0049610

DOE/RL-98-xxx

Preliminary Draft: Recommendations for Consolidation of Site-Wide Groundwater Modeling at the Hanford Site

DRAFT

June 1998

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

EXECUTIVE SUMMARY

In response to both internal and external recommendations, The Department of Energy - Richland Operations Office (RL) initiated a site-wide model consolidation process, which is to include the participation of all affected Hanford programs, eliminate redundancies, and promote consistency in groundwater analyses produced for Hanford programs. The purpose of the model consolidation is to establish a site-wide modeling process to foster 1) consistent assumptions in applications across programs, 2) model enhancements based on new data/information and improved technical capabilities, and 3) model flexibility to address new program needs and decisions. As an initial step in fiscal year (FY) 1998, the consolidation process is to provide a current Hanford site-wide groundwater model based on a consensus hydrogeologic conceptual model, a consolidated database, and the selection of a computer code to implement the numerical model developed based on the consensus conceptual model, that will meet near-term and long-term needs and requirements of internal and external Hanford site stakeholders.

At Hanford, several groundwater modeling programs have developed among the three major contractors since the Hanford mission changed from special nuclear materials production 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. Bechtel Hanford, Inc. (BHI) has implemented a site-wide groundwater model in support of past-practice operable unit investigations and cleanup activities. Pacific Northwest National Laboratory (PNNL) presently maintains groundwater modeling capabilities for the site in support of the site-wide groundwater monitoring program and vadose-zone modeling capabilities for a variety of site and national programs.

The purpose of this report is to document the overall recommendations being made by RL for consolidation of site-wide groundwater modeling. Included as the basis for the recommendations are descriptions of 1) the overall approach being used by RL to achieve the objectives of the model consolidation process, 2) the needs and requirements for a site-wide groundwater model that were developed in the initial phase of the model consolidation process, 3) an overview of the site-wide groundwater model that was proposed by RL as the starting point for a consensus site-wide model for external review, 4) a summary of technical concerns and issues raised by external reviewers on the proposed site-wide model, including input received from the EPA, Ecology, the Tribal Nations, and other stakeholders, and 5)

DRAFT

specific refinements and modifications to the proposed site-wide model recommended by RL in response to external review comments.

The specific needs and requirements, including the anticipated future uses of the site-wide groundwater model and the technical capability and administrative requirements for the selected computer code that will provide the basis of site-wide model implementation, are based in part on an initial review of current and future groundwater modeling activities being planned by the Environmental Restoration, Waste Management, and Tank Waste Remediation programs at the Hanford Site. The needs and requirements also reflect input collected from external stakeholders, including U. S. Environmental Protection Agency (EPA), Washington State Department of Ecology (Ecology), the Hanford Advisory Board, and two of the affected 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 model consolidation process.
The consolidated site-wide groundwater model should be capable of being used to meet a variety of Hanford Site project objectives including the following:

- site 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 site monitoring networks
- risk assessments.

The key future anticipated uses identified in this consolidation process over the next five years will include modeling support to

- Hanford Groundwater Project (HGWP)
- future iterations of the Composite Analysis
- Hanford Tank Initiative
- performance assessment of the Immobilized Low-Activtiy Waste Disposal Facilities

Groundwater modeling analysis may also be needed to support

- Canyon Disposition Initiative
- 200-Area soils characterization and remediation
- solid waste burial ground performance assessment maintenance

DRAFT

- liquid discharge facilities permitting
- reevaluation and update of Hanford site-wide groundwater remediation strategy
- final records of decisions for contamination currently being managed by interim remedial measures (i.e., pump and treat remediation) in 100 and 200 Areas

A technical evaluation of site-wide conceptual and numerical models and preliminary recommendations for a proposed site-wide conceptual and numerical model and computer code to implement the consensus numerical model was developed in a series of internal workshops attended by technical representatives of Hanford contractors involved in groundwater modeling. Two most recently used site-wide modeling efforts conducted for the HGWP (Wurstner et al. 1995; Cole el al. 1997, and Kincaid et al. 1998) and for the development of the Hanford Site-wide Ground-water Remediation Strategy (Law et al. 1997 and Chiaramonte et al. 1997) respectively were considered. Of these two modeling efforts, the most recent modeling was performed for the Composite Analysis (Cole el al. 1997, and Kincaid et al. 1998) and for the state of Washington permitted discharge assessment of the Effluent Treatment Facility (Barnett et al. 1997) as part of the Hanford Groundwater Project. In general the models are very similar. Most notable differences are in

- the extent of the models. The model developed by the HGWP includes an area that encompasses the North Richland well field and the city of Richland. The model used for the development of the Hanford Site-wide Ground-water Remediation Strategy did not include these areas.
- the interpretation of the number of hydrogeologic layers. The HGWP model identifies multiple and extensive mud units (e.g., nine hydrogeologic layers above the basalt), while the model used for the Hanford Site-Wide Groundwater Remediation Strategy lumps all units below the Hanford into a single Ringold hydrogeologic unit. The mud units are mapped as being areally extensive and therefore may control or influence the flow of groundwater on the Hanford Site.
- The HGWP model considers both artificial and natural recharge, while the model used to develop the Hanford Site-wide Ground-water RemediationStrategy only considers artificial recharge.

DOE/RL's current recommendation is to proceed with external peer review of the model developed by the HGWP. The basic rationale behind this decision was as follows:

- The HGWP model is the most recent effort, and the data supporting the interpretations used are available for review.

DRAFT

- The HGWP model already includes Richland north of the Yakima River and west of the Columbia and thus provides the needed capability of the HGWP to address plumes and the Richland drinking water supply.
- The HGWP model, which is more complicated, can be more easily used to investigate simplification issues related to the importance and need for the more complicated 9-layer description compared to the 2-layer description used in the Hanford Site-wide Ground-Water Remediation Strategy model, as well as the importance of natural recharge.

Review of computer codes for this initial phase of the model consolidation process was limited to the two specific computer codes: 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. 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)
- they met the technical capabilities and administrative requirements outlined in the original M-29-01 document, and they generally met the technical capabilities and administrative requirement in this report.

Analysis of near-term cost and schedule impacts indicate that selection of VAM3D-CG as the implemented code would result in higher initial purchase costs, higher potential implementation costs, and potential schedule impacts since the site-wide model selected for external peer review is not currently implemented with the VAM3D-CG code. In the interest of minimizing initial cost and potential schedule impacts, DOE/RL has reached a decision to select the CFEST-96 code as an interim code for the initial consolidated site-wide model implementation.

Once the initial phase of the model consolidation is completed, DOE/RL may consider performing more in-depth testing of the CFEST-96 code with the VAM3D-CG and other codes using a similar conceptualization of the aquifer system before making any further decision on codes. Although including the in-depth testing can provide additional quantitative information on the decision to implement other codes, DOE/RL recognizes that a detailed benchmarking of several codes can be a costly endeavor and can result in significant additional costs for the site-wide model program. DOE/RL will thoroughly evaluate the necessary scope and associated costs with this type of activity before reaching a decision to include it in future planned work.

DRAFT

ACKNOWLEDGMENTS

DOE/RL wishes to express their thanks and acknowledge the support provided by a number of representatives of major DOE/RL programs and contractor representatives who provided technical input, key technical documents, and planning information used to assemble this report. DOE/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, HRA/Land Use EIS
Brian 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 RI/FS and Interim Remediation Measures
Arlene Tortosa, 100 Areas RI/FS and Interim Remediation Measures
Donna Wanek, 200 Areas RI/FS and Interim Remediation Measures

Site Contractor Representatives

Marcel Bergeron, PNNL, Hanford Site-Wide Ground-Water Model Consoldiation
Charlie Cole, PNNL, Hanford Groundwater Project Site-Wide Modeling Activities
Mike Connelly, CH2M-Hill Hanford, Inc., ERC Groundwater Modeling Activities
Karl Fecht, BHI, ERC Site-Wide Groundwater Activities
Charlie Kincaid, PNNL, Composite Analysis
Tony Knepp, BHI, ERC Site-Wide Groundwater Activities
Philip Meyer, PNNL, Hanford Site-Wide Ground-Water Model Consoldiation
Greg Mitchem, BHI, 200 Area Soils Characterization Program
Paul Thorne, PNNL, Hanford Groundwater Project Site-Wide Modeling Activities

DRAFT

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 200 Areas, Solid Waste EIS
Alex Teimouri, Liquid Effluents Program

Site Contractor Representatives

Marc Wood, Waste Management Hanford (WMH), Performance Assessment of Solid Waste Burial Grounds in 200 Areas, Environmnetal Restoration Disposal Facility (ERDF)
Pat Mohondro, WMH, Permitting of SALDS
Brent Barnett, PNNL, Effluent Treatment Facility and permitting of SALDS

Tank Waste Remediation System Program

Department of Energy, Richland Operations Office Representatives

Robert Lober, TWRS EIS and Hanford Tank Initiative
David Shafer, TWRS Vadose Zone Program
Phil Lamont, TWRS Immobilized Low Activity Waste (ILAW) Disposal Facility

Site Contractor Representatives

Phil Rogers, Jacobs Engineering Group, Inc. (JEGI), TWRS EIS and Hanford Tank Initiative
Fred Mann, Fluor Daniel Northwest (FDNW), Performance Assessment of the TWRS ILAW Disposal Facility

DOE/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 (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:

DRAFT

U. S. Environmental Protection Agency

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

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

DRAFT

CONTENTS

EXECUTIVE SUMMARY ii

ACKNOWLEDGMENTS vi

INTRODUCTION 1

PURPOSE AND SCOPE OF REPORT 2

APPROACH FOR SITE-WIDE GROUNDWATER MODEL CONSOLIDATION 4

ANTICIPATED USES, NEEDS, AND REQUIREMENTS FOR THE SELECTED SITE-WIDE GROUNDWATER MODEL 7

ANTICIPATED USES OF THE SITE-WIDE GROUNDWATER MODEL 7

COMPUTER CODE REQUIREMENTS FOR A CONSENSUS SITE-WIDE GROUNDWATER MODEL 24
Technical Requirements 24
Administrative Requirements 27

ACCEPTABILITY OF CURRENT CODES FOR THESE REQUIREMENTS 30

DESCRIPTION OF THE PROPOSED SITE-WIDE MODEL 34

PURPOSE AND SCOPE OF MODEL 34

SYNOPSIS OF MODEL DEVELOPMENT 34

SITE-WIDE CONCEPTUAL MODEL OF THE AQUIFER SYSTEM 37
Hydrogeologic Setting 38
Major Hydrogeologic Units 39
Hydraulic and Transport Properties 41
Aquifer Boundaries 43
Aquifer Recharge and Groundwater Flow Dynamics 44
Contaminant Distributions 45

NUMERICAL IMPLEMENTATION OF SITE-WIDE CONCEPTUAL MODEL 47
Translation Of The Conceptual Model 48
Model Design and Grid Discretization 49
Flow Model Development, Calibration, and Results 50
Contaminant Transport Model Development and Implementation 52

SUMMARY OF TECHNICAL ISSUES AND CONCERNS ON PROPOSED NEEDS AND REQUIREMENTS AND SITE-WIDE GROUNDWATER MODEL 58

RECOMMENDED REFINEMENTS AND MODIFICATION SUGGESTED FROM EXTERNAL PEER REVIEW 65

APPENDIX A: SUMMARY OF GROUNDWATER MODELING ACTIVITIES 106

DRAFT

DRAFT

INTRODUCTION

In response to both internal and external recommendations, the U. S. Department of Energy - Richland Operations Office (DOE/RL) initiated a site-wide 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 Sept. 5, 1996, John Wagoner issued a DOE/RL Letter of Instruction to affected DOE/RL programs, and site contractors that said "... with DOE/RL and contractor customers, tribal and stakeholder participation, PNNL will develop and maintain a predictive Hanford standard groundwater model...." In a letter to regulators and stakeholders dated July 28, 1997, DOE/RL also made a commitment to initiate the model consolidation process in FY 1998.

At Hanford, several groundwater modeling programs have developed among the three major contractors since the Hanford mission changed from special nuclear materials production 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. Bechtel Hanford, Inc., (BHI) has implemented a site-wide groundwater model in support of past-practice operable unit investigations and cleanup activities. Pacific Northwest National Laboratory (PNNL), presently maintains groundwater modeling capabilities for the site in 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 modeling process to foster 1) consistency in assumptions in 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 fiscal year (FY) 1998, the consolidation process is to provide a current site-wide groundwater model of the site based on a consensus hydrogeologic conceptual model, database, and numerical model that will meet near-term and long-term needs and requirements of internal and external Hanford site stakeholders.

In FY 1998, the scope of the model consolidation is to 1) establish the needs and requirements of a Hanford site-wide groundwater model, 2) evaluate current interpretations,

DRAFT

data, models, and codes, 3) make recommendations for consolidation, 4) conduct review of recommendations, 5) document review and recommendations, and 6) initiate implementation of the recommendations.

Current plans also call for completing implementation of the site-wide groundwater model and development of a multi-year program plan in FY 1999 to provide continued support for the site-wide model from the years 2000 to 2005.

PURPOSE AND SCOPE OF REPORT

The purpose of this report is to document the overall recommendations being made by RL for consolidation of site-wide groundwater modeling. Included as the basis for the recommendations are descriptions of 1) the overall approach being used by RL to achieve the objectives of the model consolidation process, 2) the needs and requirements for a site-wide groundwater model that were developed in the initial phase of the model consolidation process, 3) an overview of the site-wide groundwater model that was proposed by RL as the starting point for a consensus site-wide model for external review, 4) a summary of technical concerns and issues raised by external reviewers on the proposed site-wide model, including input received from the EPA, Ecology, the Tribal Nations, and other stakeholders, and 5) specific refinements and modifications to the proposed site-wide model recommended by RL in response to external review comments.

The specific needs and requirements including the anticipated future uses of the site-wide groundwater model and the technical capability and administrative requirements for the selected computer code that will provide the basis of site-wide model implementation are based in part on an initial review of current and future groundwater modeling activities being planned by the Environmental Restoration, Waste Management, and Tank Waste Remediation programs at the Hanford Site. The needs and requirement also reflect input collected from external stakeholders including U. S. Environmental Protection Agency (EPA), Washington State Department of Ecology (Ecology), the Hanford Advisory Board, and two of the affected 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.

The report is separated into six sections and organized in the following manner:

DRAFT

- Section 1 is the Introduction.
- Section 2 provides a an overview of the approach being used in the groundwater model consolidation process.
- Section 3 provides a summary of anticipated uses, needs, and requirements for the site-wide groundwater model necessary to achieve the objectives of the model consolidation process.
- Section 4 provides a description of the proposed site-wide model including the rational for its selection and summary discussion of its conceptual model and numerical implementation.
- Section 5 provides a summary of technical issues and concerns raised by review of the proposed site-wide model by regulators, tribal nations, and other stakeholder groups. This section also provides a summary of peer review comments and recommendations. (Note: this summary is not included in this initial draft report but will be developed and included in the final draft.)
- Section 6 includes a summary of refinements and modifications to the proposed site-wide model in response to the external peer review of the model. (Note: this section is not included in this initial draft report but will be developed and included in the final draft.)

The main body of the report is also supplemented by information included in three appendices. Appendix A provides summaries of recent groundwater modeling activities of major program areas at the Hanford Site, including the Environmental Restoration, Waste Management, and Tank Waste Remediation System Programs. Appendix B provides a summary of technical issues and comments provided by regulators, tribal nations, and other stakeholders on the proposed site-wide model. Appendix C provides a summary of technical issues and comments provided by an external peer review of the proposed site-widewide model (note: Appendix C is not provided in this draft).

DRAFT

APPROACH FOR SITE-WIDE GROUNDWATER MODEL CONSOLIDATION

On October 27, 1997, DOE/RL initiated the site-wide groundwater model consolidation process with representatives of affected DOE/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 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
- recommendations for a consensus site-wide conceptual and numerical model and computer code to implement the consensus numerical model
- implementation of the recommendations.

To facilitate the development of the needs and requirements summarized in this report, program representatives 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 next section of this report.

DOE/RL also consulted with representatives of the EPA, Ecology, the Hanford Advisory Board, and affected 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 consensus site-wide conceptual and numerical model and computer code to implement the consensus numerical model was developed in series of internal workshops attended by technical representatives of Hanford contractors involved in groundwater modeling. These meetings were held between March 12 and March 31, 1998, and were attended by technical 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 conducted for the Hanford Ground-water Project (Wurstner et al. 1995, Cole et al. 1997, and Kincaid et al.

DRAFT

1998) and for development of the Hanford Site-wide Ground-water Remediation Strategy (Law et al. 1997 and Chiaramonte et al. 1997) respectively were considered. Of these two modeling efforts, the most recent modeling was performed with the Hanford Ground-Water Project model to support the Composite Analysis (Cole et al. 1997, and Kincaid et al. 1998) and the State of Washington permitted discharge assessment of the Effluent Treatment Facility (Barnett et al. 1997). In these internal meetings, the basic similarities and differences between these two recent models were discussed and evaluated. In general the models are very similar. Most notable differences are in

- the extent of the models. The model developed by the Hanford Groundwater Project includes an area that encompasses the North Richland well field and the City of Richland. The model used for development of the Hanford Site-wide Ground-water Remediation Strategy did not include these areas.
- the interpretation of the number of hydrogeologic layers. The Hanford Groundwater Project model identifies multiple and extensive mud units (e.g., nine hydrogeologic layers above the basalt) while the model used for the Hanford Site-wide Groundwater Remediation Strategy lumps all units below the Hanford into a single Ringold hydrogeologic unit. The mud units are mapped as being areally extensive [e.g., Lindsey et al. 1995, Law et al. 1997, Thorne and Charmness 1992), and therefore may control or influence the flow of groundwater on the Hanford Site.
- the HGWP model which considers both artificial and natural recharge while the model used to develop the Hanford Site-wide Remediation Startegy only considers artifical recharge.

DOE/RL's final decision is to proceed with the model developed by the HGWP. The basic rationale behind this decision was as follows:

- The HGWP model is the most recent effort and the data supporting the interpretations used are available for review.
- The HGWP model already includes Richland north of the Yakima River and west of the Columbia and thus provides the needed capability of the Hanford Groundwater Project to address plumes and the Richland drinking water supply.
- the HGWP model, which is more complicated, can be more easily used to investigate simplification issues related to the importance and need for the more complicated 9-layer description compared to the 2-layer description used the Hanford Site-wide Ground-water Remediation Strategy model as well as the importance of natural recharge.

DRAFT

Following the selection of the site-wide conceptual groundwater model developed by the Hanford Groundwater Project as the proposed site-wide groundwater model for external peer review, a technical workshop to discuss the model consolidation process was convened on April 24, 1998, and attended by technical representatives for EPA, Ecology, affected Tribal Nations (YIN, NPT, and CTUIR), and other interested Hanford contractors. The purpose of the workshop was to discuss the 1) proposed process for achieving the groundwater model consolidation objectives, 2) to review the anticipated uses, needs, and requirements of site-wide groundwater model, 3) to evaluate how current model/codes meet the needs and requirements, and 4) to discuss the basis for selection of the HGWP model for external peer review. The workshop also provided an overview of the proposed site-wide 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, technical representatives of the regulators and affected tribes were asked to review the background information for the proposed site-wide groundwater model and to raise any issues or concerns regarding the conceptual model and numerical implementation so that they can be passed on to the an outside independent peer review panel for evaluation.

A summary of the key technical issues and concerns raised by regulators, tribal nations, and other stakeholders during the original workshop and in written communications to DOE/RL (copies of the original written concerns and issues by individual groups are provided in Appendix B) is provided later in this report.

The developed recommendations documented in this report will be presented for review by an external peer panel in the summer of 1998. Comments and suggestions solicited during the review will be evaluated and to the extent possible will be incorporated into a final revised and final draft of this current report that will be published in January 1999.

Following peer review of the recommendations for model consolidation, DOE/RL will initiate the implementation of the recommendations for refinement and modification of the proposed site wide ground-water model. The proposed date for completing implementation of the proposed site-wide ground-water model, including the development, calibration, application, and documentation, is currently planned for July 30, 1999. However, this date may need to be revised based on the recommendations and resulting scope.

DRAFT

ANTICIPATED USES, NEEDS, AND REQUIREMENTS FOR THE SELECTED SITE-WIDE GROUNDWATER MODEL

ANTICIPATED USES OF THE SITE-WIDE GROUNDWATER MODEL

Site-wide groundwater modeling is a critical component of an overall system assessment methodology that is required at the Hanford Site to quantify the environmental consequences of past, present, and future Department of Energy activities at impacted compliance boundaries and receptor points at the site and within the region. The specific methods and models used must consider 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, may need to analyzed by the system assessment methodology. The temporal scales of impact to be assessed by 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 that have already impacted the unconfined aquifer system and may be seen for decades to come
- 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 methodology 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 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 declines in the underlying water table, an overall decrease in saturation of 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 on-site land uses may result as lands outside of the

DRAFT

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

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 consensus 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 this capability.

This section summarizes the modeling objectives and model characteristics used in the applications reviewed. The applications considered were conducted as key projects and activities related to the Environmental Restoration, Waste Management, and Tank Waste Remediation System Programs. A description of each modeling application reviewed can be found in Appendix A. This appendix also contains tables that summarize and compare model characteristics for the various models used.

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

- site performance assessments of proposed waste disposal facilities
  - compare predicted groundwater contaminant concentrations at the facility boundary to background levels or risk-based concentration limits
  - evaluate the effect of facility design on predicted groundwater concentrations
  - use 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

DRAFT

- estimate contaminant concentrations in the soil, groundwater, surface water, and air to which a human or ecological receptor might be exposed
- evaluate the potential impacts on groundwater quality of land use alternatives
- estimate the effect of operational facilities on future water quality

- design and evaluation of groundwater remediation strategies including natural attenuation, hydraulic control/containment, and contaminant removal/cleanup
  - estimate the effectiveness of alternative groundwater cleanup approaches
  - support planning and implementation of remediation alternatives
  - evaluate the impact of a declining water table on remediation effectiveness
- design and evaluation of site monitoring networks
  - determine whether a monitoring network is adequate to detect and monitor changes in a groundwater contaminant plume
  - evaluate the effectiveness of a monitoring network to predict the fate and transport of existing and emerging contaminant plumes under a declining water table
  - assess the ability of a monitoring network to determine the performance of a groundwater remediation strategy
- risk assessments
  - estimate dose impacts from predicted contaminant concentrations arising from past and future releases of contaminants
  - identify the sensitivity of risk predictions to flow and transport parameters
  - evaluate 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 source term, vadose zone, and exposure models. In general, this integration does not place any extraordinary requirements on the groundwater model. The integration of source term, vadose zone, and groundwater models is typically accomplished through the use of appropriate boundary conditions. In several of the Hanford Site applications reviewed, the groundwater code used in the model could also be used to model the vadose zone.

Several of the objectives require a comparison between predicted concentration or dose and some target level. These objectives, in particular, require that the degree of uncertainty in the model results be estimated. Since the prediction of groundwater behavior always involves a substantial amount of uncertainty, including an assessment of the uncertainty in results improves most modeling applications.

DRAFT

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

- Dimensionality: One-, two-, and three-dimensional models were used. In applications that considered two-dimensional models, both plan-view and cross-sectional models were used.
- Geologic framework: Conceptual models generally identified numerous geologic units in the vadose and saturated zones. In some cases, the geologic formations were modeled in detail and in others, several units were lumped together.
- Spatial variability: Homogeneity was often assumed, particularly within a given geologic unit. Some model application have considered spatial variability on the scale of the numerical grid.
- Temporal variability: Steady-state as well as transient solutions were required for both water flow and contaminant transport. Changes on a time-scale as short as one hour were considered.
- Chemicals: A wide variety of chemicals were simulated. Approaches used to approximate the environmental mobility of chemical contaminants were limited to examination of the sorption process using an equilibrium adsorption model.
- Radionuclides: Numerous radionuclides were simulated. Radioactive decay often included the in-growth of decay products. Approaches that approximate the environmental mobility of radioactive contaminants were limited to examination of the sorption process using an equilibrium adsorption model.
- Spatial scale: The spatial scale modeled varied from less than a square kilometer using local-scale models to the entire Hanford Site using a site-wide model.
- Temporal scale: Simulation times varied from less than 1 year to more than 10,000 years.
- Boundary conditions: A wide variety of boundary conditions were required, some of them natural boundaries, but some assigned for the convenience of the model (particularly for the small-scale models). Both steady-state and transient boundaries were used.
- Numerical model grid: The spatial resolution of the numerical models varied 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.

Many of the modeling applications reviewed used models that covered a relatively small portion of the Hanford Site: an operable unit in the 100 areas, for example. The greatest

DRAFT

degree of spatial and temporal variability and the finest spatial resolution was generally associated with these local-scale models.

A review of anticipated groundwater modeling applications on the Hanford Site was also completed to help identify the anticipated future uses of the selected site-wide groundwater model. The key projects, activities, and assessments that will require groundwater analyses and may use the site-wide model are summarized in Table 1. Brief summaries of the planned scope, schedule, and anticipated groundwater analysis needs for these projects, activities, and assessments are provided in the following two sections: 1) planned activities that will use site-wide groundwater modeling and 2) other activities that can potentially make use of site-wide groundwater modeling.

Planned Activities

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 (WM PEIS, DOE/EIS-0200-F), and reasonably foreseeable treatment, storage, and disposal facilities/activities. The EIS will evaluate alternatives for management of the program's radioactive and hazardous wastes, including waste generated at the Hanford Site or received from off site generators, during the same 20-year period evaluated by the WM PEIS. This EIS will comprehensively analyze impacts of the proposed action and reasonable alternatives, 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 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 low-level waste 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

DRAFT

and chemicals. The assessment is being initiated in FY 1998 and the initial draft of the EIS is expected to be completed for public review and comment in FY 1999.

Modeling Support to 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 both radiological and chemical contaminants to migrate from the Hanford Site through the groundwater pathway.

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

- development of 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
- predicting impacts of future water-level declines on site-wide monitoring wells.

In the future, this project will continue to require the use of a three-dimensional model of the unconfined aquifer system on an ongoing basis to assist in assessing and interpreting behavior of existing, emerging, or potential groundwater quality problems across the site. This capability would be required 1) to predict impacts of future water-level changes on site-wide monitoring wells and future groundwater flow patterns and 2) 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 on-site and off-site 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.

Composite Analysis

In response to the Defense Nuclear Facilities Safety Board (DNFSB) Recommendation 94-2, 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 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

DRAFT

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. The draft document summarizing this initial assessment has been recently published (Kincaid et al. 1998).

As part of the Composite Analysis, site-wide groundwater modeling was carried out to assess dose impacts for the off-site 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 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 Hanford Site Risk Assessment Methology (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.

Current plans for performing future iterations of 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.

Modeling Support to the Hanford Tank Initiative

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

- establishment of appropriate retrieval techniques
- determination of appropriate release during waste retrieval

- evaluation of the need for new tank retrieval technologies
- support for the identification of the most important field characterization and technologies development area
- support for future 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 analysis are summarized in two recent reports by JEGI (1998a and 1998b).

The detailed vadose models are under development for the AX tank farm. These models will be 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 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 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 it was already being used by members of the project team. The two-dimensional model results will be compared to the three-dimensional Hanford Groundwater Project model results as a validation exercise. Draft and final reports on the overall Retrieval Performance Evaluation assessment are currently planned to be released in November 1998 and January 1999, respectively.

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.

DRAFT

Immobilized Low Activity Waste Disposal Facility Performance Assessment

The Hanford immobilized low-activity waste (ILAW) disposal facility performance assessment provides an analysis of the long-term environmental and health impacts of the on-site disposal of Hanford immobilized low activity wastes (LAW). 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 on-site in a near-surface disposal facility located in the 200 East Area.

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.

An interim ILAW performance assessment (Mann et al. 1997, Lu 1996, Mann 1995) was prepared to provide an early assessment of the effects of the disposals using available information. The first version of the final ILAW PA will be published in FY 1998[1]. Much of the data used in the ILAW performance assessment was derived from information obtained in other on-site 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 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 down-gradient of the facility and at the Columbia River. The methods and technical approaches used to generate the data values are also described.

DRAFT

[1] Mann, F. M., R. P. Puigh II, C. R. Eiholzer, Y. Chen, N.W. Kline, A. H. Lu, B. P. McGrail, and P. D. Rittmann. 1998. *Immobilized Low-Activity Tank Waste Performance Assessment*, DOE/RL-97-69, Rev. B, in preparation

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. Current plans call for the preparation of two separate performance assessments. A performance assessment to support the decision to dispose of ILAW in the grout vault facility will be prepared by August 2000. A performance assessment to support the decision to dispose of ILAW in the new ILAW disposal facility will be prepared in FY 2002. In both cases, the analyses will require a site-wide groundwater flow and transport model to evaluate three-dimensional contaminant transport of key radioactive contaminants and potential human health impacts from facility releases at 100 m down-gradient for the facilities (to meet the requirements of DOE Order 5820.2a) and at the Columbia River boundary (to meet potential NRC licensing requirements). As in the case of LLW burial ground performance assessments, 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.

Other Possible Applications

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 221-U Canyon building.

In the initial assessment of the 221-U facility, a long-term performance 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 assessment will include a capability to evaluate the impacts of released contaminants on the unconfined aquifer system beneath the 221-U Canyon area.

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 including transport in the unconfined aquifer, and the subsequent risk and environmental impact of these contaminants at expected exposure and receptor points. The

DRAFT

specific scope and methodology used for the groundwater flow and transport component of the analysis will be developed during the initial phase of the performance assessment.

Current plans call for initiation of first phases of the performance assessment of all alternatives being considered in FY 1998. The current Tri-party Agreement schedule calls for a record of decision for disposition of the U-Canyon 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 using a phased approach after completion of the 221-U facility analysis.

200 Area Soils Characterization and Remediation

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 the establishment of 23 waste site groupings that integrate the treatment, storage, and disposal and past-practice sites and 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 decision 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 DOE/RL(1997a).

Although specific details associated with the assessment of the viable alternatives for each waste site group have not developed, it is anticipated that part of the analyses will need to evaluate the potential environmental and human health impacts of key radiological and chemical contaminants from each specific alternative on the underlying groundwater system. The site-wide groundwater model may not be used directly in each individual waste site grouping assessment but could provide an hydrologic framework or basis for the specific calculational module or methodology used to address the groundwater component of the assessment.

A qualitative risk assessment will be performed as part of the Remedial Investigation Report and Feasibility Study activities. The risk assessment will use historical process and characterization data as well as data collected from the representative site characterization activities. This data set will be sufficient to evaluate the remedial alternatives and ultimately

DRAFT

the selection of a remedial action. However, data will not be collected at this time for all the waste sites within the waste group. It is anticipated that only approximately 10% of the waste sites will be characterized at the Remeidal Investigation/Feasibility Study (RI/FS) stage. Thus, a quantitative risk assessment will not be performed as part of the RI/FS activities.

A quantitative risk assessment will be typically performed once additional data becomes available for the various waste sites in the waste group. This can be accomplished possibly as early as the collection of the confirmation data after the record of decision (ROD) but would typically be performed once the remedial action is completed. This quantitative risk assessment will require a sufficient data set to allow for detailed modeling and thus would not typically be able to be performed at the RI/FS stage. However, a limited quantitative risk assessment may be performed at the RI/FS stage where a more complex situation occurs when a large data set is required to be collected due to multiple waste site interactions, higher levels of contamination requiring more data to be collected (including data to be collected as part of an expedited response action, if required), or other drivers where a more detailed evaluation is needed for a specific waste site or location. This quantitative risk assessment would not be done for the entire waste group.

The sequence of activities anticipated for the 200 Area ER waste sites is as follows:

- The first six waste groups are considered to be low activity, medium to high volume waste sites. Thus, a sufficient volume of liquids has been disposed of at these waste sites that liquids have impacted groundwater. Where contaminants remain at significant levels in the vadose zone, a qualitative risk assessment (typically a one-dimensional model such as RESRAD) will be used during the RI/FS phase. This modeling will be performed in the late FY 2000 to early FY 2002 time frame. Actual remediation is not anticipated to be performed before FY 2003; thus data to support a quantitative risk assessment will not be available until FY 2003 or beyond.

- The characterization of the next set of waste groups could involve lower disposal volumes and higher levels of contamination. These waste groups could also include waste sites in close proximity to other more complex waste sites such as the TWRS tank farms. Thus, there may be a need to do a more detailed risk assessment during the RI/FS stage and, if sufficient data has been collected within the specific areas of concern, data will be available to do a more complex risk assessment. This risk assessment could be considered a limited quantitative risk assessment but would not be at a sufficient level to be considered a cumulative risk assessment. Thus, a more detailed two-dimensional model

DRAFT

(or simplistic three-dimensional model) may be required to support this effort in the late FY 2001 time frame.

A cumulative risk assessment is anticipated to be performed once sufficient data has been collected to allow a comprehensive evaluation to be performed as well as when final remedial actions have been defined and end states 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 and 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.

Solid Waste Burial Ground Performance Assessment

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 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 low-level waste 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 specific 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. Low-level wastes disposed in active and inactive burial grounds before September 26, 1988, were not considered in this analysis.

The performance assessment of the 200 West Area low-level burial grounds (LLBG) examined the long-term impacts of LLW and radioactive constituents of the LLMW disposed 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. Low-level wastes disposed 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.

DRAFT

Current program plans for Hanford LLW burial grounds call for ongoing maintenance of performance assessment analyses. This maintenance plan is designed to perform a routine review of the performance assessment-derived controls on waste disposal so that 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 performance assessments. Performance assessment revisions may be required to evaluate conditions or assumptions not originally included in the performance assessment 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 performance assessments, future use of the site-wide groundwater model to support the ongoing maintenance is not anticipated unless the annual performance assessment review and potential five-year revisions require its use to resolve a particular issue.

Liquid Discharge Facilities Permitting 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 discharges permits include the following sites:

- ST-4500, 200 Area Effluent Treatment Facility (ETF) managed by 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

DRAFT

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. 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 one year after first detection of tritium in groundwater.

No specific plans for further groundwater modeling at the SALDS site have been developed. Current permit requirements commit DOE/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 be dependent on the consistency of new discharge information or monitoring data with the fundamental assumptions and results simulated with the current site model.

Reevaluation and Update of 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). A summary of the key aspects of the groundwater model is provided in Appendix A.

To support the development of the site-wide groundwater remediation strategy, 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

DRAFT

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 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 HSRAM (DOE/RL, 1995d).

This work and related site-wide groundwater modeling was completed and published in 1996 and republished with revisions in 1997. At this time, there are no specific plans to revisit the developed strategy in the near future. However, should a reassessment of this strategy be required, the effort may need to reevaluate the previously predicted groundwater flow and transport modeling results. 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.

Final Records Of Decision For Contamination Currently Being Managed By Interim 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 100-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. The system also was installed to provide hydraulic control of the strontium-90 flux to the Columbia River and to support an evaluation of the adsorption barrier designed to reduce the flux of strontium-90 to the Columbia River by significantly delaying its transport to the Columbia River and to allow 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 being performed in 100-D area. While the system has proved to effective in providing hydraulic control of chromium flux 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.

DRAFT

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 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 are described in WHC (1994) (see also BHI 1996a, b). 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 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.

These pump-and-treat systems are being used as Interim Remedial Actions (IRMs) and are being monitored to evaluate their overall effectiveness in containment of 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 remediation of 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 conceivably be evaluated within the next 3- to 5- year period as additional data and information are collected on their overall effectiveness. This final assessment may require a reevaluation 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. Use of the site-wide model to support these future studies is unknown at this time.

DRAFT

COMPUTER CODE REQUIREMENTS FOR A CONSENSUS SITE-WIDE GROUNDWATER MODEL

This section of the report lists the requirements of the computer code to be used for the consensus 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 consensus site-wide model. In addition, a number of related documents describing code selection criteria were reviewed, including Simmons and Cole (1985), Kozak et al. (1989), DOE/RL (1991), and Mann and Myers (1998).

The computer code used to implement the consensus site-wide groundwater model must satisfy the requirements listed in this section. Both technical and administrative requirements are given along with a brief discussion of the rational behind each requirement.

Technical Requirements

Fluid Flow

Requirement. The code 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.

Rational. Groundwater flow at the Hanford site takes place in three-dimensions due to the geometry of the aquifers and the boundary conditions. Both confined and unconfined aquifers exist and may be important in determining flow and transport. Flow conditions are anticipated to change significantly over time due to changing site operations and land use. In general, flow is likely to be little influenced by temperature or density gradients. For certain modeling applications, however, 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 such as in-situ REDOX treatment methodologies, the ability to simulate the effects of variable density may be desirable. These features are not required in a site-wide 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 with the results of site-wide modeling.)

DRAFT

Hydrologic Properties

Requirement. The code must be capable of modeling the three-dimensional geometry of the important hydrogeologic units and the three-dimensional spatial variation of hydraulic parameters (hydraulic conductivity, transmissivity, specific storage, storage coefficient, etc.). The code must allow anisotropic hydraulic conductivity values.

Rational. The hydrologic properties of the sediments within which the aquifers occur are highly variable in both horizontal and vertical dimensions. The spatial variability has a strong influence on groundwater flow and contaminant transport, and must be modeled to accurately represent observed and future conditions.

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. It must be possible to specify longitudinal and transverse dispersivities that are not the same.

Rational. Advection and hydrodynamic dispersion are the primary mechanisms of solute transport in the groundwater at the Hanford Site. To accurately represent observed conditions, dispersivity must 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.

Contaminant Reactions and Radioactive Decay

Requirement. The code must be able to represent geochemical retardation using a linear equilibrium adsorption model. It must be possible to assign distribution coefficients that are a function of the contaminant and of the hydrogeologic unit in which transport occurs. The selected code must also be able to model first-order radioactive decay.

Rational. Adsorption and radioactive decay are major processes 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. A desirable feature of the code is the capability to model complex decay chains (for example, the decay of uranium).

DRAFT

Spatial Scale of Analysis

Requirement. The code must be capable of simulating groundwater flow and contaminant transport at the scale of the entire Hanford Site.

Rational. The purpose of the site-wide model is to be able to model the Hanford Site groundwater environment over the entire site.

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 10,000 years.

Rational. Site-wide groundwater modeling over a large range of time periods is required for the consensus model to satisfy all programmatic needs.

Coupling of Flow and Contaminant Transport

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

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

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.

Rational. Particle tracking is used to understand the movement of contaminants without the computational expense of solving the contaminant transport equation.

Boundary Conditions

Requirement. The code must be capable of incorporating time-dependent and spatially varying Dirichlet (constant head or concentration) and Neuman (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.

DRAFT

Rational. Aquifer recharge and river boundaries are spatially and temporally variable. Correctly representing these boundaries may 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) through the assignment of appropriate boundary conditions specifying water and contaminant fluxes. Output fluxes from the vadose zone model(s) are likely to vary in both space and time. Modeling future land use, site operations, and contaminant sources may require that variable sources and sinks be represented. For example, there may be a need to model the effect of future on-site irrigation wells.

Interaction with Local-scale Modeling

Requirement. The code must be capable of transferring output from the site-wide flow and contaminant transport model to local-scale (smaller than site-wide) models as appropriate.

Rational. The ability to facilitate transfer of critical information derived from the site-wide model to complex, local-scale models is required. Site-wide 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 model and that the output be time-varying. Among other applications, local scale models may be important in making remediation decisions in the 100 areas and 200 area plateau.

Administrative Requirements

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.

Rational. 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

DRAFT

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 Geographic Information Systems (GISs).

Rational. Interfaces to site GISs and site-wide model parameter database(s) allows 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 GISs and to produce outputs that can be read by the GISs. These interfaces may be part of the pre- or post-processing software.

Model Reliability Issues

Requirement. Code documentation must be 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.

Rational. 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. Even though 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.

Rational. The verification provides evidence that the solution methods used in the code are correctly implemented and should also 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.

Rational. 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

DRAFT

Ecology for environmental assessments at the Hanford Site. The code should have been used in simulations of the Hanford Site unconfined aquifer with the results published in externally reviewed documents.

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.

Rational. 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.

Configuration Control

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

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

Contractor Use

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

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

Public Availability and Cost

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

Rational. 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.

DRAFT

Proprietary Codes

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

Rational. Inspections and/or verification reviews may be required to assist DOE and its contractors in rectifying problems encountered in application of the code, or in working with the code author(s) 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 author(s)/custodian(s) will be necessary. Proprietary codes will be considered if they provide an advantage over public domain codes and only if these arrangements can be made.

Portability

Requirement. The selected code should be capable of being run efficiently on a variety of computational workstations and platforms including UNIX-based workstations.

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

ACCEPTABILITY OF CURRENT CODES FOR THESE REQUIREMENTS

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

- the VAM3D-CG code developed by Hydrogeologic, Inc in Herndon, Virginia, used for site-wide modeling developed for the Hanford Site groundwater remediation strategy
- the CFEST96 code developed by the CFEST Co. in Irvine, California, used for the site-wide modeling developed in support of the Hanford Groundwater Project.

In a qualitative comparison of the two computer codes, both VAM3D-CG and CFEST96 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)
- they met the technical capabilities and administrative requirements outlined in the original M-29-01 document

DRAFT

- they generally met the technical capabilities and administrative requirements in the recent project report on needs and requirements submitted to DOE/RL on December 31, 1997. A summary of how both VAM3D-CG and CFEST96 meet these specific capabilities and requirements outlined in the previous section is provided in Table 2.

The key discriminating factors in the code selection were related to the cost and schedule impacts of implementing one code over the other. Costs evaluated included those associated with

- code purchases by contractors and interested parties who currently do not have a license for the selected code
- code/model training for contractors and interested parties unfamiliar with selected code and model
- implementation of the underlying infrastructure and pre- and post-processing software, configuration control, and maintenance of each specific code, and
- future model application.

Code purchase cost information were compiled based on input provided by Hydrogeologic, Inc. and CFEST Co. in a response to a formal request made by PNNL on behalf of RL. Procurement of VAM3D-CG that includes a copy of the source code and additional executables to support use on four workstations would be approximately $50,000 to $65,000 higher than a similar purchase of the CFEST-96 code. The code capabilities for these purchases are comparable in that the version of the VAM3D-CG offered would be a three-dimensional saturated zone version of the code rather than the unsaturated-saturated version of the code.

The overall costs of code training for VAM3D-CG or CFEST-96 will likely be about same to RL. However, the actual incurred costs would originate in different contractor or program organizations that are unfamiliar with the code selected. The selection of VAM3D-CG would require code training by PNNL staff. Costs could be slightly higher since PNNL is the organization responsible for maintaining the overall capability of the site and would likely need to have a deeper understanding of code use than the typical code user with other contractors. Selection of the CFEST-96 code would require code training by organizations now using VAM3D-CG or other models.

A qualitative evaluation of the potential costs and schedule impacts of implemention of the necessary infrastructure, pre- and post-processing software development, configuration control, and maintenance was also developed. Assuming that the Hanford Groundwater

DRAFT

Project is the program identified to provide necessary configuration control and maintenance for the implemented site-wide model, a VAM3D-CG model implementation would cost more than CFEST implementation since HGWP staff would need to link VAM3D-CG pre-processing and post processing capabilities with current EarthVision and ARC/INFO infrastructure. The selected site-wide would need to linked to site-wide GIS capabilities and ARC/INFO processing software to display input files and model results. Additional schedule and costs would be incurred in implementing VAM3D-CG because the current preprocessing software that links the basic hydrogeologic data and information and interpreted hydrogeologic surfaces to model input files are designed to generate suitable input for CFEST-96. Actual differences in implementation costs can only be determined by detailed planning.

Little specific information is currently available on comparable costs of running the VAM3D-CG code versus the CFEST-96 code since the current model implementations with these codes are based on different conceptual model complexity. The costs of running the current CFEST-96 model implementation, which assumes a larger number of major hydrogeologic units than the VAM3D-CG model implementation (nine model layers versus two model layers), is currently higher than the current VAM3D-CG model implementation. The longer run times and associated costs of application are largely related to the differences in conceptual model complexity used in each model implementation. VAM3D-CG has numerical advantages over the CFEST-96 that may increase the speed of application for certain types of problems but some of the grid restrictions (regular grid) may pose additional implementation difficulties. Cost and implementation differentials for model application on the same conceptual model selected for model consolidation have not been evaluated. Actual differences can only be determined by specific benchmarking and testing.

DOE/RL's analysis of near-term cost and schedule impacts indicate that selection of VAM3D-CG as the implemented code would result in higher initial purchase costs, higher potential implementation costs, and potential schedule impacts since the site-wide model selected for external peer review is not currently implemented with the VAM3D-CG code. In the interest of minimizing initial cost and potential schedule impacts, DOE/RL has reached a decision to select the CFEST-96 as an interim code for the initial consolidated site-wide model implementation.

Once the initial phase of the model consolidation is completed, DOE/RL may consider performing more in-depth testing of the CFEST-96 code with the VAM3D-CG and other codes using a similar conceptualization of the aquifer system before making any further decision on codes. Although including the in-depth testing can provide additional

DRAFT

quantitative information to assist in the decision to implement other codes, DOE/RL recognizes that a detailed benchmarking of several codes can be a costly endeavor and can result in significant additional costs for the site-wide model program. As such, DOE/RL will thoroughly evaluate the necessary scope and associated costs with this type of activity before reaching a decision to include it in future planned work.

DRAFT

DESCRIPTION OF THE PROPOSED SITE-WIDE MODEL

PURPOSE AND SCOPE OF MODEL

Monitoring of groundwater across the Hanford Site has detected a number of radioactive contaminant plumes 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. Nitrate is the most extensive and widespread chemical contaminant in the unconfined aquifer. Carbon tetrachloride, chloroform, chromium, cis-1,2-dichloroethylene, fluoride, and trichloroethylene are present in smaller area at levels exceeding maximum contaminant levels.

The HGWP, managed by PNNL, is responsible for monitoring and assessing the movement of contaminants in groundwater at the Hanford Site. As part of this responsibility, the project has supported the development of groundwater models to assist in identifying and quantifying existing, emerging, or potential groundwater quality problems and in assessing the potential for contaminants to migrate from the Hanford Site to the accessible environment through the groundwater pathway. A three-dimensional numerical model of groundwater flow and contaminant transport has been developed for the unconfined aquifer system. Numerical models of the groundwater flow system were previously developed and served as important tools for estimating future conditions and predicting the movement of contaminants in the unconfined aquifer.

SYNOPSIS OF MODEL DEVELOPMENT

Summarizing from the chronology discussed in Wurstner et al.. (1995), a site-wide flow and transport model has been under continuous development by Pacific Northwest National Laboratory staff since the early 1960s as part of PNNL's continuing involvement the Hanford Site's groundwater monitoring efforts. The site-wide flow model and transport model capability has been and continues to be refined and updated as additional information is gathered and as conditions and application needs change at the Hanford Site. Pacific Northwest National Laboratory's Hanford Site unconfined aquifer model consists of a conceptual model and database that defines current system understanding.

DRAFT

Early flow models were two dimensional (e.g., the Variable Thickness Transient [VTT] code, Kipp et al.. 1972) and transport modeling, depending on the application, was either of the advective type (e.g.., the Hanford Pathline Calculation code [Friedrichs et al. 1977]); quasi-three-dimensional particle tracking type (e.g., the Multicomponent Mass Transport [MMT] code [Alhstrom et al. 1977]); or multiple stream-tube type (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]). Applications of the VTT, MMT, and TRANSS codes at the Hanford Site are described by Freshley and Graham (1988).

In the mid 1980s, the CFEST code was selected for upgrading of Pacific Northwest National Laboratory's two-dimensional modeling capability. 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 selection of 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). This two-dimensional model was recalibrated again in fiscal year 1997 (see Cole et al. 1997) when evaluation of previous calibration results indicated unrealistically high transmissivity values in some parts of the model domain. The recalibration 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).

Two-dimensional flow models used extensively at the Hanford Site prior to cessation of disposal operations were generally adequate for predicting aquifer head changes and

DRAFT

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 water table is dropping over most of the Hanford Site in response to cessation of large liquid disposals to ground. 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 geohydrology of the Hanford Site unconfined aquifer, Thorne et al. (1994) indicate 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 future water-table changes result in the de-watering of hydrogeologic layers. The water table is 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. As a result, changes in groundwater levels, groundwater flow direction, and contaminant transport can not be accurately simulated by a two-dimensional model because the three-dimensional routing of groundwater flow and contaminant mass resulting from the vertical heterogeneity can not be properly accounted for. These three-dimensional effects are especially important to the Composite Analysis because the purpose of a composite analysis is to add together different plumes by accounting for the superposition of plumes from different sources through time. Changes along the migrating front of de-saturating sediments can provide the means for plumes emanating from different places and at different times to composite. Such issues can not be properly addressed by a two-dimensional model or even a two- or three-layer, three-dimensional model because there is no ability (two-dimensional model) or limited ability (simple three-dimensional model) for one plume to migrate under another.

The initial three-dimensional model of the Hanford Site unconfined aquifer (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

DRAFT

inverse modeling was preserved during the calibration of the three-dimensional model as is described in Wurstner et al. (1995).

The final improvements and calibration of the Pacific Northwest National Laboratory site-wide model used in this Composite Analysis were carried out during FY 1996 and FY 1997 as part of the HGWP. The purpose of this effort was to assist the HGWP in interpreting monitoring data, to investigate contaminant mass transport issues and evaluate the future movement of existing contaminant plumes, and to identify and quantify potential groundwater quality problems for on-site and off-site use. The report on this effort (Cole et al. 1997) describes the improvements to the three-dimensional model, the model re-calibration, and the application of the model to predict the future transport of existing contaminant plumes in the unconfined aquifer. The Cole et al. (1997) report presents predicted changes in transient-flow conditions in the unconfined aquifer to the year 4000. This provided the hydrologic basis for simulating migration of existing contaminant plumes presented in the Cole et al. (1997) report as well as the future contaminant plume migration simulated as part of the Composite Analysis. The contaminant migration results used in the Composite Analysis (Kincaid et al 1998) that are described in the Cole et al. (1997) report include the transport of the tritium plume resulting from future operations of the State-Approved Land Disposal Site (SALDS), and the transport of the existing tritium, iodine-129, technetium-99, uranium, and strontium-90 plumes originating from the 200 Areas. Tritium plume migration resulting from future operations of the SALDS is presented in more detail in Barnett et al. (1997).

SITE-WIDE CONCEPTUAL MODEL OF THE AQUIFER SYSTEM

The conceptual model of the Hanford Site unconfined aquifer system was developed from information on the hydrogeologic structure of the aquifer, spatial distributions of hydraulic and transport properties, aquifer boundary conditions, recharge and discharge, and distribution and movement of contaminants. Most information on the groundwater flow system comes from wells. Geologic information is obtained from descriptions of drill cuttings or core samples and from geophysical logging of wells. Groundwater flow direction and gradient are inferred from water levels measured in wells. Groundwater chemistry and contaminant distributions are determined from water samples taken from wells. The greatest amount of information is available for the shallower portions (less than 10 m below the water table) of the unconfined aquifer system. Fewer wells penetrate the deeper part of the unconfined aquifer system or the basalt confined aquifers. However, the shallower

DRAFT

unconfined aquifer is the most likely to be impacted by contaminants migrating through the vadose zone.

Development of the three-dimensional conceptual model is documented in Thorne and Chamness (1992), Thorne et al. (1993, 1994), and Wurstner et al. (1995). The geologic history and hydrogeologic setting of the Hanford Site is described in the annual Hanford Site Groundwater Report (Hartman and Dresel 1998). Summaries of site-wide hydrogeologic conditions are also available in Newcomb et al. (1972), Law et al. (1997) and Wurstner et al. (1995). Studies focused on the unconfined aquifer system in the vicinity of the 200 Areas are provided in Graham et al. (1981), Lindsey et al. (1991 and 1992), and Connelly et al. (1992a and 1992b). Confined aquifers within the Columbia River Basalts were extensively studied from 1977 to 1987 as part of the Basalt Waste Isolation Project. Detailed descriptions of these studies are available in DOE (1988).

Hydrogeologic Setting

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

Figure 4 shows the stratigraphic units underlying the Hanford Site. Sediments overlying the Columbia River Basalt Group include, in ascending order, the Pliocene-aged Ringold Formation, the Plio-Pleistocene unit (including early Palouse soil), and the informally named Hanford formation. Together, the saturated portions of these sedimentary deposits make up the Hanford Site unconfined aquifer system. However, the Plio-Pleistocene unit exists only in the western portion of the Site and is generally above the water table. The saturated thickness of the unconfined aquifer system is greater than 61 m in some areas but pinches out along the flanks of the basalt ridges. Depth to groundwater ranges from less than 0.3 m near the Columbia River to more than 100 m near the 200 Areas. Ground water in the unconfined aquifer system generally flows from recharge areas in the west to the Columbia River in the east.

DRAFT

Major Hydrogeologic 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 are the 1) gravel, sand, and paleosols of the basal unit, 2) clay and silt of the lower unit, 3) sand and gravel of the middle unit, 4) mud and lesser sand of the upper unit, and 5) basaltic detritus of the fanglomerate unit (Newcomb et al. 1972 and DOE 1988). Ringold strata also have been divided on the basis of facies types (Tallman et al. 1981) and fining upward sequences (PSPL 1982). More recently, Lindsey et al. (1992) described Ringold sediment facies on the basis of lithology, stratification, and pedogenic alteration. The facies types identified include the following:

- fluvial gravel facies - These consist 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 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 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 - These are 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 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 sidestreams draining into the Pasco Basin.

As described by Lindsey (1995) and illustrated in Figure 4, 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

DRAFT

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 the 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 (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.

To support development of the three-dimensional model, the lithofacies described by Lindsey (1995) were regrouped into nine hydrogeologic units based on similarity in expected groundwater-flow properties. Flow properties generally correlate to texture, sorting, and degree of cementation. Other geologic factors such as depositional environment, lithologic composition, and time of deposition were not considered in defining hydrogeologic units for the model. Therefore, the grouping of lithofacies was similar but not identical to that of Lindsey (1995).

Hydrogeologic units defined for the conceptual model were designated by numbers and are briefly described in Table 3. Lindsey's corresponding units are shown in parentheses. A graphical comparison of the model units with Lindsey's stratigraphic column is shown in Figure 4. 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 inthe 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

DRAFT

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.

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

The water-table lies within the Hanford formation over most of the eastern and northern parts of the Hanford Site. The Hanford formation lies entirely above the water table in the western part of the Site and in some other localized areas. Figure 5 shows a west to east cross section of the Hanford Site delineating the units defined for the conceptual model. The location of the water table in 1997 is also shown. Figure 6 shows a map view of hydrogeologic units which contained the water table during 1997.

Hydraulic and Transport Properties

To model groundwater flow, the distribution of hydraulic properties including both horizontal and vertical hydraulic conductivity, storativity, and specific yield were needed for each hydrogeologic unit defined in the model. In addition, to simulate movement of contaminant plumes, transport properties including contaminant specific distribution coefficients, bulk density, effective porosity, and longitudinal and transverse dispersivities were needed. Hydraulic and transport properties are documented in DOE (1988), Thorne and Newcomer (1992), Connelly et al. (1992a and 1992b), Thorne et al. (1993 and 1994), Wurstner et al. (1995), Cole et al. (1997), and other project-specific reports.

Transmissivity (the product of hydraulic conductivity and aquifer thickness) and storage information for the unconfined aquifer system has been obtained primarily from aquifer pumping tests and slug tests conduced at wells. Hydraulic conductivity has also been determined from laboratory tests of sediment samples. Values determined from aquifer pumping tests and slug-interference tests (Spane 1992; Spane and Thorne 1995) are considered to be more reliable than single-well slug tests or laboratory measurements. Transmissivity values from these types of tests were applied to an inverse flow model to develop a transmissivity distribution for the Site (Wurstner et al. 1995). Hydraulic conditions for 1979 were used in the inverse calibration because measured hydraulic heads were

DRAFT

relatively stable at that time. Details concerning the updated calibration of the two-dimensional model are provided in Cole et al. (1997). Figure 7 shows the distribution of transmissivity data from aquifer pumping tests and slug-interference tests. Figure 8 shows the distribution of transmissivity determined from inverse flow modeling. Aquifer transmissivity is relatively high in the area between Gable Mountain and Gable Butte, and in the central part of the site. Coarse-grained Hanford formation sediments with relatively high hydraulic conductivity are present below the water table in these areas and the aquifer is relatively thick in the central part of the site.

Figure 9 shows the range of hydraulic conductivity values calculated from measured transmissivity and aquifer thickness. Hydraulic conductivity of the Hanford formation is generally an order of magnitude greater than the hydraulic conductivity of the Ringold Formation. However, measured hydraulic conductivity of both of these units varies laterally by more than two orders of magnitude. This is a result of aquifer heterogeneity. The aquifer also displays vertical anisotropy. Results of a few multiple-well aquifer tests suggest that the ratio of vertical to horizontal hydraulic conductivity is in the range of 0.01 to 0.1. Because Hanford formation sediments are so much more permeable than Ringold sediments, they tend to dominate groundwater flow where the water table is in the Hanford formation. As discussed in Cole et al. (1997), hydraulic conductivities were assigned to the three-dimensional model units so that the total aquifer transmissivity was preserved at every location.

Less reliable data is available on aquifer storage properties because they are difficult to measure accurately. Only multiple-well aquifer tests provide valid estimates and these are affected by non-ideal aquifer conditions and well configuration (Spane 1993). Measured aquifer storage properties are documented in Wurstner et al. (1995). Specific yield was estimated to range from 0.1 to 0.3 for the Hanford formation and from 0.05 to 0.2 for Ringold Formation gravel units. Storativity was estimated to range from 0.0001 to 0.0005 for the Hanford and from 0.0001 to 0.001 for Ringold Formation gravels.

Wurstner et al. (1995) and Cole et al. (1997) provide information on transport properties used in past modeling studies at the Hanford Site. Transport parameters including effective porosity and longitudinal and transverse dispersivities are also needed for transport simulations. Effective porosity was set equal to specific yield for the unconfined aquifer (e.g. 0.1 for the Ringold Formation and 0.25 for the Hanford formation). Dispersivity is theoretically expected to have an asymptotic value that can be related to the scale of uncharacterized aquifer heterogeneity (Farmer 1986). In contaminant transport simulations, large values of dispersivity result in lower peak concentration estimates, but give rise to earlier

DRAFT

first arrival times that can increase arrival concentrations of radionuclides with short half-lives. For the Composite Analysis (Kincaid et al. 1998), longitudinal dispersivity of 95 m and transverse dispersivity of 20 m were selected. Dispersivity and the basis for this selection is discussed in detail in Kincaid et al. (1998). Distribution coefficients for various contaminants in the Hanford Site unconfined aquifer system have been determined from laboratory tests and from the literature. These quantities are affected by water chemistry, grain size and mineralogy. The selection of distribution coefficients and bulk densities for application in model is discussed in detail in Cole et al. (1997) and Kincaid et al. (1998).

Aquifer Boundaries

Peripheral boundaries for the Hanford Site unconfined aquifer system are formed by the Columbia River on the north and east and by basalt ridges and the Yakima River on the south and west. The Columbia River represents a point of regional discharge for the unconfined aquifer. The amount of ground water discharging to the river is a function of local hydraulic gradient between groundwater elevation alongside and beneath the river. This hydraulic gradient is highly variable because the river stage is affected by seasonal variations in precipitation and runoff in other regions of the river drainage system. The river stage is also impacted by weekly and daily changes in river flows at numerous dams on the river, as determined by electric power generation needs, fisheries resources management, and other dam operations. To approximate the long-term effect of the Columbia River on the unconfined aquifer in the three-dimensional model, the Columbia River is represented as a constant-head boundary over the entire thickness of the aquifer. The Yakima River is also represented as a constant-head boundary. Its 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.

At the Cold Creek and Dry Creek valleys, the unconfined aquifer extends westward beyond the boundary of the Hanford Site groundwater flow model. To approximate the groundwater flux entering the modeled area from these valleys, both constant-head and constant-flux boundary conditions are 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 does a constant head boundary. Discharges from Dry Creek Valley in the model area, resulting from infiltration of precipitation and spring discharges, are approximated with a prescribed-flux boundary condition. The

DRAFT

unconfined aquifer also is recharged from springs and runoff that infiltrate the aquifer along the northern side of Rattlesnake Hills.

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. 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.

Aquifer Recharge and Groundwater Flow Dynamics

Groundwater in the unconfined aquifer generally moves from recharge areas along the western boundary of the site eastward and northward toward the Columbia River, which is a discharge location for the aquifer. However, this flow pattern has been altered locally by the formation of groundwater mounds resulting from wastewater discharge. The direction of groundwater flow is inferred from measurements of hydraulic head in wells. A site-wide network of wells is measured annually for this purpose and some wells are measured more frequently to track water level fluctuations or to monitor groundwater flow around critical facilities. The water table elevation is mapped and reported in the annual Hanford Site Groundwater Report (e.g. Hartman and Dresel 1998).

Natural recharge occurs from infiltration of runoff from elevated regions west of the site and infiltration of precipitation falling across the Hanford Site. Other potential sources of natural recharge are the Yakima River and the basalt confined aquifer system. Recharge from the western boundary of the Site enters primarily from the Cold Creek and Dry Creek drainages. These are ephemeral streams on the Hanford Site. Estimates of combined recharge from the Cold Creek and Dry Creek Valleys have ranged from 0.10 to 0.34 m^3/s (Law et al. 1997).

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). A natural recharge map was developed by Fayer and Walters (1995) based on distributions of soil and vegetation types. The average recharge from precipitation across the Site was estimated as 0.27 m^3/s.

DRAFT

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 (Wurstner et al. 1995).

Another potential source of recharge (or discharge) for the unconfined aquifer system is inter-aquifer communication with the upper basalt confined aquifers. The volume and distribution of water movement between the aquifer systems has not been quantified. Over most of the site, the amount of interflow is thought to be small because of the low hydraulic conductivity of the basalt separating the two aquifer systems. However, areas of increased vertical communication have been previously identified in the Gable Mountain and Gable Butte area on the basis of chemistry data (Graham et al. 1984; Jensen 1987). The increased communication in the area results from erosional channels that penetrate in the upper basalt confining layer. Hydraulic head data for the uppermost confined basalt aquifer also indicates the potential for water to discharge from this aquifer upward into the unconfined system in the northeastern part of the Hanford Site (Spane and Webber 1995).

Since the start of Hanford operations in the mid-1940s, artificial recharge from waste-water disposal facilities has been greater than the estimated recharge from natural sources. Sources and volumes of artificial recharge are summarized in Wurstner et al. (1995). This has caused an increase in the water table elevation over most of the Hanford Site and the formation of ground-water mounds beneath major waste-water disposal facilities. However, during the past 5 years, all production activities on the Hanford Site have been curtailed resulting in a decrease in waste-water disposal and decreases in water table elevation over much of the site.

Contaminant Distributions

Information on both the lateral and vertical distribution of contaminants is needed to establish initial conditions for the model. Observation of contaminant movement also provides an understanding of groundwater flow and allows comparison with transport modeling results.

Groundwater contaminants are monitored in over 700 wells annually. Results for FY 1997 are documented in Hartman and Dresel (1998). Unconfined and confined aquifer monitoring wells sampled in FY 1997 are shown in Figures 10 and 11, respectively. The lateral distribution of major radionuclide plumes in the upper part of the unconfined aquifer system is shown in Figure 12 and the distribution of major chemical plumes is shown in Figure 13. These plumes were inferred from measurements of samples taken from wells.

DRAFT

The vertical distribution of contaminants in the unconfined aquifer has been studied in a limited number of wells. Contaminant concentrations generally are highest near the water table and decrease with depth. However, in source areas, groundwater mounding and possible density-driven flow have moved contaminants deeper in the aquifer. In certain locations, open boreholes may also have provided a conduit for downward contaminant migration. Additional information on the vertical distribution of contaminants is provided in Wurstner et al. (1995) and Cole et al. (1997).

DRAFT

NUMERICAL IMPLEMENTATION OF SITE-WIDE CONCEPTUAL MODEL

The current three-dimensional groundwater flow and transport model developed for the Hanford Groundwater Project 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). It has also been effectively used by the chemical waste management community for conducting exposure assessments, evaluating remediation alternatives, and designing extraction and control systems for aquifers.

Descriptions of the capabilities and approach used in the CFEST code and its selection for the Hanford Groundwater Project are included in Evans et al. (1988) and Würstner et al. (1995). 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 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 work stations (Cole et al. 1988), was used for all flow and transport modeling prior to FY 1997. In FY 1997, the refinement of 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.

Results from CFEST are graphically displayed using the ARC/INFO geographic information system (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 is used to manipulate hydrogeologic data for the conceptual model.

DRAFT

Translation Of The Conceptual Model

Major Hydrogeologic Units

The lateral extent and relationships between the nine hydrogeologic units of the Ringold Formation and Hanford formation determined to be sufficient to adequately represent the unconfined aquifer 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. A brief summary of each of these units, based on descriptions in Wurstner et al. (1995), is provided in Table 3.

Aquifer Boundaries

Peripheral boundaries defined for the three-dimensional model are shown in Figure 14 together with the three-dimensional flow model grid. The flow-system is bounded by the Columbia River on the north and east and by the Yakima River and basalt ridges on the south and west. 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 constant-head boundary over the entire thickness of the aquifer. The CHARIMA river-simulation model (Walters et al. 1994) was used to generate long-term 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.

DRAFT

Recharge

Both natural and artificial recharge to the aquifer were incorporated in the model. Natural recharge to the unconfined aquifer system occurs from infiltration of 1) runoff from elevated regions along the western boundary of the Hanford Site, 2) spring discharges originating from the basalt-confined aquifer system, 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 (1993) for 1979 was applied in the model.

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. 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.

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 14. 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 rectangular in 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 a total of 7200 elements (1606 surface and 5594 subsurface elements) and 8463 nodes.

DRAFT

At the Cold Creek and Dry Creek valleys (see Figure 14), the unconfined aquifer extends westward beyond the boundary of the Hanford Site groundwater flow model. To approximate the groundwater flux entering the modeled area from these valleys, both constant head and constant flux boundary conditions are defined across these valleys. 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 does a constant head boundary. Previous versions of the three-dimensional model did not include boundary fluxes where Dry Creek enters the modeled area. In the current model, boundary fluxes are prescribed at the north and east valleys of Dry Creek along the southwestern edge of the model boundary. The addition of these boundary fluxes is consistent with observations of water levels in nearby wells in this area. The unconfined aquifer is also recharged from springs and runoff that infiltrate the aquifer along the northern side of Rattlesnake Hills.

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 for the Composite Analysis. 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.

Flow Model Development, Calibration, and Results

Prior to 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

DRAFT

modeling. A comparison of the calibrated water table surface using the three-dimensional model and the measure 1979 conditions is provided in Figure 15. 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 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 16. 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 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 17), 2100 (Figure 18), and 2350 (Figure 19) 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 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, all are predicted to reach steady state conditions by the year 2350. A complete discussion of this assessment is provided in Section 4.3.1 amd 4.3.2 (page 4.9 through 4.12) of Cole et al. (1997)

Over about a 300-year period following elimination of wastewater discharges to the ground at the Hanford Site, the water table is predicted by the model to decline significantly and return to near pre-Hanford Site conditions that were estimated to exist in 1944 (Kipp and Mudd 1974) over most of the site.. The areas that are different include 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 north of Richland, where the model simulates the hydraulic effect of the North Richland well field. Over this period, the water

DRAFT

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. The areas of the model predicted to be different from the estimated 1944 conditions include the area west of the 200 West Area, where higher predicted hydraulic heads reflect the effects of increased irrigation from upgradient regions; and the area of the North Richland well field, where annual injection and withdrawal sequences are assumed to continue.

Flow modeling results also suggested that 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. 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 would 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.

Contaminant Transport Model Development and Implementation

The FY 1997 effort includes 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 were 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 20) was primarily refined in the central area of the Hanford Site in the vicinity of the 200 Area

plateau. In this area, each 750 m a side 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 on 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.

Additional model parameters are required to model the contaminant transport processes of dispersion and adsorption. The basis of these additional model parameters, which include longitudinal and transverse dispersivities (D_l and D_t) and contaminant retardation factors (R_f) and key assumptions made in the development of the contaminant transport model listed in Table 4 are described in Cole et al. (1997).

DRAFT

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 on-site and off-site use of groundwater. Monitoring of groundwater in the unconfined aquifer has detected a number of radioactive contaminant plumes emanating from various operational areas (Hartman and Dresel 1997). The most widespread plumes are from tritium and iodine-129. Smaller plumes of strontium-90, technetium-99, and plutonium contain concentration levels of these constituents exceeding EPA and the state of Washington interim drinking water standards (DWS). Uranium concentrations are also found at levels greater than the proposed DWS. In recent years, areas of groundwater contaminated by cesium-137 and cobalt-60 have also been found at or exceeding the DWS.

The existing contaminant plumes in the unconfined aquifer simulated included the tritium, iodine-129, technetium-99, uranium, and strontium-90 plumes. Each of the transport simulations were based on the predicted future transient-flow conditions and the 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 Cole et al. (1997).

Simulations taken from Cole et al. (1997) resulted in the following conclusions:

Tritium - 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 simulation are depicted in Figure 21. Results of tritium transport for the period from 1979 through 1996 (Figure 22, 23 and 24) showed the same overall trends of contaminant migration 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 townsite and north of the 300 Area. Maximum concentrations of tritium in the 600 Area (downgradient of the 200-East Area) decline 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.

DRAFT

Beyond 1996, simulations of the tritium plume originating from the 200 Area predicted that the 200-East Area plume will continue to discharge along the Columbia River between the old Hanford townsite and an area north of the 300 Area over a period of about 90 to 100 years until it completely discharges into the river and/or decays below detection limits. The tritium plume from the 200-West Area is predicted to migrate beneath the 200-East Area as it is reduced by dispersion and decay (See Figures 25 and 26).

Iodine-129 - Predictions of the iodine-129 plume beneath the 200-East Area indicated that it will migrate toward and discharge into the Columbia River over a period of about 600 years (Cole et al. 1997). Over the period of migration, iodine-129 concentrations that are predicted to discharge into the river will decline slightly by the process of dispersion and sorption. However, initial concentrations will not fall significantly below current levels because of its long half-life. The iodine-129 plume from the 200-West Area is predicted to migrate toward the 200-East Area as it is reduced by dispersion and sorption.

Technetium-99 - Transport modeling of the technetium-99 plume indicated that the current technetium-99 plumes in the 200-East and the 200-West Areas will continue to slowly migrate laterally from source locations in the 200 Area to the Columbia River (Cole et al. 1997). The plumes in the 200-West Area decline to levels below regulatory concern as they migrate eastward toward the 200-East Area. The technetium-99 plume from the northern part of the 200-East Area is predicted to continue migrating northward through the gap between Gable Butte and Gable Mountain toward the Columbia River. However, concentration levels of the simulated plumes decline to below drinking water standards (900 pCi/L) over a period of 100 years by the processes of dilution by infiltration and plume dispersion.

Uranium - Simulations of the uranium plume in the 200 Areas predicted that the current uranium plumes will not migrate significantly from current source locations in the 200 Area because uranium is adsorbed with a distribution coefficient (kd) of 3.0 ml/g (Cole et al. 1997). Concentration levels of the simulated plumes in the 200 Area will decline below regulatory concern over the next 50 years by the processes of dilution by infiltrating rainwater, and plume dispersion. During the simulation period, the uranium plume largely remained within the exclusion and buffer areas of the 200 Area plateau.

Strontium-90 - Transport modeling of the strontium-90 plume in the 200-East Area predicted that the strontium-90 plume will likely migrate very little from its current location within the 200 Area because strontium-90 sorbs strongly to Hanford sediments (kd = 20 ml/g) (Cole et al. 1997). Concentration levels of the simulated plume in the buffer area

DRAFT

surrounding the 200 Area will decline over the next 100 years to below regulatory concern by processes of radioactive decay and plume dispersion as it migrates from the current location. The strontium-90 plume is predicted to remain largely within the 200 Area plateau.

In general, the results of transport analyses of tritium, iodine-129, technetium-99, and uranium with the three-dimensional model were in agreement with past site-wide modeling results obtained by Chiaramonte et al. (1997) in support of the Environmental Restoration Program. However, the current three-dimensional model has resulted in higher estimates of peak concentrations at shallow depths and less vertical migration than was predicted in previous site-wide model applications. These discrepancies are attributable to differences in basic assumptions made about the hydrogeologic framework and the horizontal and vertical discretization used in each model. The differences in assumptions resulting from each modeling approach affect lateral and vertical distributions of predicted hydraulic heads and contaminants in the unconfined aquifer.

The near-term impacts of existing plumes to on-site drinking water supplies were examined by evaluating predicted concentration levels in the vicinity of identified on-site water supplies over the next 30 years. Projected future levels of tritium suggest that water supply wells in the 400 Area at the Fast Flux Test Facility (FFTF) 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. Tritium levels at well locations in the 400 Area and the 200-East Area are expected to remain above the 20,000-pCi/L level until sometime between 2010 and 2020. After that time, tritium will continue to decline to below 500 pCi/L at some time between the years 2070 and 2080. Model results suggest that tritium concentrations now found in the 300 Area in excess of 2,000 pCi/L will not reach the North Richland well field.

Transport analyses suggest that only water supplies in the 200-East Area could potentially be impacted by elevated levels of iodine-129. Model-predicted levels of iodine-129 suggest that within 20 to 30 years iodine levels in excess of 1 pCi/L that are currently in the 200-East Area would be found about halfway to the Columbia River. The iodine-129 plumes in the 200-West Area will be expected to migrate slowly toward the 200-East Area but model results suggest that levels in excess of 1pCi/L would not reach the 200-East Area within 30 years.

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-

DRAFT

Plant and AY/AZ tank farm, will be impacted by future transport of these contaminants within the existing plumes.

Transport of future contaminant releases to the unconfined aquifer for source areas in the exclusive waste management area were 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 analysis, reported in Kincaid et al. (1998) indicate that the most of radionuclide inventory in past practice liquid discharge and solid waste burial sites on the 200 Area Plateau are projected to be released in the first several hundred years following Hanford Site closure and a significant fraction of the inventory was project to be released prior to 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 per year 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 per year, respectively at 2050 and also declined in subsequent years.

DRAFT

SUMMARY OF TECHNICAL ISSUES AND CONCERNS ON PROPOSED NEEDS AND REQUIREMENTS AND SITE-WIDE GROUNDWATER MODEL

Following is a summary of technical issues and concerns raised by technical representatives of regulators (EPA and Ecology), affected Tribal Nations (the NPT and the YIN) at a technical representatives 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 specific written concerns and issues provided by regulators and Tribal representatives following the workshop are included in Appendix B. Key technical issues and concerns are as follows:

NEEDS AND REQUIREMENTS

Source-Code Availability

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. Having the source code would enable the ability 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.

Regulator/Stakeholder Interaction

After the schedule for review of the proposed site-wide groundwater model and the recommendations document was presented, it was suggested that, in addition to the formal review of draft documents, informal interaction during the model/document review process would be appropriate. This suggestion was supported by regulators, tribal nations, stakeholders, and DOE/RL and contractors.

User Access

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 and has been included in this report.

Reactive Transport

DRAFT

A number of comments were made regarding a requirement for reactive transport modeling. It was questioned whether a capability to model interactions between chemical contaminants should be a requirement. The carbon tetrachloride plume and its potential decay was discussed as a point of interest. DOE 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. It was stated that the carbon tetrachloride plume was a large-scale issue, appropriate for analysis on a site-wide scale. 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 VAM3D-CG and CFEST.

Sub-Modeling Capability

Several comments were made regarding the importance of using the site-wide to interface with a local-scale model that might be used for reactive transport modeling. This involves not only the code, but also the database. However, it may not be practical to anticipate the requirements of the site-wide model to allow this interface and it is more likely that the complex, local-scale model would be designed to interface with the site-wide model.

Interested parties have 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. This specific requirement was not identified.

A concern was raised that every local-scale model would need to run the site-wide model in order to be consistent. This constraint would not be necessarily required however, site characterization data collected as part of a local-scale analysis would be a valuable addition to the site-wide database.

Vadose Zone Interface

A comment was made on whether VAM3D-CG and CFEST-96 have the capability to model unsaturated flow and transport. VAM3D-CG has this capability and CFEST-96 is a saturated aquifer code. However, 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.

DRAFT

THE PROPOSED SITE-WIDE GROUNDWATER MODEL

Large-scale Heterogeneities

Concerns have been raised about 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.

Uncertainty In Interpretation Of Geometry Of Major Hydrogeologic Units

Questions have been raised about whether sufficient data are available to support the refinement of the Ringold Formation into three sand and gravel units and three mud (fine-grained) units. It was 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. It was suggested that sensitivity analyses should be conducted to see what the effect of explicitly modeling the lower hydro-stratigraphic units might be. It was pointed out that reviewers are ultimately going to ask what the uncertainty in the results of the site-wide model are and that some effort should be made to address this area.

Impact of Structural Geologic Controls

Concerns have been raised about how some of the important structural geologic controls are being handled in the model. A concern was raised about a fault north of Gable Butte and Mountain. While there may be some evidence for a fault to exist in the basalts in this region of the model, there is no evidence of a fault in this region in the unconsolidated sediments.

A concern was raised that there should be faults represented in the model in the location of the May Junction Fault and the Cold Creek Fault. The current implementation has continuous, but thin layers in this region. A better representation of the fault would be to have offsetting layers.

Uncertainty in Hydraulic Properties

Hydraulic properties used in the modeling are based on a sparse set of data derived for hydraulic testing. Also, many of the wells tested only partially penetrate the unconfined aquifer system. Parameters values provided in tables from reference materials quite often represented with only a single number. Parameter values should be presented as a range of

DRAFT

values. Model sensitivity analyses should be conducted to evaluate the uncertainty on model flow and transport over the range of measured parameter values.

Concerns were raised about the basis for the "Book Value" hydraulic conductivities used in the translation of transmissivities derived from the two-dimensional model calibration to the three-dimensional model. References for the "Book Values" should be given.

Workshop participants commented that 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."

Workshop participants asked how much different from the two-dimensional model and 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. Consideration should be given to other viable alternatives to the method used in assigning hydraulic conductivities to the three-dimensional model.

Uncertainty In Lateral Boundary Conditions

Currently, boundary fluxes at the Cold Creek, Dry Creek, and Rattlesnake Ridge Springs are estimated based on present day hydrologic conditions. Future development and land uses in areas outside of the currently modeled area could have a significant impact on calculated fluxes estimated at these boundaries. The uncertainty of potential future development and land uses on these estimated boundary fluxes should be evaluated.

It is also unclear how the calculated boundary fluxes at Cold Creek, Dry Creek, and Rattlesnake Ridge have been distributed vertically in the three-dimensional model. This issue needs clarification.

Uncertainty in 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 was raised.

The potential for recharge to the unconfined aquifer from the upper confined aquifer was also raised as an issue. The conceptualization of the flow system assumes that flow to and

DRAFT

from the basalts is insignificant because of the assumed low permeability of the basalts. However, there are significant hydraulic gradients between the basalts 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. The consensus seemed to be that there is some indirect evidence for recharge (the historical persistence of West Lake and the occurrence of a groundwater mound north of Gable Mountain were suggested as indirect evidence of upward leakage from the underlying basalt confined aquifer). Currently, no data are available to support the estimation of recharge from the unconfined aquifer system and its use in the site-wide model. In assessing this component of recharge, it should be kept in mind that the flow from the basalts may have originated far off the Hanford Site and that these flows are part of a much larger regional flow system.

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

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

It is unclear how artifical recharge in the Richland area in the form of infiltration from ponds, agriculture and residential irrigation, and disposal of waste water at the potato-processing plants have been handled. This needs to be clarified.

Columbia River Boundary Conditions

Concerns have been raised about the 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. Moving the line of symmetry closer to the Benton County side of the river was suggested to be appropriate.

The issue was raised that there may be periods during which the actual relative river stages results in much different flow-system dynamics than those depicted by using mediam stages of the river.

Consideration should be given to using head-dependent-flux boundaries at the Columbia River rather than specified head boundaries.

DRAFT

Model Discretization Issues

Concerns were expressed about the oddly shaped elements used where the transport grid transitions from coarse to fine sediments. 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.

Flow Model Development and Calibration

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

Transport Model Development and Implementation

Data showing the vertical distribution of contaminants in the unconfined aquifer is generally lacking in most areas. This lack of information leads to uncertainty in defining initial conditions for modeling of 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 occur from pre-1944 to 1996 may be a better time 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.

DRAFT

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

DRAFT

RECOMMENDED REFINEMENTS AND MODIFICATION SUGGESTED FROM EXTERNAL PEER REVIEW

This section of the report summarizes the technical issues and concerns and the recommended refinements and modifications suggested by review of the proposed site-wide groundwater model by an external peer panel. The specific scope of the external review will be as follows:

- 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?

- 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?

- 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?

This section will be developed after completion of the external peer review of the proposed site-wide groundwater model.

DRAFT

REFERENCES

Alhstrom, S., W., H. P. Foote, R. C. Arnett, C. R. Cole, and R. J. Serne. 1977. *Multi-component Mass Transport Model: Theory and Numerical Implementation (Discrete-Parcel-Random-Walk Version).* BNWL-2127, Battelle Northwest Laboratory, Richland, Washington.

Barnett, D. B., M. D. Freshley, M. P. Bergeron, S. K. Wurstner, and C. R. Cole. 1997. *Tritium Monitoring in Groundwater and Evaluation of Model Predictions for the Hanford Site 200 Area Effluent Treatment Facility.* PNNL-11665/UC-802, Pacific National Northwest Laboratory, Richland, Washington

Bechtel Hanford Company (BHI). 1996a. *200-ZP-1 Phase II Interim Remedial Measure Quarterly Report, August- October, 1996.* BHI-00952-01, Rev. 0, Bechtel Hanford, Inc., Richland, Washington

Bechtel Hanford, Inc. (BHI). 1996b. *Engineering Evaluation/Conceptual Plan for the 200-UP-1 Groundwater Operable Unit Interim Remedial Measure.* BHI-00187, Rev. 2, Bechtel Hanford, Inc., Richland, Washington.

Cearlock D. B, K. L. Kipp, and D. R. Friedrichs. 1975. *The Transmissivity Iterative Calculation Routine – Theory and Numerical Implementation.* BNWL-1706, Pacific Northwest Laboratory, Richland, Washington.

Chiaramonte, G. R., C. W. Denslow, A. J. Knepp, R. D. Landon, and S. Panday. 1997. *Hanford Site-wide Groundwater Remediation Strategy - Groundwater Contaminant Predictions.* BHI-00469, Rev. 1, Bechtel Hanford, Inc., Richland, Washington.

Cole, C. R., F. W. Bond, S. M. Brown, and G. W. Dawson. 1984. *Demonstration/Application of Groundwater modeling Technology for Evaluation of Remedial Action Alternatives.* Contract 68-03-3116, Municipal Environmental Research Laboratory, U. S. Environmental Protection Agency, Cincinnati, Ohio.

Cole, C. R., S. B. Yabusaki, and C. T. Kincaid. 1988. *CFEST-SC: Coupled Fluid, Energy, and Solute Transport Code, Super Computer Version, Documentation, and User's Manual.* Battelle Pacific Northwest Laboratories, Richland, Washington.

Cole, C. R., S. K. Wurstner, M. P. Bergeron, M. D. Williams, P. D. Thorne. 1997. *Three-dimensional Analysis of Future Groundwater Flow Conditions and Contaminant Plume Transport in the Hanford Site Unconfined Aquifer System: FY 1997 Status Report.* PNNL-11747, Pacific Northwest Laboratory, Richland, Washington.

Connelly, M. P., B. H. Ford, and J. W. Lindberg. 1992a. *Hydrogeologic Model for the 200 East Groundwater Aggregate Area.* WHC-SD-EN-TI-019, Westinghouse Hanford Company, Richland, Washington.

Connelly, M. P., B. H. Ford, and J. V. Borghese. 1992b. *Hydrogeologic Model for the 200 West Groundwater Aggregate Area.* WHC-SD-EN-TI-014, Westinghouse Hanford Company, Richland, Washington.

Devary, J. L. 1987. The CFEST-INV *Stochastic Hydrology Code: Mathematical Formulation, Application, and User's Manual.* ICF Northwest, Richland, Washington

Dove, F. H., C. R. Cole, M. G. Foley, F. W. Bond, R. E. Brown, W. J. Deutsch, M. D. Freshley, S. K. Gupta, P. J. Gutknecht, W. L. Kuhn, J. W. Linberg, W. A. Rice, R. Schalla, J. F.

DRAFT

Washburn, and J. T. Zellmer. 1982. *AEGIS Technology Demonstration for a Nuclear Waste Repository in Basalt.* PNL-3632, Pacific Northwest Laboratory, Richland, Washington

DOE/RL - See "U. S. Department of Energy - Richland Operations Office"

Ecology - See "Washington State Department of Ecology"

Eddy, P. A., D. A. Myers, and J. R. Raymond. 1978. *Vertical Contamination in the Unconfined Groundwater at the Hanford Site, Washington.* PNL-2724, Pacific Northwest Laboratory, Richland, Washington

Evans, J. C., D. I. Dennison, R. W. Bryce, P. J. Mitchell, D. R. Sherwood, K. M. Krupka, N. W. Hinman, E. A. Jacobson, and M. D. Freshley. 1988. *Hanford Site Ground-water Monitoring for July through December 1987.* PNL-6315-2, Pacific Northwest Laboratory, Richland, Washington

Farmer, C. L. 1986. *The Dispersal of Contaminants in Heterogeneous Aquifers: A Review of Methods of Estimating Scale-Dependent Parameters.* AEEW R-2058, Atomic Energy Establishment, Winfrith, Dorchester, Dorset, England.

Fayer, M. J. and T. B. Walters. 1995. *Estimated Recharge Rates at the Hanford Site.* PNL-10285, Pacific Northwest Laboratory, Richland, Washington

Foley, M. G., D. J. Bradley, C. R. Cole, J. P. Hanson, K. A. Hoover, W. A. Perkins, and M. D. Williams. 1995. *Hydrogeology of the West Siberian Basin and Tomsk Region.* PNL-10585, Pacific Northwest Laboratory, Richland, Washington

Freshley, M. D. and M. J. Graham. 1988. *Estimation of Ground-Water Travel Time at the Hanford Site, Description, Past Work, and Future Needs.* PNL-6328, Pacific Northwest Laboratory, Richland, Washington.

Friedrichs, D. R, C. R. Cole, and R. C. Arnett. 1977. *Hanford Pathline Calculational Program: Theory, Error Analysis, and Applications.* ARH-ST-149, Atlantic Richfield Hanford Company, Richland, Washington.

Gale, J., R. Macleod, J, Welhan, C. R. Cole, and L. W. Vail. 1987. *Hydrogeological Characterization of the Stripa Site.* Technical Report 87-15, SKB, Stockholm, Sweden.

Gee, G. W., M. J. Fayer, M. L. Rockhold, and M. D. Campbell. 1992. "Variations in Recharge at the Hanford Site." *Northwest Science* 66:237-250.

Graham, M. J., M. D. Hall, S. R. Strait, and W. R. Brown. 1981. *Hydrology of the Separations Area.* RHO-ST-42, Rockwell Hanford Operations, Richland, Washington.

Graham, M. J., G. V. Last, and K. R. Fecht. 1984. *An Assessment of Aquifer Intercommunication in the B Pond, Gable Mountain Pond Area.* RHO-RE-ST-12P, Rockwell Hanford Operations, Richland, Washington.

Gupta, S. K., C. R. Cole, C. T. Kincaid, and A. M. Monti. 1987. *Coupled Fluid, Energy, and Solute Transport (CFEST) Model: Formulation and User's Manual.* BMI/ONWI-660, Battelle Memorial Institute, Columbus, Ohio.

Gupta, S. K. 1997. *Draft User's Manual, CFEST-96 Flow and Solute Transport, Constant/Variable Density, Computationally Efficient, and Low Disk PC/Unix*

DRAFT

Version. Consultant for Environmental System Technologies Company, Irvine, California.

Hartman, M. J. and P. E. Dresel. 1997. *Hanford Site Groundwater Monitoring for Fiscal Year 1996*. PNNL-11470,UC-402, 403, 702, Pacific Northwest National Laboratory, Richland, Washington.

Hartman, M. J. and P. E. Dresel. 1998. *Hanford Site Groundwater Monitoring for Fiscal Year 1997*. PNNL-11793,UC-402, 403, 702, Pacific Northwest National Laboratory, Richland, Washington.

Jacobs Engineering Group, Inc. (JEGI). 1998a. *AX Tank Farm Vadose Zone Screening Analysis for the Retrieval Performance Evaluation Criteria Assessment*. Jacobs Engineering Group, Inc., Richland, Washington.

Jacobs Engineering Group, Inc. (JEGI). 1998b. *SX Tank Farm Vadose Zone Screening Analysis for the Retrieval Performance Evaluation Criteria Assessment*. Jacobs Engineering Group, Inc., Richland, Washington.

Jacobson. E. A. 1985. *A Statistical Parameter Estimation Method Using Singular Value Decomposition with Application to Avra Valley Aquifer in Southern Arizona*. Dissertation, Department of Hydrology and Water Resources, University of Arizona, Tucson, Arizona.

Jacobson, E. A., and M. D. Freshley. 1990. *An Initial Inverse Calibration of the Groundwater Flow Model of the Hanford Unconfined Aquifer*. PNL-7144, Pacific Northwest Laboratory, Richland, Washington

Jensen, E. J. 1987. *An Evaluation of Aquifer Intercommunication Between the Unconfined and Rattlesnake Ridge Aquifers on the Hanford Site*. PNL-6313, Pacific Northwest Laboratories, Richland, Washington

JEGI - See "Jacobs Engineering Group, Inc."

Kincaid, C. T., M. P. Bergeron, C. R. Cole, M. D. Freshley, N. L. Hassig, V. G. Johnson, D. I. Kaplan, R. J. Serne, G. P. Streile, D. L. Strenge, P. D. Thorne, L. W. Vail, G. A. Whyatt, S. K. Wurstner. 1998. *Composite Analysis for Low-Level Waste Disposal in the 200-Area Plateau of the Hanford Site*. PNNL-11800, Pacific Northwest National Laboratory, Richland, Washington.

Kipp, K. L. and R. D. Mudd. 1974. *Selected Water Table Contour Maps and Well Hydrographs for the Hanford Reservation*. BNWL-B-360, Battelle Northwest Laboratory, Richland, Washington.

Kipp, K. L., A. E. Reisenauer, C. R. Cole, and L. A. Bryan. 1972. *Variable Thickness Transient Groundwater Flow Model: Theory and Implementation*. BNWL-1709, Pacific Northwest Laboratory, Richland, Washington.

Kozak, M. W., M. S. Y. Chu, C. P. Harlan, and P. A. Mattingly. 1989. *Background Information for the Development of a Low-Level Waste Performance Assessment Methodology, Volume 4, Identification and Recommendation of Computer Codes*, NUREG/CR-5453, Vol. 4, U.S. Nuclear Regulatory Commission, Washington, DC.

Law, A., S. Panday, C. Denslow, K. Fecht, and A. Knepp. 1997. *Hanford Site-wide Groundwater Flow and Transport Model Calibration Report*. BHI-00608, Rev. 1, Bechtel Hanford, Inc., Richland, Washington.

DRAFT

Lindsey, K. A., B. N. Bjornstad, and M. P. Connelly. 1991. *Geologic Setting of the 200 West Area: An Update.* WHC-SD-EN-TI- 008, Westinghouse Hanford Company, Richland, Washington.

Lindsey, K. A., B. N. Bjornstad, J. W. Lindberg, and K. M. Hoffman. 1992. *Geologic Setting of the 200 East Area: An Update.* WHC-SD-EN-TI-012, Westinghouse Hanford Company, Richland, Washington.

Lindsey, K. A. 1995. *Miocene to Pliocene-Aged Supra Basalt Sediments of the Hanford Site, South-Central Washington.* BHI-00184, Bechtel Hanford Inc., Richland, Washington.

Lu, A. H. 1996. *Contaminant Transport in the Unconfined Aquifer, Input to the Low-Level Tank Waste Interim Performance Assessment..* WHC-SD-WM-RPT-241, Westinghouse Hanford Company, Richland, Washington.

Mann, F. M. 1995. *Data Packages for the Hanford Low-Level Tank Waste Interim Performance Assessment.* WHC-SD-WM-RPT-166, Westinghouse Hanford Company, Richland, Washington.

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

Mann, F. M. and D. A. Myers. 1998. *Computer Code Selection Criteria for Flow and Transport Code(s) to be Used in Undisturbed Vadose Zone Calculations for TWRS Environmental Analyses.* (HNF-1839, Rev. B). Lockheed-Martin Hanford Company, Richland, Washington.

Neuman, S. P. and S. Yakowitz. 1979. "A Statistical Approach for the Inverse Problem of Aquifer Hydrology." Water Resources Research 15(4):845-860.

Newcomb, R. C, J. R. Strand, and F. J. Frank. 1972. *Geology and Groundwater Characteristics of the Hanford Reservation of the U.S. Atomic Energy Commission.* U.S. Geological Survey Professional Paper 717, U.S. Geological Survey, Washington, D.C.

PSPL see Puget Sound Power and Light Company

Puget Sound Power and Light Company (PSPL). 1982. *Skagit/Hanford Nuclear Project, Preliminary Safety Analysis Report,* Appendix 20, Amendment 23, Puget Sound Power and Light Company, Bellevue, Washington

Simmons, C. S. and C. R. Cole. 1985. *Guidelines for Selecting Codes for Ground-Water Transport Modeling of Low-Level Waste Burial Sites, Volume I - Guideline Approach,* PNL-4980, Vol 1., Pacific Northwest Laboratory, Richland, Washington.

Simmons, C. S., C. T. Kincaid, and A. E. Reisenauer. 1986. *A Simplified Model for Radioactive Contaminant Transport: The TRANSS Code.* PNL-6029, Pacific Northwest Laboratory, Richland, Washington

Spane, F. A., Jr. 1993. *Selected Hydraulic Test Analysis Techniques for Constant-Rate Discharge Tests.* PNL-8539, Pacific Northwest Laboratory, Richland, Washington.

DRAFT

Spane, F. A. Jr. 1996. "Applicability of Slug Interference Tests for Hydraulic Characterization of Unconfined Aquifers:(1) Analytical Assessment." *Ground Water* 34(1):66-74.

Spane, F. A. Jr., and P. D. Thorne. 1995. *Comparison of Constant-Rate Pumping Test and Slug Interference Test Results at the B-Pond Multi-Level Test Facility*, Hanford Site. PNL-10835, Pacific Northwest Laboratory, Richland, Washington.

Spane, F. A., Jr. and W. D. Webber. 1995. *Hydrochemistry and Hydrogeologic Conditions Within the Hanford Site Upper Basalt Confined Aquifer System.* PNL-10817, Pacific Northwest Laboratory, Richland, Washington.

Tallman, A. M., J. T. Lillie, and K. R. Fecht. 1981. "Suprabasalt Sediments of the Cold Creek Syncline Area." In Myers, C, W. and S. M. Price (eds.), Subsurface Geology of the Cold Creek Syncline. RHO-BWI-ST-14, Rockwell Hanford Operations, Richland, Washington.Spane 1992

Thorne, P. D., and M. A. Chamness. 1992. *Status Report on the Development of a Three Dimensional Conceptual Model for the Hanford Site Unconfined Aquifer System.* PNL-8332, Pacific Northwest Laboratory, Richland, Washington.

Thorne, P. D., and D. R. Newcomer. 1992. *Summary and Evaluation of Available Hydraulic Property Data for the Hanford Site Unconfined Aquifer System*, PNL-8337, Pacific Northwest Laboratory, Richland, Washington

Thorne, P. D., M. A. Chamness, F. A. Spane Jr., V. R. Vermeul, and W. D. Webber. 1993. *Three Dimensional Conceptual Model for the Hanford Site Unconfined Aquifer System, FY 93 Status Report.* PNL-8971, Pacific Northwest Laboratory, Richland, Washington.

Thorne, P. D., M. A. Chamness, V. R. Vermeul, Q. C. MacDonald, and S. E. Schubert. 1994. *Three Dimensional Conceptual Model for the Hanford Site Unconfined Aquifer System, FY 1994 Status Report.* PNL-10195, Pacific Northwest Laboratory, Richland, Washington.

U. S. Department of Energy (DOE). 1988a. *Radioactive Waste Management. DOE Order 5820.2A.* U. S. Department of Energy, Washington, D. C.

U. S. Department of Energy - Richland Operations Office (DOE/RL). 1988b. *Consultation Draft, Site Characterization Plan, Reference Repository Location, Hanford Site, Washington.* DOE/RW-0164, 2 Vol. U. S. Department of Energy, Richland, Washington.

U. S. Department of Energy - Richland Operations Office (DOE/RL). 1991. *Descriptions of Codes and Models to be Used in Risk Assessment.* U. S. Department of Energy, Richland Operations Office, Richland, Washington.

U. S. Department of Energy (DOE). 1993. *State Waste Discharge Permit Application for the 200 Area Effluent Treatment Facility and the State-Approved Land Disposal Site.* DOE/RL-93-44, Rev. 0. U. S. Department of Energy, Richland Operations Office, Richland, Washington.

U. S. Department of Energy - Richland Operations Office (DOE/RL). 1995. Hanford Site Risk Assessment Methodology. DOE/RL-91-45, Rev. 3, U. S. Department of Energy, Richland Operations Office, Richland, Washington.

DRAFT

U. S. Department of Energy - Richland Operations Office (DOE/RL). 1996. *200 Areas Soil Remediation Strategy - Environmental Restoration Program.* DOE/RL-96-67, rev.0, U. S. Department of Energy, Richland Operations Office, Richland, Washington.

U. S. Department of Energy - Richland Operations Office (DOE/RL). 1997a. *Waste Site Groupings for 200 Areas Soil Investigations.* DOE/RL-96-81, rev.0, U. S. Department of Energy, Richland Operations Office, Richland, Washington.

U. S. Department of Energy (DOE). 1997b. *Hanford Site-Wide Ground-Water Remediation Strategy.* DOE/RL-94-95, Rev. 1, U. S. Department of Energy, Richland Operations Office, Richland, Washington.

Walters, W. H., M. C. Richmond, and B. G. Gilmore. 1994. *Reconstruction of Radionuclide Concentrations in the Columbia River from Hanford, Washington to Portland, Oregon, January 1950 - January 1971.* BNWD-22254 HEDR, Battelle Pacific Northwest Division, Richland, Washington

Washington State Department of Ecology (Ecology). 1986. *State Waste Discharge Program.* WAC 173-126, Washington State Department of Ecology, Olympia, Washington.

Washington State Department of Ecology (Ecology), U. S. Environmental Protection Agency (EPA), U. S. Department of Energy (DOE/RL). 1989. *Hanford Facility Agreement and Consent Order.* Tri-Party Agreement (TPA), Richland, Washington.

Westinghouse Hanford Company (WHC). 1994. *Capture Zone Analysis for the 200-ZP-1 and 200-UP-1 Pilot-Scale Pump-and-Treat Tests.* WHC-SD-EN-TI-252, Rev. 0., Westinghouse Hanford Company, Richland, Washington

Wood, M. I., R. Khaleel, P. D. Rittman, S. H. Finrock, T. H. Delorenzo, and D. Y. Garbrick. 1996. *Performance Assessment for the Disposal of Low-Level Waste in the 200 East Area Burial Grounds.* WHC-SD-WM-TI-730, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Wood, M. I., R. Khaleel, P. D. Rittman, A. H. Lu, S. H. Finrock, R. J. Serne, K. J. Cantrell, T. H. Delorenzo. 1995. *Performance Assessment for the Disposal of Low-Level Waste in the 200 West Area Burial Grounds.* WHC-EP-0645, Westinghouse Hanford Company, Richland, Washington.

Wurstner, S. K., and J. L. Devary. 1993. *Hanford Site Groundwater Model: Geographic Information System Linkages and Model Enhancements, FY 1993.* PNL-8991, Pacific Northwest Laboratory, Richland, Washington.

Wurstner, S. K. and M. D. Freshley. 1994. *Predicted Impacts of Future Water-Level Decline on Monitoring Wells Using a Groundwater Model of the Hanford Site.* PNL-10196, Pacific Northwest Laboratory, Richland, Washington.

Wurstner, S. K., P. D. Thorne, M. A. Chamness, M. D. Freshley, and M. D. Williams. 1995. *Development of a Three-dimensional Groundwater Model of the Hanford Site Unconfined Aquifer System*: FY 1995 Status Report. PNL-10886, Pacific Northwest Laboratory, Richland, Washington.

DRAFT

Figure 1. An Overview Of The Model Consolidation Process

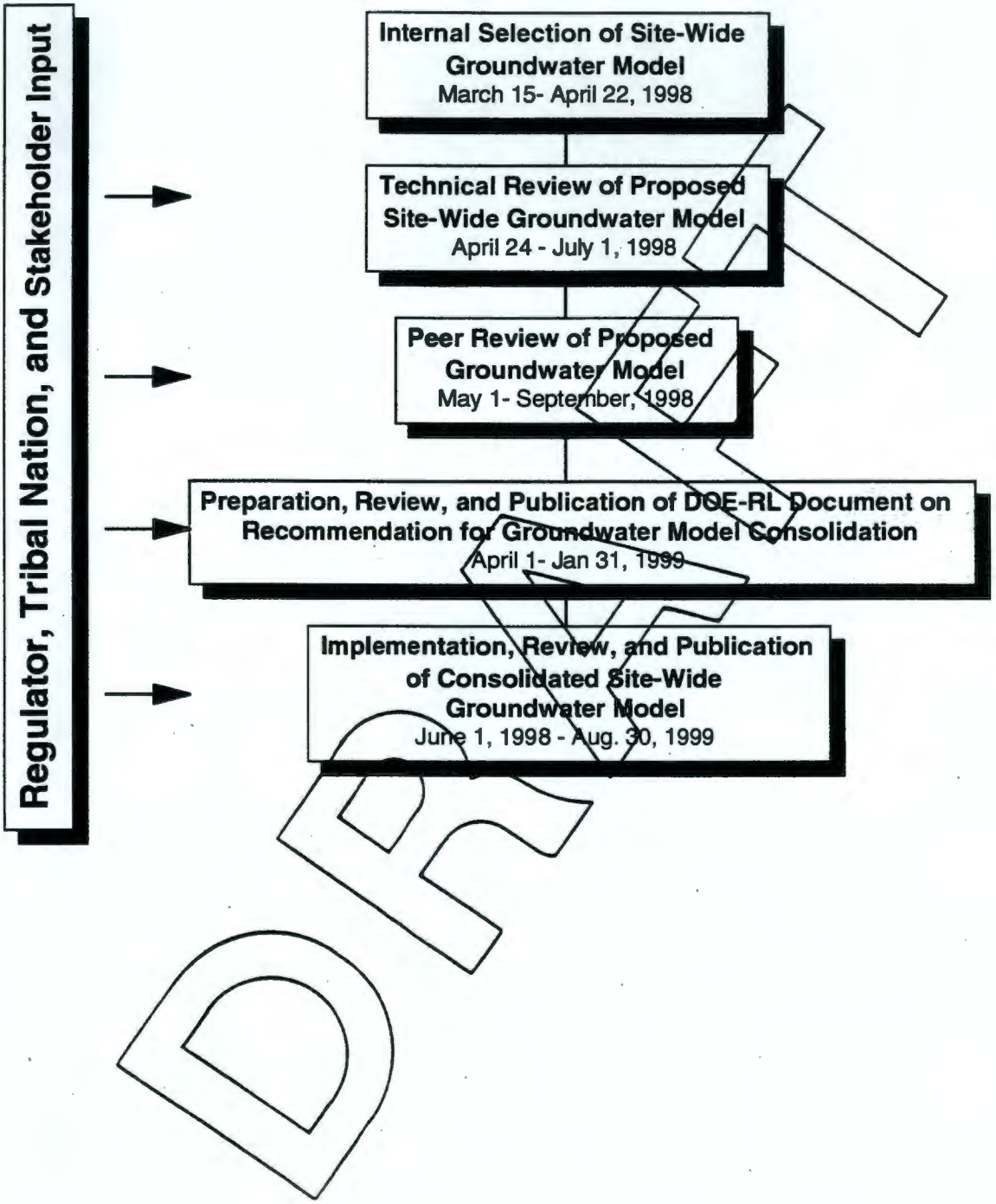
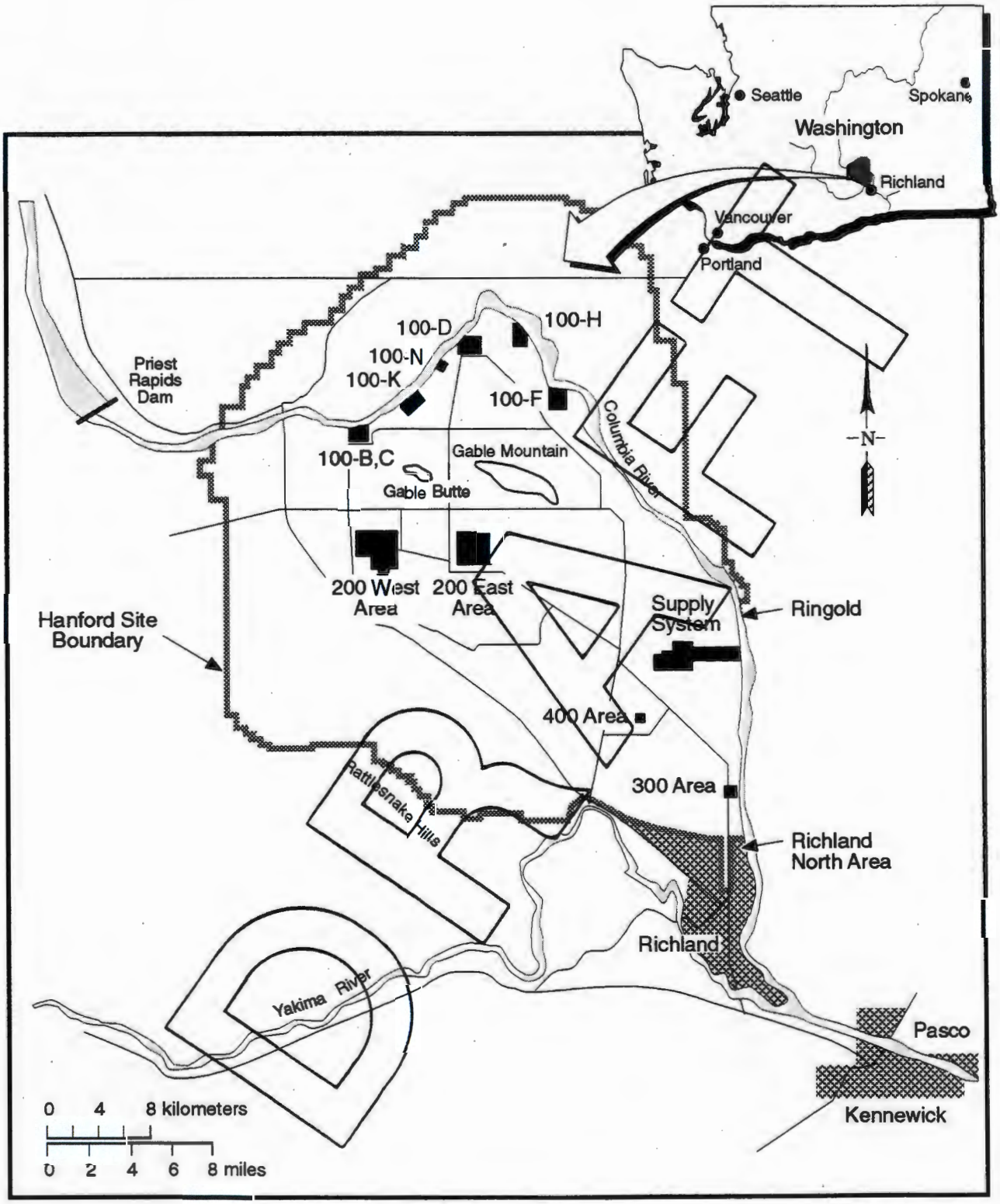


Figure 2. Location Of Operational Areas On The Hanford Site

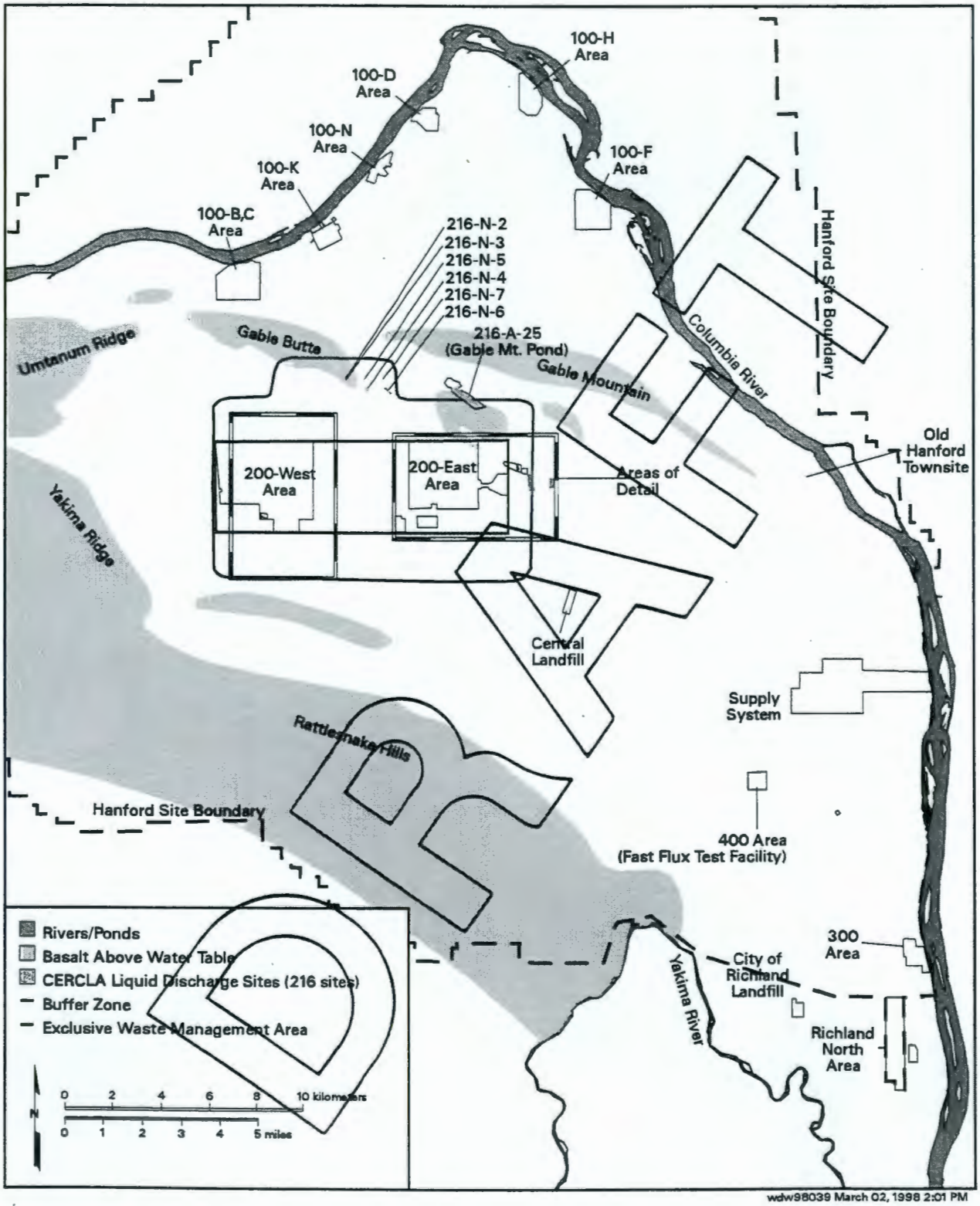
DRAFT



skw98100.fhd

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

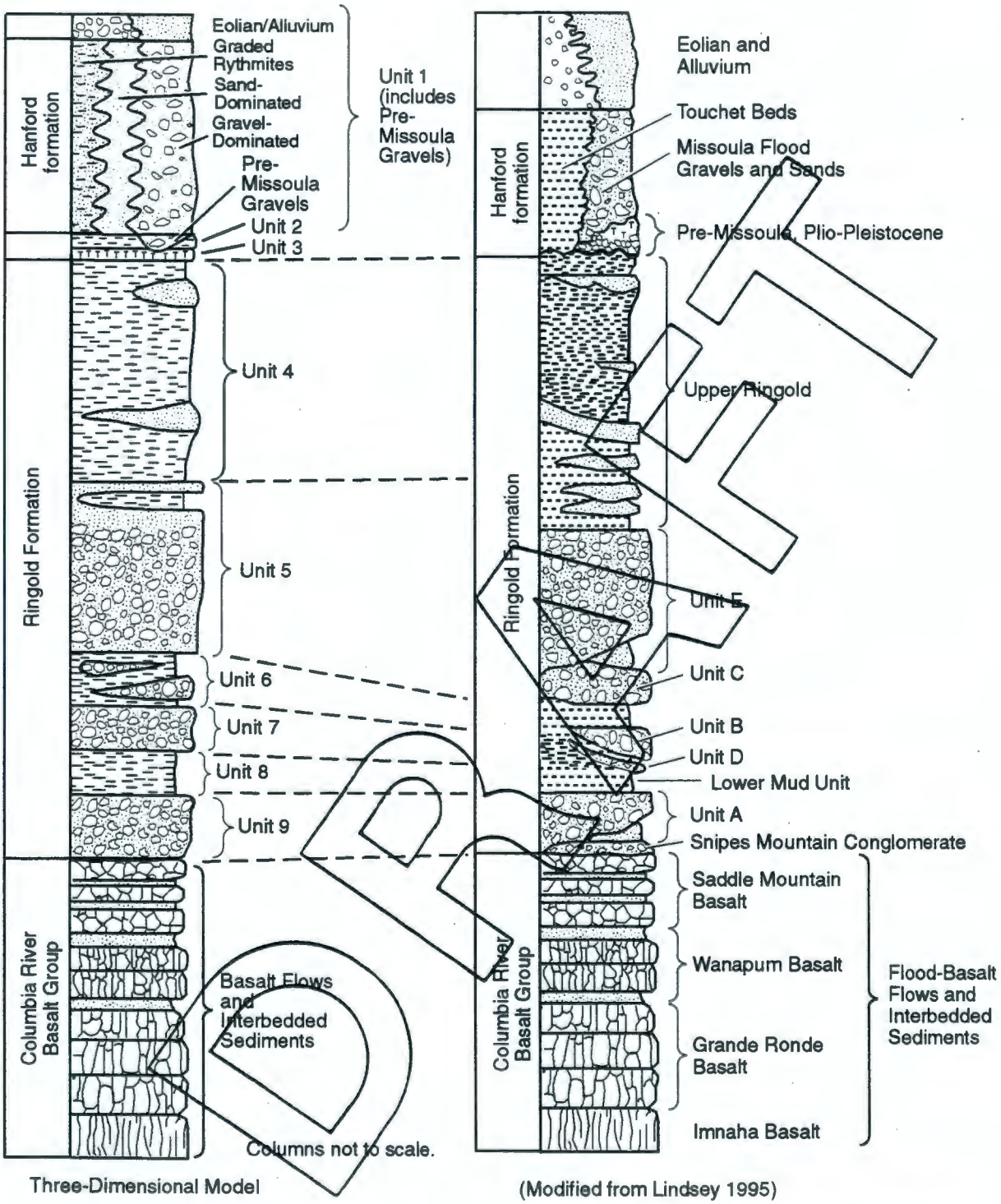
DRAFT



wdw98039 March 02, 1998 2:01 PM

Figure 4. Major Stratigraphic Units Underlying The Hanford Site

DRAFT



Three-Dimensional Model

(Modified from Lindsey 1995)

SG95110411.2

Figure 5. West To East Cross-Section Through The Hanford Site Showing Major Hydrogeologic Units

DRAFT

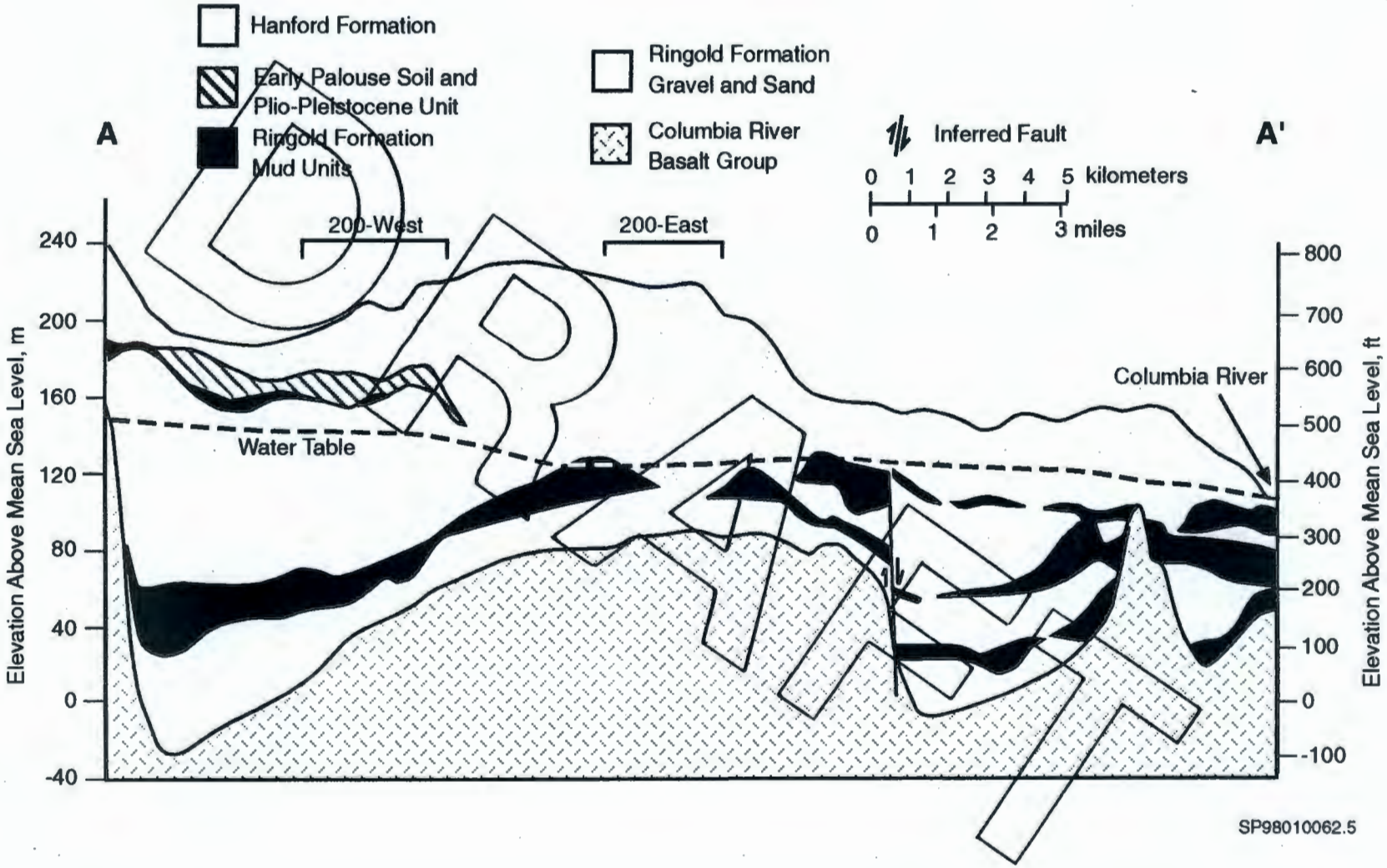
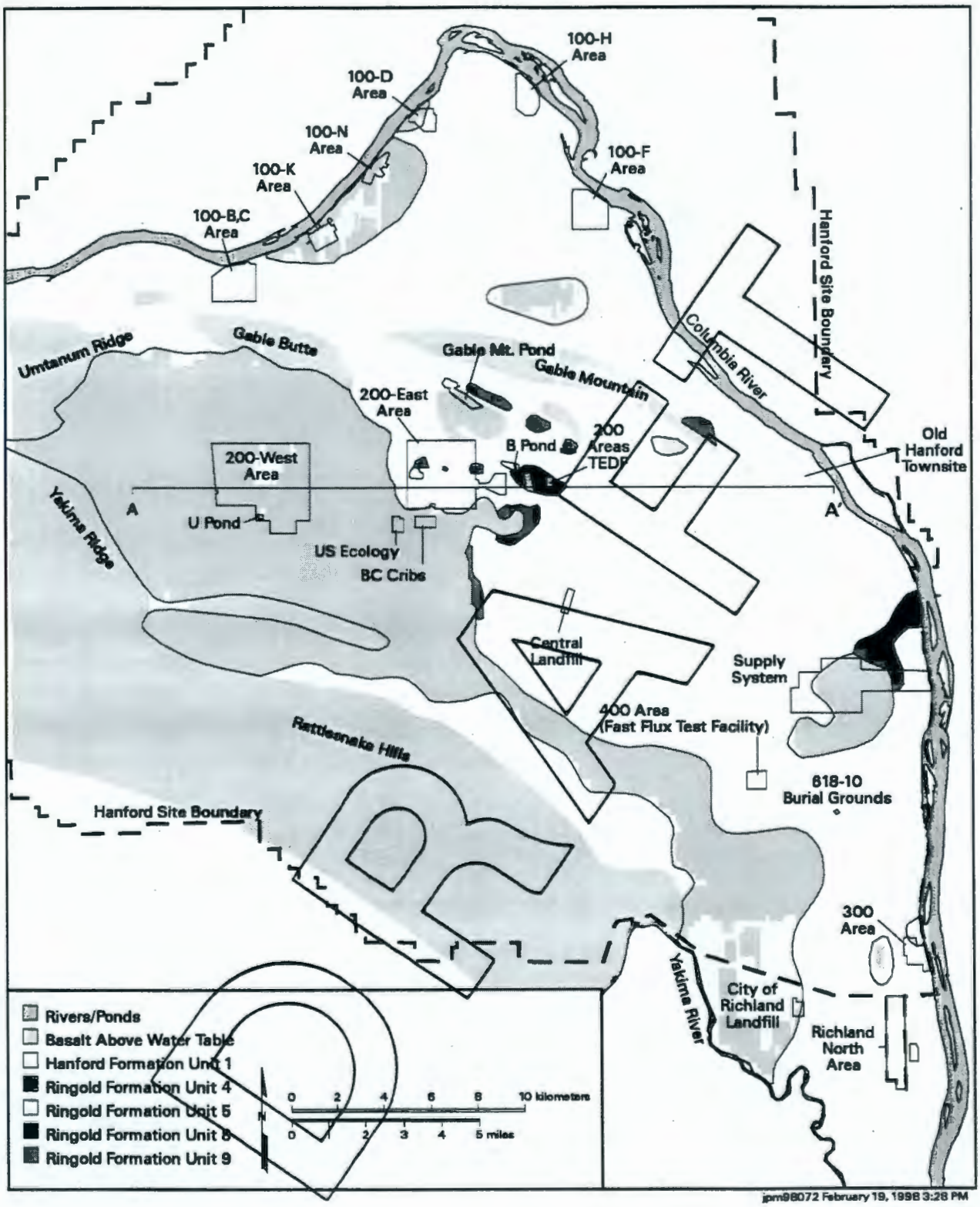

Hanford Formation
Early Palouse Soil and Plio-Pleistocene Unit
Ringold Formation Mud Units
Ringold Formation Gravel and Sand
Columbia River Basalt Group
Inferred Fault
0 1 2 3 4 5 kilometers
0 1 2 3 miles
A
A'
200-West
200-East
Water Table
Columbia River
Elevation Above Mean Sea Level, m
240
200
160
120
80
40
0
-40
Elevation Above Mean Sea Level, ft
800
700
600
500
400
300
200
100
0
-100
SP98010062.5

Figure 6. Map View Of Hydrogeologic Units Present at The Water Table, June 1997.

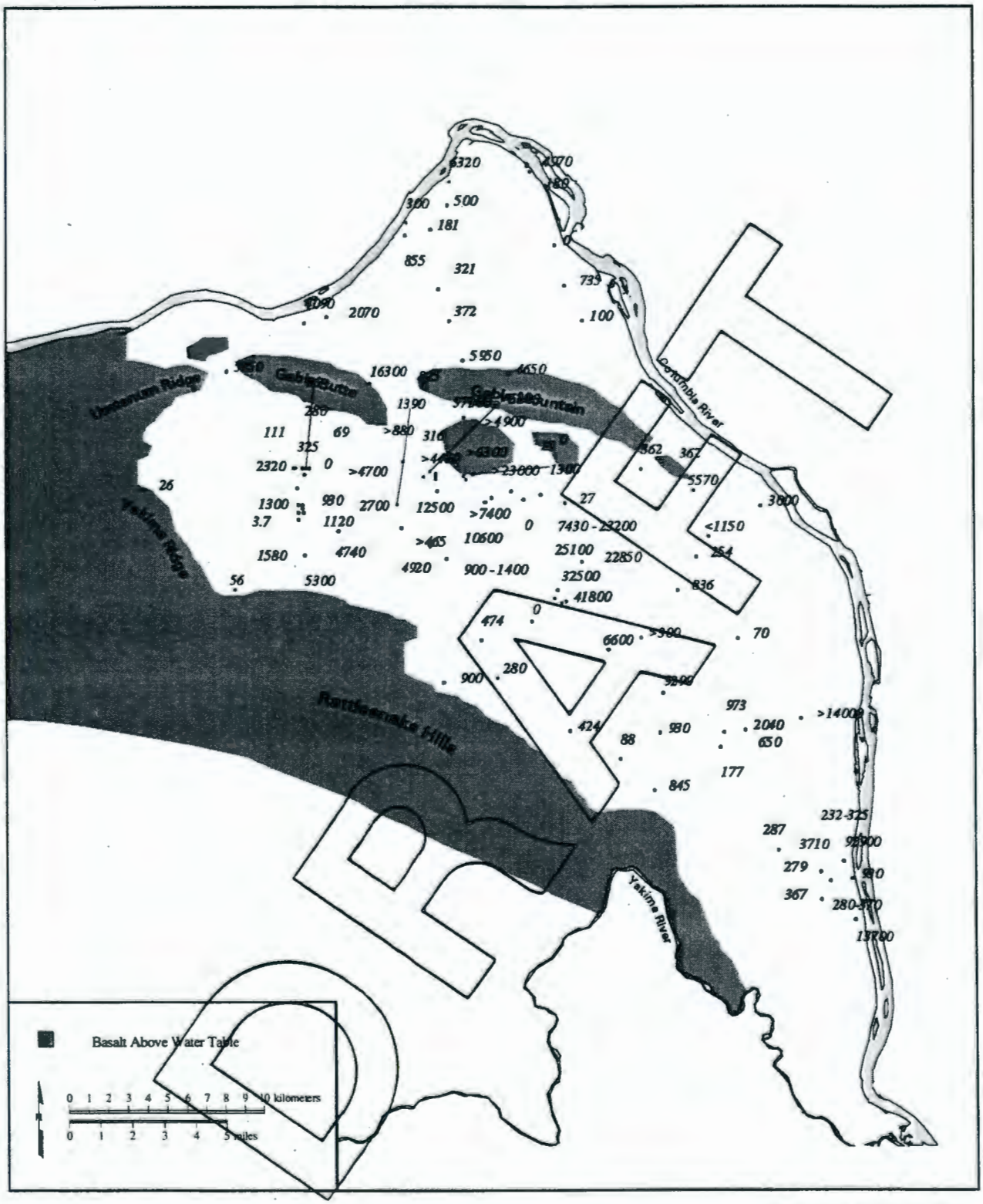
DRAFT



Geologic Units Present at the Water Table (June 1997)

Figure 7. Distribution Of Transmissivity Data From Aquifer Pumping Tests And Slug-Interference Tests At Hanford.

DRAFT

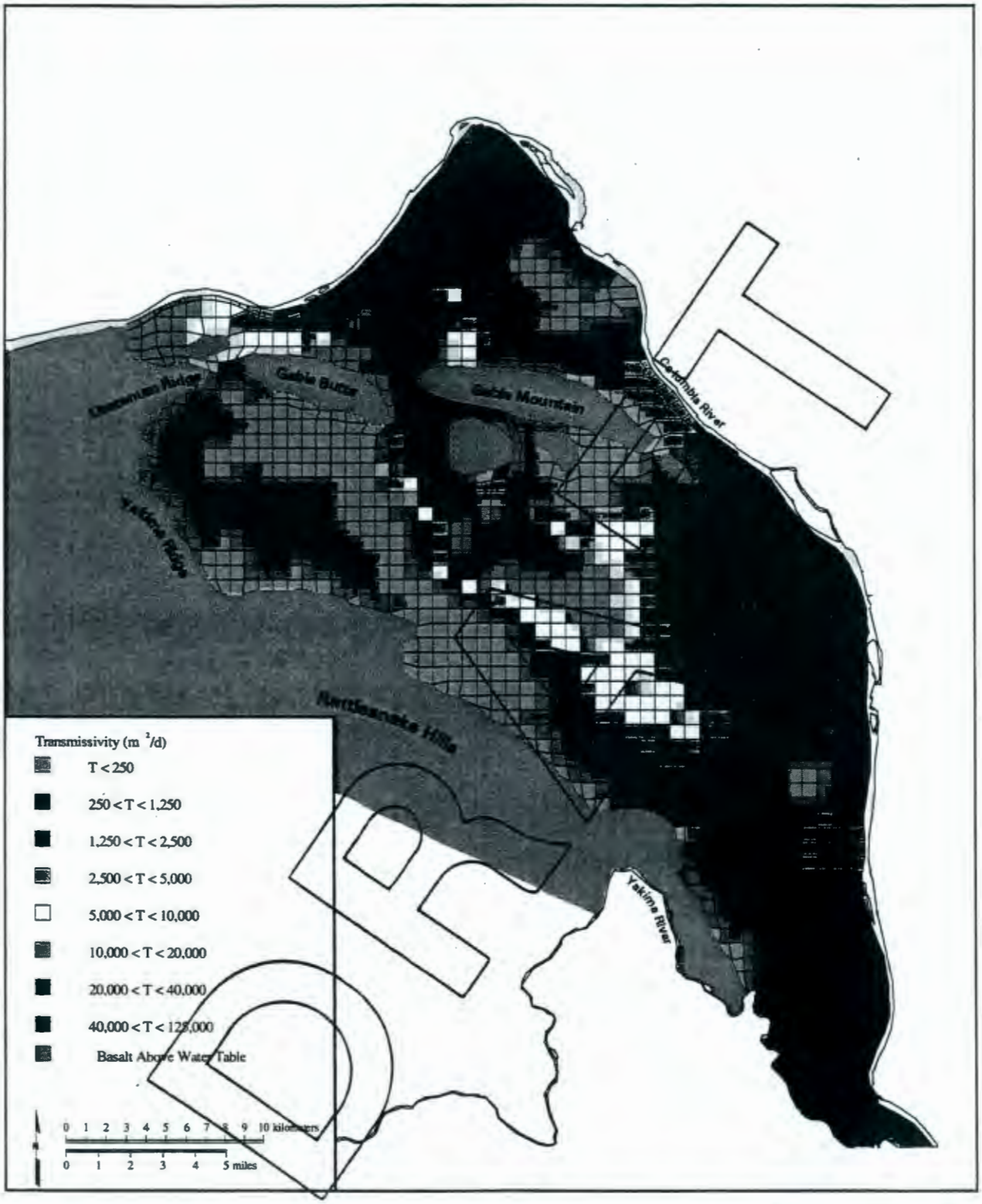


97skw018.eps November 26, 1997

Figure 3.3. Wells and Aquifer Test Results (Transmissivities in m2/d) Used in the Inverse Calibration

Figure 8. Distribution Of Transmissivity Determined From Inverse Flow Modeling

DRAFT



97skw019.eps December 02, 1997

Figure 4.1. Transmissivity Distribution Obtained from Inverse Calibration

Figure 9. Range Of Hydraulic Conductivity Values Calculated From Measured Transmissivity And Aquifer Thickness

DRAFT

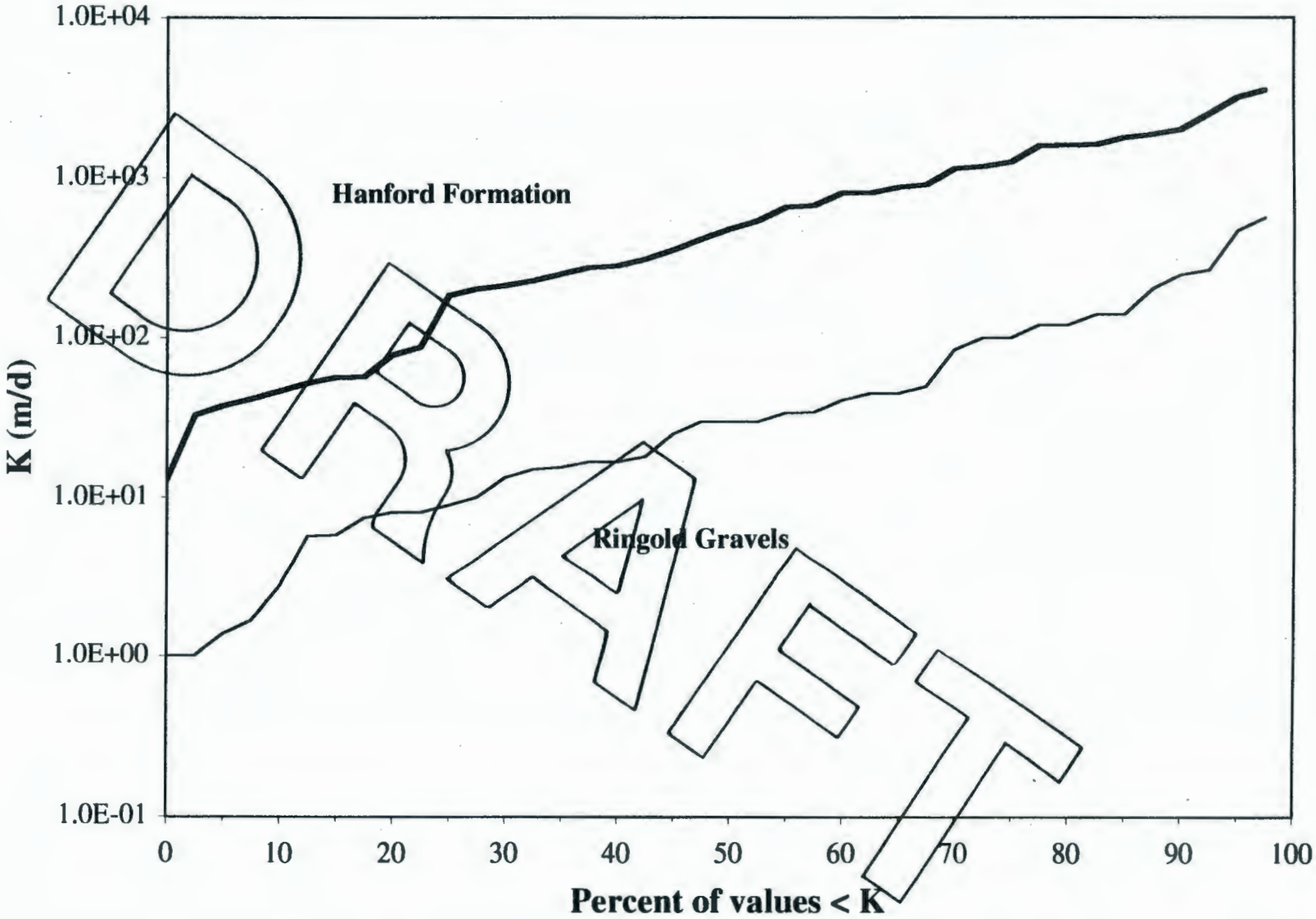
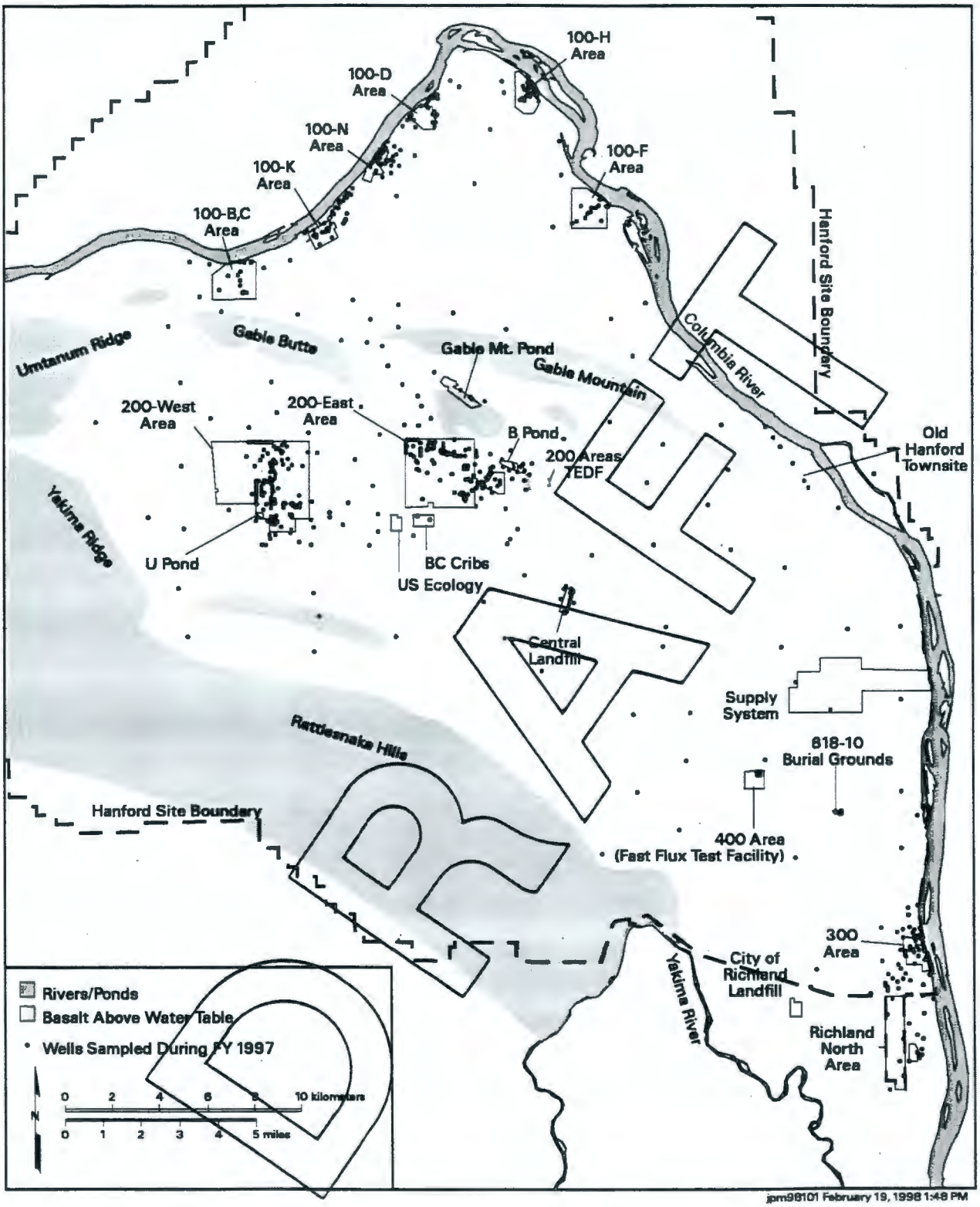

1.0E+04
1.0E+03
1.0E+02
1.0E+01
1.0E+00
1.0E-01
K (m/d)
Hanford Formation
Ringold Gravels
0
10
20
30
40
50
60
70
80
90
100
Percent of values < K
DRAFT

Figure 10. Wells Sampled In Unconfined Aquifer System During Fiscal Year 1997

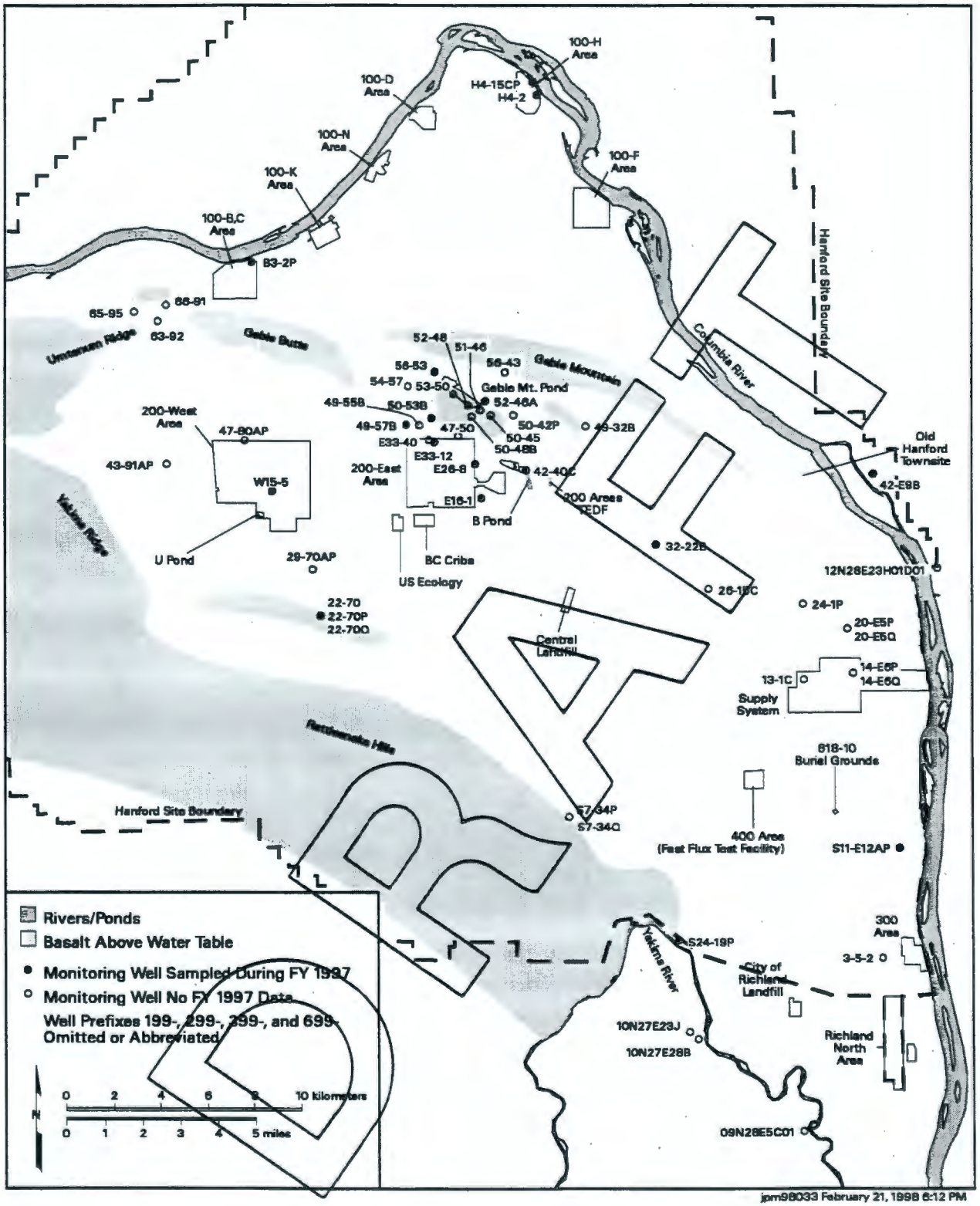
DRAFT



Wells sampled during FY97

Figure 11. Wells Sampled In Upper Basalt Confined Aquifers During Fiscal Year 1997

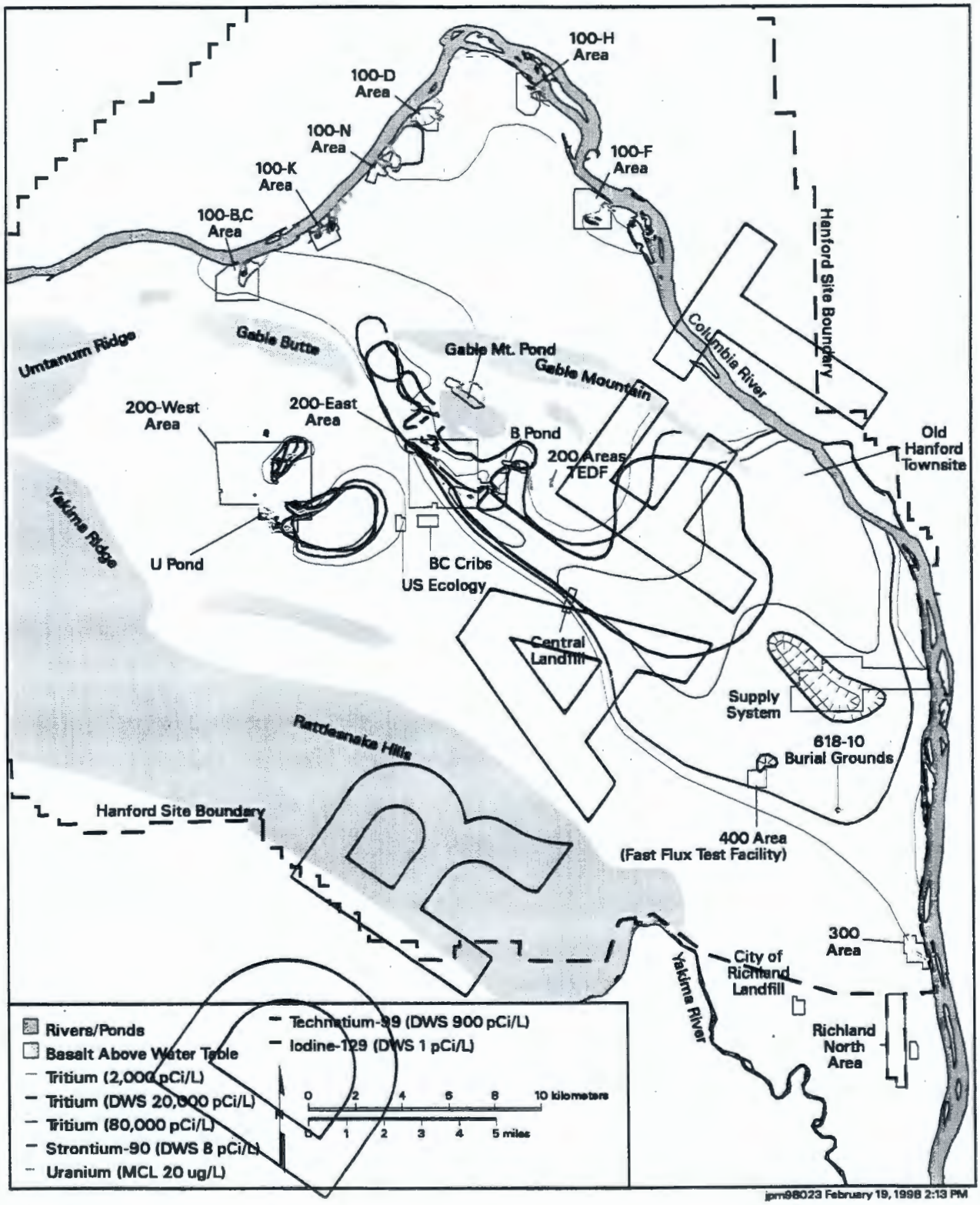
DRAFT



Upper Basalt Confined Aquifer Monitoring Wells

Figure 12. Areal Extent Of Major Radioactive Contaminant Plumes In Unconfined Aquifer

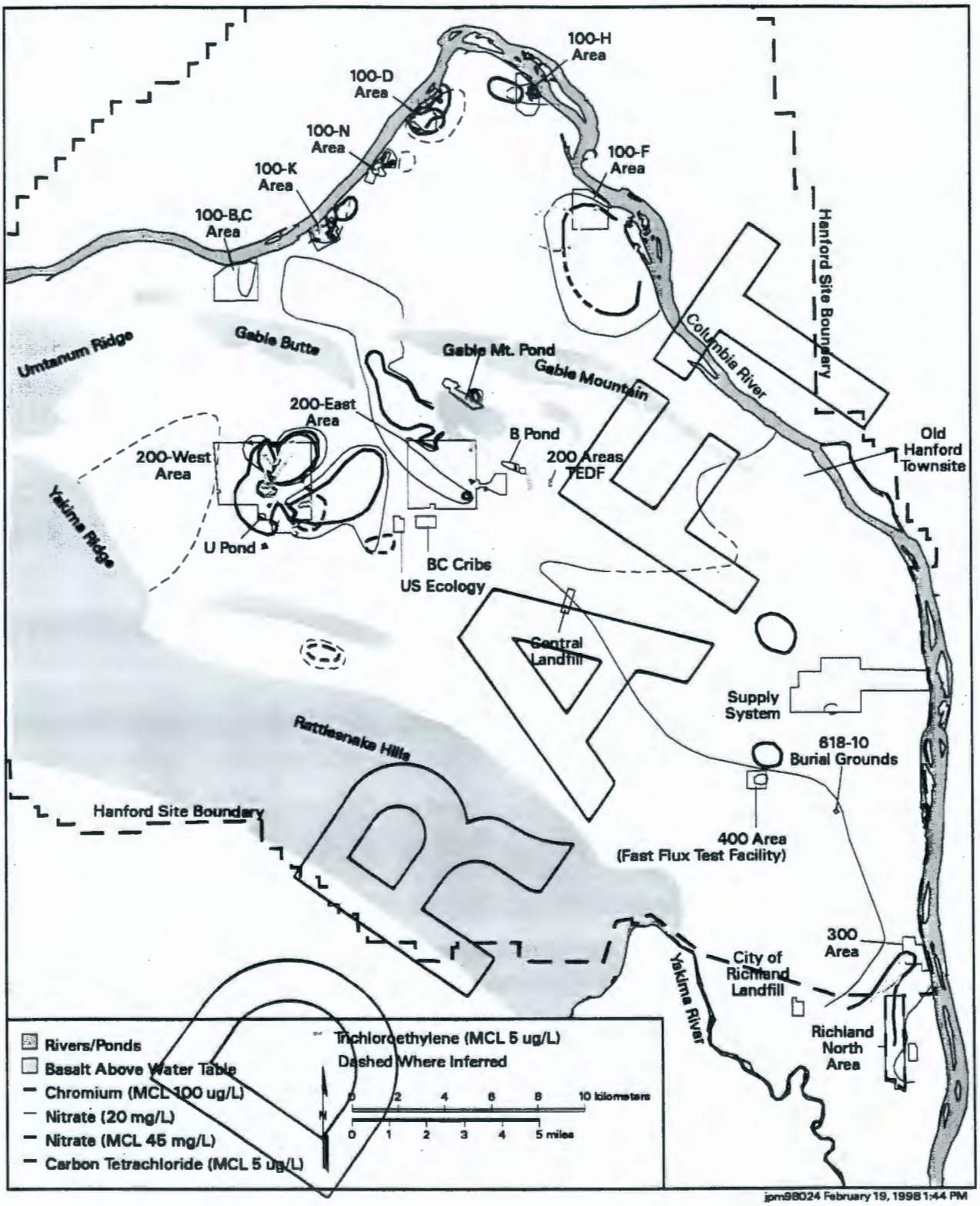
DRAFT



Hanford Site - Major Radionuclides in Groundwater (FY97)

Figure 13. Areal Extent Of Major Chemical Contaminant Plumes In Unconfined Aquifer

DRAFT



Hanford Site - Major Hazardous Chemicals in Groundwater (FY97)

Figure 14. The Surface Finite-Element Grid And Boundary Conditions Used In The Three Dimensional Flow Model

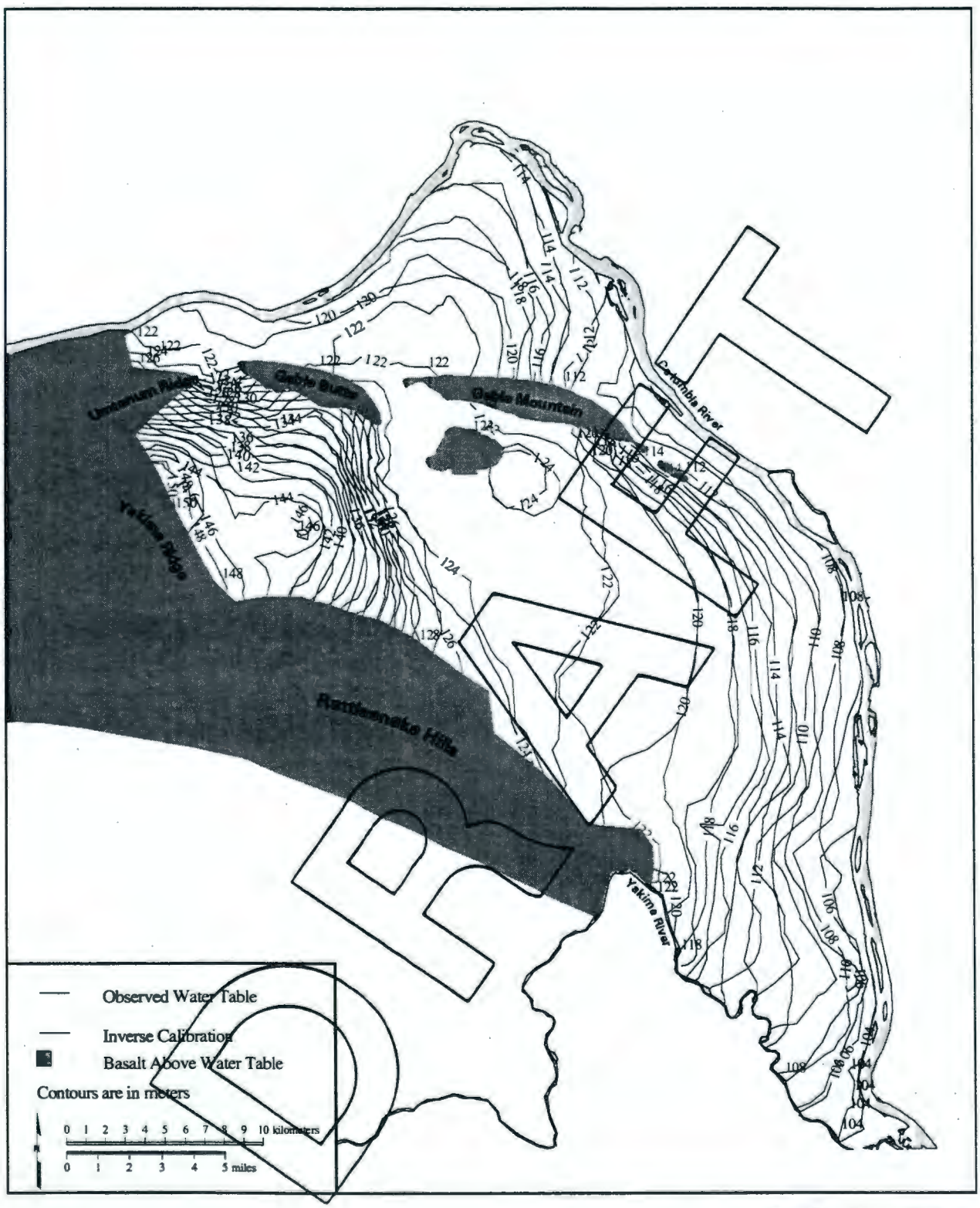
DRAFT

97skw017.eps November 26, 1997

Figure 3.2. Numerical Model Grid and Boundary Conditions

Figure 15. Comparison Of Calibrated Water Table Predicted By Three-Dimensional Flow Model With Calibrated Water Table Predicted With Two-Dimensional Model For 1979 Conditions

DRAFT

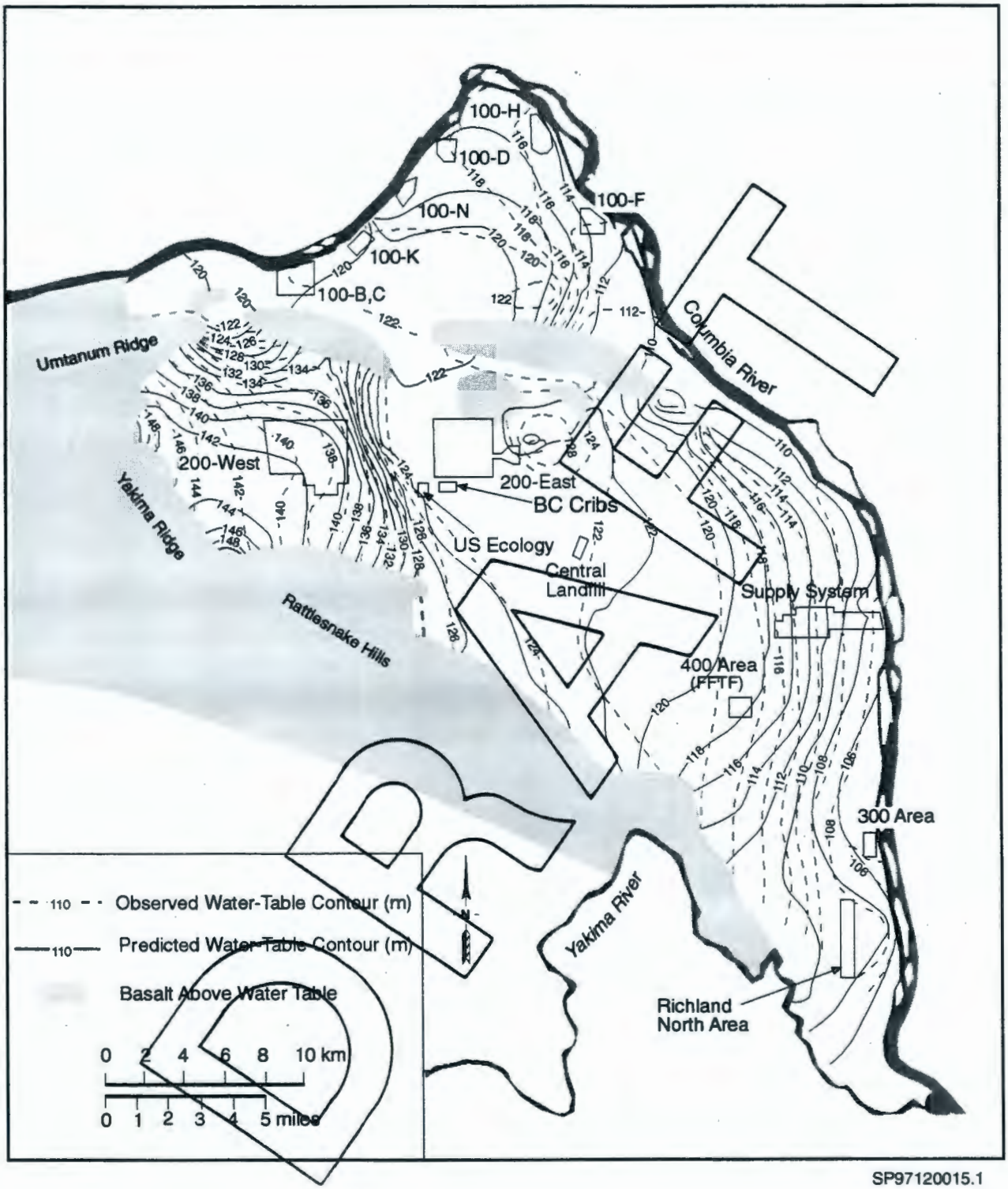


97skw020.eps November 26, 1997

Figure 4.2. Predicted Heads for 1979 Compared with Observed for the Two – Dimensional Model Using Transmissivities from the Inverse Calibration

Figure 16. Comparison Of Water Table Predicted By Three-Dimensional Flow Model With Observed Conditions For 1996

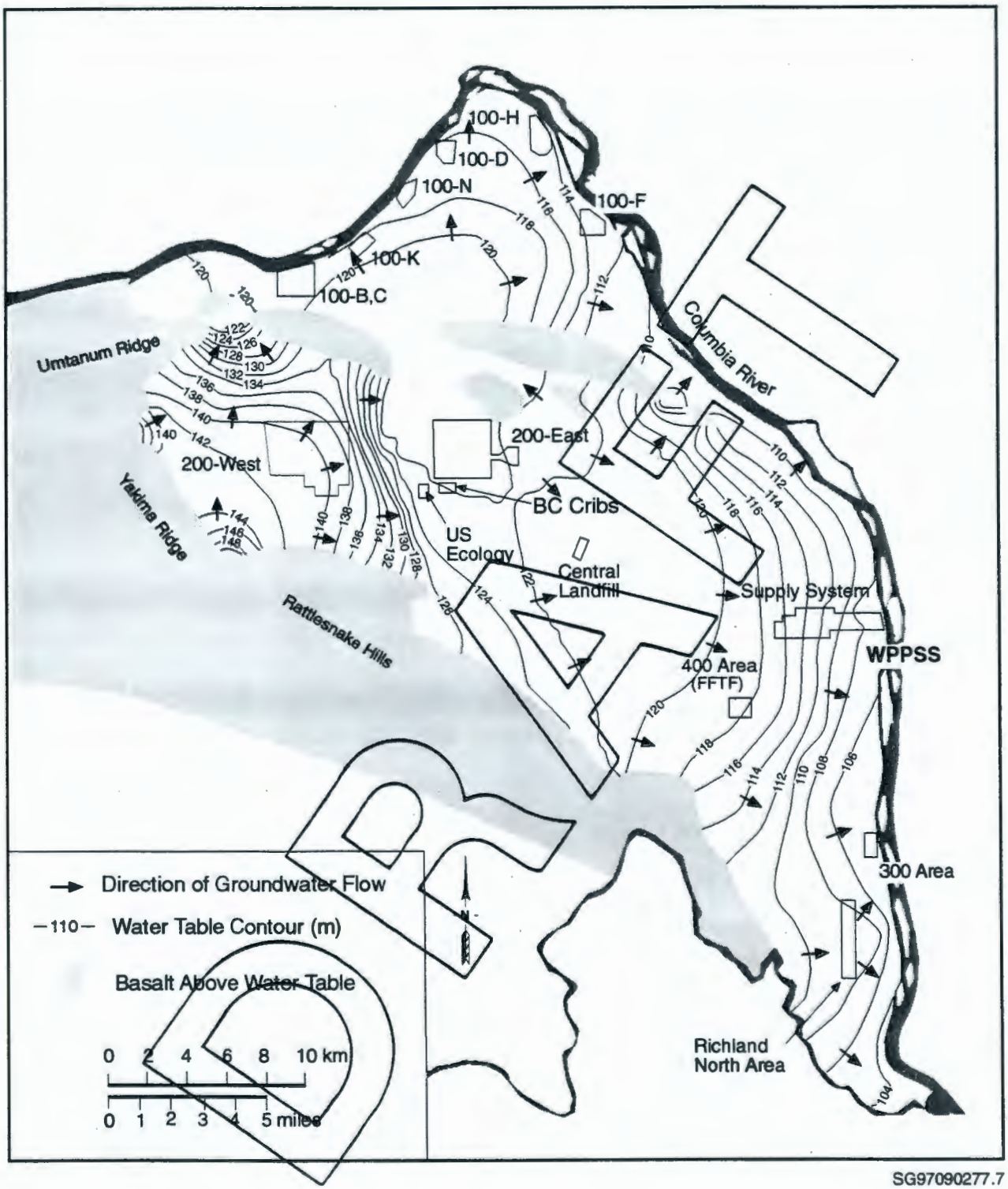
DRAFT



SP97120015.1

Figure 17. Water-Table Predicted With The Three-Dimensional Flow Model In The Year 2000

DRAFT

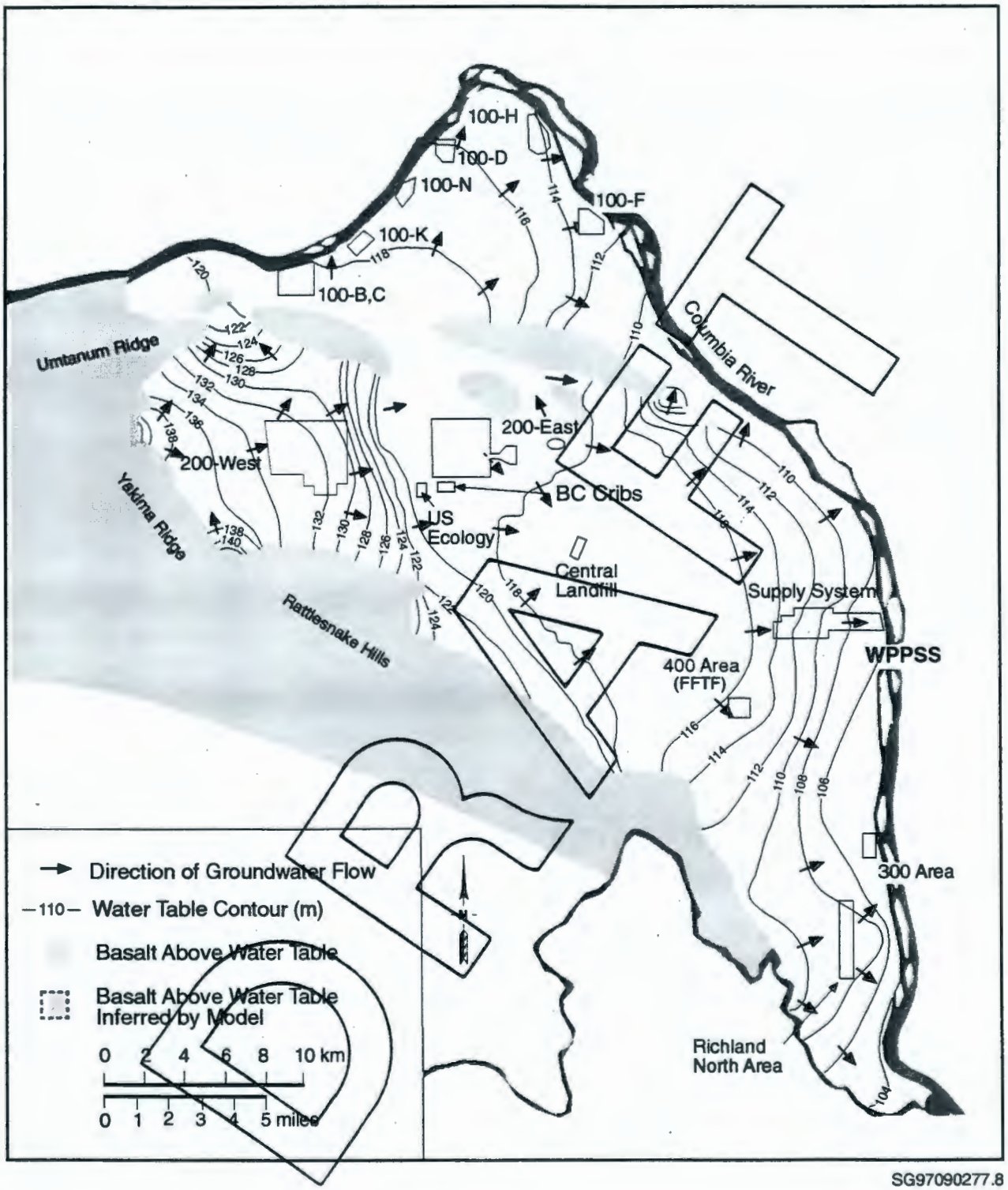


SG97090277.7

Predicted Heads for 2000 from the Three-Dimensional Model

Figure 18. Water-Table Predicted With The Three-Dimensional Flow Model In The Year 2100

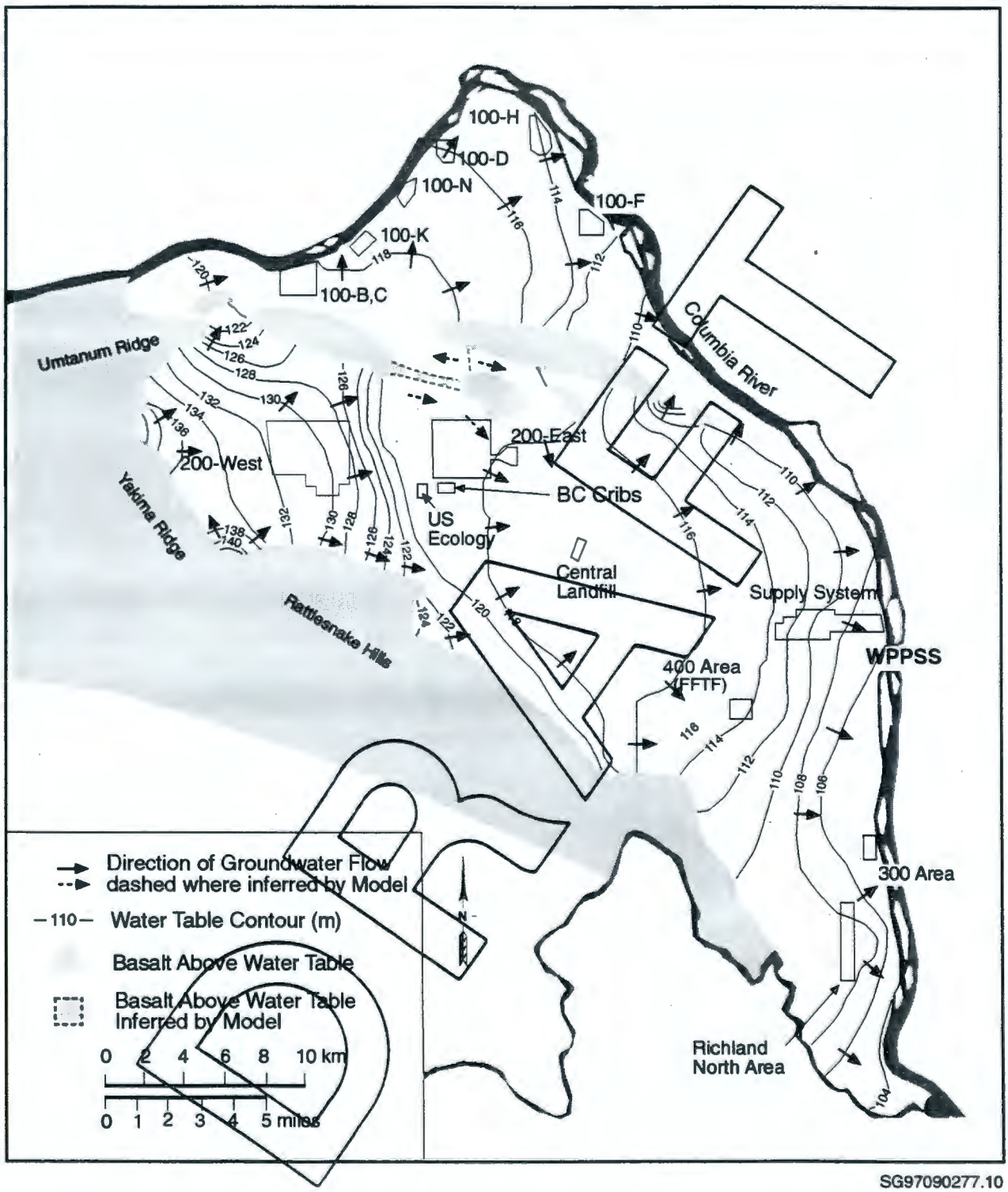
DRAFT



Predicted Heads for 2100 from the Three-Dimensional Model

Figure 19. Water-Table Predicted With The Three-Dimensional Flow Model In The Year 2350

DRAFT



SG97090277.10

Predicted Heads for 2350 from the Three-Dimensional Model

Figure 20. The Surface Finite-Element Grid And Boundary Conditions Used In The Three Dimensional Transport Model

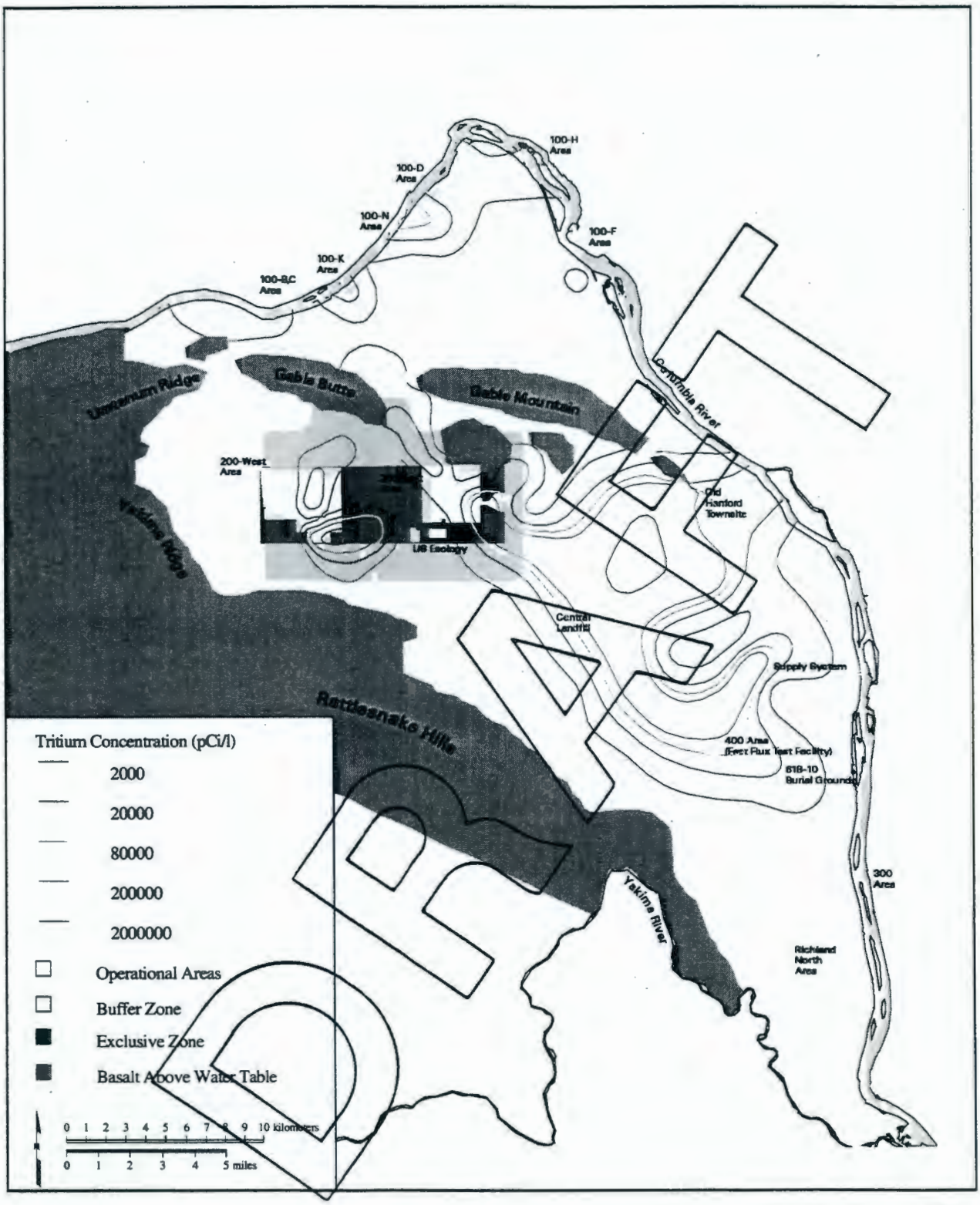
DRAFT

97skw026.eps December 01, 1997

Figure 5.1. Refined Finite-Element Grid Used for Three-Dimensional Transport Simulations

Figure 21. Initial Conditions Used For Tritium Plume Transport To Represent 1979 Conditions

DRAFT

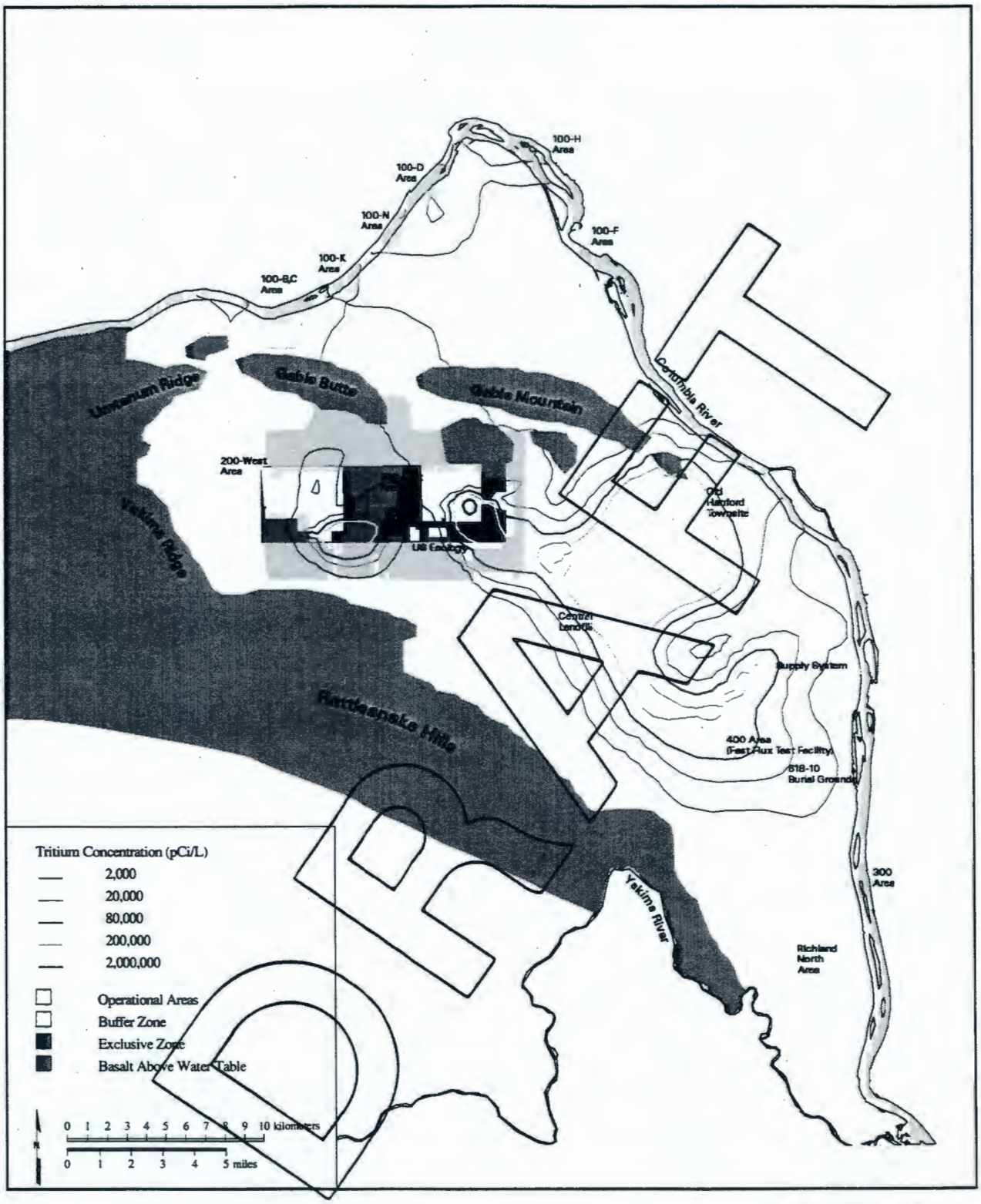


97skw027.eps December 01, 1997

Figure 5.2. Areal Distribution of Tritium Used as Initial Conditions (1979) for Transport Model

Figure 22. Tritium Plume Transport Predicted By Three-Dimensional Flow Model For Year 1985

DRAFT

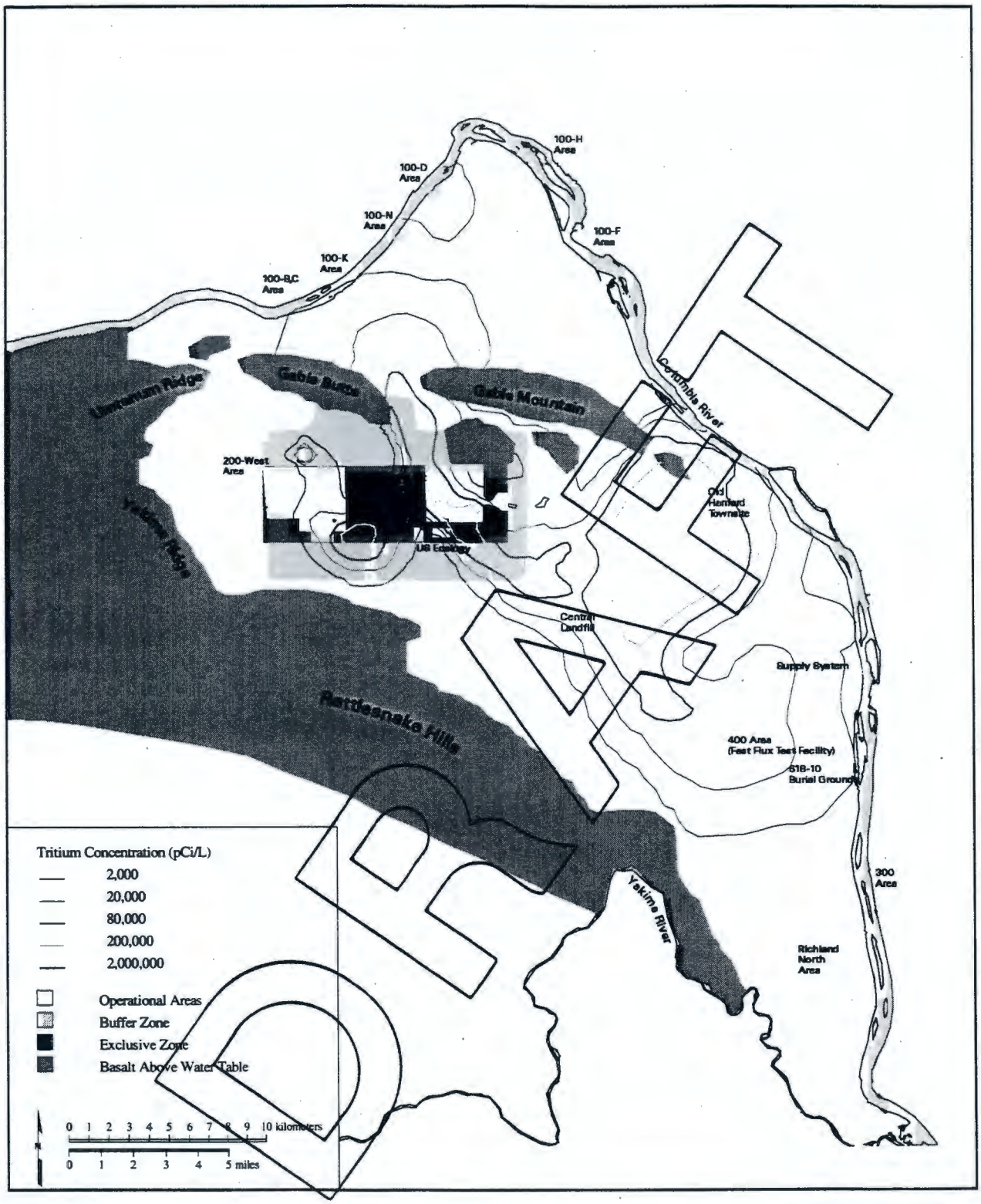


97skw031.eps December 30, 1997

Maximum Tritium Concentration in 1985

Figure 23. Tritium Plume Transport Predicted By Three-Dimensional Flow Model For Year 1996 with Observed Tritium Plume in 1996

DRAFT

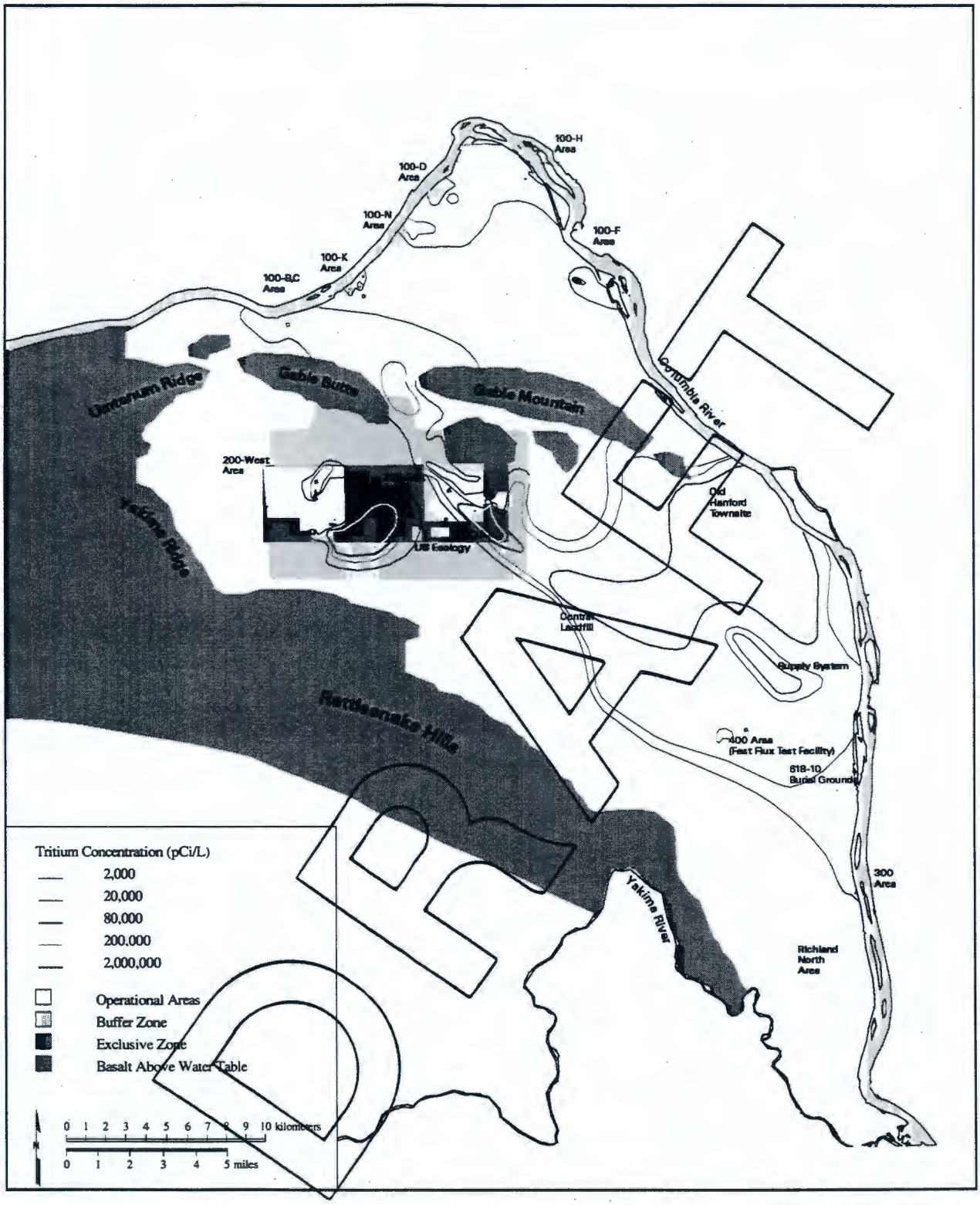


97skw032.eps December 30, 1997

Maximum Tritium Concentration in 1996

Figure 24. Observed Tritium Plume in 1996

DRAFT

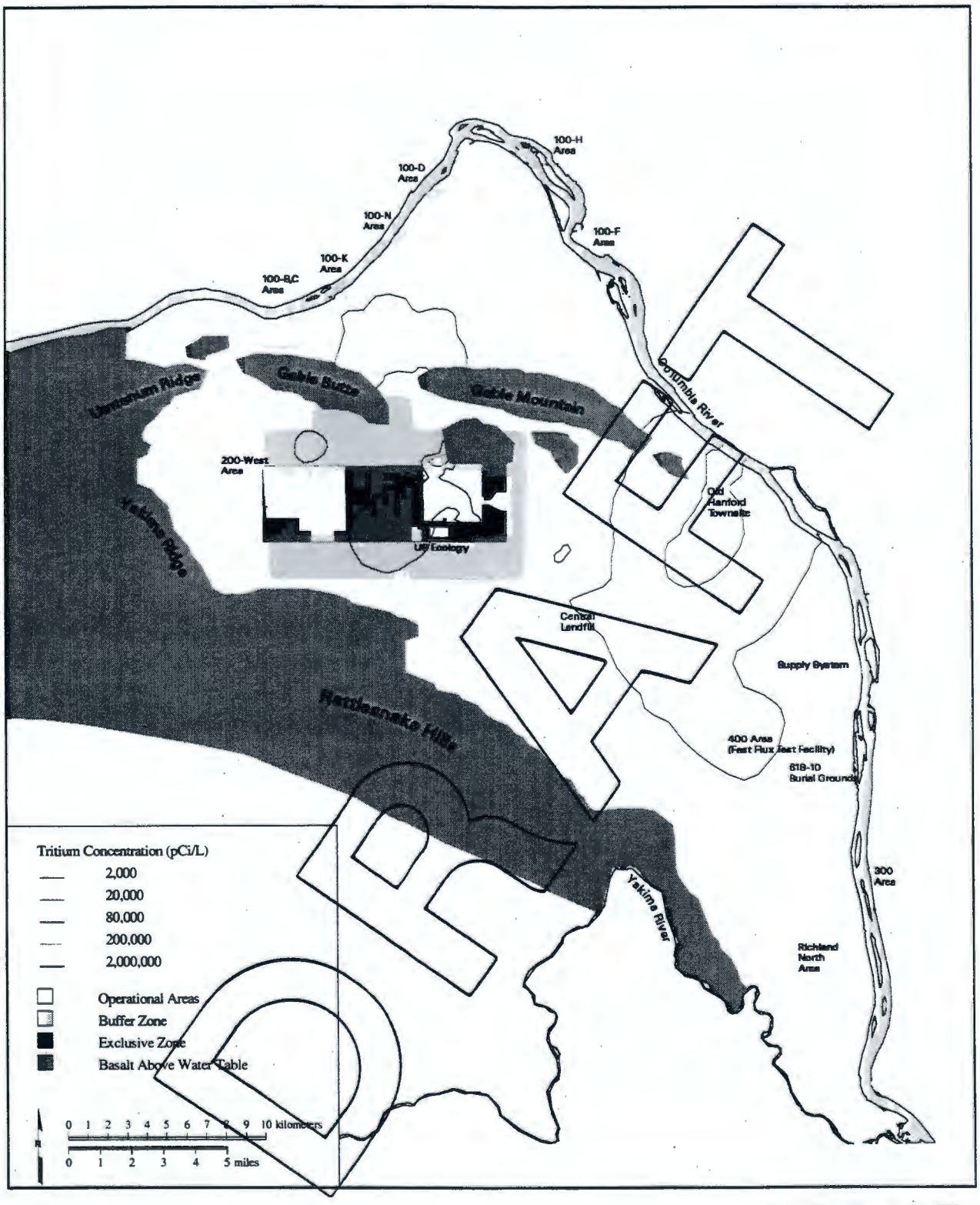


97skw030.eps December 30, 1997

Observed Tritium Plume for 1996 Conditions

Figure 25. Tritium Plume Transport Predicted By Three-Dimensional Flow Model For Year 2050

DRAFT

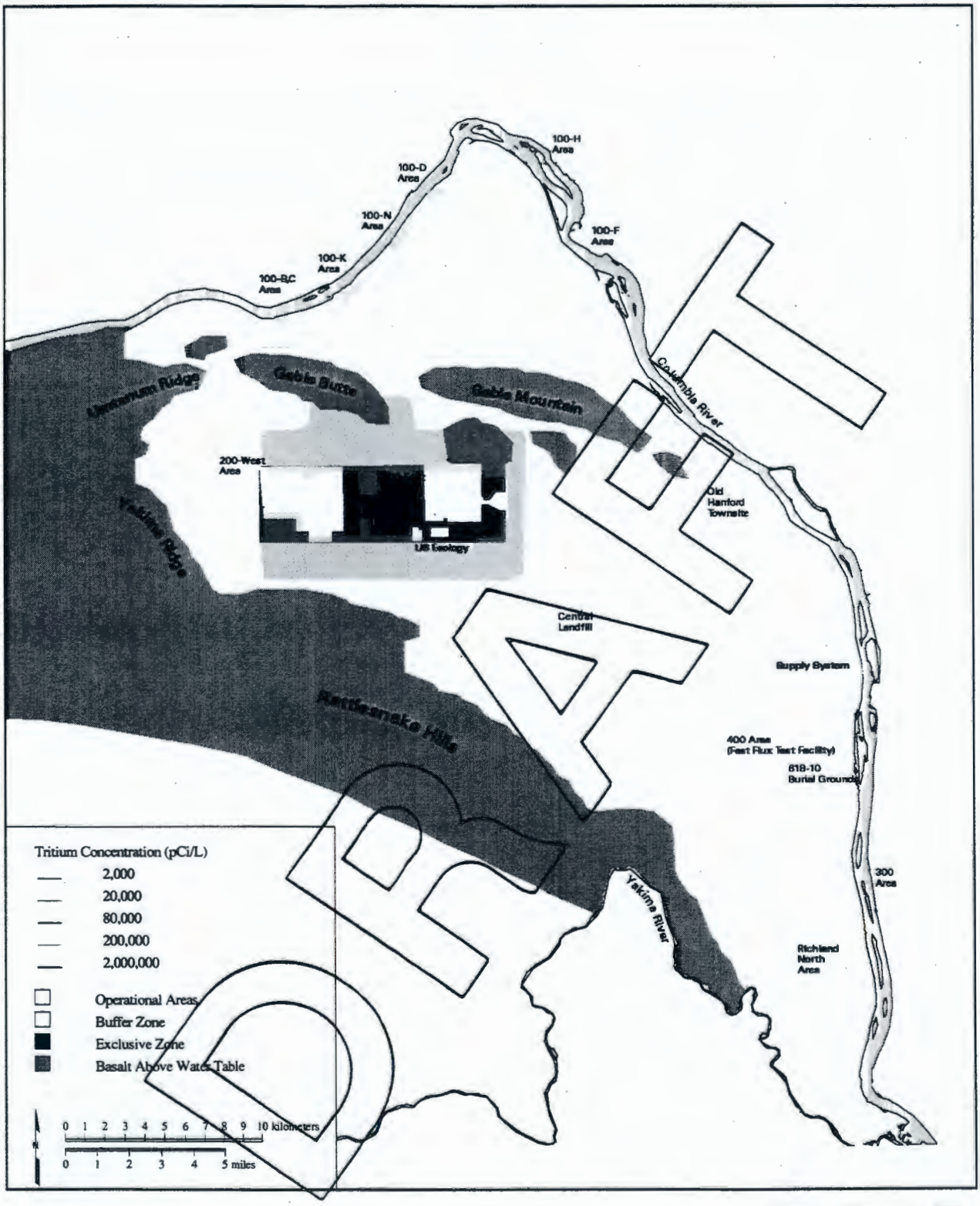


97skw035.eps December 30, 1997

Maximum Tritium Concentration in 2050

Figure 26. Comparison Of Tritium Plume Transport Predicted By Three-Dimensional Flow Model For Year 2100

DRAFT



97skw036.cps December 31, 1997

Maximum Tritium Concentration in 2100

Table 1. 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 fiscal year 1999	Site-wide groundwater modeling to support development of preliminary draft of EIS Analysis to support development of final EIS
Hanford Groundwater Project Modeling Support	present to 2003	General modeling support to address groundwater monitoring issues
Composite Analysis	fiscal year 1999 fiscal year 1999	Response to DOE headquarters comments on first iteration Initial evaluation of chemical impacts
TWRS Hanford Tank Initiative	November 1998 January 1999 fiscal year 2000 fiscal years 1999-2003	Report on modeling analysis support for the tank waste retrieval performance evaluation - Draft Report - Final Report Modeling support to technology deployment selection Modeling support to develop cleanup standards and tank waste residuals
TWRS Immobilized Low Activity Waste Performance Assessment	January - August 2000 January - August 2002	Groundwater modeling support on performance assessment of: - Grout vault disposal - New facility disposal
Canyon Disposition Initiative	fiscal year 1999-2001	Potential groundwater Modeling support to performance assessment as a part of development of ROD for final disposition 221-U facilities
200 Area Soils Characterization and Remediation	unspecified	Potential Groundwater modeling support to quantitative risk assessments
Solid Waste Burial Ground Performance Assessment Maintenance	unspecified	Potential groundwater modeling support to potential five-year cycle PA

DRAFT

		revisions
Liquid discharge facility modeling support	**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**
Final ROD's for 100 and 200 Area Interim Remedial Measures	**unspecified**	**Potential groundwater modeling support to development of final records of decisions of pump-and-treat systems implemented at 200-UP-1, 200-ZP-1, and 100-KR-3 operable units, and in 100-N Area.**

DRAFT

Table 2. A Comparison Of VAM3D-CG And CFEST-96 Capabilites With Technical and Administrative Needs And Requirements

NEEDS AND REQUIREMENTS	VAM3D-CG CAPABILITIES	CFEST-96 CAPABILITIES
TECHNICAL		
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 yrs to 10000 yrs	Option available	Option available
Streamline & Pathline Analysis	Options are 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
Direchelet (constant head & concentration) Boundary Conditions	Option available	Option available
Neuman (fluid or mass flux) Boundary Conditions	Options available	Option available
Interaction with Submodels	Option is not available with code but has been implemented at Hanford	Option available
ADMINISTRATIVE		
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; current ly 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		
- Sufficent Documentation	Both codes have acceptable documentation	
- Body of applications	Both codes have history of use at other sites and situations	

DRAFT

- **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 Efficency	Both codes run on PC and UNIX workstations with efficient solvers	

* VAM3D-CG may have some advantages but actual advantages cannot be determined without benchmarking on similar problems

DRAFT

Table 3 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 (Unit B and 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**

DRAFT

Table 4. Key Assumptions Made In The Development Of The Contaminant Transport Model

Assumption	Rationale	Impact
The unconfined aquifer system, overlying the basalts, can be adequately represented by nine hydrostratigraphic units.	**Flow of water (and transport of radionuclides) is assumed to occur in three dimensions. Nine hydrostratigraphic 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 geohydrologic 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 sitewide 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.**

DRAFT

Assumption	Rationale	Impact
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 this 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.**

DRAFT

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 sitewide 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.**

DRAFT

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 (i.e., Environmental Restoration, Waste Management and Tank Waste Remediation System Programs) and was largely derived from meetings with representatives of DOE/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 series of tables (Tables A.1, A.2, and A.3) are included with the groundwater modeling reviews. These tables provide a summary of each modeling activity and serve as a convenient means to evaluate differences between the models.

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 Program. These summaries reflect information provided by DOE/RL technical project managers and contractor personnel from BHI and 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
- Design of interim remedial measures in the 100 and 200 Areas
- 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
- Hanford Remedial Action and Comprehensive Land Use Environmental Impact Statement

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

DRAFT

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).

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). See Table A.1 for a summary of the key aspects of the groundwater model.

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 HGIS 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, 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.

DRAFT

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) and required about five hours of computational time for a 200-year simulation (using an SIG Indigo 6000 computer). 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 hundred year simulations with the fine grid (50,848 nodes) required approximately 23 hours.

Two hydro-stratigraphic 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 hydro-stratigraphic 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

DRAFT

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 HSRAM (DOE/RL, 1995d).

Environmental Restoration Disposal Facility

The Environmental Restoration Disposal Facility (ERDF) serves as the receiving facility for wastes generated by remediation of the Comprehensive Environmental Response, Compensation, and Liability Act (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.

DRAFT

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 December of 1991, 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, RCRA-compliant barriers, and the Hanford Protective Barrier.

HRA/Land Use EIS

As part of the transition from production of nuclear materials for national defense to environmental restoration and long-term management of wastes, the 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 and Comprehensive Land Use Environmental Impact Statement (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

DRAFT

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 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

DRAFT

assumed to be spatially homogeneous. Temporally variable artificial recharge from site operations was included in the 12-year simulation (1980-1992).

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

- Development of 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, and
- Predicting impacts of future water-level declines on site-wide monitoring wells.

These two groundwater modeling efforts are briefly described below.

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 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.

DRAFT

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 for 1979-1992 were compared with observed data. Predictions for 1993-2005 were used to assess the impact of declining water levels. The analysis showed that a number of wells currently being monitored will begin to go dry or will become difficult to sample during the period simulated.

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

DRAFT

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.

FY 1997 modeling activities 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/AZ tank farm, will be impacted by future transport of these contaminants.

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 off-site 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 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

DRAFT

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.

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 (LWDF's)
- 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.

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

DRAFT

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, moisture retention characteristic parameters were required. These were estimated from ten 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 ten 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,

DRAFT

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.

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 2-D 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.

DRAFT

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.

DRAFT

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,

DRAFT

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 four-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 one-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 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 100-N Area.

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

DRAFT

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 was 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.

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.

DRAFT

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

DRAFT

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.

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 stated 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 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.

DRAFT

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 June 1993 observed water table. 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.

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 associated with the Effluent Treatment Facility (ETF)

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 can comply with the appropriate performance objectives. Two separate performance assessments that have included use of groundwater

DRAFT

modeling have recently been completely for post-1988 solid low-level waste 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 specific 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 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. Low-level wastes disposed in active and inactive burial grounds before September 26, 1988 were not considered in this analysis.

The performance assessment of the 200 West Area low-level burial grounds (LLBG) examined the long-term impacts of LLW and radioactive constituents of the LLMW disposed 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. Low-level wastes disposed 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 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 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 meters 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.

DRAFT

- 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.

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 discharges permits include the following sites:

- ST-4500, 200 Area ETF managed by WMH-PHMC
- ST 4501, 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. A summary of this recent modeling support is provided in the following section.

<u>200 Area Effluent Treatment Facility</u>

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

DRAFT

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 one year after 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.

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 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

DRAFT

- Hanford Tank Initiative
- Performance Assessment of the Hanford Immobilized Low Activity Waste (ILAW) Disposal Facility.

TWRS Environmental Impact Statement

This environmental impact statement addresses actions proposed by DOE to manage and dispose of radioactive, hazardous, and mixed waste within the Tank Waste Remediation System 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 facility) 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 and Cole et al. 1988) version of the site-wide model into formats suitable for use by VAM2D.

DRAFT

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.

Hanford Tank Initiative - AX Tank Farm Retrieval Performance Evaluation Criteria Assessment

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 the HTI on:

- establishment of appropriate retrieval techniques
- determination of appropriate release during waste retrieval
- evaluation of the need for new tank retrieval technologies
- support for 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 these initial sensitivity analysis are summarized in two recent reports by JEGI (1998a and 1998b).

A 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,

DRAFT

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 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. Several 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 restrictions of the MEPAS code limited the ability to accurately model these transport mechanisms.

Detailed modeling at the AX Tank Farm is being carried out using the PORFLOW code (Runchal 1994a, b) for both the unsaturated and saturated zones (Personal communication, Phil Rogers, JEGI). 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 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 it was already being used by members of the project team. The two-dimensional model results will be compared to the three-dimensional Hanford Groundwater Project model results as a validation exercise. Draft and final reports on the overall Retrieval Performance Evaluation assessment are currently planned to be released in November of 1998 and January of 1999 respectively.

Additional analysis that may involve to 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.

DRAFT

Hanford Immobilized Low-Activity Waste Disposal Facility Performance Assessment

The Hanford immobilized low-activity waste (ILAW) disposal facility performance assessment provides an analysis of the long-term environmental and health impacts of the on-site disposal of Hanford immobilized low activity wastes (ILAW). 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 on-site in a near-surface disposal facility located in the 200 East Area.

An interim ILAW performance assessment (Mann et al. 1997; Lu 1996; Mann 1995) was prepared to provide an early assessment of the effects of the disposals using available information. The first version of the final ILAW PA will be published in FY 1998 (Mann, F. M., R. P. Puigh II, C. R. Eiholzer, Y. Chen, N.W. Kline, A. H. Lu, B. P. McGrail, and P. D. Rittmann. 1998. Immobilized Low-Activity Tank Waste Performance Assessment, DOE/RL-97-69, Rev. B). Much of the data used in the ILAW PA was derived from information obtained in other on-site 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 two to three 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

DRAFT

groundwater, environmental and health impacts were evaluated 100-m down-gradient of the facility and at the Columbia River.

During the code selection process for the interim PA, PORFLOW (Runchal 1994b) was chosen to model moisture flow and contaminant transport in the vadose zone and the groundwater. For the final ILAW PA, however, VAM3D-CG (Huyakorn and Panday, 1994) was used to model flow and transport in groundwater. VAM3D-CG was chosen over PORFLOW because a site-wide model was needed, not just a model of the area near the disposal facility. The existing site-wide model based on VAM3D-CG and used in the Hanford Site-Wide Groundwater Remediation Strategy (Law et al. 1997; Chiaramonte et al. 1997) was chosen for use in the ILAW PA. It was felt that the boundary conditions for this model were more suitable for future Site land uses than the site-wide model developed under the Hanford Groundwater Project (Wurstner et al. 1995).

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.

DRAFT

REFERENCES

Barnett, D. B., M. D. Freshley, M. P. Bergeron, S. K. Wurstner, and C. R. Cole. 1997. *Tritium Monitoring in Groundwater and Evaluation of Model Predictions for the Hanford Site 200 Area Effluent Treatment Facility.* PNNL-11665/UC-502, Pacific Northwest National Laboratory, Richland, Washington.

Bechtel Hanford, Inc. (BHI). 1996a. *Engineering Evaluation/Conceptual Plan for the 200-UP-1 Groundwater Operable Unit Interim Remedial Measure.* BHI-00187, Rev. 2, Bechtel Hanford, Inc., Richland, Washington.

Bechtel Hanford Company (BHI). 1996b. *200-ZP-1 Phase II Interim Remedial Measure Quarterly Report, August- October, 1996.* BHI-00952-01, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.

Chiaramonte, G. R., C. W. Denslow, A. J. Knepp, R. D. Landon, and S. Panday. 1997. *Hanford Site-wide Groundwater Remediation Strategy - Groundwater Contaminant Predictions.* BHI-00469, Rev. 1, Bechtel Hanford, Inc., Richland, Washington.

Cole, C. R., S. B. Yabusaki, and C. T. Kincaid. 1988. *CFEST-SC: Coupled Fluid, Energy, and Solute Transport Code, Super Computer Version, Documentation, and User's Manual.* Battelle Pacific Northwest Laboratories, Richland, Washington.

Connelly, M. P., C. R. Cole, and M. D. Williams. 1997. *Bank Storage Modeling of the 100-N Area.* CH2MHill Letter Report to Pacific Northwest National Laboratory, CH2MHill Hanford, Inc., Richland, Washington.

Connelly, M. P., J. D. Davis, and P. D. Rittman. 1991. *Numerical Simulation of Strontium-90 Transport from the 100-N Liquid Waste Disposal Facilities.* WHC-SD-ER-TA-001, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Connelly, M. P., B. H. Ford, and J. W. Lindberg. 1992a. *Hydrogeologic Model for the 200 East Groundwater Aggregate Area.* WHC-SD-EN-TI-019, Westinghouse Hanford Company, Richland, Washington.

Connelly, M. P., B. H. Ford, and J. V. Borghese. 1992b. *Hydrogeologic Model for the 200 West Groundwater Aggregate Area.* WHC-SD-EN-TI-014, Westinghouse Hanford Company, Richland, Washington.

Devary, J. L. 1987. *The CFEST-INV Stochastic Hydrology Code: Mathematical Formulation, Application, and User's Manual.* ICF Northwest, Richland, Washington.

DOE - See "U. S. Department of Energy"

DOE/RL - See "U. S. Department of Energy - Richland Operations Office"

Droppo, J. G. Jr. 1991. *Multimedia Environmental Pollutant Assessment System (MEPAS) Application Guidance, Volume 1 - User's Guide and Volume 2 - Guidelines for Evaluating MEPAS Input Parameters*, PNL-7216, Pacific Northwest Laboratory, Richland, Washington.

Environmental Restoration Contractor (ERC). 1996. *Technical Memorandum - Hydrogeologic Design Basis for the 100-HR-3 H IRM Pump and Treat.* Interoffice memorandum, CCN 029208, dated March 11, 1996, Bechtel Hanford, Inc., Richland, Washington.

DRAFT

Franz, T. and N. Guigner. 1992. *2-Dimensional Horizontal Aquifer Simulation Program, FLOWPATH 3.06.* Waterloo Hydrogeologic Software, Waterloo, Ontario, Canada.

Hartman, M. J. and P. E. Dresel. 1997. *Hanford Site Groundwater Monitoring for Fiscal Year 1996.* PNNL-11470,UC-402, 403, 702, Pacific Northwest National Laboratory, Richland, Washington.

Hemker, C.J. and G.-J. Nijsten. 1997. *Ground Water Modeling Using MICRO-FEM Version 3.1.* C. J. Hemker, Amsterdam, The Netherlands

Gupta, S. K. 1997. Draft User's Manual, CFEST-96 Flow and Solute Transport, Constant/Variable Density, Computationally Efficient, and Low Disk PC/Unix Version. Consultant for Environmental System Technologies Irvine, California.

Gupta, S. K., C. R. Cole, C. T. Kincaid, and A. M. Monti. 1987. *Coupled Fluid, Energy, and Solute Transport (CFEST) Model: Formulation and User's Manual.* BMI/ONWI-660, Battelle Memorial Institute, Columbus, Ohio.

Huyakorn, P. S., J. B. Kool, and Y. S. Wu. 1991. *VAM2D - Variably Saturated Analysis in Two Dimensions, Version 5.2 With Hysteresis and Chained Decay Transport, Documentation and User's Guide.* NUREG/CR-5352, Rev. 1, U. S. Nuclear Regulatory Commission, Washington, D. C.

Huyakorn, P. S. and S. M. Panday. 1994. *VAM3DCG: Variably Saturated Analysis Model in Three Dimensions with Preconditioned Conjugate Gradient Matrix Solves, Documentation and User's Guide*, Version 3.1, Hydrogeologic, Inc., Herndon, Virginia.

Jacobs Engineering Group, Inc. (JEGI). 1998. *AX Tank Farm Vadose Zone Screening Analysis for the Retrieval Performance Evaluation Criteria Assessment,* Jacobs Engineering Group Inc., Richland, Washington.

Jacobson, E. A., and M. D. Freshley. 1990. *An Initial Inverse Calibration of the Groundwater Flow Model for the Hanford Unconfined Aquifer.* PNL-7144, Pacific Northwest Laboratory, Richland, Washington.

Khaleel R. and E.J. Freeman. 1995. *A Compilation of Hydrologic Properties for Low-Level Tank Waste Disposal Facility Performance Assessment.* WHC-SD-WM-RPT-0165, Westinghouse Hanford Company, Richland, Washington.

Kincaid, C. T., M. P. Bergeron, C. R. Cole, M. D. Freshley, D. L. Strenge, P. D. Thorne, L. W. Vail, and S. K. Wurstner. 1998. *Composite Analysis for Low-Level Waste Disposal in the 200 Area Plateau of the Hanford Site.* PNNL-7144, Pacific Northwest National Laboratory, Richland, Washington

Law, A., S. Panday, C. Denslow, K. Fecht, and A. Knepp. 1997. *Hanford Site-wide Groundwater Flow and Transport Model Calibration Report.* BHI-00608, Rev. 1, Bechtel Hanford, Inc., Richland, Washington.

Lindsey, K. A. 1995. *Miocene- to Pliocene-Aged Suprabasalt Sediments of the Hanford Site, South-Central Washington.* BHI-00184, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.

Lu, A. H. 1990. *Simulation of Strontium-90 Transport from the 100-N Area to the Columbia River Using VAM2DH.* WHC-EP-0369, Westinghouse Hanford Company, Richland, Washington.

DRAFT

Lu, A. H. 1996. *Contaminant Transport in the Unconfined Aquifer, Input to the Low Level Tank Waste Interim PA,* WHC-SD-WM-RPT-241, Westinghouse Hanford Company, Richland, Washington.

Mann, F. M. 1995. *Data Packages for the Hanford Low-Level Tank Waste Interim Performance Assessment.* WHC-SD-WM-RPT-166, Westinghouse Hanford Company, Richland, Washington.

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

McDonald, M.G., and Harbaugh, A.W. 1988. *A modular three-dimensional finite-difference ground-water flow model.* U. S. Geological Survey Techniques of Water Resources Investigations, book 6, chap. A1, 586 p.

Nichols, W. E., N. J. Aimo, M. Oostrom, and M. D. White. 1997. *STOMP, Subsurface Transport Over Multiple Phases, Application Guide.* PNNL-11216, Pacific Northwest National Laboratory, Richland, Washington.

Reidel, S. P. and K. R. Fecht. 1994a. *Geologic Map of the Priest Rapids 1:100,000 Quadrangle, Washington, Washington Division of Geology and Earth Sciences Resources Open-File Report 94-13,* 22pp; 1 plate.

Reidel, S. P. and K. R. Fecht. 1994b. *Geologic Map of the Richland 1:100,000 Quadrangle, Washington, Washington Division of Geology and Earth Sciences Resources Open-File Report 94-8,* 21pp; 1 plate.

Runchal, A. K. 1994a. *PORFLOW: A Mathematical Model for Fluid Flow, Heat, and Mass Transport in Multifluid, Multiphase, Fractured or Porous Media, User's Manual.* Version 2.40, ACRI/016/Rev.G, Analytic and Computational Research, Inc., Bel Air, California.

Runchal, A. K. 1994b. *PORFLOW: A Software Tool for Multiphase Fluid Flow, Heat, and Mass Transport in Fractured Porous Media, User's Manual.* Version 2.50, ACRI, Analytic and Computational Research, Inc., Bel Air, California.

Runchal, A. K. and B. Sagar. 1989. *PORFLO-3: A Mathematical Model for Fluid Flow, Heat, and Mass Transport in Variably Saturated Geologic Media, User's Manual - Version 1.0.* WHC-EP-0041, Westinghouse Hanford Company, Richland, Washington.

Runchal, A. K. and B. Sagar. 1993. *PORFLOW: A Multifluid Multiphase Model for Simulating Flow, Heat Transfer, and Mass Transport in Fractured Porous Media,* (Version 2.39). NUREG/CR-5991, CNWRA 92-003, U.S. Nuclear Regulatory Commission, Washington, D.C.

Sagar, B. and A. K. Runchal. 1989. *PORFLO-3: A Mathematical Model for Fluid Flow, Heat, and Mass Transport in Variably Saturated Geologic Media, Theory - Version 1.0.* WHC-EP-0042, Westinghouse Hanford Company, Richland, Washington.

Schramke, J. A., C. S. Glantz, and G. R. Holdren. 1994. *Hanford Site Environmental Setting Data Developed for the Unit Risk Factor Methodology in Support of the Programmatic Environmental Impact Statement (PEIS),* PNL-9801, Pacific Northwest National Laboratory, Richland, Washington.

DRAFT

Thorne, P. D., and M. A. Chamness. 1992. *Status Report on the Development of a Three Dimensional Conceptual Model for the Hanford Site Unconfined Aquifer System.* PNL-8332, Pacific Northwest Laboratory, Richland, Washington.

Thorne, P. D., and D. R. Newcomer. 1992. *Summary and Evaluation of Available Hydraulic Property Data for the Hanford Site Unconfined Aquifer System,* PNL-8337, Pacific Northwest Laboratory, Richland, Washington.

Thorne, P. D., M. A. Chamness, F. A. Spane Jr., V. R. Vermeul, and W. D. Webber. 1993. *Three Dimensional Conceptual Model for the Hanford Site Unconfined Aquifer System, FY 93 Status Report.* PNL-8971, Pacific Northwest Laboratory, Richland, Washington.

Thorne, P. D., M. A. Chamness, V. R. Vermeul, Q. C. MacDonald, and S. E. Schubert. 1994. *Three Dimensional Conceptual Model for the Hanford Site Unconfined Aquifer System, FY 1994 Status Report.* PNL-10195, Pacific Northwest Laboratory, Richland, Washington.

U. S. Department of Energy (DOE). 1988. "Radioactive Waste Management. DOE Order 5820.2A." U. S. Department of Energy, Washington, D. C.

U. S. Department of Energy (DOE). 1996a. *Draft Hanford Remedial Action Environmental Impact Statement and Comprehensive Land Use Plan.* DOE/EIS-0222D, U. S. Department of Energy, Richland Operations Office, Richland, Washington.

U. S. Department of Energy (DOE). 1996b. *Final Tank Waste Remediation System Environmental Impact.* DOE/EIS-0189, U. S. Department of Energy, Richland Operations Office, Richland, Washington

U. S. Department of Energy - Richland Operations Office (DOE/RL). 1991. *Descriptions of Codes and Models to be Used in Risk Assessment.* U. S. Department of Energy, Richland Operations Office, Richland, Washington.

U. S. Department of Energy - Richland Operations Office (DOE/RL). 1994a. *100-BC-5 Operable Unit Focused Feasibility Report.* DOE/RL-94-59, Draft A, U. S. Department of Energy, Richland Operations Office, Richland, Washington.

U. S. Department of Energy - Richland Operations Office (DOE/RL). 1994b. *Remedial Investigation and Feasibility Study Report for the Environmental Restoration Disposal Facility.* DOE/RL-93-99, Rev. 1, U. S. Department of Energy, Richland Operations Office, Richland, Washington.

U. S. Department of Energy - Richland Operations Office (DOE/RL). 1995a. *100-HR-3 Operable Unit Focused Feasibility Report.* DOE/RL-94-58, Draft B, U. S. Department of Energy, Richland Operations Office, Richland, Washington.

U. S. Department of Energy - Richland Operations Office (DOE/RL). 1995b. *100-HR-3 Operable Unit Focused Feasibility Report.* DOE/RL-94-67, Rev. 0, U. S. Department of Energy, Richland Operations Office, Richland, Washington

U. S. Department of Energy - Richland Operations Office (DOE/RL). 1995c. *100-KR-4 Operable Unit Focused Feasibility Report.* DOE/RL-94-48, Rev. 0, U. S. Department of Energy, Richland Operations Office, Richland, Washington.

U. S. Department of Energy - Richland Operations Office (DOE/RL). 1995d. *Hanford Site Risk Assessment Methodology.* DOE/RL-91-45, U. S. Department of Energy, Richland Operations Office, Richland, Washington.

DRAFT

U. S. Department of Energy - Richland Operations Office (DOE/RL). 1995e. *Modeling Evaluation of the N-Springs Barrier and Pump-and-Treat System.* DOE/RL-94-132, Rev. 0, U. S. Department of Energy, Richland Operations Office, Richland, Washington.

U. S. Department of Energy - Richland Operations Office (DOE/RL). 1996a. *N-Springs Expedited Response Action Performance Evaluation Report.* DOE/RL-95-110, Rev. 0, U. S. Department of Energy, Richland Operations Office, Richland, Washington.

U. S. Department of Energy - Richland Operations Office (DOE/RL). 1996b. *Remedial Design and Remedial Action Work Plan for the 100 HR-3 and 100-KR-4 Groundwater Operable Units Interim Action.* DOE/RL-96-84, Rev. 0, U. S. Department of Energy, Richland Operations Office, Richland, Washington.

U. S. Department of Energy - Richland Operations Office (DOE/RL). 1997. *Screening Assessment and Requirements for a Comprehensive Assessment, Columbia River Comprehensive Impact Assessment.* DOE/RL-96-16, UC-630, Rev. 0, U. S. Department of Energy, Richland Field Office, Richland, Washington.

Washington State Department of Ecology (Ecology). 1986. State Waste Discharge Program. WAC 173-126, Washington State Department of Ecology, Olympia, Washington

Westinghouse Hanford Company (WHC). 1994. *Capture Zone Analysis for the 200-ZP-1 and 200-UP-1 Pilot-Scale Pump-and-Treat Tests.* WHC-SD-EN-TI-252, Rev. 0., Westinghouse Hanford Company, Richland, Washington.

White, M. D. and M. Oostrom. 1996. *STOMP: Subsurface Transport Over Multiple Phases - Theory Guide.* PNNL-11217, Pacific Northwest National Laboratory, Richland, Washington.

White, M. D. and M. Oostrom. 1997. *STOMP: Subsurface Transport Over Multiple Phases - User's Guide.* PNNL-11218, Pacific Northwest National Laboratory, Richland, Washington.

Wood, M. I., R. Khaleel, P. D. Rittman, S. H. Finrock, T. H. Delorenzo, and D. Y. Garbrick. 1996. *Performance Assessment for the Disposal of Low-Level Waste in the 200 East Area Burial Grounds.* WHC-SD-WM-TI-730, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Wood, M. I., R. Khaleel, P. D. Rittman, A. H. Lu, S. H. Finrock, R. J. Serne, K. J. Cantrell, T. H. Delorenzo. 1995. *Performance Assessment for the Disposal of Low-Level Waste in the 200 West Area Burial Grounds.* WHC-EP-0645, Westinghouse Hanford Company, Richland, Washington.

Wurstner, S. K., and J. L. Devary. 1993. *Hanford Site Groundwater Model: Geographic Information System Linkages and Model Enhancements, FY 1993.* PNL-8991, Pacific Northwest Laboratory, Richland, Washington.

Wurstner, S. K. and M. D. Freshley. 1994. *Predicted Impacts of Future Water-Level Decline on Monitoring Wells Using a Groundwater Model of the Hanford Site.* PNL-10196, Pacific Northwest Laboratory, Richland, Washington.

Wurstner, S. K., P. D. Thorne, M. A. Chamness, M. D. Freshley, and M. D. Williams. 1995. *Development of a Three-Dimensional Groundwater Model of the Hanford Site Unconfined Aquifer System: FY 1995 Status Report.* PNL-10886, Pacific Northwest Laboratory, Richland, Washington.

DRAFT

Yu. C, A. J. Zielen, J. J. Cheng, Y. C. Yuan, L. G. Jones, D. J. LePoire, Y. Y. Wang, C. O. Loureiro, E. Gnanapragasam, E. Faillace, A. Wallo III, W. A. Williams, and H. Perterson. 1993. *Manual for Implementing Residual Radioactive Material Guidelines Using RESRAD, Version 5.0.* Final Draft, Argonne National Laboratory, Argonne, Illinois.

DRAFT

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

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

DRAFT

123n/a not applicable; VZ vadose zone; GW groundwater

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

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

123n/a not applicable; VZ vadose zone; GW groundwater

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

				Hanford Groundwater Project		
Model Attributes	**Hanford Site-Wide Remediation Strategy**	**Environmental Restoration Disposal Facility**	**Hanford Remedial Action/Land Use EIS**	**Future Water Level Assessment**	**Impacts to Drinking Water Systems and GW Use**	**Composite Analysis**
MODFLOW						
MT3D						
Spreadsheet Analysis		VZ/GW				
RESRAD						
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		
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			x	x
Base of Model		n/a				
5 m below Water Table						

123n/a not applicable; VZ vadose zone; GW groundwater

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

				Hanford Groundwater Project		
Model Attributes	**Hanford Site-Wide Remediation Strategy**	**Environmental Restoration Disposal Facility**	**Hanford Remedial Action/Land Use EIS**	**Future Water Level Assessment**	**Impacts to Drinking Water Systems and GW Use**	**Composite Analysis**
Hanford/Ringold Contact						
Top of Lower Ringold Mud Unit	x				x	x
Top of Columbia River Basalts	x		x	x	x	x
Hydrostratigaphic Units	2	1	1	1	10	10
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
Chemicals	x	x	x			

DRAFT

123n/a not applicable; VZ vadose zone; GW groundwater

Table A.2. Model Attributes of Key Projects in the Environmental Restoration Program

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 Orders									
Facility Permitting									
Emergency Response									
Public Interest									
Purpose or Objective of Analysis									
Site Performance Assessment									
Design and Evaluation of Remediation Strategy		x	x	x	x	x	x	x	x
Assessment of Environmental Impacts	x								
Evaluation of Monitoring Network and Design									
Risk Assessment									

DRAFT

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

Table A.2. Model Attributes of Key Projects in the Environmental Restoration Program

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
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-sect	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
Time Scale	<50 yrs	<1 yrs	<300 yrs	<50 yrs	<50 yrs	<50 yrs	<50 yrs	<50 yrs	<50 yrs
Codes Used									
VAM3DCG or VAM2DH	VZ/GW					GW	GW		
PORFLOW or PORFLO-3	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						

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

Table A.2. Model Attributes of Key Projects in the Environmental Restoration Program

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
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
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 / Ringold Formation					x				
Palouse Soil									
Plio-Pliestocene Unit									
Upper Ringold (Unit 4)									
Middle Ringold (Unit 5)			x						

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

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

Table A.2. Model Attributes of Key Projects in the Environmental Restoration Program

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 (continued)									
Middle Ringold (Unit 6)			x						
Middle Ringold (Unit 7)									
Lower Ringold (Unit 8)									
Basal Ringold (Unit 9)									
Columbia River Basalt									
Contaminants Considered		n/a		n/a	n/a	n/a	n/a		
Radionuclides	Sr^{90}		Sr^{90}						
Chemicals								Chromium	Chromium

DRAFT

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

Table A.3. Model Attributes of Key Projects in the Waste Management and Tank Waste Remediation System Programs

Model Attributes	Waste Management				Tank Waste Remediation System			
	LLW Burial Grounds Performance Assessment		Liquid Effluents Program				TWRS Low Activity Waste Disposal Facility	
	200 East Area	200 East Area	ETF	Other Discharges	TWRS EIS	Hanford Tank Initiative	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 and Evaluation of Remediation Strategy						x		
Assessment of Environmental Impacts			x	x	x	x		x
Evaluation of Monitoring Network and Design			x	x				
Risk Assessment								

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

Table A.3. Model Attributes of Key Projects in the Waste Management and Tank Waste Remediation System Progr

Model Attributes	Waste Management				Tank Waste Remediation System			
	LLW Burial Grounds Performance Assessment		Liquid Effluents Program				TWRS Low Activity Waste Disposal Facility	
	200 East Area	200 East Area	ETF	Other Discharges	TWRS EIS	Hanford Tank Initiative	Interim PA	Final PA
Scope of Analysis								
Dimensionality	2-D	2-D	3-D	?	1-D / 2-D	2-D	2-D	2-D / 3-D
Model Orientation	X-section	X-section		?	Areal	Areal/X-sect	Areal/X-sect	X-sect
Flow Analysis				?				
Vadose Zone Flow					SS & Trans.	Transient	SS & Trans.	Steady-state
Groundwater Flow	Steady-state	Steady-state	Transient	?	Steady-state	Steady-state	SS & Trans.	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	Loc/ Site-wd	Loc/ Site-wd	Loc/ Site-wd
Time 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					
MICROFEM								
MODFLOW								

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

ble A.3. Model Attributes of Key Projects in the Waste Management and Tank Waste Remediation System Programs

Model Attributes	Waste Management				Tank Waste Remediation System			
	LLW Burial Grounds Performance Assessment		Liquid Effluents Program				TWRS Low Activity Waste Disposal Facility	
	200 East Area	200 East Area	ETF	Other Discharges	TWRS EIS	Hanford Tank Initiative	Interim PA	Final PA
MT3D								
Boundary Conditions				Undecided				
Basalt Outcrops	n/a	n/a						
No Flow			x		x	x	x	x
Rattlesnake Hills Spring Discharge			x			x		
Cold Creek Valley	n/a	n/a						
Specified Head								
Specified Flux			Steady-state		Steady-state	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	Steady-state
Yakima River								
Specified Head	n/a	n/a	Steady-state	n/a	Steady-state	n/a	Steady-state	Steady-state
Specified Flux								
Columbia River				n/a				
Specified Head	Steady-state	Steady-state	Steady-state		Steady-state	Steady-state	Steady-state	Steady-state
Specified Flux								
Local-scale Boundaries			n/a		n/a			
Specified Head	Steady-state	Steady-state					Steady-state	Transient
Specified Flux								
Natural Recharge	x	x	x		x	x	x	x
Base of Model								
5 m below Water Table	x	x						
Hanford/Ringold Contact								
Top of Lower Ringold Mud Unit								
Top of Columbia River Basalts			x		x	x	x	x

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

›le A.3. Model Attributes of Key Projects in the Waste Management and Tank Waste Remediation System Programs

Model Attributes	Waste Management				Tank Waste Remediation System			
	LLW Burial Grounds Performance Assessment		Liquid Effluents Program				TWRS Low Activity Waste Disposal Facility	
	200 East Area	200 East Area	ETF	Other Discharges	TWRS EIS	Hanford Tank Initiative	Interim PA	Final PA
Hydrostratigraphic Units Considered	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 / 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		

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

APPENDIX B: SUMMARY OF TECHNICAL ISSUES AND CONCERNS

DRAFT

Technical Representative Workshop, Site-Wide Groundwater Model Consolidation

April 24, 1998

Workshop Participants

Name	Organization	Phone	E-mail address
Brent Barnett (for P.C. Mohondro)	PNNL/WMH	376-3416	db.barnett@pnl.gov
Marcel Bergeron	PNNL	372-6104	marcel.bergeron@pnl.gov
Charlie Cole	PNNL	372-6068	cole@pnl.gov
Jerry Davis	NHC	379-9593	jerry_d_davis@rl.gov
Brian Drost	USGS	253-428-3600	bwdrost@usgs.gov
Bryan Foley	DOE-RL	376-7087	bryan_l_foley@rl.gov
Mark Freshley	PNNL	372-6094	md_freshley@pnl.gov
Larry Gadbois	EPA	376-9884	gadbois.larry@epamail.epa.gov
Dib Goswami	Ecology	736-3015	dibakar_goswami@rl.gov
Jim Hanson	DOE-RL	372-4503	
Rich Holten	DOE-RL	376-3963	richard_a_holten@rl.gov
Tony Knepp	BHI	372-9189	anthony.j.knepp@rl.gov
Philip Meyer	PNNL	503-417-7552	philip.meyer@pnl.gov
Greg B. Mitchem	BHI	372-9632	gregory_b_mitchem
Lynn Niccoli	Yakama Indian Nation	946-0101	lgniccoli@aol.com
David Olson	DOE-RL	376-7142	david_e_olson@rl.gov
Wade Riggsbee	Yakama Indian Nation	946-0101	riggsbee@3-cities.com
Phil Rogers	Jacobs	943-9297	phil.rogers@jacobs.com
Greg Sinton	DOE-RL-WPD	373-7939	gregory_l_sinton@rl.gov
Ron Smith	PNNL	376-5831	rm_smith@pnl.gov
Stan Sobczyk	Nez Perce ERWM	208-843-7375	stans@nezperce.org
K. Michael Thompson	DOE-RL	373-0750	k_m_mikethompson@rl.gov
Paul Thorne	PNNL	372-4482	pd_thorne@pnl.gov
Arlene Tortoso	DOE-RL	373-9631	arlene_c_tortoso@rl.gov
Marc Wood	WMH	373-3308	marcus_l_wood@rl.gov

DRAFT

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 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	Charlie Cole, PNNL
3:00 - 3:15	Break	

DRAFT

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

DRAFT

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

DRAFT

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.

<u>Comments on the Conceptual Model</u>

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

DRAFT

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.

DRAFT

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.

DRAFT

Technical Representative Workshop
Site-Wide Groundwater Model Consolidation

April 24, 1998

DRAFT

Proposed Agenda (8:45 - 10:15)

- **Original and Current Scope and Schedule**
- **Proposed Process for Achieving Model Consolidation Objectives**
- **Review and Discussions of Needs and Requirements**
  - Anticipated Site-Wide Groundwater Model Uses
  - Necessary Flow and Transport Capabilities
  - Administrative Requirements
- **How Do Current Models/Codes Meet Needs and Requirements?**
- **Break**

DRAFT

Proposed Agenda (10:30 -1:00)

- **Conceptual Model of Aquifer System**
  - Hydrogeologic Framework
  - Hydraulic Properties
  - Transport Properties
  - Aquifer Boundaries
  - Recharge
  - Interaction with Basalt Confined Aquifers
- **Lunch**

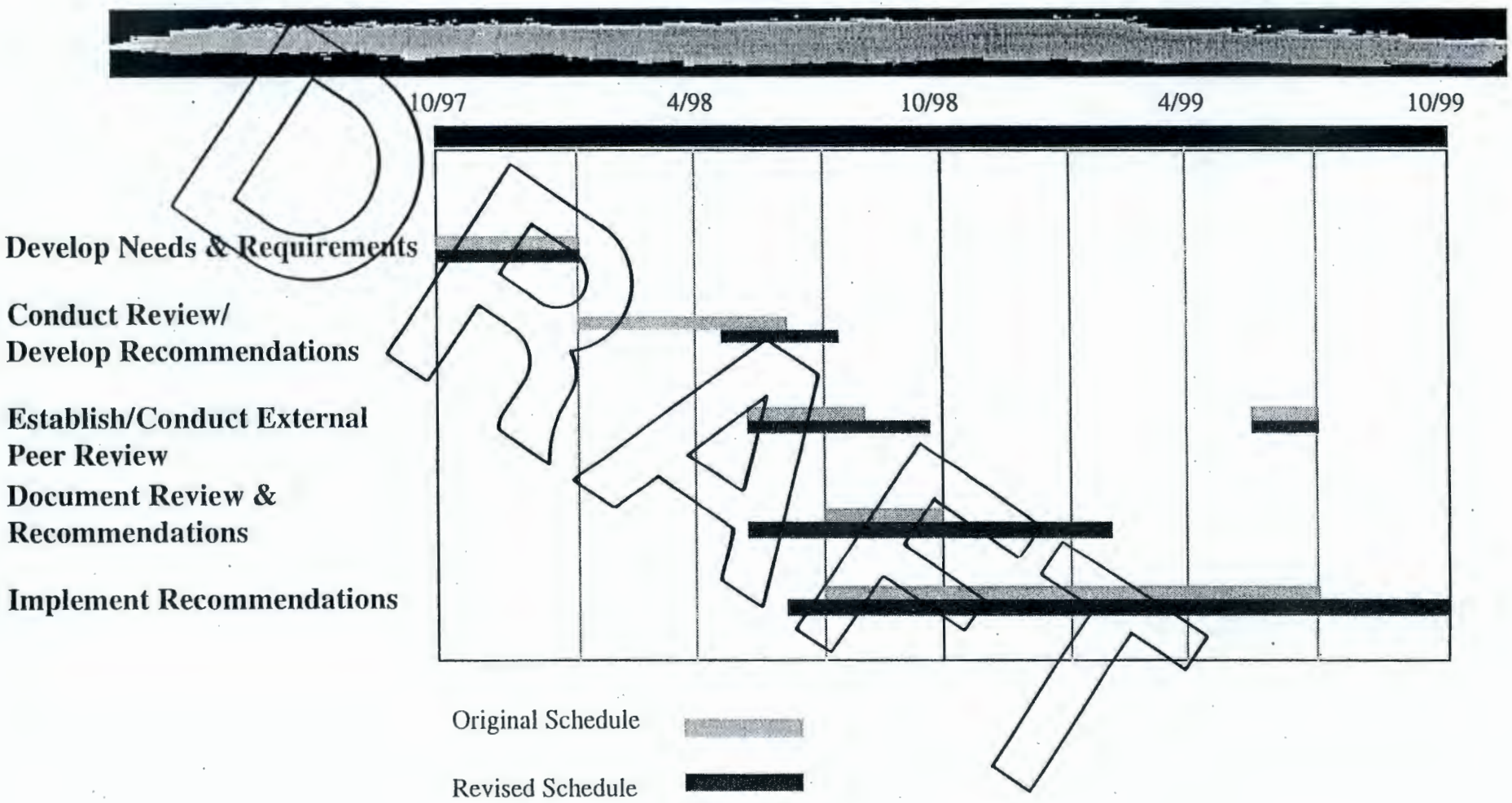
DRAFT

Proposed Agenda (1:00 -4:00)

- **Review of Selected Numerical Implementation of Conceptual Model**
  - Translation of Conceptual Model
  - Flow Model Development and Calibration
  - Transport Model Development and Implementation
  - Discussion of Recent Flow and Transport Results
- **Break**
- **Review of Technical Issues and Concerns**

DRAFT

Original and Current Schedule



DRAFT

Internal Model Consolidation Core Group

- ER Program Representatives:
  - Hanford Groundwater Project
  - Integrated Groundwater/Vadose Zone Project
  - Environmental Restoration
- Waste Management Program Representatives:
  - Solid Waste Burial Grounds PA
- TWRS Program Representatives:
  - ILAW PA
  - Hanford Tank Initiative

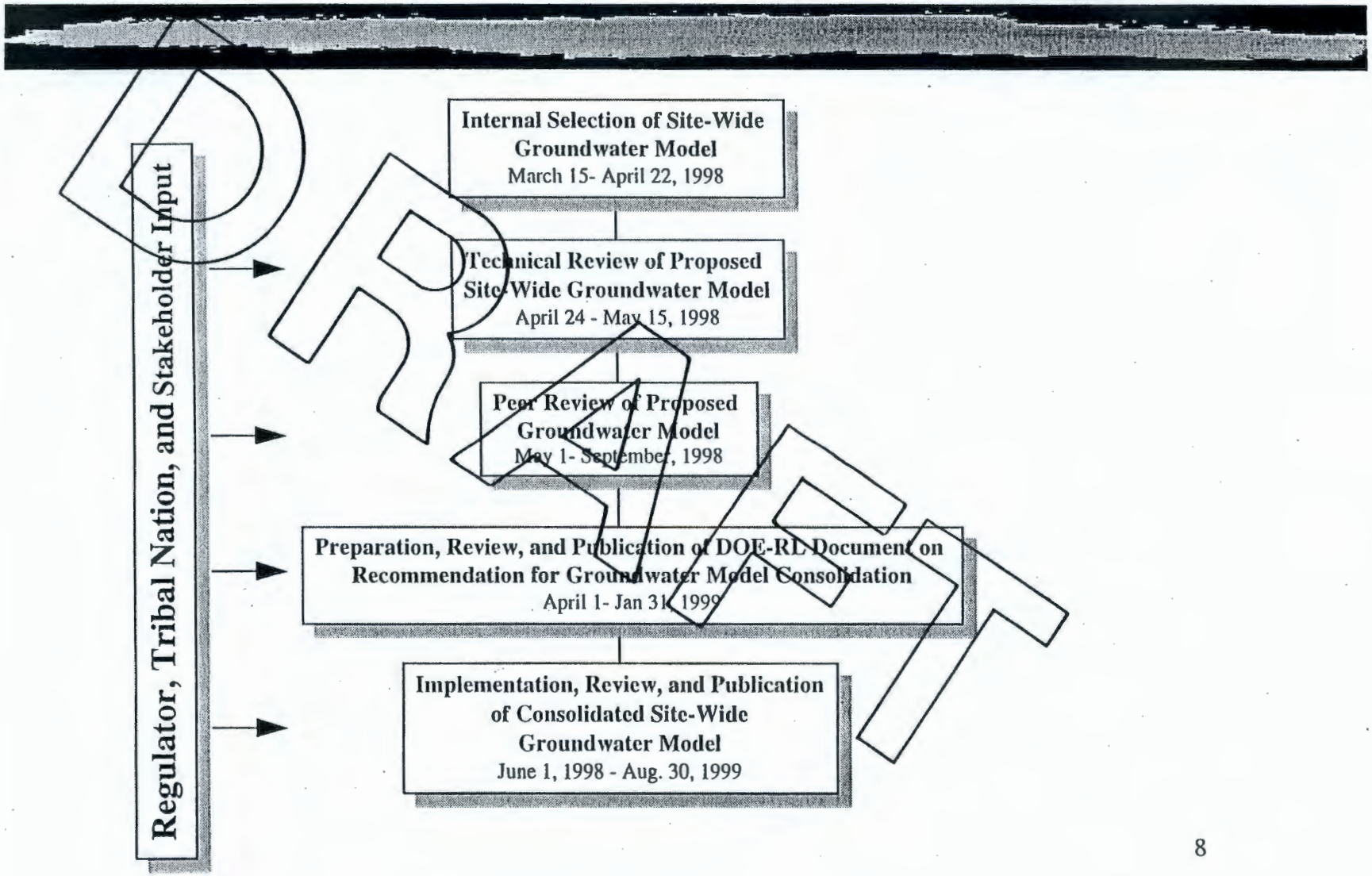
DRAFT

Elements of Proposed Approach/ Recommendations

- **The Site Should Move Forward with one Site-Wide Groundwater Model**
- **The Selected Model Should Undergo Review by:**
  - Technical Representatives of Regulators (EPA, Ecology), Tribal Nations, and Stakeholders
  - Peer Review Group
- **Further Refinements, If Necessary, Should Move Forward Based on Peer Review Comments and Recommendations**

DRAFT

Overview of Approach and Schedule



DRAFT

Proposed Approach and Schedule

Technical Review of Proposed Site-Wide Groundwater Model
April 24-May 15, 1998

Initial Workshop and Briefing with Regulators, Tribal Nation, and Stakeholders
April 24, 1998

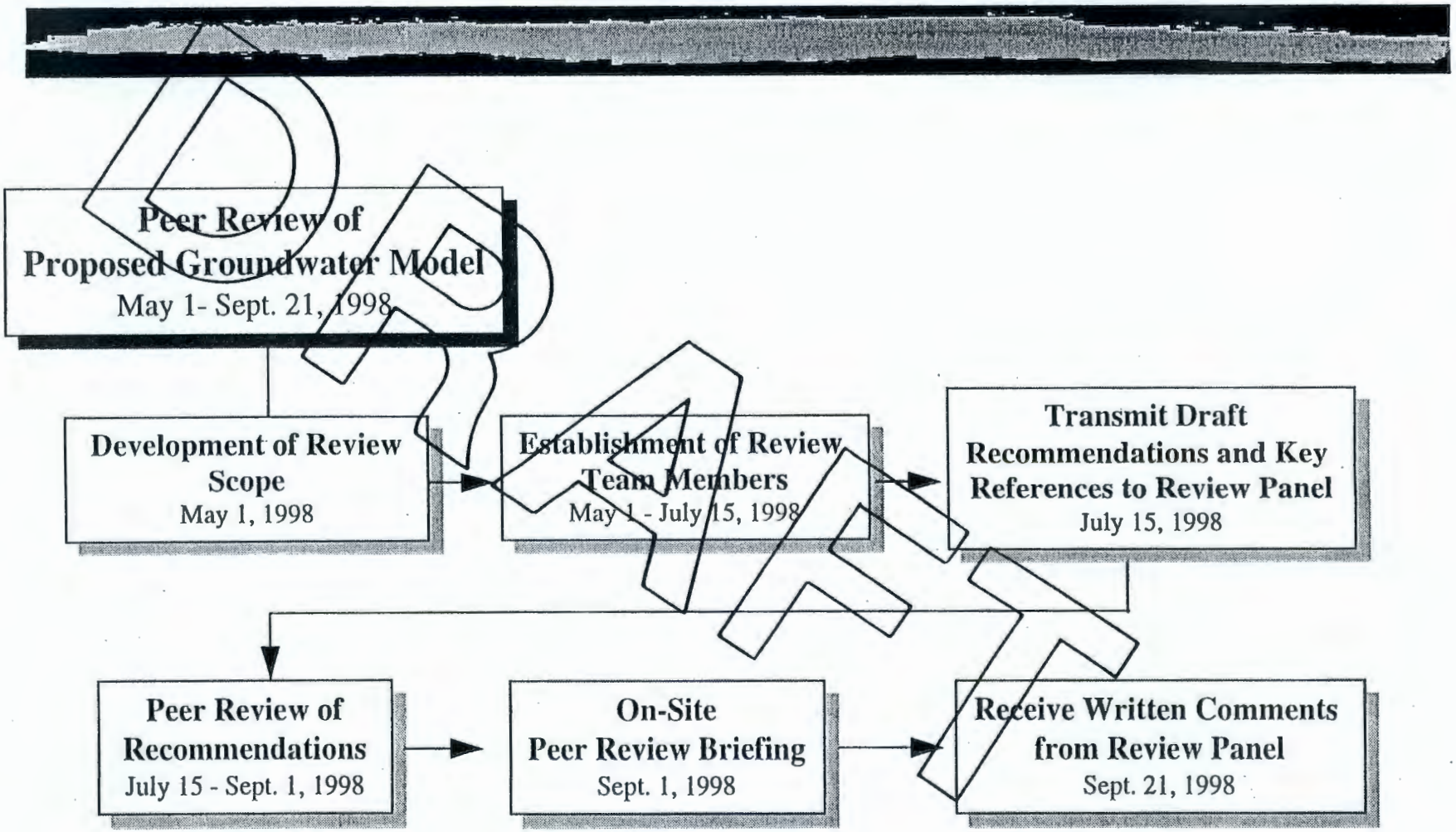
Review of Key References for Proposed Model
April 24-May 15, 1998

Receive Review Comments and Input
May 15, 1998

Incorporate Comments into Draft Recommendations Document
May 15- June 15, 1998

DRAFT

Proposed Approach and Schedule



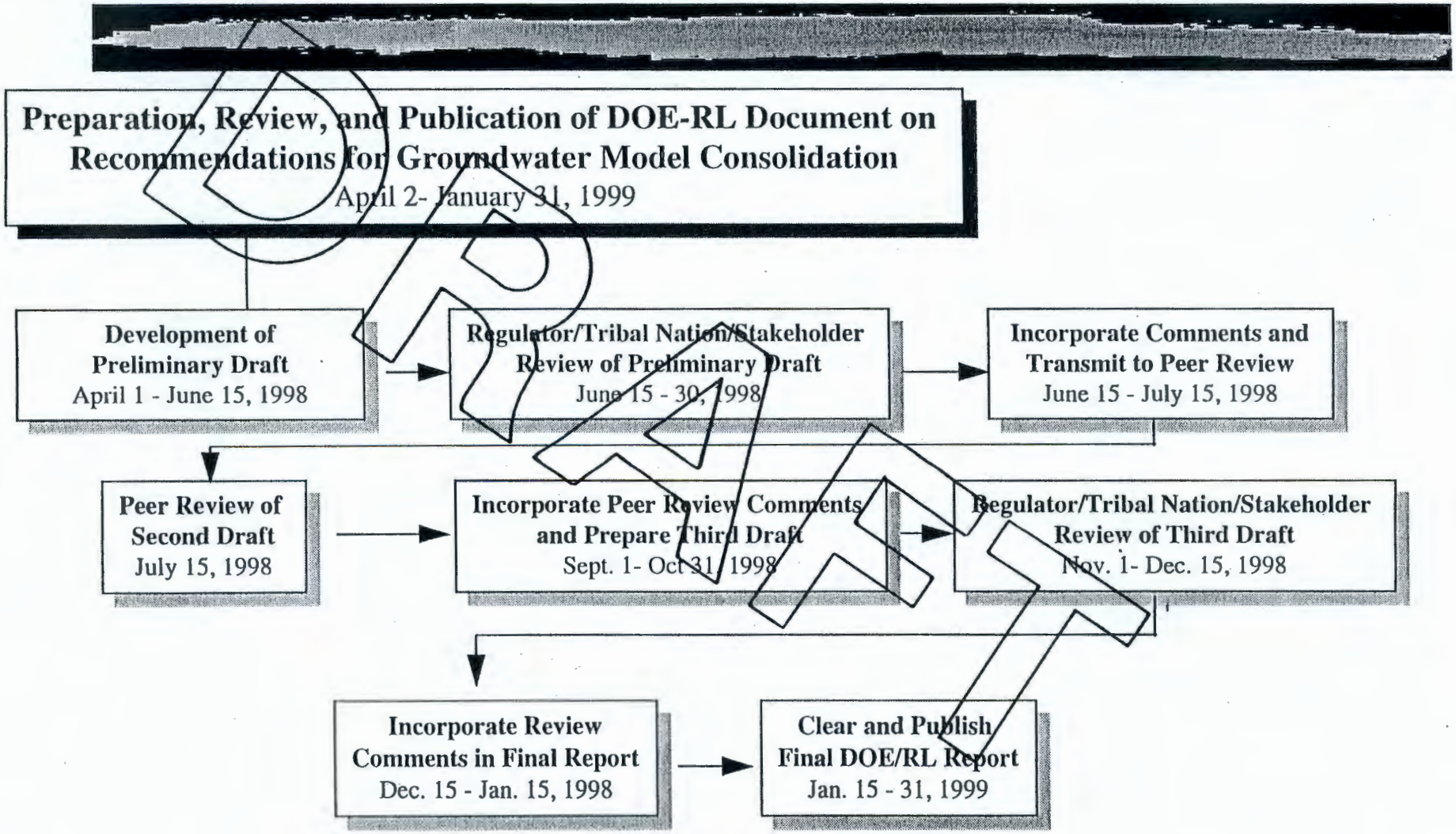
DRAFT

Proposed Scope of Review

- Are the analysis capabilities developed in the proposed site-wide groundwater model adequate to meet the anticipated PA, EIS, CA, and other regulatory requirements for the Hanford site-wide groundwater modeling?

DRAFT

Proposed Approach and Schedule



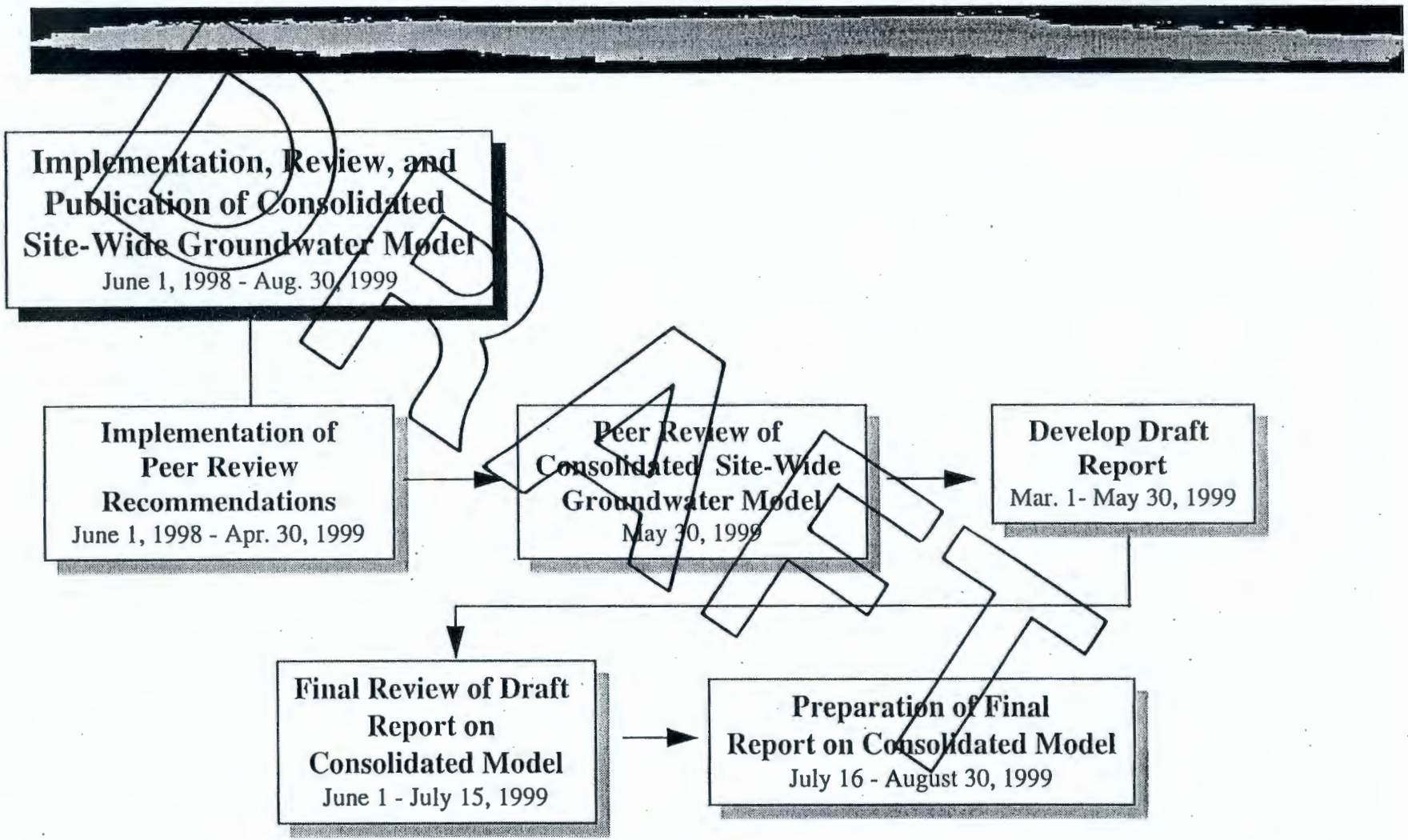
DRAFT

Elements of DOE/RL Report on Recommendations for Groundwater Model Consolidation

- **Approach for Model Consolidation**
- **Description of Needs and Requirements**
  - Anticipated Site-Wide Groundwater Analyses
  - Flow and Transport Capabilities
  - Administrative Requirements
- **Technical Overview of Proposed Conceptual and Numerical Model**
- **Recommended Changes to Proposed Model for Anticipated Uses**
- **Appendices:**
  - External Peer Review Comments
  - Regulator, Tribal Nations, and Stakeholder Review Comments

DRAFT

Proposed Approach and Schedule



Elements of Final Report on Consolidated Site-Wide Groundwater Model

- **Site-Wide Conceptual Model**
  - Key hydrogeologic units
  - Boundaries (assumed lateral, surface, lower boundary conditions)
- **Numerical Implementation**
  - Selected computer code
  - Model grid design
  - Key boundary conditions
  - Steady-state and transient calibration procedures and results
    - Distribution of hydraulic properties
    - Boundary conditions
    - Transport properties

DRAFT

Elements of Final Report on Consolidated Site-Wide Groundwater Model (continued)

- **Results from Selected Applications**
  - Future Decline of Water Table
  - Existing Plume Transport
  - Transport of Future Releases
- **Code and Model Configuration Control**
  - Input file formats, structure, and user access
  - Code executables and user access
  - Management of code and model modifications
- **Appendixes**
  - Key assumptions
  - Key hydrogeologic data and information
  - Details of estimation procedures

DRAFT

Needs and Requirements

Anticipated Analyses of Groundwater (Present - 2003)

▮ **Solid Waste EIS**	Apr. 1998-Sept. 1998	Preliminary Draft
	FY 1999	Revisions from Public
▮ **Hanford GW Project**	Present - 2003	General Modeling Support
▮ **Composite Analysis**	FY 1999	Response to HQ Comments on Radiological Impacts
	FY 2000	Initiate Evaluation of Chemical impacts and areas outside the 200 Area Plateau
▮ **Hanford Tank Initiative**	Nov. 1998	Retrieval Performance Evaluation (Draft)
	Jan. 1999	Retrieval Performance Evaluation (Final)
	FY 2000	Technology Deployment Selection

DRAFT

Needs and Requirements

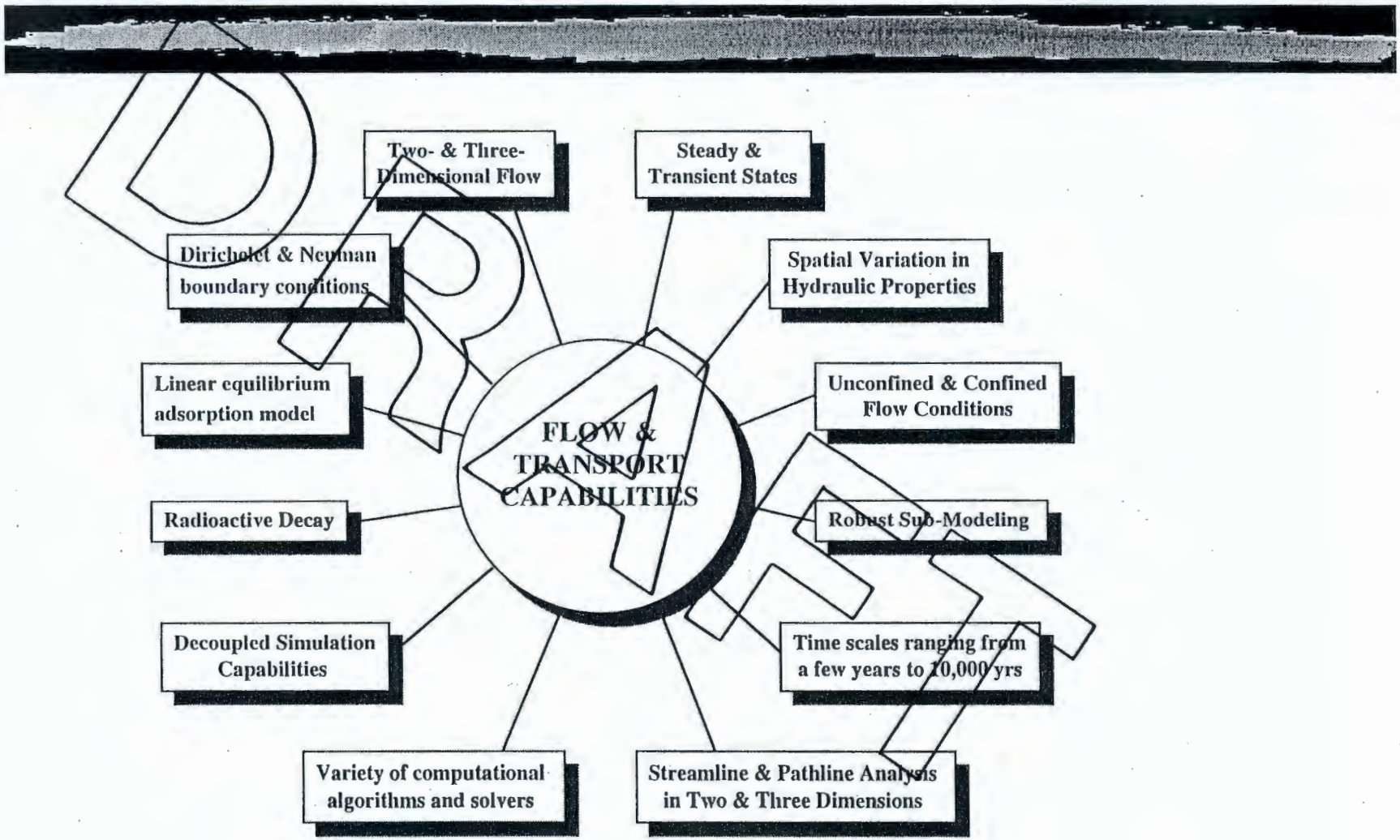
Anticipated Analyses of Groundwater System (Present - 2003)

Hanford Tank Initiative	FY 1999-2003	Technical Support to Develop Cleanup Standards and Residuals
Canyon Disposition	FY 1999-2000	D&D Support for U Canyon
TWRS ILAW Final PA	Jan. 2000-Aug. 2000	Support to Grout Vault Disposal
	Jan. 2002-Aug. 2002	Support to New Facility Disposal
PA Maintenance	FY 2000	Solid Waste Burial Grounds
216 Permit Support	FY 2002-2003	Support to SALDS or as needed to meet permit requirements

DRAFT

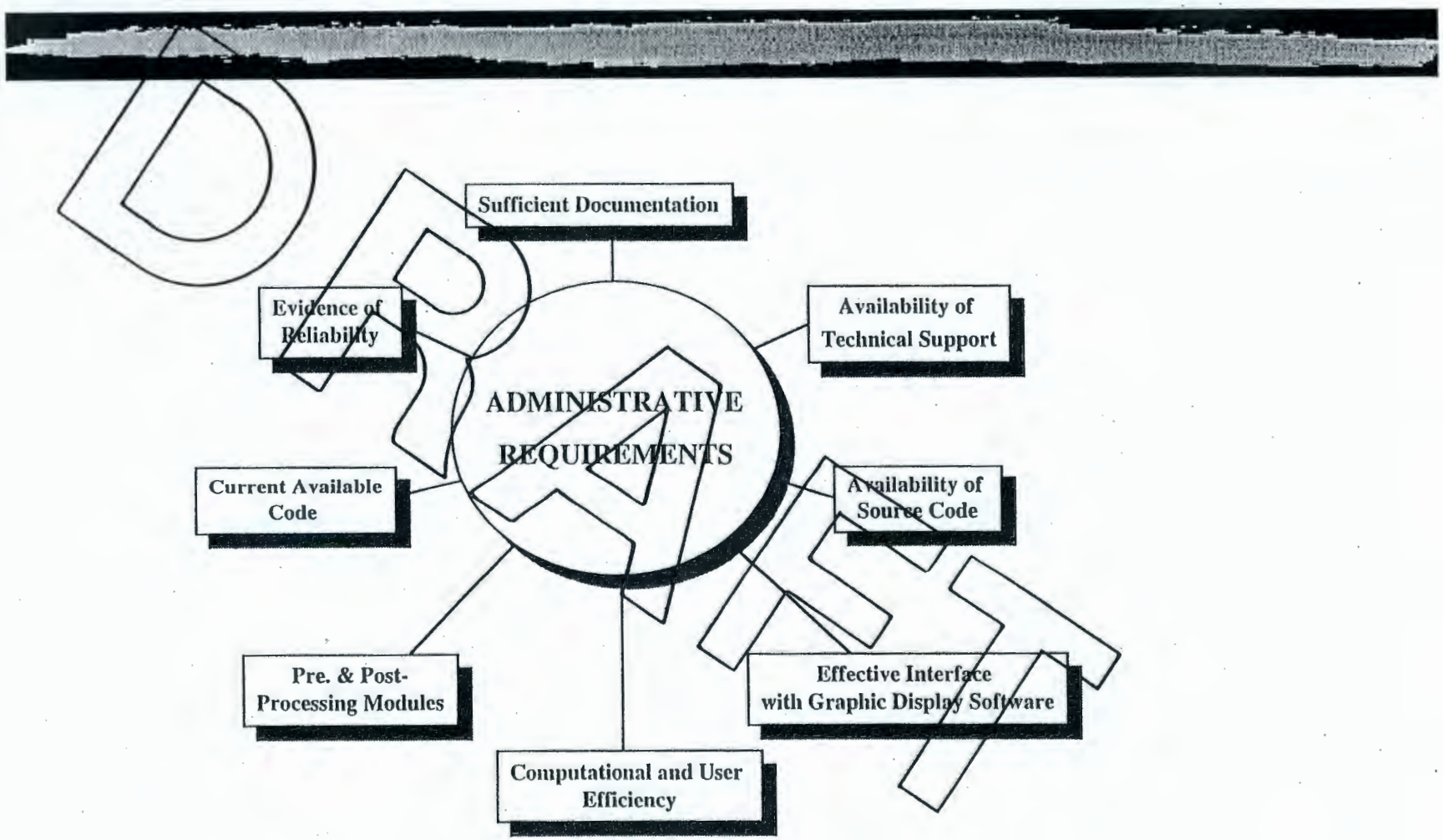
Needs and Requirements

Flow and Transport Capabilities



Needs and Requirements

Administrative Requirements



How Do Current Models and Codes Meet Needs and Requirements?

- What Models and Codes are Being Considered?
- Proposed Model for Review
- How Do Codes Fare with Needs and Requirements?
- Status - Proposed Code

DRAFT

What Models are Being Considered?

- **With the substantial investments already made by RL in Site-Wide Groundwater Modeling, models being considered are:**
  - Site-Wide Model developed as part of the Hanford Sitewide Groundwater Remediation Strategy (HSGWRS)
  - Site-Wide Model developed as part of the Hanford Groundwater Project (HGWP) and used in the Composite Analysis of radiological sources in the 200-Area Plateau
- **Justification:**
  - Most recent groundwater analysis (TRWS EIS; HRA EIS, Preliminary PA for ILAW; Solid Waste PAs) that have used a site-wide model analysis capability have relied either directly or indirectly on these two site-wide models

DRAFT

Model used for Hanford Sitewide Groundwater Remediation Strategy

- **Major Hydrogeologic Units**
  - Hanford Formation
  - Ringold Formation
- **Based on VAM3D-CG Computer Code**
- **Evaluated Future (200 yrs) Impacts of Existing Radiological and Chemical Contaminant Plumes**
- **Other Notable Recent Uses:**
  - GW Transport component of Preliminary PA (ILAW Disposal)
  - Hydraulic aspects of model used to support Solid Waste PA's

DRAFT

Model used for Hanford Groundwater Project and Composite Analysis

- **Major Hydrogeologic Units**
  - Hanford Formation
  - Ringold Formation subdivided into three sand and gravel units and three mud units
- **Based on CFEST96 Computer Code**
- **Evaluated Future (1500 yrs) Impacts of Existing Radiological Contaminant Plumes and Releases from Future Sources**
- **Other Notable Recent Uses:**
  - Hydrologic basis of TWRS and HRA EIS
  - Model being used to support aspects of Hanford Tank Initiative
  - Transport analysis supporting SALDS Permit

DRAFT

Proposed Model for Review

- **Recommendation - Model currently supported by HGWP**
- **HGWP model is the most recently used model**
  - Three-dimensional Simulation of Existing Plumes (Cole et al 1997)
  - Composite Analysis of Radioactive Sources in 200 Area Plateau (Kincaid et al 1998)
- **Captures Main Components of HSGWRS Model**
- **Added Capability to Examine**
  - effect of Ringold mud units on system hydraulics and contaminant transport
  - areal recharge
- **Model infrastructure is currently supported by Hanford Groundwater Project and Composite Analysis Budget Baseline**

DRAFT

How Do Codes Fare with Needs and Requirements?

- Acceptability of Codes
- Flow and Transport Capabilities
- Administrative Requirements

DRAFT

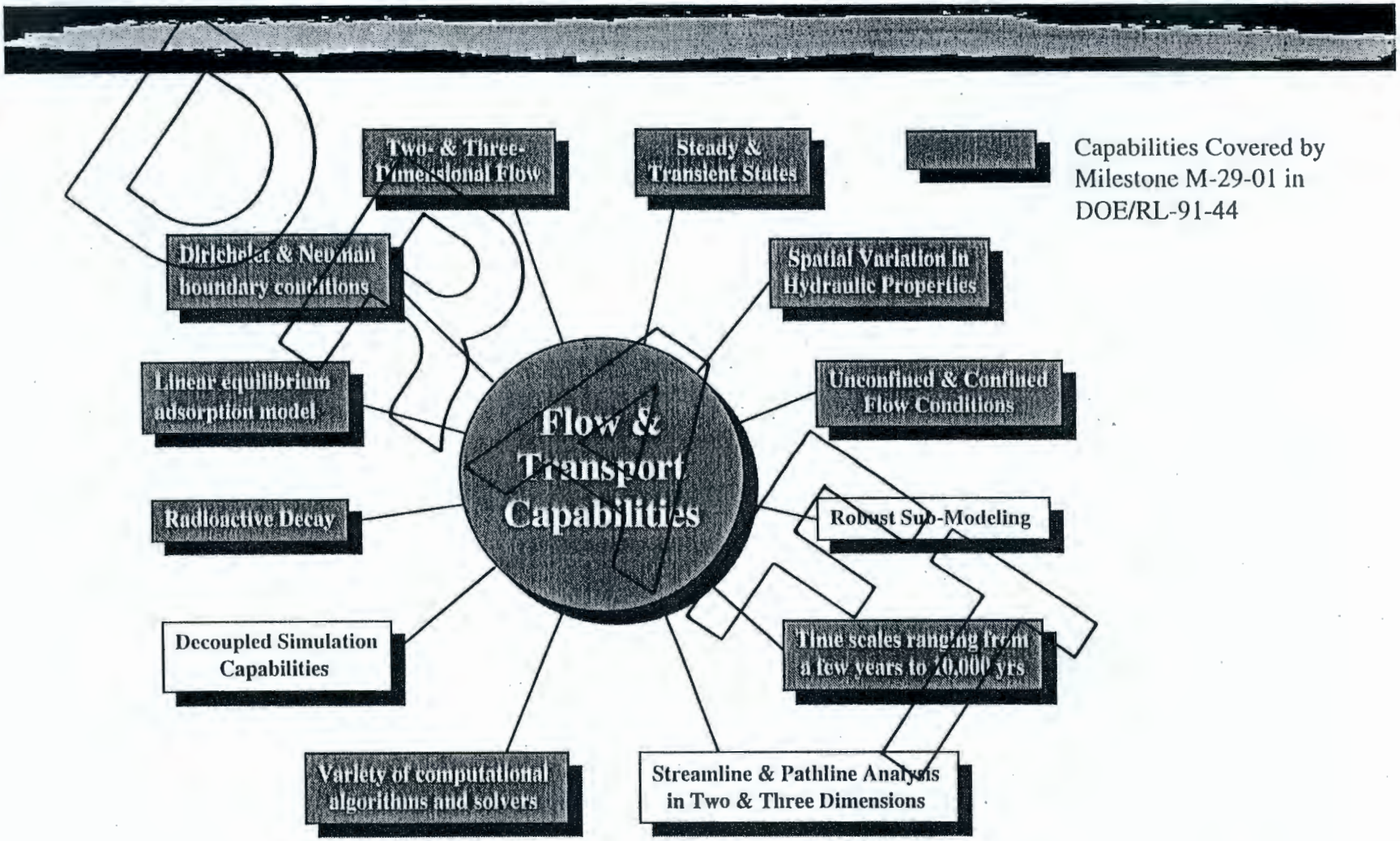
Acceptability of VAM3D and CFEST Codes

- **Both Codes:**
  - Included on recommended list of groundwater flow and transport codes in Milestone M-29-01(DOE/RL 1991)
  - Meet the administrative and technical criteria/capabilities mentioned in the M-29-01 document
  - Generally meet the technical capabilities and administrative requirements outlined in the recent draft needs and requirements.

DRAFT

Needs and Requirements

Flow and Transport Capabilities



Capabilities Covered by Milestone M-29-01 in DOE/RL-91-44

Flow and Transport Capabilities

CAPABILITIES	VAM3D-CG	CFEST96
Two- & Three Dimensional Flow	Options available	Options available
Steady & Transient States	Options available	Options available
Spatial Variation in Hydraulic Properties	Options available	Options available
Unconfined & Confined Conditions	Options available	Options available
Robust Submodeling	Option not available with code but has been developed at Hanford	Options available

DRAFT

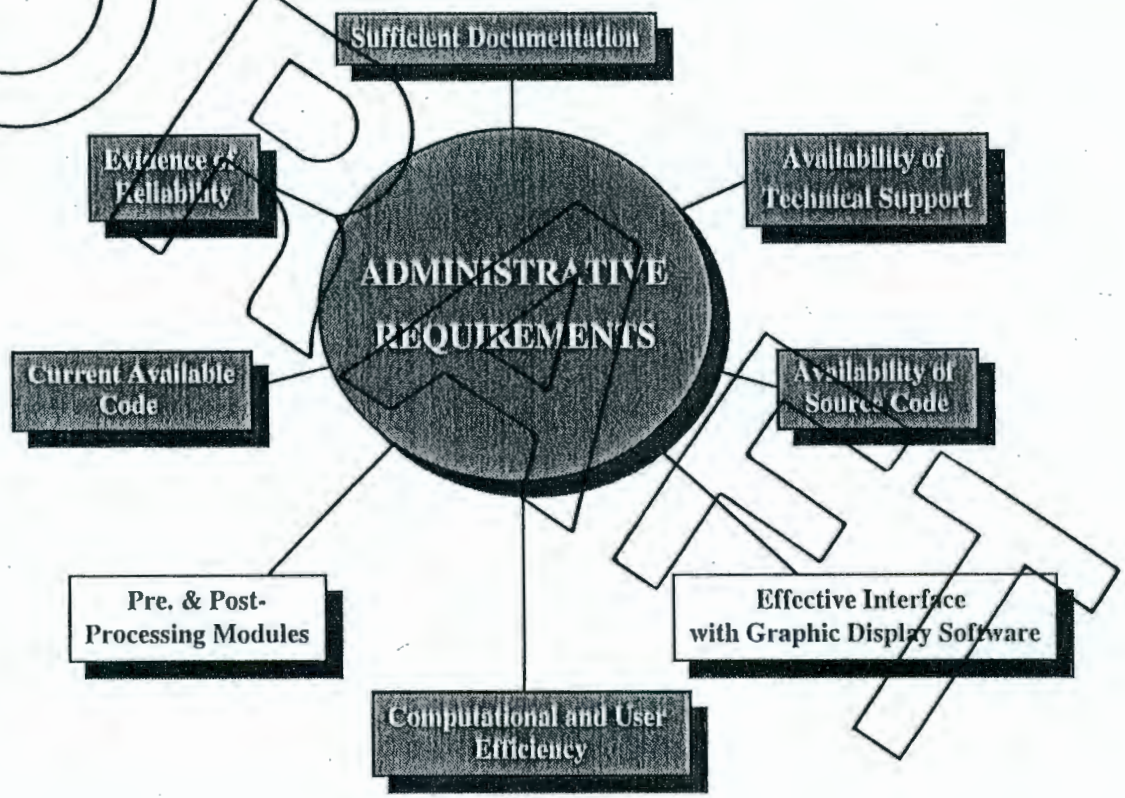
Flow and Transport Capabilities

CAPABILITIES	VAM3D-CG	CFEST96
Time Scales ranging from a few yrs to 10000 yrs	Options available	Options available
Streamline & Pathline Analysis	Option not available	Options available
Variety of Computational Algorithms and Solvers	Options available	Options available
Decoupled Simulation Capabilities	Options available	Options available
Radioactive Decay	Options available	Options available
Linear Equilibrium Adsorption Model	Options available	Options available
Direchelet & Neuman Boundary Conditions	Options available	Options available

DRAFT

Needs and Requirements

Administrative Requirements



DRAFT

Administrative Requirements

REQUIREMENTS	VAM3D-CG	CFEST
Sufficent Documentation	Both codes have acceptable documentation	
Availability of Technical Support	**Hydrogeologic, Inc** (P. Huyakorn)	**CFEST, Inc.** (S. Gupta)
Availability of Source Code	Source may be Available	Source Available
Effective Interface with Graphical Visualization Software	Graphics performed with TECPLOT	Graphics performed with ARCINFO (TECPLOT capabilities available)
Computational and User Effciency*	Both codes run on PC and UNIX workstation with efficient solvers	

* VAM3D-CG may have some advantages but actual advantages cannot be determined without benchmarking on similar problems

DRAFT

Administrative Requirements

REQUIREMENTS	VAM3D-CG	CFEST
Pre- and Post Processing	Pre- and post-processing options (resident to code) available; graphics access to TECPLOT; not currently linked to ARC/INFO	Pre- and processing options (resident to code) available; currently linked to ARC/INFO; graphics access to TECPLOT available through developer
Currently Available Code	VAM3D-CG version 3.1	CFEST96
Evidence of Reliability	Both codes have extensive evidence of reliability	

DRAFT

Status - Proposed Code

- **Both codes are technically acceptable and meet all adminstrative requirements**
- **Source code for both codes appear to be available from vendors**
- **Final recommendation may require:**
  - More detailed evaluation of cost and schedule impacts from implementation
  - Potential benchmarking to evaluate code efficiency

DRAFT

Conceptual Model

- Hydrogeologic Framework
- Hydraulic Properties
- Transport Properties
- Aquifer Boundaries
- Recharge
- Interaction with Basalt Confined Aquifers
- Contaminant Distributions

Hydrogeologic Framework

- Total of 9 hydrogeologic units above basalt
- Maximum of 7 units below the water table
- 3 Ringold mud units (4,6,8) -
  - low permeability
  - essentially no flow
- 3 Ringold gravel units
  - assumed to have similar properties
  - separated by mud units

DRAFT

Hydrogeologic Framework (cont.)

- Generally uses Lindsey's faces definitions with some differences (emphasis placed on grouping according to flow properties).
- Differences (in some places):
  - Lower, predominantly sand portion of Lindsey's upper Ringold was grouped with Lindsey's A and C to form Unit 5.
  - Unit 6 includes some coarse grained facies of Lindsey's B and D that are interfingered with the lower Ringold mud facies (assumes that these are isolated). Where they form a more extensive unit B and D are designated as Unit 7.
  - Where Unit 7 exists, the lower mud is divided into two units (6 and 8).

Hydraulic Properties

- T values
  - pumping tests and multi-well slug tests
  - most for upper aquifer unit
- K values needed for 3-D model
- K values calculated (K=T/b)
  - b=thickness of tested unit
- K distribution varies laterally within units

DRAFT

Transport Properties

- Effective porosity
  - limited measurements form core samples and specific yield measurements from multi-well aquifer tests
- Dispersivity
- Distribution coefficients
  - data from lab tests
  - affected by water chemistry, grain size and minerology

Aquifer Boundaries

- Columbia River
  - discharge area
  - fluctuating river stage / bank storage
- Yakima River
- Basalt
- Cold Creek / Dry Creek / Rattlesnake Springs
- Water Table

DRAFT

Artificial Recharge

- Approximately 1 billion m^3 have been discharged to the ground
- Maximum discharges in the separations areas were 34 million m^3/y
- Current discharges to permitted facilities are about 5 million m^3/y
- What does the future hold?

Natural Recharge

- Based on measured recharge correlated to surface soil texture and vegetation coverage
- 1979 recharge = minor revision of Fayer and Walters (1995)
- Bauer and Vaccaro (1990) for comparison
  - 0-13 mm/y most of site, maximum 50 mm/y
- Current natural recharge = 8.5 million m^3/y
- Natural recharge is much more significant with declining artificial recharge

DRAFT

Interaction with Basalt

- Upper basalt confined aquifer heads show potential discharge to unconfined system, some chemical evidence of communication
- Difficult to quantify, temperature logs of wells and differences in chemistry have been examined
- May be more significant in future because of less artificial recharge and decline of water table (more upward gradient)
- Generally ignored in models except Rattlesnake Springs

Contaminant Distributions

- Data available for upper part of the unconfined aquifer
- Limited data on vertical distribution
- Sources often not well defined

DRAFT

Numerical Implementation
HGWP Site-Wide Groundwater Model

- Translation of conceptual model (hydrostratigraphy, domain, boundary conditions, basalt outcrops, layering, grid)
- Flow model development and calibration
  - *Steady-state 2-D inverse calibration*
  - *Translation of 2-D transmissivities to 3-D hydraulic conductivity distribution*
  - *Transient 3-D flow model calibration*
- Transport model implementation
  - *Transport parameters*
- Transport model calibration (purpose, rationale, issues, approach, results)
  - *Tritium plume comparisons*
- Sensitivity to dispersivity

DRAFT

Translation of Conceptual Model

- Hydrostratigraphic Interpretation
  - 9 areally extensive units alternating between transmissive (odd numbers, e.g., Hanford formation = 1, Middle Ringold (e) = 5) and less transmissive fine grained or mud units (even numbers)

Unit Number	Hydrogeologic Unit	Lithologic Description
1	Hanford Formation	Fluvial gravels and coarse sands
2	Palouse Soils	Fine-grained sediments and eolian silts
3	Pre-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 (Unit B and 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

Numerical Implementation HGWP Site-Wide Groundwater Model

Translation of Conceptual Model

- Domain and *Boundary Conditions*

  upper boundary - *water table;* natural and artificial recharge

  lateral boundaries - *edge-centerline of Columbia and Yakima Rivers;* specified head at surface from edge-centerline no-flow vertically below river centerline *basalt subcrops*;* no-flow vertically for most subcrops, exceptions are specified flux** along parts of Rattlesnake Hills, Cold and Dry Creek Valley

* *location of basalt subcrops above water table updated throughout the modeled area*

** *specified flux determined from specified head calculations during model calibration*

Translation of Conceptual Model

- Domain and *Boundary Conditions*
  - *bottom boundary - isolating lower mud or top of basalt;* no-flow
    - SE corner top of lower mud sequence, unit 8, because lower water bearing unit, unit 9, missing.
    - Area North of Gable Mountain and Gable Butte top of lower mud sequence, unit 8, because lower water bearing unit, unit 9, is totally isolated by the unit 8 muds and basalt

DRAFT

Numerical Implementation HGWP Site-Wide Groundwater Model

Translation of Conceptual Model

- Plan View Grid
  - *flow model ~750 m grid spacing*
    - 1606 surface elements and 1784 surface nodes
    - 7200 total elements and 8465 total nodes
  - *transport model ~375 m grid near sources and ~750 m grid spacing elsewhere*
    - 2991 surface elements and 3108 surface nodes
    - 23128 total elements and 23668 total nodes
- Vertical Grid
  - *flow model calibration used the nine hydrostratigraphic layers*
  - *transport model subdivided*
    - transmissive hydrostratigraphic units were divided into multiple ~8 m layers
    - upper mud units were divided into 2 layers

DRAFT

Flow Model Development and Calibration

(Steady state 2-D inverse calibration)

- Provides areal transmissivity distribution based on:
  - *Measured transmissivity*
  - *Measured and interpreted heads*
- 1979 time period
  - *steady hydrographs and fluxes*

Statistical Comparison of Differences Between Observed And Predicted 1979 Water-Table Elevations

Statistical Categories	Values, in meters
All Nodes (1457 nodes)	
Maximum Error	5.13
Minimum Error	-6.73
Average Error	-0.65
Absolute Value of Error	1.08
RMS of Error	1.64
Nodes with Positive Errors (509 nodes)	
Average Error	0.65
RMS of Error	0.93
Nodes with Negative Errors (948 nodes)	
Average Error	-1.31
RMS of Error	1.91

Flow Model Development and Calibration

(Translation of 2-D T's to 3-D K's)

- Purpose - derive 3-D hydraulic conductivity distribution based on available information:
  - *steady state 2-D inverse transmissivity for 1979 time period*
  - *thickness of the saturated hydrostratigraphic units based on the 1979 inverse water table solution*
  - *"book values" of hydraulic conductivity for the 9 hydrostratigraphic units based on their facies description and literature values*

DRAFT

Flow Model Development and Calibration

(Translation of 2-D T's to 3-D K's)

Assigned "Book Values" K's

Unit Number	Hydrogeologic Unit	Lithologic Description	Generic K (m/day)
1	Hanford Formation	Fluvial gravels and coarse sands	500
2	Palouse Soils	Fine-grained sediments and eolian silts	0.0001
3	Plio-Pleistocene Unit	Buried soil horizon containing caliche and basaltic gravels	350
4	Upper Ringold Formation	Fine-grained fluvial/lacustrine sediments	0.0005
5	Middle Ringold (Unit E)	Semi-indurated coarse-grained fluvial sediments	8
6	Middle Ringold (Unit C)	Fine-grained sediments with some interbedded coarse-grained sediments	0.01
7	Middle Ringold (Unit B and D)	Coarse-grained sediments	1
8	Lower Mud Sequence (Lower Ringold and part of Basal Ringold)	Lower blue or green clay or mud sequence	0.00001
9	Basal Ringold (Unit A)	Fluvial sand and gravel	1

Flow Model Development and Calibration

(Translation of 2-D T's to 3-D K's)

- Approach
  - *calculate a "Book Value" transmissivity for each saturated hydrostratigraphic unit based on its thickness and its "Book Value" K*
  - *K of the saturated conductive layers based on the ratio of their "Book Value" transmissivities and ensuring that total transmissivity equals the transmissivity from the 2-D inverse*
-

Note - Mud unit K's are equal to their "Book Value"

Flow Model Development and Calibration

- Transient 3-D flow model calibration (1979-1996) performed to determine specific yield values for Hanford and transmissive Ringold units
  - *resulting specific yields were 0.1 for Ringold and 0.25 for Hanford based on comparisons of:*
    - 1996 observed vs predicted water table
    - comparison of predicted and observed hydrographs

DRAFT

Transport Model Implementation

(additional inputs)

- Initial Conditions
  - *Ground Water Monitoring Report values placed at all nodes within 25 m of water table*
- Dispersivity based on grid Peclet restrictions
  - *95 m longitudinal*
  - *20 m lateral*
- Equilibrium adsorption model used for transport
  - *Distribution coefficients constant throughout the model area based on the contaminant and the chemistry of the source (e.g., chelates and high salts, high organic and very acidic)*

Transport Model Calibration

- Purpose - test the ability of the calibrated flow model to predict 3-D transport of tritium
- Rationale
  - *tritium Kd is zero*
  - *tritium discharge and plume data available from 1979 to present*
- Issues
  - *data needed to set initial conditions - plume distribution with depth - is not available*
  - *inventory associated with initial conditions (1979) much greater than discharge between 1979 and present*

DRAFT

Transport Model Calibration

- Approach
  - *investigate different assumptions for plume thicknesses associated with the initial conditions (only constant thickness assumptions considered)*
  - *investigate predicted plume depths associated with a new source (i.e., SALDS)*

DRAFT

Transport Model Calibration

- Results
  - *initial thickness of 6 meters based on the length of the screened interval for typical monitoring wells*
    - comparison of 1996 predictions with observations poor - results were non-conservative - predicted concentrations too low and areal distribution of plume too small
  - *SALDS site modeling (new source) indicated that high volume source could drive plume to much greater depths than 6 meters*
  - *final thickness investigated for initial conditions was 25 m*
    - comparison of 1996 predictions with observations significantly improved - results were conservative - predicted concentrations slightly higher than observed and areal distribution of plumes similar
    - improving the model further requires better estimates of the depth variation in initial conditions because the initial inventory is much greater than discharge between 1979 and present

Numerical Implementation HGWP Site-Wide Groundwater Model

Sensitivity to Dispersivity

- Comparison of coarse grid large dispersivity model results with fine grid small dispersivity results for same source (SALDS)
  - *Models*
    - coarse grid 375 m by 375 m - dispersivity 95 m longitudinal, 20 m transverse
    - fine grid 45 m by 45 m - dispersivity 20 m longitudinal, 2 m transverse
  - *Results*
    - comparison at 2020
      - *plume diameter above 2000 pCi/L - coarse grid 2.4 km, fine grid 1.6 km*
      - *plume diameter above 20,000 pCi/L - coarse grid 1.1 km, fine grid 1.2 km*
    - comparison at 2050
      - *plume diameter above 2000 pCi/L - coarse grid 1.5 km, fine grid 1.6 km*

DRAFT

Key References

Proposed Site-Wide Groundwater Model
Hanford Groundwater Project

Cole, C. R., S. K. Wurstner, M. P. Bergeron, M. D. Williams, and P. D. Thorne. 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.* PNNL-11801, Pacific Northwest National Laboratory, Richland, Washington.

Wurstner, S. K., P. D. Thorne, M. A. Chamness, M. D. Freshley, and M. D. Williams. 1995. *Development of a Three-Dimensional Groundwater Model of the Hanford Site Unconfined Aquifer System, FY 1995 Status Report.* PNL-10886, Pacific Northwest Laboratory, Richland, Washington.

Thorne, P. D., M. A. Chamness, V. R. Vermeul, Q. C. MacDonald, and S. E. Schubert. 1994. *Three-Dimensional Conceptual Model for the Hanford Site Unconfined Aquifer System, FY 1994 Status Report.* PNL-10195, Pacific Northwest Laboratory, Richland, Washington.

Thorne, P. D., M. A. Chamness, F. A. Spane Jr., V. R. Vermeul, and W. D. Webber. 1993. *Three-Dimensional Conceptual Model for the Hanford Site Unconfined Aquifer System, FY93 Status Report.* PNL-8971, Pacific Northwest Laboratory, Richland, Washington.

Thorne, P. D. and M. A. Chamness. 1992. *Status Report on the Development of a Three-Dimensional Conceptual Model for the Hanford Site Unconfined Aquifer System.* PNL-8332, Pacific Northwest Laboratory, Richland, Washington.

Thorne, P. D., and D. R. Newcomer. 1992. Summary and Evaluation of Available Hydraulic Property Data for the Hanford Site Unconfined Aquifer System. PNL-8337, Pacific Northwest Laboratory, Richland, Washington.

DRAFT