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*Groundwater Annual Status Report
for Fiscal Year 1999*

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Issued: March 2000

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C. L. Nylander

*K. A. Bitner**

K. Henning

*A. S. Johnson***

E. H. Keating

P. Longmire

B. D. Newman

B. Robinson

D. B. Rogers

W. J. Stone

D. Vaniman

** Consultant at Los Alamos. Neptune & Co., 4600-A Montgomery, Suite 100,
Albuquerque, NM 87110*

*** Consultant at Los Alamos. Los Alamos Technical Associates, 1200 Trinity Drive,
Los Alamos, NM 87544*

Los Alamos
NATIONAL LABORATORY

Los Alamos, New Mexico 87545

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**GROUNDWATER ANNUAL STATUS REPORT
for
FISCAL YEAR 1999**

by

C. L. Nylander, K. A. Bitner,* K. Henning, A. S. Johnson, E. H. Keating, P. Longmire,
B. D. Newman, B. Robinson, D. B. Rogers, W. J. Stone, and D. Vaniman**

ABSTRACT

Groundwater protection activities and hydrogeologic characterization studies are conducted at Los Alamos National Laboratory annually. A summary of fiscal year 1999 results and findings shows increased understanding of the hydrogeologic environment beneath the Pajarito Plateau and significant refinement to elements of the LANL Hydrogeologic Conceptual Model pertaining to areas and sources of recharge to the regional aquifer. Modeling, drilling, monitoring, and data collection activities are proposed for fiscal year 2000.

1.0 INTRODUCTION

This is the third Groundwater Annual Status Report. It is intended to provide the Department of Energy (DOE), the New Mexico Environment Department (NMED), and other interested stakeholders with the status of groundwater protection and management activities performed during fiscal year 1999. This report includes a summary of the changes made to the Los Alamos National Laboratory's (LANL's or Laboratory's) conceptual model of the hydrogeologic setting. These changes are a result of interpretation of data collected over the past year. This report also provides a summary of activities proposed for fiscal year 2000.

This document is intended as an addendum to the Hydrogeologic Workplan and is specifically written as a summary-level report that relies on the information incorporated by the references.

1.1 Background

The need to prepare this Annual Report comes from commitments made in the Groundwater Protection Management Program Plan (GWPMPP) (LANL, 1996) and the Hydrogeologic Workplan (LANL, 1998).

The Laboratory has had groundwater programs in place since 1945. The earlier programs were focused on the need to develop reliable water supplies. Groundwater quality has been monitored through the environmental surveillance program using existing test wells, water supply wells, and springs. Since the early 1990s, there has been an increased emphasis on understanding the hydrogeologic environment in order to more effectively protect and manage the groundwater resource.

The GWPMPP (approved by DOE in 1996) provides for the submittal of an annual groundwater status report to the DOE that summarizes the status of the groundwater protection activities listed in the GWPMPP. The GWPMPP was prepared in response to the DOE requirement to conduct operations in an environmentally safe manner. DOE Order 5400.1: "General Environmental Protection Program" establishes environmental protection requirements, authorities, and responsibilities for all DOE facilities (DOE 1990). The goal of this order is to ensure that operations at DOE facilities comply with all applicable environmental laws and regulations, executive orders, and departmental policies.

The Hydrogeologic Workplan (approved by NMED in 1998) commits the Laboratory to prepare an annual report to summarize the activities of the previous fiscal year and to make recommendations for the current fiscal year activities. The Hydrogeologic Workplan was prepared at the request of the NMED and addresses the requirements of the Resource Conservation and Recovery Act (RCRA) and the Hazardous and Solid Waste Amendments of 1984 (HSWA) as detailed in the regulations and in the Laboratory's RCRA/HSWA permit. It is the implementing document for the GWPMPP and is the Laboratory's institutional commitment to complete a hydrogeologic characterization program. In addition, it describes the data collection and analysis activities that will characterize the hydrogeologic setting of the Laboratory as part of the Pajarito Plateau; within the regional context of the Española Basin.

The need for characterization of the hydrogeologic setting beyond the Española Basin has already been established. Studies over the past 50 years have been recognized as a critical step in developing an effective monitoring program and in managing the groundwater resource.

This Annual Report serves as the annual status report for both the GWPMPP and the Hydrogeologic Workplan. It also serves as the update mechanism for the scope and schedule in the Hydrogeologic Workplan. The Hydrogeologic Workplan will not be revised but the changes to the scope and schedule that are outlined in the plan will be discussed with NMED in quarterly meetings and at the annual meeting. The changes for which there is concurrence by all parties will be documented in this Annual Report.

1.2 FY99 Accomplishments Summary

This section is intended to provide a concise list of FY99 groundwater activity accomplishments. More detailed descriptions of these activities are contained in the referenced sections.

1.2.1 Program Management

- The External Advisory Group (EAG), an independent peer review panel, prepared two semi-annual peer review reports (Section 2.2).
- Stakeholder involvement was significantly increased at the FY99 Annual Meeting and two FY00 Quarterly Meetings (Section 2.1).
- The "Groundwater Annual Status Report for Fiscal Year 1998" was published as a LANL Status Report (LA-13598-SR).
- The Groundwater Protection Program was rated as "outstanding" at three LANL Division Program Reviews (ESH, EES, and CST).

1.2.2 Well Construction

- Pulled the temporary casing in borehole R-9 in Los Alamos Canyon and drilled 61 ft deeper to total depth. The well was completed in October 1999 (Section 4.0).
- Completed phase two drilling and sampling and constructed well R-15 in Mortandad Canyon (Section 4.0).
- Drilled borehole R-25 and partially constructed the well before complications with the screen #3 interval delayed completion (Section 4.0).
- Completed phase one drilling and sampling of borehole R-31 in Ancho Canyon (Section 4.0).

1.2.3 Data Interpretation and Modeling

- The FY98 Hydrogeologic Conceptual Model was updated to include new findings from FY99 studies. The model was expanded to include the current understanding of geochemical water, rock, and contaminant interactions over time (Section 3.0).
- The 3-D geologic model was improved to include new stratigraphic information from boreholes and lithologic log interpretations. Further understanding of the source and nature of basalt flows and morphologic characteristics, as well as division of flows into at least four stratigraphically distinct units, will greatly improve the models predictive capabilities (Section 4.1.2).

- The steady-state regional-scale hydrologic flow model was improved to include an embedded high-resolution grid for the Pajarito Plateau within the coarser regional-scale hydrologic flow model. The model uses the Finite Element Heat and Mass Transfer (FEHM) code, which simulates pre-development conditions (Section 4.2.2).
- The transient regional-scale hydrologic flow model was improved. The model was calibrated using water level responses over a 50-year period from the plateau and the Española basin (Section 4.2.2).
- The aquifer recharge model was comprehensively evaluated and preliminary water budget calculations for the plateau were prepared (Section 4.2.2).
- Canyon-scale and MDA-scale hydrologic flow and transport models were developed and calibrated using the FEHM code (Section 4.2.2).
- The geochemistry conceptual model was developed. A conceptual view of plateau-wide geochemical water, rock, and contaminant interactions provided the basis for including geochemical model elements into the FY99 Hydrogeologic Conceptual Model (Section 4.3.2).

1.2.4 Information Management

- Information Management system with web interface for stakeholder access conceptualized and initiated (Section 4.4).
- Comprehensive project plan was prepared, peer reviewed, and approved (Section 4.4).
- Interviews with project stakeholders were conducted to formulate a comprehensive system requirements document (Section 4.4).
- Database design was initiated and nearly completed (Section 4.4).

1.3 Report Organization

This report is organized to present the programmatic and technical activities that have been accomplished during the year. The programmatic activities are described in Section 2.0. The data that has been collected and analyzed during the year resulted in refinements to the Hydrogeologic Conceptual Model. A discussion of those refinements and the resulting FY99 Hydrogeologic Conceptual Model are presented in Section 3.0. The results of the data collection activities are presented in Section 4 and 5 contains a summary of activities proposed for FY00.

2.0 PROGRAMMATIC ACTIVITIES

Programmatic activities are those functions that are required to manage the technical, budgetary, and schedule aspects of the program and to communicate the program status to stakeholders. Technical aspects are governed by the Groundwater Integration Team (GIT), an interdisciplinary Laboratory group that provides guidance and oversight to the program. The GIT meets on a biweekly basis to consider the status of the data collection and data interpretation activities.

The GIT conducts quarterly meetings and an annual meeting each fiscal year. The purpose of these meetings is to communicate the status of program activities to the stakeholders. These meetings also provide stakeholders the opportunity to provide feedback on program plans and progress. The issues discussed and decisions made in the quarterly and annual meetings become addenda to the Hydrogeologic Workplan. Section 2.1 summarizes these meetings and the resulting decisions.

The technical aspects of the program are reviewed by the EAG, which has provided peer review for the program. A summary of the EAG semiannual reports and the action plans developed to respond to those reports are described in Section 2.2.

Data Quality Objectives (DQO) were developed and provide the basis of the activities described in the Hydrogeologic Workplan. In FY99, the original DQOs were reviewed in light of data that had been collected and the refinement of the Hydrogeologic Conceptual Model. A summary of the DQO reiteration is provided in Section 2.3.

2.1 Summary of FY99 GIT Meetings

Three meetings were held to discuss the groundwater characterization activities that occurred in FY99. The meetings participant included Laboratory staff involved in the activities, DOE representatives, and NMED representatives from the bureaus of Hazardous and Radioactive Materials (HRMB), Groundwater Quality, and DOE Oversight. Other interested stakeholders attending the meetings were representatives from San Ildefonso Pueblo, Santa Clara Pueblo, Los Alamos County, and the Northern New Mexico Citizens Advisory Board. A summary of each of the meetings and the points of agreement are provided in the following sections.

2.1.1 February 9, 1999, Quarterly Meeting

Notes from the February 9, 1999, Quarterly Meeting were issued by memorandum from Charles Nylander, LANL Water Quality and Hydrology Group (ESH-18), on March 1, 1999. Topics covered included status of well R-25, proposed FY99 drilling activities, and the Annual Report and Annual Meeting.

Significant issues discussed were:

- The presence of high explosives (HE) in the water collected while drilling the R-25 borehole and what the total depth of the well should be relative to lowest detection of HE. There was consensus that the total depth of the well would be based on numerous technical and logistical considerations, including the analytical results. The Laboratory agreed to share preliminary analytical results with the NMED to facilitate decision-making on well completion.

- Reprioritizing wells down-gradient from R-25 in response to the discovery of the HE in R-25. The Laboratory agreed to provide technical rationale for moving one of the wells downgradient of R-25 (R-18, R-19, or R-27) up in the schedule.
- The need to reach an agreement on a process for developing maximum contaminant levels was expressed by the Laboratory.
- The NMED expressed concern that intermediate perched saturated zones are receiving inadequate attention. The issues included timing of well installation in these zones and installing intermediate wells to define the extent of plumes discovered while drilling regional aquifer wells.
- FY99 drilling activities were proposed as: finish R-25, complete R-9, complete R-15, start R-31, and start one of the wells down-gradient from R-25 (R-18, R-19, or R-27).

2.1.2 March 29-31, 1999, Annual Meeting

The March 29-31 Annual Meeting is documented in notes issued in a letter addressed to John Young, Hazardous and Radioactive Materials Bureau of the New Mexico Environment Department, from Charles Nylander, ESH-18, on May 3, 1999. The agenda included presentations on modeling, information management, the hydrogeologic conceptual model, and the activities conducted in each aggregate. There were special presentations on TA-16, geophysical logging of the Guaje water production wells, the site-wide geologic model, and FY99 planned activities.

Major agreements and action items reached in the meeting were

- The FY99 drilling schedule: complete R-25, complete R-9, drill and complete R-15, move R-31 up to FY99 because it is on the boundary and will provide data in an area that is crucial to the modeling.
- Modeling will be done at three scales - regional, canyon, and Material Disposal Area (MDA). The modeling will be interconnected and is expected to provide adequate prediction of plume direction, travel time, and dispersion by the year 2003.
- Key refinements to the Hydrogeologic Conceptual Model were made. Refinements include confirmation of the high water table on the Laboratory's west side and the mountain front recharge and confirmation of connection between the surface and the regional aquifer. There was agreement that the sources of recharge that are customarily offsite, with significant recharge from the mountain front and natural streamflow, is minor; and perched water systems do exist on the west side of the Laboratory.
- A user needs assessment has been prepared for the information management system, however, it will be extended to address the needs of more stakeholders.
- A process must be established to release preliminary analytical data to stakeholders.
- The process and decision flow for addressing contamination found in R-wells must be finalized.

2.1.3 June 23, 1999, Quarterly Meeting

The notes from the June 23, 1999, Quarterly Meeting were distributed as a memorandum from Charles Nylander, ESH-18, dated July 1999. The agenda for the meeting included status reports from the GIT subcommittees, which included well construction, modeling, hydrology, geochemistry, information management, and anticipated scope and schedule for the remainder of FY99. A discussion of the following issues was presented: process for addressing contamination found during drilling, collection of hydrologic data from R-wells, possible replacement of well TW-1A with PO1-4, status of decommissioning old wells, and the role of modeling the program.

The main agreements from the June 23, 1999, Quarterly Meeting were:

- All stakeholders are invited to attend the Quarterly Meetings as well as the Annual Meeting.
- Repair of screen 3 in R-25 will consist of cementing the collapsed section and drilling through it. This will result in the loss of the screen 3 monitoring port, but will provide access to screens 4-9.
- R-15 will be completed with a single screened interval at the regional water table.
- The information management system will make data available to everyone via a web interface. The data will be accessible in a tabular format with the ability to view the data on a map. Access to output from the hydrologic model will also be available through the web site.
- Activities in the remainder of FY99: complete R-25; drill and complete R-15; start R-31.
- Anticipated FY00 schedule: complete R-9 and R-12; drill R-19, R-27, R-5, and R-28; drill intermediate well at R-9.
- Develop a process for addressing the contamination found in the regional aquifer wells that will not impede the progress of the Hydrogeologic Workplan activities.
- Money for decommissioning wells will not be available until FY00. The decision to decommission or recondition wells will be made on a case-by-case basis.

2.2 External Advisory Group Activities

The GIT formed an External Advisory Group (EAG) to provide an independent review of the GIT's implementation of the Laboratory's Hydrogeologic Workplan. The EAG consists of six members that have diverse technical and professional backgrounds. The EAG will provide a broad technical and managerial review of the Laboratory's Hydrogeologic Workplan activities and methods. The GIT plans to add additional EAG members in FY00 to further strengthen this multidisciplinary peer review group.

The EAG consists of the following members:

- Robert Charles, Ph.D.—Dr. Charles has a doctorate in Geology with a specialty in geochemistry, a Master of Arts degree in Organizational Management and has more than 25 years of experience in his disciplinary areas. Dr. Charles served as Chair of the EAG.
- Jack Powers, P.E.—Mr. Powers is a drilling consultant with more than 45 years of worldwide professional drilling experience.

- Robert Powell, M.S.—Mr. Powell has a Master of Science degree in Environmental Science with 25 years of experience. He has 33 groundwater-related publications and has expertise in the area of low-flow groundwater sampling.
- Elizabeth Anderson, Ph.D.—Dr. Anderson has a Doctorate Degree in Inorganic Chemistry and more than 20 years of experience in health and environmental science. Dr. Anderson is a nationally renowned expert on risk assessment and established the Major National Risk Assessment programs at the Environmental Protection Agency.
- David Schafer, M.S.—Mr. Schafer has 25 years of experience focused on computer modeling using numerical models, analytic element models, and proprietary analytical models that he has developed.

The EAG met in conjunction with the Annual Meeting on March 29-31, 1999 and in conjunction with a Quarterly Meeting held on October 14, 1999. The purpose of the meetings was to provide semiannual review of activities proposed under the Hydrogeologic Workplan. The EAG provides a report of findings and observations based on the semi-annual reviews. In response, the GIT develops action plans that specify how the recommendations of the EAG will be incorporated into the program. In FY99, the following reports were completed:

- Semiannual Report to the Groundwater Integration Team (GIT) of the Los Alamos National Laboratory by the External Advisory Group (November 1998)
- Los Alamos National Laboratory Groundwater Integration Team Action Plan for the External Evaluation Group November 1998 Recommendations (February 1999)
- Semiannual Report to the Groundwater Integration Team (GIT) of the Los Alamos National Laboratory by the External Advisory Group (June 1999)
- Los Alamos National Laboratory Groundwater Integration Team Action Plan for the External Evaluation Group June 1999 Recommendations (June 1999)

At the Annual Meeting (March 29-31, 1999), the EAG held a session for stakeholders to discuss concerns about the program. The stakeholders valued this session and the EAG committed to conducting similar sessions in conjunction with each semi-annual review.

In addition to the semiannual reviews, the EAG provides technical assistance when requested. In FY99, two EAG members (Jack Powers and David Schafer) provided invaluable assistance in the repair of the collapsed screen in R-25. Numerous problems were encountered during the repair process. The "hands on" assistance was critical in completing the characterization well.

2.3 Data Quality Objectives Reiteration

The Hydrogeologic Workplan was developed using the DQO Process. A critical part of the DQO process is the iteration of the DQO process outputs as new data are collected. Four boreholes have been drilled at LANL and sufficient new information on data collection methods is available to assist with the DQO outputs. Specifically, those outputs relating to collecting geologic, hydrologic, and geochemical data during drilling warranted review based on the costs incurred by the program to date. On September 13, 1999, the GIT held a working meeting with NMED, HRMB, and DOE-OB to iterate on these DQO outputs.

2.3.1 Decisions and Questions

The DQO process involves determining data needs by formulating decisions and subsidiary questions. This can be envisioned as a pyramidal structure, with a decision at the top supported by the subsidiary questions that must be answered in order to resolve the decision. At the very base of the pyramid is the data that will be required to answer the questions that will lead to final resolution of the decision. The original decisions are

- Canyons Decision 1: Are there sources of sufficient magnitude to cause contamination of groundwater?
- Canyons Decision 2: Are alluvial sediments and uppermost subsurface water at contaminant concentrations greater than regulatory limit or risk level?
- Canyons Decision 3: Is there intermediate perched groundwater at contaminant concentrations greater than regulatory limit or risk level?
- Canyons Decision 4: Is the regional aquifer as affected by the canyon systems impacted by contaminant concentrations greater than regulatory standards?
- Canyons Decision 5: Are there sufficient source terms to cause contamination if moved along the pathways in 1000 years?
- Canyons Decision 6: What are the pathways for exposure to contaminants from alluvial sediments and uppermost subsurface water?
- Mesa Decision 1: Are the soils/tuff or uppermost subsurface water from sources as contaminant concentrations greater than regulatory limit or risk level?
- Mesa Decision 2: Is the regional aquifer or underlying intermediate perched zone predicted to be impacted by contaminant concentrations above a risk level or regulatory limit using a conservative model?
- Mesa Decision 3: What are the pathways for exposure to contaminants from soils/tuff and uppermost subsurface water?
- Aggregate Decision 1: Based on cumulative data from the aggregate, are there indications of impact from Laboratory activities that would impair beneficial use and require further action?

The participants had only one suggested change to Canyon Decision 5 regarding the 1000-year time period of interest. The original decision was based on DOE requirements but the point was made that the time period of interest will vary depending on the contaminant. Hazardous constituents could be considered subject to the RCRA post-closure care period of 30 years whereas low-level radioactive waste is subject to EPA guidance suggesting 1000 years for the appropriate period of interest. Transuranic and high-level waste constituents should meet the DOE guidelines for repositories of 10,000 years.

The period of interest can make a significant difference in the types and amount of data collected. The data needed to predict contaminant migration over a 30-year period is much different than data needed to predict migration over thousands of years. Although the data required for predicting 10,000 years is likely to be quite similar to data required to predict over a period of 1000 years, the jump from 30 years to 1000 years requires a substantial investment of both time and resources.

Although no consensus on the actual time frames was reached during the meeting, there was agreement that the time frames should be tailored for classes of contaminants.

2.3.2 Data Needs

The data that must be collected from boreholes and wells was listed from the DQO outputs in the Hydrogeologic Workplan. The participants reviewed the list and made recommendations for additions and deletions. Consensus was reached before changes were made to the list. The final list is given in Table 2.3.2-1.

There was discussion regarding the scope of data required to characterize fractures. For modeling, the critical element is the permeability of the fractured zone, rather than detailed descriptions of fracture density, length, aperture, and attitude. There was agreement that the data required for fractured zones is permeability.

Table 2.3.2-1. Data to be Collected from Boreholes and Wells.

Data to be Collected from a Single Borehole/Well	Data to be Collected from More Than One Borehole/Well
Hydraulic properties	Water balance
Water level	Horizontal gradient
Moisture characteristics	Flow direction
Contaminant concentration	Tracer tests
Porosity	Flow velocity
Bulk density	
Stratigraphy	
Lithology	
Distribution coefficients for contaminants	
Fracture characteristics	
Fault characteristics	
Water quality	
Matric potential	
Vertical gradient	

2.3.3 Data Collection Methods

Table 2.3.3-1 summarizes the potential data collection methods, advantages of the methods, limitations of the methods, a relative rating of the resulting data quality and cost, and drilling requirements. There are only two data types that can not be collected in a borehole drilled using substantial volumes of drilling mud as a lubricant—air permeability by rig balance and moisture characteristics measured in the cuttings. However, the process of collecting samples in a fluid-filled borehole is generally more complicated than in a dry-drilled hole. The process involves introducing an upper and a lower packer into the borehole, sealing off an interval, circulating out the mud from the borehole, developing the interval to remove the mud cakes on the borehole sides, and collecting the sample. Additionally, input received after the meeting indicates that, in samples taken thus far, drilling mud (even in R-15, a nominally dry-drilled hole) has had significant impacts on the analyses of water samples. There was general agreement that the drilling method for any well should be selected after careful review of the expected geologic conditions and data needs.

Table 2.3.3-1. Data Collection Methods.

Data Type	Data Collection Method	Advantages	Limitations	Relative Data Quality ¹	Relative Cost ²	Drilling Method Requirements
Hydraulic Properties	Recovery/slug test during drilling	Inexpensive, does not significantly slow drilling	Need an open hole and a clean hole	3	A	Open hole, dry or fluid-filled ³
	Single packer test during drilling	Inexpensive, does not significantly slow drilling	Need an open hole and a clean hole	3	A	Open hole, dry or fluid-filled ³
	Core analysis	Easily done on intervals where core is available	Produces measurements of hydraulic properties on a small scale	3	B	Open hole, dry or fluid-filled ³
	Slug test – completed well	Standard method of measuring hydraulic properties	Limited to the screened interval of the completed well	4	B	Conducted in completed well so drilling method does not matter
	Geophysical logs	Vertically continuous	Requires an open hole; some logs are limited to fluid-filled hole	4	B	Open hole, dry or fluid-filled ³
	Air permeability by rig balance	Continuous during drilling, large scale	Less quantitative; requires dry, open hole	2	A	Open hole, air drilling only
	Air permeability by packer test	More quantitative	Requires dry, open hole	3	A	Open hole, dry or fluid-filled ³
	Pumping test in completed well	Large scale, provides best estimate of hydraulic properties	Need monitoring well nearby as an observation well	5	B	Conducted in completed well so drilling method does not matter
Water Levels	Transducer	Continuous data, good resolution	Requires open hole with no tools downhole; reliability is an issue	5	A	Open hole, dry or fluid-filled ³
	Probe/tape	Fast, can be used with tools in the hole	Single point measurements; resolution is an issue	3	A	Open hole, dry or fluid-filled ³
Measurements on Rock (porosity, lithology, stratigraphy, bulk density, fracture characteristics)	Core analysis in a lab	Direct measurement	Requires core	5	B	Dry or fluid-filled; coring advances in front of the mud, so core is not affected by mud

¹ Rating is relative between collection methods for the same data type. The scale is 1 = low to 5=high.² Rating is relative between collection methods for the same data type. The scale is A=inexpensive and B=expensive³ In fluid filled holes, the interval of interest must be isolated with packers and the mud circulated out of the interval before a test can be conducted.

Table 2.3.3-1. Data Collection Methods.

Data Type	Data Collection Method	Advantages	Limitations	Relative Data Quality ¹	Relative Cost ²	Drilling Method Requirements
Measurements on Rock (porosity, lithology, stratigraphy, bulk density, fracture characteristics)	Cuttings analysis in a lab	Direct measurement, cuttings always available		4	A	Dry or fluid-filled, although cuttings from hole drilled with mud must be washed before testing
	Geophysical logs	Continuous measurements	Indirect measurement, requires an open hole	4	B	Various logs have specific requirements for fluid-filled or dry holes
Matric Potential and Distribution Coefficients	Core analysis in a lab	Direct measurement	Requires core	5	B	Dry or fluid-filled; coring advances in front of the mud, so core is not affected by mud
	Cuttings analysis in a lab	Direct measurement, cuttings always available	Cuttings from hole drilled with mud must be washed before testing which could affect test results	4	A	Dry drilled hole
Moisture Characteristics	Core analysis in a lab	Direct measurement	Requires core	5	B	Dry or fluid-filled; coring advances in front of the mud, so core is not affected by mud
	Cuttings analysis in a lab	Direct measurement, cuttings always available	Must come from a dry drilling method	4	A	Dry drilled hole
	Geophysical logs	Continuous measurements	Indirect measurement, requires an open hole	4	B	Various logs have specific requirements for fluid-filled or dry holes
Water Quality/ Contaminant Characterization	Lab analysis of water samples	Provides the best analytical results	Chemistry is effected by drilling fluids; long turn around time	5	B	Open hole, dry or fluid-filled ³
	Field screening of water samples	Indication of presence/absence of contaminants, rapid turn around	Intended for contaminants, not water quality measurement; does not provide quantitative results	2	A	Open hole, dry or fluid-filled ³
	Field measurements of water samples	Rapid tests; necessary for sampling water		4	A	Open hole, dry or fluid-filled ³

¹ Rating is relative between collection methods for the same data type. The scale is 1 = low to 5=high.² Rating is relative between collection methods for the same data type. The scale is A=inexpensive and B=expensive³ In fluid filled holes, the interval of interest must be isolated with packers and the mud circulated out of the interval before a test can be conducted.

2.3.4 Conclusions

The major conclusions from the meeting were

- Data needs listed in the Hydrogeologic Workplan and revised during this meeting are still considered potential data to be collected. The actual data collected in each well will be based on the types of data needed from that geographic location and will be specified in the Field Implementation Plan for each well.
- Data collected for "fracture characteristics" can be limited to the permeability in the fractured zone.
- Most data types can be collected in boreholes drilled with either dry methods or fluid-based methods, although fluid-based methods require more complicated sampling process and have a significant impact on the chemistry of the water.
- Drilling methods that physically hold the borehole open are required for some stratigraphic units underlying the Pajarito Plateau; casing advance or mud rotary-type methods are likely to be the most successful.
- The drilling method for each well should be selected based on the anticipated geologic conditions and the types of data needed from that well.
- The issue of the time frame of interest for contaminant migration has not been conclusively resolved at this time and warrants further consideration.

3.0 HYDROGEOLOGIC CONCEPTUAL MODEL

In the following sections, elements of the FY98 Hydrogeologic Conceptual Model, as published in "Groundwater Annual Status Report for FY98" (Nylander et al. 1999), are revisited in light of new data collection and analyses conducted during FY99. Section 3.1 provides a list of FY98 model elements and a brief discussion of how new FY99 findings support refinements to model elements. A list of the refined elements is given in section 3.2 and constitutes the Laboratory's current understanding of the hydrogeologic setting of the Pajarito Plateau.

3.1 FY98 Hydrogeologic Conceptual Model Elements Discussion

3.1.1 Mesas

In FY98, there were five elements (A–E) of the hydrogeologic conceptual model that pertain to the mesas. The FY99 efforts continue to support these elements.

Element A: Relatively small volumes of water move beneath the mesa tops under natural conditions due to low rainfall, high evaporation, and efficient water use by vegetation. Evaporation may extend within mesas, further inhibiting downward flow.

This element continues to be supported by findings of four studies in FY99. Flux rates estimated on mesas in three quadrants of the Laboratory are consistently in the range of millimeters per year or less. Near the southern edge of the Laboratory, in TA-49, the unsaturated flow modeling found good agreement between measured and predicted moisture profiles using a flux rate of 0.1 to 1.0 mm/year. A modeling study conducted in Los Alamos Canyon found good agreement between measured and predicted moisture profile in a mesa-top borehole LADP (Section 4.2.2). Finally, near the eastern edge of the Laboratory, chloride mass balance studies conducted at TA-54 MDA G suggest downward flux rates range from less than 1 mm/yr to a few mm/yr (Section 4.2.2). These results support the idea of limited mesa recharge under natural conditions.

Element B: The amount of mesa top infiltration along the western portion of the Laboratory is uncertain. Higher rainfall, increased vegetative cover, and increased welding and jointing of the tuff might lead to different infiltration rates than those observed in better studied portions of the Laboratory.

In FY99, moisture content, chloride, and stable isotope studies conducted at the four boreholes at TA-16 suggest that the presence of fractures in the welded tuff may be a controlling factor for groundwater flow and transport of contaminants (e.g., HE).

Element C: Mesa top recharge can be locally significant under disturbed surface conditions. Such change occurs when the soil is compacted, the vegetation is disturbed, or more water is added to the hydrologic system by features such as blacktops, lagoons, or effluent disposal.

There is little uncertainty that disturbed surface conditions alter the recharge on the mesa tops. Support for this element comes from additional work conducted in FY99 at TA-16, TA-49, and TA-54. Analysis of moisture content, chloride, HE, and stable isotope data from the 90's line and Martin Canyon boreholes at TA-16 suggest that mesa-top ponds may have contributed recharge and HE at least 100 ft into the subsurface. The presence of contamination in

saturated zones in these boreholes is apparently a function of the hydraulic effects of ponded water (possibly augmented by natural recharge) and the heterogeneous stratigraphy of the mesa (Section 4.2.2)

At TA-49 MDA AB, a modeling study was conducted to examine the affect of an asphalt pad that had been placed over Area 2. The asphalt increased the flux to 60 to 400 mm/yr over the undisturbed rate of 0.1 to 1.0 mm/yr (Section 4.2.2). The study supports the hypothesis that the presence of the asphalt pad increases subsurface moisture beneath the pad. The modeling also suggests that flux rates should decrease as a result of removal of the pad.

At TA-54 MDA G, data collected from shallow boreholes beneath the asphalt suggest that moisture accumulation is occurring under the asphalt and that evaporative loss of water has been greatly reduced or eliminated. In addition, near-surface percolation rates may have increased to cm/yr levels, and focused runoff from the asphalt has increased percolation to at least cm/yr levels in localized areas adjacent to the asphalt (Section 4.2.2). The magnitude of recharge rate alteration associated with various types of disturbance and the extent of the alteration remain to be further quantified.

Element D: Fractures within mesas do not enhance the movement of dissolved contaminants unless saturation develops.

There are no refinements to this element from work completed in FY99. However, given the large uncertainty associated with this element, the language will be modified this year to include the possibility of fractures providing preferential pathways for contaminants, especially in regions of high percolation and rocks of low permeability (see Section 3.2.1).

Element E: Contaminants in vapor phase readily migrate through mesas. Vapors denser than air will sink.

Refinements to this element come from modeling of the organic vapor plume at TA-54. The results of this modeling suggest that vapor movement is due primarily to diffusion. Running the model with diffusion results in model output that matches the known shape and extent of the plume. A sensitivity study for the diffusion coefficient results in a good match, which suggests that no transport processes are omitted.

3.1.2 Alluvial Groundwater

In FY98 there were five elements (F–J) related to alluvial groundwater in the hydrogeologic conceptual model. Work completed in FY99 tends to confirm these elements.

Element F: In drier canyon bottoms, groundwater may occur seasonally in alluvium, depending on the volume of surface flow from snowmelt, storm runoff, and Laboratory NPDES-permitted effluents. As groundwater in the alluvium moves down the canyon, the groundwater is depleted by evapotranspiration and percolation into the underlying rocks.

The uncertainty associated with this element is very low. Water level measurements collected in FY99 from alluvial wells through Environmental Restoration (ER) Project studies as well as environmental surveillance activities continues to support this element.

Element G: In wetter canyon bottoms, infiltration of NPDES-permitted effluents and natural runoff reaching the stream channel may maintain shallow groundwater in the alluvium. Groundwater levels are typically highest in the late spring due to snowmelt runoff and in mid-to-late summer due to seasonal thunderstorms. Groundwater levels decline during the winter and early summer when runoff is at a minimum.

There is little uncertainty associated with this element. Environmental surveillance monitoring during FY99 continues to confirm this element. Nitrogen isotope data collected from alluvial wells in Cañon de Valle is interpreted to have spatial and temporal variation, possibly reflecting different amounts of run-off and soil-water inputs (Section 4.2.2).

Element H: Alluvial groundwater is a source of recharge to underlying intermediate perched zones, usually by unsaturated flow. In specific wetter canyon bottoms, alluvial groundwater may be a significant source of recharge to the intermediate perched zones and has contributed to the regional aquifer.

FY99 drilling of borehole R-15 and FY98 drilling of MCO 7.2 in Mortandad Canyon support this element. The perched zone encountered in R-15 and in MCO 7.2 contained constituents that are discharged through the TA-50 outfall into Mortandad Canyon (Section 4.3.2). Although the analytical results for the inorganics are confounded by the bentonite in the samples from R-15, the tritium in the perched zone is a reliable indication that surface water is recharging the perched zone in Mortandad Canyon.

Element I: Dry canyon bottoms contribute little recharge under natural conditions. Long-term addition of effluent to naturally dry canyon bottoms may result in recharge to intermediate perched zones.

There is relative certainty in this aspect of the model, which drove the prioritization of wells in the Hydrogeologic Workplan to address "wet" canyons first. There is support of this element from work completed in FY99. Although no wells were installed in dry canyons in FY99, the data collected from R-15 in Mortandad Canyon clearly shows the impact of surface water recharge in the perched zone (See Element H).

Element J: In a few cases where saturated flow might occur, faults, fractures, joints, surge beds, and permeable geologic units (e.g., Guaje Pumice, Cerro Toledo, and Puye Formation) that underlie saturated alluvium or intermediate perched zones could provide pathways for downward water movement.

This element is supported by work at TA-16 conducted in FY99. The importance of contacts between geologic units with differing permeability is clear in the chloride profiles from R-25 and the TA-16 hydro holes. There are consistent spikes in the chloride profiles at the contact between unit 4 and unit 3t (Section 4.3.2.2). Similarly, surge beds encountered in the Martin Canyon borehole may also play a role in controlling flow. Fracture flow is also important as observed in the R-25 borehole, where the flow of water out of a fracture was seen with the borehole camera (Section 4.2.2.3). Fractures appear to play a part in controlling flow in the thin wet zones encountered in the Martin and 90's line pond boreholes. All of these results confirm that lateral flow along geologic incongruities is an important process for the development of saturation at TA-16.

3.1.3 Intermediate Perched Groundwater

In FY98 there were five elements (K–O) related to intermediate perched groundwater for the hydrogeologic conceptual model. The work completed in FY99 tends to support all of the elements, although understanding of the intermediate zones is still very limited.

Element K: Intermediate perched zones occur beneath major canyon systems, particularly those that head in the Jemez Mountains. Intermediate perched zones may receive recharge from watersheds west of the Laboratory.

This element is supported by work conducted in FY99. The occurrence of perched zones beneath major canyons that head in the Jemez Mountains is supported by stable isotopes of hydrogen and oxygen which suggest that a portion of the groundwater encountered at R-25 may be derived from the eastern portion of the Jemez Mountains, specifically the Sierra de los Valles. Recharge from watersheds west of the Laboratory is supported by the major ion compositions of surface water in upper Cañon de Valle and R-25 groundwater. Their similarity suggests a common recharge source. Additionally, the activity of tritium indicates that water from the R-25 upper saturated zone is 10 to 50 years old, pointing to recharge from young surface water (Section 4.3.2).

Element L: In addition to the availability of recharge from overlying alluvial groundwater, the location of intermediate perched zones is controlled by hydrogeologic characteristics of subsurface units, mainly lithology and permeability. In some cases, such as with interlayered basalts and conglomerates, intermediate perched zones could occur at several depths beneath a canyon.

This element is supported by work conducted in FY99. The importance of the basalt to saturated zones has been consistently shown in boreholes R-9, R-12, and R-15 (Section 4.2.2). A slug test conducted in the R-15 borehole indicates that the clay-rich layer underlying the perched zone has hydraulic conductivity in the 10^{-7} cm/sec. This is considered a low hydraulic conductivity by the EPA, which requires the same hydraulic conductivity for RCRA-compliant liners beneath a hazardous waste landfills (40 CFR 264). This result may be confirmed by core samples of perching layers that have been submitted for analysis of hydraulic properties for which results are pending.

Element M: The intermediate perched zones have not been observed to extend laterally beneath mesas in the eastern portion of the Laboratory. However, some lateral spreading of perched groundwater may occur down gradient, if the canyon course and the dip of the perched zone do not coincide. Perched intermediate groundwater zones occur beneath the mesas on the western edge of the Laboratory.

This element is supported by FY99 drilling of boreholes R-15 and from work at TA-16. In Mortandad Canyon, R-15 was anticipated to encounter perched zones in the Cerro Toledo and the Guaje Pumice. However, saturated conditions were not encountered in these units, most likely because R-15 was drilled on the side of Mortandad Canyon, out of the alluvial channel. This may support the concept of limited lateral extent of saturation in perched zones in the eastern portion of the Laboratory (Section 4.2.2). R-25 encountered an upper saturated zone that does extend beneath the mesa. Additionally, springs in the TA-16 area are fed from multiple perched zones. Stable isotope data suggest that two springs (SWSC and Burning

Ground) are closely related, whereas Martin spring appears to have a different flow path or source (Section 4.3.2.2).

Element N: Along the western boundary of the Laboratory, perched groundwater occurs in at least two distinct modes: limited ribbons of shallow saturation that are sources of springs in the Tshirege Member of the Bandelier Tuff found to depths of approximately 200 ft below the mesa top, and a separate large perched zone approximately 700 ft below the mesa top occurring in the Otowi Member of the Bandelier Tuff and extending downward into the Puye Formation. The principal recharge source for these zones is probably the Jemez Mountains.

This element continues to be supported by work completed in FY99 at TA-16. Sampling of TA-16 springs and analysis of stable isotopes and tracer tests further confirm the conceptualization of shallow ribbons of saturation at TA-16. These results suggest that two springs (SWSC and Burning Ground) are closely related, whereas Martin spring appears to have a different flow path or source (Section 4.3.2.2). Fractures or other geologic incongruities probably control the ribbons of saturation. Some boreholes have encountered thin saturated zones that have relatively consistent moisture contents (90's line pond and Martin Canyon boreholes) in fractured tuff.

Water from the saturated zone at 750 ft depth in R-25 has been analyzed for stable isotopes of hydrogen and oxygen. The results suggest that a portion of the water in upper saturated zone encountered at R-25 may be derived from the eastern portion of the Jemez Mountains, specifically the Sierra de los Valles (Section 4.3.2).

Element O: Contaminant concentrations in water entering these intermediate perched zones are diluted. Lateral down-canyon flow within intermediate perched zones could contribute to significant transport of contaminants away from their surface source.

Modeling of Los Alamos Canyon in FY99 supports this element. The transport of tritium was modeled in Los Alamos Canyon and matched to the measured tritium concentrations in perched zones within the canyon. Dilution and radioactive decay are expected to result in little tritium reaching the regional aquifer (Section 4.2.2). Transport of contaminants away from sources is supported by previous observations of contaminants in boreholes R-9 and R-12. These observations support the concept that water encountered in the intermediate perched groundwater has been transported laterally a significant distance. This element will be modified this year first; to include that dilution occurs from alluvial or surface water sources and second, to make the second sentence into it's own element (see Section 3.2.3).

3.1.4 Regional Aquifer

In FY98, six elements (P-U) comprise the hydrogeologic conceptual model for the regional aquifer. Work completed in FY99 provides additional understanding of some aspects.

Element P: The slope of the regional water table suggests that the flow of groundwater is generally toward the east or southeast, toward the Rio Grande. Water supply pumping affects flow directions in the aquifer near supply wells. The variation of these effects with depth and distance is not known at present. This influence on flow directions could have an important impact on contaminant movement in the regional aquifer.

This element continues to be supported by work conducted in FY99. There is little uncertainty that, on a regional scale, the gradient is to the east and southeast. Water level measurements from boreholes and completed wells show a definite decrease of water level elevation to the east. The potential for pumping in water supply wells to affect flow directions was demonstrated by hydrologic modeling of the regional aquifer. A transport simulation of hypothetical particles released near TA-16 showed that all particles were captured by PM supply wells directly to the east.

A major source of uncertainty associated with this element is the possible effect of heterogeneities in the sedimentary sub-units of the regional aquifer which are not represented in the current 3-D Site Geologic Model. These heterogeneities may influence flow directions in ways we are unable to account for in our current models.

Element Q: Along the western edge of the Laboratory, deep perched groundwater may be a major source of recharge to the regional aquifer. The volume of on-site regional aquifer recharge from stream bottom infiltration of natural streamflow into alluvial groundwater is small relative to the amount of public water supply pumping from the regional aquifer. When considered also with potential infiltration of effluent discharge steams, however, the annual volume of on-site regional recharge from stream bottom infiltration may be significant.

This element will be refined based on FY99 studies. More certainty exists that there is hydraulic connection between perched zones and the regional aquifer from studies at R-25. The similarity of $\delta^{18}\text{O}$ and δD profiles from the upper and lower zones of saturation in R-25 suggests that the recharge source of the two saturated zones is similar or that they have some connectivity, though not necessarily in the vicinity of R-25 (Section 4.3.2). However, the magnitude of the hydraulic connection still remains to be quantified.

Element R: Regional aquifer groundwater within the eastern portion of the Pajarito Plateau (generally along the Rio Grande) is of different recharge origin than under the central part of the Plateau.

This element of the hydrogeologic conceptual model can not be refined based on the work completed in FY99. R-31 will be drilled and completed in FY00 and should provide information about this model element.

Element S: Sources of recharge to the regional aquifer are uncertain. Geochemical data show that the Valles caldera is not the source of major recharge, contrary to statements in earlier Laboratory reports. A strong downward vertical hydraulic gradient observed on the western edge of the Laboratory indicates that the area along the flank of the Jemez Mountains is a recharge area with the recharge originating in the Jemez Mountains. Additionally, major recharge may occur by southerly flow along the late Miocene trough of Purtymun (1984), or possibly via percolation beneath canyon bottoms.

This element will be refined based on FY99 data analyses. As described in Section 4.3.2, water samples collected in the eastern front of the Jemez Mountains (known as the Sierra de los Valles) are geochemically similar to water from the Pajarito Plateau, whereas water from the western portion of the Jemez Mountains (the western portion of the Valles caldera) is geochemically different. However, the data from Sierra de los Valles is too sparse and scattered to conclude that the primary source of regional aquifer recharge is limited to the Sierra

de los Valles. However, hydrologic modeling of the regional aquifer provides further support to the Sierra de los Valles as possibly the most significant source of recharge to the regional aquifer. This flow modeling pinpoints the Sierra de los Valles as the primary source and largely eliminates other recharge sources that have been proposed (e.g., the Miocene trough or the Sangre de Cristo Mountains). However, recharge via percolation beneath canyon bottoms continues to play an important role in recharge. Although the volume of this recharge source is small (compared to pumping), this recharge transports contaminants from the surface to underlying saturated zones. In support of the downward vertical gradient along the western edge of the Laboratory, isopotentials constructed at R-25 confirmed a downward gradient (Section 4.2.2).

Element T: If present, Laboratory-derived contaminants in the regional aquifer are likely to vary in concentration. The contaminant concentrations are probably below maximum contaminant levels (MCLs) for drinking water because (1) regional aquifer underflow dilutes contaminant concentrations in recharge; and (2) contaminant concentrations in alluvial and intermediate perched zone groundwater are expected to decrease with depth due to dilution and geochemical attenuation along vertical migration pathways. Vertical gradients in the upper portion of the regional aquifer affect dilution of contaminant concentrations in the recharge sources, i.e., upward gradients influence mixing of the recharging water with resident aquifer water while downward gradients inhibit this mixing.

This element is supported by sampling the regional aquifer for the Environmental Surveillance Program and for Safe Drinking Water Act compliance and by work done in FY99. The distribution of HE within the water encountered at R-25, shows that the highest concentrations are in the upper saturated zone and much lower concentrations are present in the regional aquifer (Section 4.3.1). Similarly, tritium is present in the perched zone at R-15, but not in the regional aquifer. These observations in both R-25 and R-15 suggest that contaminant concentrations decrease with depth, even for tritium and HE, which are not geochemically attenuated. Modeling of tritium transport in Los Alamos Canyon completed in FY99 lends support to the dilution of tritium as one process controlling the tritium distribution in the perched zone (Section 4.2.2). The model suggests that most of the tritium introduced since the 1960s has remained in the vadose zone, where it has been diluted, or has decayed. A relatively small amount of tritium may reach the regional aquifer beneath canyon-bottom regions of relatively high recharge.

Element U: The hydraulic properties of the regional aquifer are heterogeneous both vertically and laterally. Vertically, hydraulic properties vary greatly between geologic units thereby contributing to varying water yield. Laterally, the regional aquifer commonly exhibits confined characteristics near the Rio Grande but appears to be unconfined in other parts of the Pajarito Plateau. Water level declines due to pumping vary across the Plateau, usually ranging from 0.5 to 3 ft per year. Water levels have declined the least in wells that penetrate a thick zone of permeable sediments that transect the central part of the Plateau.

Work in FY99 supports this element. Dynamic spinner logging of water supply well PM-4 suggests that the transmissivity within the screened section of the regional aquifer varies, although there is uncertainty in the magnitude of the variations because the testing may not have sufficiently stressed the aquifer (Section 4.2.2).

3.2 FY99 Revisions to the Hydrogeologic Conceptual Model

The following section provides a summary of the current understanding of the hydrogeologic environment at LANL as modified from the FY98 conceptual model elements provided in "Groundwater Annual Status Report for Fiscal Year 1998" (Nylander et al. 1999).

This year the elements have been renumbered within each model component, e.g., mesas, alluvial groundwater, etc., to allow new elements to be numbered consecutively without confusion as to which model component they represent. Elements that have been modified this year are in bold font with added text underlined and deleted text lined through.

3.2.1 Mesas

Five elements comprise the hydrogeologic conceptual model of the mesas.

Mesa Element A: Relatively small volumes of water move beneath the mesa tops under natural conditions due to low rainfall, high evaporation, and efficient water use by vegetation. Atmospheric evaporation may extend within mesas, further inhibiting downward flow.

Mesa Element B: The amount of mesa top infiltration along the western portion of the Laboratory is uncertain. Higher rainfall, increased vegetative cover, and increased welding and jointing of the tuff might lead to different infiltration rates than those observed in better studied portions of the Laboratory.

Mesa Element C: Mesa top recharge can be locally significant under disturbed surface conditions. Such change occurs when the soil is compacted, the vegetation is disturbed, or more water is added to the hydrologic system by features such as blacktop, lagoons, or effluent disposal.

Mesa Element D: **Fractures within mesas ~~do not enhance the movement of dissolved contaminants unless saturation develops~~ could provide preferential pathways for contaminants, especially in regions of high percolation flux and in rocks of low matrix permeability. Fracture flow is less likely to be present in porous and permeable rocks, even when the rocks are fractured.**

Mesa Element E: Contaminants in vapor phase readily migrate through mesas. Vapors denser than air will sink.

3.2.2 Alluvial Groundwater

The following five elements represent the FY99 conceptual model of alluvial groundwater.

Alluvial Element A: In drier canyon bottoms, groundwater may occur seasonally in alluvium, depending on the volume of surface flow from snowmelt, storm runoff, and Laboratory NPDES-permitted effluents. As groundwater in the alluvium moves down the canyon, it is depleted by evapotranspiration and percolation into the underlying rocks.

- Alluvial Element B: In wetter canyon bottoms, infiltration of NPDES-permitted effluents and natural runoff reaching the stream channel may maintain shallow groundwater in the alluvium. Groundwater levels are typically highest in the late spring due to snowmelt runoff and in mid-to-late summer due to seasonal thunderstorms. Groundwater levels decline during the winter and early summer when runoff is at a minimum.
- Alluvial Element C: Alluvial groundwater is a source of recharge to underlying intermediate perched zones, usually by unsaturated flow. In specific wetter canyon bottoms, alluvial groundwater may be a significant source of recharge to the intermediate perched zones and has contributed groundwater to the regional aquifer.
- Alluvial Element D: Dry canyon bottoms contribute little recharge under natural conditions. Long-term addition of effluent to naturally dry canyon bottoms may result in recharge to intermediate perched zones.
- Alluvial Element E: In a few cases where saturated flow might occur, faults, fractures, joints, surge beds, and permeable geologic units (e.g. Guaje Pumice, Cerro Toledo, and Puye Formation) that underlie saturated alluvium or intermediate perched zones could provide pathways for downward water movement.

3.2.3 Intermediate Perched Groundwater

The following six elements represent the FY99 conceptual model of intermediate perched groundwater.

- Intermediate Element A: Intermediate perched zones occur beneath major canyon systems, particularly those that head in the Jemez Mountains or receive effluent discharges. Intermediate perched zones may receive recharge from watersheds west of the Laboratory.
- Intermediate Element B: In addition to the availability of recharge from overlying alluvial groundwater, the location of intermediate perched zones is controlled by hydrogeologic characteristics of subsurface units, mainly lithology and permeability. In some cases, such as with interlayered basalts and conglomerates, intermediate perched zones could occur at several depths beneath a canyon.
- Intermediate Element C: The intermediate perched zones have not been observed to extend laterally beneath the mesas in the eastern portion of the Laboratory. However, some lateral spreading of perched groundwater may occur down gradient, if the canyon course and the dip of the perched zone do not coincide. Perched intermediate groundwater zones occur beneath the mesas on the western edge of the Laboratory.
- Intermediate Element D: Along the western boundary of the Laboratory, perched groundwater occurs in at least two distinct modes: limited ribbons of shallow saturation that are sources of springs in the Tshirege Member of the Bandelier Tuff found to depths of approximately 200 ft below the

mesa top, and a separate large perched zone approximately 700 ft below the mesa top occurring in the Otowi Member of the Bandelier Tuff and extending downward into the Puye Formation. The principal recharge source for these zones is probably the Jemez Mountains.

Intermediate Element E: *Contaminant concentrations in water entering these within intermediate perched zones are can be diluted relative to sources due to seasonal fluctuation within the alluvium. Lateral down-canyon flow within intermediate perched zones could contribute to significant transport of contaminants away from their surface source.*

New Intermediate Element F: *Flow within intermediate perched zones could contribute to significant transport of contaminants away from their surface source(s).*

3.2.4 Regional Aquifer

The following six elements represent the current understanding of the hydrogeologic environment of the regional aquifer and are represented in the the FY99 conceptual model.

Regional Element A: The slope of the water table suggests that the flow of groundwater is generally toward the east or southeast, toward the Rio Grande. Water supply pumping affects flow directions in the aquifer near supply wells. The variation of these effects with depth and distance is not known at present. This influence on flow directions could have an important impact on contaminant movement in the regional aquifer.

Regional Element B: Along the western edge of the Laboratory, deep perched groundwater may be a major significant source of recharge to the regional aquifer (relative to the volume of public water supply pumping). This deep perched groundwater is largely recharged by underflow from the Sierra de los Valles and to a lesser extent by surface infiltration. Regardless of the relative volume of surface infiltration, Laboratory discharges have had significant contaminant impact on this deep perched groundwater.

The volume of on-site regional aquifer recharge from stream bottom infiltration of natural streamflow into alluvial groundwater that results from infiltration of natural streamflow is small (relative to the amount of public water supply pumping) from the regional aquifer. When considered also combined with potential infiltration of effluent discharge steams, however, the annual volume of on-site regional recharge from stream bottom infiltration may be significant.

Regional Element C: Regional aquifer groundwaters within in the eastern portion of the Pajarito Plateau (generally along the Rio Grande) is of different recharge origin that tend to be geochemically distinct from waters sampled under the central part of the Plateau. Possible causes of these differences include longer residence times (as suggested by

¹⁴ C data), different recharge origin, and/or differences in flowpaths.

Regional Element D: Sources of recharge to the regional aquifer are uncertain. Geochemical data show that the Valles caldera is not the source of major recharge, contrary to statements in earlier Laboratory reports. A strong downward vertical hydraulic gradient observed on the western edge of the Laboratory indicates that the area along the flank of the Jemez Mountains is a recharge area with the recharge originating in the Jemez Mountains. Additionally, major recharge may occur by southerly flow along the late Miocene trough of Purtymun (1984), or possibly via percolation beneath canyon bottoms. Water budget analyses and flow modeling indicate that recharge rates in the Sierra de los Valles (lying between LANL and the Valle Grande) may be sufficient to supply most of the recharge to the regional aquifer beneath the Pajarito Plateau. It is premature to draw conclusions regarding hydrologic connection between the Valles caldera and the Pajarito Plateau as hydrologic and geochemical data in the eastern caldera are sparse.

Regional Element E: ~~At most locations if present, Laboratory-derived contaminants in the regional aquifer are likely to vary in concentration. The contaminant concentrations are probably below maximum contaminant levels (MCLs) for drinking water. Contaminants reaching the regional aquifer within a plume will remain at nearly those concentrations during advective transport unless the transport time and length scales are large enough for dispersive mixing to dilute the plume. Concentrations may be much lower in water well or sampling well fluids than was present in situ because of mixing of high and low concentration fluid within the screened interval of the well. because (1) regional aquifer underflow dilutes contaminant concentrations in recharge; and (2) contaminant concentrations in alluvial and intermediate perched zone groundwater are expected to decrease with depth due to dilution and geochemical attenuation along vertical migration pathways. Vertical gradients in the upper portion of the regional aquifer affect dilution of contaminant concentrations in the recharge sources, i.e., upward gradients influence mixing of the recharging water with resident aquifer water while downward gradients inhibit this mixing.~~

Regional Element F: The hydraulic properties of the regional aquifer are heterogeneous both vertically and laterally. Vertically, hydraulic properties vary greatly between geologic units thereby contributing to varying water yield. Laterally, the regional aquifer commonly exhibits confined characteristics near the Rio Grande but appears to be unconfined in other parts of the Pajarito Plateau. Water level declines due to pumping vary across the Plateau, usually ranging from 0.5 to 3 ft per year. Water levels have declined the least in wells that penetrate a thick zone of permeable sediments that transect the central part of the Plateau.

3.2.5 Groundwater Geochemistry

The following 11 new elements reflect the current understanding of the geochemistry of groundwater and are represented in the FY99 geochemistry conceptual model.

- Geochemistry Element A: Due to geochemical processes, the natural composition of groundwater can vary within alluvium, perched intermediate zones, and the regional aquifer.
- Geochemistry Element B: Residence times of groundwater and chemical solutes (mass of water or solute/flux of water or solute) increase with depth and from west to east across the Pajarito Plateau. Accordingly, increasing concentrations of major ions and trace elements are observed along the flow paths.
- Geochemistry Element C: Reactive minerals and solid phases approach equilibrium with groundwater when the residence time exceeds the reaction half time (amount of time required for 50% of reactant A to form product B). These reactive constituents, consisting of CaCO_3 , Ca-smectite, Na-feldspar, amorphous SiO_2 , and $\text{Fe}(\text{OH})_3$, may control groundwater composition for the major ions and selected trace elements including iron and aluminum.
- Geochemistry Element D: Alluvial aquifer materials provide the largest reservoir for effluent discharged constituents such as strontium-90, cesium-137, uranium, plutonium-238, plutonium-239, 240, and americium-241 due to the constituents nature to readily adsorb onto clay and silt sized particles.
- Geochemistry Element E: In general, sorption of radionuclides and organic and inorganic species decreases as follows: cesium-137 (highest sorption) = americium-241 > strontium-90 > uranium > nitrate = sulfate = chloride = perchlorate = TNT = RDX = tritium (lowest sorption). Sorption capacities of sediments and aquifer material may change over time due to changes in solution speciation and mineralogy.
- Geochemistry Element F: Activities of sorbing radionuclides and concentrations of inorganic species generally decrease downgradient along the groundwater flow path.
- Geochemistry Element G: Non- and semi-sorbing constituents can migrate from alluvial groundwater to perched intermediate zones and to the regional water table.
- Geochemistry Element H: Adsorption processes dominate over mineral precipitation for removing metal and radionuclide constituents from groundwater. However, in isolated cases where effluent discharges have changed alluvial groundwater alkalinity or pH, elements such as strontium and barium may precipitate as SrCO_3 , BaO_3 , and BaSO_4 or coprecipitate as $(\text{Sr-Ba})\text{SO}_4$ in alluvial groundwater.

Geochemistry Element I: Transport of constituents in groundwater occurs as both dissolved solutes and as colloids. Colloids may include natural material (silica, clay minerals, organic matter, and ferric hydroxide) and possibly solid phases associated with the treated Laboratory discharges.

Geochemistry Element J: A component of groundwater within the perched zones and to the regional water table is less than 58 years old, based on measureable tritium activities considerably above the cosmogenic baseline of 1 pCi/L.

4.0 FY99 DATA COLLECTION, INTERPRETATION, AND MANAGEMENT

In FY99, the new geologic, hydrologic, and geochemical data were collected from boreholes and newly completed wells of the Monitoring Wells Installation Project (MWIP) and from existing wells and surface water sampling conducted through the Environmental Surveillance Program. Other data comes from ongoing geologic and hydrologic studies conducted through programs and projects such as the Seismic Hazards Program and the ER Project.

The majority of new data comes from the drilling, sampling, and logging of new boreholes. The following is a synopsis of the history of drilling, sampling, logging and well completion activities through FY99. Figure 4.0-1 shows the locations and status of regional aquifer wells that were proposed as part of the *Hydrogeologic Workplan* (LANL, 1998). Figure 4.0-2 shows the locations and status of the proposed alluvial wells.

- **Well R-9:** Temporary well R-9 was completed February 3, 1998, in Los Alamos Canyon at a total depth of 710 ft. It was drilled using air rotary/casing advance methods. Five perched zones were encountered above the regional aquifer. These zones were sampled during drilling. The regional aquifer was encountered at the top of the Santa Fe Group at a depth of 688 ft in basalts. Several geophysical logs were run through different sections of both the open and cased borehole. A transducer was placed in the well to record water level measurements in the regional aquifer from March 1998 to March 1999.

The temporary PVC well casing was removed on September 22, 1999, and the borehole was advanced to total depth of 771 ft by October 18, 1999. Attempts to pull steel casings and complete the well ran into early FY00. The well was completed on October 18, 1999, with one 65-ft screen at the regional water table. Geophysical logging of the cased hole, screen development, and pump installation are scheduled for early FY00. Figure 4.0-3 provides well construction, stratigraphic, and hydrologic information for completed well R-9.

- **Well R-12:** Temporary well R-12 was completed June 4, 1998, in Sandia Canyon at a total depth of 847 ft. It was drilled using air rotary/casing advance methods. One perched zone was encountered above the regional aquifer. This zone was sampled during drilling. At the top of the Santa Fe Group, the regional aquifer was encountered at a depth of 805 ft in basalts. Several geophysical logs were run through different sections of both the open and cased borehole. A transducer was placed in the well to record water level measurements in the regional aquifer from June 1998 to March 1999.

The temporary casing was scheduled to be removed and a permanent well completed by the end of FY99. Complications with the construction of well R-25 caused schedule delays and permanent well construction of R-12 did not begin until November 1999. Figure 4.0-4 provides well construction, stratigraphic, and hydrologic information for well R-12 as of the end of FY99.

- **Well R-15:** R-15 was drilled in Mortandad Canyon using both hollow stem auger and air rotary/casing advance methods. Phase one drilling with the hollow stem auger was completed on October 1, 1998 to a depth of 420 ft. Phase one drilling included continuous coring of the borehole. Phase two drilling began June 8, 1999. The borehole was advanced to total depth of 1107 ft using the air rotary with casing advance drilling method. One definable perched zone was encountered above the regional water table. Two other perched zones possibly exist but were not positively identified. Drilling fluids containing bentonite were

Figure 4.0-1. Completed, in progress, and proposed MWIP regional aquifer wells as of the end of FY99.

Figure 4.0-2. Completed and proposed MWIP alluvial wells as of the end of FY99.

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Figure 4.0-4. Construction, stratigraphic, and hydrologic information for well R-12 as of end of FY99.

introduced into the borehole to keep the advance casing from binding. The regional water table was encountered at a depth of 964 ft in the lower part of the Puye Formation. Several geophysical logs were run through different sections of both the open and cased borehole.

The well was constructed with one 60-ft stainless steel screen placed at the regional water table. The well was completed September 8, 1999. Screen development and pump installation is scheduled for early FY00. Figure 4.0-5 provides well construction, stratigraphic, and hydrologic information for completed well R-15.

- *Well R-25:* R-25 was drilled at TA-16 on the mesa above Cañon de Valle. Drilling began July 22, 1998, using air rotary/casing advance drilling methods. Total depth of 1942 ft was reached by February 24, 1999. One perched zone was encountered followed by an interval of alternating wet and dry conditions. The regional water table was encountered at a depth of 1286 ft.

Many complications arose during drilling and casing advance, mainly difficulty sealing the upper perched zone and the advance casing binding in the borehole. Well construction began March 1999. Well design included nine screens, three in the upper saturated zone, one in the alternating wet and dry zone, and five in the regional aquifer. Further complications arose during well construction, mainly damage to screen #3 in the upper saturated zone. At the end of FY99, attempts were being made to repair screen #3. Figure 4.0-6 provides well construction, stratigraphic, and hydrologic information for well R-25.

- *Well R-31:* R-31 was drilled at TA-39 in the north fork of Ancho Canyon. Phase one drilling of R-31 was completed September 17, 1999 using the hollow stem auger method and continuous coring. A depth of 250 ft was reached. No perched zones were encountered during phase one drilling. Geophysical logging of the open borehole was conducted down to total depth. Phase two drilling began January 17, 2000. Figure 4.0-7 provides borehole construction, stratigraphic, and hydrologic information for well R-31 as of the end of FY99.

4.1 Geologic Data Collection and Interpretation

4.1.1 Geologic Data Collection

New information has been collected on the lithologies that comprise units of the Bandelier Tuff and the underlying sediments and volcanic units. Sources of information include samples from field studies and associated mapping efforts, new analyses of samples from cores drilled prior to FY99, and analyses from the new drill cores of R-15 and R-25. These were all key sources in the development of the FY99 update to the 3-D Site Geologic Model.

4.1.1.1 Petrology

New information from field studies, principally in the southwestern part of the Laboratory, and new data from drill hole SHB-3 collected for the LANL Seismic Hazards Investigations have provided better understanding of the petrology of the upper Tshirege Member of the Bandelier Tuff. Particular attention was given to the series of ash flows and surges between units 2 and 4 of the Tshirege Member.

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Figure 4.0-5. Construction, stratigraphic, and hydrologic information for completed well R-15.

Figure 4.0-6. Construction, stratigraphic, and hydrologic information for completed well R-25.

Figure 4.0-7. Construction, stratigraphic, and hydrologic information for borehole R-31 as of end of FY99.

New information on basaltic lithologies has been obtained principally from samples that were collected during the earlier drilling of R-9 (FY98). This was supplemented by 68 new analyses of basalts from the older drill holes PM-4, PM-5, Otowi-1, and Otowi-4.

New information on lithology of the Puye Formation has been obtained principally from samples collected during the drilling of R-15 and R-25. Surface mapping efforts conducted in the volcanic domes of the Tschicoma Formation near the western portion of the Laboratory help provide a regional context for sources of transported materials that comprise the Puye Formation. Studies were conducted of clasts and ash beds sampled from the Puye Formation during the drilling of borehole R-25.

4.1.1.2 Stratigraphy

New stratigraphic information has been obtained principally from geologic and geophysical logging of drill holes R-15 and R-25. These data have been incorporated into the 3D Site Geologic Model.

The borehole geophysical methods that were used during the drilling of boreholes R-15 and R-25 include natural gamma radiation measurements and electrical resistivity measurements (Table 4.1.1-1). Gamma measurements record total gamma radiation in the borehole and are useful for stratigraphic correlation and for identification of rocks and sediments that have high clay content. Gamma measurements for boreholes R-15 and R-25 are displayed in Figures 4.1.1-1 and 4.1.1-2. Electrical resistivity measurements record the composite electrical resistivity (or its inverse, conductivity) of the rocks and their pore fluids. Electrical resistivity measurements are most useful for detecting the presence of continuous fluids in pore spaces of the rocks. Electrical resistivity must be measured in an open borehole, i.e., no casing, but gamma measurements can be made in either open or cased boreholes.

Table 4.1.1-1. Geophysical Logs Collected in R-wells.

Well	Depth Range (ft)	Logs
R-15	0-1085	gamma
R-15	0-360	resistivity
R-25	0-1942	gamma
R-25	580-1000	resistivity

4.1.1.3 Fracture Characteristics

Limited new information on fracture characteristics has been obtained principally from a video log taken at R-25. The log was taken during open borehole drilling in the Otowi member. Two fractures, one at 752-756 ft depth and one at 761-764 ft depth, were observed in borehole video log taken at R-25 in the Otowi member. Neither fracture showed evidence of mineral alteration. Discharge was noted from the upper fracture which had an aperture of about 2 cm. These observations suggest that fractures within the upper saturated zone at this site have not experienced extensive alteration (e.g., to clay minerals) but also do not all connect within a single transmissive network.

Figure 4.1.1-1. Natural gamma measurements in borehole R-15.

Figure 4.1.1-2. Natural gamma measurements in borehole R-25.

4.1.2 Geological Interpretation

The major additions to geological interpretation derived from studies in FY99 are improvements to the 3-D Site Geologic Model and improvements in understanding of unit properties relevant to hydrologic processes. Improvements in the 3-D Site Geologic Model include:

- Increased control of the upper units of the Bandelier Tuff,
- Refined understanding of the distributions of basalts within the Puye Formation,
- New understanding of more limited distribution of Tschicoma units in the Puye Formation, and
- Improved realizations of the lithologies that intersect the water table.

The impact of the new information from these drill holes is evident in comparing the predicted stratigraphy prior to drilling, based on the FY98 Site Geologic Model, with the stratigraphic contacts as encountered (see Section 4.1.2.4). Geophysical logs collected to date (particularly the gamma logs) show good consistency from well to well for particular stratigraphic units. These logs are helpful for locating contacts between major stratigraphic divisions and within units such as the Puye Formation.

4.1.2.1 Bandelier Tuff

The new geochemical data from the Tshirege unit Qbt3 demonstrate continuous chemical variation in the transition from high-silica rhyolite in unit 2 (~78% SiO₂) to rhyolite (~73% SiO₂) in unit 4. These chemical parameters provide a reliable guide to stratigraphic position within the transition between units 2 and 4. The range of variation in these chemical parameters also supports the new subdivision of what had been unit 3 of the Bandelier Tuff into two subparts of generally equal thickness, the lower subpart retaining the designation unit 3 and the upper assigned the designation unit 3T (signifying "transitional unit 3"). Accordingly, in the 3-D Site Geologic Model, the Tshirege unit Qbt3 has now been subdivided into a lower unit Qbt3 and upper unit Qbt3t. These changes have been propagated across the model.

The observation of extensive saturation within the Guaje pumice and lower Otowi ash flows of the Bandelier Tuff in R-25 presents opportunities for understanding glass-water interactions beneath the LANL site. Preliminary petrographic data indicate significant alteration of the Guaje pumices to clay but very little alteration of the Otowi ash. The extent and mineralogy of alteration can provide information on both the longevity of saturation and the extent to which the alteration system has been open to transport. Information on these topics will be obtained as the R-25 samples are studied in more detail.

4.1.2.2 Basalts

The basalts can be divided into four units (Table 4.1.2-1) based on 68 new petrographic and geochemical analyses from core samples. Within each basalt unit there are multiple lava flows of varying composition. The possibilities for complexity in stratigraphy of the lavas are many. Nevertheless, some systematic features are beginning to emerge from the petrologic studies of these basalts and associated mafic lavas. Individual eruptive units are recognizable from the details of major element chemistry, trace element chemistry, and petrographic character.

Table 4.1.2-1. Major Basalt Units of the Pajarito Plateau

Unit Name	Unit Symbol	Age Range	Subepoch
Basalts of Cerros del Rio (TPc)	Tb4	1.6-3.4 Ma	Late Pliocene
Basalts of Pueblo Canyon (TPEc)	Tb3	3.4-5.3 Ma	Early Pliocene
Basalts of Bayo Canyon (TMLc)	Tb2	5.3-11.2 Ma	Late Miocene
Basalts of Santa Clara Canyon (TMMc)	Tb1	11.2-16.5 Ma	Middle Miocene

A single eruptive sequence can have local variations in cooling history that produce rocks with very different appearance and mineralogic development. Volcanic rocks within a sequence that cool before completely crystallizing have the lowest percentage of minerals and the lowest abundances of late-crystallizing minerals. Despite the different appearance these samples can have the same chemical composition and radiometric age. The combined information of chemical composition, age, and mineralogy can be used to link lava flows between drill holes and to map different eruptive forms with differing porosity and permeability. Fracture distributions through different basalt units vary, affecting the transmissivity and hydrologic storage capacity of basalts that can host perched waters. Relations between fracture properties and individual units are yet to be determined, but the basalt stratigraphy for the 3-D Site Geologic Model has been improved. The four principal basaltic units given in Table 4.1.2-1 have been constructed within the model using data from R-15, R-12, R-9, older drill holes, and new information from outcrop studies. The result is the first version of the 3-D Site Geologic Model in which basalt units can be automatically incorporated into cross-sections, transport-simulations, and other model products.

4.1.2.3 Puye Formation

The ability to recognize different source regions for components of the Puye Formation, particularly for clasts within the fanglomerates, can help in reconstructing the morphologies of different units within these deposits. In the past, the Puye fanglomerates were treated as a single massive unit, even though the Puye is a key unit that has variable hydrologic properties. It is within the Puye in drill hole R-25 that barrier lithologies occur, separating the upper and lower saturated zones. The Puye is also a unit that often contains the present regional aquifer. Figure 4.1.2-1 is a recent map summarizing the petrologic distinctions between those units of the Tschicoma Formation that are likely sources for volcanic detritus within the Puye Formation beneath the LANL site. Notable distinctions between these sources are the occurrence of quartz-bearing rhyodacite north of Los Alamos Canyon, remnants of a more mafic clinopyroxene andesite within Los Alamos Canyon, and distinctive two-pyroxene or hornblende-orthopyroxene dacites farther to the south. These are distinct lithologies that are being used to subdivide units within the Puye Formation.

One of the inferences that can be drawn from the various intermediate volcanic compositions shown within Figure 4.1.2-1 is that the sequence of volcanic sources shown varies greatly in composition, from relatively mafic to quite silicic. This range of variability is evident in the signal response of gamma well-logging instruments, as seen in the deepest gamma-log data for drill hole R-15 (Figure 4.1.1-1). The Puye formation in this drill hole was separated into upper and lower fanglomerates at 973 ft depth when the cuttings were logged; the gamma log shows that the boundary is also evident as a drop in the gamma signal with depth. The cuttings analyzed from the upper Puye fanglomerate were principally poorly-consolidated sand, pebbly sand, and gravel derived from the Tschicoma Formation, including distinctive clasts from the rhyodacite unit shown in Figure 4.1.2-1. Gravel units in the upper Puye fanglomerate are thicker and

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Figure 4.1.2-1. Petrologic distinctions between units of the Tschicoma Formation.

coarser than in the lower fanglomerate. The cuttings from the lower Puye fanglomerate were of unconsolidated tuffaceous sandstone and pebbly sandstone with abundant pumice. The abundance of tuffaceous material in this lower unit can be correlated with similar lithology in the lower Puye Formation of drill hole R-12, to the east. Correlations at greater distances (e.g., in drill hole R-25) will require further study.

This correlation indicates that the Puye can be subdivided at least on this scale and may be mapped out on a regional basis using data from future drill holes. Significant changes in signal intensity within gamma logs will be particularly helpful in this effort, providing a link between cuttings and log data in mapping the contact between upper and lower fanglomerates. The gamma mapping method appears to be useful even where alteration may be superimposed over initial depositional differences.

4.1.2.4 Applied Stratigraphy

Figure 4.1.2-2 compares the actual stratigraphy encountered in R-15 with the predicted stratigraphy. The FY98 3-D Site Geologic Model was largely influenced by the data from older drill holes TW-8, PM-3, PM-4, PM-5, and O-4 in the region where R-15 was drilled. The upper basalt within the Puye Formation was predicted by the model, albeit thinner than actually encountered. The deeper latite and basaltic volcanic units predicted by the model were not encountered. The absence of these deeper volcanic units is not surprising, because there are very few data on the deeper volcanic rocks and correlations based on the few data available, especially for the thinner volcanic units, are speculative. However, the Totavi Lentil was encountered at a depth within 7 feet of prediction. In the initial versions of the 3-D Site Geologic Model the extension of the Totavi quartzite-bearing gravels to this part of the plateau was considered somewhat speculative and the occurrence of this contact as predicted helps to reinforce this part of the model.

Figure 4.1.2-3 compares the actual and predicted stratigraphy in drill hole R-25. Drill hole R-25 penetrated a section in the southwestern portion of the LANL site where there are few other drill holes to strengthen predictions from the Site Geologic Model. The differences between the predicted and actual results at R-25 illustrate some weaknesses of the Site Geologic Model in this area. Upper units of the Bandelier Tuff (Qbt) are in part mappable at the surface in this area; hence the differences in predicted and actual depths to contacts for these units are minimal. One difference arises from the subdivision of Qbt3 into two parts, as units Qbt3 and Qbt3t. The deeper units of the Bandelier Tuff, beginning with Qbt1, show significant deviation from the predictions. Particularly notable is the penetration of R-25 to a total depth of 1942 ft without encountering Totavi or Santa Fe Group sediments. The Puye fanglomerates are much thicker than predicted in this part of the Pajarito Plateau.

The current 3-D Site Geologic Model is useful as a starting point from which cross-sections can be generated for specific purposes. One of these purposes is to examine the model for evidence of inconsistencies and components that require further investigation. Figure 4.1.2-4 is an east-west cross-section through drill hole R-15 and extending to drill holes TW-8 and R-12. This cross-section shows thinning of the Cerros del Rio basalts from east to west, consistent with previous concepts for this unit. Although the Totavi Lentil was predicted to occur in both R-12 and R-15, and the upper contact for the Totavi was within 7 feet of predicted depth in R-15, the Totavi was missing entirely in R-12. The "hit-or-miss" nature of Totavi occurrences is apparently related to its depositional environment. As axial gravels of the ancestral Rio Grande, the Totavi deposits apparently occur as sets of channel deposits; as such they are likely to be

Figure 4.1.2-2. Comparison of actual and predicted geologic contacts in R-15.

Figure 4.1.2-3. Comparison of actual and predicted geologic contacts in R-25.

Figure 4.1.2-4. West-to-east geologic cross section through wells TW-8, R-15, and R-12

absent from any local elevations isolated between channels as the river migrated from west to east across the top of the Santa Fe Group.

The new additions to the 3-D Site Geologic Model from R-25 have added greatly to model control in the southwestern part of the LANL site, but questions remain about both the stratigraphy and the hydrology in this area. Two cross-sections through R-25, one trending NW-SE (Figure 4.1.2-5) and one trending NNE to ENE (Figure 4.1.2-6), illustrate new insights and old problems. Figure 4.1.2-6 uses information from earlier drill holes SHB-3 and PM-2, along with R-25, to illustrate predicted stratigraphy at future drill sites R-19 and CDV-15-3. The knowledge gained in drilling R-25 precludes extension of Tschicoma units this far to the east, where they are now known not to occur, but uncertainties remain concerning the extent of the upper saturated zone that was confirmed in R-25 but is still enigmatic in volume and shape. The apparent upward arch in the top of the Santa Fe Group in the vicinity where CDV-15-3 and R-19 will be drilled was inherited from the earlier versions of the 3-D Site Geologic Model. This arch does not match those portions of the model where it is believed that the upper surface of the Santa Fe Group provided a broad slope across which the Totavi gravels were deposited as the ancestral Rio Grande swept from the west to its present position. Future drilling will provide clarification of these issues.

The NNE-ENE cross-section extending from R-25 (Figure 4.1.2-6) extends through the older drill holes H-19 and TW-4. These earlier drill holes encountered significant thicknesses of Tschicoma lava. The upper Tschicoma lava of H-19 has a lower contact at roughly the same stratigraphic level as the lower boundary of the upper saturated interval in R-25. Clastic depositional effects beyond the toe of a major dacite flow can be significant, but whether this has any relation to the gap between the two saturated intervals in R-25 is speculative. Between the Tshirege and Otowi Members of the Bandelier Tuff there is a lack of Cerro Toledo deposits in H-19 and TW-4 that suggests deposition within paleovalleys. Future drilling will help to determine whether this unit is absent beneath broad areas of the Pajarito Plateau.

Figure 4.1.2-7 illustrates the development of modified block diagrams, using information resident in the 3-D Site Geologic Model, to visualize the relationship between contaminant migration problems and geohydrologic components in three dimensions. In this figure the historic high explosive (HE) release sites within TA-16 are shown relative to those zones within drill hole R-25 where migration of HE was detected. Communication between the upper and lower saturated zones is likely to account for the transmission of HE from the upper to the lower saturated zone. Petrologic studies of the barrier between these two saturated zones is still in progress, but the nature of this horizon is clearly one of the keys to understanding HE migration at this site. Visualizations such as this, developed with the help of the 3-D Site Geologic Model, provide assistance in focusing on those components of the site geohydrology that need more detailed analysis in order to understand the movement and fate of contaminants.

There are presently several known subdivisions of the units shown in Figure 4.1.2-4 that will not be incorporated in the 3-D Site Geologic Model until further information on the mappability of these subdivisions is obtained in future drilling. These subdivisions include splitting of the Cerros del Rio basalt into upper tholeiite and lower alkalic basalt units and the splitting of the Puye Formation to show the upper and lower fanglomerates (Figure 4.1.1-1). Both of these subdivisions were well represented in both R-9 and R-12; preliminary results from R-15 indicate that both can be extended at least that far to the west. However, all three of these drill holes are relatively close together and further information on the lateral extents of these subdivisions is needed before they are incorporated into the 3-D Site Geologic Model.

Figure 4.1.2-5 Northwest-to-southeast cross section through R-25 and the southern part of the Laboratory.

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Figure 4.1.2-6. North-northeast cross section from R-25 to H-19, and east-northeast to TW-4.

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4.2 Hydrologic Data Collection and Interpretation

4.2.1 Hydrologic Data Collection

Several kinds of data for characterizing hydrologic systems at LANL were collected in FY99. These include observations on the occurrence and movement of water in both unsaturated and saturated conditions.

Also in FY99, a preliminary hydrogeologic atlas was prepared based on the 1998 version of the 3-D Site Geologic Model together with topographic and water-level data (Stone et al. 1999). The atlas consists of a set of 25 maps at a scale of 1:36000 (1 inch=0.6 mile). These include a topographic map of the Laboratory area; a thickness map for the Tshirege Member of the Bandelier Tuff; a series of three maps (structure or elevation of the top of the unit, depth to the top of the unit and thickness of the unit) for each of the underlying geologic units, a regional piezometric-surface map and a geologic map drawn at the regional piezometric surface. Documentation describing purpose and scope, data sources and quality, and specifications for each map type accompanies the atlas.

4.2.1.1 Unsaturated Zones

In FY99, data collection efforts to increase understanding of hydrologic processes in unsaturated zones included a surface condition flux rate study at TA-54 Material Disposal Areas (MDA) G, and continued alluvial groundwater and springs monitoring at TA-16. In addition to these studies, moisture content and matric potential data from boreholes R-15, R-25, and R-31 were collected.

Also, eight samples of core from boreholes R-9, R-12, and R-25 from the unsaturated zone have been submitted to a commercial laboratory for hydraulic properties testing (unsaturated and saturated hydraulic conductivity, gravimetric and volumetric moisture content, wet and dry bulk density, porosity, moisture characteristics, and estimation of van Genuchten parameters). These include one sample from R-9 (calcareous sandstone in the Puye Formation), three samples from R-12 (lakebeds in the Old Alluvium as well as sandstone and conglomerate in the Puye Formation), and four samples from R-25 (very welded tuff and poorly welded tuff in the Tshirege Member of the Bandelier Tuff, pumice from the Tsankawi Pumice Bed, and non-welded tuff in the Otowi Member of the Bandelier Tuff). Hydraulic properties testing results were not received in FY99.

Surface Condition Flux Rates at MDA G

Nine boreholes were drilled at MDA G to assess near surface hydrology between three different surface conditions: crushed tuff waste pit covers, asphalt pad covers, and undisturbed areas adjacent to covers (Newman et al. 1999). Core was collected and analyzed for moisture content, matric potential, pore water chloride, and stable isotopes of oxygen and hydrogen.

Alluvial Groundwater and Springs Monitoring at TA-16

Along the western edge of the Laboratory, at TA-16, the rates of surface processes are expected to be different than at TA-54. At TA-16, monitoring efforts are being conducted for a large number of geochemical and hydrologic parameters for the alluvial perched groundwater and springs (Hickmott et al. 1999). These efforts include both continuous monitoring and

monitoring several times a week to support water and contaminant balance efforts and future risk assessment activities. In addition, quarterly sampling of the alluvial perched zone in Cañon de Valle has continued. The alluvial boreholes were instrumented in FY99 with pressure transducers and probes for temperature and electrical conductivity. Sampling of precipitation, spring waters, and alluvial waters for stable isotopes ($\delta^{18}\text{O}$ and δD) was initiated to estimate residence times and mixing of groundwater and surface water.

Moisture Content from Boreholes R-15, R-25, and R-31

Moisture content and matric potential data for R-15, R-25, and R-31 were collected in FY99. The moisture content profile from R-15 shows relatively high moisture contents in the Bandelier Tuff and much lower values in the underlying Cerros del Rio Basalts (Figure 4.2.1-1). The moisture content in the Otowi member is about 20%, corresponding to a saturation of about 53% (assuming bulk density of 1.2 g/cm^3 and porosity of 45%, Rogers and Gallaher, 1995). Moisture content in the basalt ranges from 0.5 to 14.6%, which probably reflects lithologies ranging from intact or vesicular basalt to fracture fill or interbedded materials.

The moisture content profile from R-25 shows relatively low moisture contents in the Tshirege member of the Bandelier Tuff of about 2% to 5% (Figure 4.2.1-1). Moisture content increases through lower units Qbt 1vc and Qbt 1g of the Tshirege member to 21% in the top of the Cerro Toledo interval. Moisture content in the Otowi member starts at about 7% and increases to about 20% over roughly 150-ft depth.

Moisture content data from R-31 were collected for the first 250 ft of borehole in late FY99. Data collection is scheduled to continue through early FY00 as the borehole is advanced through the unsaturated zone. Results of moisture content will be available in the final well completion report and summarized in the Groundwater Annual Status Report for FY00.

Matric potential values were also determined from the core or cuttings samples for both R-15 and R-25 using the chilled mirror psychrometer. In general, the data are consistent with the dry portions of previously obtained moisture retention curves. Complete discussions of matric potential data for each well will be available in the final completion reports for each well, e.g., *Completion Report for Characterization Well R-9*, October 1999.

4.2.1.3 Saturated Zones

Data on groundwater occurrence and movement in saturated zones were collected in FY99 from R-9, R-12, R-25, R-15, and water supply well PM-4. The data collected from each of these wells is described in this section.

R-9 and R-12 Data Collection

When the boreholes for R-9 and R-12 were drilled, temporary wells were installed in the boreholes. Transducers were placed in the temporary wells and continuous water-level data for the regional aquifer were collected in FY99. In the early part of FY00, the temporary wells were removed, the boreholes deepened, and permanent wells were installed. At this time, one core sample from each well, taken from an interval in the Cerros del Rio basalt, were submitted for laboratory measurement of hydraulic conductivity. Results of hydraulic conductivity testing were not received in FY99.

Figure 4.2.1-1. Moisture content from boreholes R-25 and R-15.

R-25 Data Collection

Static water-level depths at various borehole depths were measured during the drilling of R-25 (Figure 4.2.1-2). These were converted to elevations and used to construct isopotentials through R-25 (Figure 4.2.1-3). Additionally, new observations on water flow in fractures were made in drill hole R-25 using the borehole video. One sample from R-25 (nonwelded tuff, Otowi Member, Bandelier Tuff) was submitted for laboratory analysis of hydraulic conductivity. Results of hydraulic conductivity testing were not received in FY99.

R-15 Data Collection

At R-15, both perched and regional zones of saturation were encountered. Perched groundwater was found to occur between the depths of 646 and 740 ft in the Cerros del Rio basalt. Although zones of saturation were expected to occur in the Cerro Toledo interval and the Guaje pumice bed, no such perched water was encountered. Regional saturation occurred at a depth of 1087 ft in the Puye Formation. A transducer will be placed in R-15 after its completion as a well with a single screened interval in the regional aquifer.

Although the direction of groundwater movement cannot be determined by water-level measurements in a single well. The potential flow rate can be evaluated by measuring hydraulic conductivity of the saturated medium in the field or in the laboratory. Hydraulic conductivity was measured in the field at R-15 using a slug test. The hydraulic properties of perching horizons are of particular interest for groundwater modeling. A 5-ft thick clay-rich zone in the Cerros del Rio basalt at a depth of approximately 740 ft is apparently responsible for the intermediate perched water. A hydraulic conductivity value of 2.54×10^{-7} cm/sec was obtained, which is at the lower end of the range of values typical for silt.

Two attempts were made to obtain field measurements of hydraulic conductivity at R-15 using a single-packer method, one in the perching layer and one in the regional aquifer. Unfortunately, both tests were unsuccessful due to faulty wiring and equipment failure. No field tests of hydraulic properties were attempted in the basalt for fear of borehole collapse.

PM-4 Data Collection

A series of hydrologic and chemical tests were conducted at water supply well PM-4 in March 1999. The purposes of the tests were to ascertain the depths where water enters the well, and to see whether HE recently found at borehole R-25 might be detected. Well PM-4 is 2920 ft deep, is screened from 1260 to 2854 ft, and had a 1997 nonpumping water depth of 1093 ft. The 1997 water depth during pumping was 1142 ft.

Dynamic spinner log survey was obtained while pumping the well at a rate of 1000 gpm (the well is pumped at a rate of approximately 1350 gpm when operating). The survey showed that most of the water was produced from the upper 500 ft of the 1604 ft-long screened interval.

Groundwater samples were collected from the following depths: 1340, 1406, 1505, 1635, and 2085 ft. They were analyzed for inorganic species (major ions and trace elements); high explosive (HE) compounds; stable isotopes of hydrogen, oxygen, and nitrogen; selected radionuclides; and organic compounds including PCBs (in the samples from the upper zone only). Alpha spectroscopy analyses were performed on samples from the upper two zones.

Figure 4.2.1-2. Screened water-level data versus borehole depth for R-25.

Figure 4.2.1-3. Northwest-to-southeast cross section showing isopotentials and flow near R-25.

4.2.2 Hydrologic Interpretation

The goal of hydrologic data interpretation is to quantify the processes that control the flow of water through the hydrologic system. The rates at which processes occur, under both natural and disturbed conditions, are important parameters for conceptualizing the hydrologic system and for modeling flow and transport. This section provides interpretation of the hydrologic data collected in FY99 from surface processes through the vadose zone, intermediate perched zones, and the regional aquifer.

4.2.2.1 Unsaturated Zones

Surface Condition Flux Rates at MDA G

At TA-54 MDA G, the results of the near-surface hydrologic study indicate that hydrologic behavior between pit covers and undisturbed areas are similar as observed in nine boreholes and core analyses. Downward flux estimates using the chloride mass balance method suggest that there is as much variability within the pit covers or undisturbed areas than there is between the two types. Flux estimates for the nonasphalt holes were a few millimeters per year or less (with one exception that is discussed below). There was also variability within the asphalt pad boreholes in all of the parameters. Data from two of the asphalt boreholes suggests that moisture accumulation is occurring under the asphalt, which is increasing flux. Stable isotope data for the three asphalt boreholes show that evaporative loss of water has been greatly reduced or eliminated by the asphalt. In addition to affecting the hydrology under the pads, the asphalt is affecting surrounding areas by focusing runoff near the edges of the pads. One of the boreholes from an undisturbed area has an apparent flux of about 1 cm/yr largely due to runoff from the adjacent asphalt pad.

Alluvial Groundwater and Springs Monitoring at TA-16

The TA-16 surface water (springs, surface flow, and alluvial water) stable isotope data ($\delta^{15}\text{N}$, $\delta^{18}\text{O}$, and δD) from the three springs continue to support the TA-16 conceptual model. The data indicates that SWSC and Burning Ground springs are closely related, whereas Martin spring appears to be affected by a different flow path or source(s). Monitoring for the bromide tracer applied at the 260 outfall has continued. There were no detections of the tracer in the springs in FY99. Sampling of soils and core in the 260 outfall area will be conducted as part of the interim measure to see where the bromide has gone. The interim measure is scheduled to start FY00 and involves removing highly contaminated soils and tuff at the outfall. Nitrogen isotope data show spatial and temporal variation in the Cañon de Valle alluvial aquifer, possibly reflecting different amounts of runoff and soil-water input and N-related contamination (e.g., barium nitrate and RDX) (Hickmott et al. 1999).

Moisture Content from Boreholes R-15, R-25, and R-31

The pattern of increasing moisture content at the base of the Tshirege seen at R-15 and R-25 is also seen in Cañada del Buey well CDBM-1 (Rogers and Gallaher 1995), at several wells at MDA G (Rogers and Gallaher, 1995; Neeper and Gilkeson, 1996), in LADP-4 at TA-21 (Broxton et al. 1995), and at TA-49 (Neeper and Gilkeson 1996). The occurrences of these moisture maxima probably relate to changes in pore sizes of the rock at interfaces between layers. Even in the case of no vertical flow, finer grained rock will hold more moisture than adjacent rock with larger pore sizes. In the event that moisture is moving downward, it may build up at an interface

where pore size changes. Where a fine grained rock overlies a coarser grained rock, moisture builds up above the boundary in the finer grained unit until sufficient water pressure exists to force water into the larger pores of the underlying coarser grained material (Hillel 1980).

The increase of moisture content at the base of the Tshirege is also predicted by groundwater flow modeling of Mortandad Canyon by Dander (1998). These modeling simulations examined steady state moisture profiles below Mortandad Canyon using assumed infiltration rates and measured or assumed hydrologic properties for the lithologic units. One difference between the simulations and R-15 is that saturation in the Guaje Pumice bed was predicted by modeling but not observed in the well. The moisture contents observed in the basalt at R-15 are lower than model results, which used a uniform basalt matrix porosity of 23%. For intact, dense basalt, porosity is probably about 1%.

Vadose Zone Modeling

Flow and transport models for the vadose zone beneath Los Alamos Canyon, TA-49 MDA AB, and TA-54 MDA L have been developed in the past year. The Los Alamos Canyon model represents a canyon area and the TA-49 MDA AB model represents a mesa-top area. TA-54 MDA L model represents Volatile Organic Constituents (VOC) plume migration. These models support the Laboratory's Hydrogeologic Workplan and Environmental Restoration Project's goals by providing a synthesis of the available information on subsurface flow at these areas.

Los Alamos Canyon Model: Los Alamos Canyon is an area containing several potential contaminant sources and several locations where contaminants have been detected in vadose-zone water samples. This synopsis discusses the methodology for developing the model and summarizes the key results.

The first step in the development of the model was to build numerical grids that honor the available models for stratigraphy at this site. For this version of the model, the 3D Site Geologic Model available as of January 1999 was used. This version of the geology was the first to incorporate information on the basalt units. Two and three-dimensional numerical grids were developed based on this geologic model.

To provide appropriate rock properties and boundary conditions, relevant data were compiled from existing databases and reports. Hydrologic property data for the tuff units and other hydrologic formations were obtained from compilations of Rogers and Gallaher (1995) and other modeling studies (Dander, 1998, Birdsell et al. 1999). Recharge estimates along the canyon bottom (150-1000 mm/yr) were estimated based on the water balance study of Gray (1997). Elsewhere in the model, much lower recharge rates were applied (0.5 mm/yr), consistent with estimates in mesa settings at the Laboratory. Tritium input was estimated by combining the historic information of tritium concentrations in the shallow alluvial groundwater with the estimates of recharge along the canyon.

To calibrate the model, measurements of water content in characterization wells and observations of perched water were considered. For many of these data, adequate matches to the observations are obtained using base-case hydrologic properties and recharge estimates. Three-dimensional effects of varying recharge (canyon versus mesa) captured in the 3D model allow moisture content profiles in wells LADP-3 (canyon) and LADP-4 (mesa) to be matched. Thus, in a single model, both the canyon and mesa flow regimes were simulated and agree adequately with the field data. Despite these results, sensitivity analyses indicate that uncertainties in recharge and hydrologic parameter values remain, and these uncertainties

influence the model results. To incorporate perched water scenarios into the model, a new modeling technique was developed that applies a permeability reduction factor at unit interfaces where barriers to downward flow such as thin clay layers are suspected. The interface of the Guaje pumice bed and Puye Formation was selected for this feature to explain the presence of perched water at that location.

The base-case model is in qualitative agreement with observations of tritium concentrations in perched water in several wells, including LADP-3. The model suggests that most of the tritium introduced since the 1960's has either remained in the vadose zone or has decayed. However, a relatively small amount reaches the regional aquifer beneath canyon-bottom regions of relatively high recharge. Future concentrations in the vadose zone are predicted to decline over the next 50 to 100 years due to further radioactive decay and changes in Laboratory practices that have resulted in lower input concentrations. The time period over which these concentration changes are predicted to occur implies that monitoring of contaminant concentrations will be a long-term process in which trends should be expected only over a period of several years or even decades.

TA-49 Model

TA-49, specifically Areas 2, 2A, and 2B of MDA AB, are legacy waste sites where underground nuclear safety tests were conducted in 1960 and 1961. Tests involving HE and special nuclear materials were conducted in six-ft diameter shafts ranging in depths from 57 to 78 ft. Plutonium, uranium-235, uranium-238, beryllium, and lead were among the main constituents used in the tests. The site was originally chosen because the hydrologic characteristics of the geologic units would naturally contain the contaminants thus protecting groundwater.

However, the hydrologic characteristics of the site were unfavorably altered in 1961 by the addition of an asphalt pad over Area 2 (LANL OU 1144 RFI Work Plan, 1992). The pad not only inhibited evapotranspiration at this naturally dry site, it also dammed surface water along its edges and potentially channeled water through the pad into the underlying shafts. Modeling estimates of 60-400 mm/yr beneath the pad were obtained by calibration to moisture profile information. The asphalt pad was removed in 1998, the site regraded, and a surface-water diversion channel added upstream of the site. These measures should return the site's hydrologic characteristics to naturally favorable conditions.

In FY99, preliminary flow and transport calculations were made to predict the present-day subsurface migration of uranium and cesium from Area 2 through the subsurface (Birdsell et al. 1999). These predictions provide estimates of radionuclide concentrations in the unsaturated zone beneath the shafts and will be used to site monitoring holes. The data and the model support the hypothesis that the presence of the asphalt pad from 1961 through 1998 resulted in increased subsurface moisture that was detrimental to performance.

The model indicates that the recent removal of the asphalt pad, along with other site improvements, will lead to less recharge at the site (on the order of 0.1-1 mm/yr), resulting in drier subsurface conditions and slower contaminant migration rates. This hypothesis should be confirmed through long-term moisture monitoring that has been carefully designed to assure meaningful results. Two new shallow boreholes will be installed in FY99 in order to improve moisture monitoring at the site. Transport simulations indicate that very little contamination has left the source region. Because the uranium source consists of particles that are generally larger than the matrix pore sizes, and these particles have low solubility, over 98% of the uranium should remain within the fractured region that surrounds the bottom of the experimental shafts.

Plutonium should behave similarly. These results should also be verified with carefully planned field testing.

VOC Plume Modeling at MDA L

A modeling study of the voc plume at TA-54 MDA L was initiated in the past year. The numeric site model was created using data from many sources, including: DEM data to create realistic topography, the site geologic model to capture the stratigraphy of the site, GIS data to accurately locate boreholes, high resolution aerial photos to help determine the timing of pavement at the site, and to visualize the results. In addition, hydrogeologic properties, including the diffusion coefficient for TCA, were extracted from various LANL reports and databases. Data from these sources were used in conjunction with the FEHM computer code to model the migration of vocs at MDA L from 1975 through 2010.

The VOC plume modeling results at TA-54 MDA L are able to capture the plume behavior using relatively simple logic based mainly on diffusion theory and the specific history of the site. The results are being used to assist in the development of the HSWA permit for MDA L. The model shows that plume growth can be adequately captured with yearly monitoring, as opposed to the quarterly monitoring currently employed. A second important result concerns the calculation of surface flux near the site, which allows surface monitoring to be designed based on computed values of VOC flux. Finally, the model suggests that the process of paving 2.5 acres at this site has inhibited the venting of the VOC plume and forced it to migrate further into the subsurface.

4.2.2.3 Saturated Zones

Occurrence of Perched Zones

Perched water was encountered at R-15 in the Cerros del Rio basalt. Based on water encountered in near-by wells and modeling simulations, perched water was expected to be present within the Cerro Toledo interval and Guaje pumice at R-15. The absence of perched water in these sections could be due to one or more factors: 1) saturation in these units is ephemeral, 2) saturation is restricted to the main axis of streams draining the canyons, and/or 3) saturation does not spread very far laterally. Data from R-15 alone is not sufficient to distinguish between these potential explanations.

The occurrence of saturation in the Cerros del Rio basalt at R-15 is consistent with occurrences at both R-9 and R-12. Intermediate perched water associated with the basalts is a more common element of the hydrologic system at LANL than previously thought.

Perched water occurred at R-25 in the Otowi member of the Bandelier Tuff. The impact of fractures on flow in the Otowi member comes from direct observation of flow in the borehole video from R-25. Discharge from a fracture of about 2-cm aperture was observed from 752-756 ft depth, within the lower part of the Otowi ash flow, and about 28 ft above the standing water level at the time the video was made (October 17, 1998). The upper part of the perched zone was encountered at 747 ft depth but quickly rose to a temporarily stable level of 711 ft depth. The transmissive fracture at 752-756 ft in the once-saturated lower Otowi member of R-25 has no visible evidence of mineral alteration in the video log. Another open fracture without visible alteration or filling, at 761-764 ft depth, was not discharging water at the time the video was made. These observations suggest that fractures in the Otowi member within the upper saturated zone have not experienced extensive alteration (e.g., to clay minerals) but also do not all connect within a single transmissive network.

Regional Aquifer

Interpretation of flow in the regional aquifer comes from work conducted at R-25, PM-4, and the synthesis of hydrologic data collected thus far by hydrologic modeling. At R-25, isopotential lines have confirmed a downward vertical hydraulic gradient. The flow testing at PM-4 provides additional basis for the permeability structure of the regional aquifer. The permeability structure is an important element of the hydrologic modeling. In FY99, hydrologic modeling of the regional aquifer was applied to the HE plume detected in R-25.

At PM-4, the spinner log survey showed that most of the water was produced from the upper 500 ft of the 1604 ft-long screened interval. The productive zones correlate to the lower part of the Puye Formation including the Totavi Lentil, and the upper part of the Santa Fe Group. This observation could mean that the upper 1600 ft of the regional aquifer is the most transmissive and hence produces the most water. However, the testing method may have skewed the result because the thickness of the production zone could be dependent on the pumping rate. Thus, if the pumping rate was closer to the usual pumping rate for the well (1350 gpm compared to 1000 gpm for the test), the thickness of the producing zone may have been greater.

Developing the saturated-zone flow and transport model for the regional aquifer beneath the Pajarito Plateau was continued in FY99. The primary focus of this effort was to support the Groundwater Protection Plan by integrating site-wide geologic, geochemical, and hydrologic data and by providing quantitative estimates of groundwater flow directions and fluxes. One application of these models was to predict fate and transport of dissolved HE in groundwater originating at TA-16. The results from this study should be treated as very preliminary; more definitive results will require both further model development and field data collection as part of the deep well drilling program. The goals were to present several plausible transport scenarios, explain the uncertainties inherent in these predictions, and summarize the types of data that could be collected to increase predictive capabilities.

At present, it is known that dissolved HE occurs in waters sampled from deep well R-25, but the spatial extent of this contamination remains unknown. For the purposes of this study, two hypothetical cases were examined: 1) all HE is confined to a small area near R-25 and occurs as a small, shallow plume at the water table, and 2) HE has been transported downstream in the near-surface alluvial aquifer of Cañon de Valle, transported vertically through the unsaturated zone, and then introduced to the water table below as a quasiline source. For both cases, particle paths and travel times away from the source at the water table to the ultimate groundwater discharge point were simulated. Since aquifer parameters are uncertain, the parameters were varied within reasonable ranges and the resulting range of paths and travel times were reported. For all the simulations, nearly all HE introduced to the water table was predicted to be eventually captured by the closest water supply well, PM-4. Predicted travel times to PM-4 range from 80 years to 1500 years; however, qualitative information about aquifer properties suggests the most likely travel times are in the upper end of this range. A more accurate analysis of travel times will require consideration of chemical reactions, including natural biodegradation. The tentative conclusion of this analysis is that under current water use scenarios, the HE contamination poses little or no short-term threat to water supply wells in the area.

Another focus of the regional aquifer modeling work in FY99 was quantifying recharge. Several techniques were used to evaluate recharge. These techniques included a literature review of previous studies in the Española Basin, a chloride-mass balance analysis, a detailed water

budget analysis for the Pajarito Plateau, and a flow model calibration process. The flow model calibration process included aquifer discharge data (springs and baseflow to the Rio Grande) as constraints on the total inflow to the aquifer. Preliminary results from these analyses include: 1) areally-averaged recharge rates for the plateau range from nearly 0 (low elevations) to 2 in/yr (0.7 cm/yr) (high elevations), 2) recharge rates may be much higher locally (e.g., Los Alamos Canyon recharge may be as high as 7 in/yr [2.4 cm/yr]), and 3) the majority of recharge to the aquifer probably occurs west of LANL and east of the caldera rim.

It is important to note that as model development continues and new data is collected, these estimates may change. Data required to substantiate the model and reduce the uncertainty are

- Geochemical data to constrain travel times
- A multiwell hydrologic test to measure aquifer flow properties
- An interwell tracer test to measure transport times directly and to determine whether fast pathways exist in the regional aquifer

4.3 Geochemical Data Collection and Interpretation

4.3.1 Geochemical Data Collection

Geochemical data collection in FY99 included analyses of core, cuttings, and groundwater samples at boreholes R-15, R-25, and in the TA-16 area (LANL 1999, 50290). Previously published data and information were also used for geochemical interpretation (Blake et al. 1995; Adams et al. 1995). The data collected are used to characterize the vadose zone and saturated zones; provide guidance in well construction or placement of screens; provide data for input to transport modeling and risk analysis; and establish baseline borehole groundwater chemistry before materials such as bentonite or non-native water are introduced during well completion and development.

In addition to data collection, available data were compiled on the major ion chemistry and stable isotopes for groundwater sampled from a large number of wells throughout the Española Basin. An understanding of the geochemistry of the regional aquifer in the Española Basin is necessary for defining geochemical processes that control major ion chemistry and for refining flow paths beyond that which is possible based on water level data and flow modeling alone.

All hydrochemical data collected from boreholes and pre-developed monitor wells are screening data. These data, however, are useful for geochemical interpretation and decision making during well completion. Hydrochemical data appropriate for regulatory decisions will be collected from R wells once they are completed and properly developed as monitor wells.

4.3.1.1 Geochemistry of Groundwater

Borehole R-15

At borehole R-15, filtered and non-filtered samples were collected from four depths representing an alternating wet and dry zone (482 ft), an upper saturated zone (646 ft), and the regional aquifer (1,007 and 1,100 ft). Samples were analyzed for contaminants of concern identified for Mortandad Canyon (LANL 1997, 56835) as provided in Table 4.3.1-1. Results of tritium analyses are shown in Table 4.3.1-2.

Table 4.3.1-1. Analyses of Groundwater at Borehole R-15.

Sample Depth (ft)	Analyses	Sampling Zone
Puye Fm		
482	Tritium	Wet/dry Zone
Basalt		
646	Full Suite, ¹ Field meas ²	Upper Saturated
Puye Fm		
1007	Screen, ³ Field meas	Regional Aquifer
1100	Partial Suite, ⁴ Field meas	Regional Aquifer

¹ HE compounds, HE degradation products, trace elements, major cations and anions, organic compounds, radionuclides, stable isotopes, and dissolved organic carbon.

² Field-measured parameters: pH, temperature, specific conductance, and turbidity.

³ Inorganic analytes.

⁴ Trace elements, major cations and anions, radionuclides, stable isotopes, and dissolved organic carbon fractionation.

Table 4.3.1-2. Tritium Activity in Groundwater Zones at R-15.

Depth (ft)	Activity (pCi/L)	Analytical Laboratory (Method)	Sampling Zone
Puye Fm			
482 (drilling mud)	57.5 ± 9.6	Univ. Miami (direct counting)	Perched Zone
Basalt			
646	3,770 ± 850	CST-9 (LSC)	Perched Zone
646	4,151	Univ. Miami (LSC)	Perched Zone
Puye Fm			
1007	220 ± 620	CST-9 (LSC)	Regional Aquifer
1007	<3.192 ± 9.576	Univ. Miami (direct counting)	Regional Aquifer
1100	1.21 ± 0.70	Univ. Miami (direct counting)	Regional Aquifer

Analytical error is ±1 standard deviation. LSC means liquid scintillation counting.

Several observations on the chemistry of groundwater collected from the R-15 borehole were made.

- The upper saturated zone occurs at a depth of 646 ft in basalt within the Puye Formation.
- The initial groundwater sample collected from the upper saturated zone in R-15 is predominantly a sodium-calcium-bicarbonate type as represented by the sample collected at depth of 646 ft.
- Elevated sodium concentrations were observed in R-15. The R-15 sodium concentrations, however, are mainly due to the presence of colloidal bentonite used during drilling.
- The upper saturated zone was found to contain 3,770 ± 850 pCi/L tritium (CST-9 analytical results) and 1.2 µg/L dissolved uranium. Under the oxidizing conditions in the perched zone,

uranium is predicted to predominately occur as $\text{UO}_2(\text{CO}_3)_2^{2-}$ and $\text{UO}_2(\text{CO}_3)_3^{4-}$, based on model simulations using the computer code MINTEQA2 (Allison et al. 1991).

- The upper saturated zone was found to contain 11.5 mg/L dissolved chloride, 63.9 mg/L dissolved sodium, 1.15 mg/L dissolved fluoride, 35.4 mg/L dissolved sulfate, <0.02 mg/L dissolved ammonium, <0.01 mg/L nitrate (as nitrate).
- The major anion chemistry of the upper saturated zone is similar to that of the TA-50 treated discharge water (LANL 1997, 56835) and alluvial groundwater (Environmental Surveillance and Compliance Programs 1997, 56684) in Mortandad Canyon. Sulfate, fluoride, and tritium are solutes associated with the TA-50 discharge (LANL 1997, 56835) that are not significantly adsorbed at near-neutral pH conditions that occur in the alluvium and in underlying saturated zones.
- The regional water table occurs in a tuffaceous section of the Puye Formation at a depth of 984 ft. Initial screening of groundwater samples collected from the regional aquifer at R-15 (depths of 1007 and 1100 ft) are characterized by a sodium-bicarbonate ionic composition. The major cation and anion chemistry of the groundwater samples collected from the regional aquifer was also impacted by bentonite drilling mud resulting in biased concentrations of sodium and other major ions.
- Concentrations of dissolved chloride and sulfate are 4.47 mg/L and 15.4 mg/L, respectively, in the regional aquifer (1,007 ft) at borehole R-15. The concentration of nitrate (as nitrogen) is 1.53 mg/L. Groundwater samples were analyzed for stable isotopes of nitrogen for evaluation of possible nitrogen sources. Analytical results for nitrogen stable isotopes suggest multiple sources (Clark and Fritz, 1997) of nitrate and other forms of nitrogen (-5.6 and -6.7 permil for the perched zone and + 5.4 permil for the regional aquifer at 1,100 ft).
- Activities of tritium are less than detection in the regional aquifer at R-15 (Table 4.1.3-2).

Borehole R-25

At borehole R-25, filtered and non-filtered samples were collected from fourteen depths representing an upper saturated zone, an alternating wet and dry zone, and the regional aquifer. Samples were analyzed for contaminants of concern identified for TA-16 (LANL 1999, 50290) as given in Table 4.3.1-3.

Selected trace element and major ion analyses are given in Table 4.3.1-4 for each zone of saturation. Observations on the chemistry of groundwater collected from the R-25 borehole are

- Most of the groundwater samples collected from the R-25 borehole have very similar major ion compositions. The upper saturated zone is characterized as a mixed calcium-sodium-bicarbonate ionic composition based on two groundwater samples. The alternating wet and dry zone above the regional aquifer is characterized as a sodium-bicarbonate ionic composition based on one sample. The regional aquifer is dominantly a calcium-sodium-bicarbonate type based on eight samples.

Table 4.3.1-3. Analyses of Groundwater at Borehole R-25.

Sample Depth (ft)	Analyses	Sampling Zone
Otowi Member		
747	Full Suite ^{1,2}	Upper Saturated Zone
Puye Fm		
7867	Full Suite	Upper Saturated Zone
1047	Full Suite, no Rad ²	Upper Saturated Zone
1137	Full Suite, no Rad	Wet/Dry Zone
1181	Full Suite, no Rad	Wet/Dry Zone
1286	Full Suite	Regional Aquifer
1407	Full Suite	Regional Aquifer
1507	Full Suite, no Rad	Regional Aquifer
1607	Full Suite, no Rad	Regional Aquifer
1,747	Full Suite, no Rad	Regional Aquifer
1867	Full Suite, no Rad	Regional Aquifer
1938	Full Suite, no Rad	Regional Aquifer
1940	Full Suite, no Rad	Regional Aquifer
1,942	HE and degradation products ²	Regional Aquifer

¹ Full Suite analyses include HE compounds, HE degradation products, trace elements, major cations and anions, organic compounds, radionuclides (tritium, uranium isotopes, gamma spectroscopy, gross alpha-beta-gamma, plutonium isotopes, americium-241, and strontium-90), stable isotopes, and dissolved organic carbon fractionation.

² Field measured parameters: pH, temperature, specific conductance, and turbidity.

Table 4.3.1-4. Selected Screening Analytical Results for Groundwater in R-25.

Depth (ft)	Sampling Zone	Ba mg/L	Cl mg/L	B mg/L	NO ₃ (N) mg/L	Fe mg/L	Mn mg/L
Otowi Member							
747	Upper Saturated	0.006	11.1	0.12	0.95	0.04	1.39
Puye Fm							
867	Upper Saturated	0.005	9.80	0.058	0.91	0.02	0.27
1047	Upper Saturated	0.007	9.13	0.090	0.81	0.05	0.19
1137	Wet/Dry Zone	0.005	8.04	0.074	0.87	0.13	0.11
1184	Wet/Dry Zone	0.008	5.79	0.027	0.75	<0.01	0.18
1286	Regional Aquifer	0.014	1.09	0.014	0.39	0.02	0.25
1407	Regional Aquifer	0.016	8.03	0.087	0.54	0.17	0.21
1507	Regional Aquifer	0.010	3.80	0.037	0.30	0.07	0.19
1607	Regional Aquifer	0.014	2.49	0.027	0.42	0.12	0.19
1747	Regional Aquifer	0.013	1.54	0.011	0.42	1.75	0.10
1867	Regional Aquifer	0.009	1.65	0.010	0.44	0.61	0.11
1940	Regional Aquifer	0.015	2.15	0.013	0.41	0.76	0.14
1942	Regional Aquifer	0.006	1.77	0.016	0.35	0.52	0.30

New Mexico WQCC groundwater standard for dissolved barium is 1 mg/L, for dissolved chloride is 250 mg/L, for dissolved boron is 0.75 mg/L, for dissolved nitrate (as nitrate) is 44 mg/L or 10 mg/L for nitrate (as nitrogen), for dissolved iron is 1.0 mg/L, and for dissolved manganese is 0.2 mg/L. Analytical results shown in this table are for screening purposes only.

- Results of radiochemical analyses were generally less than detection. Tritium was measured at 81.4 pCi/L in the upper saturated zone within the Puye Formation. Activities of uranium-238, uranium-235, and uranium-234 are less than 1 pCi/L for both filtered and nonfiltered samples collected at R-25. Activities of gross alpha, gross beta, and gross gamma are greater than 1 pCi/L for both filtered and nonfiltered groundwater samples. Activities of americium-241, cesium-137, plutonium-238, plutonium-239/240, and strontium-90 are less than detectable levels in the upper saturated zone and the regional aquifer. Dissolved uranium concentrations in groundwater samples collected at R-25 are less than 1 µg/L.
- Inorganic chemicals such as barium, boron, nitric acid, were used at TA-16 for high explosive manufacturing and research. Table 4.1.3-4 provides screening analytical results for selected solutes measured at borehole R-25. Chloride concentrations at Water Canyon Gallery and upper Cañon de Valle Spring west of the Laboratory are approximately 1 mg/L. Concentrations of boron at Water Canyon Gallery and upper Cañon de Valle Spring range between 0.005 and 0.008 mg/L for water samples collected in 1998. Concentrations of barium are fairly constant with depth while concentrations of chloride, boron, nitrate, and manganese decrease with depth.
- High explosive compounds and associated degradation products were present in most of the groundwater samples collected from R-25 (Table 4.3.1-5). RDX and TNT are the two contaminants of most concern because they exceed EPA health advisory limits (2 µg/L) for drinking water. They are mobile in groundwater and adsorption onto aquifer material is not significant (Schwarzenbach et al. 1993). The highest concentrations of RDX (84 µg/L) and HMX (12 µg/L) were measured in a groundwater sample collected from 1047 ft, whereas the highest concentration of TNT (19 µg/L) was measured at 867 ft. Degradation products of TNT that were detected include 4-A-2,6-DNT and 2-A-4,6-DNT, which are stable under anaerobic conditions (Hofstetter et al. 1999). Other HE-related compounds analyzed for but not detected include 1,3-dinitrobenzene, tetryl, nitrobenzene, 2,6-dinitrotoluene, 2,4-dinitrotoluene, 2-nitrotoluene, 4-nitrotoluene, and 3-nitrotoluene. Nitrotoluene isomers are additional degradation products of TNT. The detection limit for these compounds typically is 1 µg/L using the high pressure liquid chromatography (HPLC) method (EPA Method 8330).
- Stable isotope ratios for hydrogen, oxygen, and nitrogen were measured in groundwater samples collected from borehole R-25. These results are similar to the isotopic composition of springs west of the Laboratory, suggesting a meteoric source and that the springs are a source of recharge for R-25 groundwater. Results of nitrogen stable isotopes suggest that the elevated nitrate concentrations found in groundwater are from a nitric acid source. Nitric acid is used in the preparation of RDX and TNT (Card and Autenrieth, 1998).

Supply Well PM-4

During a spinner test conducted at well PM-4, groundwater samples were collected from the following depths: 1340, 1406, 1505, 1635, and 2085 ft. They were analyzed for inorganic species (major ions and trace elements); high explosive (HE) compounds; stable isotopes of hydrogen, oxygen, and nitrogen; selected radionuclides; and organic compounds including PCBs (in the samples from the upper zone only). Alpha spectroscopy analyses were performed on samples from the upper two zones.

Table 4.3.1-5 High Explosive Chemistry of R-25 Groundwater Samples.

Sample Depth (ft)	Sampling Zone	RDX ¹ (ug/L)	HMX (ug/L)	4-A-2,4-DNT (ug/L)	2-A-4,6-DNT (ug/L)	TNB (ug/L)	TNT (ug/L)
Otowi Member							
747	Upper Saturated	12	<1	0.38	0.51	<0.26	<0.25
Puye Fm							
867	Upper Saturated	63	8.3	3.7	5.2	2.2	19
1047	Upper Saturated	84	12	4.6	5.7	<2.5	5.3
1137	Wet/Dry Zone	50	9.2	4.3	2.9	<1.3	<1.3
1181	Wet/Dry Zone	4.2	<1	<0.25	0.43	<0.26	<0.25
1287	Regional Aquifer	<0.84	<1.0	<0.25	<0.25	<0.26	<0.25
1407	Regional Aquifer	62	9.7	<1.3	2	<1.3	7.1
1507	Regional Aquifer	4.4	<1	<0.25	<0.26	<0.26	<0.25
1607	Regional Aquifer	15	2.6	5	0.46	<0.26	0.84
1747	Regional Aquifer	<0.84	<1	<0.25	<0.25	<0.25	<0.25
1867	Regional Aquifer	0.97	<1	<0.25	<0.25	<0.26	<0.25
1939	Regional Aquifer	<0.84	<1	<0.25	<0.25	<0.26	<0.25
1940 (air lifted)	Regional Aquifer	8.8	1.5	1.7	0.69	<0.26	0.77
1940 (bailer)	Regional Aquifer	9.6	1.6	1.8	0.79	<0.26	1.1
1942	Regional Aquifer	5.9	<1	1.1	<0.25	<0.26	0.64
EPA HA ² (ug/L)		2	400				2

¹ RDX (hexahydro-1,3,5-trinitro-1,3,5-triazine), HMX (octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine), 4-A-DNT (4-amino-2,6-dinitrotoluene), 2-A-DNT (2-amino-4,6-dinitrotoluene), TNB (1,3,5-trinitrobenzene), and TNT (2,4,6-trinitrotoluene) analyzed by high pressure liquid chromatography (HPLC) (EPA Method 8330) at Paragon Analytics, Inc., Fort Collins, Colorado.

² USEPA (Region 6) lifetime health advisory level.

The chemical character of the zones sampled is uniform, indicating that the water sampled was homogenous and suggesting that groundwater mixing may have occurred within the well and along the filter pack material in the annulus of the well prior to or during sampling of the well. Alternatively, water in the aquifer at these depths may be of homogeneous composition. The following specific observations on the PM-4 water chemistry were made.

- HE compounds, including RDX, HMX, TNT, and associated degradation products were not detected in the groundwater samples collected from PM-4.
- Activities of tritium in the groundwater samples from PM-4 are less than 0.38 ± 0.32 pCi/L ($\pm$ one standard deviation) suggesting that the age of the groundwater is greater than 50 years.
- Activities of strontium-90, plutonium-238, plutonium-239/240, cesium-137, and uranium-235 in the samples from PM-4 were below detection limits.
- The stable isotopes of hydrogen and oxygen, isotopic nitrogen-15/nitrogen-14, and chlorine-36 were analyzed. The results of the analysis of the zonal groundwater samples from PM-4 indicate that mixing of groundwater occurred prior to or during sampling, either within the aquifer or the well. The method used to collect the groundwater samples did not insure collection of water directly from the formation and allows for mixing of water in the annulus of the well, which probably occurs over the 1604 ft of screen.

4.3.1.2 Geochemistry of Borehole Materials

Borehole R-15

At borehole R-15, 24 samples of core and cuttings were submitted for geochemical analyses. All samples are from the vadose zone and were collected during phase one drilling using hollow stem auger. Samples were analyzed for contaminants of concern identified for Mortandad Canyon in the *Workplan for Mortandad Canyon* (LANL 1997, 56835) as given in Table 4.3.1-6. In addition to the 24 samples, 14 samples were submitted for moisture characteristic analyses. These samples were also analyzed for tritium. No core samples from phase two drilling (air-rotary method) were collected for geochemical analyses.

Activities of tritium in moisture extracted from core samples collected at borehole R-15 are provided in Table 4.3.1-7. A plot of selected metals with depth is given in Figure 4.3.1-1.

The following observations are made from the analytical results of solid materials collected from R-15:

- Results of organic analyses showed no anthropogenic (manmade) organic compounds present in the core samples.
- Preliminary results of radiochemical data showed detectable uranium (uranium-234, uranium-235, and uranium-238), tritium, gross alpha, gross beta, and gross gamma (LANL 1999). Activities of gross alpha, gross beta, and gross gamma are greater than 1 pCi/g, where measurable, and vary with depth. Activities of tritium measured in moisture extracted from core samples range from 5.3 to 5405 pCi/L, which suggest that tritium has migrated through the vadose zone within the Bandelier Tuff (Table 4.1.3-7). Activities of americium-241, cesium-137, plutonium-238, plutonium-239/240, and strontium-90 are less than detection (LANL 1999).
- Increased activities of tritium generally correlate with increased moisture contents of the core and cutting samples (Table 4.1.3-7).
- Activities of isotopic uranium are higher in samples collected from the Bandelier Tuff, reflecting the high total uranium in this unit (Otowi Member) (Ryti et al. 1998). Lower activities of uranium-234, uranium-235, and uranium-238 were found in samples collected from the Cerro Toledo interval. Activities of total isotopic uranium are not elevated above Laboratory background for the Bandelier Tuff (Ryti et al. 1998).
- Iron, barium, beryllium, chromium, and lead were present above levels of detection. These elements are found within naturally occurring minerals and solid phases including ferric hydroxide, clay minerals, feldspars, magnetite, and hematite (Langmuir, 1997). Concentrations of antimony, arsenic, cadmium, cobalt, copper, iron, lead, mercury, manganese, nickel, selenium, silver, thallium, and vanadium in the core samples, however, are less than detection using ICP-OES and CVAA methods.

Table 4.3.1-6. Analyses of Core and Cuttings at Borehole R-15.

Sample Interval (ft)	Sample Type	Analyses	Sampling Zone
Alluvium			
0 to 17	Cuttings	Full Suite ¹	Unsaturated
Tshirege Member			
17.5 to 20.0	Core	Full Suite	Unsaturated
25.0 to 25.3	Core	Full Suite	Unsaturated
40.0 to 41.5	Core	Full Suite	Unsaturated
63.3 to 64.3	Core	Full Suite	Unsaturated
Cerro Toledo Interval			
65.0 to 65.8	Cuttings	Full Suite	Unsaturated
68.3 to 69.3	Cuttings	Full Suite	Unsaturated
75.8 to 76.6	Cuttings	Full Suite	Unsaturated
87.0 to 87.4	Cuttings	Full Suite	Unsaturated
90.8 to 91.6	Cuttings	Full Suite	Unsaturated
100.0 to 101.3	Cuttings	Full Suite	Unsaturated
105.0 to 105.8	Cuttings	Full Suite	Unsaturated
112.5 to 114.5	Cuttings	Full Suite	Unsaturated
115.0 to 115.8	Cuttings	Full Suite	Unsaturated
Otowi Member			
120.0 to 120.8	Cuttings	Full Suite	Unsaturated
148.3 to 149.3	Cuttings	Full Suite	Unsaturated
150.0 to 150.8	Cuttings	Full Suite	Unsaturated
170.0 to 170.8	Cuttings	Full Suite	Unsaturated
230.0 to 231.3	Cuttings	Full Suite	Unsaturated
270.0 to 272.5	Cuttings	Full Suite	Unsaturated
325.0 to 327.5	Cuttings	Full Suite	Unsaturated
380.0 to 384.0	Cuttings	Full Suite	Unsaturated
380.0 to 384.0 (duplicate)	Cuttings	Full Suite	Unsaturated
415.0 to 419.0	Cuttings	Full Suite	Unsaturated

¹ Full Suite analyses include major and trace elements, organic compounds, radionuclides (tritium, uranium isotopes, gamma spectroscopy, gross alpha-beta-gamma, plutonium isotopes, americium-241, and strontium-90), stable isotopes, and wt% carbon.

Table 4.3.1-7. Tritium Activities and Moisture Contents in R-15 Core Samples.

Depth (ft)	Tritium Activity		Moisture Content (wt. %)
	(pCi/g)	(pCi/L)	
<i>Tshirege Member</i>			
22.3	0.665	69.2	9.42
39.8	0.077	5.3	6.49
59.8	11.64	2,374	16.94
<i>Cerro Toledo interval</i>			
69.8	7.78	3,021	27.97
84.8	6.39	1,132	15.05
104.8	3.99	502	11.18
114.8	5.7	621	9.82
<i>Otowi Member</i>			
144.8	12.11	2,852	19.06
169.8	18.3	3,199	14.88
229.8	2.88	567	14.46
269.8	4.97	952	16.08
319.8	21.8	5,338	19.67
379.8	22.2	5,405	19.58
414.8	0.216	54.3	20.08

Figure 4.3.1-1. Concentrations of iron, barium, beryllium, chromium, and lead in core samples from borehole R-15.

- Organic carbon contents were highest within the alluvium and upper portion of unit 1g of the Bandelier Tuff, ranging from 0.07 to 0.14 wt. %. These values may represent recycling of solid organic matter within the alluvium and unit 1g. Organic carbon contents of the remaining samples were less than 0.05 wt. %, indicating small amounts of solid organic carbon are present within the lower section of unit 1g and the Otowi Member of the Bandelier Tuff and Cerro Toledo interval.

Borehole R-25

At borehole R-25, thirteen samples of core and cuttings were submitted for geochemical analyses. Samples are from the alternating wet and dry zone and the upper saturated zone. Samples were analyzed for contaminants of concern identified for TA-16 (LANL 1999, 50290) as given in Table 4.1.3-8. Pore water anion concentrations and $\delta^{18}\text{O}$ and δD analyses were determined on the same samples collected for moisture content in the unsaturated zone. In the vicinity of R-25, samples from four hydro holes (SWSC, Building 300, Martin Canyon, and 90's line pond) at TA-16 were analyzed for HE, moisture, chloride, and stable isotopes (Newman et al. 1999a).

Table 4.1.3-8. Analyses of Core and Cuttings at Borehole R-25

Sample Interval (ft)	Sample Type	Analyses	Sampling Zone
Otowi Member			
110.25 to 110.65	Cuttings	Full Suite	Unsaturated
223 to 225	Cuttings	Full Suite	Unsaturated
243.7 to 244.7	Cuttings	Full Suite	Unsaturated
318 to 319	Cuttings	Full Suite	Unsaturated
353 to 354	Cuttings	Full Suite	Unsaturated
366 to 366.8	Cuttings	Full Suite	Unsaturated
387.2 to 388.2	Cuttings	Full Suite	Unsaturated
440 to 445	Cuttings	Full Suite	Unsaturated
448 to 449	Cuttings	Full Suite	Unsaturated
550.2 to 551.2	Cuttings	Full Suite	Unsaturated
687 to 695	Cuttings	Full Suite	Unsaturated
768.5 to 769.45	Cuttings	Full Suite	Upper Saturated
Puye Fm			
1132 to 1137	Cuttings	Full Suite, no Rad	Wet/Dry Zone

¹ Full Suite analyses include HE compounds, HE degradation products, trace elements, major and trace elements, organic compounds, radionuclides (tritium, uranium isotopes, gamma spectroscopy, gross alpha-beta-gamma, plutonium isotopes, americium-241, and strontium-90) and stable isotopes.

Observations based on the analytical results from solid materials collected from R-25 are

- HE compounds and degradation products were not detected in core and cutting samples collected from the R-25 borehole.
- Results of organic analyses showed no anthropogenic organic present in the core samples.

- Trace element analyses results show that concentrations of most elements, including barium, are within LANL background upper tolerance limits (UTLs) for the Bandelier Tuff (Ryti et al. 1998). Some naturally occurring elements were at concentrations less than quantitation limits using ICP-AES and CVAA methods. These include antimony, arsenic, cadmium, cobalt, copper, lead, mercury, nickel, selenium, silver, thallium, and vanadium.
- Isotopes of natural uranium (uranium-234, uranium-235, and uranium-238), gross alpha, gross beta, and gross gamma were detected in core samples from the R-25 borehole. Activities of gross alpha, gross beta, and gross gamma in samples of core and cuttings are greater than 1 pCi/g, where measurable, and vary with depth. Activities of isotopic uranium are higher in samples collected from the Bandelier Tuff, reflecting the high total uranium in this volcanic rock (Ryti et al. 1998). Lower activities of uranium-234, uranium-235, and uranium-238 were generally found in samples collected from the Puye Formation. Activities of total isotopic uranium are not elevated above LANL background for the Bandelier Tuff. Activities of americium-241, cesium-137, plutonium-238, plutonium-239/240, and strontium-90 are less than detection in the samples of core and cuttings, indicating that no Laboratory-derived contamination from these isotopes is detectable in these core samples collected from R-25.

4.3.2 Geochemical Interpretation

Interpretation of the screening geochemical data collected and analyzed in FY99 is described in this section. The discussion moves from area-specific interpretations to the regional scale (Española Basin) interpretation. Finally, these interpretations are woven together in a geochemical conceptual model.

4.3.2.1 Borehole R-15 (Mortandad Canyon)

The $\delta^{18}\text{O}$ and δD results for borehole R-15 are plotted in Figure 4.3.2-1. These results indicate an evaporative zone (heavy isotope value) at the top of the alluvium that is typical of the near surface. The bulge of light water between about 16 and 75 ft may be from winter or spring precipitation because the isotope values are typical of these seasons. Below the evaporative zone, the isotope profiles show little variation with depth compared to borehole R-9. Isotopic values become lighter with depth and become heavier at the top of unit 1g until the Cerro Toledo interval contact is reached. Isotopic values through the Cerro Toledo interval and Otowi Member appear to be in quasi-steady state down to 420 ft.

4.3.2.2 Borehole R-25 (TA-16)

In general, the anions in R-25 pore water all showed similar behavior with multi-peaked profiles with depth, although some differences and the magnitude of concentrations (especially for chloride and sulfate) are not always consistent. Vertical profiles for chloride, oxalate, phosphate, and sulfate are presented in Figure 4.3.2-2. The chloride spike at about 50 ft corresponds to the contact between unit 4 and unit 3t within the Tshirege Member. This contact appears to provide an important control in vadose zone behavior based on results from other TA-16 boreholes drilled by the ER project. The chloride spike between 231 and 332 ft corresponds to a region of moderately to densely welded tuff at unit 2 and unit 1vu which lies between non- to poorly welded tuff. The increase in chloride below 600 ft may be related to the upper perched zone at 711 ft. In other boreholes (e.g., R-9), a spike in anion concentrations was observed above

Figure 4.3.2-1. Pore water oxygen isotope profile of core samples from borehole R-15.

GIT/GWASR/99-4.3.2-2_r25_strat_anions

perched saturated zones. The increase also corresponds to an increase in moisture content in the Otowi Member.

The $\delta^{18}\text{O}$ and δD results show that borehole R-25 has a fairly consistent isotopic signature below Tshirege unit 2. The $\delta^{18}\text{O}$ and δD profiles are similar and show a noisy, but decreasing trend down to 566 ft. Figure 4.3.2-3 shows the $\delta^{18}\text{O}$ results. The observations at 1158 and 1184 ft are from the perching unit for the upper saturated zone, and the decreasing trend is also supported by the δD analyses. No samples were taken between 566 ft and 1158 ft. This observation suggests that either the recharge source of the two saturated zones is similar or they have some connectivity, though not necessarily in the vicinity of R-25.

At TA-16, geochemical analysis of samples from the four hydro holes suggest lateral flow is responsible for HE contaminated transient saturated zones in the 90's line and Martin canyon boreholes at about 130 and 90 ft, respectively. The stable isotope data suggest that an evaporated recharge source such as mesa top ponds has recharged the wet zones.

Quarterly neutron probe monitoring in the four holes show relatively consistent moisture contents through time, and the wet zones in the 90's line and Martin canyon boreholes occur at consistent depths. The thin wet zones identified by the neutron probe monitoring suggest that fractures may be partially controlling flow. This observation is also supported by the fact that most of the wet zones occur in welded tuff, which is typically fractured.

In the Martin Canyon borehole, surge beds may also be playing a role in controlling flow. Standing water was observed in the Martin Canyon borehole on a couple of occasions in FY99, and the stable isotope compositions shifted to lighter values possibly reflecting seasonal variation in recharge. In the SWSC and Building 300 boreholes, volumetric moisture contents are low (typically 10% or less). Saturated conditions have not been observed in these holes. In addition, chloride mass balance studies suggest downward flux rates are on the order of a few mm/yr. Chloride mass balance estimates for the area above the saturated zones in the Martin, 90's line pond, and R-25 boreholes also have similar flux estimates.

These results reinforce the hypothesis that lateral flow is an important process for the development of saturation at TA-16. Also, lateral flow as an integral process is supported given the presence of HE. Downward rates in the vicinity of the boreholes are too slow to account for the HE at the depths that they were observed. FEHM modeling of hydro hole moisture contents also suggest that multidimensional flow is important at TA-16 (Birdsell et al. 1999)

4.3.2.3 Geochemistry of the Regional Aquifer in the Española Basin

Trace element concentrations and major ion ratios in the regional aquifer beneath the Pajarito Plateau are dramatically different from waters sampled in the western caldera (Shevenell et al. 1987; Blake et al. 1995). Therefore, it is reasonable to conclude that the western half of the caldera is not a plausible recharge area for the regional aquifer beneath the Pajarito Plateau. Water samples collected in the eastern portion of the caldera, although sparse, are geochemically similar to plateau waters and, therefore, this region can not be excluded from the potential recharge area based on geochemical evidence alone. Analysis of oxygen and deuterium isotope data produced a similar result. Trends in oxygen isotope ratios in precipitation, averaging over many storms, (Adams et al. 1995) generally support the elevation/oxygen isotope correlation proposed by Vautaz et al. (1986). However, the tremendous scatter to the data, especially at high elevation precipitation stations, suggests that oxygen isotope ratios in

Figure 4.3.2-3. Pore water oxygen isotope profile from borehole R-25.

the regional aquifer *cannot be used* to distinguish between recharge from the Valles caldera, Sierra de los Valles, or the Sangre de Cristo Mountains (for samples near the Rio Grande). In conclusion, available geochemical data are insufficient for establishing a hydrologic connection, or lack thereof, between the regional aquifer beneath the Pajarito Plateau and portions of the Valles caldera.

4.3.2.4 Geochemical Conceptual Model

A discussion on the geochemical conceptual model, based on data collected at Laboratory background groundwater sampling stations, ESH monitor wells, ER Project characterization wells, supply wells, R-9, R-12, R-15, R-25, and TA-16 is presented. These interpretations shall be refined as additional geochemical data and information are collected at boreholes and completed wells.

Recharge Chemistry, Natural Distribution of Solutes, and Residence Times

Figure 4.3.2-4 depicts recharge water chemistry for the Sierra de Los Valles (upper Cañon de Valle Spring) and the alluvium in Los Alamos Canyon (LAO-B). These two groundwaters are characterized by calcium-sodium-bicarbonate ionic compositions with total dissolved solids (TDS) contents less than 130 ppm. The shallow groundwater is generally oxidizing because of its proximity to recharge zones. Concentrations of iron and manganese are less than 0.5 and 0.05 ppm, respectively, which also suggest overall oxidizing conditions. Natural concentrations of uranium are typically less than 1 µg/L in the volcanic rocks and alluvium. Activities of tritium vary in the recharge water due to presence of atmospheric water, seasonal variations in tritium activities, and shallow groundwater that has been isolated from the atmosphere for a short period of time. In 1998, activities of tritium measured at upper Cañon de Valle Spring and LAO-B were 45 pCi/L and 64 pCi/L, respectively. Tritium activity at Spring 9B, discharging from basalt in White Rock Canyon, are less than 0.32 pCi/L, which suggests that the age of this groundwater is greater than 50 years. The temperature of the recharge water is generally less than 15°C, whereas groundwater with the perched intermediate zones within the basalt and Puye Formation and regional aquifer are generally greater than 15°C reflecting the geothermal gradient associated with the Jemez Mountains.

Results of stable isotope analyses of hydrogen and oxygen suggest that a portion of the groundwater encountered at R-25 is derived from the Sierra de los Valles. Major ion compositions of surface water in upper Cañon de Valle, Water Canyon, and R-25 groundwater are similar, suggesting a common recharge source.

Residence times of groundwater and chemical solutes (mass of water or solute/flux of water or solute) increase both with depth and from west to east across the Pajarito Plateau. Accordingly, increasing concentrations of major ions and trace elements are observed along the flow paths, whereas activities of tritium tend to decrease with depth. Residence times of the recharge groundwater are short as indicated by fracture flow within the Bandelier Tuff and Tschicoma Formation and porous media flow in the coarse-grained alluvium in upper Los Alamos Canyon. Short residence times occur within the alluvium in upper Los Alamos Canyon and in other canyons, whereas increasing residence times occur within perched intermediate zones and in the regional aquifer. A component of groundwater within the perched zones and the regional aquifer at boreholes R-9, R-12, R-15, and R-25 is less than 58 years, based on measurable tritium considerably above 1 pCi/L (cosmogenic baseline).

Figure 4.3.2.4. Geochemical conceptual model.

Reactive Minerals

Geochemically reactive minerals and solid phases approach equilibrium with groundwater when the residence time exceeds the reaction half time (amount of time required for 50% of reactant A to form product B assuming there is no B initially present) (Langmuir, 1997). These reactive constituents, consisting of CaCO_3 , Na-feldspar, Ca-smectite, amorphous SiO_2 , and $\text{Fe}(\text{OH})_3$, may control groundwater composition for the major ions and selected trace elements including iron and aluminum (Figure 4.3.2-4).

Extensive zones of calcium-rich smectite were encountered in the Puye Formation in boreholes R-9 and R-12 (Figure 4.3.2-4). Hydrolysis reactions of volcanic glass forming this clay mineral indicate that large quantities of groundwater have migrated through the Puye Formation during the past several million years. Calcium smectite is characterized by a large surface area, which enhances its sorption capacity for cations at near-neutral pH conditions.

Contaminant Distributions and Transport

The largest mass distribution of contaminants in Los Alamos Canyon and Mortandad Canyon occurs within the alluvium (ESH monitoring data). Alluvial groundwater in Los Alamos Canyon and Mortandad Canyon contain elevated activities of tritium, strontium-90, cesium-137, uranium, plutonium-238, plutonium-239/240, and americium-241. This observation supports the concept that most of these radionuclides, excluding uranium and tritium, adsorb onto sediments and aquifer material.

In general, sorption of these radionuclides and organic and inorganic species decrease as follows: cesium-137 (highest sorption) = americium-241 > strontium-90 > uranium > nitrate = sulfate = chloride = perchlorate = TNT = RDX = tritium (lowest sorption). Activities and concentrations of these sorbing radionuclides and inorganic species generally decrease downgradient along the groundwater flow path. Storm events, however, can remobilize contaminated sediments, and desorption of contaminants may take place resulting in a redistribution of contaminants. Elevated concentrations of nitrate, total Kjeldahl nitrogen (TKN), chloride, sulfate, sodium, potassium, and alkalinity are also observed in alluvial groundwater. Tritium was observed in the 646-ft perched zone at R-15 at activities of 3770 pCi/L. This is the highest activity of tritium observed in the basalt perched zones encountered at R-9, R-12, and R-15.

Uranium, tritium, chloride, oxalate, nitrate, and sulfate were detected in groundwater samples collected from boreholes R-9 and/or R-12 (Figure 4.3.2-4). Most of these conservative (nonsorbing) species have migrated from alluvial groundwater to perched intermediate zones and to the regional water table in Los Alamos Canyon and Sandia Canyon. Flow paths are possibly step-wise in orientation, based on the occurrence of unsaturated zones and lithologies of core samples collected at R-9, R-12, R-15, and LAOI-1.1.

Adsorption processes dominate to mineral precipitation for certain radionuclides because the groundwater is undersaturated with respect to solids containing plutonium and americium. Strontium may precipitate as SrCO_3 or coprecipitate as $(\text{Sr-Ba})\text{SO}_4$ in alluvial groundwater in Mortandad Canyon due to increased alkalinity and sulfate associated with the treated TA-50 discharge. Mineral precipitation, however, can be important for metals including barium, which is observed in alluvial groundwater and springs at TA-16. BaSO_4 and BaCO_3 have precipitated from solution and these two minerals probably control dissolved concentrations of barium in alluvial groundwater and springs at TA-16.

Colloid transport has been documented in Mortandad Canyon. The sources of colloids probably include natural materials (clay minerals, silica, ferric hydroxide, and solid organic matter) and possibly solid phases (silica and calcium carbonate) associated with the treated TA-50 discharge.

Anionic complexes of uranium and nitrogen are mobile in groundwater under near-neutral pH conditions typical of perched zones and the regional aquifer (Figure 4.3.2-4). Dissolved uranium (48.4 ppb) is present in the lower perched zone (275 ft) in the basalt at R-9 and is predicted to be dominantly stable as the $\text{UO}_2(\text{CO}_3)_3^{4-}$ complex. Model simulations using the computer code MINTEQA2 suggest that uranium in this form partly adsorbs (58%) onto hydrous ferric oxide at pH 8.8. Results of nitrogen isotope analyses suggest that the nitrate encountered in the basalt perched zones (443-503 ft) at R-12 is mainly derived from sewage effluent and that denitrification is occurring in the subsurface.

Presence of calcium smectite in boreholes R-9 and R-12 should enhance the sorption capacity of the Puye Formation. Sorption processes decrease concentrations of Laboratory-derived contaminants (cations including strontium-90, americium-241, and plutonium isotopes) potentially migrating through these zones. These characterization data are useful in developing a conceptual model for intrinsic remediation at R-9, R-12, and R-15.

HE compounds (RDX and TNT) and degradation products (2-A-4,6-dinitrotoluene and 4-A-2,6-dinitrotoluene) were observed at borehole R-25 in both the upper saturated zone (750-1287 ft) and in the regional aquifer (1407-1942 ft). RDX and TNT are mobile in the subsurface at R-25 due to small amounts of solid organic carbon present, which is the dominant adsorbent for these anthropogenic (manmade) contaminants (Rosenblatt et al. 1991). Degradation of TNT to 2-A-4,6-dinitrotoluene and 4-A-2,6-dinitrotoluene, however, occurs under reducing conditions. Dissolved organic carbon (DOC) possibly provides electrons necessary to reduce the nitro (NO_2^-) functional group(s) to amino functional (NH_2^-) group(s). DOC oxidizes to form bicarbonate during this process. RDX is considered to be recalcitrant in nature. RDX degradation products have not been analyzed for at R-25.

Gradients in oxidation-reduction potential (Eh) may occur at R-25 based on distributions of dissolved iron and manganese (Table 4.3.1-4). Concentrations of manganese decrease with depth, whereas concentrations of iron increase with depth. Dissolved Mn (II) species are stable at higher Eh values relative to dissolved Fe(II) species (Langmuir, 1997). Reduction of Mn(IV) to Mn(II) occurs at higher Eh conditions than does the reduction of Fe(III) to Fe(II), in which manganese reduction occurs before iron reduction. This is consistent with the elevated manganese concentrations observed at shallower depths in borehole R-25 (Table 4.3.1-4). These trace element distributions suggest that the Eh of the groundwater-aquifer material system decrease with depth at R-25.

Geochemical and hydrological data and information are essential in evaluating intrinsic remediation of HE compounds at R-25. More characterization data and information are required to quantify the fate and transport of RDX and TNT at R-25 and elsewhere.

4.4 Data Management

4.4.1 FY99 Information Management Summary

The Information Management subcommittee made significant progress in FY99 toward the development of an information management system that supports the efforts of the GIT. The majority of FY99 efforts were focused on project analysis, planning, and requirement specification.

Toward the end of FY99, intense system design efforts began in preparation for system development, testing, and implementation. These activities resulted in a change to the information management project name from the Groundwater Database Project (GWDB) to the Water Quality Database Project (WQDB). This name change recognizes that a single database development effort can be leveraged to provide an institutional repository for water data that includes (but is not limited to) groundwater data. Towards this end, a significant cooperative design effort has been ongoing between members of the ER and GIT information management system project teams. The goal for both teams has been to design an underlying database structure that will simplify data sharing, particularly the data associated with the Monitoring Well Installation Program. The end product will be a database information system that supports water data management activities for ESH-18 and the GIT and is accessible to the greater Laboratory and public stakeholder communities.

The WQDB is being implemented using an Oracle relational database management system and complimentary Oracle application development tools. The system will be hosted primarily on existing hardware that is supported by the Laboratory's ESH and CIC Divisions.

Project management assistance was gained from the Advanced Database and Information Technology Group (CIC-15) in June 1999. At that time, formal project management processes were implemented in preparation for development and implementation of the groundwater database system. The project began operating under standard software engineering methodologies including the DOE Software Engineering Methodology and the Software Engineering Institute's Capability Maturity Model.

During FY99, the information management system requirements were carefully analyzed and documented. The deliverables for this activity include a project plan and a system requirements document, which are available upon request from the Water Quality and Hydrology Group.

During the FY99 project planning and requirements specification efforts, it was decided that a modular approach to system design and implementation (Figure 4.4.2-1) would provide the best overall results. Multiple functional system requirements were identified for each system module including legacy data migration, support for ongoing data collection and insertion into the WQDB, and data retrieval capabilities via standardized reports and ad-hoc reporting tools with Internet access to data for external stakeholders. Once clearly defined, the WQDB system modules were prioritized (Table 4.4.2-1). The order of implementation of system modules is fixed for modules 1 and 2 because they are interdependent and are prerequisites for development of the remainder of the system modules. The order of implementation of modules 3-9 is based on consensus reached by the members of the GIT Information Management Subcommittee, additional WQDB project team members, and input from the EAG. Completion of this task corresponds to FY99 Planned Activity "Consensus will be sought by the HWPDB Project Leader on the priorities for loading the various data sets" given in last year's Annual Report.

Figure 4.4.2-1. Software development lifecycle.

Table 4.4.2-1. Proposed Order of Module Implementation.

Order	WQDB System Modules
1	Sampling Locations
2	Well Construction
3	Water Levels
4	Samples Taken
5	Field Data
6	Analytical Chemistry
7	Hydrologic Properties
8	Geophysical Logs
9	Geologic Units/Contacts

At the close of FY99, the WQDB project team worked extensively with the ER Project team to complete a preliminary database design for all WQDB system modules. The WQDB system will be based on a relational database design including entities (tables) and attributes (fields). The current design contains over 75 tables.

Primary information management accomplishments during FY99 and soon after are given in Table 4.4.2-2. Also provided is a correlation to three of the four "FY99 Planned Activities" that were called out in last year's Annual Report (Nylander et al. 1999). The fourth activity, "Development of a Data and Records Management Plan for the HWPDB by the HWPDB Project Leader", has not been completed and is discussed in section 5.3.

Table 4.4.2-2. Information Management Accomplishments through Early FY00.

Accomplishments	Completion Date	Corresponding "FY99 Planned Activity"
Project Plan Document*	07/09/1999	"Development and formalization of the 'end state vision' by the HWPDB Project Leader."
Preliminary Database Design* (all modules)	11/05/1999	"A data repository will be created and loading or linking of existing data and data currently being collected will begin in FY99."
System Requirements Document* (includes proposed project schedule & budget)	11/09/1999	"Development and formalization of the 'end state vision' by the HWPDB Project Leader."
Prioritization of WQDB System Modules	11/09/1999	"Consensus will be sought by the HWPDB Project Leader on the priorities for loading the various data sets."

* Documents available upon request.

5.0 FY00 PLANNED ACTIVITIES

This section summarizes project management, data collection, data interpretation, and data management activities that are to be carried out during FY00.

5.1 Project Management

The following bullets capture on-going project management activities:

- Hold GIT meetings on a biweekly basis, or as often as necessary to respond to program activities. Attempt to have one meeting each month address a technical topic related to the progress of the program.
- Collect input and regulatory direction in quarterly meetings and an annual meeting with stakeholders, DOE and NMED representatives.
- Facilitate the interaction of GIT subcommittees for an integrated approach to refining the Hydrogeologic Conceptual Model and consolidating hydrologic, geologic, and geochemical interpretations of data collection results into the annual status reports.
- Ensure external program review and review of documents by the EAG as necessary.
- Implement EAG recommendations as addressed in the EAG Action Plans to date.

5.2 Data Collection

The majority of data collection activities planned for FY00 are associated with the drilling, construction and completion of scheduled wells. These include MWIP wells R-31, R-19, R-7, and R-5 and others not in the original MWIP scope, namely the TA-15-CDV-15-3 well in Cañon de Valle and R-9i in Los Alamos Canyon. Data collection activities will be conducted as boreholes are drilled to depth and after completion as wells.

5.2.1 Geologic Data

Geologic data collection activities will mainly be centered around the installation of boreholes R-9i, R-31, R-19, TA-15-CDV-15-3, R-7, and R-5. Currently, drilling methods are to include hollow stem auger and air rotary with casing advance. Data collection activities will include:

- Continuous collection of cuttings for construction of lithologic logs of each borehole.
- Collection of core as needed for petrographic analyses and verification of the lithologic nature of geologic units, including the nature of fractures.
- Performing borehole geophysical methods on uncased boreholes whenever open-borehole drilling can be accomplished, and on the cased holes otherwise.
- Video logging sections of open boreholes when possible and deemed necessary.

5.2.2 Hydrologic Data Collection

Hydrologic data collection activities planned for FY00 include data collected from newly installed boreholes and wells as well as water level information collected from existing supply wells and test wells. Data collection activities will include:

- Collection of water-level data during the drilling of boreholes R-31, R-19, R-27, R-28, R-7 and R-5 to permit evaluation of vertical hydraulic gradients.
- Conducting field hydrologic testing to determine aquifer properties as appropriate for conditions encountered. This will involve slug (injection) tests or single-well pumping tests in both perched and regional zones of saturation.
- Submission samples of core to a commercial laboratory for hydrologic properties analyses as necessary to characterize perching layers or provide information on specific geologic units necessary for refining model parameters.
- Collection of water-level data in intermediate wells POI-4, LADP-3, and LAOI-1.1 using automatic recording pressure transducers.
- Collection of water-level data from alluvial boreholes at TA-16 using automatic recording pressure transducers.
- Collection of water-level data from existing test wells and supply wells on and adjacent to the plateau as part of annual environmental surveillance and compliance monitoring activities.

5.2.3 Geochemical Data Collection

Geochemical data collection activities planned for FY00 include data collected from newly installed boreholes and wells as well as groundwater sampling of existing supply wells and test wells. Data collection activities will include:

- Collection of core and cuttings for geochemical analysis during drilling of boreholes R-19, R-31, R-7 and R-5.
- Collection of groundwater samples both during drilling and from newly completed wells to evaluate natural element and contaminant distributions in perched zones and the regional aquifer.
- Collection of groundwater samples from alluvial boreholes at TA-16 to evaluate water and contaminant balance, and estimate residence times and mixing of groundwater and surface water.
- Collection of water quality samples from existing test wells and supply wells on and adjacent to the plateau as part of annual environmental surveillance and compliance monitoring activities.

5.3 Data Interpretation

Raw data requires interpretation before it can be used to make decisions on sampling and data collection efforts and be incorporated into the various modeling efforts. Once data is incorporated into the models, modeling simulations provide the next level of data interpretation that can then be used to make decisions on locations and number of wells, and where and what types of additional data are needed to have a comprehensive understanding of the hydrogeologic system.

5.3.1 Geologic Data Interpretation

In FY00, interpretation of geologic data collected from the newly installed boreholes will continue to be the main source of data for refining the 3-D Site Geologic Model. The interpretation process does however continue to rely upon review of, and comparison to, historic data such as borehole logs, lithologic interpretations, and geologic surface maps. Geologic data interpretation will include:

- Interpretation of newly collected data from boreholes: petrographic analyses, lithologic nature of geologic units, nature of fractures, etc.
- Interpretation of borehole geophysical logs.
- Review of existing borehole and geologic data.
- Incorporation of new data and interpretations into the 3-D Site Geologic Model.

5.3.2 Hydrologic Data Interpretation

In FY00, interpretation of hydrologic data will include:

- Interpretation of water-level data collected from new and existing wells and boreholes. Incorporation of new data and interpretations into the various hydrologic modeling efforts.
- Interpretation of aquifer characteristics from field hydrologic tests performed in both boreholes and completed wells.
- Estimate transmissivity and storage coefficients of the regional aquifer from water-level fluctuation data
- Incorporation of data interpretation into the various hydrologic models.
- Update the Hydrogeologic Atlas.

5.3.3 Geochemical Data Interpretation

In FY00, interpretation of geochemical data will include:

- Completion of the LANL background groundwater investigation for the ER Project and preparation of a report detailing natural distributions of inorganic and radionuclide solutes

and dissolved organic carbon within alluvium, perched zones, and the regional aquifer at 15 sampling stations considered to be upgradient of any LANL operations.

- Initiation of a strategy for incorporating the effects of natural attenuation into the decision-making process within the GIT. Geochemical data and information collected from various characterization and monitoring wells will be used to begin quantifying the site-specific and site-wide effects of this natural geochemical process with respect to Laboratory contamination.
- The Geochemical Conceptual Model will be refined based on knowledge gained from FY00 data collection and analytical results.

5.3.4 Modeling

Modeling efforts include geologic, hydrologic, and geochemical modeling. Newly collected data and interpretations will be used to refine these models. Table 5.3.4-1 provides FY99 status and future activities necessary to accomplish the modeling goals identified in the Hydrogeologic Workplan (LANL, 1999).

5.3.4.1 Geologic Modeling

The 3-D Site Geologic Model will be updated in FY00 to incorporate new data and interpretation of stratigraphic sequences and contacts. Specifically, updates to the model will include:

- Improved interpretation of the occurrences and nature of basalt units in the Puye Formation and the Santa Fe Group.
- Improved interpretation of stratigraphic subdivisions of the Puye Formation.
- Improved interpretation of stratigraphic subdivisions of the Bandelier Tuff.
- New understanding of the spatial distribution and varying thicknesses of the Totavi lentil.

5.3.4.2 Hydrologic Modeling

Los Alamos Canyon modeling:

The Los Alamos Canyon model activities for FY00 will focus on improving the flow model based on new information, and performing many additional transport simulations.

- In FY 99, geologists developed a new version of the 3-D Site Geologic Model. This version will be incorporated into the flow model. Parameter sensitivity analyses will be carried out for a greater number of hydrologic units with alternate conceptual models for infiltration. These models will be tested against the data to attempt to narrow the range of possible infiltration rates that are consistent with field observations.
- The hydrologic representations of the basalt units and the Puye formation will be improved. Transport simulations will again address tritium, but will also include more important contaminants such as Sr and U. Reactive chemical transport models will be developed for these two contaminants.

Table 5.3.4-1. Status of FY99 Non-Field Activities

Task	Subtasks	1999 Status	Future Activities
Develop Geologic Model	Compile and publish drilling and completion data from all significant boreholes.	Interim completion reports completed for R-9, R-12 and R-15.	Develop completion reports for alluvial, perched intermediate, and regional wells as installed.
	Perform comprehensive review of three-dimensional (3-D) stratigraphy including analytical chemistry and mineralogy necessary to make stratigraphic correlations between boreholes, integrate newly-collected geologic data into structure-contour maps, isopach maps and cross section	3-D Geologic Model migrated to Stratamodel. Data from R-9, R-12, R-25, R-15 and other boreholes incorporated into cross sections and structure contour maps. New data on basalts and Tshicoma Formation incorporated into model Model used to develop Hydrogeologic Atlas	Incorporate new data from FY00 boreholes into cross sections and structure contour maps. Incorporate additional information on extent and nature of basalts and Totavi lentil. Develop a data model for the Chaquehui Fm. Update Hydrogeologic Atlas as 3-D model updated
	Develop 3-D geological database to include surface geology, structural geology, and borehole stratigraphy.	Information management database design complete. Mechanism for capturing existing and new geologic data implemented.	Develop web access to geologic information
	Salvage of data from stratigraphic and geochemical analysis of available canyon bottom core samples	Because of budgetary constraints, this activity has been deferred	
Develop Hydrologic Model	Compile and publish hydraulic characteristic data:		
	Bandelier Tuff - Assemble hydrologic laboratory test results of Bandelier Tuff core from across the Plateau. Evaluate test results for validity. Calculate unsaturated hydraulic properties from moisture retention characteristics. Summarize data by stratigraphic unit and locations.	Core samples of Bandelier Tuff from boreholes R-25, R-9, R-12, and R-15 submitted for hydrologic properties analyses.	Hydraulic properties of Bandelier Tuff will be evaluated for testing in each characterization borehole.
	Determination of vadose zone fluxes in Los Alamos mesas using chloride and stable isotope profiles. Analyze soil moisture for chloride mass and isotope ratios. Calculate fluxes from tracer profiles.	Isotope data collection for determining flux on mesa tops at TA-16, TA-49, and TA-54 for variety of disturbed and undisturbed conditions	Continue to analyze soil moisture for chloride mass and isotope ratios at regular intervals in each characterization borehole.
	Hydrologic parameter estimation for the Pajarito Plateau, including in-situ hydraulic testing of wells. Load available hydrologic measurements in 3-D database. Statistically describe zones and regions.	New hydraulic properties data were incorporated into the regional-scale hydrologic model.	Estimate transmissivities and storage coefficients from water-level fluctuations. Use existing and newly collected hydrologic properties of the regional aquifer in plateau-scale model.
	Inventory springs on-site and near Laboratory boundaries by reviewing existing Laboratory and the United States Geological Survey (USGS) reports for initial inventory. Perform additional field reconnaissance. Supplement with aerial photography where possible. Select springs with discrete discharge points. Install flow and monitoring probes.	Several springs in and around TA-16 equipped with flow meters for water balance data collection during FY99 and FY00.	Continue to obtain field observations from Laboratory and NMED personnel. Continue ER investigations at critical discharge points (particularly TA-16 and TA-18) where there is uncertainty if flow is natural spring-fed or perennial. Continue monitoring of flow and for bromide tracer and other chemical constituents. Analyses of the flow and chemistry time series will be conducted

Table 5.3.4-1. Status of FY99 Non-Field Activities (concluded)

Task	Subtasks	1999 Status	Future Activities
Develop Hydrologic Model (continued)	Long-term water balance estimates for the Pajarito Plateau. Install stream gages at upstream and downstream boundaries of the Laboratory. Continuously measure evapotranspiration (ET), precipitation, and groundwater levels.	Data collected in most regional aquifer test wells, and some intermediate and shallow alluvial wells. Stream flow measurements collected from 19 stations. Precipitation data collected from 7 stations and ET data collected from 2 stations. New on-site gaging station network installed as part of a watershed management program to provide continuous monitoring of flow and data necessary for ET estimation	Water level data will be collected annually. Gaging stations are planned for installation upstream of LANL (west of the western boundary)
	Groundwater flow modeling using the FEHM code	Improved calibration of the regional-scale model, published conceptual and numerical models. Created a high-resolution Pajarito Plateau-scale model, conducted sensitivity analyses to identify areas of critical data needs, used geostatistics to simulate heterogeneity within hydrostratigraphic units, and incorporated pumping effects/transients	Incorporate geochemical data and new version of basin hydrostratigraphy. Incorporate new permeability and water-level data from deep wells. Update flow calibration. Initiate facies-based stochastic permeability modeling for sedimentary units.
Develop Geochemical Model	Evaluate Water Quality Data: Consolidate historical water quality data in database and perform trend analysis.	Completed report on the trend analysis San Ildefonso Pueblo. Made water quality data available via the Internet.	Continue trend analysis on the historic data and focus on evaluating trends by drainage basins.
	Evaluate water quality variations and vertical stratification within the regional aquifer using water samples from supply wells. Pull permanent pump and isolate discrete sample zones (46-ft lengths) in each well using hydraulic packers. Sample with temporary pump.	Zonally sampled well PM-4.	Zonally sample water supply wells as the opportunity arises during maintenance. Complete the background investigation and prepare report.
	Hydrogeochemical and statistical evaluation of solute distributions on the natural surface and groundwaters	Expanded statistical evaluation of solute distributions for LANL background distributions. Incorporated geochemical data from R-9, R-12, R-15, and R-25.	Continue hydrochemical analyses of groundwater and surface water to develop representative distributions that can be used in hydrologic modeling.
	Geochemical characteristics of key subsurface hydrogeologic units	Characterized hydrochemistries of alluvium, perched intermediate zones, and regional aquifer and associated aquifer material in R-9, R-12, R-15, and R-25.	Continue to characterize hydrochemistry of alluvium, perched intermediate zones, and regional aquifer and associated aquifer material from boreholes as they are drilled and completed.
	Geochemical modeling	Performed speciation, mixing, and mineral saturation calculations using MINTEQA2 and PHREEQC for water collected from R-9, R-12, R-15, and R-25.	Continue geochemical modeling to understand important processes occurring along groundwater flow paths.

- The role of perched water in altering the pathways of water and enhancing transport velocities will be investigated more thoroughly.

Regional aquifer modeling:

Goals pertaining to continued regional aquifer model development and incorporation of new data from the drilling program:

- Incorporate water chemistry data into flow calibration process (postponed to FY00 because of FY99 budget cut)
- Incorporate new Stratamodel version of basin hydrostratigraphy (from EES-1) and update flow calibration.
- Incorporate any new permeability or water level data collected in deep wells, update flow calibration
- Initiate facies-based stochastic permeability modeling for sedimentary units (*share cost with Pajarito Plateau modeling program*)

Goals pertaining to regional aquifer model applications:

- Provide HE transport calculations in support of Pajarito Plateau program, incorporating relevant reactions, if necessary (to be funded by Pajarito Plateau modeling program)
- Provide detailed sensitivity analysis of flow and transport simulations in order to identify critical needs for future data collection. This goal would provide the coupling between modeling and data collection that would benefit both programs.
- Update the Hydrogeologic Atlas based on the incorporation of the new version of the 3-D Site Geologic Model and the Regional Aquifer Model

5.3.4.3 Geochemical modeling

Geochemical modeling will be performed using MINTEQA2 for quantifying the speciation, mineral reactions and sorption of strontium and uranium onto hydrous ferric oxide (HFO) in upper Los Alamos Canyon.

5.4 Data Management

In FY00, the WQDB project intends to complete the iterative design, development, testing, and implementation cycle for multiple WQDB system modules. At the close of FY99, the WQDB project team secured additional funding and personnel to be utilized throughout FY00 for modular system development, testing, and implementation. Modules and their delivery dates are currently estimated in Figure 5.4-1.

Figure 5.4-1. Proposed WQDB project schedule.

During the detailed design phase for each system module, issues of data management are being addressed (FY99 Planned Activity "Development of a Data and Records Management Plan for the HWPDB by the HWPDB Project Leader"). Data management is an operational issue related to the individuals and teams generating and collecting data for intended incorporation into the WQDB. A data steward has been identified for each module, and the data management procedures related to the module are reviewed and incorporated into the design of each module. This design process enables data stewards and their teams to more specifically define system requirements and to adjust their existing data management practices (where necessary) to support the use of a centralized database.

5.5 MWIP Borehole Status

The priority and a summary of the MWIP borehole installation activities and well completion status is provided here in tabular form to consolidate the information provided throughout this report. Table 5.5-1 provides a list of boreholes ordered by priority of installation. Table 5.5-2 captures FY98 changes in installation scheduling as published in the Hydrogeologic Workplan (LANL 1998) and provides the status of drilling activities and decisions on well completion. Figure 4.0-1 shows the location and completion status of the proposed regional aquifer boreholes.

**Table 5.5-1. MWIP Proposed Regional Aquifer Boreholes
Priority and Start Dates**

Priority	Borehole	Funding Source	Current Start Date	FY99 Drilling Status
1.	R-9	ER	Sep FY98	Complete
2.	R-12	ER	Mar FY98	Complete
3.	R-25	NWT	Jul FY98	Complete
4.	R-15	ER	Aug FY98	Complete
5.	R-31	NWT	Aug FY99	Started
7.	R-19	ER	Feb FY00	Started
12.	R-7	ER	May FY00	-----
8.	R-5	NWT	Jul FY00	-----
9.	R-28	NWT	Oct FY01	-----
6.	R-27	ER	Nov FY01	-----
10.	R-22	ER	Feb FY01	-----
13.	R-1	NWT	Feb FY01	-----
11.	R-32	NWT	Jul FY01	-----
14.	R-18	ER	Nov FY02	-----
15.	R-8	NWT	Feb FY02	-----
16.	R-10	ER	May FY02	-----
17.	R-2	NWT	Aug FY02	-----
18.	R-3	ER	Nov FY03	-----
19.	R-20	NWT	Feb FY03	-----
20.	R-4	ER	May FY03	-----
21.	R-14	NWT	Aug FY03	-----
22.	R-13	ER	Nov FY04	-----
23.	R-11	NWT	Feb FY04	-----
24.	R-17	ER	May FY04	-----
25.	R-6	NWT	Aug FY04	-----
26.	R-23	ER	Nov FY05	-----
27.	R-29	NWT	Feb FY05	-----
28.	R-16	NWT	Feb FY05	-----
29.	R-21	ER	May FY05	-----
30.	R-26	NWT	May FY05	-----
31.	R-24	NWT	Aug FY05	-----
32.	R-30	ER	Aug FY05	-----

Table 5.5-2. Status of MWIP Proposed Regional Aquifer Boreholes

Borehole	Original Start Date	Current Start Date	FY98 Status	Funding Source	Status of Installed Boreholes/Rationale of Proposed Boreholes
R-9	FY98	FY98	Borehole drilled, well constructed, completion scheduled for Mar 00	ER	Borehole R-9 has been installed at the eastern Laboratory boundary in Los Alamos Canyon, but not yet completed as a single-completion monitoring well. It was designed to provide water-quality and water-level data for potential intermediate perched zones and for the regional aquifer downgradient of Aggregate 1. Borehole R-9 encountered two perched intermediate saturated zones at 180 and 275 ft. Additionally, three separate saturated zones (579, 615, and 624 ft) were encountered above the regional aquifer (688 ft). The stratigraphic, hydrologic, and geochemical description of R-9 is included in Section 4.1.1.
R-12	FY98	FY98	Borehole drilled, well constructed, completion scheduled for Mar 00	ER	Borehole R-12 has been installed at the eastern Laboratory boundary in Sandia Canyon, but not yet completed as a monitoring well. It was designed to provide water-quality and water-level data for potential intermediate perched zones and for the regional aquifer downgradient of Aggregate 1. Due to the proximity of R-12 to R-9, PM-1, and O-1 which provided stratigraphic information, it was not continuously cored. R-12 serves as a water-supply protection well for PM-1. Sandia Canyon has received treated effluents from Laboratory operations (TA-3, TA-53, TA-60, and TA-61) though no contaminants have been detected in nearby water supply well PM-1. Intermediate perched zone groundwater was encountered at a depth of 443 ft and the zone is about 75 ft thick. The stratigraphic, hydrologic, and geochemical description of R-12 is included in Section 4.1.1.
R-25	FY98	FY98	Borehole drilled, well constructed, completion scheduled for Mar 00	NWT	Borehole R-25 has been partially installed as a multipurpose borehole located adjacent to MDA P in Aggregate 5. Core collected from this borehole will support site-wide studies of the hydrogeologic framework because it is located in a largely uncharacterized area in the southwest part of the Laboratory. It was not continuously cored. This hole will provide critical information about the depth to the regional aquifer for this area. R-25 will also provide water quality data for intermediate perched zones and the regional aquifer downgradient from MDA P and from other release sites further west in the Cañon de Valle watershed. Springs issuing from the upper Bandelier Tuff in this area are contaminated with HE, nitrate, and barium. R-25 is part of a southeasterly traverse of reference wells that includes R-28 and R-32 and a north-south traverse that includes R-6.
R-15	FY00	FY98	Borehole drilled, well constructed, completion scheduled for Feb 00	ER	Borehole R-15 has been partially installed in Mortandad Canyon downstream from active and inactive outfalls at TA-5, TA-35, TA-48, TA-50, TA-52, TA-55, and TA-60. The presence of intermediate perched zones within Aggregate 7 will be investigated and, if present, characterized. Characterization data from R-15 are critical for supporting the TA-50 Discharge Plan and for addressing citizens concerns about releases in Mortandad Canyon. R-15 may replace TW-8 completed in 1960. The location of R-15 is described in the ER Work Plan for Mortandad Canyon (LANL, 1997).
R-31	FY01	FY99	Borehole drilled, well construction and completion scheduled for Mar 00	NWT	Site-wide characterization borehole R-31 is planned for installation downgradient of open burning/open detonation sites in Aggregate 6 and upgradient of firing sites in Aggregate 4. The primary objective of this borehole is to provide water quality data for potential intermediate perched zones and for the regional aquifer. This is a part of the Laboratory with no well control, and data from this borehole is critical to the modeling activities. This borehole will contribute to the optimization of long-term monitoring wells for Aggregates 4 and 6 by placing better constraints on the geometry of the regional aquifer in this area.

Table 5.5-2. Status of MWIP Proposed Regional Aquifer Boreholes (continued)

Borehole	Original Start Date	Current Start Date	FY98 Status	Funding Source	Status of Installed Boreholes/Rationale of Proposed Boreholes
R-19	FY01	FY00	Borehole started	ER	R-19 is planned for installation to provide information about intermediate perched zone groundwater, depth to the regional aquifer, and water quality in the poorly-characterized central part of the Laboratory. R-19 provides downgradient water quality data for release sites in upper Pajarito Canyon and upgradient data for TA-18. R-19 will help constrain the location of the axis of the south-draining pre-Bandelier paleo-drainage which trends through this area.
R-7	FY98	FY00	Accelerated due to reprioritization	ER	R-7 is planned for installation in upper Los Alamos Canyon to provide water-quality and water-level measurements for the intermediate perched zones and the regional aquifer in an area of Los Alamos Canyon that is in close proximity to release sites of contaminated effluent (TA-2 and TA-21). R-7 is located between existing boreholes LADP-3 and LAOI(A)1.1 in Los Alamos Canyon. These existing boreholes, and H-19 located west of Los Alamos Canyon bridge, penetrated a 5- to 22-ft thick perched intermediate zone. The water quality data suggest that the perched zone is recharged both by infiltration from overlying alluvium and by recharge sources in the mountains to the west. R-7 is sited in this area of suspected recharge and will provide information about stratigraphic and structural controls on infiltration. Also, R-7 will penetrate the full extent of saturation at the top of the Puye Formation and identify deeper intermediate perched zones beneath Los Alamos Canyon. Hydrologic and geologic properties of pre-Bandelier units in R-7 will be used for ER Project assessments of mesa-top sites at TA-21, TA-53, and TA-73.
R-5	FY00	FY00	Planned	NWT	R-5 is planned for installation in lower Pueblo between the Los Alamos County Sewage Treatment Plant and water supply well O-1 and nearby test wells TW-1 and TW-1A. Laboratory surveillance data (EPG 1995, EPG 1996) show the presence of NO ₃ (TW-1, TW-1A, TW-2A), ^{239,240} Pu (TW-2A), and ¹³⁷ Cs (TW-1A) at various concentrations and activities below MCLs, except for NO ₃ (23 mg/l NO ₃ -N; MCL NO ₃ -N = 10 mg/l). R-5 will provide a monitoring point between the sewage treatment plant and wells TW-1, TW-1A, and O-1. R-5 will also provide information on whether a recharge mound occurs below the canyon floor and is responsible for the anomalously-high regional aquifer water levels in TW-1. R-5 could serve as a replacement well for TW-1 drilled by cable tool in 1950.
R-28	FY01	FY01	Planned	NWT	R-28 is planned for installation as a multipurpose borehole in the middle reach of Water Canyon. This borehole will provide water-quality information for potential intermediate perched zones and for the regional aquifer beneath PRSs in Aggregate 6, and it will provide information for optimizing the placement of monitoring wells in this part of the Laboratory. R-28 is presently scheduled to be completed as a Type 3 well, but the option is preserved to advance these boreholes to a total depth of 4000 ft and to include multiple completions of the well if funding agencies decide further characterization of regional aquifer groundwater resources is required.

Table 5.5-2. Status of MWIP Proposed Regional Aquifer Boreholes (continued)

Borehole	Original Start Date	Current Start Date	FY98 Status	Funding Source	Status of Installed Boreholes/Rationale of Proposed Boreholes
R-27	FY00	FY01	Planned	ER	R-27 is planned for installation at the confluence of Water Canyon and Cañon de Valle to characterize baseline water quality in intermediate perched zones and in the regional aquifer groundwater upgradient of Aggregate 3. High explosives were detected in water from borehole R-25. R-27 also will provide baseline information on the geology, hydrology, and water quality for the poorly-characterized south-central part of the Laboratory. These data will be used in conjunction with data from R-28 and R-30 to optimize placement of monitoring wells in the vicinity of Aggregates 3, 5, and 6. A more detailed analysis of well placement in Water Canyon and Cañon de Valle will be included in the ER sampling and analysis plan to be prepared by FY00.
R-22	FY98	FY01	Planned	ER	R-22 is planned for installation near the southeastern Laboratory boundary in Pajarito Canyon to provide water-quality and water-level data for potential intermediate perched zones and for the regional aquifer downgradient of Aggregate 2. Aggregate 2 includes MDA L and MDA G. In addition, this location is downgradient of numerous other Laboratory technical areas which released HE, radionuclides, organic solvents, and inorganic solutes. Large springs (e.g., Pajarito Spring) discharge from basalts in lower Pajarito Canyon into White Rock Canyon. Water-quality characteristics will be compared for R-22 and the springs to evaluate whether these groundwater-bearing zones are hydrologically connected.
R-1	FY01	FY01	Planned	NWT	R-1 is planned for installation as a multipurpose borehole located north of Aggregate 1 in Rendija Canyon. R-1 is sited along the northward projection of Purtymun's (1995) mid-Miocene high-permeability zone at the top of the Santa Fe Group, and this borehole could significantly extend the known northern limit of this important water-supply feature. This borehole is presently scheduled to be completed as a Type 3 well, but the option is preserved to advance the boreholes for these wells to a total depth of 4000 ft and to include multiple completions of the wells if funding agencies decide further characterization of regional aquifer groundwater resources is required. Water-level and water quality data from this borehole will be used to test hypotheses concerning possible recharge to the regional aquifer from the north. R-1 is part of a north-south traverse of reference wells that includes R-14 and R-28.
R-32	FY01	FY01	Planned	NWT	R-32 is planned for installation west of Ancho Spring in lower Ancho Canyon. This borehole is designed to provide baseline information on the geology, hydrology, and water quality for the poorly studied southeastern boundary of the Laboratory. It is located within Aggregate 4 and will provide water-quality and water-level data for intermediate perched zones and the regional aquifer in this area. Water quality data for R-32 will be compared to similar data for springs in White Rock Canyon to identify potential groundwater flow paths near the Rio Grande. Water samples from Ancho Spring contain HE and depleted U which probably originated from firing sites in Aggregates 4 or 6.

Table 5.5-2. Status of MWIP Proposed Regional Aquifer Boreholes (continued)

Borehole	Original Start Date	Current Start Date	FY98 Status	Funding Source	Status of Installed Boreholes/Rationale of Proposed Boreholes
R-18	FY99	FY02	Planned	ER	R-18 is planned for installation above the confluence of Pajarito and Twomile Canyons to provide information about intermediate perched zone groundwater, depth to the regional aquifer, and water quality of perched zones and the regional aquifer in the poorly-characterized west-central part of the Laboratory. It is located downstream from Laboratory release sites at TA-8, TA-9, TA-14, TA-22, TA-40, and TA-69, but is in an area that has not been characterized for either groundwater or contaminants. The occurrence of surface flow through most of the year indicates perched alluvial groundwater is present in this part of the canyon.
R-8	FY00	FY02	Planned	NWT	R-8 is planned for installation near the confluence of Los Alamos Canyon and DP Canyon as a water-supply protection well for Otowi-4. When in service, Otowi-4 will provide ~25% of the water supply to Los Alamos County including the Laboratory. Laboratory surveillance data indicated the presence of ^3H (~50 pCi/l) and ^{90}Sr (35 pCi/l) in TW-3 located ~300 ft northeast of Otowi-4. Los Alamos Canyon has a long history of facility releases with contaminants detected in alluvial groundwater (^3H , ^{90}Sr , and ^{137}Cs) and in an intermediate perched zone in the Guaje Pumice Bed (^3H). These perched zones may provide recharge to the regional aquifer. DP Canyon contains radionuclides released from the north side of TA-21. R-8 could be used as a replacement well for TW-3 drilled by cable tool in 1949.
R-10	FY00	FY02	Planned	ER	R-10 is planned for installation in upper Sandia Canyon to provide water-quality information for a potential intermediate perched zone in the Guaje Pumice Bed. The large intermediate perched zone in Los Alamos Canyon is located in this horizon and contains significant ^3H . This perched zone appears to be largely confined to the area beneath Los Alamos Canyon west of TA-21 (the Guaje Pumice Bed was not saturated in boreholes 21-2523 and LADP-4 north of Los Alamos Canyon), but structure contour maps (Broxton and Reneau 1996; Davis et al. 1996) suggest that the gradient of the perching layer changes in the vicinity of R-7 and R-10, and water perched in this zone will move southward along the axis of a large pre-Bandelier paleo-drainage. R-10 is designed to investigate the southward extension of this perched system from the Los Alamos Canyon area.
R-2	FY00	FY02	Planned	NWT	R-2 is planned for installation near the confluence of Acid Canyon and Pueblo Canyon within Los Alamos townsite. Laboratory surveillance data collected at nearby mesa-top borehole TW-4 indicate the presence of ^{90}Sr (6.2 pCi/l, MCL = 8 pCi/l) in the regional aquifer (EPG 1996). This remediated area (former TA-45) has documented releases of Am, Pu, NO_3 , U, and other contaminants to alluvial groundwater in Acid and Pueblo Canyons in the late 1940s and early 1950's. R-2 is sited in Pueblo Canyon and is downgradient of the Rendija Canyon fault. Recharge contaminated from past releases may be reaching intermediate perched zones and the regional aquifer along this fault. Analyses of core and water samples collected from R-2 will be used to evaluate the fault as a preferential groundwater pathway. R-2 could replace TW-4 drilled by cable tool in 1950.

Table 5.5-2. Status of MWIP Proposed Regional Aquifer Boreholes (continued)

Borehole	Original Start Date	Current Start Date	FY98 Status	Funding Source	Status of Installed Boreholes/Rationale of Proposed Boreholes
R-3	FY99	FY03	Planned	ER	R-3 is planned for installation in upper Pueblo Canyon to provide water-quality information for potential intermediate perched zones and for the regional aquifer beneath upper Pueblo Canyon downgradient of former TA-45. In the past, natural surface water flow in Pueblo Canyon was augmented by Laboratory releases and by effluent from the former sewage waste-water treatment plant in upper Pueblo Canyon. Because of the augmented surface flow, upper Pueblo Canyon may have been a source of recharge to intermediate perched zones and the regional aquifer. The available data suggest that mobile contaminants associated with former TA-45 (^3H , ^{90}Sr , and NO_3) are present in a groundwater plume that extends at least 1.75 mi down Pueblo Canyon and may extend further. Additional mapping of intermediate perched zones and characterization of water quality is needed to assess the nature of groundwater contamination in upper Pueblo Canyon.
R-20	FY02	FY03	Planned	NWT	R-20, water-supply protection well for PM-2, is planned for installation in lower Pajarito Canyon southwest of MDA L and MDA G at TA-54. MDA L has an organic vapor plume(s) consisting of 1,1,1-TCA; TCE; and CCl_4 that has migrated to a depth at least 500 ft within basalts under the Bandelier Tuff. R-20 is sited between PM-2 and MDA L. Alluvial groundwater within lower Pajarito Canyon contains above background activities of solvents, HE , ^3H , NO_3 , and U , all of which are below MCLs. Intermediate perched zones may occur within the Bandelier Tuff, based on drilling logs for PM-2, and within basalts.
R-4	FY01	FY03	Planned	ER	R-4 is planned for installation to provide water-quality and water-level information for potential intermediate perched zones and for the regional aquifer beneath middle Pueblo Canyon. R-4 will provide information about the downgradient extent of groundwater contamination from former TA-45. This borehole is located between TW-1A and TW-2A, both of which were completed in intermediate perched zones containing contaminant levels that are above background levels. R-4 will place constraints on the lateral extent of the perched zone(s) and identify deeper perched zones within the Puye Formation and basalts in middle Pueblo Canyon near the northern Laboratory boundary. R-4 will also characterize groundwater water quality upgradient of the county's Bayo Sewage Treatment Plant.
R-14	FY02	FY03	Planned	NWT	R-14 is planned for installation as a water-supply protection well for PM-5. Previous investigations and surveillance data show that surface water and alluvial groundwater in Mortandad Canyon contain ^3H , Pu , and NO_3 released from the Laboratory's liquid radioactive waste treatment plant at TA-50. Elevated activities of ^3H occurs in core samples collected 100–200 ft below the canyon floor (Stoker et al. 1991). Sampling of TW-8 confirmed the presence of ^3H (89 pCi/l), ^{90}Sr (2.1 pCi/l), $^{239,240}\text{Pu}$ (0.188 pCi/l), ^{241}Am (0.034 pCi/l), and NO_3 (as N, 5.1 mg/l) in the regional aquifer beneath Mortandad Canyon (EPG 1996). R-14 will provide information about the radius of influence of pumping from PM-5, and its location will be optimized to detect the migration of contaminants from Mortandad Canyon towards the water supply well. R-14 is part of a southeasterly traverse of reference wells that includes R-6 and R-16 and a north-south traverse that includes R-1 and R-28.

Table 5.5-2. Status of MWIP Proposed Regional Aquifer Boreholes (continued)

Borehole	Original Start Date	Current Start Date	FY98 Status	Funding Source	Status of Installed Boreholes/Rationale of Proposed Boreholes
R-13	FY01	FY04	Planned	ER	R-13 is planned for installation to provide water-quality and water-level data for potential intermediate perched zones and for the regional aquifer within Aggregate 7. Laboratory surveillance data collected in Mortandad Canyon show elevated concentrations or activities of NO ₃ , ³ H, ⁹⁰ Sr, ¹³⁷ Cs, ^{239,240} Pu, ²⁴¹ Am, and U in ephemeral surface water and in alluvial groundwater. Vertical migration of ³ H beneath the canyon floor has been documented by Stoker et al. (1991).
R-11	FY03	FY04	Planned	NWT	R-11, planned for installation as a water-supply protection well for PM-3, is located in middle Sandia Canyon east of the TA-72 firing range. PM-3 is downgradient from source terms with a long history of releases at TA-53 and TA-21. R-11 is located between PM-3 and the potential release sites. R-11 will also provide information about groundwater gradients near PM-3, which has water levels that are anomalously high compared to elevations expected from regional water level maps.
R-17	FY02	FY04	Planned	ER	R-17 is planned for installation in Twomile Canyon, a major tributary to Pajarito Canyon, to provide information about intermediate perched zones, depth to the regional aquifer, and water quality of intermediate perched zones and the regional aquifer in the poorly-characterized northwest part of the Laboratory. It is located downstream from Laboratory release sites at TA-3, TA-6, TA-58, TA-59, TA-62, and TA-69, but is in an area that has not been characterized for either groundwater or contaminants. R-17 will also provide upgradient water-quality information for Aggregate 7.
R-6	FY03	FY04	Planned	NWT	R-6, planned for installation in upper Los Alamos Canyon, is designed to provide baseline information about the geology, hydrology, and water quality for the western boundary of the Laboratory. This borehole will determine background water quality for intermediate perched zones and the regional aquifer upgradient of Aggregate 1. It also will provide information about the depth to the regional aquifer for the western part of the Laboratory, and contribute to the construction of accurate groundwater maps for placing monitoring wells in this part of the Laboratory. R-6 is part of a southeasterly traverse of reference wells that includes R-14 and R-16 and a north-south traverse that includes R-25.
R-23	FY02	FY05	Planned	ER	R-23, located near the southeastern Laboratory boundary, is planned for installation to provide water-quality and water-level data for potential intermediate perched zones and for the regional aquifer downgradient of active firing sites in Potrillo Canyon. R-23 is sited within a hydrological sink, a broad area of infiltration on the canyon floor that typically marks the easternmost occurrence of surface water flow in this canyon. R-23 will evaluate the hydrological sink as a possible recharge zone for perched groundwater and for the regional aquifer.
R-29	FY03	FY05	Planned	NWT	R-29 is planned for installation in lower Water Canyon. It will provide information about the depth to the regional aquifer in a poorly-characterized area, and the water-level data will be used to optimize the placement of downgradient monitoring wells along the eastern Laboratory boundary. Water quality data from perched and regional groundwaters in R-29 will be compared to similar data for springs in White Rock Canyon to identify potential groundwater flow paths near the Rio Grande.

Table 5.5-2. Status of MWIP Proposed Regional Aquifer Boreholes (continued)

Borehole	Original Start Date	Current Start Date	FY98 Status	Funding Source	Status of Installed Boreholes/Rationale of Proposed Boreholes
R-16	FY03	FY05	Planned	NWT	R-16, planned for installation in White Rock, will provide baseline information on the geology, hydrology, and water quality for a large uncharacterized area between the eastern boundary of the Laboratory and the Rio Grande. Numerous springs in White Rock Canyon probably represent discharge points for intermediate perched zones and the regional aquifer based on significant differences in major ion chemistry and stable isotopes. R-16 will determine background water quality for intermediate perched zones and the regional aquifer between the Laboratory and the Rio Grande, provide information about the depth to the regional aquifer for the eastern part the Laboratory, and clarify the relationship between springs in White Rock Canyon and various groundwater zones. R-16 is part of a southeasterly traverse of reference wells that includes R-6 and R-14.
R-21	FY02	FY05	Planned	ER	R-21 is planned for installation to evaluate and monitor hydrologic and geochemical conditions in the regional aquifer beneath MDA L. The ER Project has detected dense non-aqueous phase vapors beneath MDA L; these organic vapors have migrated through fractures in the Bandelier Tuff and the underlying basalts to a depth of 500 ft.
R-26	FY02	FY05	Planned	NWT	R-26 is planned for installation near the trace of the Pajarito fault system near the southwest corner of the Laboratory. This borehole will provide water-quality and water-level data for perched systems and the regional aquifer on the downthrown block of the Pajarito fault system. Numerous springs, including the large Water Canyon Gallery, issue from the Bandelier Tuff in Water Canyon. The location and occurrence of perched water and water level data for the regional aquifer, when compared with similar data from R-24 and R-25 on the downthrown and upthrown blocks, respectively, will be used to evaluate the influence of the Pajarito fault system on the regional piezometric surface and provide information about its role as a recharge zone. Water quality data from intermediate perched zone and regional groundwater in R-26 will define background conditions in a large wet canyon upgradient from the Laboratory, and in particular for Aggregate 5. These background geochemical data will be used to define potential impacts on groundwater from Laboratory facilities and to provide input data for geochemical and hydrological modeling of different groundwater systems.
R-24	FY02	FY05	Planned	NWT	R-24 is planned for installation near the trace of the Pajarito fault system west of Aggregate 5. This borehole will provide water-quality and water-level data for intermediate perched zones and the regional aquifer on the upthrown block of a major spray of the Pajarito fault system. The location and occurrence of perched water and water level data for the regional aquifer, when compared with similar data from R-25 and R-26 on the downthrown block, will be used to evaluate the influence of the Pajarito fault system on the regional piezometric surface and provide information about its role as a recharge zone. R-24 will be used to establish boundary conditions on the western side of the Laboratory for numerical models of groundwater flow. Water quality data from intermediate perched zone and regional groundwater in R-24 will define background conditions upgradient from the Laboratory, and in particular for Aggregate 5. These background geochemical data will be used to define potential impacts on groundwater from Laboratory facilities and to provide input data for geochemical and hydrological modeling of different groundwater systems.

Table 5.5-2. Status of MWIP Proposed Regional Aquifer Boreholes (concluded)

Borehole	Original Start Date	Current Start Date	FY98 Status	Funding Source	Status of Installed Boreholes/Rationale of Proposed Boreholes
R-30	FY02	FY05	Planned	ER	R-30 is planned to deepen borehole 49-2-700-1 in Aggregate 3 from the current depth of 700 ft to approximately 1600 ft. This borehole will determine water quality in intermediate perched zones and in the regional aquifer beneath MDA AB, which was used for underground hydronuclear experiments.

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