

8.3.1 Boundaries

Technical Issues and concerns related to treatment of boundary conditions in the site-wide groundwater model are summarized with respect to lateral, top, and bottom boundaries of the model.

A general concern is that all boundary conditions and fluxes should be re-inspected because of some inconsistencies with existing information and because of an insufficient conceptual basis for use of these conditions for applications of the site-wide groundwater model at both large and small scales.

8.3.1.1 Lateral Boundaries

In general, the lateral domain covered by the site-wide groundwater model must be better justified. The site-wide groundwater model simulates groundwater flow and contaminant transport only in the unconfined sedimentary aquifer in the Pasco Basin south and west of the Columbia River. The unconfined aquifer to the north and east of the river and the bedrock basalt aquifer are not represented in the site-wide groundwater model, though the major discharge area for both aquifers is the Columbia River.

8.3.1.1.1 Cold Creek, Dry Creek, and Rattlesnake Ridge Springs

The boundary fluxes at Cold Creek, Dry Creek, and Rattlesnake springs are estimated based on present-day hydrologic conditions. There could be significant temporal variability in these values depending on future development and land use in areas outside the current model domain with proportional impacts on model results. This merits evaluation.

Stream flow in upstream reaches of Dry Creek and Cold Creek are a likely lower boundary on underflow from these areas. A comparison of upstream stream-flow values and boundary fluxes is needed; for example, the 1997 USGS estimates of recharge from the creeks to the alluvial system are lower than values used in the calibrated model. A uniform 3D distribution of values along each flux-boundary was assumed. Some rationale for this distribution is needed, or these values must be redistributed in a less arbitrary manner. Along the western boundary it appears that boundary fluxes may in fact be leakage from Cold and Dry Creeks within the Hanford Site, in which case most of the flux should be apportioned to the upper part of the aquifer.

8.3.1.1.2 Columbia River

Treating the Columbia River centerline as a line of symmetry is questionable, given that the heads in the aquifer are so much greater on the Franklin County side. Moving the line of symmetry closer to the Benton County side of the river may be appropriate.

There may be periods when the actual river stage results in much different flow dynamics than are predicted using median river stages.

Consideration should be given to using head-dependent flux boundaries at the Columbia River (and Yakima River) rather than the specified-head boundaries. Because the flow pattern and lithologies at these boundaries are probably more complex than at most other locations in the model, and the complexity is probably at a scale smaller than the size of an element, the values of horizontal and vertical hydraulic conductivities that are assigned probably artificially differ from the actual values to compensate for the complexities. It might be better to absorb the complexities into the empirical head-dependent-flux coefficient.

The locations and types of boundary conditions specified in 3D over time must be re-inspected. In general for large-scale applications to the Hanford site, the specified head boundary corresponding to rivers is adequate. However, the use of a specified head along the Columbia River may be inadequate for small-scale sites near the river or for short-term analyses potentially affected by the river. For example, the observed and predicted water levels for 1996 near the 100-B, C Area indicate flow directions that are at right angles to each other. In such cases, time-dependent heads and/or head-dependent fluxes should be considered.

8.3.1.1.3 Yakima River

Consideration should be given to using head-dependent flux boundaries at the Yakima River rather than the specified-head boundaries, at least for some cases. Because the flow pattern and lithologies at these boundaries are probably more complex than at most other locations in the model, and the complexity is probably at a scale smaller than the size of an element, the values of horizontal and vertical hydraulic conductivities that are assigned probably artificially differ from the actual values to compensate for the complexities. It might be better to absorb the complexities into the empirical head-dependent-flux coefficient.

8.3.1.1.4 No-Flow Lateral Boundaries

Assuming the locations of lateral boundary fluxes are reasonable, there remains an inadequate conceptual model of the existing boundary fluxes. Based on the map of recharge values used during calibration and the locations of Gable Butte and Gable Mountain, significant internal boundary fluxes apparently exist and are not considered in the active model domain. Similarly, fluxes along the western boundary are non-zero only along a small portion. Given the large drainage area in the Rattlesnake Hills and associated mountain area, some rationale must be supplied for assuming no-flow conditions, or those boundary fluxes must be reconsidered.

8.3.1.2 Upper Boundaries

Fluxes considered at the upper boundary of the site-wide groundwater model include natural recharge (resulting from precipitation over the Hanford Site) and artificial recharge (discharges to groundwater of water imported from outside the model domain through human activities). Technical issues and concerns related to these boundary conditions are summarized here.

A general conceptual model concern is whether the site-wide groundwater model will have the capability to model unsaturated flow and transport.

8.3.1.2.1 Natural Recharge

As the effect of artificial recharge diminishes and the overall water table declines, the effect of natural recharge will become more important. The applicability of present-day estimates of recharge in long-term simulations of unconfined aquifer behavior should be justified.

The effect of macropore recharge has not been considered in current estimates of recharge. In other areas (e.g., the Southern High Plains regions of Texas and New Mexico) the macropore recharge represents a high percentage of the total recharge estimated.

Areal recharge is potentially the dominant source of water to the aquifer. The spatial distribution of recharge appears to have varied greatly in the past. As such, it is unclear how simulation of future events should represent this distributed water flux. The recharge map constructed by Fayer et al. (1996) is a good starting point to determine an average recharge map and a companion map of recharge uncertainty. Once available, this information can be used in identifying the range of model predictions (mentioned previously). Experts at PNNL should develop a strategy to represent the spatial distribution of recharge for a range of climatic conditions, consequent vegetation, and antecedent soil-moisture conditions.

Spatial variability of recharge should be treated geostatistically to determine expected values, spatial correlation, and estimated uncertainties.

The conceptual model does not consider evapotranspiration directly from the water table. This component of groundwater discharge probably would be significant only near the Columbia and Yakima Rivers, and perhaps the ponds in the 200 Areas. Even if analysis shows this flux is insignificant, and thus, unnecessary to include in the numerical implementation, it should still be included in the conceptual model.

8.3.1.2.2 Artificial Recharge

It is not clear how artificial recharge at disposal ponds was calculated. Was evapotranspiration considered in the estimate?

It is unclear how artificial recharge in the Richland area in the form of infiltration from ponds, agricultural and residential irrigation, and disposal of wastewater at the potato-processing plants has been handled. This needs to be clarified.

8.3.1.3 Lower Boundaries

There may be potential for recharge to the unconfined aquifer from the upper confined aquifer. Currently, the site-wide groundwater model assumes that flow to and from the basalt is insignificant because of the assumed low permeability of the basalt. However, there are significant hydraulic gradients between the basalt and the unconfined aquifer system over most of the Hanford Site. These gradients and the large potential area of vertical leakage across the Hanford Site may lead to significant vertical fluxes that have not been accounted for. There is some indirect evidence for upward leakage from the underlying basalt confined aquifer (e.g., historical persistence of West Lake and the occurrence of a groundwater mound north of Gable Mountain). Currently, no data are available to support the estimation of recharge from the unconfined aquifer system and its use in the site-wide groundwater model. Flow from the basalt may have originated far off the Hanford Site and constitute part of a much larger regional flow system.

The no-flow boundary between the basalts and the alluvial material at the base of the model may not be appropriate for areas of increased vertical permeability such as in the area northeast of the 200-East Area and in known or suspected fault areas. Further documentation of the justification for the treatment of the lower boundary throughout the domain needs to be provided. Such documentation should begin with the conceptual model and should include a water balance that accounts for flow in the basalts.

8.3.2 Hydrogeologic Structures

Technical issues and concerns related to the division of the model domain into major hydrostratigraphic units and the treatment of geologic structures (faults) are summarized here.

8.3.2.1 Major Units (Lithologies)

It is questionable whether sufficient data are available to support the refinement of the Ringold Formation into three sand/gravel units and three mud (fine-grained) units. In general, data at the Hanford Site get sparser with depth. How does the current conceptual model address the increasing uncertainty with depth? Sensitivity analyses should be conducted to see what the effect of explicitly modeling the lower hydrostratigraphic units might be.

An alternative conceptual model has been offered with regard to the existence of fine-grained units in the Ringold Formation. Coarse-grained "stringers" may exist within the fine-grained units and may be continuous enough to provide preferred pathways of flow (and contaminant transport). Existing geologic data are not sufficient to prove or disprove this possibility. The possibility of these coarse-grained pathways should be considered and the possible effect tested at some point in the modeling process.

Another concern is the way the heterogeneity of Hanford Site soils was incorporated in the conceptual model. At this point, the heterogeneity included in the model is limited to large regional features and the differences between hydrostratigraphic units.

8.3.2.2 Geologic Structures

There may be some evidence for a fault to exist in the basalt in this region north of Gable Butte and Gable Mountain, but there is no evidence of a fault in this region in the unconsolidated sediments.

The current implementation of the site-wide groundwater model has continuous but thin layers in this region of the May Junction Fault and the Cold Creek Fault. There should be faults represented in the model in this location. A better representation of the fault would be to have offsetting layers.

8.4 Model Parameters

As a general concern, the concept of uncertainty should be acknowledged and embraced from the outset. A new modeling framework should be established that is stochastic rather than purely deterministic. Both the expected values of heads and concentrations as well as the range (distribution) of predictions should be products of the model. Furthermore, parameter uncertainty estimates are an essential part of the model and its ability to provide an expected range of predicted values. Proper parameter estimates and parameter uncertainty estimates (covariance) should be developed and used to assess the uncertainty in predicted heads and concentrations.

Technical issues and concerns related to specific model parameters are detailed by parameter in the remainder of this section.

8.4.1 Hydraulic Conductivity (Transmissivity)

Hydraulic properties used in the modeling are based on a sparse set of data derived from hydraulic testing. Many of the wells tested only partially penetrate the unconfined aquifer system. Parameter values provided in tables from reference materials are quite often represented with only a single number. Parameter values should be presented as a range of values. Model sensitivity analyses should be conducted to evaluate the uncertainty on model flow and transport over the range of measured parameter values.

The use "book value" hydraulic conductivities used in the translation of transmissivities derived from the two-dimensional model calibration to the three-dimensional model are a concern. References for the "book values" should be given. The difference between the Hanford and Ringold gravel "book value" hydraulic conductivities were larger than expected. U.S. Geological Survey (USGS) studies observed approximately a 20:1 difference with the difference being that the USGS observed higher Ringold conductivities than were given as the "book value." Consideration should be given to other viable alternatives to the method used in assigning hydraulic conductivities to the three-dimensional model.

Another concern is the effect of using transmissivities measured in wells that are partially screened in the aquifer as observed transmissivities for the entire thickness of the alluvial aquifer. The selection of weights used in the matching procedure for heads and transmissivities is a concern as well.

Some of the hydraulic conductivities that were determined through inverse modeling seemed impossibly large. The extremely large values are perhaps the result of the assigned ratios between units. For example, the relatively thin Pasco Gravel might be assigned the largest part of the transmissivity at a particular location when in reality the Ringold gravels are extremely conductive at that location.

8.4.2 Effective Porosity

Although the values used for effective porosity and specific yield may sometimes be similar for a given aquifer material, there is no physical justification to base effective porosity values on measured specific yield values. There is considerable ambiguity in the literature regarding the term effective porosity. For purposes of the site-wide groundwater model, effective porosity is the quantity by which the seepage velocity must be multiplied to obtain the Darcy velocity. The seepage velocity is the average speed that water travels between two points due to advection. Specific yield is the drainable porosity, i.e., the volume of water that can be drained by gravity from a unit volume of initially saturated porous medium. In general, specific yield represents a much smaller fraction of total porosity than does effective porosity. Effective porosity values must be estimated, and the impact of their uncertainties must be assessed.

8.4.3 Specific Yield

The use of a specific yield of 0.1 for Ringold sediments might be inappropriate. This value is typical of that obtained from aquifer testing and could be an appropriate value to use for simulating seasonal changes in water levels. However, when the water table at Hanford falls permanently, and the sediments have years to drain, the appropriate specific yield to use for simulating this process could be considerably higher. The specific yield for the Hanford formation may also need to be increased.

8.4.4 Storage Coefficient

The error introduced by using wrong storage coefficient values may be responsible for some predictive errors. The storage parameter used in the model may be too high (or the hydraulic conductivity may be too small), based on comparison of observations and simulation results for the propagation of a water pulse.

8.4.5 Distribution Coefficient

Distribution coefficients (K_d) are used to represent the retardation of contaminants due to sorption. The use of a retardation approach precludes use of the model for prediction of the behavior of the majority of contaminants of concern at the Hanford Site. For applications involving the migration of tritium through the aquifer, the chemical processes in the site-wide groundwater model (decay and no sorption) are adequate. For other contaminants, such as carbon tetrachloride, the model may provide reasonable predictions if no volatilization occurs, water quality is nearly constant, and the chemistry can be represented by first-order decay and linear sorption. In any application of the site-wide groundwater model, justification of the engineering approach to retardation is needed.

This issue is also summarized in Section 8.2.1 (Adsorption).

8.4.6 Dispersivity

The selection of dispersivity values based solely on model element sizes and the Peclet number criterion is problematic for the following reasons: 1) Any physical interpretation of dispersivity values is lost. 2) An empirical or theoretical relationship between dispersivity and travel distance scale is not used. 3) The resolution of the mesh dictates the dispersion of the plume. Thus, a fine mesh will result in a simulated plume dominated by advection and the simulated plume will display little lowering of the plume peak as the plume advects and a small degree of spreading). Alternatively, a course mesh will show that as the plume travels, its peak will be greatly reduced and the plume will become elongated.

The transverse dispersivities are unlikely to be one fifth of the longitudinal dispersivity for all scales of interest. Furthermore, vertical transverse dispersivity values are most likely smaller than the horizontal transverse dispersivity values. CFEST-96 does not have the capability for specifying different vertical and horizontal transverse dispersivities, and it is recommended that the code be modified to incorporate this feature.

It is recommended that an independent method be used to estimate dispersivity values and that mesh spacing be selected such that the Peclet criterion is met.

8.5 Model Implementation

Technical issues and concerns with respect to model discretization and calibration of the flow model and of the transport model are summarized here.

8.5.1 Model Discretization

The oddly shaped elements used where the transport grid transitions from coarse to fine sediments are a concern. These elements have not caused any observed problems in the flow. Modeling staff suggested that this was the case because, using the finite element method, the flow comes through the nodes, not across the element boundaries.

8.5.2 Flow Model Calibration

The model is calibrated to heads only (i.e., none of the significant inflows and outflows is measurable), so modeling results will always contain significant uncertainty. Calibration also focused on matching measured water-table elevations. Future work should consider examining vertical head data or information where it is available.

The calibration procedure for the current model is indefensible. Reasons include the insufficient justification for using a single snapshot of presumed steady-state conditions in 1979, over-parameterization of zonal transmissivities given an insufficient number of independent data, potential for incompatibility between pumping-test results and model representation of the aquifer, 2D model calibration for a 3D model, and use of interpolated head values.

Hydraulic conductivities for each of the model layers were calculated based on transmissivities estimated from a 2D model of the entire unconfined aquifer. Hydraulic conductivities in a 3D model should be estimated using a 3D inverse model. Short of 3D estimation, an assessment must be undertaken regarding the use of detailed stratigraphy and "text-book value" hydraulic conductivities as the basis for disaggregating transmissivities for a 2D unconfined aquifer into hydraulic conductivities in 3D.

The head data used in the inverse model were, in fact, not head data. Rather, they were interpolated values at model node locations. These interpolated values carry a bias. The parameter estimation procedure provides two pieces of information: the parameter estimates and the covariance of these estimates. When the "data" used in the inversion process are values interpolated at all nodal locations, the covariance of the parameter values is artificially reduced and the estimates are unreliable. That is, the creation of data through interpolation leads to biased estimates of model parameter values and artificial estimates of model parameter uncertainty.

In much of the previous groundwater modeling work, the predictive value of the groundwater flow and transport models has been evaluated by comparing contour maps of observed data to contour maps of simulated data. Contour maps of observed data are interpretations of data; not actual data. When assessing the predictive value of models, the observed data should be compared to simulated data on a point-by-point (well-by-well) basis, and that this comparison is done in an accepted statistical framework. An example of such a statistical framework is ASTM D5447-93 Standard Guide for Application of a Ground-Water Flow Model to a Site-Specific Problem.

8.5.3 Transport Model Calibration

Data showing the vertical distribution of contaminants in the unconfined aquifer are generally lacking in most areas. This lack of information leads to uncertainty in defining initial conditions for modeling the contaminant plumes and verification of modeling transport results in three dimensions.

The finer grid discretization used at selected locations in the transport model is a good approach. However, the vertical discretization of most of the model area may be too coarse to accurately simulate the vertical migration of contaminants. The lack of data on the vertical distribution of contaminants may limit the usefulness of finer discretization.

Data being used to calibrate the transport model may not be sufficient. Although there is adequate information on areal distributions of contaminants in 1985 and 1995, the differences between the distributions are not large. Even with input data limitations, the large changes in contaminant distributions that occurred from pre-1944 to 1996 might represent a better period for transient calibration.

In addition to matching simulated with observed spatial distributions of contaminant concentrations, the transport model (or a particle-tracking model) should be used to check simulated travel or first-arrival times against observed data. These comparisons may be useful in identifying the existence of preferred pathways. The model should also be used to test the impact of adding highly permeable layers on contaminant-transport behavior.

Future simulations of existing plumes have assumed that no new contaminants will reach the aquifer in the future. Although little or no new contaminants may be added to the vadose zone, there may still be significant movement of contaminants already in the vadose zone that will reach the aquifer system in the future.

The vertical extent of the contaminant plumes at the Hanford site is poorly defined, and therefore, the initial concentration conditions for contaminant transport simulations have a large uncertainty associated with them. This uncertainty must be considered in making predictive simulations. In the most recent modeling analysis, the thickness of the contaminant plume was the calibration parameter, and a value of 25 meters was assigned in the calibration process. There are clearly many other uncertain parameters in the site-wide groundwater model, and the calibration of thickness may be meaningless. One of the reports indicates that the tritium plume in some areas is over 60 meters thick. The site-wide groundwater model framework must have a method for dealing with this uncertainty.

8.6 Model Uncertainty

Technical issues and concerns related to the general topic of model uncertainty and the treatment of alternative conceptual models are summarized here. Uncertainty is treated more specifically in other issue and concern summaries elsewhere, as noted.

8.6.1 Uncertainty

The existing deterministic modeling effort has not acknowledged that the prescribed processes, physical features, initial and boundary conditions, system stresses, field data, and model parameter values are not known and cannot be know with certainty. Consequently, predictions of heads and concentrations in three dimensions will be uncertain as well. The concept of uncertainty should be acknowledged and embraced from the outset. A new modeling framework should be established that is stochastic rather than purely deterministic. Both the expected values of heads and concentrations as well as the range (distribution) of predictions should be products of the model.

Issues and concerns related to uncertainty as it pertains to the conceptual model are summarized in Section 8.6.2 (Alternative Conceptual Models). Issues and concerns related to model parameter uncertainty are summarized in Section 8.4 (Model Parameters).

8.6.2 Alternative Conceptual Models

A priority task is to construct a comprehensive list of alternate conceptual model components and to assess each of their potential impacts on predictive uncertainty. Assessment can be initiated with hypothesis testing and sensitivity analysis within the general framework already established with the existing site-wide model. If uncertainties due to alternate conceptual models are significant, then a Monte Carlo analysis is required to estimate both the expected value of the prediction and its uncertainty.

8.7 Model Applications

Technical issues and concerns regarding model application scope, source-code availability, interaction with regulators and stakeholders during model development, support for sub-modeling capability, and consideration of alternative conceptual models are summarized here.

8.7.1 Scope of Model Application

The spectrum of anticipated uses and needs is so broad (ranging from time scales of less than one day to thousands of years and spatial scales of meters to kilometers) that this, or any general-use, site-wide groundwater model cannot be expected to be adequate for all potential uses. An initial task should be to specify a narrower, and perhaps more pragmatic, list of model uses that involve less disparate temporal and spatial scales and contaminants whose behavior can be adequately characterized by linear sorption and first-order decay.

8.7.2 Sub-Modeling Capability

The site-wide model must be able to interface with specialized local-scale models, which will developed primarily to analyze the migration of contaminants whose behavior in the subsurface cannot be accurately simulated with first-order decay and linear sorption. Also, there will likely be cases where there is a significant inventory of the contaminant in the vadose zone, requiring coupled unsaturated-saturated models of small regions to answer the questions posed. Specialized local models may also be developed for areas where short-term transient effects, such as variations in river stage, are important. In all of these cases, site-wide groundwater model can be used to define hydraulic boundary conditions for a model of the smaller-scale problem.

The requirement to interface with local-scale models involves not only the code, but also the database. However, it may be impractical to anticipate the requirements of the site-wide groundwater model to allow this interface. It is more likely that the complex, local-scale model would be designed to interface with the site-wide groundwater model. Pre- and post- processors should be developed, if they do not already exist, so that it is relatively easy to create sub-models of the site-wide groundwater model and to create the hydraulic boundary conditions for specialized local-scale models. It is difficult to anticipate requirements of the specialized local models, but it is important that thought be given to how they might interface with the site-wide groundwater model.

For the development of specialized local models it is essential that an up-to-date, easy to use geologic database be maintained. In models of small regions, it is very likely that the appropriate number of hydrogeologic units will differ from that defined in the site-wide groundwater model. The geologic database will be needed to define these hydrogeologic units on a refined scale.

It should be clearly identified whether the location of actual contaminant release sites needed to coincide with the computational nodes of the site-wide model to interface local-scale models.

There is concern that every local-scale model would need to run the site-wide groundwater model to be consistent. This constraint would not necessarily be required. However, site characterization data collected as part of a local-scale analysis would be a valuable addition to the site-wide database.

Spatial variability of hydraulic parameters exists at scales smaller than that of the hydrogeologic facies. This small-scale variability may be important to model applications involving specific sites. The geologic data, such as well logs, should be maintained apart from the interpreted hydrogeologic-facies information. Such segregation would enable modelers of particular applications to go back to the data and potentially extract smaller-scale information about fine structures and parameter values. Work is needed to estimate the geostatistical parameters at the sub-hydrogeologic facies scale.

8.8 Model and Code Management

Issues and concerns dealing with the availability of source code, interaction with regulators and stakeholders during model documentation and review, as well as configuration management and database management are summarized here.

8.8.1 Source Code Availability

Source code should be available to ensure the ability to modify the code if the need arises, and to repeat analyses. This concern could become particularly important should the code become unsupported.

8.8.2 Regulator/Stakeholder Interaction

In addition to formal document review, informal interaction with regulators, Tribal Nations, stakeholders, during the model and document review process would be appropriate. User access to the site-wide groundwater model by regulators, Tribal Nations, and other interested parties is desirable. However, a high degree of specialized knowledge is required to use the site-wide groundwater model. Regulators, Tribal Nations, and other stakeholders may lack the necessary expertise to use the model. Consequently, training workshops on the use of the model, including the use of pre- and post-processors should be provided.

8.8.3 Database Management and Configuration Control

It is premature to initiate a campaign to collect new data. The highest priority should be on adoption of a broader modeling framework that accepts conceptual model uncertainty.

Both *databases*, comprising original field measurements, and *information-bases*, comprising interpretations and/or interpolations, should be maintained and kept distinct from one another. This will serve to support sub-modeling (see Section 8.7.2, Sub-Modeling Capability).

The site-wide groundwater model should be thought of as a flexible and evolving platform for analyzing groundwater flow and contaminant transport. The adopted framework must be one in which new concepts can readily be tested, and enhancements readily included.

9.0 Approach to Address Technical Issues and Concerns

Technical issues and concerns raised by representatives of regulatory agencies (EPA and Ecology), Tribal Nations (the NPT, the YIN, and the CTUIR), and the External Peer Review Panel on the Proposed Site-Wide Groundwater Model are summarized in Section 8.0. This section presents the general approach that will be followed to address these technical issues and concerns.

While many issues and concerns are documented in Section 8.0, the Site-wide Groundwater Model External Peer Review Panel urged during its site visit on June 22 and 23, 1999 that attention be focused on certain high-priority, critical tasks. Consequently, DOE/RL does not plan to respond specifically to every comment and suggestion provided to the project by the panel in their original report received in January of this year. Rather, the model consolidation team will focus on the highest priority items identified by the External Peer Review Panel. These are development of alternative conceptual models, development of an uncertainty framework, and improvement of the recharge estimates.

In addition, it is vital to continue to communicate with the regulatory agencies, Tribal Nations, stakeholders, and the External Peer Review Panel as consolidated site-wide groundwater model development continues, and provisions for this are discussed in this section.

9.1 Alternative Conceptual Models

The consolidated site-wide groundwater modeling team will continue implementation of the activities related to refinement and calibration of alternative conceptual models as suggested by external peer review. The results of these activities and their implications of site-wide groundwater model predictions of flow and contaminant transport and their uncertainty will be documented. It is anticipated that several alternative conceptual models will emerge that will reflect different credible combinations of boundary conditions and interpretations of the hydrogeologic framework. Each alternative conceptual model will require a corresponding numerical implementation and inverse calibration.

Developing and supporting parallel alternative conceptual and numerical models at the scale of the Hanford Site is a novel activity. Staff will write an article to submit to an appropriate peer-reviewed technical journal to share the approach and lessons learned with a larger technical audience.

Throughout this activity, staff will work closely with the Systems Characterization activity within the Integrated GW/VZ project to develop and implement an consistent approach for development of management of alternative conceptual models. This will use the Features, Events, and Processes (FEP) approach to management of technical issues and concerns.

9.2 Development of an Uncertainty Framework

A complete uncertainty framework will be developed in the long term, providing for inclusion of uncertainties associated with prescribed processes, physical features, initial and boundary conditions, system stresses, field data, and model parameter values. This analysis framework will ultimately be used to assess uncertainty in results produced by the range of alternative site-wide groundwater conceptual and numerical models.

9.3 Historical Database Extension

Natural and artificial recharge across the Hanford Site will be re-examined with the issue of uncertainty in the forefront. Artificial recharge data from prior to 1979 will be compiled to the extent historical documentation permits to permit a longer time-transient re-calibration of flow and transport models.

Historical observations of hydraulic head, hydraulic testing results, and contaminant concentration data will be gathered, digitized, and organized to extend the database in support of a greater-duration model transient recalibration.

9.4 Model Recalibration

The inverse calibration must be repeated for the site-wide groundwater model to incorporate many of the changes arising from the peer review process, as well as to incorporate any new information. In addition, an inverse calibration will be required for each alternative conceptual model supported (see Section 9.1). This is a nontrivial process that will consume large computer and analyst resources.

9.5 Ongoing Communication

Communication with the Peer Review Panel, regulators, Tribal Nations, and stakeholders is being facilitated by means of an internet-based forum. A web page (available on the World Wide Web at http://etd.pnl.gov:2080/gwmodeling/) has been dedicated to the purpose of tracking technical issues and concerns and posting white papers, sensitivity study results, and other related information. This approach provides for instant and wide communication on technical issue and concern resolution with all concerned parties, as well as enhancing feedback from concerned parties. The process of regulator and stakeholder interaction already has already been initiated in the consolidation process and will continue through the web-based approach.

Provision will be made to meet on a regular basis with regulators, stakeholders, and Tribal Nations to brief and discuss project progress. Topics for these briefings and discussion will include development and calibration of numerical versions of the alternative conceptual models and development of an uncertainty framework. The current External Peer Review Panel assembled to review the site-wide groundwater flow and transport will be retained for periodic review of the modeling activities. Specifically, they will provide independent technical review of the alternative conceptual models selected for inverse calibration and the overall technical approach and strategy being used to address uncertainty in site-wide groundwater flow and transport results using the alternative conceptual models.

Additional effort will be devoted to providing application and training support. The CFEST96 User's Guide will be enhanced substantially, and a Site-wide Groundwater Model Applications Guide will be promulgated.

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APPENDIX A.

Summary of Groundwater Modeling Activities

Appendix A. Summary of Groundwater Modeling Activities

The following is a brief review of recent and current groundwater modeling activities that have been undertaken by the major programs at the Hanford Site. The information presented is organized by major program areas (e.g., Environmental Restoration, Waste Management and Tank Waste Remediation System Programs) and was largely derived from meetings with representatives of U. S. Department of Energy- Richland Operations Office (DOE/RL, referred to hereafter as RL) programs and site-contractor personnel and from review of related key technical documents. The majority of the groundwater modeling activities reviewed were completed within the last three years (i.e., since 1994). A high-level summary of each modeling activity is provided in a series of tables (Tables 1, 2, and 3), included in Section 2 in the main body of the report as a convenient means to evaluate differences between each of the modeling activities.

A.1 Key Projects in the Environmental Restoration Program

The following is a review of project activities that have used groundwater modeling to support major objectives for the Environmental Restoration (ER)Program. These summaries reflect information provided by DOE/RL technical project managers and contractor personnel from Bechtel Hanford Inc. (BHI) and Pacific Northwest National Laboratory (PNNL). The modeling activities summarized include those associated with the following key activities within the ER program.

- Development of the Hanford Site-Wide Groundwater Remediation Strategy
- Remedial investigation / feasibility study of the Environmental Remediation Disposal Facility
- Hanford Remedial Action and Comprehensive Land Use Environmental Impact Statement
- Assessments being done under the Hanford Groundwater Project, including:
  - Monitoring network assessments
  - Impacts on drinking water systems and groundwater uses from existing contaminant plume transport
- Composite Analysis being performed in response to the Defense Nuclear Facility Safety Board recommendation 94-2
- Design of interim remedial measures in the 100 and 200 areas

The following summary focuses on groundwater modeling being done to support evaluation of groundwater impacts and does not specifically discuss risk assessment methodologies being used to support cleanup of soil contamination at many Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) sites in the 100 and 200 areas. Much of this type of remediation work at the Hanford Site has been supported with RESRAD, a dose assessment code developed by DOE for deriving site-specific soil remediation guidelines (Yu et al. 1993).

A.1.1 Hanford Site-Wide Groundwater Remediation Strategy

The Hanford Site-Wide Groundwater Remediation Strategy describes the approach to remediate the major groundwater contaminant plumes in the 100 and 200 areas of the Hanford Site. As part of the strategy, a site-wide groundwater model was developed to be used in estimating the effectiveness of alternative groundwater cleanup approaches to support planning and implementation of remediation alternatives, to support risk assessments, and to evaluate the impact of changes in the groundwater flow field. The groundwater modeling for the Hanford Site-Wide Groundwater Remediation Strategy is summarized in detail in Law et al. (1997) and Chiaramonte et al. (1997).

Geologic and hydrogeologic conceptual models were based primarily on a synthesis of data and information presented in a number of previous studies. The geologic model was based primarily on Lindsey (1995) with the geologic mapping taken from Reidel and Fecht (1994a, b). A new map of the top of the basalt bedrock was developed for this study. The geologic mapping and the top-of-basalt surface map are part of the Hanford Environmental Information System (HEIS) database. The bottom of the unconfined aquifer was taken to be the lower mud unit of the Ringold formation where it exists. Where this mud unit is absent, the bottom of the unconfined aquifer was taken to be the top of the basalt.

Recharge to the unconfined aquifer was assumed to occur from the Cold Creek and Dry Creek basins. The actual recharge rate used was determined during the calibration (see below). Recharge from the surface due to natural precipitation and recharge from the confined aquifer were assumed to be negligible. Discharge to the Columbia River was modeled. Artificial recharge from the major liquid-waste-disposal facilities in the 200 East and West areas was based on available reports (see Law et al. 1997 for the values used).

Hydraulic conductivity data from aquifer tests reported in Connelly et al. (1992a, b) and Thorne and Newcomer (1992) were used. Scaling from the pump test point measurements to the areal values consistent with the groundwater numerical model was done with the EarthVision software.

Twelve numerical codes were evaluated for use in the site-wide groundwater modeling. The VAM3D-CG code (Huyakorn and Panday 1994) was selected because 1) it uses a robust set of solution algorithms, 2) the original developer is a well-known expert and was available for technical support, 3) the code efficiently simulates unconfined aquifer conditions, 4) the code allows the use of transitional elements to refine the numerical grid over specific areas, and 5) the code can be used to model unsaturated zone problems.

Grid sizes were chosen to balance resolution (accuracy) and required computational time. The initial grid chosen to model groundwater flow and tritium transport used uniform 600-m by 600-m elements in the horizontal plane (18,277 nodes in the three-dimensional grid. This grid proved to be too coarse to model smaller contaminant plumes, and the grid was refined in the 200 areas to have 150-m by 150-m elements. All elements in the horizontal plane were rectangular (or square).

Two hydrostratigraphic units were represented in the model, the pre-Missoula/Hanford formation and the Ringold Formation. Six elements were used in the vertical dimension to resolve the contaminant transport, three for the pre-Missoula/Hanford formation and three for the Ringold

Formation. Element size in the vertical direction varied from 0.5 m to 20 m. The elements were deformed (non-rectangular) in the vertical direction to match the contours of the formations.

Hydraulic conductivity and porosity varied spatially in the horizontal direction. Initial assignment of conductivity to elements was based on observed aquifer test data. Conductivity was isotropic in the horizontal direction. Hydraulic properties within each of the two hydrostratigraphic formations was vertically homogeneous. Vertical hydraulic conductivities were set to one-tenth the horizontal value for each element.

Calibration was carried out by adjusting the assigned hydraulic conductivities, solving for the steady-state flow field, and comparing the model results to the average water level measurements from 1976-1979. During this calibration, the boundaries along the Cold Creek, Dry Creek, and Yakima River were held at constant heads. These boundaries were subsequently set to constant flux boundaries using the recharge values obtained from the calibration. Transient flow simulations of 14 years were also carried out during the calibration, with comparisons of the hydraulic head field during 1988 and 1993 used to evaluate the numerical model. Finally, a simulation of tritium transport was carried out for the same 14-year period to further evaluate the calibrated model. Tritium concentrations from 1979 were used as the initial condition. The mean difference between the observed and estimated water table elevations at 124 wells in 1979, 1988, and 1993 was calculated for the calibrated model. This mean difference was less than 0.72 m in all three cases, which was felt to be reasonable.

The calibrated groundwater model was used to predict water table elevations and contaminant transport for several key contaminant plumes (tritium, iodine-129, uranium, technetium-99, nitrate, carbon tetrachloride, trichloroethylene, and chloroform) for 200 years using 1995 data as the initial condition. Initial sources in the 100 and 200 areas were modeled. The only sources of future releases of contaminants considered during the simulations were for tritium, which considered releases from the Effluent Treatment Facility (ETF), and for carbon tetrachloride, which considered releases from the 216-Z-9 trench. Limited sensitivity analyses were carried out to provide some estimate of critical parameters and the effect of uncertainties. For those contaminants that contributed to risk, an estimate of cumulative risk was made using the industrial and residential scenarios defined in the Hanford Site Risk Assessment Methodology (HSRAM) (DOE/RL 1995d).

A.1.2 Environmental Restoration Disposal Facility

The Environmental Restoration Disposal Facility (ERDF) serves as the receiving facility for wastes generated by remediation of CERCLA past practice units at the Hanford Site. This disposal facility will receive remediation wastes, which are expected to consist of hazardous/dangerous wastes, polychlorinated biphenyl (PCB) waste, asbestos waste, radioactive waste, and mixed waste (containing both hazardous/dangerous and radioactive waste). A large portion of the waste in the ERDF is expected to originate from areas along the Columbia River where it is anticipated that operable unit records of decision (RODs) will require excavation and removal of large volumes of remediation-generated wastes to the ERDF.

A remedial investigation/feasibility study (RI/FS) (DOE/RL 1994b) was completed to examine the impacts of construction and operation of the ERDF, which is located in the south-central part of the 200 Area plateau. As part of the RI/FS, a fate and transport model was developed to predict groundwater concentrations at the ERDF boundary. Model predicted concentrations were compared to Hanford Site background concentrations to identify contaminants that would exceed background levels. In addition, model estimates were compared to risk-based *de minimis* concentrations to develop a list of contaminants of potential concern. A 10,000-year travel-time constraint was also used as a criterion for identifying key groundwater contaminants; some contaminants having a travel time in excess of 10,000 years were not considered to be of concern.

This analysis used a fate and transport spreadsheet model that was developed to represent hydrogeological conditions of the ERDF site, the physical and chemical properties of the waste form, and the fate and transport properties of each contaminant constituent. The estimation of these parameters relied first on ERDF-specific information and then on Hanford Site background information, when available. Saturated zone parameters included 1) the average hydraulic gradient estimated at ERDF (0.0035) from water table conditions in December1991, 2) saturated hydraulic conductivity of the uppermost aquifer (30 m/day) estimated from pump-tests results from wells near the ERDF, 3) an assumed saturated zone porosity of 0.30, 4) saturated zone density of 1.6 kg/L, and 5) a saturated zone mixing depth of 5 m.

The methodology described above and summarized in more detail in Appendix A of DOE/RL (1994b) was used to evaluate various alternatives considered in the RI/FS, including: 1) a no action alternative and 2) a series of alternatives focusing on specific design characteristics associated with the implementation of the ERDF. The latter set of alternatives considered the impacts of implementing various combinations of liners, low-infiltration soil barriers, Resource Conservation and Recovery Act (RCRA)-compliant barriers, and the Hanford Protective Barrier.

A.1.3 Hanford Remedial Action and Comprehensive Land Use Environmental Impact Statement

As part of the transition from production of nuclear materials for national defense to environmental restoration and long-term management of wastes, DOE must determine the optimum use of Hanford Site lands, facilities, and resources and how these lands and facilities should be remediated to allow for beneficial future uses. The Hanford Remedial Action (HRA) and Comprehensive Land Use Environmental Impact Statement (EIS) (DOE 1996a) documents, in the public forum, the process of determining the best combination of potential land uses, remediation benefits, and remediation costs. As a part of this EIS, environmental-consequence analyses were performed to evaluate the potential impacts of land-use alternatives, including unrestricted, restricted, and exclusive future land use.

The approach used to assess the human-health impacts for the land-use alternatives combined individual waste sites into groups and integrated the effects of potential releases to the environment. This was accomplished by grouping waste sites by medium (e.g., soils, groundwater) and aggregating the waste sites into 1-km^2 (0.4-mi^2) cells in a grid overlaid on the Hanford Site. The potential contaminant release and transport through the environment from each 1-km^2 (0.4-mi^2) cell were estimated using the MEPAS computer model (Droppo 1991). Modeling results from multiple cells were combined to estimate the contaminant concentrations in the soil, groundwater, surface water, and air to which a human or ecological receptor might be exposed. Source-term data were compiled from the Waste Information Data System, Solid Waste Information Tracking System (SWITS), and Hanford Environmental Information System (HEIS) databases, and from field investigation reports and other sources, when applicable.

The risk to a given receptor was determined by estimating the quantity of contaminant transported from a source to that receptor. Risk calculations were simplified by separating the computational process into discrete modules. These modules included the source (waste) terms, contaminant-transport mechanisms, exposure scenarios, and the variables used to calculate the risk or hazard index from a given exposure. The MEPAS model was used to estimate risk.

As stated in DOE (1996a) MEPAS was selected because it was the only multimedia computer model that included all of the required features, namely, it 1) addresses radioactive and hazardous chemical wastes, 2) provides user flexibility by allowing the use of site-specific data, 3) performs on- and off-site calculations, 4) is largely based on the solutions to the advection-dispersion equations for solute transport, 5) includes the ability to model various atmospheric transport mechanisms, 6) addresses both active and inactive sites and releases, 7) allows for arbitrary time-varying source-term emission rates, and 8) addresses contaminated soils, ponded sites, liquid discharges, injection wells, and point, line, and area sources.

To better represent the distribution of contaminants (and risk) over the Hanford Site, the groundwater transport portion of MEPAS was solved along aquifer flow pathlines originating at all 1-km^2 cells representing waste sites. Straight-line approximations to the pathlines were used to accommodate the assumption of one-dimensional advection used in MEPAS. The pathlines were based on the predicted flow-field from 1992.

To generate pathlines for input to MEPAS, the unconfined aquifer at the Hanford Site was simulated with a site-wide groundwater model developed under the Groundwater Surveillance Project (Wurstner and Devary 1993). This two-dimensional groundwater flow model used the finite element code CFEST (Gupta et al. 1987). The model consisted of 997 nodes. Constant-head boundary conditions were used for the Columbia and Yakima Rivers and for Cold Creek Valley recharge. The river values represented average heads. A constant-flux condition was used to represent Rattlesnake Hills Spring discharge. No-flow boundaries were used for the bottom and top of the model domain and along basalt outcrops. The distribution of transmissivity was taken from the inverse simulation of Jacobson and Freshley (1990) and represented an integrated value across the Hanford and Ringold formations. Storativity was assumed to be spatially homogeneous. Temporally variable artificial recharge from site operations was included in the 12-year simulation (1980-1992).

A.1.4 Hanford Groundwater Project

Groundwater modeling is being used to actively support key objectives of the Hanford Groundwater Project, which include 1) to identify and quantify existing, emerging, or potential groundwater quality problems and 2) to assess the potential for contaminants to migrate from the Hanford Site through the groundwater pathway.

Two recent assessments related to the Hanford Groundwater Program that made extensive use of groundwater modeling include

- predicting impacts of future water-level declines on site-wide monitoring wells
- developing a three-dimensional groundwater model and its application to evaluating the impacts of existing contaminant plume migration on Hanford Site drinking water systems and groundwater use

These two groundwater modeling efforts are briefly described below.

A.1.4.1 Predicted Impacts of Future Water-Level Declines on Site-Wide Monitoring Wells

Wurstner and Freshley (1994) used a two-dimensional, site-wide groundwater flow model to evaluate the impact of declining water levels on existing monitoring wells in the unconfined aquifer. The model was used to predict water-level declines in selected wells in the operating areas (100, 200, 300, and 400 Areas) and the 600 Area. The model used in this study was described in Wurstner and Devary (1993) and was based on the CFEST code (Cole et al. 1988; Gupta et al. 1987). CFEST was chosen because of its historical use in the Hanford Site Ground-Water Surveillance Project.

The boundary conditions for the model consisted of constant head along the Columbia and Yakima Rivers and along the Cold Creek Valley. Constant-flux boundaries were used in the Rattlesnake Hills Spring discharge and along the Dry Creek Valley. No-flow boundaries were used along basalt outcrops. The base of the model was the top of the basalt and was assumed to be a no-flow boundary. Natural recharge was not modeled. Artificial recharge from site operations was based primarily on historical records and projected Site operations.

Transmissivity values were spatially variable and were based on the inverse calibration of Jacobson and Freshley (1990). Specific yield was assumed to be homogeneous and was based on a trial-and-error calibration, with the selected value providing the best match to interpolated water-table contours based on 1992 data.

Water table predictions of transient changes from the period between 1979 and 1992 compared favorably with the overall trends observed in hydrographs at a few selected wells in the 200 areas. For most of the 200 area plateau, the 1992 water table surface was in good agreement with interpretations of conditions observed in 1992. Significant differences were observed in areas north of Gable Mountain where perched water is hypothesized to exist and in the southeast part of the modeled regions where the water table is defined by measurements at only a few well locations. A specific yield of 0.35 provided the best match to interpretations of measured head values.

Predictions for 1993-2005 were used to assess the impact of declining water levels. The analysis showed that a large number of wells currently being monitored will begin to go dry or will become difficult to sample during the period simulated. In general, the projections made with the model showed that wells in the 200-West and B-Pond areas will be impacted the most by water-table changes. Maximum water-level declines simulated by 2005 in these areas were on the order of 2 to 3 m.

A.1.4.2 Evaluation of Impacts of Existing Contaminant Plume Migration on Hanford Site Drinking Water Systems and Groundwater Use

A three-dimensional site-wide model of groundwater flow and transport was developed under the Hanford Groundwater Project to increase the understanding of contaminant transport on the Site and to better forecast the migration of the contaminant plumes being monitored by the project. A description of the model can be found in Thorne and Chamness (1992), Thorne et al. (1993), Thorne et al. (1994), and Wurstner et al. (1995). The initial model was based on the CFEST code

(Gupta et al. 1987; Cole et al. 1988). The model has since been updated using a newer version of the CFEST code called CFEST-96 (Gupta 1997). The CFEST codes were selected for use in this study because 1) they have a history of application to site-wide modeling at the Hanford Site, 2) the use of the finite element method allows the three-dimensional structure of the unconfined aquifer to be represented accurately, and 3) the expertise in applying and modifying the code(s) was readily available.

The geologic conceptual model for the three-dimensional application was developed from available well logs, which were used to define the lateral and horizontal extent of the major hydrogeologic units of the Ringold and Hanford formations. Interpreted areal distributions and thicknesses for the major units were integrated with EarthVision, a three-dimensional visualization software package, which was then used to construct a database of the three-dimensional site conceptual model. The resulting conceptual model contains nine hydrogeologic units above the uppermost basalt.

The boundary conditions for the three-dimensional model were similar to those used in the two-dimensional CFEST model described in the previous section. To determine the three-dimensional spatial distribution of hydraulic parameters, the steady-state, two-dimensional model of the unconfined aquifer system used in Jacobson and Freshley (1990) was re-calibrated to 1979 water-table conditions using the statistical inverse method implemented in CFEST-INV (Devary 1987). The three-dimensional hydraulic conductivity was set such that it was consistent with the two-dimensional results of the re-calibration and also with knowledge of the three-dimensional structure of the aquifer and the estimated properties of the hydrogeologic units. Specific yield of the three-dimensional model was also calibrated to match the observed, transient water-table elevations between 1979 and 1996.

The three-dimensional model was applied to predict the future response of the water table to postulated changes in Hanford operations. Over about a 300-year period following elimination of wastewater discharges to the ground at the site, model results showed that the water table will drop as much as 11 m in the 200-West Area and 7 to 8 m in the 200-East Area near B Pond. The resulting decrease in the saturated thickness of the unconfined aquifer could cause the unconfined aquifer to the north and south of the Gable Butte anticline to become hydrologically separated. As a result, flow paths from the 200-West Area and the northern half of 200-East Area which currently extend through the gap between Gable Butte and Gable Mountain, may be effectively cut off in the future.

Modeling activities in FY 1997 included three-dimensional model simulations of the existing tritium, iodine-129, technetium-99, uranium, and strontium-90 plumes originating from the 200 Area plateau. Each of the transport simulations was based on the predicted future transient-flow conditions and a high-resolution, finite-element grid designed to resolve transport calculations in the areas of current and future contamination.

Projected future levels of tritium suggested that water-supply wells in the 400 Area and emergency water supply wells in the 200-East Area will continue to be impacted by the tritium plume originating from the 200-East Area for the next 10 to 20 years. Model results suggested that tritium concentrations now found in the 300 Area in excess of 2,000 pCi/L will not reach the North Richland well field. The transport analysis suggested that only water supplies in the 200-East Area could be impacted by elevated levels of iodine-129. Projected future levels of technetium-99, uranium, and strontium-90 show that none of the identified water supplies on the

Hanford Site, including those in the 200-East Area near B-Plant and AY/AŻ tank farm, will be impacted by future transport of these contaminants.

A.1.5 Composite Analysis

In response to Recommendation 94-2 of the Defense Nuclear Facilities Safety Board (DNFSB), DOE has directed field sites to include in site performance assessments an analysis of the impact of other radioactive sources that could add to the dose from active or planned low-level waste (LLW) disposal facilities. In response to this, an initial composite analysis of the Hanford Site was initiated in FY 1996 and is currently being conducted as part of the Hanford Groundwater Project. This composite analysis is focusing on the 200 Area central plateau because of the variety of LLW facilities (e.g., 200 West and 200 East burial grounds, LLW from tank wastes, and the ERDF trench) impacted by the DNFSB recommendations. A draft document summarizing this initial assessment is scheduled to be completed by March 31, 1998 (Kincaid et al. 1998).

As part of the Composite Analysis, site-wide groundwater modeling was carried out to assess dose impacts for the offsite transport of existing plumes and future releases of contaminants in the 200 areas. Efforts were made to identify and screen all sources that could potentially interact with contaminants from Hanford LLW disposal facilities. Inventories and projected releases of radionuclides that are expected to contribute to the predicted doses were established for each of these sources.

Flow and transport in the unsaturated zone beneath each individual source was modeled in one-dimension using STOMP (White and Oostrom 1996, 1997; Nichols et al. 1997). Contaminant fluxes to the aquifer resulting from the STOMP simulations were used as input to a three-dimensional model of groundwater flow and transport. This three-dimensional unconfined aquifer model was based on the model described in the previous section. The CFEST-96 finite element grid was modified for the Composite Analysis to accommodate the large number of sources. Cell sizes were reduced in the neighborhood of the 200 Areas (to 375 m on a side) to accurately represent the many contaminant plumes and the three-dimensional structure of the aquifer (23,668 total nodes were used).

Hydraulic conductivity was calibrated as described in the previous section by preserving the results from a two-dimensional calibration and interpreting this with the available three-dimensional hydraulic property information. Specific yield was calibrated by matching transient water table data from 1979-1996. Specific yield was homogeneous within the Hanford sediments and within the Ringold sediments. Dispersivity values were based primarily on computational and geometric considerations. Transverse dispersivity was taken to be 20% of the longitudinal value. Distribution coefficients were estimated from a variety of information. Bulk density and effective porosity were assumed to be homogeneous and were based on selected Hanford Site data.

Flow conditions were simulated from 1996 to the year 4000 using projected operational discharges and estimates of natural recharge. Current and future contaminant plume transport was simulated from present day conditions to the year 3000. Forecasts of concentrations of key radioactive contaminants provided the basis for final dose calculations using standard dose conversion methodologies and exposure scenarios and parameters identified by the HSRAM (DOE/RL 1995d). Dose impacts from the existing plumes and future releases of contaminants were assessed in the area outside of the waste-management exclusion areas and the surrounding buffer areas established by the Future Site Uses Working Group. Potential dose impacts to the public after site closure in 2050 for four potential exposure scenarios derived from HSRAM (the agricultural, residential, industrial, and recreational exposure scenarios) were evaluated.

A.1.6 100-Area Remediation Activities

Groundwater modeling on a relatively small scale has been carried out at several of the 100 Areas to support the remediation of contaminated groundwater. The modeling activities discussed in this section have been used to support focused feasibility studies and interim remedial actions. The activities briefly summarized here include

- numerical simulation of strontium-90 transport from the 100-N Area liquid waste disposal facilities (LWDFs)
- evaluation of the N-Springs barrier and pump-and-treat system
- evaluation of the impact of bank storage at the 100-N Area
- focused feasibility studies in the 100-H, 100-D, and 100-K areas
- design of the interim remedial action for the 100-H, 100-D, and 100-K areas.

A.1.6.1 100-N Area LWDF Simulation

Strontium-90 transport was simulated in the 100-N Area to estimate the effect of the LWDF on the future water quality of the unconfined aquifer at the shoreline of the Columbia River (Connelly et al. 1991). This included estimating dose under a no-action alternative. Water levels were expected to change given the cessation of discharges to the LWDF.

Two models were developed for this study. VAM2D (Huyakorn et al. 1991) was used to simulate a two-dimensional cross-section of the unsaturated and saturated zone. (A similar study using VAM2D had been previously carried out for the 100-N Area; see Lu 1990.) In addition, PORFLO-3 (Sagar and Runchal 1989; Runchal and Sagar 1989) was used to simulate flow and transport in a three-dimensional domain consisting of the unsaturated zone and the unconfined aquifer. Reasons given for using both models were compliance with in-house development and maintenance procedures and previous use at the Hanford Site. The PORFLO-3 model used a Cartesian grid with variable grid spacing and a total of 34,816 grid cells (32 by 34 by 34 grid cells).

The Columbia River was modeled as a constant-head boundary that was allowed to vary over time according to the observed seasonal change in river elevation. The bottom of the model domain was a no-flow boundary, representing the lower mud unit of the Ringold Formation. A small, constant flux was applied at the top boundary to represent long-term average recharge of 5 mm/yr. The remaining three sides of the domain were constant-head boundaries, with the head values set to result in a gradient across the domain of 0.00095, the observed gradient in 1964 (the year discharges to the LWDF began). The discharge of water and strontium-90 from the LWDF was based on available data. Discharges were estimated for those years with no data.

Since the model explicitly simulated flow in the unsaturated zone, characteristic parameters of moisture retention were required. These were estimated from 10 soil samples obtained in the 100-N Area for this purpose. Parameters for each of the samples were estimated using a curve-fitting program. Parameters from the sample judged most representative were used in the numerical model (i.e., the unsaturated zone properties were homogeneous). The average saturated hydraulic conductivities were estimated from previous studies. Horizontal hydraulic conductivities were taken to be 10 times the vertical values. Hydraulic conductivities were assumed to be homogeneous within the Hanford and the Ringold formations.

Effective porosity of the vadose zone was based on the moisture retention of the representative soil sample. Effective porosity in the aquifer was based on a previous study. Specific yield and dispersivities were based on literature values. The diffusion and distribution coefficients were based on previous studies of Hanford sediments.

Calibration using the flow model compared simulated and observed arrival times of a conservative solute and water table elevations in July 1969. The only parameter adjusted was the hydraulic conductivity. The arrival times and the water table elevations could not be simultaneously matched by varying the conductivity alone. The conductivity value chosen for use in the simulation was a value between that matching the arrival times and that matching the water-table elevations.

Calibration of the solute-transport model compared the simulated and observed concentration of strontium-90 at N Springs in 1974. The parameter adjusted was the distribution coefficient. A large value for this parameter was applied over a thin layer (0.68 m thick) beneath the strontium-90 source area to represent potential filtration of particulate strontium-90 by a sludge layer. The calibration simulation was carried out from 1964 to 1974, although there were no source-term data for strontium-90 over the years 1964-1972. The limitation of this calibration analysis was recognized.

Results from the model were shown as plan and cross-sectional views of the water-table elevation and the strontium-90 concentration. Travel paths were also shown. The simulation was carried out from 1964 (the start of discharge to the LWDF) to 2020. Strontium-90 concentrations at the river boundary and water flux into the river were used to calculate doses.

A.1.6.2 Evaluation of N-Springs Interim Remedial Action

A model of the 100-N Area groundwater was also developed to evaluate the ability of proposed interim remedial alternatives to limit the flux of strontium-90 into the Columbia River (DOE/RL 1995e; see also DOE/RL 1996a). The alternatives considered were a barrier wall, with and without a pump-and-treat system.

Two codes were used in this modeling activity. FLOWPATH (Franz and Guigner 1992) was used to model two-dimensional groundwater flow in plan view. PORFLOW (Runchal and Sagar 1993) was used to model two-dimensional flow and transport in a cross section. Both codes used the finite difference method. Both models looked at saturated flow only (i.e., flow and transport in the unsaturated zone were not considered). Both models used Cartesian grids with variable node spacing. The plan-view model based on FLOWPATH used 1334 nodes with cell size varying from 25 feet by 25 feet to 1000 feet by 500 feet. The cross-sectional model based on PORFLOW used 5100 nodes with cell size varying from 0.25 feet by 2 feet to 1 foot by 2 feet.

Steady-state flow conditions were assumed for both models. Although the daily and seasonal variation in the Columbia River stage was acknowledged, it was assumed that the presence of the barrier wall would lead to steady-state conditions in the region of concern. The head along the river boundary was set at the mean yearly river level from automated, hourly measurements taken during 1993, taking into account the measured downstream river gradient. A no-flow condition was set along the vertical barrier wall. For the plan-view model based on FLOWPATH, the top and bottom boundaries were no-flow (i.e., recharge from precipitation, and discharge to or from the confined aquifer were assumed to be nil). Sensitivity of the model results to non-zero recharge was examined. The remainder of the boundaries were assumed to be constant head boundaries with individual nodal-head values determined from an interpolated map of March 1994 water-level measurements.

For the cross-sectional model based on PORFLOW, an assumption was made as to how high the steady-state water level would be in the presence of a vertical barrier wall. This assumption was based on the results of previous modeling. The water level value arrived at was applied to the up-gradient boundary for those cases in which a barrier was used. Top and bottom boundaries were no-flow as was the down-gradient boundary representing that portion of the aquifer under the river.

The transport portion of the cross-sectional model based on PORFLOW used constant concentration boundaries everywhere. Initial conditions for the transport set the relative concentration to 1.0 in the top 20 feet of the aquifer and to 0.0 elsewhere. The transport boundary and initial conditions were based on previous reports that strontium-90 is limited to the top of the unconfined aquifer.

All parameters were assumed to be spatially homogeneous. Only the Ringold Formation upper-gravel unit and the upper-mud unit were modeled. Horizontal hydraulic conductivity in the gravel unit was taken as the average value from six aquifer tests in the 100-N Area. Vertical hydraulic conductivity was taken as one-tenth the horizontal value. The conductivity in the mud unit was taken from the literature for a similar soil. For the mud unit, conductivity was isotropic in all but one case. Limited sensitivity analyses were conducted by varying the hydraulic conductivity used in the model.

The thickness of the unconfined aquifer was assumed to be constant and was based on existing data. For the cross-sectional model, the distribution coefficient for strontium-90 was determined by assuming a retardation factor of 100, based on previous studies. No explanation was given for the source of the bulk density and effective porosity values. For the cross-sectional model, the longitudinal dispersivity was set to 0.1 feet, approximately one-tenth the size of the grid cell. Transverse dispersivity was set at one-tenth the longitudinal value.

A number of remediation alternatives involving vertical barrier walls of different lengths and various number of pumping/injection wells were simulated with the plan view model. Strontium-90 concentrations at the river were estimated from calculated travel times and interpolated initial concentrations. The extraction wells were found to have a minimal effect on the flux of strontium-90 into the Columbia River. The effect on strontium-90 flux from varying the position of the bottom of the barrier water (from 1.2 m into the mud unit to 0.6 m above the mud unit) was examined with the cross-sectional model.

A.1.6.3 Bank-Storage Modeling at 100-N Area

The time-variance of the Columbia River stage and its effect on contaminant transport at the 100-N Area were modeled by Connelly et al. (1997). Several previous modeling studies conducted at the 100-N Area (Lu 1990; DOE/RL 1995e, 1996a) had assumed a time-invariant boundary condition for the Columbia River. Connelly et al. (1991) considered only seasonal changes in the river stage. The Columbia River's stage is known to vary, however, on annual, seasonal, and daily cycles. This time varying boundary condition was shown by Connelly et al. (1997) to have potentially significant impacts on contaminant transport in the groundwater.

The two-dimensional cross-sectional model developed by Connelly et al. (1997) used the STOMP code (White and Oostrom 1996, 1997; Nichols et al. 1997) to simulate the interaction between the rise and fall of the Columbia River, the unconfined and the capillary fringe directly above the water table in the 100-N Area. The numerical grid consisted of 10,286 cells varying in size from 0.5 by 0.5 m at the vadose-zone seepage face to 3 by 0.5 meters away from the vadose-zone seepage face. Of the 10,286 grid cells modeled, 3585 cells lay above the Columbia River bed or on the land surface.

The stratigraphy used in the modeling was based on geologic data from boreholes drilled in the 100-N Area. The two major hydrogeologic units considered included the Hanford Gravel and the Ringold Unit E, which is a variably cemented pebble to cobble gravel with a fine- to coarse-grained sand matrix. The vertical sequence modeled ranged from an elevation of 125 m to a depth of 107 meters, where the base of the model was assumed to be the top of the lower Ringold Mud unit.

The lower boundary on the top of the Ringold Mud Unit was assumed to be a no-flow boundary. The upper boundary was a constant-flux boundary representing natural recharge of 2 cm/yr. The boundary of the model inland from the river was set at no flow in the vadose zone and to a time-dependent constant-head boundary in the saturated zone. The value of the head in the saturated zone was varied on an hourly basis based on water-level data recorded at a well (well number 199-N-67). Nodes on the river bed were set to a time-dependent constant-head boundary based on river-stage measurements made at the 100-N Area river-monitoring station. The remaining boundary was set as no flow.

Initial estimates of hydraulic conductivity and porosity were developed based on aquifer tests and soil analyses collected near the LWDF facilities. Estimates of the unsaturated zone hydraulic properties were also made using available information on hydraulic conductivity, particle density, specific storage, porosity, and the assumed van Genuchten curve fitting parameters. The estimates of hydraulic conductivity and porosity were varied to calibrate the model to transient observed water-level measurements in wells between the Columbia River and well 199-N-67.

A 125 hour transient simulation was used to develop initial conditions for a 4-week period of simulation. During this period, the model was used to simulate the transient interaction of the Columbia River and the unconfined aquifer in 1-hour time steps. Because of the large volume of data generated by the simulation, the modeling results were summarized in a time-series animation of river stage and aquifer-head fluctuations during the period of simulation. This animation was used to display changes in water travel times in the riverbank and water-flux calculation to and from the Columbia River due to both bank storage and regional groundwater gradients.

Results of the modeling demonstrated that the variation in the Columbia River stage has a significant impact on the unconfined aquifer system close to the river. Particle-tracking analyses showed that consideration of the transient conditions of the river increased water velocities over those calculated for steady-state conditions. Water-mass calculations also demonstrated the importance of bank storage in calculating total water movement from the unconfined aquifer and the Columbia River at the100-N Area.

A.1.6.4 Focused Feasibility Studies in the 100 Areas

Focused feasibility studies at the 100-HR-3 and 100-KR-4 groundwater operable units used groundwater flow and transport modeling to compare remediation alternatives for chromium contamination. These modeling activities are described in DOE/RL (1995a, b, and c). The modeling was not intended to be used for design purposes or for quantifying a measure of remediation effectiveness or efficiency. Separate models were developed for each of the areas within the two operable units. MODFLOW (McDonald and Harbaugh 1988) was selected for flow modeling based on its ability to simulate unconfined flow on a desktop computer. MT3D (S. S. Papadopulos and Associates 1991) was used for transport because it is well documented and interfaces with MODFLOW.

Natural recharge was assumed to occur at a rate of 5 cm/yr. In the 100-H area, however, a recharge value of 7.3 cm/yr was used because this produced a better fit to water table data. It was assumed that there is no hydrologic communication between the unconfined aquifer and lower layers, that the contaminants are uniformly mixed throughout the aquifer depth, and that there is no source of chromium in the unsaturated zone. The Columbia River was modeled as a head-dependent flux boundary, with no change in depth of the river over the length of the model. Steady-state flow was modeled.

Elevations for the bottom of the model were derived from interpretation of contoured borehole data. Conductivities were determined in a calibration using the steady-state flow model and matching water table data from 11/16/93. For the 100-D Area model, a single layer for the aquifer was used. The hydraulic conductivity was uniform except for a limited area around a set of four wells. For the 100-H Area model, a second layer representing the Ringold formation was added to improve the calibrated fit. Different conductivities were used for the two layers of the model representing the Hanford and the Ringold Formations. For the river, the bed thickness was assumed to be 1 m. The conductivity of the river bed was determined in the calibration. The River Package in MODFLOW was used to model the river.

A sensitivity analysis of the 100-D Area transport model was performed to gauge the sensitivity to porosity, dispersivity, and retardation. A calibration of the 100-H Area transport model was performed by adjusting model dispersivity, retardation and porosity. A table was provided listing the parameter values used in the calibration runs. Observed chromium concentration data from October and November 1992 were used to evaluate the calibration. The parameters resulting in the lowest mean error were used.

Various modifications to the basic model were made to simulate each of the remediation alternatives, including the modification of conductivities (to represent a barrier wall) and the location and pumping rates of injection/discharge wells. Simulation times varied from 14 to 21 years.

A.1.6.5 Interim Remedial Action Design in the 100 Areas

Models were developed of the 100-HR-3 and 100-KR-4 operable units to help determine the placement of new wells and the use of existing wells to support the pump and treat interim remedial action, and to estimate extraction/injection rates for design (ERC 1996; DOE/RL 1996b). The MicroFem code (Hemker and Nijsten 1997) was used for this design study. This code is a two-dimensional finite element flow simulator with built-in pre- and post-processing and automatic (triangular) mesh generation. Stated reasons for selecting this code were the ability to get high-resolution grids around pumping and injection wells, use of the finite element method, capability to model transient and steady-state conditions (flow), and the generation of graphical output.

The Columbia River was assumed to be one of the boundaries for the 100-H, 100-D, and 100-K Area models. The river was modeled as a constant-head boundary with the river stage known and constant in time. The flux through the river boundary was calculated as the product of a vertical resistance between the river and the aquifer and the difference in head between the river stage and the aquifer. The 100-H and 100-K Areas were felt to have no natural boundaries, so the model boundaries were located far from the wells to minimize boundary effects. No-flow boundaries were adopted approximately perpendicular to the river and constant head boundaries were used parallel to the river. The constant-head boundaries were placed along the interpolated hydraulic-head contours from water level measurements. For the 100-D Area model, constant-head boundaries were used. These boundaries were based on knowledge of discharge across natural boundaries and on a water-table map of June 1995. The bottom boundary was set to the Hanford and Ringold contact for the 100-H Area model and to the top of the upper mud unit of the Ringold Formation at 100-D.

The model parameters required were transmissivity, porosity, and aquifer thickness. In all cases the aquifer porosity was assumed constant. For the 100-H Area model, a constant conductivity was assumed based on the average value of aquifer test results. A variable aquifer thickness was assigned based on interpolations of water level data and Hanford/Ringold contact data. Transmissivities were therefore spatially variable. Calibration was conducted using a steady-state flow model and comparing predicted and observed heads for 1/94 to 8/95. The resistance term between the river and the aquifer was varied.

For the 100-D Area model, aquifer thickness was assigned a uniform value because there was insufficient data to support a spatially variable thickness. Transmissivity was based on a weighted average of the Ringold and Hanford formation conductivities, which were average values from limited aquifer test data. Weighting was by the estimated thickness of the Hanford and Ringold formations. Calibration was conducted using a steady-state flow model and adjusting the constant-head values at the boundaries and attempting to match water-level data from 6/93 to 5/95.

For the 100-K Area model, thickness and transmissivity were assumed constant. Conductivity was based on limited aquifer test data. Calibration was similar to that used for the 100-D Area model.

Steady-state flow fields were calculated for the 100-D and 100-K Area models. Five-year transient simulations were carried out for the 100-H area. Streamlines and capture zones were calculated for a number of pump-and-treat scenarios (different well placements and injection/extraction rates). No simulations of contaminant transport were conducted, but concentrations in the 100-D Area were estimated based on the flow-model results.

A.1.7 200-Area Remediation Activities

As part of the design process for pilot-scale pump-and-treat tests, capture-zone analyses of the 200-UP-1 and 200-ZP-1 groundwater operable units were carried out. These modeling analyses are described in WHC (1994) (see also BHI 1996a, b). The stated objectives of this study were to evaluate alternative interim remedial actions, to assess refinements or expansions of interim actions, and to help choose a final remedy. Additional specific objectives were to assess impacts of changes in the water-table elevation, to evaluate well configurations for the pump-and-treat, to design and evaluate monitoring networks, to evaluate hydraulic control and containment, and to predict contaminant-transport pathways and travel times.

The VAM3D-CG computer code (Huyakorn and Panday 1994) was selected for the following reasons. It was being used for the site-wide modeling, and thus the 200 Area results could be more easily integrated into the larger scale model. The finite-element method used by VAM3D-CG allows for non-rectangular elements and boundaries. VAM3D-CG uses of transitional elements allows for a fine grid around wells and a coarse grid in areas with less steep gradients. The pseudo-soil function used in VAM3D-CG provides an efficient means to approximate the water-table condition, and VAM3D-CG has been approved for use on the Hanford Site.

The final three-dimensional grid used to model the 200-West Area had 19,383 elements, ranging in size from 600 m to 9.5 m in the horizontal direction. The vertical dimension was made up of six elements, equally divided over the depth of the unconfined aquifer at each node location in the horizontal plane.

The water-table elevation as measured in June 1993 was used as the initial condition. The bottom boundary and the boundaries along the Yakima Ridge and Gable Butte were no-flow boundaries. The remaining side boundaries were held at a constant head, with head values based on the June 1993 water-table map. Artificial recharge from site operations was applied at appropriate locations, but the natural recharge was assumed to be zero. To represent the conditions in 1976, a large artificial recharge was applied to the center of the 200-West Area model, and a steady-state simulation was performed. This steady-state solution was used as the initial condition for transient solutions in which the artificial recharge was gradually reduced. Recharge fluxes were based on previous studies.

Hydraulic conductivities were assigned based on a previous study (Connelly et al. 1992b) modified by more recent data. Where data did not exist, average values were used. Conductivity was uniform in the vertical direction except in a region where the aquifer becomes quite thin. Four of the elements in the vertical direction were made inactive in this region to avoid computational difficulties. Conductivities were isotropic in the horizontal plane. Vertical conductivity was assigned a value one-tenth the horizontal conductivity. A spatially uniform effective porosity value was used in the travel time calculations.

The transient simulation (with decreasing artificial recharge) used the steady-state simulation results as an initial condition for 1976. The simulation results were qualitatively compared to the water table observed in June 1993. Significant differences in the predicted and observed heads were noted, but no boundary conditions or parameter values were adjusted to provide a better fit.

Capture zones using one pumping and one injection well were calculated for various well locations and for times up to 150 days. In addition, the uncertainty in the spatial distribution of hydraulic conductivity was recognized, and a single simulation was carried out in which the wells were located near a boundary between a high-conductivity and a low-conductivity zone. The capture zones were found to change drastically.

A.2 Key Projects in the Waste Management Program

Following is a review of project activities that have used groundwater modeling to support major objectives for the Waste Management Program. These summaries reflect information provided by DOE/RL technical project managers and contractor personnel from Fluor Daniel Northwest and Waste Management Federal Services Hanford. The modeling activities summarized include those associated with

- performance assessments of solid-waste burial grounds in the 200 East and West areas
- permitting of liquid effluent facilities, including the State-Approved Liquid Discharge Site (SALDS) associated with the Effluent Treatment Facility (ETF)

A.2.1 Performance Assessments of Solid Waste Burial Grounds in the 200 Areas

Since September 26, 1988, performance-assessment analyses have been required by DOE Order 5820.2A to demonstrate that DOE-operated waste-disposal facilities containing DOE-generated low-level radioactive wastes (LLW) can comply with the appropriate performance objectives. Two separate performance assessments that have included use of groundwater modeling have recently been completely for post-1988 solid LLW disposal facilities located in the 200-East and 200-West Areas (Wood et al. 1995, 1996). The following is a brief description of the scope and groundwater modeling activities carried out to support these analyses.

The performance assessment of the 200 East Area low-level burial grounds (LLBG) examined the long-term impacts of LLW and radioactive constituents of the low-level mixed wastes (LLMW) disposed of in waste burial areas in two locations: 1) the active 218-E-10 burial ground and adjacent burial grounds in the northwest corner of the 200-East Area and 2) the active 218-E-12B burial ground and adjacent inactive burial grounds located in the northeast corner of 200-East Area. A separate analysis was included to examine the impacts of reactor compartment wastes disposed of in trench 94 of the 218-E-12B disposal facility. LLW disposed of in active and inactive burial grounds before September 26, 1988, were not considered in this analysis.

The performance assessment of the 200 West Area LLW burial grounds examined the long-term impacts of LLW and radioactive constituents of the low-level radioactive mixed wastes (LLMW) disposed of in several active waste burial areas situated along the west boundary of 200-West Area. Burial grounds considered in the analysis included 218-W-3A, 218-W-3E, 218-W4C, and 218-W-5. LLW disposed of in retired or inactive burial grounds before September 26, 1988, (218-W-2, 218-W-4A, 218-W-4B, and 218-W-11), were not considered in this analysis.

To address the performance objectives related to groundwater contamination, two groundwater exposure scenarios were considered. One scenario consisted of an all-pathways exposure in which 1) radionuclides are leached from the disposal facilities and are subsequently transported by infiltrating water through the vadose zone to the underlying unconfined aquifer, and 2) an individual drills a well that draws contaminated water for drinking, crop irrigation, and livestock production, and a dose is received by ingestion of contaminated water, crops, milk, and beef, direct exposure to gamma-producing radionuclides in soil, and inhalation of contaminated dust. The second exposure scenario involved a drinking water scenario where only ingestion of contaminated water from the unconfined aquifer was considered.

The conceptual model of the analyses by Wood et al. (1995 and 1996) focused on incorporating two general processes that fundamentally control projected concentrations of radionuclides released from the LLW disposal facilities in groundwater withdrawn from the unconfined aquifer from a downstream well: 1) the total radionuclide mass flux being leached from the disposal facility per unit time and 2) the dilution that occurs as the radionuclide activity mixes with the volume of groundwater determined by the regional flow characteristics to flow beneath the facilities. To represent these processes, Wood et al. (1995 and 1996) assumed that the waste volume representative of the total wastes disposed of in the LLW facilities could be approximated by a three-dimensional rectangular box projected onto a two-dimensional plane oriented parallel to the general direction of groundwater flow.

The numerical representation of this conceptual model was established in a two-dimensional cross-sectional model based on the VAM3D-CG code (Huyakorn and Panday 1994) that extended from the disposal facility to the uppermost 5 m of the unconfined aquifer. The position of the water table in the cross-section was estimated using the site-wide model developed for use in the performance assessment (see Appendix E of Wood et al. 1996). The model was used to estimate steady-state post-Hanford site conditions underlying the various LLBG areas.

The radionuclide-release modeling results for the representative two-dimensional cross-section were extrapolated to different waste volumes and waste inventories. The following points are key aspects of the extrapolation process.

- The cross-section oriented parallel to the direction of flow and the downstream receptor well are in the same plane. Given these constraints, all activity released from the facility reaches the water table and is captured by the volume of groundwater that passes beneath the facility and ultimately intersects the downstream well. Thus, the radionuclide concentration in the water withdrawn from the well is proportional to both the integrated flux exiting across the entire trench floor and the volume of groundwater into which the contaminants are released.

- The integrated flux is dominated by the selected release mechanism. Three conditions were considered in different cases in this analysis, including

- advective releases where the radionuclide inventory was uniformly dispersed throughout the waste volume and was released by the infiltrating rainwater. In this case, the integrated flux is proportional to the radionuclide inventory and infiltration rate and is insensitive to the waste area of release.

- solubility-controlled release in which chemical conditions impose a constant concentration in contaminated water leaving the facility. In this case, the flux is not proportional to the inventory; it is proportional to the assumed radionuclide concentration, the infiltration rate, and the waste area over which the release is occurring.

- diffusion-controlled release where radionuclide release rates are controlled by an assumed diffusion coefficient. In this case, the integrated flux is proportional to the inventory, the area-to-volume ratio of individual containers, and the diffusion coefficient.

The volume of groundwater that mixes with the radionuclides released to the water table is proportional to the linear dimension of the waste volume footprint that is perpendicular to the direction of flow. Relatively little dispersion is allowed in the model, and the area over which the groundwater and the contaminant plume intersect is essentially the same as that of the area underneath the waste volume. The orientation of the areal footprint of the waste volume relative to groundwater flow remains constant. Thus, as the linear dimension of the footprint perpendicular to flow decreases or increases, the volume of mixing groundwater increases or decreases.

A.2.2 Liquid Effluents Program Support

Under the Hanford Site State Waste Discharge Permit Program, the site discharges treated cooling and wastewater to the soil column at several locations in accordance with the Washington State Administrative Code (WAC) 173-216 and DOE Order 5400.5. Individual discharge permits include the following sites:

- ST-4500, 200 Area ETF managed by Waste management Hanford – Project Hanford Management Contractor (WMH-PHMC)
- ST 4501, Fast Flux Test Facility (FFTF) secondary cooling tower water managed by WMH-PHMC
- ST 4502, 200 Area Treated Effluent Disposal Facility (TEDF) managed by WMH-PHMC
- ST 4503, 183-N backwash discharge pond managed by BHI
- ST 4507 100-N sewage lagoon managed by Dyncor-PHMC
- ST 4508, Hydrotest, Maintenance, and Construction Discharges. This is a site-wide permit managed by both BHI and contractor personnel from the PHMC.

Of these facilities, the only facility that has used groundwater modeling is the 200 Area ETF. A summary of this recent modeling support is provided in the following section.

A.2.2.1 200 Area Effluent Treatment Facility

In 1997, groundwater modeling was performed to support ongoing permitting requirements for the ETF disposal site located just north of the 200-West Area (Barnett et al. 1997). The ETF disposal site, also known as the State-Approved Land Disposal Site (SALDS), receives treated effluent containing tritium, which is allowed to infiltrate through the soil column to the water table. The facility operating permit, promulgated by WAC 173-216 (Ecology 1986), requires groundwater monitoring for tritium, reporting of monitoring results, and periodic review of the monitoring network.

The ETF began operations in November 1995, and tritium was first detected in groundwater monitoring wells around the facility in July 1996. The SALDS groundwater monitoring plan requires a reevaluation of the monitoring-well network and a revision of the predictive groundwater model used in the original permit 1 year after the first detection of tritium in groundwater.

The SALDS groundwater model was a modification of the three-dimensional site-wide groundwater model developed for use in the Hanford Groundwater Project (see discussion above). This model used the CFEST-96 code (Gupta 1997). The decision to modify the Hanford Groundwater Project model was made because of the ease in refining the pre-existing model and assigning appropriate parameter values and because of the experience in using that model. The horizontal grid spacing of the SALDS model was 350 m over most of the Hanford Site, but was refined to a 45-m grid in the region around the SALDS. Vertical discretization in this region was refined to a 6-m grid spacing. Boundary conditions and the model parameters were based on the Hanford Groundwater Project model, but were obtained for this model using a separate calibration. Effluent discharge to the SALDS, a portion of which contained tritium, was modeled. Flow and transport in the unsaturated zone were not modeled.

The model was used to simulate transient flow and tritium transport from the SALDS over the next approximately 100 years. Results were presented as plan-view contours of hydraulic head and tritium concentration and as cross-sectional views of tritium concentration.

A.3 Key Projects in the Tank Waste Remediation System Program

The following is a review of project activities that have used groundwater modeling to support major objectives for the Tank Waste Remediation System (TWRS) Program. These summaries reflect information provided by DOE/RL technical project managers and contractor personnel from Jacobs Engineering Group, Inc. (JEGI) and Lockheed-Martin Hanford Company (LMHC). The modeling activities summarized include those associated with the following key TWRS projects:

- TWRS Environmental Impact Statement (EIS)
- Hanford Tank Initiative
- Performance Assessment of the Hanford Immobilized Low Activity Waste (ILAW) Disposal Facilities.

A.3.1 TWRS Environmental Impact Statement

This EIS addresses actions proposed by DOE to manage and dispose of radioactive, hazardous, and mixed waste within the TWRS program at the site (DOE 1996b). The waste includes more that 177 million curies in about 212 million liters of waste stored or to be stored in underground tanks in the 200 Area plateau. This EIS also addresses DOE's plans to manage and dispose of 1930 capsules containing 68 million curies of cesium and strontium.

As part of this EIS, environmental consequence analyses were performed to evaluate the impacts of a number of tank-waste-management alternatives including continued management alternatives with no retrieval, minimal-retrieval alternatives, partial-retrieval alternatives, and extensive-retrieval alternatives. The groundwater part of the consequence analysis evaluated contaminant transport through the saturated unconfined aquifer using a model based on the VAM2D code (Huyakorn et al. 1991) at each of the eight tank-source areas and the ILAW disposal facility. Reasons for the selection of VAM2D were not given.

A conceptual model was developed for the unconfined aquifer that included Hanford Site stratigraphy, the upper and lower aquifer boundaries, and a table of material units and corresponding flow and transport parameters. The primary source of information for parameter values was Schramke et al. (1994). The numerical model used a grid spacing of 250 m (820 ft) overlain onto a map of the Hanford Site containing physical features and the source-area boundaries. Node numbers of model boundaries (e.g., basalt outcrop and sub-crop areas, river nodes, wastewater-effluent discharge points, the eight tank-source areas, and the ILAW disposal facilities) were determined to allow numerical representation of these features for the modeling effort.

The first phase of the modeling effort entailed establishing the steady-state flow field that was consistent with previous site-wide groundwater flow simulations (Wurstner and Devary 1993). This was accomplished by adopting, as closely as possible, the hydraulic parameters from the previous effort. The steady-state results with the VAM2D model matched results previously reported. This effort made use of EarthVision and ARC/INFO software capabilities to translate parameter distributions used for the CFEST (Gupta et al. 1987; Cole et al. 1988) version of the site-wide model into formats suitable for use by VAM2D.

Once the initial flow modeling was completed, input files were developed to perform transient transport modeling from each source area for each of the alternatives. The results of vadose-zone modeling were used to develop input records for the groundwater model. Consequently, each groundwater simulation calculated contaminant levels in the unconfined aquifer resulting from a single source area. These were later combined during post-processing to represent contaminant levels from all source areas.

The approach of performing separate contaminant transport simulations for each source area and each K_d group and later combining the results during post-processing allowed one model simulation to represent all contaminants with similar mobility from one source area.

A.3.2 Hanford Tank Initiative - AX and SX Tank Farm Assessment of Retrieval Performance Evaluation Criteria

Vadose zone and groundwater modeling assessments are being conducted as part of the Hanford Tank Initiative to provide engineering and scientific analysis necessary to evaluate the impact of tank closures. These analyses are being designed to assist RL on

- establishing appropriate retrieval techniques
- determining appropriate release during waste retrieval
- evaluating the need for new tank-retrieval technologies

- supporting the identification of the most important field characterization and technologies development area.

In the initial phases of this work, the effort has focused on performing screening-level sensitivity analyses of the AX and SX Tank farms to identify and rank transport parameters and evaluate transport phenomena in the vadose zone. These analyses are being used to better focus the development and application of more-refined two- and three-dimensional vadose-zone models, and to support field-characterization efforts by defining data needs to reduce uncertainties in the risk-assessment process. Results of these initial sensitivity analysis are summarized in two recent reports by JEGI (1998a, 1998b).

Screening-level sensitivity analyses have used the MEPAS code developed by Droppo (1991). MEPAS was chosen because it is a screening code (i.e., it uses relatively simple models for flow and transport and thus is relatively undemanding computationally, and it can provide conservative results) and has a built-in sensitivity and uncertainty analysis capability. Other advantages cited include review by a number of government agencies and other groups, wide application, an integrated risk analysis using accepted procedures, a coupled database of chemical and radionuclide properties, and a user-friendly interface.

The structure of the MEPAS code required a steady-state flow analysis with one-dimensional flow in the unsaturated and saturated zone. Based on detailed geologic studies, a simplified, nine-layer vadose zone model was constructed for the AX tank farm. Soil parameters were based on data from a number of locations in and near the 200 East and West areas (Khaleel and Freeman 1995). Distributions of parameters used in a probabilistic sensitivity analysis were obtained from the same data.

Detailed modeling at the AX and SX Tank Farm is being carried out using the PORFLOW code (Runchal 1994a, b) for both the unsaturated and saturated zone. Several retrieval and closure scenarios were evaluated with the numerical model: the influence on transport of reduced sorption near the tank release, the influence of preferential transport via the annular space in boreholes or via clastic dikes, the effect of enhanced infiltration around the tanks, and the effect of unsaturated-zone heterogeneity.

The purpose of the detailed modeling is to evaluate alternative remediation and closure options at the AX tank farm. The saturated-zone model is a two-dimensional site-wide model involving both groundwater flow and contaminant transport with risk as the endpoint. Parameters and boundary conditions of the saturated zone numerical model are based on the parameters of the three-dimensional site-wide model of the Hanford Groundwater Project. A two-dimensional model was used in part to reduce the computational requirements of the analysis. PORFLOW was selected because it is on the list of approved codes for the Hanford Site, and members of the project team were already using it. The two-dimensional model results will be compared to the three-dimensional Hanford Groundwater Project model results as a validation exercise. Draft and draft final reports on the overall retrieval performance evaluation assessment will be released in September of 1998 and January of 1999 respectively.

Additional analysis that may involve using a site-wide groundwater model will focus on analysis to support the retrieval technology selection in FY 2000 and the development of cleanup standards and tank waste residuals through FY 2003.

A.3.3 Performance Assessment of the Hanford ILAW Disposal Facility

The Hanford ILAW disposal facility performance assessment provides an analysis of the long-term environmental and health impacts of the on-site disposal of ILAW (Mann et al. 1998). DOE/RL is currently proceeding with plans to permanently dispose of radioactive and mixed wastes that have accumulated over the last 50 years in single- and double-shell tanks in the 200 areas of the site. Waste currently stored in single- and double-shell tanks will be retrieved and pretreated to separate the low-activity liquid fraction from the high-level and transuranic wastes. The low-activity fraction will then be immobilized and disposed of onsite in two near-surface disposal facilities located in the 200 East Area.

The first version of the final ILAW performance assessment (PA) was published in FY 1998 (Mann et al. 1998). An interim ILAW PA (Mann et al. 1997; Lu 1996; Mann 1995) was prepared to provide an early assessment of the effects of the disposals using available information. Much of the data used in the ILAW PA was derived from information obtained in other onsite programs. The data and information documented include the disposal site locations, geology, waste inventory, estimates of recharge, disposal package and facility design, release rates from glass waste forms, hydrologic parameters, geochemical parameters, and dosimetry. The methods and technical approaches used to generate the data values are also described. Several future revisions of the ILAW PA are planned; these will use more site-specific, waste-form specific, and facility-specific data that are planned to be generated over the next 2 to 3 years.

The proposed location for the TWRS ILAW disposal complex includes two sites. The principal site, which is located in the south-central part of the 200-East Area, will store the bulk of the ILAW generated as wastes are retrieved from single-shell and double-shell tanks for vitrification by private vendors. Another site, which is located at the previously constructed grout-disposal facility just east of the 200-East area, will be modified to receive initial quantities of ILAW from private vendors while the principal waste disposal facility is being developed.

The transport analysis of contaminants from the disposal facility considered the key physical and chemical processes causing release from the glass waste form and subsequent vertical and lateral transport through the vadose zone to the underlying groundwater. Once in the groundwater, environmental and health impacts were evaluated for a variety of points between 100 m down gradient and the Columbia River, the most important being the 200 Area fence line.

Although PORFLOW (Runchal 1994b) was chosen to model moisture flow and contaminant transport in the vadose zone and the groundwater during the code selection process for the interim PA,. VAM3D-CG (Huyakorn and Panday 1994) was used to model flow and transport in groundwater in the final ILAW PA. VAM3D-CG was chosen over PORFLOW because a site-wide model was needed, not just a model of the area near the disposal facility. An existing site-wide model based on VAM3D-CG and used in the development of the Hanford Site-Wide Groundwater Remediation Strategy (Law et al. 1997; Chiaramonte et al. 1997) was chosen for use in the ILAW PA.

The aquifer hydraulic parameters for the ILAW PA groundwater model were not modified from those used in the Hanford Site-Wide Groundwater Remediation Strategy (see section above) because of a lack of site-specific data. Longitudinal dispersivity was assigned a value one-tenth the travel length. Transverse dispersivity was set at one-tenth the longitudinal value. Recharge through the disposal facility from precipitation was assumed to occur at 0.5 mm/yr for the period when the cover is intact (1000 yr) and 3 mm/yr thereafter. As with the Hanford Site-Wide Groundwater Remediation Strategy model, however, natural recharge on a site-wide basis was not modeled.

A steady-state source of contaminants from the vadose zone was assumed. Groundwater transport simulations reached steady-state within 100 years for locations within the 200 East-Area. Calculations of dose impacts were used to demonstrate compliance with the performance objectives.

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APPENDIX B.

Summary of Technical Issues and Concerns with Proposed Site-Wide Groundwater Model Identified During April 1998 Workshop

APPENDIX B: SUMMARY OF TECHNICAL ISSUES AND CONCERNS

The following is a brief review of technical issues and comments provided by regulators, tribal nations, and other stakeholders on the proposed site-wide model. Included in the appendix are meeting handouts and notes from a workshop held with regulators, tribal nations, and other stakeholders on April 24, 1998 and written comments on the proposed site-wide model from the U. S. Environmental Protection Agency.

Technical Representative Workshop, Site-Wide Groundwater Model Consolidation

April 24, 1998

Workshop Participants

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AGENDA FOR

SITE-WIDE GROUNDWATER MODEL CONSOLIDATION

Technical Representative Workshop
Wanapum Room, ISB2
April 24, 1998

8:30 - 8:45	Welcome and Introduction	Rich Holten, DOE/RL
8:45 - 9:00	Original and Current Schedule for Model Consolidation Process	Doug Hildebrand, DOE/RL
9:00 - 9:30	Proposed Process for Model Consolidation	Doug Hildebrand DOE/RL
9:30 - 10:15	Review of Needs and Requirements - Need for Site-Wide Groundwater Model - Anticipated Uses - Required Flow and Transport Capabilities - Administrative Requirements - How do current codes/models meet needs and requirements? - Cost considerations of implementation	Marcel Bergeron, PNNL
10:15 - 10:30	Break	
10:30 - 11:45	Review of Conceptual Model of Unconfined Aquifer System - Hydrogeologic Framework - Hydraulic Properties of Major Hydrogeologic Units - Transport Properties - Aquifer Boundaries - Recharge - Relation to Basalt Confined Aquifers - Contaminant Distribution	Paul Thorne, PNNL
11:45 - 1:00	Lunch	
1:00 - 3:00	Review of Numerical Implementation	Charlie Cole, PNNL

	of Conceptual Model for HGWP and Composite Analysis of 200 Area Plateau - Translation of Conceptual Model - Flow Model Development and Calibration - Transport Model Implementation - Discussion of Flow and Transport Results
3:00 - 3:15	Break
3:15 - 4:00	Group Review of Key Technical Issues and Concerns with: - Conceptual Model - Numerical Implementation of Conceptual Model - Model Access Issues - Other Issues

Summary of Key Technical Comments and Issues

Following are meeting notes from the Technical Representative Workshop, Site-Wide Groundwater Model Consolidation held on April 24, 1998. The abbreviations of represented organizations in the notes are as follows:

Bechtel Hanford, Inc. - BHI
Jacobs Engineering Group, Inc. - JEGI
Nez Perce Tribe - NPT
Pacific Northwest National Laboratory - PNNL
U. S. Department of Energy - Richland Operations Office - DOE/RL
U. S. Environmental Protection Agency - EPA
U. S. Geological Survey - USGS
Washington State Department of Ecology - Ecology
Waste Management Hanford - WMH
Yakama Indian Nation - YIN

Comments on Scope, Schedule, Process, Needs, and Requirements

The needs and requirements for the computer code used in the consolidated site-wide groundwater model identified the availability of the source code as an administrative requirement. This point was emphasized by DOE/RL. Having the source code means having the capability to make modifications to the source code, if the need arises, and to repeat analyses even if the code author(s) no longer supports the code.

After the schedule for review of the proposed site-wide groundwater model and the recommendations document was presented, Ecology suggested that, in addition to the formal review of draft documents, that informal interaction during the model/document review process would be appropriate. This suggestion was seconded by others, including DOE/RL.

It was pointed out by the YIN representative that a requirement for user access (by regulators, tribal nations, and others) was not listed as an administrative requirement. It was felt that this is an important issue that should be discussed in the recommendations report.

A number of comments were made regarding a requirement for reactive transport modeling. Ecology questioned whether a capability to model interactions between chemical contaminants should be a requirement. YIN stated that the decay of the carbon tetrachloride plume was of interest. DOE/RL stated that applications would probably use another model, capable of more complex reactive transport modeling but limited to a smaller scale, to address the effect of chemical reactions and natural attenuation. Ecology stated that the carbon tetrachloride plume was a large-scale issue, appropriate for analysis on a site-wide scale. PNNL stated that in some cases it may be possible to adequately model complex reactive processes using a half-life decay model, which is a capability of both VAM3DCG and CFEST.

EPA stated that it is important that the site-wide model be able to interface with a model that might be used for reactive transport modeling and that this involves not only the code, but also the database. USGS added that it may not be practical to anticipate the requirements of the site-wide model to allow this interface. It is more likely that the complex, local-scale model would be designed to interface with the site-wide model.

BHI asked whether the location of actual contaminant release sites needed to coincide with the computational nodes of the site-wide model in order to interface local-scale models. PNNL said no.

DOE/RL stated a concern that every local-scale model would need to run the site-wide model in order to be consistent. PNNL responded that this would not be necessary and added that site characterization data collected as part of a local-scale analysis would be a valuable addition to the site-wide database.

DOE/RL asked whether VAM3DCG and CFEST have the capability to model unsaturated flow and transport. PNNL responded that this is not a requirement of code used for the site-wide model because it is currently impractical to model unsaturated flow at the scale of the Hanford Site.

Comments on the Conceptual Model

The NPT representative inquired about the way the heterogeneity of Hanford Site soils was incorporated in the conceptual model. This issue was discussed in the afternoon presentation, but PNNL also stated at this point that the heterogeneity included in the model is limited to large regional features and the differences between hydrostratigraphic units.

JEGI pointed out that, in general, data at the Hanford Site get more sparse with depth and asked how the current conceptual model deals with the increasing uncertainty. JEGI also suggested trying sensitivity analyses to see what the effect of explicitly modeling the lower hydrostratigraphic units might be. There was general agreement that this was a good idea. JEGI pointed out that reviewers are ultimately going to ask what the uncertainty in the results of the site-wide model are. Some effort should be made to address this.

Ecology observed that the lack of data was discussed, but the tables showed only a single number for parameters. Ecology asked whether parameters could be presented as a range of values and stated that the regulators would like to see not only a range of parameter values, but also these ranges used in the model applications.

YIN asked what the potential was for recharge to the unconfined aquifer from the upper confined aquifer. The consensus seemed to be that there is some indirect evidence for recharge, but there are currently no data to support its use in the site-wide model. It was felt that this issue would be of concern to the external reviewers. USGS stated that the effect of preferential flow on recharge estimates is also an issue that the reviewers will question (but that no data currently exist to quantify).

Comments on the Numerical Implementation

The NPT representative asked whether there should be a fault north of Gable Butte/Mtn. represented in the model. USGS and PNNL stated that there is no evidence of a fault in this region in the sediments, just in the basalt.

USGS stated that there should be a fault represented in the model in the location of the May Junction Fault. The current implementation has continuous, but thin layers in this region. A better representation of the fault would be to have offsetting layers.

USGS questioned using the centerline of the Columbia River as a line of symmetry given that the heads in the aquifer are so much greater on the Franklin County side. Moving the line of symmetry closer to the Benton County side of the river was suggested to be appropriate.

USGS also questioned the oddly shaped elements used where the transport grid transitions from coarse to fine. PNNL responded that these elements have not caused any observed problems in the flow and suggested that this was the case because, using the finite element method, the flow comes through the nodes, not across the element boundaries.

WMH asked what the "Book Value" hydraulic conductivity values were based on. The "Book Values" were used in assigning appropriate hydraulic conductivity values to the three-dimensional flow model. References for the "Book Values" should be given.

USGS commented that the difference between the Hanford and Ringold gravel "Book Value" hydraulic conductivities were larger than expected. USGS studies observed approximately a 20:1 difference with the difference being that the USGS observed higher Ringold conductivities than were given as the "Book Value."

USGS asked how much different from the two-dimensional model the transmissivities from the three-dimensional model would be if the "Book Value" conductivities were applied and the transmissivity calculated using the interpreted unit thicknesses. Also, were there alternatives to the method used in assigning hydraulic conductivities to the three-dimensional model?

USGS asked about the quality of the dataset for discharge to ground for the 1979-1996 period used in the three-dimensional flow calibration.

Ecology asked whether the SALDS modeling results presented, describing the depth of penetration in the aquifer of the tritium plume, were applicable to the uranium plume in the 200 West Area.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 10 HANFORD PROJECT OFFICE
712 SWIFT BOULEVARD, SUITE 5
RICHLAND, WASHINGTON 99352

May 13, 1998

Mr. Doug Hildebrand
U.S. Department of Energy
P.O. Box 550 H0-12
Richland, Washington 99352

SUBJECT: EPA Comments on Hanford Site-Wide Groundwater Model

Dear Mr. Hildebrand:

Enclosed are the U.S. Environmental Protection Agency (EPA) review comments regarding the Hanford Site-Wide Groundwater Model Project. This review is based primarily on;

1) Handouts and discussions at the April 24, 1998 "Technical Representative Workshop, Site-Wide Groundwater Model Consolidation".
2) Cole et al., 1997, "Three-Dimensional Analysis of Future Flow Conditions and Contaminant Plume Transport in the Hanford Site Unconfined Aquifer System: FY 1996 and 1997 Status Report" (PNNL-11801).
3) Wurstner et al., 1995, "Development of a Three-Dimensional Groundwater Model of the Hanford Site Unconfined Aquifer System, FY1995 Status Report" (PNL-10886).

The following documents were consulted in part;

1) Thorne and Chamness, 1992, "Status Report on the Development of a Three-Dimensional Conceptual Model for the Hanford Site Unconfined Aquifer System" (PNL-8332).
2) Thorne and Newcomer, 1992, "Summary and Evaluation of Available Hydraulic Property Data for the Hanford Site Unconfined Aquifer System" (PNL-8337).

If you have any questions, please contact me at (509) 376-9884.

Sincerely,

Laurence E. Gadbois

Laurence E. Gadbois
Environmental Scientist

Enclosure: As stated.

Cc: Marcel Bergeron, PNNL
Charlie Cole, PNNL
Dirk Dunning, Oregon DOE
Dib Goswami, Ecology
Stuart Harris, CTUIR
Wade Riggsbee, YIN
Stan Sobczyk, NPT
Wayne Soper, Ecology
K. Mike Thompson, DOE
Paul Thorne, PNNL
Administrative Record: Site-wide.

EPA Comments on Hanford Site-Wide Groundwater Model

The comments are organized into major categories regarding the conceptual model and the numerical implementation of the conceptual model.

Conceptual Model

Hydrogeologic Framework

- A possible conceptual problem may exist regarding coarse-grained "stringers" within the finer-grained units. It's possible that these "stringers" might represent continuous coarse-grained features that may provide preferred pathways of flow (and contaminant transport). Existing geologic data are not sufficient to prove or disprove this possibility. The possibility of these continuous coarse-grained pathways should be considered and the possible effect tested at some point in the modeling process.

Hydraulic Properties

- The use of a specific yield of 0.1 for Ringold sediments may be inappropriate. This value may be typical of that obtained from aquifer testing, and could be the appropriate value to use for simulating seasonal changes in water levels. However, when the water-table at Hanford falls permanently, and the sediments have years to drain, the appropriate specific yield to use for simulating this process could be considerably higher. The specific yield for the Hanford Formation may also need to be increased.
- Some of the hydraulic conductivities determined through the inverse modelling seem impossibly large (PNL-10886, p. 2.18); e.g., a value >1,000,000 m/d. The indicated maximum tested value of 10,000 m/d (Thorne and Newcomer, 1992) is consistent with the maxima found by previous investigators (10,000 ft/d, aquifer test, Myers 1985; 12,000 ft/d, flow model, Connelly et al. 1991; 78,000 ft/d specific-capacity conversion, Drost et al. 1997). Perhaps the extremely large values are the result of the assigned ratios between units -- i.e., perhaps a large value results from a relatively thin Pasco Gravel being assigned the largest part of the transmissivity at a particular location when in reality the Ringold gravels are extremely conductive at this site.

Transport Properties

- The report PNNL-18801 implies that the transport model uses the same dispersivity (called transverse dispersivity) for the vertical and horizontal directions at right angles to the ground-water flow direction. The horizontal and vertical dispersivities should be different, with the vertical the smaller of the two.
- The conceptual model of transport does not consider "reactive transport". This may be an important issue, particularly where plumes of different contaminants intersect. However, it is probably not possible to model this type of effect in a regional-scale model.

Aquifer Boundaries

- The use of median river stages is probably appropriate, although, as pointed out on page 5.6 of PNL-11801, ignoring the fluctuations of the Columbia River may lead to some misrepresentation of the details in plume extents. Another complication may result from the relative stages of the

Columbia and Yakima Rivers -- there may be periods in which the actual relative stages result in much different flow-system dynamics than those depicted by using the median stages of each river.
- The conceptual model does not consider evapotranspiration from the water table. This component of ground-water discharge probably would be significant only near the Columbia and Yakima Rivers, and perhaps the ponds in the 200 Areas. However, the issue should be included in the conceptual model -- if analysis shows it to be insignificant it will not be required in the numerical implementation.

Recharge
- It's not clear how the artificial recharge values at the disposal ponds were calculated. Was evapotranspiration considered or were "discharges to ground" used directly as recharge values?
- The conceptual model does not address macropore recharge. The various methods used to calculate recharge at Hanford have addressed, almost exclusively, the matrix (interstitial) recharge. Recent work done in the Southern High Plains region of Texas and New Mexico (Wood et al., 1997, "Quantifying Macropore Recharge: Examples from a Semi-Arid Area", Ground Water Nov-Dec 1997) indicates that macropore recharge represents between 60 and 80 percent of the total recharge. Hanford conditions, although semi-arid, are probably significantly different than the High Plains and macropore recharge probably represents a much(?) smaller portion of the total recharge. However, this is a potentially significant issue and should be addressed in the conceptual model.
- Artificial recharge in the Richland area in the form of infiltration ponds, agriculture and lawn irrigation, and ground disposal of waste water at a potato-processing plant is discussed (PNL-10886), but it is unclear if/how these are represented in the model.

Interaction with Basalt Confined Aquifer
- The conceptualization of the flow system seems to include the assumption that flow to and from the basalts is insignificant. This assumption appears to be based on the assumed low vertical hydraulic conductivity of the basalts. However, as shown in PNL-10886 (Fig. 2.3), there are significant hydraulic gradients between the basalts and unconfined aquifers over most of the Hanford Site. These hydraulic gradients coupled with the large cross-sectional area of flow (essentially the entire Hanford Site) may lead to significant vertical fluxes, even with the assumed very low hydraulic conductivity of the basalts. This is also pointed out by Spane and Webber (10817, p. 4.1) -- "Pervasive areal discharge from the upper basalt to the overlying unconfined aquifer is also expected to occur in the eastern part of the Hanford Site...". A complicating factor may be secondary vertical connections (faults, eroded segments, etc.) which may result in much greater vertical hydraulic conductivities than those presently assumed. In determining how to best represent the basalts, it should be kept in mind that the flow from the basalts may have originated far off the Hanford Site -- the basalts are part of a much larger regional flow system. The present conceptual model only allows for recharge within the model area and limited lateral flow into the model area (Cold Creek, etc.).

Contaminant Distribution
- Data showing the vertical distribution of contaminants in the ground-water system appear to be insufficient in most areas.

Numerical Implementation of Site-Wide Groundwater Model

Translation of Conceptualization

- Consideration should be given to using head-dependent-flux boundaries at the Columbia and Yakima Rivers rather than specified-head boundaries. Because the flow pattern and lithologies at these boundaries are probably more complex than at most other locations in the model, and the complexity is probably at a scale smaller than the size of an element, the values of horizontal and vertical hydraulic conductivities that are assigned probably artificially differ from the actual values in order to compensate for the complexities. It might be better to absorb the complexities into the empirical head-dependent-flux coefficient.
- Using the centerline of the Columbia River as a boundary may not be the most accurate representation. Due to the much higher hydraulic heads in the unconfined (and confined) aquifer across the river from Hanford, flow to the river is probably not symmetrical.
- At least two faults have been identified in the Ringold sediments (May Junction Fault and Cold Creek Fault). PNL-10886 (p.23) states that the May Junction Fault was developing as the older Ringold sediments were being deposited and that the faulting continued until middle Ringold resulting in maximum vertical offset of 150m. Do the faults complete truncate/offset any of the highly permeable zones or did these zones develop continuously across the fault? If any of these units are completely offset, how does the model handle this? It is uncertain whether these faults are being accurately represented in the model.
- The process used to convert 2-D-transmissivities to 3-D-conductivities is reasonable. However, the process assumes a constant ratio of conductivities between the units. This is probably not the case.
- The nature of the vertical distribution of recharge along the Cold Creek and Dry Creek Valleys is unclear (PNL-11801 p. 4.7). Also, from the discussion of previous investigations, it is apparent that there has been a wide range of estimates of the rate of recharge at these boundaries (as well as at Rattlesnake Ridge) -- if there is great uncertainty in the estimated rate used, the sensitivity of this parameter should be tested.

Flow Model Development and Calibration

- Because the model is calibrated to heads only (none of the significant inflow or outflows are measurable), modelling results will always contain significant uncertainty.
- It appears that all calibration is done to water-table heads. The model should be checked against sets of vertical-head data also.

Transport Model Implementation

- The finer vertical discretization at selected locations in the transport model is a good approach. However, the vertical discretization over most of the model area may be too coarse, even though it is consistent with the existing knowledge of the lithology. The thickness of a layer should be such that there are no large differences vertically within the layer. However, the lack of data on the vertical distribution of contaminants may limit the usefulness of finer discretization.
- It appears that the transport model is based on the assumption of no new contaminants reaching the water table -- future scenarios based on present concentration distributions only. Although little or no new contamination may be added to the surface, there may still be significant movement of contaminants already in the vadose zone which will reach the water table in the

future.
- The transport model uses a much finer grid than the flow model in some areas (PNL-11801, fig. 5.1). How is the transition (distribution of heads/flows) made from the coarser-grid flow model to the finer-grid transport model?

Transport Model Calibration
- The data presently being used to calibrate the transport model may not be sufficient. Although there is adequate information on areal distributions of different contaminants in 1985 and 1996, the differences between distributions at these two times is not large. Even with some input data limitations, the large contaminant distribution changes that occur from pre-1944 to 1996 may be a better time period for transient calibration.
- In addition to calibrating the transport model by matching simulated with observed spacial distributions of contaminant concentrations, the transport model (or a particle-tracking model) should be used to check simulated "travel" or "first-arrival" times against observed data. These comparisons might indicate the existence of preferred flow pathways. It may be useful to test the model by adding thin highly permeable layers to see the nature of preferred pathway flow -- the failure of previous investigators to acknowledge or consider the possible existence of such pathways received much public criticism.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 10 HANFORD PROJECT OFFICE
712 SWIFT BOULEVARD, SUITE 5
RICHLAND, WASHINGTON 99352

August 13, 1998

Richard A. Holten, Director
Restoration Projects
U.S. Department of Energy
P.O. Box 550 H0-12
Richland, WA 99352

SUBJECT: EPA Comments on "Preliminary Draft: Recommendations for Consolidation of Site-Wide Groundwater Modeling at the Hanford Site", DOE/RL-98-xxx, June 22, 1998 Draft.

Dear Mr. Holten:

The subject document was sent to the U.S. Environmental Protection Agency (EPA) for review and comment. Enclosed are our comments on this document. Most of the comments that EPA submitted to DOE on May 13, 1998 on an earlier draft of this document still apply. If you have any questions on these comments, please contact me at (509) 376-9884.

Sincerely,

Laurence E. Gadbois

Laurence E. Gadbois
Environmental Scientist

Enclosure: As stated

Cc: Marcel Bergeron, PNNL
Charlie Cole, PNNL
Dirk Dunning, Oregon DOE
Dib Goswami, Ecology
Michael Graham, ERC
Stuart Harris, CTUIR
Doug Hildebrand, DOE
Wade Riggsbee, YIN
Stan Sobczyk, NPT
Wayne Soper, Ecology
K. Mike Thompson, DOE
Paul Thorne, PNNL
Administrative Record, Site-wide

Mr. Richard Holten Enclosure: EPA Comments August 13, 1998

"Preliminary Draft: Recommendations for Consolidation of Site-Wide Groundwater Modeling at the Hanford Site", DOE/RL-98-xxx, June 22, 1998 Draft.

1. Page 25
It is not sufficient for the model to use different dispersivities in longitudinal and transverse directions. Dispersivity in vertical transverse direction should be different than in horizontal transverse direction. (Note: this comment was in the May 13, 1998 list of comments, but was not mentioned in the document currently being reviewed.)

2. Page 25 and 59
Simulation of reactions only by 1st-order (half-life) decay is probably insufficient. Consideration should be given to the simulation of other processes such as the creation of daughter products that result from the radioactive decay of some radionuclides, and degradation processes whose rates are functions of concentrations of some other consituent.

3. Page 30
Portability -- Give additional examples of platforms. Mention PC's, specifically, and perhaps Windows 95, Windows NT,and MAC OS.

4. Page 30
Limiting the models under consideration to VAM3D-CG and CFEST96 almost makes the remainder of the requirements superfluous.

5. Page 43
If head is specified at the Columbia River model boundary, the head should be specified only at the upper boundary of the aquifer, not over its entire thickness.

6. Page 43
The model developers should consider using head-dependent-flux instead of a specified-head boundaries at the Columbia and Yakima Rivers. Because the flow pattern and lithology at these boundaries probably are more complex than at most other locations in the model, and the complexity probably is at a scale smaller than the size of a model element, the values of horizontal and vertical hydraulic conductivities that are assigned to the nodes or elements at these boundaries probably must artificially differ from the actual values in order to compensate for the complexities. It probably would be better if the complexities were absorbed into the empirical head-dependent-flux coefficient rather than a hydraulic conductivity.

7. Page 62
Justification for not including the basalts in the model is weak. It should not matter if the source of the water in the basalts is far from the Hanford Site, or if the flow in the basalts is part of a larger regional system; if there is flow between the sediments and the basalts, the model should have the capability of simulating this flow. It probably makes more sense to include this capability now and not use it, than to not include it and need it later.

8. Page 108-109
"Mean head difference" is not a good measure of model accuracy,it is a measure of model bias. "Mean absolute head difference" or "root-mean-square" difference would be better.

9. The May 13 comment letter contained the following comment about specific yield. Although specific yield is not mentioned in the current document, this comment was not listed in the section begining on page 58 as a technical issue or concern.

> "I question the use of a specific yield of 0.1 for sediments in the Ringold Formation. I don't doubt that this may be the typical value obtained from aquifer tests, and could be the appropriate value to use for simulating seasonal changes in water levels; however, when the water-table at Hanford falls permanently, and the sediments have may years to drain, the appropriate specific yield to use for simulating this process could be considerably higher. The investigators my also consider increasing the specific yield of the Hanford Formation."

APPENDIX C.

Summary of Technical Issues and Concerns on Proposed Site-Wide Groundwater Model Identified during November 1998 Workshop

Proposed Site-Wide Groundwater Model Consolidation: Conceptual Model Workshop II

February 17, 1999
PNNL EMSL Auditorium
Richland, Washington

Attendees

Name	Organization	Phone
Marcel Bergeron	PNNL	(509) 372-6104
Jerry Davis	PHMC	(509) 376-9593
Dirk Dunning	State of Oregon	(503)378-3187
Wade Riggsbee	Yakama Indian Nation	(509) 946-0101
Dib Goswammi	Washington Department of Ecology	(509) 736-3015
Larry Gadbois	US Environmental Protection Agency	(509) 376-9884
Edmund A. Prych	US Geological Survey for US Environmental Protection Agency	(253) 428-3600 Ext. 4623
Charlie Cole	PNNL	(509) 372-6068
Tom Ferns	DOE/AME	(509) 372-0649
Shri Mohan	Washington Department of Ecology	(509) 736-5704
Curt Wittreich	Environmental Restoration Contractor	(509) 372-9586
Ron Smith	PNNL	(509) 376-5831
Will Nichols	PNNL	(509) 372-6040
Signe Wurstner	PNNL	(509) 372-6115
Steve Reidel	PNNL	(509) 376-9932
Stan Sobczyk	Nez Perce Tribe ERWM	(208) 843-7375

Proposed Site-Wide Groundwater Model
Conceptual Model Workshop II

FEBRUARY 17, 1999
PNNL EMSL Auditorium
Richland, Washington

Time	Topic	Presentor
1:00 – 1:15 pm	**Welcome** • *Recap of November Workshop on the Hydrogeologic Framework* • *Objective of this workshop*	*Doug Hildebrand*
1:15 – 3:00 pm	**Discussion of Aquifer Boundaries** • *Recharge (Artificial and Natural)* • *Dry Creek and Cold Creek* • *Rattlesnake Hills Springs* • *Columbia River* • *Yakima River*	*Signe Wurstner/ Mike Fayer/ Paul Thorne*
3:00 – 3:15 pm	*Break*	
3:15 – 3:45 pm	**Discussion of Aquifer Boundaries (continued)** • Interaction with Basalt confined aquifers	*Charlie Cole/ Steve Reidel*
3:45 – 4:45 pm	**Expert Panel Review Comments** • *Review of Key Findings/Comments* • *Path Forward*	*Marcel Bergeron*
4:45 – 5:15 pm	**Open Discussion** • *Review of Key Issues and Concerns* • *Review of Alternative Conceptual Models* • *Tentative Dates and Topic for Next Workshop*	*Marcel Bergeron/ Doug Hildebrand*

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APPENDIX D.

Summary of Technical Issues and Concerns on Proposed Site-Wide Groundwater Model Identified in a Workshop held in February 1999

Peer Review Agenda
Proposed Site-Wide Groundwater Model
Hanford Site Applications

Columbia River Room, ETB

November 20, 21, 1998

Friday, November 20, 1998

8:00 – 8:05 AM	Opening Remarks	Dr. Steven M. Gorelick, Chair
8:05 – 8:15 AM	Introduction	Doug Hildebrand, DOE RL
8:15 – 8:45 AM	Review of Needs and Requirements	Marcel Bergeron, PNNL
8:45 – 10:00 AM	Review of Proposed Conceptual Model	Paul Thorne, PNNL
10:00 – 10:15 AM	Break	
10:15 – 12:00 PM	Proposed Conceptual Model (cont.)	Paul Thorne, PNNL
12:00 – 1:00 PM	Lunch	
1:00 – 1:15 PM	Regulator/Stakeholder Issues	Dib Goswami, Washington State Department of Ecology
1:15 –3:00 PM	Review of Numerical Implementation of Conceptual Model	Charles Cole, PNNL
3:00 – 3:15 PM	Break	
3:15 PM – 5:15 PM	Numerical Implementation (cont.)	Charles Cole, PNNL
5:15 PM - 6:00 PM	Open Discussion	

Saturday, November 21, 1998

Panel Closed Session (PNNL staff available to answer questions)

End of Day Closeout with Panel

Peer Review Team:

Dr. Steven M. Gorelick, Stanford University, Chair
Dr. Charles Andrews, S. S. Papadopulos and Associates, Inc.
Dr. James W. Mercer, HIS-Geotrans, Inc.

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Proposed Site-Wide Groundwater Model
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Saturday, November 21, 1998

Panel Closed Session (PNNL staff available to answer questions)

End of Day	Closeout with Panel

Peer Review Team:

Dr. Steven M. Gorelick, Stanford University, Chair
Dr. Charles Andrews, S. S. Papadopulos and Associates, Inc.
Dr. James W. Mercer, HIS-Geotrans, Inc.

APPENDIX E.

Gorelick, S., C. Mercer, J. Mercer. 1999.

Report of the Peer Review Panel on the Proposed Hanford Site-Wide Groundwater Model

Report of the Peer Review Panel on the Proposed Hanford Site-Wide Groundwater Model

Report prepared by:

Steven Gorelick
Charles Andrews
James Mercer

January 14, 1999

Table of Contents

Executive Summary

External peer review of the Proposed Hanford Site-Wide Groundwater Model was conducted in the Fall of 1998. The three-member review panel commented on three specific issues: 1) adequacy of the conceptual model and its technical capabilities to meet the anticipated uses and needs, 2) possible improvements to the modeling framework / implementation, and 3) immediate new data needs.

The Panel unanimously agreed that:

1) The concept of developing a broadly applicable site-wide groundwater model is excellent. Scientists working for the U.S. Department of Energy–Richland Operations Office have made significant progress and should be commended for their superior efforts in dealing with voluminous data and complex field conditions, and for their integrated/interdisciplinary approach to model building.

2) With regard to the issue of model adequacy, the spectrum of anticipated uses and needs is so broad, ranging from time scales of less than 1 day to thousands of years and spatial scales of meters to kilometers, that this or any general-use, site-wide model cannot be expected to be adequate for all potential uses. An initial task should be to specify a narrower, and perhaps more pragmatic, list of model uses that involve less disparate temporal and spatial scales and contaminants whose behavior can be adequately characterized by linear sorption and first-order decay.

3) With regard to improvements in the modeling framework:

   - The existing deterministic modeling effort has not acknowledged that the prescribed processes, physical features, initial and boundary conditions, system stresses, field data, and model parameter values are not known and cannot be known with certainty. Consequently, predictions of heads and concentrations in three dimensions over time will be uncertain as well.
   - A new modeling framework must be established that accepts the inherent uncertainty in model conceptual representations, inputs, and outputs. Given such a framework, the expected values of heads and concentrations, as well as the range (distribution) of predictions, would be products of the site-wide groundwater model.
   - A priority task is to construct a comprehensive list of alternate conceptual model components and to assess each of their potential impacts on predictive uncertainty.
   - Assessment can be initiated with hypothesis testing and sensitivity analysis within the general framework already established with the existing site-wide model. If uncertainties due to alternate conceptual models are significant, then a Monte Carlo analysis is required to estimate both the expected value of the prediction and its uncertainty.

4) With regard to improvements in model implementation:

The Panel has identified a series of important improvements to the current site-wide modeling effort. A few of the most significant ones are listed below.

- The calibration procedure for the current model is not defensible. Reasons include the insufficient justification for using a single snapshot of presumed steady-state conditions in 1979, over-parameterization of zonal transmissivities given an insufficient number of independent data, potential for incompatibility between pumping-test results and model representation of the aquifer, 2D model calibration for a 3D model, and use of interpolated head values.
- The existing representation of chemical reactions is limited to first-order decay and linear sorption. This representation is potentially adequate for some of the prevalent contaminants found in Hanford groundwater; however, for most of the contaminants of concern found in the vadose zone, reactive transport needs to be represented. The decision that must be made at this stage is whether or not the umbrella of the site-wide groundwater model should cover reactive transport simulation or whether chemical processes are better handled by specialized local models. If the decision is to delegate chemical processes to specialized local models, it still may be possible to use hydraulic boundary condition values from the hydraulic component of the site-wide model. If the decision is to include reactive chemistry in the site-wide model, then the simulation framework must be based on a flexible open architecture that embraces complexities such as transport of multiple species, microbial degradation, and perhaps nonlinear feedback to the flow model as aquifer or water properties change.
- The domain covered by the site-wide groundwater model must be better justified. The site-wide groundwater model simulates groundwater flow and contaminant transport only in the unconfined sedimentary aquifer in the Pasco Basin south and west of the Columbia River. The unconfined aquifer to the north and east of the river and the bedrock basalt aquifer are not represented in the site-wide groundwater model even though the major discharge area for both aquifers is the region adjacent to the Columbia River.
- Boundary conditions and boundary fluxes should be re-inspected because of some inconsistencies with existing information and because of an insufficient conceptual basis for use of these conditions for applications of the site-wide model at both large and small scales.
- Spatial variability of recharge should be treated geostatistically to determine expected values, spatial correlation, and estimated uncertainties.

5) With regard to collection of new data:

- The Panel believes that it is premature to initiate a campaign to collect new data. The highest priority is to adopt a broader modeling framework that accepts conceptual model uncertainty. Within this new framework the site-wide model would serve as an important tool to help guide new data collection efforts. First, the degree of likely impacts of the various sources of uncertainty can be assessed through analysis of all uncertainties including those introduced by alternate conceptual models. Second, the worth of new data for reducing costs and risks can be evaluated. Only then can the issue of additional data collection be logically addressed.

- The integration of the site-wide model with a geographic information system (GIS) is an excellent means to preserve the site data for applications at a variety of spatial scales. The Panel recommends that both *data-bases* (original field measurements) and *information-bases* (interpretations or interpolations) be maintained. For example, details in well logs found in the data-base could be used to develop a geostatistical model for scales smaller than that found in the interpreted hydrogeologic facies information-base.

- The Panel recommends that the site-wide groundwater model be thought of as a flexible and evolving platform for analyzing groundwater flow and contaminant transport. The model itself must not be stagnant because, as more data are collected, it is likely that the conceptual model of the groundwater system will change. In addition, new predictive capabilities undoubtedly will be desired. The adopted model framework must be one in which new concepts can be tested and enhancements readily included. It must have the capability of being modified to test alternative conceptual models, reflect the most recent consensus conceptual model, and address differing concerns regarding water resources and water quality.

Introduction

This report is the product of a peer review of the Proposed Hanford Site-Wide Groundwater Model by a panel of three external reviewers who have been contracted by Pacific Northwest National Laboratory (PNNL) on behalf of the US DOE Richland Operations Office (DOE/RL). The external panel members are Dr. Steven Gorelick, Stanford University (Panel Chair), Dr. Charles Andrews, S.S. Papadopulos and Associates, Inc., and Dr. James Mercer, HSI GeoTrans, Inc. The charge of the Panel was to review the Proposed Hanford Site-Wide Groundwater Model and specifically address three questions:

1. Is the conceptual model and technical capabilities embodied in the numerical implementation of the proposed site-wide groundwater model adequate to meet the anticipated needs, requirements and uses for the Hanford Site?
2. If not, what model refinements/modifications or alternative conceptual models should be investigated to further improve the conceptual model and its numerical implementation to meet the anticipated Hanford Site needs, requirements, and uses?
3. Are there major conceptual model, parameter, and data uncertainties that can and should be resolved by collection of additional data and information in order for the proposed model to be adequate for Hanford Site needs, requirements, and uses?

The Panel reviewed the documents listed in Appendix A and met on November 20, 1998 with representatives of DOE, PNNL, Washington Department of Ecology, and the Yakima Indian Nation. Presentations were made on the Site-Wide Groundwater Model and briefly discussed (see Appendix B for the meeting agenda). The scope of the Panel's work includes a follow-up meeting within the next year, after PNNL's response to this report.

Definitions and Understanding of Panel

The following concepts are defined and used by the Panel in this report:

- **Site-wide groundwater model** (SGM) is the application of the CFEST-96 code to the conditions at the Hanford Site for prediction of steady-state and transient saturated flow in 3D and dissolved-phase transport of contaminants of concern.

- **Anticipated uses, needs, and requirements** for the SGM are defined in two parts as:

  Anticipated Uses -- The SGM would be applied to a range of problems including: current and near-term impacts of operations facilities and proposed waste-disposal facilities; planning, design, and evaluation of remediation strategies including monitoring, natural attenuation, hydraulic control/containment, and contaminant removal/cleanup; long-term performance assessment involving risk assessment and management; and assessment of site-wide cumulative environmental impacts.

Anticipated Needs and Requirements -- To meet these anticipated uses, the SGM needs to have the capability to interface with vadose-zone models of flow and transport; risk assessment models; specialized, high-resolution, local-scale simulation potentially involving reactive chemical processes, and perhaps more sophisticated models of surface-water – groundwater interactions (both hydrologically and chemically). Thus, the SGM must be applicable to different problems involving a wide-range of processes and complexity. Furthermore, the SGM must handle disparate spatial scales extending from local facility areas to regional site-wide, and temporal scales ranging from less than 1 day to 10,000s of years.

- **Alternative conceptual models** are different constructs of the geometry of the model domain, number and configuration of hydrogeologic units, hydrologic and chemical stresses, initial conditions, boundary condition types and values, as well as processes that control the behavior and response of groundwater flow and contaminant transport. Each alternative construct is a conceptual model.

- **Numerical implementation** is the translation of a conceptual model into the input data for a numerical code, CFEST-96.

- **A sub-model** of the SGM is an application of the CFEST-96 computer code in which the spatial discretization is reduced in a sub-region of the area modeled in the SGM to allow for the more precise definition of hydraulic and contaminant sources and sinks, and/or to allow for the more accurate solution of the governing equations. The hydraulic boundary conditions for the sub-model are calculated either explicitly or implicitly from the SGM. A **specialized local model** is the numerical implementation of a conceptual model other than that used in the SGM to simulate groundwater flow and contaminant transport in a sub-region of the area modeled in the SGM. The hydraulic boundary conditions for a specialized local model are calculated explicitly from the SGM. An example of a specialized local model would be a reactive-chemical transport model developed to simulate chromium behavior in the vicinity of a reactive wall.

Review Comments on Questions Posed by PNNL to Panel

Question 1:

Is the conceptual model and technical capabilities embodied in the numerical implementation of the proposed site-wide groundwater model adequate to meet the anticipated needs, requirements and uses for the Hanford Site?

Given the broad anticipated needs, requirements, and uses as defined above, the Panel concludes that the SGM is inadequate at this stage. No single model may be adequate for all of the anticipated needs and uses.

Question 2:

If not, what model refinements/modifications or alternative conceptual models should be investigated to further improve the conceptual model and its numerical implementation to meet the anticipated Hanford Site needs, requirements, and uses?

Conceptual Model

The modeling framework for the SGM does not acknowledge that the physical and chemicals processes, internal 3D structure, flow and solute stress locations and magnitudes, 3D initial conditions, 3D boundary conditions, field data, and model parameter values are not known and cannot be known with certainty. Therefore, predictions of heads and concentrations in 3D over time will be uncertain as well.

The Panel recommends that:

1. The concept of uncertainty be acknowledged and embraced from the outset. A new modeling framework should be established that is stochastic rather than purely deterministic. Both the expected values of heads and concentrations as well as the range (distribution) of predictions should be products of the model.
2. Each type of application of the SGM will have different requirements depending on the consequence of uncertainty in predictions.
   - To assess the relative importance of uncertainties due to alternative constructs of processes, features, stresses, and parameter values, hypothesis testing and sensitivity analysis can be used to evaluate the likely range of predictions.
   - For cases in which the only significant source of uncertainty is the estimated model parameter values, then Monte Carlo analysis or first-order analysis of uncertainty on the parameter values alone can be used to determine the expected value of the prediction and its uncertainty.

- If uncertainties due to alternate constructs are significant, then a full Monte Carlo analysis is required to estimate the uncertainty of predictions.

3. Alternative conceptual models should be developed and investigated. Some examples are:

   - The effects of larger-scale regional flow on the Hanford Site-Wide Groundwater Model domain, including flow through the basalt, flow through faults and fractures, and vertical flow through the lower boundary
   - Chemical processes in both the aqueous phase and between solids and water
   - The existence of immobile-domains and solute movement via diffusive mass-transfer (kinetics)
   - Evapotranspiration (for example, at West Lake and other areas where the water table is near the land surface or along the river)
   - The existence of non-aqueous phase liquids
   - Focused recharge
   - Boundary conditions and values (e.g., inflows and their consistency with stream flow measurements, or impermeability of the lower boundary).

   The importance of these and other conceptual model features must be evaluated before assuming that uncertainty in hydraulic conductivity is the only source of uncertainty in predictions.

Because these are just a few examples, the Panel believes that a priority item is to construct a comprehensive list of alternative conceptual model components and assess each of their potential impacts on predictive uncertainty. One method of assessment is hypothesis testing within the framework of the existing SGM. Tools that will aid in this hypothesis testing include water-balance calculations, particle tracking, and sensitivity analysis. If these tools are inappropriate to evaluate the impact of any particular source of uncertainty on predictions, then Monte Carlo analysis is recommended.

Numerical Implementation

The recommended modifications and refinements of the numerical implementation include:

Model calibration
Representation of contaminant chemistry
Boundary conditions
Boundary fluxes
Recharge
Dispersivity (and mixing versus spreading)
Effective porosity versus specific yield
Storage coefficient values
Subscale spatial variability
Representing diffusive mass-transfer

Measured (versus observed) heads and concentrations
Initial conditions in 3D
Interfaces and output needs
Flexible model framework.

Following is a brief discussion of each recommendation.

Model calibration:

The calibration process and consequent estimates of hydraulic conductivity are not defensible. Reasons for this are the following:

1) Parameter estimation was based on the selection of a single snapshot of hydraulic heads in 1979 that was assumed to represent steady-state conditions. Given the transient nature of areal recharge and source fluxes from disposal of wastewater, this approach is questionable. Further work should aim to justify this assumption and/or to perform a transient calibration.

2) The zonal parameterization of transmissivities resulted in 262 parameter values that were estimated. The data used in the inverse procedure considered 217 hydraulic heads and 52 local estimates of transmissivity. This is a clear example of over-parameterization. Resulting transmissivity estimates lead to simulated heads that match observed heads, but the predictive value of the model is low.

3) Hydraulic conductivities for each of the model layers were calculated based on transmissivities estimated from a 2D model of the entire unconfined aquifer. The panel believes that, in general, hydraulic conductivities in a 3D model should be estimated using a 3D inverse model. Short of 3D estimation, an assessment must be undertaken regarding the use of detailed stratigraphy and "text-book value" hydraulic conductivities as the basis for disaggregating transmissivities for a 2D unconfined aquifer into hydraulic conductivities in 3D.

4) The head data used in the inverse model were, in fact, not head data. Rather, they were interpolated values at model node locations. These interpolated values carry a bias. The parameter estimation procedure provides two pieces of information: the parameter estimates and the covariance of these estimates. When the "data" used in the inversion process are values interpolated at all nodal locations, the covariance of the parameter values is artificially reduced and the estimates are unreliable. That is, the creation of data through interpolation leads to biased estimates of model parameter values and artificial estimates of model parameter uncertainty.

5) The Panel is also concerned about the effect of using transmissivities from wells that are partially screened in the aquifer to serve as observed transmissivities for the entire thickness of the alluvial aquifer. An additional concern is the selection of weights used in the matching procedure for heads and transmissivities.

6) Within the framework suggested earlier, parameter uncertainty estimates are an essential part of the model and its ability to provide an expected range of predicted values. Proper parameter estimates and parameter uncertainty estimates (covariances) should be developed and used to assess the uncertainty in predicted heads and concentrations.

Representation of contaminant chemistry:

The site-wide model is capable of representing transport of individual non-interacting solutes undergoing first-order decay and linear sorption. First-order decay is appropriate to represent radioactive decay, and may be appropriate for representing simple degradation processes. These processes are a small subset of all possible chemical processes, and may not be adequate for some compounds of major concern at the Hanford Site. As it stands, the responsibility for the use of the limited chemistry in the SGM to simulate a particular contaminant rests on the model user.

The use of K_ds is an engineering approach to represent the retardation of contaminants due to sorption. Such an approach restricts the use of the model for prediction of the behavior of the majority of contaminants of concern at the Hanford Site. For applications involving the migration of tritium through the aquifer, the chemical processes in the SGM (decay and no sorption) are adequate. For other contaminants, such as carbon tetrachloride, the model may provide reasonable predictions if no volatilization occurs, water quality is nearly constant, and the chemistry can be represented by first-order decay and linear sorption. In any application of the SGM, justification of the engineering approach to retardation is needed.

Boundary conditions:

The locations and types of boundary conditions specified in 3D over time must be re-inspected. In general for large-scale applications to the Hanford site, the specified head boundary corresponding to rivers is adequate. However, the use of a specified head along the Columbia River may be inadequate for small-scale sites near the river or for short-term analyses potentially affected by the river. For example, the observed and predicted water levels for 1996 near the 100-B, C Area indicate flow directions that are at right angles to each other. In such cases, time-dependent heads and/or head-dependent fluxes should be considered. The specified head boundary along the Yakima River may be better represented by a head-dependent flux for some cases.

Boundary fluxes:

Assuming that the locations of lateral boundary fluxes are reasonable, there is an inadequate conceptual model of the existing boundary fluxes. Based on the map of recharge values used during calibration and the locations of Gable Butte and Gable Mountain, significant internal boundary fluxes apparently exist and are not considered in the active model domain. Similarly, fluxes along the western boundary are non-zero only along a small portion. Given the large drainage area in the Rattlesnake Hills and associated mountain area, some rationale must be supplied for assuming no-flow conditions, and/or those boundary fluxes must be reconsidered. Stream flow in upstream reaches of Dry Creek and Cold Creek are a likely lower boundary on underflow from these areas. A comparison of upstream stream-flow values and boundary fluxes is needed; for example, the 1997 USGS estimates of recharge from the creeks to the alluvial system are lower than values used in the calibrated model. A uniform 3D distribution of values along each flux-boundary was assumed. Some rationale for this distribution is needed, or these values must be redistributed in a less arbitrary manner. Along the western boundary it appears that boundary fluxes may in fact be leakage from Cold and Dry Creeks within the Hanford Site, in which case most of the flux should be apportioned to the upper part of the aquifer.

The no-flow boundary between the basalts and the alluvial material at the base of the model may not be appropriate for areas of increased vertical permeability such as in the area northeast of the 200-East Area and in known or suspected fault areas. Further documentation of the justification for the treatment of the lower boundary throughout the domain needs to be provided. Such documentation should begin with the conceptual model and should include a water balance that accounts for flow in the basalts.

Recharge:

Areal recharge is potentially the dominant source of water to the aquifer. The spatial distribution of recharge appears to have varied greatly in the past. As such, it is unclear how simulation of future events should represent this distributed water flux. The recharge map constructed by Fayer et al. (1996) is a good starting point to determine an average recharge map and a companion map of recharge uncertainty. Once available, this information can be used in identifying the range of model predictions (mentioned previously). In addition, the Panel recommends that experts at PNNL develop a strategy to represent the spatial distribution of recharge for a range of climatic conditions, consequent vegetation, and antecedent soil moisture conditions.

Dispersivity (and mixing versus spreading):

The selection of dispersivity values based solely on model element sizes and the Peclet number criterion is problematic for the following reasons: 1) Any physical interpretation of dispersivity values is lost. 2) An empirical or theoretical relationship between dispersivity and travel distance scale is not used. 3) The resolution of the mesh dictates the dispersion of the plume. That is, a very fine mesh will result in a simulated plume dominated by advection; this simulated plume will display little lowering of the plume peak as the plume travels and a small degree of spreading. Alternatively, a course mesh will show that as the plume travels, its peak will be greatly reduced and the plume will become elongated.

The transverse dispersivities are unlikely to be 1/5 of the longitudinal dispersivity for all scales of interest. Furthermore, vertical transverse dispersivity values are most likely smaller than the horizontal transverse dispersivity values. Our understanding is that CFEST-96 does not have the capability for specifying different vertical and horizontal transverse dispersivities; we recommend that the code be modified to incorporate this feature.

The Panel recommends that an independent method be used to estimate dispersivity values and that mesh spacing be selected such that the Peclet criterion is met.

It also must be recognized that the concentrations produced by the SGM do not represent local values when using large field-scale dispersivities. If the SGM is integrated with a multi-species interactive chemical module that relies on accurate prediction of local concentrations, then the issue of predicted concentrations due to local mixing (versus those predicted using a macrodispersion-approach) must be addressed.

Effective porosity vs. versus specific yield:

Although the values used for effective porosity and specific yield may sometimes be similar for a given aquifer material, there is no physical justification to base effective porosity values on measured specific yield values. There is considerable ambiguity in the literature regarding the term *effective porosity*. For purposes of the SGM, effective porosity is the quantity by which the seepage velocity must be multiplied to obtain the Darcy velocity. The seepage velocity is the average speed that water travels between two points due to advection. Specific yield is the drainable porosity, i.e., the volume of water that can be drained by gravity from a unit volume of initially saturated porous medium. In general, specific yield represents a much smaller fraction of total porosity than does effective porosity. Effective porosity values must be estimated, and the impact of their uncertainties must be assessed.

Storage coefficient values:

The error introduced by using wrong storage coefficient values may be responsible for some predictive errors. For example, hydrographs for Areas 5, 6, 7, 8, and 9 show an observed pulse of water. This pulse propagates through the subsurface faster and with a higher amplitude than does the simulated pulse of water. This comparison suggests that the storage parameter used in the simulation may be too high, or the hydraulic conductivity may be too small as the rate of propagation of the pulse is related to the ratio of hydraulic conductivity to the storage coefficient.

Subscale spatial variability:

Spatial variability of hydraulic parameters exists at scales smaller than that of the hydrogeologic facies. This small-scale variability may be important to model applications involving specific sites. The geologic data, such as well logs, should be maintained apart from the interpreted hydrogeologic-facies information. Such segregation would enable modelers of particular applications to go back to the data and potentially extract smaller-scale information about fine structures and parameter values. Work is needed to estimate the geostatistical parameters at the sub-hydrogeologic facies scale.

Representing diffusive mass-transfer:

It is noted that in almost all applications of groundwater transport models the simulated plume of a contaminant exhibits much less tailing (late arrival of mass) than is observed in the field. There are a number of processes that can explain the observed tailing, but in many instances the dominant process is diffusive mass-transfer from an immobile domain to a mobile domain. In alluvial sedimentary groundwater systems, the immobile domain may well correspond to zones of lower hydraulic conductivity, such as silt or clay lenses, within an aquifer unit. Experience suggests that, in any situation in which the effective porosity is significantly smaller than the total porosity, transfer to and from an immobile domain likely is important. In these cases, the immobile domain can be thought of as a functionally stagnant volume of water corresponding to the difference between the total porosity and the effective porosity.

The Panel believes that tailing of contaminant plumes is likely to be significant in the unconfined aquifer at the Hanford site. Therefore, the SGM will overestimate the rate at which contaminant plumes migrate and dissipate after a source has been removed because diffusive mass-transfer to and from immobile domains is not considered. The Panel recommends that diffusive mass-transfer be addressed by modifying CFEST-96 to permit the option of including a mobile-immobile domain formulation.

Measured versus observed heads and concentrations:

In much of the previous groundwater modeling work, the predictive value of the groundwater flow and transport models has been evaluated by comparing contour maps of observed data to contour maps of simulated data. The Panel notes that contour maps of observed data are interpretations of data and not the actual data. The Panel strongly recommends that when assessing the predictive value of models, the observed data be compared to simulated data on a point-by-point (well-by-well) basis, and that this comparison is done in an accepted statistical framework (see for example, ASTM D5447-93 Standard Guide for Application of a Ground-Water Flow Model to a Site-Specific Problem).

Initial conditions in 3D:

The vertical extent of the contaminant plumes at the Hanford site is poorly defined, and as a result, the initial concentration conditions for contaminant transport simulations have a large uncertainty associated with them. This uncertainty must be considered in making predictive simulations. In the most recent modeling analysis, the thickness of the contaminant plume was the calibration parameter, and a value of 25 meters was assigned in the calibration process. There are clearly many other uncertain parameters in the SGM, and the calibration of thickness may be meaningless. The Panel notes that one of the reports indicates that the tritium plume in some areas is over 60 meters thick. As noted below, the Panel does not advocate installation of new monitoring wells at this time to better define the vertical extent of groundwater contamination. Even with a large number of wells to monitor the vertical distribution of contaminants, uncertainty associated with the vertical definition of contaminants will exist due to the large size of the Hanford site and the complexity of the stratigraphy. Therefore, the SGM framework must have a method for dealing with this uncertainty.

Interfaces and output needs:

Selected Computer Code

An important factor in the selection of CFEST-96 was the availability of the source code. The Panel agrees that this is an important criterion. The implementation of the SGM by groups other than PNNL requires the use of CFEST-96 as well as supporting codes, such as GEOFEST. It is important that the suite of codes (i.e., simulation model, inversion model, GIS, and data translators) be available, their interaction be documented and to a certain degree be user friendly.

The Panel concludes that CFEST-96 is an appropriate computer code to use for the site-wide groundwater model for a subset of the anticipated uses. The Panel notes though, that there are several other computer codes that would also be appropriate for the SGM. There is currently a large knowledge base at DOE/RL on the application of CFEST-96, and an automated system has been developed to create input files from the hydrogeologic databases and to process the output files from CFEST-96. Given that a large investment has already been made in the application of CFEST-96 and that the code has many of the required capabilities, it is sensible to use this code. The Panel has noted some changes that would be useful in the CFEST-96 code (such as the ability to use both horizontal and vertical transverse dispersivities and the ability to simulate mobile-immobile domain mass-transfer). The Panel has assumed that making these changes in CFEST-96 would be relatively straightforward.

The Panel is concerned that a high degree of specialized knowledge will be required to use the SGM (and CFEST-96). As a result, regulators, tribal nations, and other stakeholders may not have the expertise to use the SGM. The Panel recommends that DOE/RL provide training workshops on the use of the SGM, including the use of pre- and post-processors. The Panel has assumed that model source and executable codes, and all model-input files will be made available to concerned parties.

A vision for the SGM is the use of the simulated groundwater contaminant concentrations and contaminant fluxes as input data for other computer analysis programs (for example, risk assessment programs). The Panel believes that the output format is sufficiently well documented and flexible that simple computer programs can be developed to provide the linkage with other analysis programs. Development of the SGM at this stage should provide for easy access to output of simulated head and contaminant values and fluxes over space and time.

Sub-Models of the SGM and Specialized Local Models

The SGM is an appropriate tool for analyzing groundwater flow and contaminant transport on a large scale. For addressing many issues that involve groundwater flow and contaminant transport on a smaller scale, it may be appropriate to use a sub-model of the SGM or a specialized local model. In either case, the SGM can be used to define hydraulic boundary conditions for a model of the smaller-scale problem. The Panel recommends that pre- and post- processors be developed, if they do not already exist, so that it is relatively easy to create sub-models of the SGM and to create the hydraulic boundary conditions for specialized local-scale models. It is difficult to anticipate requirements of the specialized local models, but it is important that thought be given to how they might interface with the SGM.

For the development of specialized local models it is essential that an up-to-date, easy to use geologic database be maintained. In models of small regions, it is very likely that the appropriate number of hydrogeologic units will differ from that defined in the SGM. The geologic database will be needed to define these hydrogeologic units on a refined scale.

The Panel anticipates the specialized local-scale models will be developed primarily to analyze the migration of contamination whose behavior in the subsurface cannot be simulated accurately with first-order decay and linear sorption. In some cases, where there is a significant inventory of the contaminant in the vadose zone, coupled unsaturated-saturated models of small regions may be required to answer the questions posed. Specialized local models may also be developed for areas where short-term transient effects, such as variations in river stage, are important.

Flexible Model Framework:

The Panel recommends that the modeling framework for the SGM permit evolving sophistication of groundwater flow and contaminant transport. The SGM must not be stagnant because as more data are collected, it is very probable that the conceptual model of the groundwater system will change. The framework must be setup so that modifications are possible to test alternative conceptual models and to properly reflect the current consensus conceptual model.

Question 3

Are there major conceptual model, parameter, and data uncertainties that can and should be resolved by collection of additional data and information in order for the proposed model to be adequate for Hanford Site needs, requirements, and uses?

It is expected that reports such as this will conclude with the statement, "more data are needed." The Panel has elected to avoid such a recommendation at this time for two reasons. The first is the inability to judge the relative importance and impacts of alternate model constructs on predictions and predictive uncertainty. The second is, given its limited scope and mission, the Panel is unable to appraise the degree to which existing historical data (such as hydraulic heads and concentrations in 3D, information on boundary fluxes, and hydraulic test results) have been assembled and interpreted. The highest priority is to address the conceptual model uncertainty and model implementation issues described previously in this report. Then, within the model uncertainty framework the SGM would serve as an important tool to help guide new data collection efforts. Once the degree of likely impacts from the various sources of uncertainty is assessed, the worth of new data to reduce costs and risks can be evaluated, and the issue of additional data collection can be logically addressed.

The use of a GIS is a valuable approach to consolidate data and information used for model input and should be continued. The Panel encourages the project to distinguish between ***data-bases*** and ***information-bases*** in the GIS. For example, a contour map of head measurements is an example of an information-base while the data themselves are part of a data-base. Well logs would be components of a data-base, while hydrostratigraphic interpretations are part of an information-base. This distinction is important because certain analyses must rely on the data and not the information, and vice versa.

Conclusions

This Review Panel has addressed three specific issues: a) adequacy of the conceptual model and its technical capabilities to meet the anticipated uses and needs, b) possible improvements to the modeling framework / implementation, and c) immediate new data needs.

The Panel has unanimously agreed that:

1. The concept of developing a broadly applicable site-wide groundwater model is excellent. Scientists working for the U.S. Department of Energy – Richland Operations Office have made significant progress and should be commended for their efforts in dealing with voluminous data, complex field conditions, and integrated/interdisciplinary approach to model building.

2. With regard to the issue of model adequacy, the spectrum of anticipated uses and needs is so broad -- ranging from time scales of less than 1 day to thousands of years and spatial scales of meters to kilometers -- that this or any general-use site-wide model cannot be expected to be adequate for all potential uses. An initial task should be to specify a narrower, and perhaps more pragmatic, list of model uses that involve less disparate temporal and spatial scales and contaminants whose behavior can be adequately characterized by linear sorption and first-order decay.

3. With regard to improvements in the modeling framework:
   - The existing deterministic modeling effort has not acknowledged that the prescribed processes, physical features, initial and boundary conditions, system stresses, field data, and model parameter values are not known and cannot be known with certainty. Consequently, predictions of heads and concentrations in 3D over time will be uncertain as well.
   - A new modeling framework must be established that accepts the inherent uncertainty in model conceptual representations, inputs, and outputs. Given such a framework the expected values of heads and concentrations, as well as the range (distribution) of predictions, would be products of the SGM.
   - The geometry of the site-wide model must be better justified. The site-wide groundwater model only simulates groundwater flow and contaminant transport in the unconfined sedimentary aquifer in the Pasco Basin south and west of the Columbia River. The unconfined aquifer to the north and east of the river and the bedrock basalt aquifer are not represented in the site-wide groundwater model even though the major discharge area for both aquifers is the region adjacent to the Columbia River.

- A priority item is to construct a list of alternate conceptual model components and assess each of their potential impacts on predictive uncertainty.
- Assessment can be initiated with hypothesis testing and sensitivity analysis within the general framework already established with the existing site-wide model. If uncertainties due to alternate conceptual models are significant, then a Monte Carlo analysis is required to estimate both the expected value of the prediction and its uncertainty.

4. With regard to improvements in model implementation:

The Panel targeted a series of important improvements to the current site-wide modeling effort. A few of the most important ones are listed below.

- The current model calibration procedure is not defensible. Reasons include the insufficient justification for using a single snapshot of presumed steady-state conditions in 1979, over-parameterization of zonal transmissivities given an insufficient number of independent data, potential for incompatibility between pump-test results and model representation of the aquifer, 2D model calibration for a 3D model, and use of interpolated head values.
- The existing representation of chemical reactions is limited to first-order decay and linear sorption. Although potentially adequate for some of the prevalent contaminants found in Hanford groundwater, for most of the contaminants of concern found in the vadose zone, reactive transport needs to be represented.
- Boundary conditions and boundary fluxes should be re-inspected given some inconsistencies with existing information and because there is an insufficient conceptual basis for use of these conditions for applications of the site-wide model at both large and small scales.
- The spatial representation of recharge should be represented as a parameter having an expected value and estimated uncertainty.

5. With regard to new data collection efforts:.

The Panel believes that it is premature to initiate a campaign to collect new data. The highest priority is to adopt the broader modeling framework that accepts conceptual model uncertainty. Within this new framework, the site-wide model would serve as an important tool to help guide new data collection efforts. First, the degree of likely impacts of the various sources of uncertainty can be assessed through analysis of all uncertainties including those introduced by alternate conceptual models. Second, the worth of new data for reducing costs and risks can be evaluated. Only then can the issue of additional data collection be logically addressed.

The integration of the site-wide model with a GIS is an excellent means to preserve the site data for applications at a variety of spatial scales. The Panel recommends that data-bases (original field measurements) and information-bases (interpretations or interpolations) both be maintained. For example, this would enable details in well logs found in the data-base to be used to develop a geostatistical model for scales smaller than that found in the interpreted hydrogeologic facies information-base.

The Panel recommends that the site-wide groundwater model be thought of as a flexible and evolving platform for analyzing groundwater flow and contaminant transport. The model itself must not be stagnant because, as more data are collected, it is likely that the conceptual model of the groundwater system will change. In addition, new predictive capabilities undoubtedly will be desired. The model framework adopted today must be one in which new concepts can be tested and enhancements readily included. It must have the capability of being modified to test alternative conceptual models, reflect the most recent consensus conceptual model, and address concerns regarding water resources and water quality.

APPENDIX A
DOCUMENTS REVIEWED BY THE PANEL

Chiaramonte, G.R., Denslow, C.W., Knepp, A.J., and others, 1996: **Hanford Sitewide Groundwater Remediation Strategy - Groundwater Contaminant Predictions;** Report prepared for the U.S. Department of Energy, BHI-00469, Rev. 1, September 1996.

Cole, C.R., Wurstner, S.K., Bergeron, M.P., and others, 1997: **Three-Dimensional Analysis of Future Groundwater Flow Conditions and Contaminant Plume Transport in the Hanford Site Unconfined Aquifer System: FY 1996 and 1997 Status Report;** Report prepared for the U.S. Department of Energy under Contract DE-AC06-76RLO 1830, December 1997.

Fayer, M.J., Gee, G.W., Rockhold, M.L., and others, 1996: **Estimating Recharge Rates for a Groundwater Model Using a GIS;** Journal of Environmental Quality, Volume 25, no. 3, , pages 510-518, May-June 1996.

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Thorne, P.D., and Chamness, M.A., 1992: **Status Report on the Development of a Three-Dimensional Conceptual Model for the Hanford Site Unconfined Aquifer System;** Prepared for the U.S. Department of Energy under Contract DE-AC06-76RLO 1830, November 1992.

Thorne, P.D., and Newcomer, D.R., 1992: **Summary and Evaluation of Available Hydraulic Property Data for the Hanford Site Unconfined Aquifer System;** Prepared for the U.S. Department of Energy under Contract DE-AC06-76RLO 1830, November 1992.

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U.S. Department of Energy, 1998: **Preliminary Draft: Recommendations for Selection of a Site-Wide Groundwater Model at the Hanford Site - Volume I - Section 1-8, References;** DOE/RL-98-xxx, October 1998.

U.S. Department of Energy, 1998: **Preliminary Draft: Recommendations for Selection of a Site-Wide Groundwater Model at the Hanford Site - Volume II - Appendices;** DOE/RL-98-xxx, October 1998.

Wurstner, S.K., Thorne, P.D., Chamness, M.A., and others, 1995: **Development of a Three-Dimensional Ground-Water Model of the Hanford Site Unconfined Aquifer System: FY 1995 Status Report;** Prepared for the U.S. Department of Energy under Contract DE-AC06-76RLO 1830, December 1995.

APPENDIX B - MEETING AGENDA

Friday, November 20, 1998

8:00 – 8:05	Opening Remarks	Steven Gorelick, Chair
8:05 – 8:15	Introduction	Doug Hildebrand, DOE RL
8:15 – 8:45	Review of Needs and Requirements	Marcel Bergeron, PNNL
8:45 – 10:00	Review of Proposed Conceptual Model	Paul Thorne, PNNL
10:00 – 10:15	Break	
10:15 – 12:00	Proposed Conceptual Model (continued)	Paul Thorne, PNNL
12:00 – 1:00	Lunch	
1:00 – 1:15	Regulator/Stakeholder Issues	Dib Goswami, Washington State Department of Ecology
1:15 – 3:00	Review of Numerical Implementation of Conceptual Model	Charles Cole, PNNL
3:00 – 3:15	Break	
3:15 – 5:15	Numerical Implementation (continued)	Charles Cole, PNNL
5:15 – 6:00	Open Discussion	

Peer Review Team:

Dr. Steven M. Gorelick, Stanford University, Panel Chair
Dr. Charles Andrews, S.S. Papadopulos and Associates, Inc.
Dr. James W. Mercer, HSI-Geotrans, Inc.