Los Alamos
NATIONAL LABORATORY

Risk Reduction & Environmental Stewardship Division
PO Box 1663, MS K497
Los Alamos, New Mexico 87545
(505) 665-4681/Fax: (505) 665-9344

Date: April 25, 2002
Refer to: RRES-DO: 02-09

Mr. John Young
Hazardous and Radioactive Materials Bureau
New Mexico Environment Department
2044 Galisteo St., Building A
P.O. Box 26110
Santa Fe, New Mexico 87505

SUBJECT: GROUNDWATER ANNUAL STATUS REPORT FOR FISCAL YEAR 2001

Dear Mr. Young:

Enclosed please find the document "Groundwater Annual Status Report for Fiscal Year 2001." This report fulfills the commitment in the Hydrogeologic Workplan to provide an annual status report. The report describes accomplishments in the hydrogeologic characterization program in FY01 and the proposed activities for FY02. This document was also distributed at the Groundwater Integration Team/NMED Groundwater Annual Meeting that was held April 10-11, 2002.

This report is being sent to you because you are on the Hydrogeologic Characterization Program distribution list. If you are not interested in continuing to receive reports and documents, please contact me at the above address, via e-mail at nylander@lanl.gov, or by telephone at (505) 665-4681.

Sincerely,

Charles L. Nylander
Program Manager
Groundwater Protection Program
Risk Reduction & Environmental Stewardship Division

CN/tml

13619

Enclosures: a/s

Cy: M. Manzanares, NNMCAB, w/enc. (2 copies)
H. Daneman, NNMCAB, w/enc.
J. Arends, CCNS, w/enc.
K. Agogino, EPD, DOE/AL, Albuquerque, NM 87116, w/enc.
D. Youngberg, DOE/HQ/DP-13, Germantown, MD, w/enc.
T. Longo, DOE/HQ/EM-45, Germantown, MD, w/enc.
W. Holman, ERD/DOE, Oakland, CA, w/enc.
E. Anderson, EAG, Sciences International Inc., Alexandria, VA, w/enc.
R. Charles, EAG, Ranchester, WY, w/enc.
R. Powell, EAG, Powell & Associates, Las Vegas, NV, w/enc.
J. Powers, EAG, Murray, UT, w/enc.
J. Powers, EAG, Bloomington, MN, w/enc.
D. Schafer, EAG, Stillwater, MN, w/enc.
C. McLane, EAG, Princeton, NJ, w/enc.
P. Davis, Envirologic Inc, w/enc.
R. Mayer, EPA, Dallas, TX, w/enc.
D. Neleigh, EPA, Dallas, TX, w/enc.
T. Glasco, Los Alamos County, Los Alamos, NM, w/enc.
P. Padilla, Los Alamos County, Los Alamos, NM w/enc.
M. Bates, Los Alamos Study Group, w/enc.
K. Bitner, Neptune & Co., Albuquerque, NM, w/enc.
K. Hull, Neptune & Co., Albuquerque, NM, w/enc.
J. T. Grubesic, Assistant Attorney General, w/enc.
L. Lovejoy, NM Atty Genl Ofc, w/enc.
J. Bearzi, NMED/HRMB, Santa Fe, NM, w/enc.
J. Young, NMED/HRMB, Santa Fe, NM, w/enc.
M. Leavitt, NMED/GWQB, Santa Fe, NM, w/enc.
D. McQuillan, NMED/GWQB, Santa Fe, NM, w/enc.
C. Frischkorn, NMED/GWQB, Santa Fe, NM, w/enc.
J. Davis, NMED/SWQB, Santa Fe NM, w/enc.
J. Parker, NMED/DOE/OB, Santa Fe, NM, w/enc.
P. Maggiore, NMED Secretary, Santa Fe, NM, w/enc.
G. Lewis, NMED/HRMB, Santa Fe, NM w/enc.
C. Ash, NMTC, Santa Fe, NM, w/ enc.
B. Jacobs, Bandelier, NM, w/enc.
J. Pecos, Cochiti Pueblo, Cochiti, NM, w/enc.
D. Gonzalez, Cochiti Pueblo, w/enc.
G. Valdo, Pueblo Cochiti, w/enc.
D. Duffy, Jemez Pueblo, Jemez, NM, w/enc.
J. Chavarria, Santa Clara Pueblo, Espanola, NM, w/enc.
R. Gutierrez, Santa Clara Pueblo, Espanola, NM, w/enc.
N. Weber, San Ildefonso Pueblo, Santa Fe, NM, w/enc.
K. Nasser, Revision, Denver, CO, w/enc.
F. Lauffer, SNL, w/enc.
R. Lewis, Schlumberger, Englewood, CO, w/enc.

Cy (continued):
D. Larrsen, Westbay, N. Vancouver, w/enc.
B. Johnson, Westbay, N. Vancouver, w/enc.
C. Abeyta, USGS, w/enc.
Congressman T. Udall, Santa, Fe, NM, w/enc.
J. Ahlquist, UC, w/enc.
R. Enz. DOE/LAAO, MS A316, w/enc.
T. Taylor, LAAME, w/enc., DOE/LAAO, MS A316
J. Vozella, DOE/OLASO, w/enc., MS A316
M. Johansen, DOE/OLASO, w/enc., MS A316
G. Turner, DOE/OLASO, w/enc., MS A316
P. Reneau, IT Corp., w/enc., MS M892
R. Hull, LATA, w/enc., MS M321
S. Maez, LATA, w/enc., MS M321
M. Everett, MK/PMC, w/enc., MS M327
A. Crowder, MK/PMC, w/enc., MS M327
M. Dale, NMED/DOE/OB, w/enc., MS J993
S. Yanicak, NMED/DOE/OB, w/enc., MS J993
R. Koch, SAIC, w/enc., MS J521
K. Henning, RRES-WQH, w/enc., MS K497
IM-5, w/enc., MS A150
B. Grimes, CER-30, w/enc., MS A117
J. Aldrich, EES-16, w/enc., MS D462
D. Broxton, EES-16, w/enc., MS J462
G. Cole, EES-16, w/enc., MS D462
F. Goff, EES-16, w/enc., MS D462
D. Hickmott, EES-16, w/enc., MS D462
P. Longmire, EES-16, w/enc., MS D469
D. Vaniman, EES-16, w/enc., MS D462
R. Warren, EES-16, w/enc., MS D462
W. Carey, EES-16, w/enc., MS D462
K. Birdsell, EES-16, w/enc., MS T003
E. Keating, EES-16, w/enc., MS T003
B. Robinson, EES-16, w/enc., MS T003
B. Stone, EES-16, w/enc., MS T003
A. Pratt, EES-13, w/enc., MS M992
A. Dorries, EES-13, w/enc., MS M992
S. Bolivar, EES-13, w/enc., MS H865
D. Farley, EES-13, w/enc., MS H865
E. Springer, EES-15, w/enc., MS J495
B. Newman, EES-15, w/enc., MS J495
A. Gallegos, EES-15, w/enc., MS J495
C. LaDelfe, EES-17, w/enc., MS D462
P. Stauffer, EES-16, w/enc., MS T003
M. Witkowski, EES-DO, w/enc., MS C306
T. Antan, EES-13, w/enc., MS M992

Cy (continued):
J. Skalski, EES-17, w/enc., MS H865
C. Echohawk, EES-9, w/enc., MS C323
M. Baker, EM-DO, w/enc., MS J591
B. Ramsey, RRES-DO, w/enc., MS J591
A. Lee, RRES-R, w/enc., MS M992
J. Canepa, RRES-R, w/enc., MS M992
R. Vocke, RRES-DO, w/enc., MS J591
D. Hollis, RRES-R, w/enc., MS M992
M. Cummings, RRES-R, w/enc., MS M992, (2 copies)
W. Neff, RRES-R, w/enc., MS M992
S. Pearson, RRES-R, w/enc., MS M992
S. Natalie, PM-PPC, w/enc., MS M992
L. Maassen, RRES-R, w/enc., MS M992
D. McInroy, RRES-R, w/enc., MS M992
D. Bradbury, RRES-R, w/enc., MS M992
J. McCann, RRES-R, w/enc., MS M992
L. Goen, ADO, w/enc., MS F627
L. McAtee, HSR-DO, w/enc., MS K491
D. Erickson, ADWP, w/enc., MS A106
B. Gallaher, RRES-WQH, w/enc., MS K497
S. Kinkead, RRES-WQH, w/enc., MS K497
S. McLin, RRES-WQH, w/enc., MS K497
K. Mullen, RRES-WQH, w/enc., MS K497
C. Nylander, RRES-WQH, w/enc., MS K497
S. Rae, RRES-WQH, w/enc., MS K497
D. Rogers, RRES-WQH, w/enc., MS K497
B. Turney, RRES-WQH, w/enc., MS K497
S. Veenis, RRES-WQH, w/enc., MS K497
B. Beers, RRES-WQH, w/enc., MS K497
A. Barr, RRES-SWRC, w/enc., MS K498
C. Bare, RRES-ECO, w/enc., MS M887, (3 copies)
P. Schumann, RRES-R, w/enc., MS M992
J. Sisneros, FWO-SEM, w/enc., MS P908
D. Woitte, LC-GL, w/enc., MS A187
P. Wardwell, LC-GL, w/enc., MS A187
C. Thayer, LC-GL, w/enc., MS A187
J. Holt, ADO, w/enc., MS A104
P. Sanchez, ADO-IF&C, w/enc., MS F627
C. Zerkle, ADO-IF&C, w/enc., MS F627
LANL Reading Room, MS A117
RRES-WQH File (02-166), w/enc., MS K497
IM-5, w/enc., MS A150

LA-13931-SR
Status Report

Groundwater Annual Status Report for Fiscal Year 2001

Los Alamos
NATIONAL LABORATORY

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36.

An Affirmative Action/Equal Opportunity Employer

LA-13931-SR
Status Report

Issued: April 2002

Groundwater Annual Status Report for Fiscal Year 2001

C. L. Nylander
T. T. Ball
*K. A. Bitner**
K. Henning
E. H. Keating
P. Longmire
B. Robinson
D. B. Rogers
W. J. Stone
D. Vaniman

**Neptune and Company, 46000-A Montgomery, Suite 100, Albuquerque, NM*

Los Alamos
NATIONAL LABORATORY
Los Alamos NM 87545

GROUNDWATER ANNUAL STATUS REPORT for FISCAL YEAR 2001

Los Alamos National Laboratory
April 2002

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

GROUNDWATER ANNUAL STATUS REPORT for FISCAL YEAR 2001

by

C. L. Nylander, T. T. Ball, K. A. Bitner,* K. Henning, E. H. Keating, P. Longmire, 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 2001 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 2002.

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

1.0 INTRODUCTION

This is the fifth Annual Report since 1997 and is intended to provide the Department of Energy (DOE), the New Mexico Environment Department (NMED), and other interested stakeholders with a status of the groundwater protection and management activities performed during fiscal year 2001. This report presents a summary of the data collected over the past five years which has been integrated to revise the Los Alamos National Laboratory's (LANL's or Laboratory's) conceptual model of the hydrogeologic setting and used to resolve the decisions that form the basis of the Hydrogeologic Workplan. It also provides a projection of activities for fiscal year 2002.

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

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 early 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 submittal of an annual groundwater status report to DOE summarizing the status of groundwater protection activities listed in the GWPMPP. The GWPMPP was prepared in response to the DOE requirement to conduct operations in an environmentally compliant 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 in response to the NMED request to prepare a hydrogeologic work plan to address 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. The Hydrogeologic Workplan is the implementing document for the GWPMPP and the Laboratory's institutional commitment to complete a hydrogeologic characterization program. 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 that already established by studies over the past 50 years has been recognized as a critical step in developing an effective monitoring program and in managing the groundwater resource.

Therefore this Annual Report serves as the annual status report for both the GWPMPP and the Hydrogeologic Workplan. Further, this Annual Report serves as the update mechanism for the scope and schedule in the Hydrogeologic Workplan. Specifically, the Hydrogeologic Workplan will not be revised; however, changes to the scope and schedule outlined in the plan will be discussed with NMED in quarterly meetings and at the annual meeting. Changes for which there is concurrence by all parties will be documented in this Annual Report.

1.2 FY01 Accomplishments Summary

This section is intended to provide a concise description of FY01 groundwater activity accomplishments. The list of accomplishments below is followed by more detailed descriptions of these activities in the subsequent subsections.

Field-Based Activities

- Completed three Hydrogeologic Workplan wells (R-22, R-7, R-5) and three investigation wells (MCOBT-8.5, MCOBT-4.4, CdV-R-37-2)
- Started drilling two Hydrogeologic Workplan wells (R-13, R-8)
- Completed four rounds of characterization sampling at R-15, R-9, R-12, R-9i, R-19

Analytical Activities

- Analyzed large-scale and small-scale permeability of the regional aquifer
- Conducted uncertainty analysis, focusing on how much flow might be entering/leaving the regional aquifer from the north, west, and south
- Vadose zone - first order groundwater pathway assessment

Information Management

- Completed the migration of stream flow data (25 stations 1994-2000) and 30+ years of ESH-18 analytical chemistry data into the Water Quality Database (WQDB)
- Started Environmental Restoration (ER) and Environment, Safety, and Health (ESH) data exchange pilot project

QA and Reports

- Distributed Well Completion Reports for R-9, R-9i, R-12, R-15, R-19
- Completed peer review drafts of Well Completion Reports for R-25, R-31
- Conducted drilling program peer review by Schlumberger
- External Advisory Group (EAG) reviewed Hydrogeologic Characterization Program and sampling standard operating procedures
- Supported Value Engineering study

Project Management

- Completed negotiations with Prime Contractor to submit and perform against its own Quality Management Plan
- Completed construction and implementation of the DP-funded well drilling baseline
- Supported Laboratory efforts to conclude the unallowable cost issue for R-25
- Conducted iteration of groundwater characterization data quality objective (DQO) process to refine remaining scope of the HWP.
- Held Groundwater Integration Team (GIT) bi-weekly meetings, three quarterly meetings, and the Annual Meeting

1.2.1 Field-Based Activities

In FY01, field-based activities included well installation and characterization sampling. Three deep characterization wells were drilled, as required by the "Hydrogeologic Workplan" (LANL, 1998). One deep well (CdV-R-37-2) and two intermediate depth wells (MCOBT-4.4 and MCOBT-8.5) were installed by the

ER Project to further evaluate the extent of contaminants in groundwater. Two other characterization wells were started and characterization sampling of the completed wells was conducted.

1.2.1.1 Characterization Well Installation

The characterization wells were drilled using air rotary/casing advance with fluid assist methods. Geologic core and water samples were collected at defined intervals during the drilling operations and analyzed for the presence of both natural and man-made constituents. The three completed characterization wells include Wells R-5, R-7 (Los Alamos/Pueblo Canyon), and R-22 (Pajarito Canyon). Wells R-13 (Mortandad Canyon) and R-8 (Los Alamos Canyon) were started in FY01. Figure 1.2-1 shows the locations and status of regional aquifer wells that were proposed as part of the Hydrogeologic Workplan (LANL, 1998).

1.2.1.1.1 Well R-5

R-5 is located in lower Pueblo Canyon between the Los Alamos County Sewage Treatment Plant and water supply well Otowi-1 (O-1). Drilling started May 5, 2001 and was completed May 20, 2001. The samples and logs for R-5 are shown in Table 1.2-1. The stratigraphy encountered in the borehole was 35 ft of Guaje Pumice Bed at the surface, then nearly 500 ft of Puye Formation. About 75 ft of Cerros del Rio basalt was found near the top of the Puye Formation. Below the basalt are fanglomerate, river gravel, and pumiceous fanglomerate mixed with river gravels. The Santa Fe Group was encountered at a depth of 534 ft and consists of basalts interbedded with sediments. Water was initially encountered at a depth of 169 ft but was found to be dry after a sample was collected. One saturated zone was encountered in the river gravel section of the Puye Formation from 350 ft to 387 ft. The regional aquifer was encountered at a depth of about 685 ft in the first Santa Fe Group sedimentary unit.

Well construction and development were completed June 21, 2001. The well was developed by a combination of brushing, bailing, and pumping. Westbay sampling equipment was installed between June 13 and June 19, 2001. The ground surface elevation is 6472.6 ft above sea level (asl) and the total depth of the borehole was 902 ft. R-5 was completed with four screened intervals. Two screens were installed in the perched zone at depths of 326 and 373 ft. Two screens were installed in the regional aquifer at depths of 677 and 859 ft. Samples of the regional aquifer collected from the borehole during drilling contained nitrate, but no other contaminants were detected. The well construction, stratigraphic, and hydrologic information is summarized on Figure 1.2-2.

Table 1.2-1 Samples and Logs Collected from R-5

Sample Type/Log	Depths/Number of samples
Groundwater samples from the borehole submitted for geo-chemical characterization	1 sample at 169 ft 1 sample at 387 ft 1 sample at 860 ft 1 sample at 892 ft
Geologic samples submitted for analysis of geologic properties (mineralogy, petrography, chemistry)	38 samples
Lithologic log	0-902 ft
Video log	570 - 685 ft
Natural gamma	0-851 ft: cased 851-902 ft: open hole
Compensated Thermal and Epithermal Neutron, Spectral Gamma, and Litho-Density	0-851 ft: cased 851-898 ft: open hole

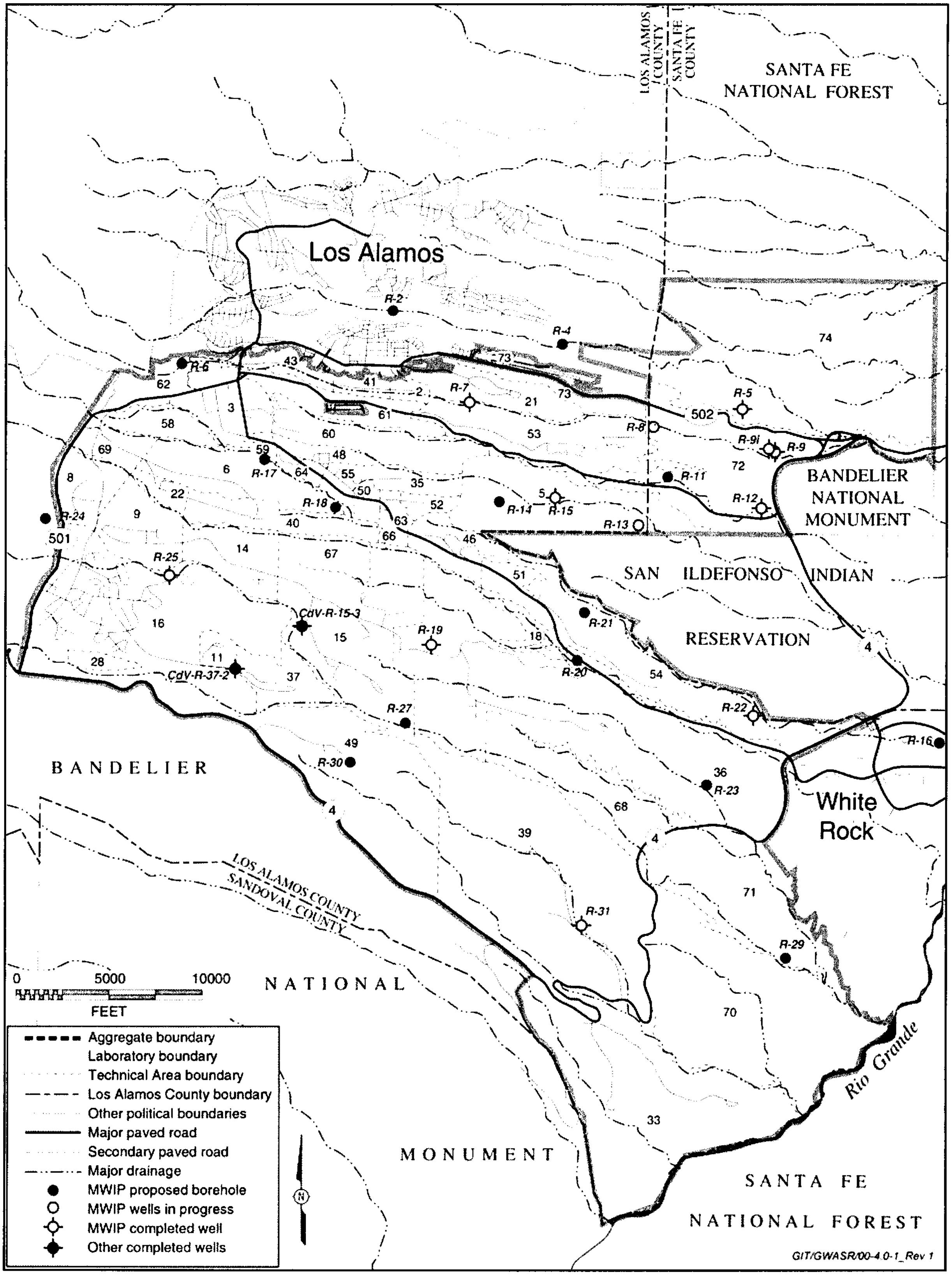


Figure 1.2-1 Completed, in progress, and proposed MWIP regional aquifer wells as of the end of FY01.

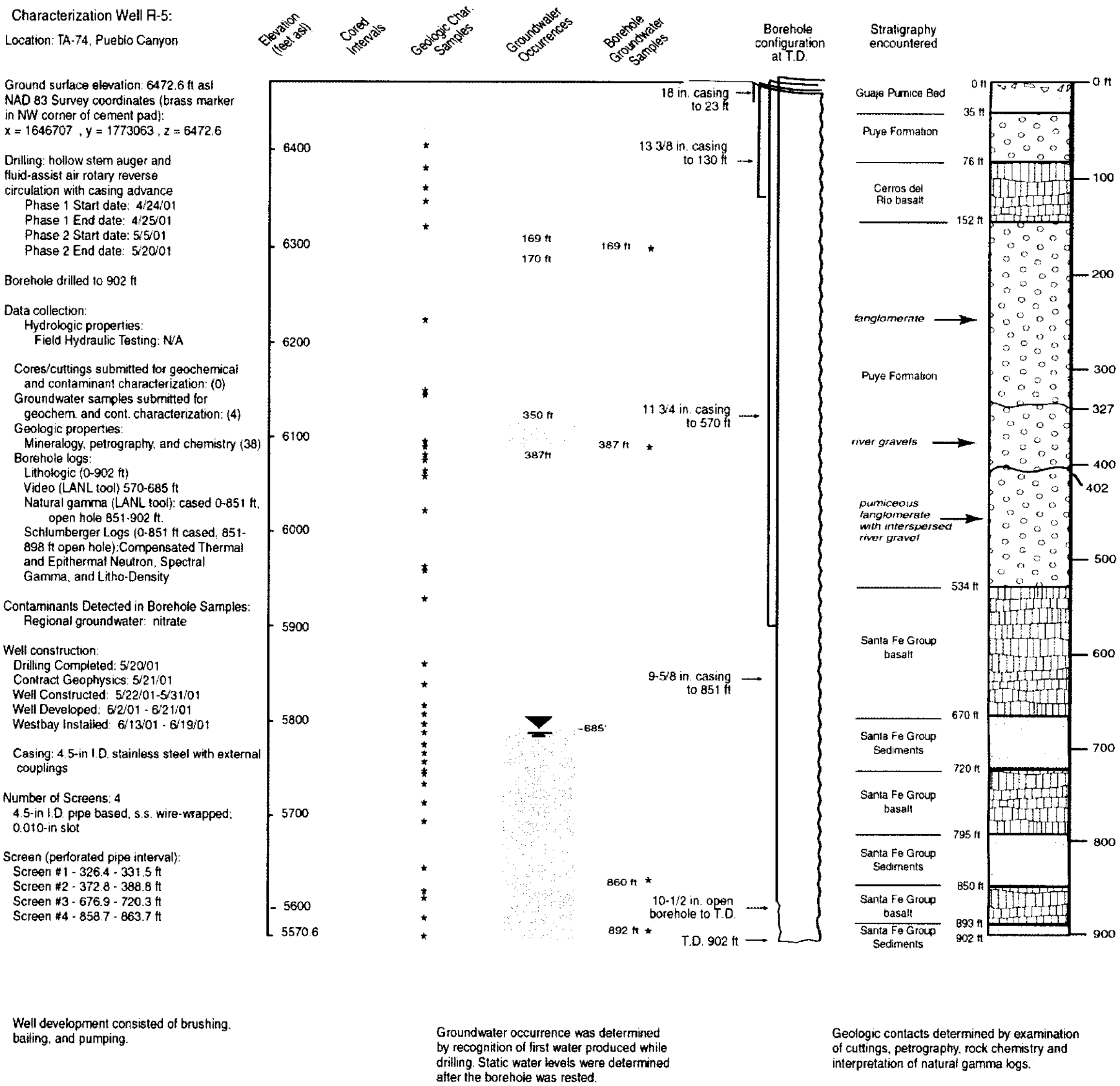


Figure 1.2-2 Construction, stratigraphic, and hydrologic information for completed well R-5.

1.2.1.1.2 Well R-7

Well R-7 is located in upper Los Alamos Canyon. Drilling started December 11, 2000 and was completed January 16, 2001. The samples and logs for R-7 are shown in Table 1.2-2. The stratigraphy encountered in the borehole was 25 ft of alluvium at the surface and 300 ft of the Otowi Member of the Bandelier Tuff. Just above the contact with the Puye Formation was 25 ft of Guaje Pumice Bed. The remainder of the borehole encountered about 745 ft of Puye Formation; the bottom 13 ft of borehole was identified as Totavi lentil. A perched saturated zone, about 20 ft thick (362 to 382 ft), was encountered at the top of the Puye Formation. Beneath the perched zone, the Puye Formation was slightly to mostly saturated from 362-382 ft. The regional aquifer was encountered at a depth of 902.8 ft.

Table 1.2-2 Samples and Logs Collected from R-7

Sample Type/Log	Depths/Number of samples
Groundwater samples from the borehole submitted for geochemical characterization	1 sample at 373 ft 1 sample at 903 ft
Geologic samples submitted for analysis of geologic properties (mineralogy, petrography, chemistry)	27 samples
Lithologic log	0-1097 ft
Video log	0-849 ft and 0-977 ft
Natural gamma	0-972 ft and 0-977 ft
Litho-Density, Gamma Ray, Caliper, Combinable Magnetic Resonance, Formation Micro Imager, Spectral Gamma, Thermal/Epithermal Neutron, Array Induction, Natural Gamma	0-290 ft: cased 290-1064 ft: open hole

Well construction and development were completed February 8, 2001. The well was developed by a combination of wire brushing, bailing, and pumping from screen 3 and the sump. Attempts to pump and bail water from screens 1 and 2 were unsuccessful because of insufficient water from these zones. Westbay sampling equipment was installed between February 21 and February 26, 2001. The ground surface elevation is 6779.2 ft asl and the total depth of the borehole was 1097 ft. The R-7 well is completed with three screened intervals: one in the perched saturated zone at a depth of 363 ft, one in the middle of the slightly to mostly saturated section at 730 ft, and one in the regional aquifer at 895 ft. Samples of water from the borehole were collected in the perched saturated zone (373 ft) and from the regional aquifer (903 ft). No contaminants were detected in either borehole sample. The well construction, stratigraphic, and hydrologic information are summarized on Figure 1.2-3. The well completion report for this well is expected to be complete in February 2002.

1.2.1.1.3 Well R-8

R-8 is located Los Alamos Canyon, near the confluence with DP Canyon. It was started in late FY01, and in FY01 the surface casing was set and drilling with open hole methods began.

1.2.1.1.4 Well R-13

R-13 is located in Mortandad Canyon. It was drilled to a total depth of 1133 ft and was completed with a single 50-foot long screen in the regional aquifer. At the end of FY01, the drilling and well construction was complete. The well will be developed and completed in FY02.

1.2.1.1.5 Well R-22

Well R-22 was drilled on Mesita del Buey east of TA-54, MDA G. Drilling started September 8, 2000 and was completed October 11, 2000. The samples and logs for R-22 are shown in Table 1.2-3. The stratigraphy encountered in the borehole was 190 ft of Bandelier Tuff at the surface, composed of the Tschirege Member (0-128 ft), Otowi Member (128-179 ft), and the Guaje Pumice Bed (179-190 ft). Below the Bandelier Tuff were 983 ft of Cerros del Rio basalt including 10 ft of flow-top sediments and 8 ft of flow-base sediments. The Cerros del Rio basalt is underlain by volcaniclastic gravel with quartzite, tentatively assigned to the Puye Formation and basaltic lava of probable Miocene age. No zones of saturation were encountered above the regional aquifer. The regional aquifer was observed in the Cerros del Rio basalt at a depth of 883 ft.

Characterization Well R-7:

Location: TA-53, Los Alamos Canyon, east of Omega West reactor facility.

Survey coordinates (brass marker in NW corner of cement pad):
x: 1631666 E y: 1773653 N (NAD 83)
z: 6779.2 ft asl (NGVD 29)

Drilling: hollow stem auger and fluid-assist air rotary reverse circulation with casing advance
- Phase 1 Start date: 02/22/00
- Phase 1 End date: 02/25/00
- Phase 2 Start date: 12/11/00
- Phase 2 End date: 01/16/01

Borehole drilled to 1097 ft bgs (T.D.)

Data collection:
- Hydrologic properties:
  - Field Hydraulic Testing: No tests were conducted.
- Cores/cuttings submitted for geochemical and contaminant characterization: (0)
- Groundwater samples submitted for geochem and contaminant characterization: (2)
- Geologic properties:
  - Mineralogy, petrography, and chemistry (27)
- Borehole logs:
  - Lithologic (0-1097 ft)
  - Video (LANL tool) 0-849 ft and 0-977 ft.
  - Natural gamma (LANL tool): 0-972 ft, and 0-977 ft. bgs.
  - Schlumberger Logs (0-290 ft cased, 290-1064 ft open hole): Litho density, Gamma Ray, Caliper, Combinable Magnetic Resonance, Formation Micro Imager, Spectral Gamma, Thermal/Epithermal Neutron, Array Induction, Natural Gamma.

Contaminants Detected in Borehole Samples:
- Borehole screening data indicate no contaminants detected above background.

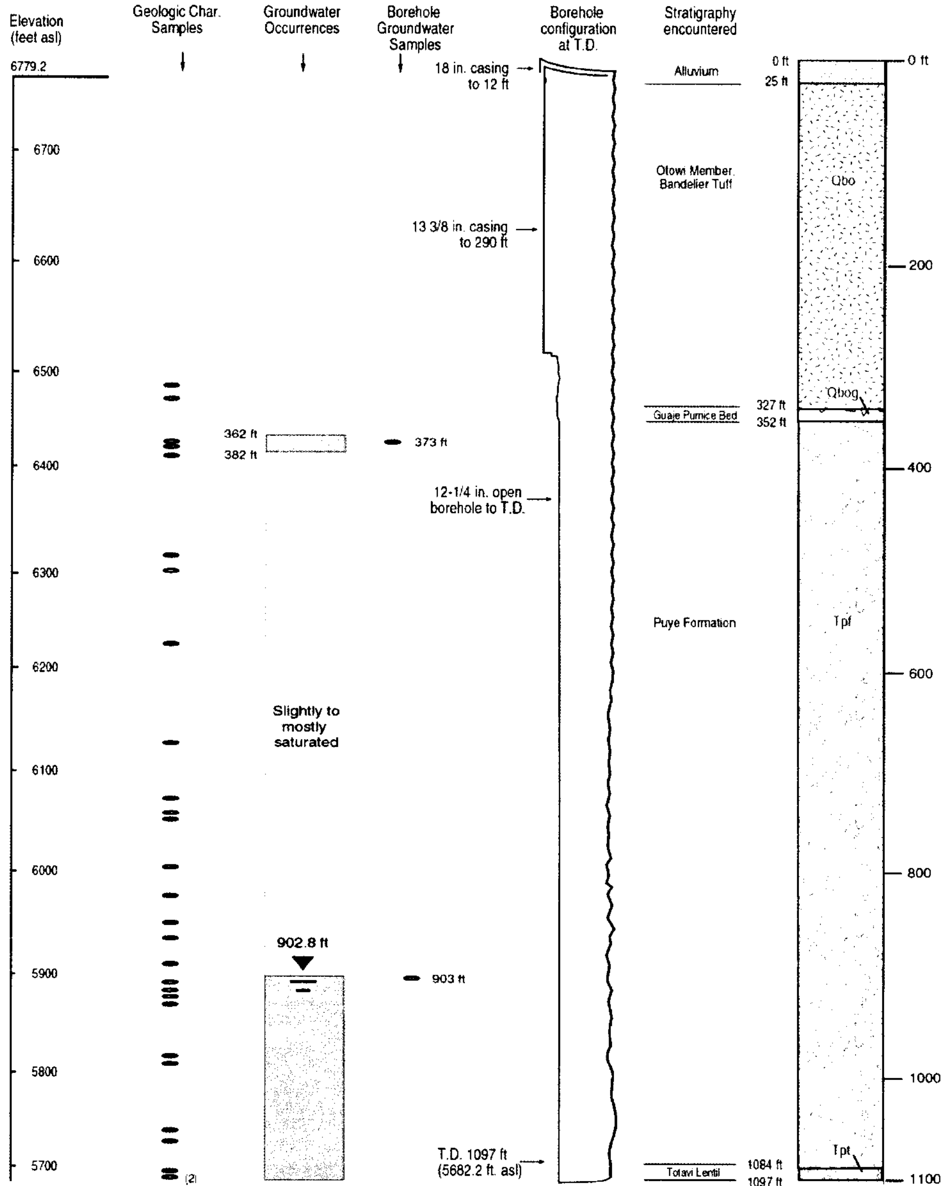
Well construction:
- Drilling Completed: 01/16/01
- Contract Geophysics: 01/12/01 through 01/13/01, and 01/14/01
- Well Constructed: 01/20/01 through 01/31/01
- Well Developed: 02/01/01 through 02/08/01
- Westbay Installed: 02/21/01 through 02/26/01

Casing: 4.5-in I.D. stainless steel with external couplings

Number of Screens: 3
- 4.5-in I.D. pipe based, s.s. wire-wrapped; 0.010-in slotted.

Screen (perforated pipe interval):
- Screen #1 - 363.2-379.2 ft bgs
- Screen #2 - 730.4-746.4 ft bgs
- Screen #3 - 895.5-937.4 ft bgs

Well development consisted of wire brushing, bailing, and pumping from Screen #3 and sump. Attempts to pump and bail water from Screens #1 and #2 were unsuccessful because of insufficient water from these zones.



Groundwater occurrence was determined by recognition of first water produced while drilling, by borehole geophysics, and by borehole video. The rocks above the regional water table appeared to be partly to mostly saturated. Screens 1 & 2 were sited to sample the potential saturation above the regional water table. Static water levels were determined after the borehole was rested.

Geologic contacts determined by examination of cuttings and interpretation of natural gamma logs. Contacts may be refined by analysis of geologic samples by petrography and rock chemistry.

Figure 1.2-3 Construction, stratigraphic, and hydrologic information for completed well R-7.

TABLE 1.2-3 SAMPLES AND LOGS COLLECTED FROM R-22

Sample Type/Log	Depths/Number of samples
Groundwater samples from the borehole submitted for geo-chemical characterization	1 sample at 883 ft 1 sample at 1489 ft
Geologic samples submitted for analysis of geologic properties (mineralogy, petrography, chemistry)	28 samples
Lithologic log	0-1489 ft
Video log	187-254 ft and 580-740 ft
Natural gamma	0-1330 ft: cased 1330-1475 ft: open hole
Neutron Porosity, Spectral Gamma, Gamma-Gamma Density, and Elemental Capture Spectroscopy	0-1330 ft: cased 1330-1477 ft: open hole

Well construction and development were completed November 14, 2000. The well was developed by a combination of wire brushing, bailing, and pumping each screen and bailing and pumping the sump. Westbay sampling equipment was installed between December 7 and December 10, 2000. The ground surface elevation is 6650.5 ft asl and the total depth of the borehole was 1489 ft. The R-22 well is completed with five screened intervals in the regional aquifer:

- Screen 1: 872.3 - 914.2 ft
- Screen 2: 947.0 - 988.9 ft
- Screen 3: 1272.2 - 1278.9 ft
- Screen 4: 1378.2 - 1384.9 ft
- Screen 5: 1447.3 - 1452.3 ft

Samples of water from the borehole were collected from two depths in the regional aquifer (883 ft and 1489 ft). Tritium was the only contaminant detected in either borehole sample. The well construction, stratigraphic, and hydrologic information is summarized on Figure 1.2-4. The well completion report for this well is expected to be completed in February 2002.

1.2.1.2 Investigation Well Installation

The following provides brief descriptions of wells that were installed for further investigation of contaminants in groundwater:

- CdV-37-2 was drilled in Water Canyon in August 2001. The total depth of the well is 1664 ft. The well was completed with four screened intervals. Water samples collected from the CdV-37 borehole yielded no contaminant detection.
- MCOBT-4.4 in Mortandad Canyon was drilled to a total depth of 767 ft in June 2001. The borehole was plugged to a depth of 725 ft and a single completion well was installed.
- MCOBT-8.5 in Mortandad Canyon was drilled to a total depth of 740 ft in June 2001. The borehole was plugged to a depth of 670 ft in order to install a well in Cerros del Rio basalt. However, after several days of monitoring, the borehole did not yield water and MCOBT-8.5 was plugged back to the surface.

1.2.1.3 Characterization Sampling

Characterization sampling consists of four rounds of collecting water samples from each screen in the well, generally collected on a quarterly basis. The water samples are submitted for chemical analysis. After four characterization samples are analyzed, a geochemical report is prepared to present characterization data and provide evaluations and interpretations of the data. The regional well sampling status at the end of FY01 was:

Characterization Well R-22:

Location: TA-54, Mesita del Buey near White Rock, NM.

NAD 83 Survey coordinates (brass marker in NW corner of cement pad):
x:1645324.4 E y: 1757111.1 N
z: 6650.5 ft asl

Drilling: hollow stem auger and fluid-assist air rotary reverse circulation with casing advance
- Phase 1 Start date: 8/17/00
- Phase 1 End date: 8/21/00
- Phase 2 Start date: 9/8/00
- Phase 2 End date: 10/11/00

Borehole drilled to 1489 ft

Data collection:
- Hydrologic properties:
  - Field Hydraulic Testing: Slug tests conducted on screens 2, 3, 4, and 5.
- Cores/cuttings submitted for geochemical and contaminant characterization: (0)
- Groundwater samples submitted for geochem and cont. characterization: (2)
- Geologic properties:
  - Mineralogy, petrography, and chemistry (28)
- Borehole logs:
  - Lithologic (0-1489 ft)
  - Video (LANL tool) 187-254 ft and 580-740 ft.
  - Natural gamma (LANL tool): cased 0-1330 ft, open hole 1330-1475 ft.
  - Schlumberger Logs (0-1330 ft cased, 1330-1477 ft open hole):Neutron porosity, Spectral Gamma, Gamma-Gamma Density, and Elemental Capture Spectroscopy

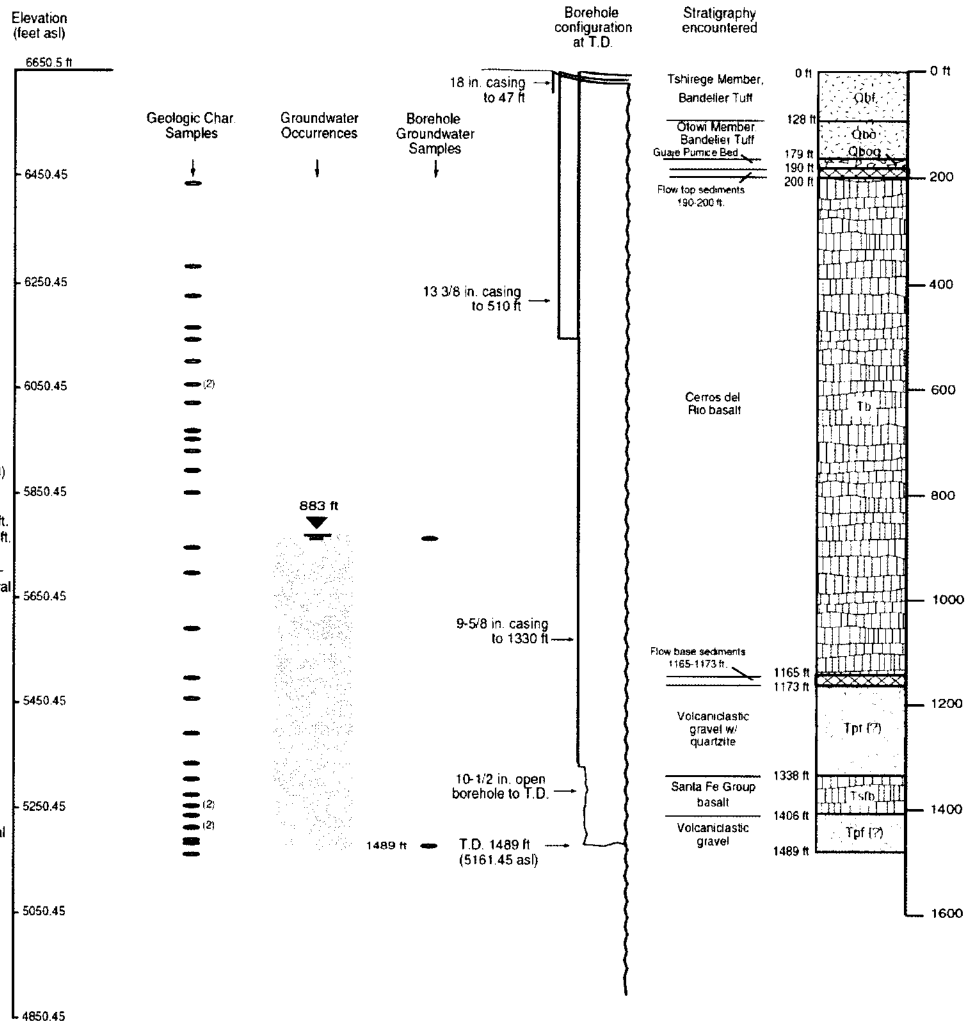
Contaminants Detected in Borehole Samples:
- Regional groundwater: borehole screening data indicate tritium above background.

Well construction:
- Drilling Completed: 10/11/00
- Contract Geophysics: 10/13/00
- Well Constructed: 10/17/00-11/03/00
- Well Developed: 11/04/00-11/14/00
- Westbay Installed: 12/07/00-12/10/00

Casing: 4.5-in I.D. stainless steel with external couplings

Number of Screens: 5
4.5-in I.D. pipe based, s.s. wire-wrapped; 0.010-in slot

Screen (perforated pipe interval):
- Screen #1 - 872.3 ft to 914.2 ft
- Screen #2 - 947.0 ft to 988.9 ft
- Screen #3 - 1272.2 ft to 1278.9 ft
- Screen #4 - 1378.2 ft to 1384.9 ft
- Screen #5 - 1447.3 ft to 1452.3 ft



Well development consisted of brushing, bailing, and pumping each screen, and bailing and pumping the sump. Pump development was conducted with a single packer inflated below each targeted screen.

Groundwater occurrence was determined by recognition of first water produced while drilling. Static water levels were determined after the borehole was rested.

Geologic contacts determined by examination of cuttings and interpretation of natural gamma logs. Contacts may be refined by analysis of geologic samples by petrography and rock chemistry.

Figure 1.2-4 Construction, stratigraphic, and hydrologic information for completed well R-22.

- R-25: the third characterization-sampling event has been completed.
- R-31, R-22: the second characterization-sampling events have been completed.
- R-15, R-9, R-12, R-9i, R-19: the four characterization sampling events have been completed and the geochemical reports are in preparation. These wells will be transferred to the Water Quality and Hydrology Group (ESH-18), which has the responsibility for custodial care of the wells and maintaining the monitoring network.
- R-7: The first two characterization-sampling events have been completed.

1.2.2 Analytical Activities

The analytical activities in FY01 were reflected in the modeling for the regional aquifer and the vadose zone. Recent water level data from R-wells was incorporated into the model, resulting in better estimates of large-scale permeability of the Puye Formation. There remains a concern with the estimates of large-scale permeability because the model-derived estimates for the Santa Fe Group are substantially lower than field-based estimates (e.g., pump tests in Los Alamos Canyon). This may be due to scaling effects or structural features such as north-south trending low-permeability fault zones. In-situ hydraulic testing in R-wells and geophysical estimates of permeability have provided more evidence of large variation in medium- and small-scale permeability within the Puye Formation. The adequacy of hydrostratigraphic zonation (defined by the 3-D Geologic Model) was evaluated by comparing simulated and observed water levels under a variety of parameter combinations. It appears that the delineation between basalt flows and sedimentary rocks has real hydrologic significance; the basalt flows appear to be substantially higher in permeability. However, the delineation between the "Los Alamos Aquifer" and the lower Santa Fe Group does not appear to have hydrologic significance, nor does the delineation between the Puye fanglomerate and the Totavi Lentil.

Two formal analyses for the effects of parameter uncertainty (permeability, recharge rates, and specific storage) on model predictions were completed. The first is an analysis of the uncertainty in the predictions made using the basin model for lateral fluxes to the aquifer beneath LANL. This analysis showed that water level and flux data (base flow discharge to the Rio Grande) is sufficient to support model predictions that little or no groundwater enters the aquifer from the north or leaves the aquifer to the south. In contrast, there is large uncertainty in flux estimates from the west (none or a relatively large amount relative to the total water withdrawn from municipal supply wells). However, subsequent transport calculations were insensitive to these uncertain fluxes. The importance of this uncertainty will depend on the model application.

The second analysis was of uncertainty in flow directions downgradient from R-25. This analysis demonstrated fairly low uncertainty in lateral flow directions (regardless of parameter values, calibrated models always predict generally easterly flow); however, much greater uncertainty accompanies the vertical component of flow and the ultimate discharge point (PM-2 or the Rio Grande). Sensitivity analysis showed that of multiple possible locations for new water level data to reduce predictive uncertainty, multi-level data at or near R-25 would be the most valuable. This analysis was completed before many of the recent water level data became available (including data from R-25) and therefore may overestimate uncertainty.

Vadose zone modeling focused on developing a first order groundwater pathway assessment. The goal of the first order groundwater pathway assessment is to rank contaminants of potential risk-significance to groundwater receptors on a site-wide basis, rather than focusing on one specific area. The approach is to use the regional aquifer model, the geologic model, and GIS tools to synthesize information from contaminant sources and hydrogeologic data to assess transport times and visualize pathways. Components of the analysis include percolation rates, vadose zone flow and transport, regional aquifer flow and transport, and contaminant sources.

1.2.3 Information Management

The Water Quality Database (WQDB) is a centralized data repository for water quality data. It is intended to improve access to water quality data, streamline research and reporting capabilities, and to enhance the data quality. In response to the September 11, 2001, terror attacks, the WQDB is currently offline for LANL review and is anticipated to be online in the near future. The data that is available from the WQDB includes 900 records for sampling station information, analytical chemistry data from 1942-2001 (340,000 records), stream flow data from 1994-2000 (700,000 records), and data in look-up tables (3,000 records). The WQDB and the ER Database have collaborated to use the same structures to allow exchange of data. All of the R-well data collected for the Hydrogeologic Workplan was intended to go initially into the ER Database and shared with the WQDB. Due to resource constraints, the exchange of data between the two databases did not occur in FY01. An ER Database and WQDB exchange pilot project will facilitate the completion of the well construction module of the WQDB, incorporation of water levels into the database, and availability of R-well construction data as well as geophysical logs and hydrological properties in the WQDB.

1.2.4 QA and Reports

In FY01, Well Completion Reports were published for R-9, R-9i, R-12, R-15, and R-19. The reports were published as Los Alamos National Laboratory Reports and the citation information is:

- Broxton, D. E., R. Gilkeson, P. Longmire, D. Vaniman, J. Marin, R. Warren, A. Crowder, B. Newman, B. Lowry, D. Daymon, D. Wycoff, 2000. Completion Report for Characterization Well R-9, ER2000-0218 and LA-UR-00-4120, Los Alamos National Laboratory, Los Alamos NM.
- Broxton, D. E., D. Vaniman, W. Stone, S. McLin, M. Everett, A. Crowder, 2000. Characterization Well R-9i Completion Report, ER2000-0446 and LA-UR-00-4255, Los Alamos National Laboratory, Los Alamos NM
- Broxton, D. E., R. Warren, D. Vaniman, B. Newman, A. Crowder, M. Everett, R. Gilkeson, P. Longmire, J. Marin, W. J. Stone, S. McLin, D. B. Rogers, 2000. Characterization Well R-12 Completion Report, ER2000-0290 and LA-UR-00-3785, Los Alamos National Laboratory, Los Alamos NM
- Longmire, P., D. E. Broxton, W. Stone, B. Newman, R. Gilkeson, J. Marin, D. Vaniman, D. Counce, D. Rogers, R. Hull, S. McLin, R. Warren, 2000. Characterization Well R-15 Completion Report, ER2000-0308 and LA-UR-00-4139, Los Alamos National Laboratory, Los Alamos NM
- Broxton, D. E., D. Vaniman, W. Stone, S. McLin, J. Marin, R. Koch, R. Warren, P. Longmire, D. Rogers, N. Tapia, 2000. Characterization Well R-19 Completion Report, ER2000-0398 and LA-UR-00-4085, Los Alamos National Laboratory, Los Alamos NM.

Additionally, peer review drafts of well completion reports for R-25 and R-31 were completed. The R-25 and R-31 well completion reports will be published as Los Alamos National Laboratory Reports in FY02.

Three programmatic reviews were conducted in FY 01:

- Drilling program peer review conducted by Schlumberger
- External Advisory Group (EAG)
- Value Engineering study

The results of these reviews are summarized in Section 2 of this report.

1.2.5 Project Management

Project management activities in FY01 were maintaining scope, schedule, and costs and promoting communication. In order to define the remaining scope of the Hydrogeologic Characterization Program, the GIT conducted an iteration of the groundwater characterization DQO process. The FY01 DQO iteration began with a comprehensive evaluation of all groundwater-related data collected, analyzed, and interpreted to date in the program in order to determine what is known and what data are necessary to complete the Hydrogeologic Workplan. The next step is to establish a small core group of LANL, DOE, and NMED decision-makers to review and develop consensus on the proposed revisions. In summary, the revised scope for the completion of the Hydrogeologic Workplan includes:

- 15 regional aquifer wells
- 13 other field-based activities: hydrologic testing, geochemical, geologic mapping, and sampling
- 10 analytical activities: regional aquifer modeling, geochemical modeling, and information management
- Three project management activities

The next steps to define the scope are:

- Establish a core team of DOE, LANL, and NMED decision-makers to reach consensus on the proposed revision of scope
- Continue to formulate the comprehensive groundwater monitoring program
- Establish a long-term stewardship program to conduct the monitoring

The cost and schedule for the Hydrogeologic Characterization Program are incorporated into the ER Baseline. A separate work breakdown structure is in place that defines scope, schedule, and cost for each activity and well of the project. An integrated schedule that incorporates all task activities and associated costs for drilling, installation, sampling, and data analysis for each well has been prepared. In FY01 DP-funded well drilling baseline was completed and integrated with the ER Baseline.

In FY01, GIT meetings were held bi-weekly. The purpose of the GIT meetings is to keep all Laboratory participants informed about program activities and to provide a forum for discussion of new data and analysis and future data collection. There were three quarterly meetings and an annual meeting to exchange information with stakeholders. The results of the quarterly and annual meetings are summarized in Section 2.

An additional project management activity was supporting Laboratory efforts to conclude the unallowable cost issue for R-25. DOE has challenged the additional time and expense to repair screens 3 and 9 and the cost to recover the well from "dropped tremie pipe" incident, citing these as unallowable costs. The Laboratory has been required to submit information to DOE explaining and justifying the additional costs. DOE is still considering further action regarding the potential unallowable costs.

1.3 Annual 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. A synthesis of data that have been collected and analyzed during the past four years has resulted in a major revision to the Hydrogeologic Conceptual Model. The resulting FY01 Hydrogeologic Conceptual Model is presented in Section 3 and the bases for the hydrogeologic model are presented in Section 4.

A major component of the hydrogeologic characterization is management of the data. Section 5 describes the data management activities in FY01. Section 6 summarizes the progress made toward resolving the decisions described in the Hydrogeologic Workplan by integrating the data collected in the past four years. Section 7 contains a summary of activities proposed for FY02.

2.0 PROGRAMMATIC ACTIVITIES

Programmatic activities are those functions that are required to manage the technical, cost, and schedule aspects of the program and to communicate the status and results of the program to stakeholders. The technical aspects of the program are tracked by the GIT, an interdisciplinary Laboratory group that provides guidance and oversight to the program. The GIT meets on a bi-weekly basis to consider the status of the data collection and data interpretation activities.

The GIT holds three quarterly meetings and one annual meeting per fiscal year. The purpose of these meetings is to communicate the status of the program activities with stakeholders and provide an opportunity to receive feedback and input from the stakeholders on the progress and plans for the program. The issues discussed and decisions made in the quarterly and annual meetings become addenda to the Hydrogeologic Workplan. Section 2.1 summarizes those meetings and the resulting decisions.

The technical aspects of the program have also been reviewed by the EAG, which has provided peer review of the program. A summary of the EAG semi-annual reports and the action plans developed to respond to those reports are described in Section 2.2. In FY 01, there were two additional programmatic reviews. The first was a drilling management review conducted by Schlumberger. The second was a Value Engineering Study conducted by DOE. These reviews are summarized in Sections 2.3 and 2.4, respectively.

2.1 Summary of FY01 Meetings

Four meetings were held to discuss FY01 groundwater characterization activities. The participants of the meetings were Laboratory staff involved in the activities, DOE representatives, and NMED representatives from the bureaus of Hazardous Materials (HMB), Groundwater Quality, and DOE Oversight. Other interested stakeholders that attended the meetings were representatives from San Ildefonso Pueblo, Santa Clara Pueblo, Cochiti Pueblo, Los Alamos County, New Mexico Attorney General, Northern New Mexico Citizens Advisory Board, and Concerned Citizens for Nuclear Safety. A summary of each meeting and the points of agreement are provided in the following sections.

2.1.1 October 3-5, 2000 Quarterly Meeting

The notes from the October 3-5, 2000 Quarterly Meeting were issued by memorandum from Charles Nylander, ESH-18, on November 20, 2000. Topics included were status reports from the GIT subcommittees (Information Management, Well Construction, Geochemistry, Hydrology, and Modeling), descriptions of modeling activities, quality assurance, modeling activity updates for the vadose zone and regional aquifer and the geochemical conceptual model, performance review of the hydrogeologic characterization program, presentations on technical topics, and a session for stakeholders to give feedback directly to the EAG.

Significant issues discussed were:

- Well construction schedule for FY01: drill and complete R-5, R-7, R-8, and possibly R-13.
- Six Hydrogeologic Workplan wells were completed (R-9, R-12, R-25, R-15, R-31, R-19); one investigation well was completed (CdV-R-15-3), and one well was started (R-22).
- A modeling demonstration was conducted to show how the database and the GIS system support the modeling and provide tools to visualize modeling results. The demonstration focused on Los Alamos Canyon and simulated the hydrologic response to an area of ponded water near the confluence of Los Alamos and DP Canyons.
- A proposed revision to Section 3 of the Hydrogeologic Workplan involving information management and modeling were presented.
- A Quality Assurance Management Assessment was conducted, specifically drilling activities associated with R-25 and CdV-R-15-3. The Management Assessment identified problems, requirements, and corrective actions to address identified non-conforming conditions.

2.1.2 January 30, 2001 Quarterly Meeting

The January 30, 2001 Quarterly Meeting is documented in notes issued in memoranda from Charles Nylander, ESH-18, on February 7, 2001 and February 23, 2001. The agenda included presentations on modeling, information management, well construction, geochemistry, and hydrology from the GIT subcommittees. There were special presentations on modeling, Groundwater Focus Area, and a proposed sampling and analysis approach.

Significant issues discussed were:

- R-7 and R-22 were completed and drilling R-5 was expected to begin in January.
- Water supply wells were sampled. There was no Sr-90 or high explosives detected in any water supply well. Tritium (40 pCi/L) and perchlorate were detected in water supply well O-1.
- The *Groundwater Annual Status Report for Fiscal Year 2000* was to be mailed out to everyone on the mailing list by February 9.

2.1.3 March 20-23, 2001 Annual Meeting

The notes from the March 20-23, 2001 Annual Meeting were distributed as a memorandum from Charles Nylander, ESH-18, dated April 19, 2001. The agenda for the meeting included status reports from the GIT subcommittees (Well Construction, Modeling, Hydrology, Geochemistry, and Information Management) and discussion of management issues (anticipated scope and schedule for the remainder of FY01 and FY02), and quality assurance. There were technical presentations and posters on:

- Evolution of well drilling, construction, and development
- Observations on geology from regional wells
- Well logs, geology, and hydrology
- Hydraulic conductivity and geology
- Quantifying heterogeneity within the Puye Formation
- Databases: Water Quality and Environmental Restoration
- DOE role in oversight
- Water supply well sampling
- Results of quarterly sampling
- Overview of modeling activities and deliverables
- Los Alamos Canyon flow and transport model
- NMED/DOE-OB conceptual model for Los Alamos Canyon
- Validation of conceptual models for vadose zone flow and transport beneath the Pajarito Plateau
- Model uncertainty, sensitivity analysis, and data needs

The significant issues discussed at the March 29-31 Annual Meeting were:

- Drill and complete the following wells in FY02: R-8, R-14, R-20 (DP-funded) and R-13, R-18, and R-21 (ER -funded)
- Conduct quarterly sampling in FY02 in R-5, R-7, R-8, R-13, R-14, R-18, R-22, R-25, and R-31
- Develop an Annual Plan to be submitted to NMED by April 30
- Issue a letter to stakeholders requesting input on the Annual Plan. The letter was to explain the newly instituted Annual Plan process and rationale for each well and alternatives considered.
- Distribute the Groundwater Annual Status Report at least 10 days before the Annual Meeting

- Reserve a section of each quarterly meeting for planning activities and welcome stakeholder participation
- Develop a master list of publications, update quarterly, and distribute to stakeholders
- Add to the ER Public Involvement Plan to address the Hydrogeologic Workplan and obtain stakeholder input on that plan
- Distribute currently available modeling reports to stakeholders that request them

2.1.4 June 27, 2001 Quarterly Meeting

The notes from the June 27, 2001 Quarterly Meeting were distributed as a memorandum from Charles Nylander, ESH-18, dated August 16, 2001. The agenda for the meeting included status reports from the GIT subcommittees (Well Construction, Modeling, Hydrology, Geochemistry, Information Management), discussion of characterization sampling and analysis, and the FY02 plan. A planning session was held with the participation of stakeholders.

Significant issues discussed at the June 27 Quarterly Meeting were:

- FY02 planned drilling: R-13 (ER -funded) and R-8 and R-20 (DP-funded). Other ER-funded wells will be planned and prioritized if more money becomes available. R-20 near TA-54 could be exchanged for R-14 in Mortandad Canyon. Both are of interest to LANL and NMED.
- The URL for the Water Quality Database is: http://wqdbworld.lanl.gov (external) and http://wqdb.lanl.gov (internal)
- The planned drilling for the remainder of FY01: CdV-37-2 followed by R-13. R-13 was to be drilled after CdV-R-37-2 because of uncertainties in the location for R-13.
- The proposed analytical strategy includes an equilibration period and full suite analysis for first and fourth characterization sampling. Analyses for second and third sampling can be adjusted based on results of first sampling event. The proposal was to be discussed with NMED before finalizing.
- An iteration of the Hydrogeologic Workplan DQOs was underway to define the remaining scope of the Hydrogeologic Workplan. The result was to be presented at the October 2001 quarterly meeting and discussed with NMED.

2.2 External Advisory Group Activities

The GIT formed the EAG to provide an independent review of the GIT's implementation of the Laboratory's Hydrogeologic Workplan. The EAG consists of six members with diverse technical and professional backgrounds to provide a broad technical and managerial review of the Laboratory's Hydrogeologic Workplan activities and methods.

The EAG consists of the following members:

- Robert Charles, Ph.D.—Dr. Charles has a doctorate in Geology with a specialty in geochemistry. He also has a Master of Arts degree in Organizational Management, and has more than 25 years of experience in his disciplinary areas. Dr. Charles serves as Chair of the EAG.
- Jack Powers, P.E.—Mr. Powers is a drilling consultant with more than 45 years of world-wide professional drilling experience.
- Robert Powell, M.S.—Mr. Powell has a Master of Science degree in Environmental Science and 25 years of experience and 33 groundwater-related publications. Mr. Powell 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.
- Charles McLane, Ph.D. - Dr. McLane, the founder of McLane Environmental, has over 20 years of experience in hydrogeology, environmental investigation and remediation, and exposure and risk assessment.

The EAG met in conjunction with the October 3-5, 2000 Quarterly Meeting and the March 20-23, 2001 Annual Meeting for semi-annual reviews 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 an action plan that specifies how the recommendations of the EAG will be incorporated into the program. In FY01, the following reports were completed:

- Semi-Annual Report to the Groundwater Integration Team (GIT) of the Los Alamos National Laboratory by the External Advisory Group, Meeting Dates 3-5 October 2000 (December 5, 2000)
- Los Alamos National Laboratory Groundwater Integration Team Action Plan for the External Evaluation Group December 2000 Recommendations (March 15, 2001)
- Semi-Annual Report to the Groundwater Integration Team (GIT) of the Los Alamos National Laboratory by the External Advisory Group, Meeting Dates 19-23 March 2001 (June 19, 2001)
- Los Alamos National Laboratory Groundwater Integration Team Action Plan for the External Evaluation Group June 2001 Recommendations (July 15, 2001)

At both of the EAG semi-annual reviews, there were sessions for stakeholders to discuss concerns about the program. The stakeholders appreciated these sessions and the EAG has committed to holding similar sessions in conjunction with each semi-annual review.

2.3 Drilling Management Review

Schlumberger was contracted to evaluate Laboratory drilling costs, observe the drilling of several wells, and make recommendations on how the drilling program could be improved and drilling costs reduced for future wells. A draft report has been submitted to the Laboratory and is currently in review.

This project was initially intended to evaluate the drilling of two to three of the deep monitoring wells (the R wells) proposed in the Hydrogeologic Workplan. The Laboratory underwent a two and one-half month drilling stand down shortly after this project started; this time was used to evaluate, in detail, the drilling records of earlier wells drilled. Consequently, the drilling of only one R-well was observed.

An evaluation of drilling management and methods employed as part of the Hydrogeologic Workplan was conducted from January to June 2001. The goal was to determine why drilling costs were greater than budgeted and make recommendations on actions that the Laboratory can employ to reduce costs. The review focused on:

- Evaluation of drilling costs for the first nine wells drilled for the Hydrogeologic Workplan
- Onsite evaluation of the drilling of three shallow wells at the Low-Head Weir site in Los Alamos Canyon
- Onsite evaluation of R-5 drilling, a deep monitoring well located in Pueblo Canyon

The draft report noted strengths of the drilling program and made recommendations to address weaknesses observed. The strengths of the drilling program:

- Successfully completed 10 wells
- Very intelligent staff
- Produced a Hydrologic Workplan that has satisfied all parties involved
- Sound report writing

- Flexibility to work within system that can rapidly change focus
- Able to address stakeholder concerns
- Sincere concern for the environment and belief in cleaning up environment around the Laboratory and State of New Mexico
- Zero tolerance on safety violations

Recommendations for improving the drilling program:

- Hire or contract a drilling expert who will represent the interests of the Laboratory
- Work with drilling fluid companies to develop a mud program that will enhance wellbore stability and respect, as well as possible, the need for representative groundwater samples;
- Conduct a workshop where drilling, drilling fluids, testing, and completion technologies used in private industry are presented to Laboratory staff
- Document lessons learned from past wells and use them to improve efficiency
- Institute a daily report that monitors costs

2.4 Value Engineering Study

At the request of the DOE Albuquerque Operations Office, the Office of Project Management (EM-6) conducted a Value Engineering (VE) study of the Laboratory Hydrogeologic Characterization Program. The EM-6 VE Study Team reviewed the multi-year deep well drilling and hydrogeologic analysis program designed to characterize the hydrogeologic setting of the Pajarito Plateau. The VE Study Team's on-site review took place during the week of April 29, 2001, with a presentation of its recommendations on May 4, 2001. The final DOE-approved report had not been delivered as of the end of FY01.

The VE study for this project followed the general study guidelines established by the Society of American Value Engineers (SAVE). The phases of such a study are:

Information Collection Phase - The initial effort of the VE Team was to obtain as much information about the project as possible. LANL presentations, existing documentation, and personal contacts were all used.

Functional Analysis Phase - The VE Team determined the functions involved in obtaining the desired objectives. Basic and secondary functions were determined and Functional Analysis Systems Technique (FAST) diagrams were developed to establish the relationships among the functions involved. These FAST diagrams helped shape the thinking and analysis of the VE Team, and their insights have been incorporated into this report.

Creative Phase - After studying the program, the VE Team used techniques such as brainstorming to identify a range of alternatives to the various functions. A total of 81 potentially valid alternatives were suggested.

Analytical Phase - Alternatives were developed focusing on the most cost effective.

Proposal Development Phase - The best alternatives were developed to assure achievement of the basic functions. These alternatives were prepared as recommendations.

Presentation Phase - Two presentations were made. The first was given to DOE/Los Alamos Area Office and LANL senior management on Thursday, May 3, 2001. The second was given to LANL staff on May 4, 2001. Audience comments from both presentations have been incorporation into the report. The VE recommendations were reviewed to assure that skilled managers could implement them. One or more further tele-conferences or videoconferences are planned to answer implementation questions.

The VE Study Team consisted of ten members from DOE/EM and private sector contractors. Observers from DOE/HQ and DOE/AL were present to help guide the team through organizational issues. None of the team members were directly affiliated with the project.

The draft Value Engineering report was provided to DOE for review in May and June 2001. The most significant recommendations are best considered as both a programmatic shift in focus under present mandates and a new strategic approach to LANL's Hydrogeologic Characterization Program. Significant portions of the Workplan's characterization requirements are now finished, and reevaluation at this time is reasonable. Therefore, the VE Study Team is convinced that an integrated analysis of the data produced by the 10 wells already installed, along with information obtained from other sources, will develop a compelling story. The characterization phase of the program can be demonstrated to be complete, and the enhanced knowledge of the regional aquifer can be the basis for installation of a long-term monitoring network. Primary recommendations are to:

- Prepare a comprehensive hydrogeologic report on the regional aquifer based on the extensive information already collected to date
- Focus on installing a regional aquifer monitoring system by installing a limited number of single-completion monitoring wells

The GIT was asked to review the draft VE Report and provided comments to DOE. The pre-publication draft document was reviewed at the September 12, 2001 GIT meeting. Although DOE maintains confidence in the findings, the Laboratory's review team was disappointed to find that the draft appears to be based on misunderstanding of the regulatory drivers for the Laboratory's Hydrogeologic Workplan and fundamental processes by which it is being implemented; the Laboratory's RCRA/HSWA permit requirements, especially related to groundwater characterization and investigations; and the Laboratory's relationship with the NMED and other stakeholders. The draft document contains many recommendations that have been or are being implemented by the Laboratory, but the GIT recommended that major technical recommendations be revised.

3.0 FY00 HYDROGEOLOGIC CONCEPTUAL MODEL

The FY01 Hydrogeologic Conceptual Model constitutes a concise description of the current understanding of the hydrogeologic setting of the Pajarito Plateau. Section 3.1 describes the elements of the hydrogeologic conceptual model relating to the mesas. Section 3.2 describes the elements related to alluvial groundwater. Section 3.3 addresses the elements related to perched intermediate groundwater and Section 3.4 addresses the elements relating to the regional aquifer. Section 3.5 describes elements of the geochemical conceptual model.

3.1 Mesas

1) Within drier mesas (generally in the eastern portion of the Laboratory), water occurs in the Bandelier Tuff under unsaturated conditions. Relatively little water (~1 mm/yr) moves downward beneath the mesa tops under natural conditions, due to low rainfall, high evaporation, and efficient water use by vegetation. Atmospheric evaporation extends within mesas, drying out the mesa interior and decreasing downward flow. Moisture content of the tuff varies with recharge rate and with texture of the lithologic units.

2) For wet mesas (generally along the western portion of the Laboratory) water occurs in the Bandelier Tuff primarily under unsaturated conditions. Groundwater also occurs as transient zones of saturation and in perennial saturated ribbons of limited spatial extent, which feed springs on the mesa sides. The saturated zones are localized by fractures and by permeability changes related to lithologic variations within the Bandelier Tuff. Higher rainfall and increased welding and jointing of the tuff lead to greater recharge rates for wet mesas than observed in drier mesas.

3) In addition to spring discharge at mesa sides, saturated and unsaturated flow through mesas results in recharge to the underlying intermediate perched zones of the regional aquifer.

4) Mesa top recharge under disturbed surface conditions is higher than under natural conditions. Increased recharge occurs when the soil is compacted, when vegetation is disturbed, or when more water is added to the hydrologic system by features such as pavement, lagoons, or effluent disposal.

5) Fractures within mesas could provide preferential pathways for contaminants, especially in regions of high infiltration and in rocks of low matrix permeability. Fracture flow is less likely to occur when the rock matrix is porous and permeable, because water is drawn out of the fractures. Contaminants in vapor phase readily migrate through mesas.

6) Water quality within mesas reflects the initial composition of rainwater, chemical interaction with the surrounding rocks, evaporative concentration of solutes, and effluent discharges at the mesa surface.

3.2 Alluvial Groundwater

1) Infiltration of surface water flow (caused by effluent discharges, spring discharge, or stormwater runoff) maintains shallow groundwater in the alluvium of some canyons. Alluvial groundwater is unconfined and is perched on or within underlying Bandelier Tuff, Cerros del Rio basalts, or Puye Formation. Evapotranspiration and percolation into the underlying rocks deplete alluvial groundwater as it moves down the canyons. Alluvial groundwater is a source of recharge to underlying intermediate perched zones and to the regional aquifer, usually by unsaturated flow.

2) Dry canyons have little surface water flow. In these canyons, groundwater may occur seasonally in the alluvium. Dry canyons are generally those that head in the eastern portion of the Pajarito Plateau.

3) In wet canyon bottoms, infiltration of surface water maintains shallow groundwater in the alluvium. Wet canyons generally have large surface water flow, head in the Jemez Mountains, or receive effluent discharges. Groundwater levels are typically highest in the late spring due to snowmelt runoff and in mid-to-late summer due to thunderstorms. Groundwater levels and extent of saturation decrease during the winter and early summer when runoff is at a minimum.

4) Percolation losses from alluvial groundwater by unsaturated flow account for an important source of contaminants in recharge and relatively rapid rates of groundwater flow (reaching the regional aquifer in decades or less). In some cases, percolation might occur by saturated flow. Faults, fractures, joints, surge beds, and higher permeability geologic units that underlie saturated alluvium (such as the Guaje Pumice Bed, Cerro Toledo Interval, Cerros del Rio basalts, and Puye Formation) could provide pathways for downward movement of water and contaminants.

5) Water quality of the alluvial groundwater reflects the composition of base flow, storm runoff, snowmelt, and effluent discharges where present. In canyons affected by effluents, the alluvial groundwater and sediments contain the majority of adsorbing contaminants (such as plutonium). Mobile solutes (such as tritium, high explosive compounds, and anions) migrate with moving groundwater, and are present in recharge.

3.3 Intermediate Perched Groundwater

1) Intermediate perched zones occur beneath major canyons and in the western portion of the Laboratory. Intermediate perched zones are found particularly beneath wet canyons that receive effluent discharges, have large surface water flow, or head in the Jemez Mountains. These intermediate perched zones occur in the Guaje Pumice Bed at the base of the Bandelier Tuff, the underlying Cerros del Rio basalts, and the Puye Formation. The location of intermediate perched zones is determined by presence of sufficient recharge, permeability variations of the rocks (reflecting lithologic variations), and geologic structure. Intermediate perched zones may be confined or unconfined. Discharge at springs and percolation into the underlying rocks (resulting in recharge to the underlying regional aquifer) deplete intermediate perched groundwater.

2) Intermediate perched zones beneath canyons do not generally extend laterally beneath the mesas. Neither are the intermediate perched zones continuous along the length of the canyon. Variations in stratigraphy and in both recharge and percolation losses along the canyon cause changes in thickness or presence of the intermediate perched zones. Lateral movement of intermediate perched groundwater away from the canyon axis may occur if the dip of the perching horizon and the canyon orientation do not coincide.

3) In the western portion of the Laboratory, groundwater occurs as a large, 300-ft-thick, intermediate perched zone within the lower Bandelier Tuff and the Puye Formation, approximately 700 ft below the mesa top. Most recharge for this zone originates as underflow of groundwater from the Jemez Mountains, with some contribution from recharge through mesas and canyon bottoms. Percolation losses from this intermediate perched zone result in recharge to the underlying regional aquifer.

4) Water quality within intermediate perched zones reflects that of the recharge water including effluent discharges and native groundwater. Flow within intermediate perched zones could transport contaminants some distance away from their surface source.

3.4 Regional Aquifer

1) The regional aquifer beneath the Pajarito Plateau occurs in rocks of the Puye Formation, the Cerros del Rio basalts, the Tschicoma Formation, and the Santa Fe Group. The hydraulic conductivity of aquifer rocks is heterogeneous and averages approximately 140 m/yr. The aquifer is unconfined in the west and confined or partially confined in some locations near the Rio Grande.

2) At the western edge of the plateau the water table is located approximately 300 to 400 m below ground surface. The hydraulic gradient in the western portion of the aquifer is generally downwards. The flow of groundwater is east/southeast, towards the Rio Grande. The hydraulic gradient in the eastern portion of the aquifer near the Rio Grande is generally upwards. Groundwater velocities vary spatially with a typical value of 10m/yr. Local deviations in flow direction occur due to lithologic heterogeneities and water supply pumping.

3) The Rio Grande is the main discharge area for the regional aquifer. The largest component of recharge occurs as underflow of groundwater from the Sierra de los Valles, to the west of the Pajarito Plateau. Recharge also occurs by leakage from mesas, from alluvial groundwater in canyon bottoms on the Pajarito Plateau, and from intermediate perched groundwater. Both stream and spring discharge provides discharge to the Rio Grande in addition to the groundwater underflow. Local recharge on the Pajarito Plateau is important because it provides pathways for contaminants that originate from effluent discharges.

4) The radiocarbon ages of water from deep wells beneath the Pajarito Plateau range from about 1 to 6 thousand years, although activities of tritium indicate that a portion of the water is less than 50 years old. The chemistry of groundwater in many wells near the Rio Grande (high total dissolved solids, high concentrations of naturally occurring solutes such as arsenic, boron, uranium, and fluoride, and depleted stable isotope values) is different from that beneath the Pajarito Plateau and from the eastern Española Basin. This suggests that old water (about 30 thousand years) discharges near the river. Water flowing east/southeast from beneath the Pajarito Plateau mixes with this older water as it approaches the Rio Grande.

3.5 Geochemical Conceptual Model

The following 11 elements reflect the current understanding of the geochemistry of groundwater and are represented in the FY01 geochemistry conceptual model.

1) Due to geochemical processes, the natural composition of groundwater can vary within the alluvium, perched intermediate zones, and the regional aquifer.

2) 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.

3) 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). These reactive constituents, consisting of $CaCO_3$, Ca-smectite, kaolinite, sodium feldspar, amorphous SiO_2, MnO_2, and Fe $(OH)_3$, may control groundwater composition for the major ions and selected trace elements including aluminium, iron, and manganese.

4) Alluvial aquifer materials provide the largest reservoir for effluent discharged constituents such as strontium-90, cesium-137, plutonium-238, plutonium-239, 240, and americium-241 due to the ready adsorbtion of these constituents onto clay- and silt-sized material.

5) In general, adsorption of radionuclides and inorganic species decreases at circum -neutral pH conditions as follows: cesium-137 (highest sorption) = americium-241 > strontium-90 > uranium > nitrate = sulfate = chloride = perchlorate = TNT = RDX = tritium (lowest sorption). Adsorption capacities of sediments and aquifer material may change over time due to changes in solution speciation and mineralogy.

6) Activities of adsorbing radionuclides and inorganic species generally decrease down gradient along the groundwater flow path.

7) Non- and semi-sorbing constituents can migrate from alluvial groundwater to perched intermediate zones and to the regional water table.

8) 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 $SrCO_3$ or $BaCO_3$ and precipitate as $(Sr\text{-}Ba)SO_4$ in alluvial groundwater.

9) Transport of constituents in groundwater occurs as both dissolved solutes and as colloids. Colloids may include natural material (silica, organic matter, calcium carbonate, clay minerals, and ferric hydroxide) and possibly solid phases associated with Laboratory discharges.

10) A component of groundwater within perched intermediate zones and to the regional water table is less than 59 years old, based on measurable tritium activities considerably above the cosmogenic baseline of 1 pCi/L.

11) Increasing concentrations of dissolved organic carbon, carbonate alkalinity, calcium, potassium, iron, manganese, and other solutes occur in alluvial groundwater since the Cerro Grande fire. Oxidation and reduction reactions and carbonate complexation with metals influence aqueous speciation of redox-sensitive solutes.

4.0 FY01 SUMMARY OF DATA ANALYSIS AND INTERPRETATION

In FY01, new geologic, hydrologic, and geochemical data were collected from boreholes and newly completed wells. In past years, this section of the Groundwater Annual Status Report has focused exclusively on data that were collected and interpreted during the fiscal year. This year, approximately mid-way through the implementation of the Hydrogeologic Workplan, a synthesis of the data collected, analyzed, and interpreted since the beginning of the program is presented. The data synthesis is focused on how the data are used to develop, support, and refine the Hydrogeologic Conceptual Model (Section 3). Section 4.1 presents a summary of geologic data, Section 4.2 summarizes the vadose zone hydrologic data, Section 4.3 describes regional aquifer hydrologic data, and Section 4.4 describes the geochemical data analysis and interpretation.

4.1 Geologic Data Analysis and Interpretation

Drilling has been the principal source of information about deeply buried geology at LANL. This information includes data from 1) petrologic analysis of core and cuttings tied to outcrop information (where available) and borehole geophysical surveys, 2) chemical analysis of groundwater from different strata, and 3) hydrologic testing of different strata. Data from all available boreholes are used for analysis and interpretation. Figure 4.1-1 shows specifically those boreholes discussed in this section. The petrologic data provide the basis from which a three-dimensional geologic model can be constructed. The other two data sets can then be distributed in the model by assigning appropriate hydrologic and groundwater-chemical properties to the constituent strata. Conceptual cross-sections, such as one that is located by the west-east line in Figure 4.1-1 and shown in Figure 4.1.1-1, are used to determine if similar sections generated from the 3-D Geologic Model honor age, structural, and other constraints. If not, either the concepts or the model need revision.

4.1.1 Geologic Setting Overview

The Laboratory is situated in the southwestern part of the Española Basin, one of several distinct structural basins within the Rio Grande Rift. Facilities of the Laboratory are situated on the mesas and in the canyons of the Pajarito Plateau, which is the geomorphologic remnant of the last Bandelier Tuff eruptions of ~1.2 Ma. This volcanic system is well exposed and reasonably well characterized by both surface and drill-hole studies. However, components of older volcanic and sedimentary systems beneath the Laboratory are largely or entirely buried beneath the Bandelier Tuff where their extent, thickness, and interstratification can only be determined by drilling and associated indirect (geophysical) studies.

As a result of its position on an active rift margin with attendant volcanism and sedimentation, the Laboratory is underlain by strata of five volcanic and three sedimentary systems. Figure 4.1-1 shows the placement of the Laboratory and a line of schematic cross-section (Figure 4.1.1-1) that illustrates a concept of the Laboratory's geologic setting based on recent studies for the Hydrogeologic Workplan. This cross-section is updated with all current drill hole information, and it is used here to present an overview of the Laboratory's geologic setting and as a reference for the discussion of geologic conceptual model elements and uncertainties in this section.

Basic components within the geologic setting are the source regions and depositional systems that fed materials into the western Española Basin. Table 4.1.1-1 summarizes these systems and their ages. Some of the ages cited are abbreviated to represent only the duration of volcanism or sedimentation most relevant to the Laboratory site. Going back in time, the age and nature of each system becomes more uncertain; these uncertainties and their relevance to the Hydrogeologic Workplan are discussed in Section 4.1.3.

Table 4.1.1-1 Five Volcanic Systems and Three Sedimentary Systems within the 3-D Geologic Setting of Los Alamos National Laboratory

Volcanic systems	Sedimentary systems
(1) Bandelier Tuff (1.6 – 1.2 Ma*)	
(2) Cerros del Rio lava flows (2.8 – 2.3 Ma)	(1) Rio Grande (riverine, ~5 Ma to present): Source from the north
(3) Tschicoma volcanic domes (7 – 2.3 Ma)	(2) Puye Formation (proximal basin fill, >5 Ma to present): Source from the west
(4) Keres volcanic centers (12.4 – 7 Ma)	(3) Santa Fe Group (distal basin fill, ~17 Ma to ~5 Ma): Source from the east
(5) Older basalt flows (12.8 – 8 Ma)	

* Duration of activity in millions of years ago (Ma). Ages for the Bandelier Tuff include the Cerro Toledo Interval.

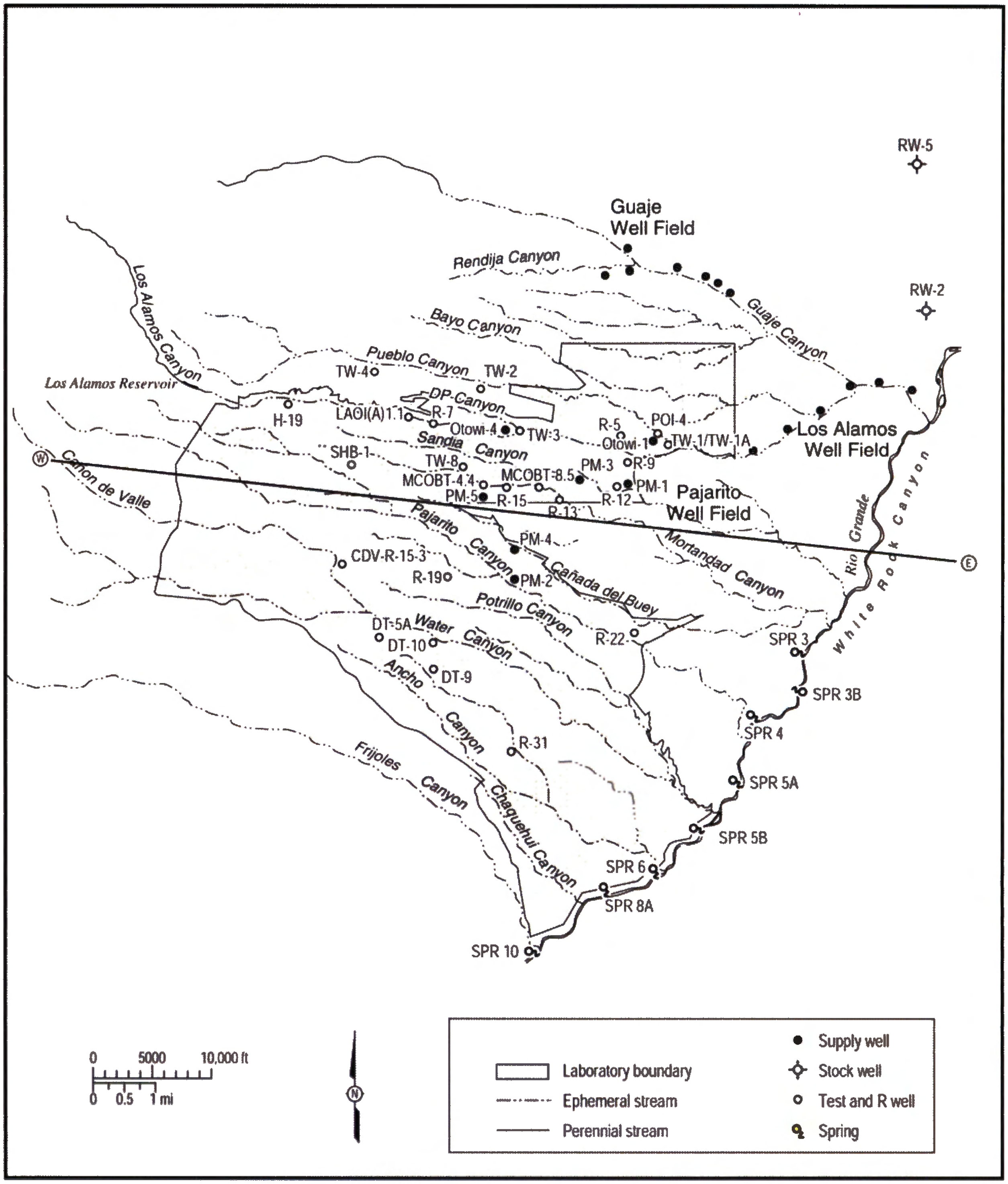


Figure 4.1-1 Laboratory boundary and locations of drill holes discussed in Section 4.1. The west-east line (W-E) drawn across the Laboratory to the Rio Grande shows the approximate location of the schematic geologic section of Fig. 4.1.1-1, which is a conceptual interpretation of stratigraphic relations based on drill hole and outcrop data collected across the Laboratory.

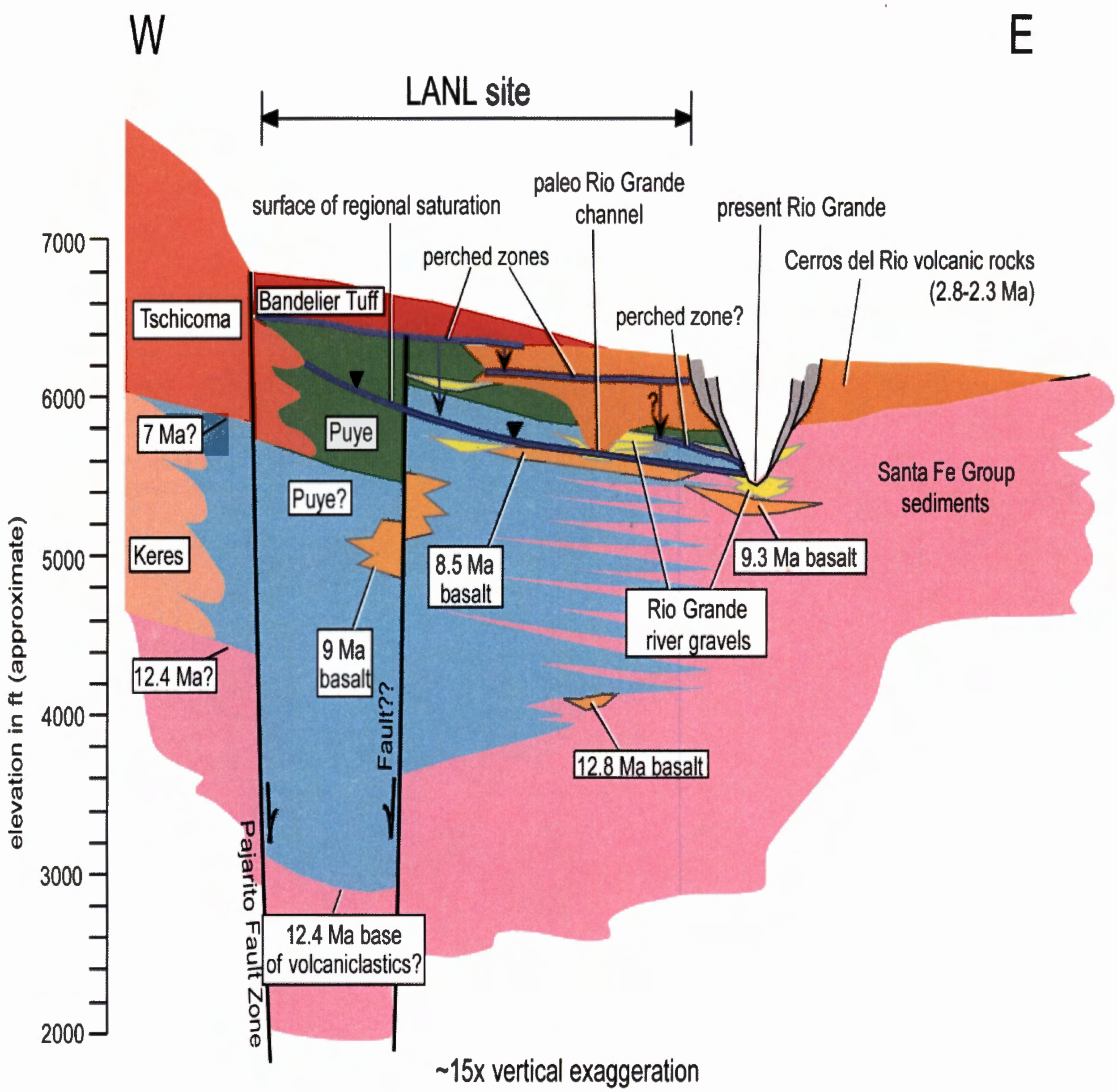


Figure 4.1.1-1 Schematic cross-section through the Laboratory illustrating current conceptual relationships between major stratigraphic components. Unit colors correspond with those used in the illustration of volcanic and sedimentary depositional history, Figure 4.1.1-2.

Figure 4.1.1-2 gives some spatial and temporal sense to the systems described in Table 4.1.1-1. Volcanic systems affecting the Laboratory site have been centered principally to the west (Keres-Tschicoma-Bandelier systems) or to the east (Cerros del Rio system; sources of older basalts remain enigmatic). Sedimentary systems have been supplied with detritus either from the west (Puye and older poorly-known equivalents), from the east (Santa Fe Group sediments), or from the north (Rio Grande sediments). The interfingering of these volcanic and sedimentary systems is important to the hydrogeologic setting because porosity, permeability, and other hydrologic properties are dependent on such volcanic characteristics as fracturing and breccia development and on sedimentary lithologic features such as clast size and sorting.

A brief volcanic and sedimentary history is described below with references to Table 4.1.1-1 and Figures 4.1.1-1 and 4.1.1-2. Santa Fe Group sediments were deposited in the Española basin starting about 17 Ma. The Espanola basin was a fault-bounded north-south trending valley, bounded on the east by the Santa Fe block and on the west by the Nacimiento block (Ingersoll et al., 1990). The Española basin was deeper on the western side than on the east, and the Santa Fe Group represents sediments eroding off the Santa Fe block and from the Picuris range to the northeast, resulting in interfingering of two alluvial aprons in the vicinity of the present LANL location and in the central Española basin. The sediments in the central Española basin were deposited as alluvial fans, braidplains, sandflats, and ephemeral lakes (Ingersoll et al., 1990).

The western edge of the Española basin was disrupted by major volcanism and faulting about 13 Ma (Ingersoll et al., 1990). Fault movement uplifted the western bounding Nacimento block while the Keres volcanic centers became active. During this time in the western Española basin, "older basalt flows" were interlayered in the Santa Fe Group sediments (Figure 4.1.1-2). However, there was also a source of sediments from the west, as the "lower volcanic debris" (labeled "Puye?" in Figure 4.1.1-2) was eroded from probable Keres Group volcanic rocks of the early Jemez volcanic field.

About six to seven million years ago there was a transition in volcanic processes, marked by the appearance of the Tschicoma volcanic domes, a change from predominantly bimodal (basalt and rhyolite) to dacitic volcanism. Since this time, most fault motion along the west side of the Española basin has been along the Pajarito Fault Zone and the "upper volcanic debris" of the Puye Formation (Figure 4.1.1-2) was produced by sediment eroded from the Tschicoma volcanic centers. The Puye Formation is well exposed to the north but remains poorly defined beneath the Laboratory. Recent studies based on Hydrogeologic Workplan drill holes show that the deeper Puye Formation is vitric to the south and west and clay-rich to the northeast; clay-altered zones could affect the flow of groundwater. The sources of sediment in the "traditional" Puye Formation show a distinct progression from northwest to west through time; the newly recognized older (pre-Tschicoma?) pumiceous Puye deposits complicate this picture. The transition to deeper pumiceous material in the Puye Formation also drops in elevation to the south, consistent with the presence of a major basinal structure under the central-southern Laboratory.

About five million years ago, the Rio Grande became a through-going river, connecting source areas in the north (e.g., Tusas Mountains and Picuris Range) through the Espanola basin to the Albuquerque basin to the south, carrying gravels rich in distantly derived quartzites (Ingersoll et al., 1990). Beneath the area that is now Los Alamos, these river gravels were deposited in shifting channels displaced by the toes of the alluvial fans (Puye Formation) coming off the Tschicoma volanic highlands to the west. The interplay between fanglomerates shed from the west and the river deposits is not well understood and could be a significant factor in determining groundwater flow transitions between different lithologies. The top of the regional aquifer beneath the Laboratory often occurs in rocks that are close to the stratigraphic level of these river gravels (Figure 4.1.1-1). The potentially high hydraulic transmissivity of the river gravels makes them an important component of the 3-D Geologic Model.

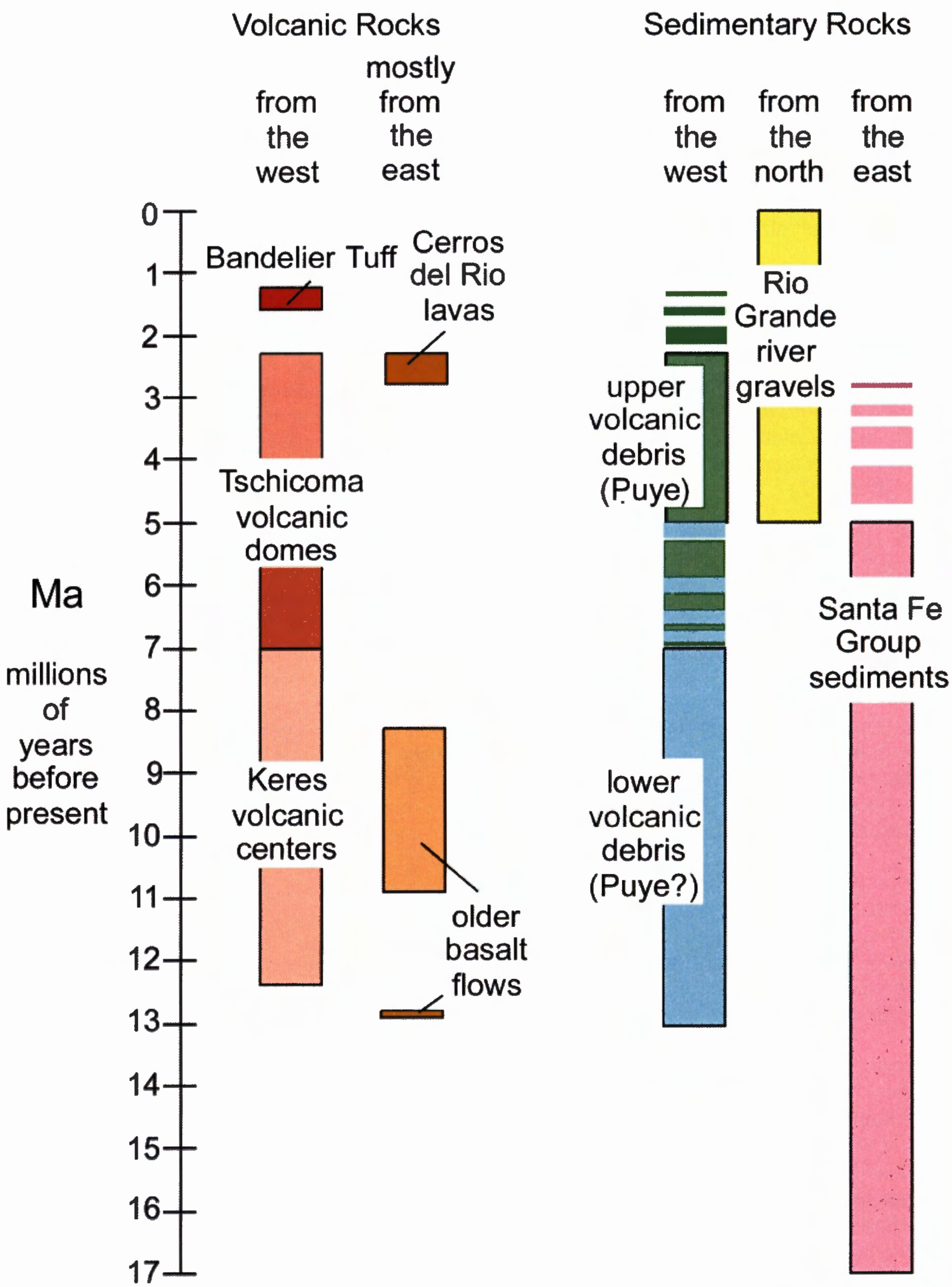


Figure 4.1.1-2 Depositional history of volcanic and sedimentary units beneath the Laboratory. Deeper units have greater uncertainty in timing and duration. Some units, particularly the older Puye (?), are recently recognized and of yet uncertain stratigraphic assignment. Locations of source regions (west, north, or east) are indicated. Unit colors correspond with those used in the schematic cross-section, Figure 4.1.1-1.

Along the eastern edge of the river, perhaps trapping it along the western highlands front, was the Cerros del Rio volcanic field, which erupted significant volumes of lava well into the Laboratory area from about 2.3 to 2.8 Ma. (The Cerros del Rio volcanic field is one of several middle Pliocene to Pleistocene basaltic volcanic fields of the axial Rio Grande Rift in central and northern New Mexico.) Most of the volcanic flows and some cinder deposits extended out over the Puye fanglomerates, a surface of varied topography. Canyons cut in the Puye deposits by streams from the western highlands provided a rough terrain beneath the lavas. Prediction of lava base elevations is difficult in this situation. For example, Cerros del Rio lavas and cinder deposits in R-22 were over 1000 ft thick, twice as thick as predicted by the geologic model available when that hole was drilled. Rio Grande river gravels are present beneath the thick basalts at R-31 but not at R-22; channels beneath the basalt thus appear to include both local and through-going stream systems. The Cerros del Rio deposits were themselves deeply incised by the Rio Grande.

Previously unstudied, but important among hydrogeologic components, is the degree in which alteration has affected volcanic and sedimentary systems after emplacement. Data from the characterization program indicate that the geological materials in the northeastern portion of the Laboratory (R-9 and R-12) were altered after deposition. Extensive clay alteration was found above the regional aquifer in the Puye Formation, within pumiceous volcanic sediments. This area of alteration extends to Otowi-1 and R-5, where the alteration includes zeolite and calcite formation as well as clays such as smectite with oxide-mineral associations that are highly sorptive for some contaminants (Section 4.4.2.3). This alteration affects both physical and geochemical hydrogeologic properties and is an overprint on the depositional components that are illustrated in Figure 4.1.1-1.

4.1.2 Discussion of Geologic Aspects of Conceptual Model Elements

The Laboratory's Hydrogeologic Conceptual Model (Section 3) has been updated and refined several times since the inception of the Hydrogeologic Workplan. The geologic model, described in Section 4.1.1, is the underpinning of many of the elements of the Hydrogeologic Conceptual Model. This section focuses on the current geologic information supporting elements of the conceptual model.

4.1.2.1 Mesa Conceptual Model Elements

The Bandelier Tuff underlies the mesas of the Pajarito Plateau. Lithologic variations (welding, surge beds, ash-flow structures, air-fall pumice beds) and fractures exert the primary control on the flow of water through the mesas. Lithologic variations in the Bandelier Tuff are the result of multiple eruption sequences and highly variable cooling history. The formation of the Bandelier Tuff began with the eruption of the Otowi Member, about 1.61 Ma (Izett and Obradovich, 1994). At the base of the Otowi Member is the Guaje Pumice Bed. Overlying the Guaje Pumice Bed are an air-fall pumice bed and pyroclastic flow deposits with minor surge deposits (Goff et al., 1989). After deposition of the Otowi Member, the Cerro Toledo pyroclastic and volcanogenic alluvial deposits were emplaced on locally eroded Otowi ash flows (Goff et al., 1989). The eruption of the Tshirege Member (1.22 Ma) defined the current outline of the Valles Caldera. This eruption began with deposition of the thin Tsankawi Pumice followed by ash flows of the Tshirege Member that are more densely welded and have more abundant north-south trending fracture in the western part of the Laboratory.

In a study of the unsaturated hydraulic properties of the Bandelier Tuff, Rogers and Gallaher (1995) found that hydraulic properties, such as saturated hydraulic conductivity, differ significantly between units. Moisture content of the tuff varies with recharge rate and with texture of the lithologic units. For all mesas, including wet mesas (generally along the western portion of the Laboratory), water occurs in the Bandelier Tuff primarily under unsaturated conditions. Groundwater also occurs as transient zones of saturation and in perennial saturated ribbons of limited spatial extent, which feed springs on the mesa sides. The saturated zones are localized by fractures and by permeability changes related to lithologic variations within the Bandelier Tuff. Higher rainfall and increased welding and jointing of the tuff lead to greater recharge rates for wet mesas than observed in drier mesas.

An important factor in estimating contaminant travel time through the vadose zone is the overall thickness of the Bandelier Tuff. This thickness is reasonably well known and represented in the 3-D Geologic Model, but thickness and nature of deeper units within the Bandelier Tuff are more uncertain. The Otowi remains the least well-known part of the Bandelier system because the upper part of the Otowi Member was extensively eroded during Cerro Toledo time through incision by stream channels. As a result of this erosion, predicted depths to the top of the Otowi Member are not as accurate as predicted depths to the base of the unit. Thus, the Otowi is thicker than expected in some places (e.g., R-31) and the Cerro Toledo is thicker than expected in other places (e.g., R-19 and CdV-R-15-3). The greatest uncertainties occur in the southern part of the Laboratory, where erosion of the Otowi ash flows was extensive.

4.1.2.2 Geologic Aspects of Alluvial Groundwater Conceptual Model Elements

Alluvial groundwater recharges the underlying intermediate perched zones (where present) and regional aquifer by percolation. In some of the wetter canyons percolation can occur by saturated flow. Faults, fractures, joints, surge beds, and higher permeability geologic units that underlie saturated alluvium (such as the Guaje Pumice Bed, Cerro Toledo Interval, Cerros del Rio basalts, and Puye Formation) could provide pathways for downward movement of water and contaminants.

Data from Los Alamos Canyon (LAOI-1.1) show that the Otowi contains significant clay alteration under some canyon reaches. This alteration provides mappable evidence of groundwater incursion into the Bandelier Tuff beneath canyon bottoms in the past. However, because effective porosity decreases in these clay-rich tuffs, their presence may inhibit downward percolation of groundwater under present-day conditions.

As hydrogeologic entities, faults may be most important as pathways in the vadose zone, linking saturated alluvium on canyon floors and vadose-perched horizons with the regional aquifer. For future work, a new digital elevation model, which is accurate within ± 0.5 ft, can be used to identify inflections in the surface that are one source of evidence pointing to buried structure. Separate studies being conducted for seismic hazards are also providing information on faulting and associated tectonic fractures.

4.1.2.3 Geologic Aspects of Intermediate Perched Groundwater Conceptual Model Elements

Intermediate perched zones can occur in the Guaje Pumice Bed at the base of the Bandelier Tuff and in the underlying Cerros del Rio basalts or in the Puye Formation. The location of intermediate perched zones is determined by presence of sufficient recharge, permeability variations of the rocks (reflecting lithologic variations or clay alteration variations), and geologic structure.

The distribution and geometry of the Guaje Pumice Bed is of interest because it hosts or is part of an intermediate-depth perched groundwater zone at least 4.5 km in length along the axis of Los Alamos Canyon. However, the 3-D Geologic Model shows that the Guaje Pumice Bed was deposited across a large paleovalley draining to the south-southwest in the central part of the Laboratory. New data from recent drill holes, particularly MCOBT-4.4 and MCOBT-8.5, have further constrained the axis of this paleovalley. Thus far there is no evidence that perched water from Los Alamos Canyon is diverted along the course of the paleodrainage toward the south (e.g., to Sandia Canyon or Mortandad Canyon), but the possibility will be considered further and tested against future analyses of groundwater.

On a site-wide basis, contours for the base of the Cerros del Rio define a paleosurface that generally slopes toward the south but may be crossed by several paleocanyons. These lava units are important hydrogeologically, as breccia zones between basalt flows can provide laterally extensive zones of high hydraulic conductivity (if the breccias are not clay-filled). In addition, preliminary groundwater chemistry data suggest differences between Cerros-hosted and Puye-hosted groundwater hydrochemistry with differences that may affect contaminant speciation and the abundance and mobility of colloids. In the vicinity of Mortandad Canyon, flow of perched water in the Cerros del Rio basalt may be to the south, following the dip of the unit. Cerros del Rio lava flows can produce confined/perched aquifers and may provide tabular zones of enhanced flow beneath the water table. Volcanic deposits of the Cerros del Rio have varied hydrogeologic impact because they can occur above, at, and below the water table.

As noted above, clay accumulation can change a transmissive lava flow breccia into a poorly transmissive zone. The variable distribution of clays in Cerros del Rio basalts can be seen in the clay content in intermediate boreholes MCOBT-4.4 and MCOBT-8.5 (Figure 4.1.2-1). In MCOBT-4.4, in a wetter portion of Mortandad Canyon, clay has accumulated near the top of Cerros del Rio basalt. In the drier drill hole MCOBT-8.5 there is not much clay near the top, but there is a peak in clay content in the lower part of the Cerros del Rio lavas. The clay distribution may reflect zones of major transport if the clays are translocated, but studies to address this are still in progress.

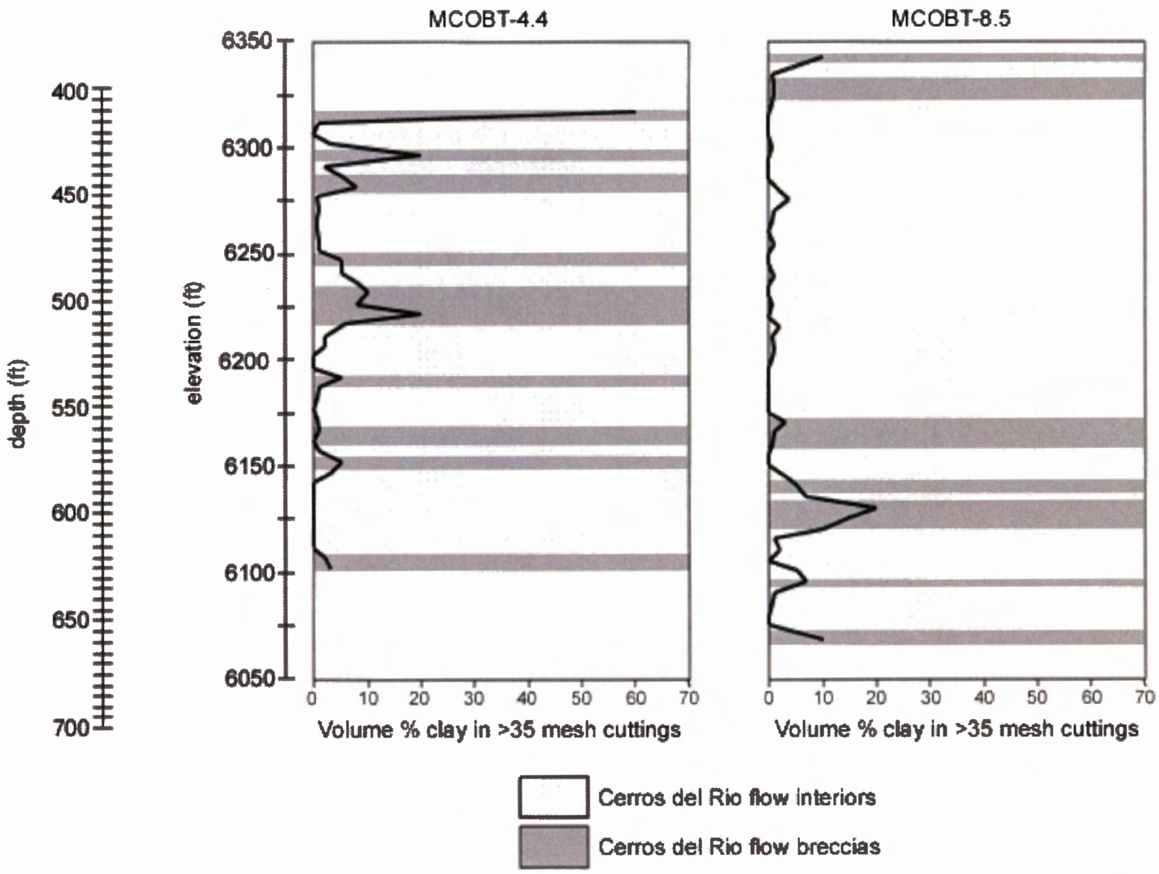


Figure 4.1.2-1 Clay distributions in Cerros del Rio lavas of drill holes MCOBT-4.4 and MCOBT-8.5. In drill hole MCOBT-4.4, to the west, clays are concentrated in flow breccias high in the lava series; in drill hole MCOBT-8.5, to the east, the clays are concentrated in lower flow breccias. The Cerros del Rio lavas are above the regional water table in both of these drill holes.

4.1.2.4 Geologic Aspects of Regional Aquifer Conceptual Model Elements

The regional aquifer beneath the Pajarito Plateau occurs in rocks of the Puye Formation (fanglomerates and pumiceous deposits), the Cerros del Rio lavas, lavas of the Tschicoma Formation, and the Santa Fe Group. Permeability is a key parameter in estimating contaminant transport times in the regional aquifer. The available permeability data for hydrogeologic units beneath the Laboratory are derived by pump testing and interpretation of borehole geophysical measurements, plus ongoing injection tests in the current drilling campaign (see Table A-2). With the production of a revised 3-D Geologic Model in FY02 and the analysis of hydrologic testing data from recent wells it will be possible to reassess the correlation between lithology and permeability.

The nature of the Puye/Santa Fe contact is still poorly defined. Much of the deeper sedimentary material previously classified as Santa Fe is in fact earlier Puye-type volcanogenic material provided by sources that were closer and depositionally more energetic than the Santa Fe system. The contact between the Santa Fe Group and the Puye Formation may be more properly represented as interfingering, provenance-distinct wedges (Figure 4.1.1-1) that can be mapped into the 3-D Geologic Model. Further, gravels distributed by the Rio Grande may or may not provide a contiguous hydrostratigraphic unit under some portions of the Laboratory. If the gravel units maintain continuity through significant portions of the lab area, and if they are more permeable than surrounding units (i.e., well sorted, little or no alteration), they could function as buried channels of focused groundwater flow.

The Hydrogeologic Workplan places special emphasis on faults and fractures. There are faults to the north and south of the Laboratory, known from surface mapping, but structure beneath the Bandelier Tuff on Laboratory property is poorly known. Information on faults comes from surface mapping and from earlier Seismic Hazards boreholes. Two faults were identified in core from SHB-1 (near TA-55), one in a lava (Cerros del Rio?) and the other in Bandelier Tuff. Both faults had abundant sheared clay, suggesting that these portions of the faults are not transmissive to water. Faults along the western boundary of the Laboratory (the Pajarito Fault and splays) are best known because of detailed mapping and trench studies by the Seismic Hazards Program. These western faults are often filled with clay but have secondary fractures that may be transmissive. Where faults are clay-filled, the fracture zones associated with them may be more transmissive than the faults themselves.

Hydrothermal alteration is suspected in the clay-altered lower Puye beneath the northeastern portion of the Laboratory. There are clay zones in R-9, R-12, Otowi-1, and R-5 where extensive alteration has occurred, but such alteration is missing at R-19, CdV-R-15-3, R-22, and R-31. The newly recognized lower pumiceous subunit of the Puye is completely altered to clay at R-9 and R-12, but apparently not to the west and south, though the depths and lateral extents of these clay zones are not yet known. Geochemical effects are associated with clay alteration of Puye pumice. The clay-rich Puye sediments from R-9 and R-12 are sodium-depleted when compared with comparable unaltered pumiceous Puye sediments from R-19 (Figure 4.1.2-2); along with this depletion there is an enrichment of some heavy elements (e.g., Ba). Reassessment of samples from Otowi-1 shows that clay alteration extends well down into sediments of the Santa Fe Group, accompanied by formation of zeolites and calcite. All of these alteration minerals have effects on permeability, sorption, and groundwater chemistry. Field reconnaissance conducted this year indicates that there are equivalent clay zones in some Rio Grande river gravels that include zeolites and complex manganese-oxides.

4.1.3 Geologic Uncertainties

Early in FY01, a series of meetings was held to evaluate the understanding of the LANL Site geology, especially with regard to hydrogeology. These meetings identified those data that are most needed to support conceptual and spatial models and that are adequate for risk-assessment activities. Some of the data deficiencies have been met by new data from the characterization wells, by reassessment of data and samples from earlier drill holes, by new geologic maps of the Puye and Frijoles Quadrangles, and by other geologic studies being conducted at the Laboratory (e.g., Seismic Hazards Program studies). Geologic uncertainties for the Laboratory fall into several categories. Five principal categories of uncertainty are described below.

(1) What are the three-dimensional relationships between subsurface strata at the Laboratory?

Figure 4.1.1-1 is a schematic view of stratigraphic relationships at the Laboratory. Uncertainties in the placement of stratigraphic boundaries are minimal within boreholes (usually within 5 ft or less), but extrapolations between boreholes are less uncertain. In general, the uncertainty in stratigraphy increases

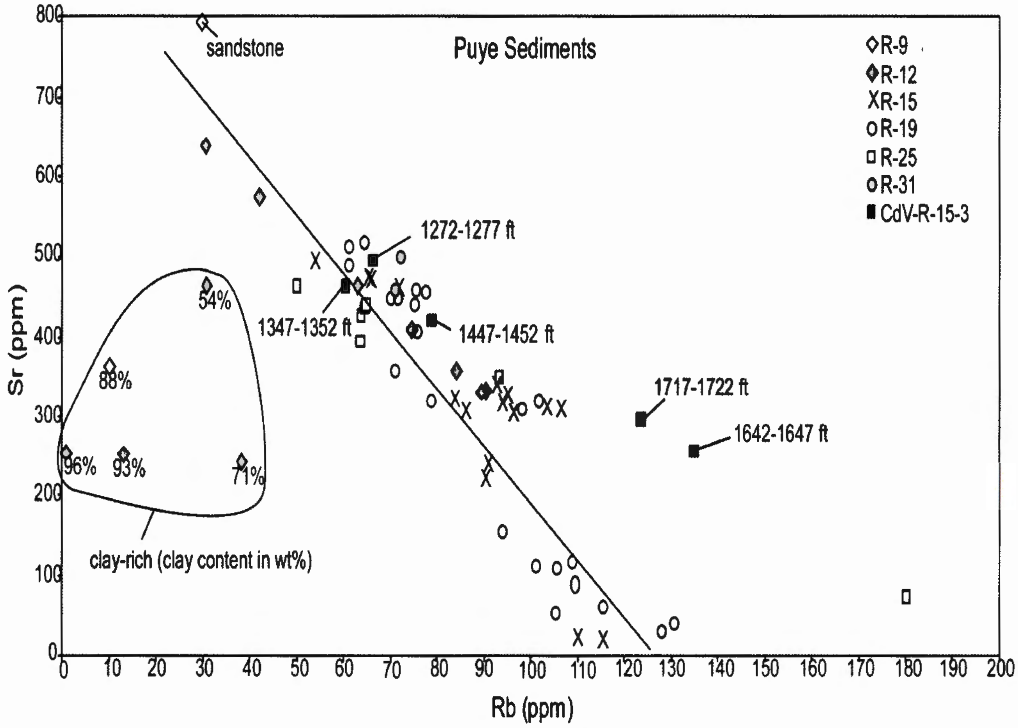


Figure 4.1.2-2 Plot of strontium (Sr) versus rubidium (Rb) in Puye fanglomerate and pumiceous Puye (?) sediments from several drill holes. Mafic (lower silica, more iron-rich) volcanic sources produce sediments with higher Sr and lower Rb; less mafic volcanic sources have lower Sr and higher Rb. The line shown is the predominant trend in this mafic to less mafic compositional series for unaltered Puye sediments. Clay-altered samples are significantly Rb-depleted as a consequence of the alteration process; other alkali elements, most notably Na, are also lost when clays are formed from volcanic glass.

with depth, for there are more shallow drill holes than deep (hence more shallow stratigraphic control). Some units are prone to be less predictable in extrapolation between drill holes; in particular, the basal surface of the Cerros del Rio lavas has been difficult to predict because early eruptions filled canyons of unknown size and orientation. There are also uncertainties with respect to sedimentary units. As noted in Figures 4.1.1-1 and 4.1.1-2, the deeper pumice-rich volcaniclastic sediments are described as part of the Puye (?) Formation but there is considerable uncertainty about the age of these sediments, where they came from, and whether they are really related to the overlying Puye fanglomerates. Such questions are important because they provide constraints on inference of thickness, structure, continuity, and lithology for a deposit that is seen only in drill holes. There is also uncertainty about the nature of the transition between these deep pumiceous sediments and the Santa Fe Group sediments to the east; Figure 4.1.1-1 shows a zone of interfingering sedimentation between these two units, but this is largely speculative.

(2) What alteration features transect the boundaries of depositional stratigraphic units?

There is sufficient evidence in hand to show that clay alteration of the pumiceous Puye is extensive at drill holes R-5, R-9, R-12, and Otowi-1; the depth and lateral distribution of this alteration is not well constrained. Uncertainty in the distribution and nature of alteration arises largely because these features are imprinted on the strata after deposition and therefore do not follow depositional contacts. An understanding of the origin of alteration can help to determine both its distribution and its hydrogeologic properties. For example, if the alteration is hydrothermal it might be zoned in structure, chemical composition, and mineralogy around specific volcanic centers, perhaps of the Cerros del Rio volcanic field. There are clay zones in R-9, R-12, Otowi-1, and R-5 where extensive alteration has occurred, but such alteration is missing at R-19, CdV-R-15-3, R-22, and R-31. Additionally, these alteration features are associated with enrichments of some elements (e.g., Ba and Sr) that can also occur as contaminants and could be misinterpreted as such. Understanding of alteration zones with perturbed chemical signatures will help to avoid possible confusion.

The distribution of pumiceous glass alteration zones is poorly understood. Preservation or loss of glass, and the alteration products formed from glass, are hydrogeologic parameters that provide information about reactive transport pathways that is yet to be interpreted. Based on data collected to date:

- Preservation of glass (little clay) in the pumiceous Puye persists well below the regional aquifer in some areas (R-19, CdV-R-15-3, R-2.2, R-31).
- Significant alteration of glass to clay above the regional aquifer occurs in the Otowi beneath some canyons (e.g., LAOI-1.1).
- The pumiceous Puye above the regional aquifer to the east in Los Alamos Canyon (R-9 and R-12) is also altered, but the type and extent of alteration differs from that in the Otowi ash flow.
- It is not known how the alteration in the pumiceous Puye above the regional aquifer in R-9 and R-12 relates to alteration below the regional aquifer in Otowi-1.

(3) What are the relations between lithology and permeability, and does lithology play a role in flow rates and in reactive transport? [This question needs to be addressed in both the vadose zone and in the regional aquifer.]

The delineation between basalt flows and sedimentary rocks has real hydrologic significance; portions of some basalt flows appear to be substantially higher in permeability, particluarly in flow breccias that lack clay filling. Differing transport characteristics, assuming that flow in basalts occurs primarily through breccia zones, amplify the importance of this delineation. Therefore, understanding flow in basalt may be the most important uncertainty to overcome. Lanthanide-element signatures and other geochemical parameters can be used to assess whether clay present in fractures formed in situ or was translocated. Flow directions and redox reaction rates can be determined from studies of clay, Mn-oxide, and other secondary mineral systems.

Lithologic controls may be important to reactive transport. Most importantly, clays are likely to be among the colloid formers in the flow system. Near-surface (to 20 m depth) clays studied at Pajarito Mesa show that heavy metals that are redox-sensitive are strongly held by Mn oxides. This phenomenon was studied at Yucca Mountain by examining what happens to Ce (a Pu analog) in the presence of Mn oxides (Vaniman and Chipera, 1996). These studies show that Ce is removed from groundwater by manganese oxides along all vadose-zone pathways within flow distances of a few tens of meters. Positive Ce anomalies can be used to identify those portions of the hydrogeologic system where redox-sensitive heavy metals (particularly Pu) may accumulate.

(4) What role does lithology play in groundwater chemistry (cation composition, phase saturation, Eh, and colloid formation in particular)?

Little data are yet available to assess the uncertainties in lithologic controls on groundwater chemistry. Most of the data collected from recent wells that isolate specific strata were obtained soon after drilling, when groundwater compositions perturbed by drilling had not recovered to pre-drilling compositions. Post-development characterization sampling will provide the data needed to address this question.

(5) Do faults or fracture zones play a significant role in transport rates, transport directions, or reactive transport?

The structure beneath the Laboratory east of the Pajarito fault zone is poorly known. Geophysical studies recently conducted and planned for the near future may help in locating faults that are yet unknown. The newly acquired digital elevation model for the Laboratory may reveal surface expressions of buried structure that have not yet been recognized. The question of fault-related structure beneath the Laboratory is largely outside the scope of the Hydrogeologic Workplan but will benefit from seismic hazard studies being conducted for the site. Fault transmissivity can be varied in hydrologic modeling to evaluate whether specific data (e.g., water-table elevation) reveal any significant effect attributable to fault-related flow zones or barriers. The data available indicate that fracture and breccia zones in the Cerros del Rio lavas may be a major source of permeability variation in this unit; this variability can be distributed within the lavas based on borehole video and geophysical logging information. Uncertainties in the distribution of fracture transmission can be expressed as a variable factor in modeling, with results that can be compared with field data from completed wells.

4.2 Vadose Zone Data Analysis and Interpretation

In general terms, the conceptual model for vadose zone flow and transport has not changed considerably since it was originally developed and outlined in the Hydrogeologic Workplan. Data collected and incorporated into vadose zone modeling has emphasized that complete understanding of the intermediate perched groundwater zones on a site-wide basis is neither possible nor necessary. However, a more complete understanding the vadose zone hydrology in specific canyons where contaminant releases are known to have occurred will be necessary.

4.2.1 Vadose Zone Overview

Deep infiltration on the Plateau is predominantly associated with canyons, whereas mesas experience much lower infiltration rates. Above the water table of the regional aquifer, groundwater bodies exist within the alluvium of the wetter canyons and at intermediate depths within the Puye Formation, the Cerros del Rio lava flows, and within the Guaje Pumice bed, probably with impermeable zones within the Puye Formation forming the perching horizon for the latter.

Perched intermediate zones of saturation occur beneath several canyons, including Pueblo Canyon, Los Alamos Canyon, Sandia Canyon, Mortandad Canyon, and Cañon de Valle. Perched zones possibly occur beneath Pajarito Canyon; however, there are no wells at present to verify this. Based on hydrostratigraphy, hydraulic gradient, hydraulic conductivity, and porosity, shallow groundwater infiltrates below the alluvium/bedrock contact. This provides a line source of recharge to underlying saturated zones within canyons.

The alluvial groundwater flow path represents a large lateral pathway at relatively rapid transport velocities for conservative contaminants. From the base of the alluvium, water percolates in downward migration through the relatively high permeability matrix of the Bandelier Tuff until it reaches one of these intermediate groundwater zones. Water and contaminant migration may occur either laterally within the intermediate groundwater or in vertical flow. For conservative contaminants, travel times to the regional aquifer have been estimated to be 50 years or less from some canyons due to the presence of anthropogenic solutes introduced since the beginning of Laboratory operations. However, there is no evidence that similar transport times exist from mesas unless lateral migration to canyons or significant modification of the natural infiltration setting (ponds, pavements, etc.) has taken place.

4.2.2 Discussion of Vadose Zone Aspects of Conceptual Model Elements

This section briefly summarizes the key components of the alluvial aquifer and intermediate perched groundwater elements of the Hydrogeologic Conceptual Model (Section 3) from the standpoint of assessing the key issues that need to be resolved in order to reliably model flow and transport through the vadose zone. The uncertainties associated with these processes and some approaches for handling these uncertainties is discussed in the following section.

Percolation rates are different beneath the canyons and within the mesas. Percolation rates beneath mesas are less than 1 mm/yr or less but vary across the lab due to the variability in precipitation and vegetation with elevation. Beneath canyons, percolation rates range from about 10 to 1000 mm/yr. Based on model results, uncertainty in the percolation rates beneath Los Alamos Canyon is +/- a factor of 3. In a few stratigraphic units (for example, the Otowi Member) the range in values of hydrologic properties is due to variability in texture. More measurements will not reduce that range of values. The range is the result of variability, not uncertainty. Moisture content measurements and water budgets can only reduce uncertainty in travel times to about one order of magnitude. Joint inversion of moisture content and contamination front data can reduce this uncertainty.

Water flow under unsaturated conditions is principally one-dimensional and downward. There is lateral diversion beneath regions of high infiltration where low permeability barriers restrict downward percolation (for example, alluvial water, Bandelier Tuff perched water, and Puye formation perched water). There has been rapid lateral transport over some distance along canyons as indicated in a tracer test in the alluvial groundwater in Mortandad Canyon and movement of tritium in the alluvial groundwater in Los Alamos Canyon. There has also been rapid lateral diversion to canyons from mesas with travel times of months (for example, within the mesa at TA-16 and tracer tests and geochemical monitoring).

Velocity and direction of flow in intermediate zones is uncertain. Velocity in perched zones can be conceptualized with a bathtub model as a trough filled with water and slow percolation out of the trough, resulting in a delay in flow time. Another conceptual model is of lateral diversion and flow through porous media. Modeling done to date has been based on the lateral diversion porous flow model, and it does reproduce the perched zones. A third conceptual model of flow in the perched zones is a lateral diversion model with fast-path flow. It is difficult to distinguish between the two lateral diversion models. Flow direction is controlled by the dip of the unit on which perching occurs and/or the dip of local permeability features not represented in the geologic model.

The key issues that need to be resolved in order to reliably model flow and transport through the vadose zone are:

- Percolation rates: The rate of downward water percolation from mesa tops and from the base of the alluvium is needed for two reasons. First, the velocity of migration of a contaminant depends, to first order, on the percolation rate. Also, the quantity of contaminant infiltrating the vadose zone from a canyon is the product of the concentration within the alluvial groundwater (measured for many contaminants) and the percolation rate. Therefore, it is important to address uncertainties in this parameter.
- Pathways: Sufficient knowledge of the direction of movement of water and contaminants in the vadose zone is required to bound the travel times and locations at the water table where contamination is likely to enter the regional aquifer.
- Travel times: Decisions regarding the placement of monitoring wells require information on the velocity of migration of both conservative and sorbing contaminants. These travel times are a function of the hydrostratigraphy, the percolation rate of water, the nature of the flow pathways, and the sorption behavior of the contaminant.

4.2.3 Vadose Zone Uncertainties

Data collected during the characterization program, interpretation of previous data, and numerical modeling has led to an evolution in the approach to characterize the vadose zone to a degree necessary to make key regulatory decisions. Now discussed is the current state of knowledge and ideas for reducing or addressing uncertainties in vadose zone flow and transport.

Moisture profile measurements in the vadose zone, combined with knowledge about the unsaturated hydraulic characteristics of the rocks, allow us to estimate the percolation rate at the location of a well. Rogers and Gallaher (1995) compiled data collected up to that time, and more recent work in the R-wells and other characterization boreholes is now used to make point estimates of the percolation rate. However, due to uncertainties in the moisture measurements and the characteristic curve that relates the hydraulic conductivity to the moisture content, it is estimated that percolation rates estimated in this way are valid only to within about a factor of plus or minus three.

Whether this degree of uncertainty matters to a regulatory decision depends on the question being asked. A simple calculation illustrates this point. For an infiltration rate of 1 mm/y, typical of a mesa location, and water content of 0.1, downward velocities will be on the order of 0.01 m/y. Under these conditions, a non-sorbing contaminant front would take 10,000 years to percolate through 100 m of unsaturated Bandelier Tuff. A similar calculation for a wet-canyon scenario (500 mm/y, water content of 0.25) yields a transport velocity of 2 m/yr, or a travel time of 50 years to traverse 100 meters of Bandelier Tuff. To a first approximation, this travel time scales linearly with the percolation rate. Therefore, the range of travel times for the uncertainty in percolation rate is 3,000 to 30,000 years for the mesa, and 15 to 150 years for the canyon. Travel times from mesas are judged to be sufficiently bounded and refined estimates of percolation rates are not needed; whereas for canyons, better estimates are required.

In the future, estimates of percolation rate will be augmented by moisture content data that include travel time information more directly. For example, the locations of contaminant fronts in the vadose zone, when combined with moisture measurements, should narrow the uncertainty in percolation rate. In fact, one might argue that the contaminant information is actually what is needed, and that the percolation rate itself is only an intermediate parameter that controls contaminant migration in models, but is not really needed for decision-making. However, a consistent picture of vadose zone flow and transport behavior requires the measurement or estimate of both contaminant front locations and percolation rates. The current sampling strategy in the well drilling program reflects this conclusion. Other information relevant to the estimation of percolation rate can be obtained using canyon-specific water budget analyses and infiltration monitoring sites. Whether or not these or other approaches are used in the future will be decided based on estimates of risk associated with specific groundwater contaminants.

Besides the percolation rate, an additional aspect of the vadose zone that influences the predicted travel time is the hydrostratigraphy. Based on the conceptual model of matrix-dominated flow through the Bandelier Tuff, numerical modeling suggests that the thickness of the Bandelier Tuff is the key stratigraphic factor controlling the travel time to the regional aquifer. In contrast, because transport times through the basalts and Puye Formation are likely to be short, fine-tuning of the geologic model for these units is unlikely to change predictions of vadose zone travel times significantly. Note, however, that the nature of the Puye Formation and intercalated basalts is likely to control contaminant transport in the regional aquifer. Therefore, this conclusion regarding the lack of importance of these units applies only to vadose zone characterization.

The pathways within the vadose zone are complicated by the presence of intermediate groundwater, which may suggest lateral transport. However, lateral flow is not the only possibility. Consider the conceptual models for the nature of flow in the intermediate zones described above. In either case, it is assumed that the intermediate groundwater is caused by the presence of a relatively impermeable perching horizon that impedes the downward percolation of water. Collecting information that would allow us to differentiate between these conceptual models is extremely difficult. This problem is fundamental to characterizing such a system using current technologies, which are limited in ability to drill and sample intermediate groundwater. In simple terms, these samples allow one to perhaps locate where the water came from, but not where it is going. This limitation implies that an extremely dense network of boreholes would have to be drilled and tested in order to resolve this fundamental question. Even in locations such as Mortandad Canyon, where several wells have detected intermediate groundwater, the picture is still fairly uncertain. Based on this experience, it is believed that significant residual uncertainty will continue to exist with respect to the pathways in the vadose zone unless alternate approaches are proven to work, such as geophysical techniques. Nevertheless, the generalized knowledge base about the intermediate groundwater has improved during the characterization program. For example, observations to date suggest that intermediate groundwater of significant quantities is typically associated with canyons, and does not extend under the mesas. This does not rule out large-scale lateral diversion along the canyon, but does limit the extent to which the conceptual model should consider water to travel laterally north or south underneath mesas.

Given the discussion just presented, it is believed that a realistic path forward is to carefully bound the range of possible behavior of the intermediate groundwater and determine whether the pathway issue is worth pursuing for the purpose of guiding regulatory decision making. It may be that intermediate groundwater does not need to be better understood on a site-wide basis, but that the locations where a more complete understanding is necessary can be pinpointed to a small number of canyons or reaches. Two aspects of the prediction of contaminant migration that are influenced by the pathway uncertainty are 1) the location of arrival of mass at the water table and 2) the vadose zone travel time. Regarding the arrival location, the bathtub model is likely to result in predominantly vertical pathways, whereas the lateral pathway model is, by definition, one for which the arrival of contaminant at the water table would be at a different location than the source. If lateral flow in the intermediate groundwater is predominantly in the direction of the canyon, it is probably not necessary to resolve in detail because the system already has a large-scale lateral diversion feature in the form of the alluvial groundwater that distributes contaminants very rapidly. Regarding travel time differences due to the pathway uncertainty, initial bounding calculations show that these influences are relatively small because transport through the overlying Bandelier Tuff controls the travel time. Thus, the strategy for dealing with this very difficult uncertainty on a site-wide scale is to constrain the issue using bounding analyses and testing of alternate conceptualizations.

In summary, the following are key conclusions regarding the uncertainties in the vadose zone flow and transport system:

- Travel times estimates, which are influenced strongly by the percolation rate, are probably precise enough for transport from mesas, but further refinement for canyon bottom sources is needed.
- With respect to uncertainty in hydrostratigraphy, the travel times are controlled by the thickness of the Bandelier Tuff and its uncertainty, rather than by the nature of the basalts and Puye Formation.
- Data do not exist to distinguish between alternate conceptual models for flow in the intermediate groundwater zone.
- Bounding approaches for addressing pathway uncertainties on a site-wide basis are the realistic next step in the characterization of this aspect of the vadose zone behavior.

4.3 Regional Aquifer Data Analysis and Interpretation

This section summarizes data compilation and analysis, including flow and transport modeling, in support of regional aquifer characterization. This section describes new hydrologic data that have been collected to characterize the regional aquifer. New data is combined with older datasets to provide a comprehensive summary of the knowledge of water levels, permeability, and porosity for the Pajarito Plateau.

4.3.1 Regional Aquifer Overview

The primary goals of FY01 have been to update estimates of flow directions and velocities using the regional aquifer model, supplemented with new data collected from R-wells. There were also efforts to evaluate model uncertainty and prioritize new data collection accordingly and to continue development of a facies-based model of heterogeneity for the Puye Formation. New data have strengthened the conceptual model of easterly flow on the plateau, with significant downward flow also evident in some locations. New permeability data continues to demonstrate substantial heterogeneity within the aquifer; however, the relation between permeability and lithology continues to be weak. Flow and transport modeling has demonstrated that large-scale effective permeability of the important hydrostratigraphic units is fairly well constrained by existing data. Uncertainty analyses on flow model results have shown that lateral fluxes to the aquifer beneath LANL are fairly certain, in the case of flow to/from the north and south. In contrast, flow from the west is much less certain. Uncertainty analyses also demonstrated that lateral groundwater flow directions are fairly well constrained by existing data. However, vertical flow and the details of capture zones for water supply wells are much less certain.

4.3.1.1 Water levels

Significant progress has been made since October 2000 in the collection and compilation of water level data. Appendix A lists the most recent water level data available for all wells completed in the regional aquifer, including recent data collected in R-wells. Because of the increased density of water level data collected in test wells that penetrate only the uppermost portion of the aquifer, it is possible to construct a water table map for the plateau that does not include data from water supply wells. Figure 4.3.1-1 shows a contoured map of water levels in these wells (Appendix A, Table A-1). This figure demonstrates that the slope of the water table is generally to the east. Table 4.3.1-1 shows calculated horizontal gradients for several well pairs; estimated gradients range from 0.01 to 0.03.

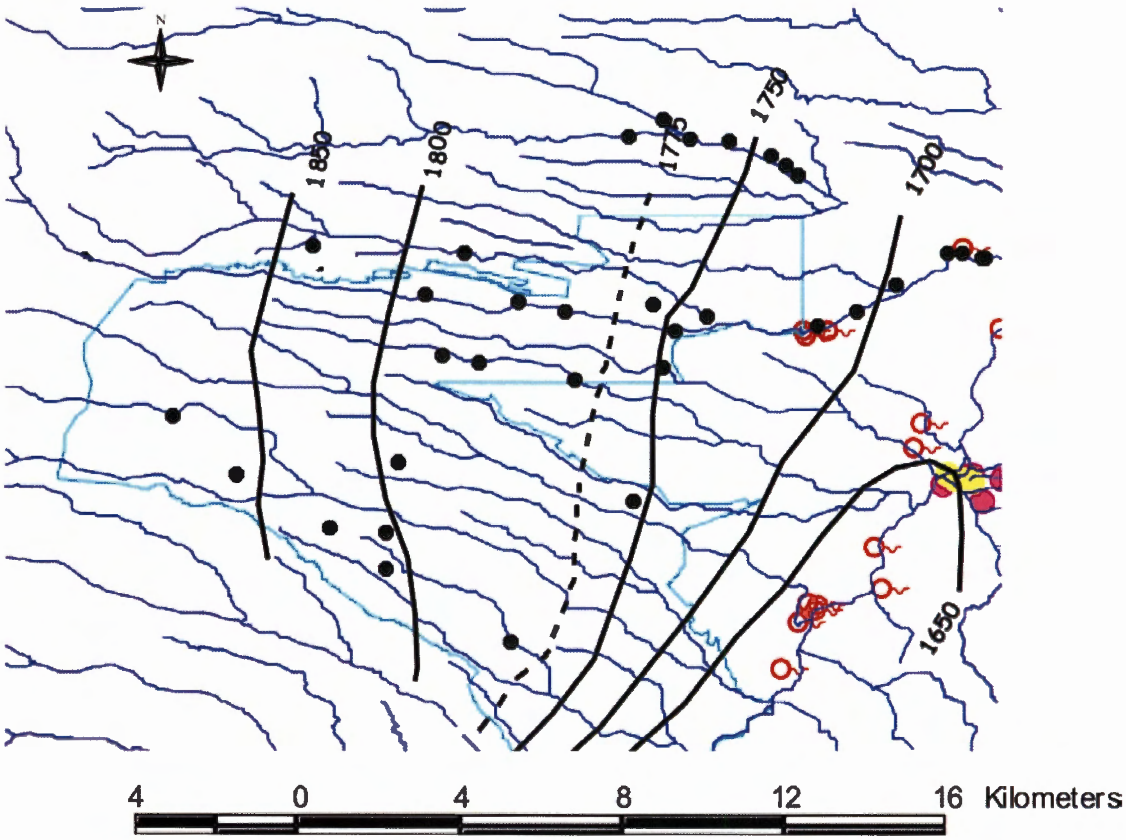


Figure 4.3.1-1 Water table elevation. Only wells completed at or near the top of the regional aquifer (shown as black circles) are used to develop contours. These data presented in Table A-1.

Table 4.3.1-1 Estimated east-west hydraulic gradients

Pair of Wells				East-West Distance (m)	Gradient (m/m)
Up gradient well	Water level (m)	Down gradient well	Water level (m)		
R-25-5	1898	CDV-15-3	1835	2189	0.03
CDV-15-5	1835	R-19-3	1795	2522	0.02
DT-10	1805	R-22-1	1755	5195	0.01
R-15	1785	R-12	1736	3684	0.01

Figure 4.3.1-2 shows head data in vertical cross-section; each well is projected onto an east-west plane. This figure illustrates the downward gradients to the west and the upward gradients to the east. In general, the gradients shown in Figures 4.3.1-1 and 4.3.1-2 show gradients that would be expected in a relatively homogeneous aquifer with topographically driven flow (recharge in high areas, discharge in low areas; i.e., the Rio Grande).

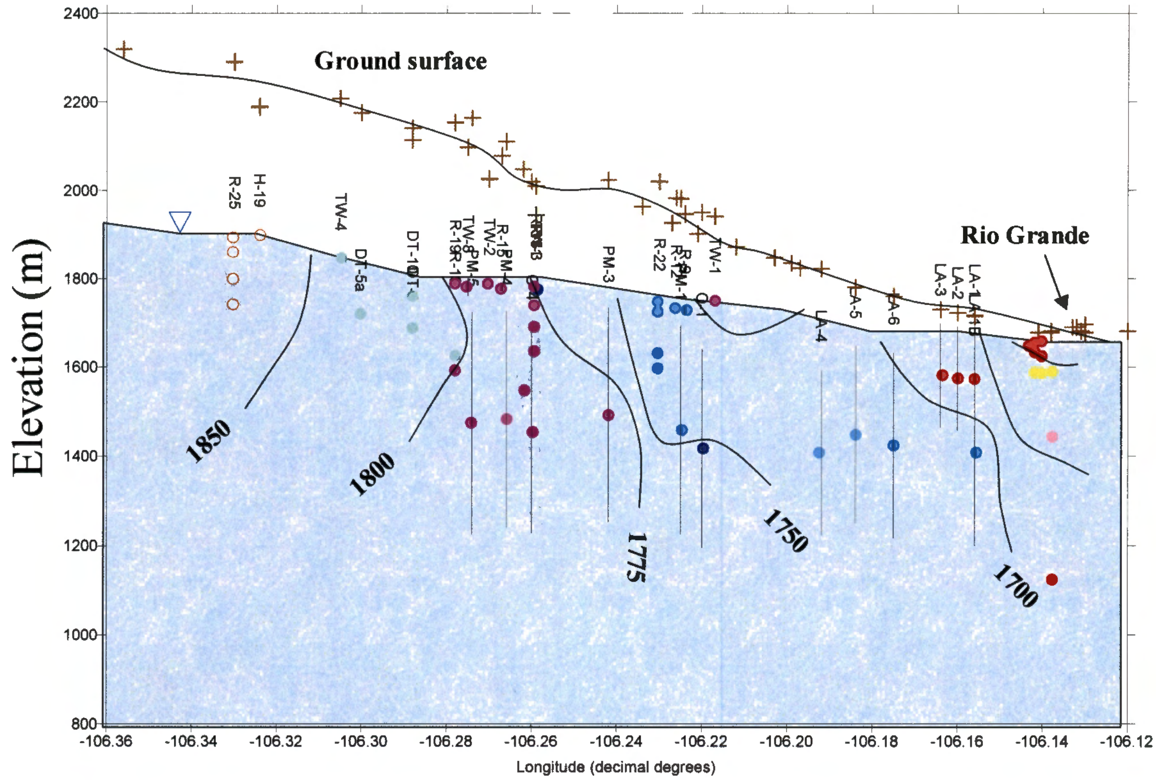


Figure 4.3.1-2 Heads projected onto an east-west cross-section through Pajarito Plateau

Table 4.3.1-2 lists the estimates of vertical gradients for the plateau. Some of these estimates are quantitative, calculated using water levels measured in R-wells with multiple screens. Others are qualitative, calculated using water levels measured in pairs of nearby wells. These estimates show that by far the strongest vertical gradients measured have been downward (R-25, R-19). Moderate downward gradients are also present near TW-1 and R-22. Slight upward gradients have been estimated in the vicinity of R-9 and TW-3. In general, all the measured upward gradients have been fairly small and are possibly within the margin of error for water level measurement accuracy. Significant downward gradients are important because they indicate possible zones of recharge and potential pathways for contaminant migration downward.

Table 4.3.1-2 Estimated vertical gradients, ordered by magnitude

Well	Vertical gradient	Comments
R-19-6	0.08	Weakly upward
R9/PM-1	0.05	
TW3/O-4	0.05	
R9/O-1	0.03	
CdV-R-15-3-6	0.02	

Table 4.3.1-2 Estimated vertical gradients, ordered by magnitude

Well	Vertical gradient	Comments
R-31-4	0.01	Nearly neutral
R-31-3	0.01	
R-31-5	0.02	
R-22-2	0.07	
TW1/O-1	0.10	Weakly downward
R-22-4	0.11	
R-25-7	0.13	
R-25-8	0.13	
R-22-3	0.14	
R-25-6	0.15	
R-19-7	0.28	
R-25-4	0.86	
R-25-5	1.10	
R-25-3	1.72	Strongly downward

4.3.1.2 Porosity

Geophysics data provide us with the first site-specific estimates of effective porosity. Geophysical estimates of porosity are shown in Table 4.3.1-3 and Figure 4.3.1-3. Average effective porosity for the Puye ranges from 0.07 to 0.1, with some relatively small zones with significantly higher porosity. For the two zones in R-19 that showed high permeability in hydraulic testing, the porosity estimates were approximately 0.2. These zones correspond with the pumiceous Puye(?) described in Section 4.1.

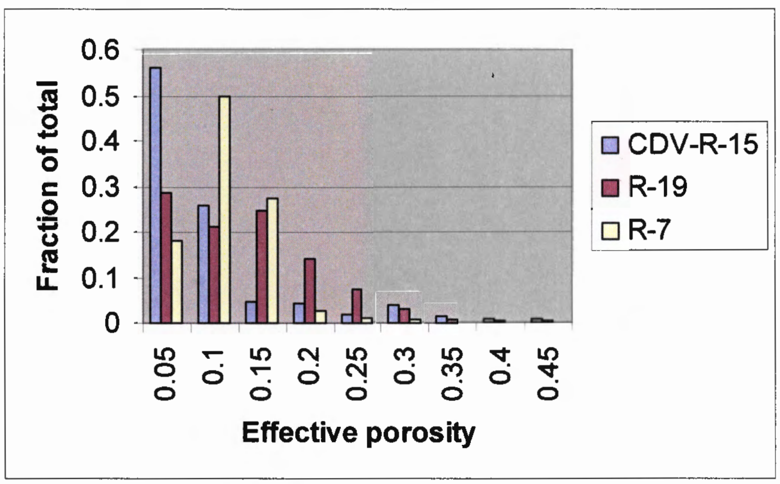


Figure 4.3.1-3 Effective porosity estimates for the Puye Formation, based on geophysical logs

Table 4.3.1-3 Effective porosity estimates based on geophysics data

Well	Mean	N	Formation
CDV-R-15a	0.07	744	Tpf, Tpp
CDV-R-15-4	0.06	87	Tpf
CDV-R-15-5	0.01	13	Tpf
CDV-R-15-6	0.16	15	Tpp
R19a	0.1	1466	Tpf, Tpp
R19-6	0.2	14	Tpp
R19-7	0.2	15	Tpp
R7a	0.09	293	Tpf, Tpp

[a] all depths within Puye Formation

4.3.1.3 Permeability

Two field-based methods have been used to estimate permeability since October 2000: hydraulic testing of wells and analysis of geophysical logs. The permeability *k* is derived from porosity using geophysical logs. All the data from the Puye Formation is shown in Figure 4.3.1-4. Summary statistics are provided in Table 4.3.1-4. In two wells, both methods were used which provides an opportunity for comparison. Unfortunately, these two estimates are in poor agreement, even in a relative sense. The most probable reasons for this include scaling effects, poor test performance, or some combination of both. In CDV-R-15, the two methods were of the same order of magnitude. In R-19, hydraulic testing suggests a much higher permeability than geophysics. It is interesting to note, however, that geophysics data suggests that a very permeable zone is present just below the zone of hydraulic testing; perhaps this lower zone impacted the hydraulic test results.

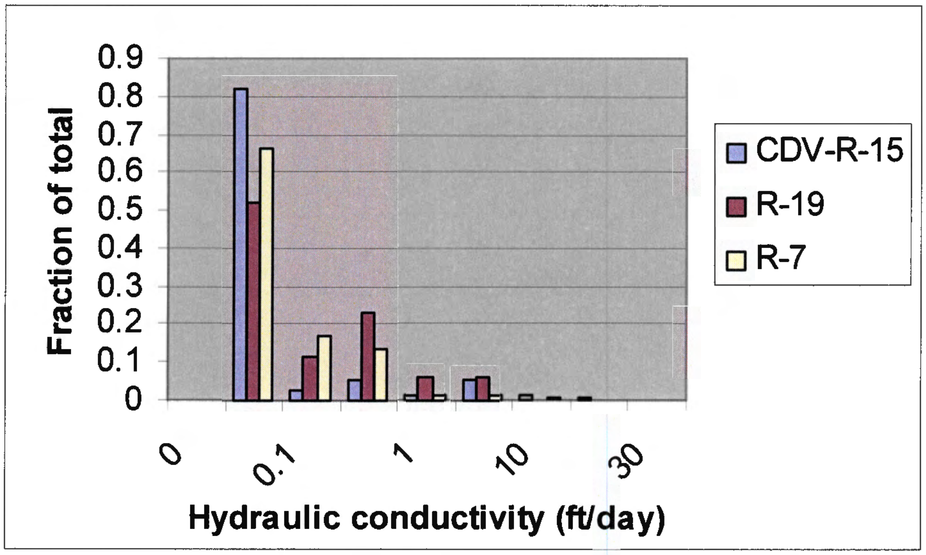


Figure 4.3.1-4 Hydraulic conductivity estimates for the Puye Formation, based on geophysical logs

Table 4.3.1-4 Summary of recent hydraulic conductivity estimates within the Puye, using field-based testing (ft/day)

Well	Geophysics		Hydraulic testing	Formation
	Mean[a]	N		
R19*	0.35	1466		Puye
R19-6	1.4	14	17.5	Puye (Tpp)
R19-7	0.6	15	19.6	Puye (Tpp)
CDV-R-15*	0.56	744		Puye
CDV-R-15-4	0.22	87		Puye (Tpf)
CDV-R-15-5	0.18	13	0.25	Puye(Tpf)
CDV-R-15-6	0.74	15	0.1	Puye (Tpp)
R-7*	0.1	293		Puye
R31-4			5.7	Puye (Tpt)
R31-5			23.3	Puye (Tpt)

[a] geometric mean
* indicates all data available for that well within the Puye

Figure 4.3.1-5 shows all the field-based permeability estimates currently available for the plateau. Different symbols correspond to different methods. Strictly speaking, this dataset cannot be used to compare methods because in most cases (excepting those listed in Table.4.3.1- 2), the tests were conducted in different portions of the aquifer. The addition of injection test and geophysical data to the previous dataset shows that the range of permeability for both the Puye and the basalts is larger than pump test estimates suggested. These estimates clearly show the presence of low permeability zones within both the basalts and the Puye Formation.

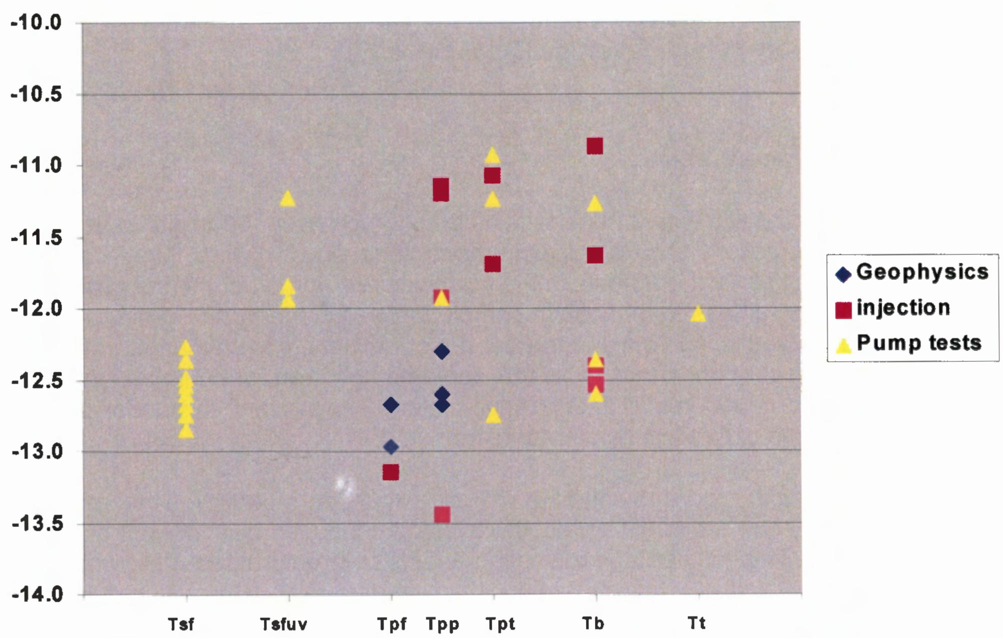


Figure 4.3.1-5 Permeability estimates from field-based methods. Tsf=Santa Fe Group; Tsfuv=Upper Santa Fe Group; Tpf=Puye Formation; Tpp=Pumiceous Puye; Tpt=Totavi Lentil; Tb=Tertiary Basalts; Tt=Tertiary Tschicoma Formation

4.3.2 Discussion of Regional Aquifer Aspects of Conceptual Model Elements

The new data and analyses generally support the conceptual model for the regional aquifer. With new information integrated into the 3-D flow and transport model, a more detailed picture of flow directions and velocities than is summarized in the general conceptual model can be provided. These are described in Keating et al. (2001). Because of the heterogeneous aquifer and the spatial variation in hydraulic gradients, predicted velocities vary widely. Figure 4.3.2-1 shows a histogram of the simulated velocities (east-west component) at the water table.

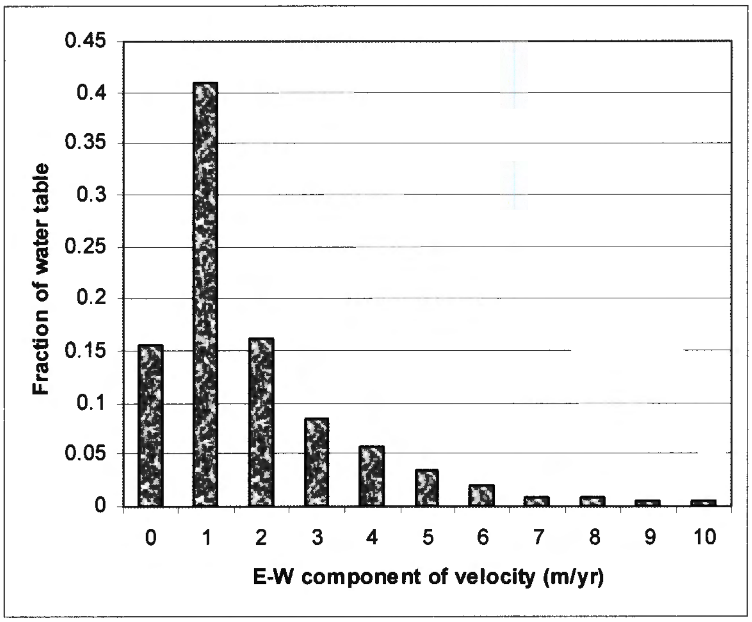


Figure 4.3.2-1 Histogram of simulated velocities at the water table. The median value is approximately 1 m/yr (average linear velocity).

4.3.3 Regional Aquifer Uncertainties

This section describes the most significant uncertainties that compromise the ability to accurately estimate groundwater flow directions and velocities in the regional aquifer. First, significant uncertainty exists in the understanding of vertical gradients in the northwestern portion of the Laboratory. This can be readily addressed by siting at least one multiple-completion well in the northwestern portion of the site. In addition, uncertainty analyses using flow and transport models have shown that lateral flux to the aquifer from the west are still very uncertain. This flux could be near zero or could be fairly large relative to the total amount of water pumped in well fields on the plateau. At present, this uncertainty is being incorporated into model analyses through sensitivity tests.

The outstanding uncertainty with regard to estimates of large-scale permeability is that model-derived estimates for the Santa Fe Group are substantially lower than field-based estimates (e.g., pump tests in lower Los Alamos Canyon). This may be due to scaling effects or structural features such as north-south trending low-permeability fault zones. Unfortunately, collecting data to conclusively prove or disprove this hypothesis would require very expensive multi-hole testing. Other possible reasons for the discrepancy (dramatic underestimation of flux through the aquifer and/or overestimation of aquifer thickness) do not appear to be plausible at present but are worthy of further evaluation.

Furthermore, the calibrated flow models show that significant discrepancies exist between observed and simulated water levels in some wells. This result, in combination with the small- and medium-scale heterogeneity observed within the Puye Formation and the lack of apparent hydrologic significance of several defined hydrostratigraphic zones, has important implications. Clearly, small- and medium-scale heterogeneity exists that is not incorporated in the flow model and which compromises the ability to simulate local effects within the flow field. Large-scale heterogeneity, with the exception of basalt flows interfingering with sedimentary units, does not appear to be controlled by existing stratigraphic designations. Further characterization is necessary to determine if large-scale heterogeneity is present within the sedimentary rocks, and, if so, what relation it may have to lithology or stratigraphy. Ongoing development of facies-based models for the Puye and revision of the 3-D Geologic Model may help to resolve some of these issues.

Finally, although geophysical estimates of porosity have helped provide site-specific data there is still a large uncertainty in field-scale porosity of important hydrostratigraphic units such as basalt flows and the Puye Formation. Since porosity estimates are critical to the ability to predict travel times in the regional aquifer, field samples will be collected from outcrops to compare with geophysical estimates. In addition, cross-hole or single-well tracer tests may be necessary in the future to better understand the effective porosity of aquifer rocks.

4.4 Geochemical Data Analysis and Interpretation

The purpose of this section is to provide a discussion on geochemical data analysis and interpretation and data quality objectives (DQOs). The Laboratory has drilled 15 characterization wells since 1997 to address technical and regulatory issues presented in the Hydrogeologic Workplan, the Hazardous and Solid Waste Amendments (HSWA) permit, and ER Project Workplans for the canyons and TA-16. Geochemistry DQOs provide guidance to well location, well drilling methods, well design, well development, analytical methods, data validation, characterization and monitoring parameters, monitored natural attenuation (MNA), groundwater remediation strategies, and pathway and risk analysis. During the course of characterization well drilling at the Laboratory, the type and quality of geochemical data have evolved depending on well-specific DQOs. The Cerro Grande fire has influenced the aqueous chemistry of surface water and alluvial groundwater within several watersheds transecting the Pajarito Plateau.

4.4.1 Geochemical Setting Overview

Groundwater occurs in three hydrostratigraphic settings beneath the Pajarito Plateau, which include the alluvium, perched intermediate zones (Bandelier Tuff, Cerros del Rio basalt, and the Puye Formation), and the regional aquifer (Puye Formation, Cerros del Rio lavas, and Santa Fe Group). Groundwater also occurs in unsaturated zones above the regional water table. The natural composition of groundwater can vary between and within these saturated zones because of geochemical processes, which include precipitation/dissolution and adsorption/desorption reactions, age of the groundwater, and residence time. Natural groundwater ranges from calcium-sodium bicarbonate to sodium-calcium bicarbonate ionic compositions (Blake et al. 1995; LANL, 2000, 2001). Residence times increase with depth and along groundwater flow paths within each aquifer type. The highest natural solute (dissolved) concentrations are associated with older groundwater within the regional aquifer.

Groundwater impacted by Laboratory-derived effluent is characterized by (LANL, 2000):

- Elevated concentrations of major ions (calcium, magnesium, potassium, sodium, chloride, bicarbonate, nitrate, and sulfate)
- Trace solutes (molybdenum, perchlorate, barium, boron, and uranium)
- High explosive compounds and other volatile organic compounds
- Radionuclides (tritium, americium-241, cesium-137, plutonium isotopes, strontium-90, technetium-99, and uranium isotopes)

Ash and muck produced from the Cerro Grande fire has impacted surface water and alluvial groundwater in several canyons transecting the Pajarito Plateau (LANL, 2001; Longmire et al., 2001a, Katzman et al., 2001). Distribution of radionuclides derived from worldwide fallout and the Laboratory, as well as naturally occurring metals, has been affected by the fire and increased runoff during storm events.

With regard to interconnection between alluvial groundwater, perched zones, and the regional water table, contaminant source terms correlate reasonably well with chemical data for mobile solutes collected at down gradient characterization wells (Broxton et. 2001a, 2001b, 2001c; Longmire et al., 2001b, 2001c; LANL, 2000, 2001; Kendrick, 1999). Non-adsorbing contaminants (perchlorate, nitrate, RDX, and TNT) are the most mobile and travel the furthest distances along groundwater-flow paths. Perchlorate, RDX, and TNT have action and/or health advisory levels less than 4 μg/L. Concentrations of these chemicals in groundwater above recommended health and action levels have been observed in several wells (MCOBT-4.4, R-25, and alluvial wells) (LANL-18, 2001; Kendrick, 1999; Broxton et al., in press; Longmire, 2001b, 2001c). These chemicals are resistant to reductive breakdown to non-toxic forms in the environment.

Other contaminants including actinides, metals, and fission products are found within alluvial groundwater (Los Alamos Canyon and Mortandad Canyon). These contaminants adsorb onto alluvial sediments and migrate at different rates through the subsurface. It is important to evaluate the transport of these constituents because of their potential migration over 100 to 1,000 years. Important considerations to resolve include aquifer types and time frames for risk analysis because these variables drive characterization, monitoring, and potential remediation options.

4.4.2 Discussion of Geochemical Conceptual Model Elements

The geochemical conceptual model for the Laboratory and Pajarito Plateau is an evolving model that includes flow paths, composition of water chemistry (natural and anthropogenic), geochemical reactions occurring in unsaturated and saturated zones, age of groundwater, and residence times. 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. A component of groundwater within perched intermediate zones and the regional aquifer (at and near the regional water table) at some wells is less than 60 years old, based on measurable tritium activities that are considerably above the cosmogenic baseline of 1 pCi/L. Other chemical tracers such as perchlorate and nitrate provide additional information on recent recharge to perched zones and the regional aquifer. Portions of the regional aquifer also contain groundwater with ages in excess of 10,000 years based on preliminary ^{14}C dating. Portions of the regional aquifer are dead with respect to tritium (<0.5 pCi/L), which is consistent with ^{14}C dating of groundwater.

4.4.2.1 Flow Paths

Flow path(s) in the unsaturated zone and perched groundwater can be represented by a stepwise function based on permeability contrasts due to the presence of clay minerals, fine-grained material (silt), and massive aquifer material including non-fractured Cerros del Rio basalt. Core samples collected from LAOI-1.1(A), LADP-3, R-8, R-9, and R-12 provide evidence for the presence of clay minerals serving as perching layers and aquitards in upper Los Alamos Canyon and Sandia Canyon.

4.4.2.1.1 Alluvial Systems

Alluvial aquifer material provides the largest reservoir for effluent-derived constituents such as RDX, TNT, strontium-90, cesium-137, plutonium-238, plutonium-239,240, and americium-241 (LANL, 2000, 2001). These constituents adsorb onto clay- and silt-sized materials resulting in decreasing mobility in the subsurface. The interface between the alluvium and weathered Bandelier Tuff probably concentrates contaminants because glass-rich portions of the tuff have hydrolyzed to form smectite and kaolinite. These minerals have larger surface areas than glass and provide additional adsorption sites for cations under circum-neutral pH conditions. This alteration process has been observed in core samples collected from R-8, R-9, R-12, and LAOI-1.1 and provides information relevant to MNA. Non- and semi-adsorbing constituents (anions and neutral-charged solutes) migrate from alluvial groundwater to perched intermediate zones eventually reaching the regional aquifer. These constituents include perchlorate, tritium, nitrate, uranium, and high explosive compounds and associated degradation products.

4.4.2.1.2 Perched Systems

Groundwater flow within perched zones (Bandelier Tuff, Puye Formation, and Cerros del Rio lavas) is generally from west to east-southeast. Depths to perched saturated zones range from 175 to 750 ft. The aqueous chemistry of perched zones has been initially evaluated by sampling several wells (LAOI-1.1, LADP-3, R-9I, R-12, R-25, and MCOBT-4.4). Tritium, nitrate, perchlorate, and high explosive compounds and degradation products are detected in perched zones in Los Alamos Canyon, Pueblo Canyon, Sandia Canyon, Mortandad Canyon, and Cañon de Valle. All of the above constituents, excluding tritium, can exceed MCLs, health advisory limits, or groundwater action levels in specific locations.

4.4.2.1.3 Regional Aquifer

Groundwater within the regional aquifer generally flows from west to east-south east beneath the Pajarito Plateau. Aqueous chemistry of the regional aquifer varies with depth and position along the flow path(s). Concentrations of silica, calcium, sodium, and bicarbonate contribute to increasing total dissolved solids (TDS) within perched zones and the regional aquifer (Blake et al., 1995; LANL, 2000, 2001). Groundwater in these saturated zones changes from a calcium-sodium bicarbonate composition within the Sierra de los Valles to a sodium-calcium bicarbonate composition near the Rio Grande (Blake et al., 1995). This change from calcium- to sodium-dominated groundwater is probably due to cation exchange. pH values in the regional aquifer typically range between 7.5 and 8.5. Discharge zones for perched systems and the regional aquifer occur on cliff faces above and along the Rio Grande, respectively, within White Rock Canyon (LANL, 2000, 2001). Concentrations of trace elements including arsenic, barium, boron, bromide, and strontium increase with depth in the regional aquifer (Blake et al., 1995; LANL, 2000, 2001).

4.4.2.2 Cerro Grande Fire

The Cerro Grande fire (May 2000) perturbed the surface water and alluvial groundwater chemistry (Katzman et al., 2001; Longmire et al., 2001a). These perturbations are expected to be temporary, perhaps for several years, consistent with what has been observed after other wildland fires (Bitner et al., 2001). Ash produced from the fire has been transported within canyon systems reacting with rain and surface water. Increasing concentrations of total and dissolved organic carbon (DOC), carbonate alkalinity, calcium, potassium, iron, manganese, and other solutes occur in surface water and alluvial groundwater since the Cerro Grande fire. In most canyons, carbonate alkalinity in surface water increased by factors of 3-6 after the fire. Surface water and alluvial groundwater did show increases in turbidity due to ash and enhanced erosion. Colloid transport of the ash in the subsurface is possible depending on particle size, surface chemistry of the particles, fracture flow, and aquifer porosity.

Oxidation and reduction reactions between organic-rich ash and metals and radionuclides influence aqueous speciation of solutes and adsorption processes. Increasing concentrations of iron and manganese have been observed in surface water and alluvial groundwater since the fire because solid phases containing these two metals have dissolved. DOC produced from the fire serves as an electron donor (reducing agent) during oxidation to bicarbonate and carbonic acid. Concurrently, iron(III) and manganese(IV) solids become electron acceptors (oxidizing agents) and are reduced to more soluble aqueous species. Geochemical data collected by the Laboratory in Pueblo Canyon, Los Alamos Canyon, and Pajarito Canyon support the occurrence of these oxidation-reduction reactions with respect to DOC and dissolved iron and manganese.

Alkalinity affects the speciation and mobility of radionuclides including uranium, plutonium, and americium by forming metal-carbonate complexes that are negatively charged at circum-neutral pH. These anionic complexes desorb from mineral surfaces and are more readily transported in groundwater. For example, increased activities of dissolved plutonium-239,240 (0.1 pCi/L) have been observed in alluvial groundwater (PAO-4) in Pueblo Canyon since the Cerro Grande fire. The most likely oxidation states for plutonium are IV and V because large amounts of organic-rich ash, DOC, and alkalinity are present in surface water. Surface water containing ash also provides a source of recharge to shallow alluvial groundwater in Pueblo Canyon and other canyons. It is hypothesized, based on geochemical modeling performed using MINTEQA2 (Allison et al. 1991) that Pu(IV)-carbonate (anionic) complexes ($Pu((CO_3)_3^{2-})$) have become stable in groundwater and adsorption of these negatively-charged complexes onto negatively-charged surfaces (organic ash) is minimal at near-neutral pH (McGraw and Longmire, 2001). It is possible, however, that plutonium(V) species (PuO_2^+) adsorb onto ash above pH 6 based on the abundance of surface carboxylate functional groups ($RCOO^-$).

Precipitation of americium(III), plutonium(IV and V), and uranium(VI) solids is not likely in alluvial groundwater in Pueblo Canyon since the fire, based on results of mineral saturation index calculations using MINTEQA2 (McGraw and Longmire, 2001). Alluvial groundwater in the canyon is calculated to be undersaturated with actinide minerals. These calculations suggest that desorption processes and colloid transport are more important than mineral precipitation for the actinides observed in Pueblo Canyon since the fire.

4.4.2.3 Adsorption and Mineral Precipitation

Glass within the Bandelier Tuff occurring beneath saturated alluvium has been partially altered to clay minerals (smectite and kaolinite). These clay minerals contain inclusions and partial coatings of ferric oxyhydroxide and manganese oxide, which adsorb contaminants (cations including strontium-90 and anions including uranium complexes). Fracture coatings consisting of smectite, kaolinite, and hydro ferric oxide have been observed within the Cerros del Rio basalt at R-9. Unlined fractures, however, have a low adsorption capacity for removing contaminants from groundwater including TNT and uranium.

Adsorption processes dominate over mineral precipitation for removing metals and radionuclides from groundwater, based on contaminant concentrations at source terms, field and laboratory investigations, and geochemical modeling. However, in isolated cases where effluent discharges have changed carbonate alkalinity, solute concentrations, and pH, solutes such as strontium and barium may precipitate as $SrCO_3$, $BaCO_3$, and coprecipitate as $(Sr\text{-}Ba)SO_4$ in alluvial groundwater. The fate and transport of strontium-90 can be influenced by coprecipitation due to the moderately low solubility ($10^{-9.27}$ moles/liter) of $SrCO_3$. Surface water and alluvial groundwater in Pajarito Canyon, Los Alamos Canyon, and Pueblo Canyon are calculated to approach equilibrium with $CaCO_3$ (calcite) because of increased calcium and carbonate alkalinity since the Cerro Grande fire.

4.4.2.4 Summary of R Well Chemistry

To date (FY01), nine R-characterization wells have been drilled, developed, and sampled (borehole and developed well) for various constituents. Two R-characterization wells were started in FY01 (R-13 and R-8) and borehole samples were collected from these boreholes. Four additional investigation wells (CdV-15-3, CdV-37-2, MCOBT-4.4, and MCOBT-8.5) also have been drilled and installed. Validated results for selected chemicals and radionuclides are summarized in Table 4.4.2-1. Constituents of interest include tritium, nitrate, perchlorate, RDX, TNT, and uranium because of their persistence and mobility in the subsurface. The intermediate borehole MCOBT-8.5, drilled in Mortandad Canyon, was dry within both the alluvium and Cerros del Rio basalts. The borehole was plugged and abandoned in July 2001.

Table 4.4.2-1 Summary of Selected Constituents Measured at Boreholes and Characterization Wells from 1997 through 2001

Well	Zone	Date (mo/yr)	Sample	Constituent	Concentration
R-5	perched	05/01	borehole	tritium	25 pCi/L
R-5	regional	05/01	borehole	none	
R-7	perched	01/01, 06/01	borehole/well	tritium	tritium, 6.5 pCi/L
R-7	regional	01/01, 06/01	borehole/well	none	
R-9	perched	10/97	borehole	uranium	48 μg/L
R-9	perched	09-10/97	borehole	tritium	106 and 347 pCi/L

Table 4.4.2-1 Summary of Selected Constituents Measured at Boreholes and Characterization Wells from 1997 through 2001

Well	Zone	Date (mo/yr)	Sample	Constituent	Concentration
R-9	regional	12/98	borehole	tritium	14.43 pCi/L
R-9	regional	01/01	well	tritium	13.73 pCi/L
R-9i	perched	05/01	well	uranium	0.64 and 0.07 μg/L
R-9i	perched	01/01	well	tritium	246 and 167 pCi/L
R-12	perched	04/98	borehole	nitrate (N)	4.93 and 5.50 mg/L
R-12	perched	03/01	well	nitrate (N)	<0.10 and 0.13 mg/L
R-12	perched	04/98	borehole	tritium	255, 208, and 249 pCi/L
R-12	perched	03/01	well	tritium	189 and 111 pCi/L
R-12	regional	06/98	borehole	tritium	46.9 pCi/L
R-12	regional	03/01	well	tritium	64 pCi/L
R-13	regional	09/01	borehole	tritium	.051 pCi/L
R-15	perched	07/99	borehole	perchlorate	12 μg/L
R-15	perched	07/99	borehole	tritium	3,770 pCi/L
R-15	regional	08/99	borehole	tritium	1.12 pCi/L
R-15	regional	08/99	borehole	nitrate	<0.01 mg/L
R-15	regional	05/01	well	tritium	2.17 pCi/L
R-15	regional	05/01	well	perchlorate	4.19 μg/L
R-15	regional	05/01	well	nitrate	2.40 mg/L
R-19	perched	02/00, 07/01	borehole/well	none	
R-19	regional	02/00, 07/01	borehole/well	none	
R-22	regional	09/00	borehole	tritium	109 pCi/L
R-22	regional	03/01	well	tritium	2.0 pCi/L
R-22	regional	03/01	well	uranium	16 μg/L
R-22	regional	03/01	well	technetium-99	4.9 pCi/L
R-25	perched	09/98-10/98	borehole	HMX, RDX, TNT	12, 84, and 19 μg/L
R-25	perched	09/98-10/98	borehole	tritium	77.2, 81.4, 44.7 pCi/L
R-25	perched	05/01	well	tritium	52, 55.2, 38.3 pCi/L
R-25	perched	05/01	well	HMX, RDX, TNT	4.5, 30, 1.10 μg/L
R-25	perched	05/01	well	TCE, toluene	1.4, 3.6 μg/L
R-25	regional	02/99	borehole	HMX, RDX, TNT	9.7, 62, 7.1 μg/L
R-25	regional	05/01	well	HMX, RDX, TNT	1.9, 10.7, 1.2 μg/L
R-25	regional	05/01	well	tritium	17.2, 14.4 10.8, 11.4 pCi/L
R-31	perched	01/00, 12/00	borehole/well	none	
R-31	regional	02/00, 12/00	borehole/well	none	
CdV-15	perched	03/00, 04/01	borehole/well	none	
CdV-15	regional	04/00, 04/01	borehole/well	none	
CdV-37	perched	08/01	borehole	none	
CdV-37	regional	08/01	borehole	none	
MCO-BT-4.4	perched	06/01	borehole	perchlorate, tritium, nitrate(N)	145 ppb, 2,020 pCi/L, 12.7 ppm
MCO-BT-8.5	dry	06/01	borehole	no groundwater	
R-8	regional	10/01	borehole	tritium	16 pCi/L

4.4.2.4.1 Tritium

Sources of tritium discharged into Los Alamos Canyon include TA-2 and TA-21. At R-9i, activities of tritium range between 100 to 300 pCi/L (Table 4.4.2-1), which confirms that the two perched zones within the Cerros del Rio basalt have been recharged by both surface water and alluvial groundwater. Tritium activities at R-9 typically range between 5 and 20 pCi/L suggesting that the regional aquifer contains a portion of groundwater that is less than 60 years of age. Tritium was detected at 6 pCi/L in a perched zone within the Puye Formation at R-7, west of R-9 and R-9i. The regional aquifer at R-7 and elsewhere (R-19, R-31, CdV-15, and CdV-37) contains tritium less than detection (< 1pCi/L) and the groundwater is much older than 60 years. Flow paths in the regional aquifer at R-7 may extend from beneath the Sierra de los Valles based on non-detectable tritium. Tritium activities in perched groundwater within the Cerros del Rio basalt at R-5 are 25 pCi/L, which is consistent with those measured further to the east at POI-4.

Tritium has been measured at R-12 within both the perched zone(s) (111-255 pCi/L) and the regional aquifer (64 pCi/L) (Table 4.4.2-1). The source(s) of tritium may include discharges within both Sandia Canyon and Mortandad Canyon. Groundwater movement in the saturated zones at R-12 is characterized by fracture and porous media flow based on lithology (Broxton et al., 2001a). Residence times probably vary.

Elevated activities of tritium were measured in the alluvium (80-29,300 pCi/L) (LANL, 2000) and in perched groundwater (Cerros del Rio basalt) (3,770 pCi/L) in Mortandad Canyon (Longmire et al., 2001a). Tritium activities, however, are much lower in the regional aquifer at R-15 (< 3 pCi/L) due to its short half-life (12.43 yr), volatilization, dilution, and dispersion within the vadose zone. Tritium activities are less than detection at R-13 near the Laboratory boundary, suggesting that tritium has not reached the regional aquifer at this well location.

Tritium has been measured at R-25 within both the upper saturated zone (33-81 pCi/L) (Table 4.4.2-1) and the regional aquifer (11-17 pCi/L). The age of groundwater within the upper saturated zone probably varies from 10 to 60 years. Activities of tritium are decreasing in the regional aquifer at R-25 as the well re-equilibrates with native groundwater. R-25 is within a recharge zone east of the Sierra de los Valles, which is characterized by steep downward pressure gradients (Section 4.3; Broxton et al., 2001c).

Tritium activities at R-19, CDV-15, R-31, R-13, and CDV-37 are at or less than detection, using the analytical method of electrolytic enrichment. This indicates that groundwater within perched zones and in the regional aquifer at these well locations is greater than 60 years of age. Minimal recharge has occurred in mesas and dry canyon bottoms in the central and southern portions of the Laboratory where these wells are located.

4.4.2.4.2 Uranium

Elevated concentrations of dissolved uranium were detected in a perched zone in the Cerros del Rio basalt at R-9 during drilling (Table 4.4.2-1); however, this actinide is less than 1 μg/L at R-9i drilled immediately west of R-9. Uranium is stable in the IV and VI oxidation states in aqueous solution (Langmuir, 1997). Uranium(VI) forms strong complexes with carbonate ligands (anions), ($UO_2CO_3^0$, $UO_2(CO_3)_2^{2-}$, and $UO_2(CO_3)_3^{4-}$,), which are semi-adsorbing onto clay minerals and ferric oxyhydroxide. The apparent decrease in uranium concentration at R-9i could be the result of changes in the oxidation-reduction conditions with the introduction of drilling fluids used at R-9i. Chemically reducing conditions enhance adsorption and precipitation of uranium(IV) minerals ($USiO_4$ and UO_2). Another possibility is that during initial drilling, fresh mineral surfaces were exposed and uranium desorbed from the mineral surfaces resulting in a temporary increase in uranium concentrations. If this process accounts for the elevated uranium observed at R-9, then this analyte should be observed in similar concentrations at R-5, R-12, R-15, R-19, and R-31 which penetrate the Cerros del Rio lavas. However, anomalous uranium to thorium ratios (approximately 3) measured on clay minerals at R-9 suggests that additional uranium has been introduced to the system (Broxton et al., 2001b). Typical uranium to thorium ratios are approximately 0.25 or less for the Bandelier Tuff (Longmire et al., 1996) and Cerros del Rio lavas. (Broxton et al., 2001b)

Dissolved concentrations of uranium (16 μg/L) were detected in screen number 3 (1273 ft) at R-22 along with technetium-99, sulfate, and sodium in March 2001. Low-level or thermal ionization mass spectrometry (TIMS) analysis of a groundwater sample collected from this zone showed natural isotopic uranium characterized by atom $^{238}U/^{235}U$ of 137.88. It is hypothesized that the uranium, sodium, and sulfate were derived from the bentonite backfill and from colloidal bentonite entering screen number 3 during pumping and sampling of the well. Sodium bentonite used during well construction contains natural uranium and sulfate. Concentrations of uranium have decreased to 2 μg/L during additional characterization sampling at R-22. Activities of technetium-99 have also decreased in screen number 3 during the second sampling round conducted in June 2001.

4.4.2.4.3 Nitrate and Perchlorate

Nitrate was initially observed in Cerros del Rio basalts during drilling of R-12 (Table 4.4.2-1) (Broxton et al., 2001a); however, nitrate concentrations have decreased during characterization sampling. Well R-12 is down canyon (east) from the Sanitary Wastewater Systems (SWS) Facility discharge in upper Sandia Canyon. This decrease in nitrate concentration may be due to denitrification, the reduction of nitrate to nitrogen gas, which is possible in the presence of residual drilling fluids including EZ-MUD®. Concentrations of total organic carbon (TOC) exceed 5 mgC/L in the uppermost screen at R-12, suggesting that residual EZ-MUD® is present. Perchlorate (ClO_4^-) was not detected at R-12 during characterization sampling.

Results of $\delta^{15}N$ analyses for borehole groundwater samples collected during drilling of R-12 suggest that nitrate was derived from a sewage source as evidenced by $\delta^{15}N$ ratios of +11.3 to +21.3 ‰ (Broxton et al., 2001a). Denitrification results in positive $\delta^{15}N$ ratios due to the cometabolic consumption of ^{14}N in organisms. $\delta^{15}N$ ratios have shifted to less positive (nitrate) and negative (ammonium) values during characterization sampling suggesting the nitrogen (nitrate and ammonium) is of an inorganic origin possibly due to the presence of residual EZ-MUD®.

Nitrate and perchlorate are two mobile anions observed within the alluvium, Cerros del Rio basalt (MCOBT-4.4), and the Puye Formation (R-15) in Mortandad Canyon. In 1999, concentrations of perchlorate in alluvial groundwater range from <50 to 440 μg/L (parts per billion [ppb]) (Kendrick, 1999). This anion was detected at 12 μg/L in a groundwater-screening sample collected from the 646 ft perched zone during drilling of R-15 (Longmire et al., 2001b). Perchlorate was recently detected in perched groundwater at MCOBT-4.4 at 145 μg/L at sample depths ranging from 494 to 532 ft (Table 4.4.2-1) (Longmire, 2001c). Concentrations of perchlorate at well R-15 range from <2.8 to 4.19 μg/L during four rounds of characterization sampling conducted from February 2000 through May 2001. The analytical laboratory detection limit for this analyte is 1 μg/L with a reporting limit of 4 μg/L, using ion chromatography. Concentrations of perchlorate measured at well R-15 are very close to both limits and are flagged estimates, or J values, by the analytical laboratory. The only detection of perchlorate at well R-15 is at a concentration of 4.19 μg/L measured during the fourth sampling round conducted on May 22, 2001.

Perchlorate has not been detected at R-5, R-7, R-9, R-9i, R-12, R-19, R-31, or CdV-15. One source of perchlorate was the effluent discharged within Mortandad Canyon from the Radioactive Liquid Wastewater Treatment Plant at TA-50. Perchloric acid ($HClO_4$) is used in actinide research conducted at the Laboratory and is a constituent of the treated effluent discharged from TA-50. LANL is working to reduce perchlorate discharges with an eventual goal of zero discharges in the coming years. In addition, the influent and effluent of the TA-50 Radioactive Liquid Waste Treatment Facility are being monitored for perchlorate, perchlorate levels discharged are being determined, and treatment and removal efficiencies are being established. The monthly composite samples have between 3 and 950 μg/L. Seven effluent grab samples collected in February 2000 had perchlorate concentrations that ranged from 24 to 50 μg/L. Modifications to treatment operations are also planned to reduce perchlorate concentrations in water discharged from the treatment facility. Otowi-1, in Pueblo Canyon, has shown the presence of perchlorate at concentrations less than 6 μg/L.

Perchloric acid is a strong oxidizing agent that dissociates to perchlorate at negative pH values ranging from -4.8 to -2.12, depending on the hydration state of the acid. Perchlorate is mobile in groundwater and does not adsorb onto aquifer material under circum-neutral pH conditions. Perchlorate is not easily reduced to chloride (Cl^-) under aerobic conditions typical of groundwater in Mortandad Canyon. The lack of reduction is due to four strong covalent bonds between the oxygen and chlorine atoms within the tetrahedral perchlorate molecule. Subsequently, perchlorate persists in aerobic surface water and groundwater environments for an unknown amount of time. Strong reducing agents, such as reactive organic matter and hydrogen sulfide with appropriate microbial populations, however, are capable of reducing perchlorate to chloride under anaerobic conditions. Reduction of perchlorate to chloride ion in aqueous solution is given by the following half reaction:

$$ClO_4^- + 8H^+ + 8e^- = Cl^- + 4H_2O \qquad \text{Equation 1}$$

This reaction is represented by:

$$Eh\ (\text{volts}) = 1.39 - 0.0592pH \qquad \text{Equation 2}$$

where Eh is the oxidation-reduction potential for the half reaction and the activity of Cl^- is equal to the activity of ClO_4^-.

At pH0, chloride ion is stable relative to perchlorate ion at an E^o value less than 1.39 volts; perchlorate and chloride are at equilibrium at an E^o value of 1.39 volts; and perchlorate is stable above an Eh value of 1.39 volts. At pH7, chloride is stable below an Eh of 0.98 volt. Chlorate (ClO_3^-) is a reductive intermediate of perchlorate and has been measured at DP Spring in concentrations ranging from less than detection (20 µg/L) to 780 µg/L in 1991. Chlorate has not been observed at any of the R wells drilled in Mortandad Canyon or elsewhere.

4.4.2.4.4 High Explosive Compounds

Presence of high explosive compounds (RDX, TNT, HMX) and reductive degradation products (2-amino-4,6-dinitrotoluene and 4-amino-2,6-dinitrotoluene) at R-25 provides evidence that surface water is infiltrating to the upper saturated zone within the Bandelier Tuff and Puye Formation (Broxton et al., 2001c). Presence of mono-amino-dinitrotoluene compounds provides evidence that TNT is degrading and it is possible that DOC is an electron donor enhancing reduction of TNT. These degradation products also provide evidence for natural attenuation of TNT at R-25. The Laboratory is currently analyzing for degradation products of RDX including mono-di-and tri-amino-hexahydro-1,3,5-triazine (MNX, DNX, and TNX, respectively) at R-25. Analytical results should be available in FY02.

4.4.2.4.5 Drilling Fluids

During drilling of R-7, R-19, and R-22, acetone was apparently detected at the regional water table. Presence of this organic compound may be due to oxidation of QUIK-FOAM used during drilling. QUIK-FOAM contains isopropyl alcohol. Isopropyl alcohol has the same retention time and mass units similar to acetone. The overall oxidation-reduction reaction leading to the formation of acetone is:

$$CH_3CHOHCH_3 + 0.5O2 = (CH_3C)_2CO + H_2O. \qquad \text{Equation 3}$$

The results reported for acetone from the analytical laboratory are most likely measurements of the isopropyl alcohol, and thus are false positives for acetone. This conclusion is supported by the mass spectral data. Acetone is being misidentified because the secondary ion for isopropyl alcohol is 43, which is the primary ion for acetone. The analysis of the QUIK-FOAM confirms this suspicion.

EZ-MUD® has been used for lubricity purposes during drilling of R-5, R-7, R-8, R-9i, R-12, R-13, R-15, R-22, R-25, R-31, CdV-15, CdV-37, and MCOBT-4.4. EZ-MUD® consists of a copolymer (polyacrylamide (($-CH_2CHCONH_2-$)n)-polyacrylate (($H_2C=CH-COO-$)n)) containing nitrogen, carbon, and hydrogen. EZ-

MUD® eventually biodegrades (electron donor) and oxidizes to inorganic carbon (alkalinity), and solutes such as sulfate, nitrate, iron, manganese, and dissolved oxygen are reduced (electron acceptors).

4.4.2.5 Summary of Geochemical Conceptual Model Elements

Geochemical data collected at the Laboratory as part of the Hydrogeologic Workplan and canyon-specific workplans have advanced the understanding of groundwater flow paths, saturated and unsaturated zone chemistry, contaminant migration, and relative age(s) of groundwater. Non-adsorbing contaminants found in Mortandad Canyon (nitrate, tritium, and perchlorate) and Cañon de Valle at R-25 (RDX and TNT) have migrated the furthest from discharge sources. The chemicals, RDX, TNT, and perchlorate are of special interest because of their mobility, toxicity, and persistence in the subsurface.

4.4.3 Geochemical Setting Uncertainties

The above discussion presented the state of knowledge for the geochemical setting at the Laboratory and Pajarito Plateau. There are data gaps in the geochemical setting that result in uncertainties in water and aquifer material chemistry and contaminant migration. The need to address these uncertainties is provided in the HSWA permit and Hydrogeologic Workplan. Resolving the uncertainties will improve and focus characterization efforts, provide technically defensible results for flow and transport modeling, and help to design and implement an effective monitoring network for the Laboratory. Uncertainties in the geochemical setting are discussed below and presented in Table 4.4.3-1.

Table 4.4.3-1 Data and Information Needs Addressing Geochemical Setting Uncertainties

Uncertainty	Purpose and Application
Pathway Analysis	Form a specialized team to focus on pathway analysis. Team should consist of risk, hydrology, modeling, geology, and geochemistry.
Chemical Characterization of Perched Zones	Chemical characterization of perched zones in Mortandad Canyon (Cerros del Rio basalt) could help to delineate flow paths, chemical gradients, and continuity. Nitrate, perchlorate, and tritium have been observed in the basalt and overlying unsaturated zone. This perched zone probably provides recharge to the regional aquifer.
Representative Groundwater Chemistry	Single screen wells help to minimize redox reactions and false positives with high explosive compounds and acetone produced by drilling fluids. R-4, R-8, R-10, R-11, R-14, and R-17 are in contaminated canyons and are likely candidates for single completion wells, based on geochemical DQOs and monitoring objectives.
Distribution and Concentration of Reactive Minerals	Distribution and concentration of reactive minerals are needed for input to reactive transport modeling, quantifying and verifying MNA, and validating geochemical and transport model simulations. Adsorption data (field [empirical] Kds for Sr, U, Pu, and other chemicals) are required for modeling reactive transport and demonstrating MNA in Mortandad, Los Alamos, and Pueblo Canyons. Perform this work using core samples and analyzing for constituents of interest on core and in the aqueous phase (leachates). Adsorption data are needed for the alluvium, Bandelier Tuff, Cerros del Rio basalt, and Puye Formation, because contamination is observed in these hydrostratigraphic units
Age and Travel Times within Regional Aquifer	Determine age and groundwater travel times in regional aquifer (R wells). Modelers are using the dates for calculating residence times in the regional aquifer. Previous ages for groundwater assume a marine $\delta^{13}C$. Calcite in the regional aquifer precipitated from non-marine groundwater. Current dates may not be very accurate based on previous assumptions. Need to obtain representative calcite samples from core collected at R wells and outcrops to correct $\delta^{13}C$ for recalculating C-14 dates.
LANL Baseline Groundwater Geochemistry	These data are used as input to the geochemical conceptual model, defining geochemistry in recharge zones and along flow paths, and evaluating contaminant distributions. These data are useful to the ER Project and LANL. Finalize publication and make database available.

4.4.3.1 Pathway and risk analysis

A technical team of the GIT members has been formed to provide recommendations on pathway analysis to the ER Project and ESH Division. Team composition includes one representative from each GIT subcommittee (hydrology, modeling, geology, and geochemistry) complemented by the ER Project risk assessment staff. This team will evaluate and model input parameters and characterization data needs, perform transport calculations in addition to those provided by the modeling subcommittee, and provide other technically defensible data and information relevant to groundwater characterization and modeling.

4.4.3.2 Distribution of contaminants within perched zones

Although site-wide characterization of perched intermediate groundwater may not be warranted (Section 4.2.2), perched zones in specific areas where contamination is present may need to be characterized by the ER Project to determine contaminant distributions, flow paths, age of groundwater, and spatial continuity. Mortandad Canyon and TA-16-Cañon de Valle are known to contain contaminants in perched zones near regulatory limits that may migrate to the regional water table. Further ER Project characterization would provide data on distribution of contaminants presently observed and could also address potential future migration. Placement of wells in perched zones will help in making decisions of whether or not a regional aquifer well is needed in a specific location. The probability that the regional aquifer may be impacted from surface discharges is much lower if the perched system(s) is not contaminated. Chemical characterization of these perched systems (Cerros del Rio lavas, Bandelier Tuff, and Puye Formation), with sustained saturation, would provide an important forecast for contaminant migration. Evaluating the geochemistry and transport characteristics of these contaminants would help in making accurate and meaningful predictions regarding contaminant distributions at the well.

4.4.3.3 Chemical data representative of saturated zones

Characterization wells are designed with specific DQOs regarding the primary objective(s) for well completion (single screen or multiple screen well). Single screen wells have been installed in perched systems and in the regional aquifer where there is a presence of contaminants at the water table. Single screen wells, through extensive well purging prior to collecting samples, help to minimize redox reactions and false positives with high explosive compounds and acetone produced by residual drilling fluids. The wells R-4, R-8, R-10, R-11, R-14, and R-17 are to be placed in contaminated canyons and are likely candidates for single completion wells, based on geochemical DQOs and monitoring objectives. Wells with multiple screens have been installed for obtaining geochemical and hydrological data at various depths within saturated zones. Some contaminants may enter the regional aquifer upgradient of an R well and flow lines may increase with depth along the flow path. Wells completed with several screens are necessary to sample contaminated groundwater under such conditions, particularly near the eastern boundary of the Laboratory.

4.4.3.4 Distribution and concentration of adsorptive phases

Modeling fate and transport of contaminants requires technically defensible geochemical and hydrological data as input to computer simulations. Most of the contaminants (americium-241, cesium-137, strontium-90, plutonium isotopes, and uranium isotopes) found in alluvial groundwater at the Laboratory are controlled by adsorption processes. The Laboratory has hypothesized that in the canyons most contaminants adsorb onto clay minerals, solid organic matter, and metal oxyhydroxides within the weathered Bandelier Tuff beneath the alluvium. Characterization of adsorbents is needed to determine their concentration and distribution within selected zones. These site-specific data are used as input to reactive transport and geochemical modeling and MNA. Field-derived adsorption constants (distribution coefficients) can help to quantify this process and provide site-specific parameters for transport modeling. Adsorption constants can be determined by analyzing core and groundwater for radionuclides and metals of interest.

Strontium-90 is a radionuclide of interest in Los Alamos Canyon and Mortandad Canyon. Initial adsorption experiments (Kd) for strontium-90 have been conducted using sediment and Bandelier Tuff (Longmire et al., 1996). The uncertainty in Kd values for strontium-90 in the Bandelier Tuff ranges from 10 to 70 ml/g. The rate of movement of strontium-90 relative to average groundwater flow ranges between 0.005 and 0.032. This calculation assumes a bulk density of 1.5 g/cm^3 and an effective porosity of 0.5 for the Bandelier Tuff. If groundwater flow velocity in the Bandelier Tuff is 100 ft/yr under saturated flow conditions, then strontium-90 is calculated to migrate between 0.5 and 3.2 ft/yr. Migration of strontium-90 to the Guaje Pumice bed (320 ft depth) is calculated to take between 100 and 640 years. Assuming the initial activity of strontium-90 is 200 pCi/L, with a half-life of 28.78 yr, the activity of strontium-90 in the Guaje Pumice bed is 18 pCi/L after 100 years and 4.0E-05 pCi/L after 640 years, which would be essentially non-detectable. If perched zones such as the Guaje Pumice bed are a significant element of a pathway leading to groundwater risk, then future monitoring could be important depending on the rate of strontium-90 movement through the Bandelier Tuff.

4.4.3.5 Age and travel time of regional aquifer groundwater

A review of the published C-14 ages for the regional aquifer (Spangler, 1994) has found that some of the assumptions made for the calculated ages are incorrect. Problems occur with the correction of raw C-14 ages because of the addition of dead carbon to the aquifer as a result of calcite dissolution. Problems also occur with the assumption that calcite dissolution is taking place within the entire aquifer. Modeling data suggest that calcite precipitation is occurring in some regional aquifer groundwater. Because of the importance of these data in current laboratory modeling activities and in future monitoring activities, the ages should be revised. In addition, new C-14 samples will be collected as part of Hydrogeologic Workplan activities and the proposed work will provide a basis for correcting new C-14 ages. A preliminary set of calculations shows that using more appropriate calcite δ^{13}C values will make a significant change in the C-14 ages.

4.4.3.6 Baseline water chemistry

It is recommended that comparisons be made to baseline groundwater data to determine if contamination is occurring within alluvial, perched systems, and the regional aquifer. The baseline data provide information to the Laboratory geochemical model including hydrochemistry of perched zones and regional aquifer and delineation of recharge and discharge zones. It is recommended that the ER Project Baseline Groundwater Study results be published and used in conjunction with other historical Laboratory surveillance program data for comparison and interpretation.

5.0 FY01 INFORMATION MANAGEMENT

5.1 Hardware & Infrastructure

The Water Quality Database (WQDB) continues to operate on servers located both behind the LANL firewall and outside the firewall, open to the public. Sites can be found at the following URL's:

http://wqdb.lanl.gov
http://wqdbworld.lanl.gov

Late in FY01 the internal database was upgraded from Oracle 8.0.4 to Oracle 8.1.7 for performance and technical support reasons. Also late in FY01, tracking reports concerning the number and origin of visitors to the public web page became available.

5.2 System Security

Following the September 11th attack on the United States, LANL security requirements concerning website data distribution were tightened. As a result, certain WQDB data was required to be temporarily removed from the public website. The GIT is hopeful that with time, security restrictions will be revisited and this data will be reinstated on the public website.

5.3 Software

Additional web-based forms used to support data entry into the WQDB were developed this year. These forms support advanced sample planning and analytical data tracking functions and data entry and update of chemical data screening levels.

The chemistry data parsing software used to import chemistry data received from analytical laboratories into the database was enhanced to include numerous additional data quality checks.

The storm water flow and gage data infrastructure were successfully redesigned to significantly improve performance and conserve space in the database. This effort was very important because of the nature of the data, which is collected for dozens of stations in five-minute increments over many years.

5.4 Data Import

In FY01, analytical chemistry data continued to be loaded into the WQDB. The following illustrates the data import effort during 2001.

	Stations	Samples	Results
2001 GROUNDWATER SAMPLES	82	545	17,090
2001 ALL ESH-18 SAMPLES	234	1243	78,695

This data is available internal to the Laboratory and to the public via the WQDB websites. The WQDB system has significantly improved ESH-18 data availability/data turnaround times. Analytical results are now available via the WQDB websites an average of 60 days after the sample is collected. This data is recognized to be preliminary and is subject to change pending external verification and validation.

5.5 Legacy Data Migration

In FY01 a significant legacy data migration effort was completed. In this effort, legacy groundwater, surface water, and sediment monitoring data collected between 1942 and 1999 were imported into the WQDB. Statistics related to this effort are as follows:

	Stations	Samples	Results
LEGACY DATA MIGRATION (1942-1999)	785	19,070	241,543

This legacy data is undergoing continued QA/QC reviews and being moved in "batches" from the internal website to the public website.

5.6 Reports

In FY01, a new chemical data screening report was developed to screen current data against historical averages. This is a tool available only to LANL internal users at this time. New sample tracking reports were also developed in order to improve data turnaround times and improve communication with analytical laboratories. Station maps were also added to the WQDB websites. Since September 11th, these maps have been removed from the public website for security reasons.

Another significant accomplishment during FY01 was the use of the WQDB for input to the Laboratory's annual Environmental Surveillance Report. This effort demonstrated the successful operational switch from legacy data management systems to the new WQDB. Finally, in FY01 the WQDB system became the primary database used to generate EPA regulatory Stormwater Discharge Monitoring Reports.

6.0 STATUS WITH RESPECT TO HYDROGEOLOGIC WORKPLAN DECISIONS

The Hydrogeologic Workplan was developed as a response to multiple groundwater characterization needs identified by the Laboratory, DOE, and NMED. The primary purpose of the Hydrogeologic Workplan is to gain an understanding of the hydrogeologic setting adequate to design a monitoring network capable of detecting water quality threats to the regional aquifer. The Hydrogeologic Workplan provides for an iterative process of learning from each activity, especially wells that are installed, thus guiding the succeeding data quality objectives and the location and data collection of the succeeding wells. The interpretive process is equally as important as well installation and data collection, although it is a process that is not as visible as data collection. Numerical modeling is a primary tool used to interpret the data collected from drilling and testing in the wells. The iteration process is done when sufficient new data have been collected and interpreted to change the conceptual understanding. In FY01, the data collection and modeling reached the level of maturity to allow iteration on the DQOs. This section describes the FY01 DQO process iteration and resulting proposed amendments to the scope of the Hydrogeologic Workplan. The iteration process will be conducted as often as the new data and interpretation warrant.

The groundwater protection decision flow diagram was developed for the Hydrogeologic Workplan and summarizes the decisions that must be resolved to characterize the hydrogeologic setting. The decisions were formulated to guide data collection and ensure that the resulting data are adequate to provide the critical elements of monitoring network design. These decisions apply to each aggregate defined in the Hydrogeologic Workplan individually. Resolution of these decisions for all aggregates will signal the successful completion of the hydrogeologic characterization program. The DQO iteration process carefully considered the status of each aggregate with respect to these decisions.

The FY01 DQO iteration process began with a comprehensive evaluation of all groundwater-related data collected, analyzed, and interpreted to date in the program in order to determine what is known and what data are necessary to complete the Hydrogeologic Workplan. The comprehensive evaluation took place between June and October 2001. It was intended to familiarize all of the GIT members with the state of groundwater characterization knowledge and to develop a complete and consistent understanding of the hydrogeologic system with the available information. To accomplish this task, each scientific discipline (GIT subcommittee) provided a presentation that reflects an overview of the information collected to date (Section 4).

Following the comprehensive evaluation, a list of data needs was compiled. The remaining regional aquifer wells and interpretive activities listed in the Hydrogeologic Workplan were reviewed by the GIT with respect to the list of data needs. The GIT as a whole determined which of the remaining wells and other studies were still necessary and added new studies as needed to provide the data.

Table 6-1 summarizes the decisions in the Hydrogeologic Workplan for each aggregate, the data needed to resolve the decisions, and the proposed data collection activities. Table 6-2 lists the field activities (other than R-wells), analytical activities, and project management activities that are necessary to complete the scope of the Hydrogeologic Workplan. Additionally, Table 6-2 provides a crosswalk of the non-well-based activities to the 1998 Hydrogeologic Workplan. Table 6-3 provides a graphic summary of the progress toward resolution of the decisions in all of the aggregates.

In most aggregates, the first four decisions, which involve the presence of contaminants in saturated zones, are largely resolved. As anticipated, contamination of saturated zones has occurred in wet canyon systems (e.g., Los Alamos and Pueblo Canyons) and is not seen in dry canyon systems (e.g., Ancho Canyon). The remaining decisions, which involve identification of pathways and prediction of the potential for contamination in the future, are not resolved.

For example, some conservative contaminants (e.g., tritium and perchlorate) are observed in the regional aquifer beneath Pueblo Canyon. It is not clear from these observations whether the contamination is moving through the vadose zone as a point source (intersecting the regional aquifer at a relatively small locus) or as a line source (intersecting the regional aquifer in a line below the length of the canyon). The resultant plume in the regional aquifer would be of substantially different proportions depending on the outline of the source. Similarly, the monitoring network design would be quite different in response to the anticipated shape of a plume. Thus, many of the proposed data collection activities are targeted at identifying the pathways and the factors that affect transport within the saturated zones. These activities are concentrated in wet canyons where contaminants were discharged because those are the areas where contamination of saturated zones is anticipated.

Data collection in dry canyon systems and upgradient of LANL is focused on regional aquifer hydrologic characteristics, particularly boundary conditions, permeability, porosity, vertical and horizontal gradients, and faulting effects on the hydrology. This information is critical for predicting the direction and rate of water flow and contaminant transport from any site at the Laboratory.

7.0 FY02 PLANNED ACTIVITIES

This section summarizes the project management, data collection, data interpretation, and data management activities planned for FY02.

7.1 FY02 Project Management Activities

The following project management activities are planned for FY02.

- Hold GIT meetings on a bi-weekly basis, or as often as necessary to respond to program activities. One meeting each month will be dedicated to technical topics related to the progress of the program.
- Collect input and regulatory direction in quarterly meetings and an annual meeting with stakeholders, NMED, and DOE representatives.
- Facilitate interaction of GIT subcommittees for an integrated approach to refining the Hydrogeologic Conceptual Model and consolidating hydrologic, geologic, and geochemical interpretations of data into the annual status reports.
- Ensure external program review and review of documents by the EAG as necessary.
- Implement EAG recommendations as described in the Action Plans for EAG recommendations.

7.2 FY02 Data Collection, Analysis, and Interpretation Activities

The geologic, hydrologic, geochemical, and modeling activities planned for FY02 are described in the following subsections. The FY02 proposed scope of well drilling activities was included in a letter sent to NMED and the Hydrogeologic Characterization Program distribution list. The FY02 proposed scope includes completing R-8 and R-13. In addition to R-13, if there are cost efficiencies in the ER Project, funding may be available for drilling either R-18 or R-21. In addition to R-8, the anticipated DP-funded wells for FY02 are R-14 and R-20, if the budget requested from DP is provided. The budget requested from DP is $6.0 million. But until Congress passes the FY02 budget, operations are under "continuing resolution", which means that all agencies and programs are funded at the previous year level. Until resolution, the DP budget is $3.0 million.

Table 6-1 Status of Aggregates with Respect to Decisions and Data Necessary to Resolve Decisions

Decision	Aggregate 1: Los Alamos/ Pueblo	Data Needs	Planned Data Collection (Refer to Table 6-2 for descriptions)
Are there sources of sufficient magnitude to cause contamination of groundwater?	Yes		
Are the alluvial sediments and uppermost subsurface water at contaminant concentrations > regulatory risk limit or risk level?	Yes		
Is the intermediate perched groundwater at contaminant concentrations > regulatory limit or risk level?	Yes		
Is the regional aquifer as affected by the canyon systems by contaminant concentrations > regulatory limit or risk limit?		• Regional aquifer water quality • Geochemical modeling • Information management • 3-D Geologic Model	• R-2, R-4, R-6, R-24 • A-7, A-8, A-10, A-11
What are the pathways for exposure to contaminants from alluvial sediments and uppermost subsurface water?		• Distribution and rates of percolation. • Sorption parameters • Range of measured permeability - small scale • Mappable perched zones • Geochemical modeling • Information management • 3-D Geologic Model	• R-2, R-4, R-6, R-24 • OF-5, OF-6, OF-8, OF-10, OF-11 • A-2, A-7, A-8, A-10, A-11 • PM-1, PM-2, PM-3
Are there sufficient source terms to cause contamination if moved along the pathways in 1000 years?		• Range of measured permeability - large scale • Spinner logs • Pre-Bandelier sedimentology • Effective porosity on a field scale. • Head Data - Horizontal Gradients • Head Data -Vertical Gradients • Chemical stratification in regional aquifer • Determine age and groundwater travel times in regional aquifer • Regional aquifer modeling • Baseline geochemistry • Geochemical modeling • Information management • 3-D Geologic Model	• R-2, R-4, R-6, R-24 • OF-1, OF-2, OF-3, OF-4, OF-7, OF-9, OF-10, OF-11, OF-12 • A-1, A-2, A-3,A-4, A-5, A-7, A-8, A-9, A-10, A-11 • PM-1, PM-2, PM-3

Table 6-1 Status of Aggregates with Respect to Decisions and Data Necessary to Resolve Decisions

Decision	Aggregate 2: Canada del Buey/ Pajarito	Data Needs	Planned Data Collection (Tables 1 and 2)
Are there sources of sufficient magnitude to cause contamination of groundwater?	Yes		
Are the alluvial sediments and uppermost subsurface water at contaminant concentrations > regulatory risk limit or risk level?		• Presence of alluvial aquifer water • Quality of alluvial aquifer water • Geochemical modeling • Information management • 3-D Geologic Model	• R-6, R-16, R-18, R-24, R-27 • A-7, A-9, A-10
Is the intermediate perched groundwater at contaminant concentrations > regulatory limit or risk level?		• Presence of intermediate perched water • Quality of intermediate perched water • Geochemical modeling • Information management • 3-D Geologic Model	• R-6, R-16, R-18, R-24, R-27 • OT-5 • A-7, A-9, A-10
Is the regional aquifer as affected by the canyon systems by contaminant concentrations > regulatory limit or risk limit?		• Regional aquifer water quality • Geochemical modeling • Information management • 3-D Geologic Model	• R-6, R-16, R-18, R-24, R-27 • A-7, A-9, A-10
What are the pathways for exposure to contaminants from alluvial sediments and uppermost subsurface water?		• Sorption parameters • Range of measured permeability - small scale • Mappable perched zones • Geochemical modeling • Information management • 3-D Geologic Model	• R-6, R-16, R-18, R-24, R-27 • OF-5, OF-6, OF-8, OF-10, OF-11 • A-2, A-7, A-8, A-10, A-11 • PM-1, PM-2, PM-3
Are there sufficient source terms to cause contamination if moved along the pathways in 1000 years?		• Range of measured permeability - large scale • Spinner logs • Pre-Bandelier sedimentology • Effective porosity on a field scale. • Head Data - Horizontal Gradients • Head Data -Vertical Gradients • Chemical stratification in regional aquifer • Determine age and groundwater travel times in regional aquifer • Regional aquifer modeling • Baseline geochemistry • Geochemical modeling • Information management • 3-D Geologic Model	• R-6, R-16, R-18, R-24, R-27 • OF-1, OF-2, OF-3, OF-4, OF-7, OF-9, OF-10, OF-11, OF-12 • A-1, A-2, A-3,A-4, A-5, A-7, A-8, A-9, A-10, A-11 • PM-1, PM-2, PM-3

Table 6-1 Status of Aggregates with Respect to Decisions and Data Necessary to Resolve Decisions

Decision	Aggregate 3: TA-49	Data Needs	Planned Data Collection (Tables 1 and 2)
Are there sources of sufficient magnitude to cause contamination of groundwater?	Yes ○		
Are the alluvial sediments and uppermost subsurface water at contaminant concentrations > regulatory risk limit or risk level?	⊘	• Presence of alluvial aquifer water • Quality of alluvial aquifer water • Geochemical modeling • 3-D geolgic model	• R-6, R-24,R-30 • A-7, A-9, A-10
Is the intermediate perched groundwater at contaminant concentrations > regulatory limit or risk level?	◠	• Presence of intermediate perched water • Quality of intermediate perched water • Geochemical modeling • 3-D Geologic Model	• R-6, R-24, R-30 • OT-5 • A-7, A-9, A-10
Is the regional aquifer as affected by the canyon systems by contaminant concentrations > regulatory limit or risk limit?	◠	• Regional aquifer water quality • Geochemical modeling • 3-D geologic model	• R-6, R-24, R-30 • A-7, A-9, A-10
What are the pathways for exposure to contaminants from alluvial sediments and uppermost subsurface water?	⊘	• Sorption parameters • Range of measured permeability - small scale • Mappable perched zones • Geochemical modeling • 3-D geologic model • Information management	• R-6, R-24, R-30 • OF-5, OF-6, OF-8, OF-10, OF-11 • A-2, A-7, A-8, A-10, A-11 • PM-1, PM-2, PM-3
Are there sufficient source terms to cause contamination if moved along the pathways in 1000 years?	⊘	• Range of measured permeability - large scale • Pre-Bandelier sedimentology • Effective porosity on a field scale. • Head Data - Horizontal Gradients • Head Data -Vertical Gradients • Chemical stratification in regional aquifer • Determine age and groundwater travel times in regional aquifer • Regional aquifer modeling • Geochemical modeling • 3-D Geologic Model • Information management	• R-6, R-24, R-30 • OF-2, OF-3, OF-4, OF-7, OF-9, OF-10, OF-11, OF-12 • A-1, A-2, A-3,A-4, A-5, A-7, A-8, A-9, A-10, A-11 • PM-1, PM-2, PM-3

Table 6-1 Status of Aggregates with Respect to Decisions and Data Necessary to Resolve Decisions

Decision	Aggregate 4: Ancho/Indio/ Chaquehui	Data Needs	Planned Data Collection (Tables 1 and 2)
Are there sources of sufficient magnitude to cause contamination of groundwater?	Yes		
Are the alluvial sediments and uppermost subsurface water at contaminant concentrations > regulatory risk limit or risk level?	No		
Is the intermediate perched groundwater at contaminant concentrations > regulatory limit or risk level?	No		
Is the regional aquifer as affected by the canyon systems by contaminant concentrations > regulatory limit or risk limit?	No		
What are the pathways for exposure to contaminants from alluvial sediments and uppermost subsurface water?		• Mappable perched zones • Geochemical modeling • Pre-Bandelier sedimentology • Information management • 3-D Geologic Model	• R-6, R-24, R-29, R-30 • OF-6, OF-8, OF-10, OF-11 • A-2, A-7, A-8, A-10, A-11 • PM-1, PM-2, PM-3
Are there sufficient source terms to cause contamination if moved along the pathways in 1000 years?		• Range of measured permeability - large scale • Pre-Bandelier sedimentology • Effective porosity on a field scale • Head Data - Horizontal Gradients & Vertical Gradients • Chemical stratification in regional aquifer • Determine age and groundwater travel times in regional aquifer • Regional aquifer modeling Information management • 3-D Geologic Model • Information management • Baseline geochemistry	• R-6, R-24, R-29, R-30 • OF-2, OF-3, OF-4, OF-7, OF-9, OF-10, OF-11, OF-12 • A-1, A-2, A-3,A-4, A-5, A-7, A-8, A-9, A-10, A-11 • PM-1, PM-2, PM-3

Table 6-1 Status of Aggregates with Respect to Decisions and Data Necessary to Resolve Decisions

Decision	Aggregate 5: Canon del Valle	Data Needs	Planned Data Collection (Tables 1 and 2)
Are there sources of sufficient magnitude to cause contamination of groundwater?	Yes ○		
Are the alluvial sediments and uppermost subsurface water at contaminant concentrations > regulatory risk limit or risk level?	Yes ○		
Is the intermediate perched groundwater at contaminant concentrations > regulatory limit or risk level?	Yes ○		
Is the regional aquifer as affected by the canyon systems by contaminant concentrations > regulatory limit or risk limit?	◠	• Regional aquifer water quality • Geochemical modeling • Information management • 3-D Geologic Model	• R-6, R-18, R-24, R-27 • A-7, A-9, A-10
What are the pathways for exposure to contaminants from alluvial sediments and uppermost subsurface water?	◠	• Mappable perched zones • Geochemical modeling • Pre-Bandelier sedimentology • Information management • 3-D Geologic Model • Spring flow and quality monitoring	• R-6, R-18, R-24, R-27 • OF-5, OF-6, OF-8, OF-10, OF-11 • A-2, A-7, A-8, A-10, A-11 • PM-1, PM-2, PM-3
Are there sufficient source terms to cause contamination if moved along the pathways in 1000 years?	⊘	• Range of measured permeability - large scale • Pre-Bandelier sedimentology • Effective porosity on a field scale • Head Data - Horizontal Gradients & Vertical Gradients • Chemical stratification in regional aquifer • Determine age and groundwater travel times in regional aquifer • Regional aquifer modeling Information management • 3-D Geologic Model • Information management • Baseline geochemistry	• R-6, R-18, R-24, R-27 • OF-2, OF-3, OF-4, OF-7, OF-9, OF-10, OF-11, OF-12 • A-1, A-2, A-3,A-4, A-5, A-7, A-8, A-9, A-10, A-11 • PM-1, PM-2, PM-3

Table 6-1 Status of Aggregates with Respect to Decisions and Data Necessary to Resolve Decisions

Decision	Aggregate 6: Water/Potrillo/ Fence	Data Needs	Planned Data Collection (Tables 1 and 2)
Are there sources of sufficient magnitude to cause contamination of groundwater?	Yes		
Are the alluvial sediments and uppermost subsurface water at contaminant concentrations > regulatory risk limit or risk level?		• Presence of alluvial aquifer water • Quality of alluvial aquifer water • Chloride and stable isotope analysis • Geochemical modeling • Information management • 3-D Geologic Model	• R-6, R-18, R-23, R-24, R-27, R-29 • A-5, A-7, A-9, A-10
Is the intermediate perched groundwater at contaminant concentrations > regulatory limit or risk level?		• Presence of intermediate perched water • Quality of intermediate perched water • Geochemical modeling • Chloride and stable isotope analysis • Geochemical modeling • Information management • 3-D Geologic Model	• R-6, R-18, R-23, R-24, R-27, R-29 • OT-5 • A-5, A-7, A-9, A-10
Is the regional aquifer as affected by the canyon systems by contaminant concentrations > regulatory limit or risk limit?		• Regional aquifer water quality • Geochemical modeling • Information management • 3-D Geologic Model	• R-6, R-18, R-23, R-24, R-27, R-29 • A-7, A-9, A-10
What are the pathways for exposure to contaminants from alluvial sediments and uppermost subsurface water?		• Mappable perched zones • Geochemical modeling • Chloride and stable isotope analysis • Geochemical modeling • Pre-Bandelier sedimentology • Information management • 3-D Geologic Model	• R-6, R-18, R-23, R-24, R-27, R-29 • OF-5, OF-6, OF-8, OF-10, OF-11 • A-2, A-6, A-7, A-8, A-10, A-11 • PM-1, PM-2, PM-3
Are there sufficient source terms to cause contamination if moved along the pathways in 1000 years?		• Range of measured permeability - large scale • Pre-Bandelier sedimentology • Effective porosity on a field scale • Head Data - Horizontal Gradients & Vertical Gradients • Chemical stratification in regional aquifer • Chloride and stable isotope analysis • Geochemical modeling and baseline geochemistry • Determine age and groundwater travel times in regional aquifer • Regional aquifer modeling • 3-D Geologic Model and information management	• R-6, R-18, R-23, R-24, R-27, R-29 • OF-2, OF-3, OF-4, OF-7, OF-9, OF-10, OF-11, OF-12 • A-1, A-2, A-3, A-4, A-5, A-7, A-8, A-9, A-10, A-11 • • PM-1, PM-2, PM-3

Table 6-1 Status of Aggregates with Respect to Decisions and Data Necessary to Resolve Decisions

Decision	Aggregate 7: Mortandad	Data Needs	Planned Data Collection (Tables 1 and 2)
Are there sources of sufficient magnitude to cause contamination of groundwater?	Yes		
Are the alluvial sediments and uppermost subsurface water at contaminant concentrations > regulatory risk limit or risk level?	Yes		
Is the intermediate perched groundwater at contaminant concentrations > regulatory limit or risk level?	Yes		
Is the regional aquifer as affected by the canyon systems by contaminant concentrations > regulatory limit or risk limit?		• Regional aquifer water quality • Geochemical modeling • Information management • 3-D Geologic Model	• R-6, R-14, R-16, R-24 • A-7, A-9, A-10
What are the pathways for exposure to contaminants from alluvial sediments and uppermost subsurface water?		• Mappable perched zones • Geochemical modeling • Pre-Bandelier sedimentology • Information management • 3-D Geologic Model	• R-6, R-14, R-16, R-24 • OF-5, OF-6, OF-8, OF-10, OF-11 • A-2, A-7, A-8, A-10, A-11 • PM-1, PM-2, PM-3
Are there sufficient source terms to cause contamination if moved along the pathways in 1000 years?		• Range of measured permeability - large scale • Pre-Bandelier sedimentology • Effective porosity on a field scale • Head Data - Horizontal Gradients & Vertical Gradients • Determine age and groundwater travel times in regional aquifer • Regional aquifer modeling • Information management • 3-D Geologic Model • Information management • Baseline geochemistry	• R-6, R-14, R-16, R-24 • OF-2, OF-3, OF-4, OF-7, OF-9, OF-10, OF-11 • A-1, A-2, A-3,A-4, A-5, A-7, A-8, A-9, A-10, A-11 • PM-1, PM-2, PM-3

Table 6-1 Status of Aggregates with Respect to Decisions and Data Necessary to Resolve Decisions

Decision	Aggregate 8: Guaje/Bayo/ Rendija	Data Needs	Planned Data Collection (Tables 1 and 2)
Are there sources of sufficient magnitude to cause contamination of groundwater?	No ○		
Are the alluvial sediments and uppermost subsurface water at contaminant concentrations > regulatory risk limit or risk level?	No ○		
Is the intermediate perched groundwater at contaminant concentrations > regulatory limit or risk level?	No ○		
Is the regional aquifer as affected by the canyon systems by contaminant concentrations > regulatory limit or risk limit?	No ○		
What are the pathways for exposure to contaminants from alluvial sediments and uppermost subsurface water?	No ○		
Are there sufficient source terms to cause contamination if moved along the pathways in 1000 years?	No ○		

Table 6-2 Planned Data Collection and Interpretation Activities

Task ID Number	Task Name	Task Description	Cross-Walk to Hydrogeologic Workplan (Table 3-1)
Other Field (Non-Well) Activities			
OF-1	Spinner logs	Spinner logs, to determine the most productive zones in a well, should be run in water supply wells where a sentry well is planned. High priority wells for spinner logs are PM-3, PM-5, and O-1.	**Task:** Develop Hydrologic Model **Subtask:** Compile Hydraulic Characteristic Data 3) Hydrologic parameter estimation for Pajarito Plateau
OF-2	Multiple-Well Hydrologic Testing for Large-Scale Permeability	Multiple well pump test(s) to determine medium-to-large scale permeability & to reconcile model parameters with test data. R-20 and R-11 could be close enough to water supply wells to conduct testing.	**Task:** Develop Hydrologic Model **Subtask:** Compile Hydraulic Characteristic Data 3) Hydrologic parameter estimation for Pajarito Plateau
OF-3	Tracer test for Effective Porosity	Conduct cross-hole forced-gradient tracer tests to estimate field scale effective porosity. Requires construction of a test facility with two wells screened in intervals of interest.	**Task:** Develop Hydrologic Model **Subtask:** Compile Hydraulic Characteristic Data 3) Hydrologic parameter estimation for Pajarito Plateau
OF-4	In Situ Downhole Velocity Tests	Tests to be conducted in water supply wells if they become available. The test results would provide a check on the modeling.	**Task:** Develop Hydrologic Model **Subtask:** Compile Hydraulic Characteristic Data 3) Hydrologic parameter estimation for Pajarito Plateau
OF-5	Airborne Electro-magnetic Survey	To map the extent of intermediate perched groundwater. The data collection is about 75% complete.	
OF-6	Percolation Rates	Install a number of approximately 300-ft deep wells in a canyon to look at moisture and contaminant distribution. The shallow wells would be used for estimating percolation rates and travel times.	**Task:** Develop Hydrologic Model **Subtask:** Compile and publish hydraulic characteristic data, 1) Bandelier Tuff
OF-7	Refine Groundwater Age Estimates	Determine age and groundwater travel times in regional aquifer (R wells). Perform this work activity during sampling of R wells. Need to obtain representative calcite samples from core collected at R wells and outcrops to correct $\delta^{13}C$ for recalculating C-14 dates.	**Task:** Develop Geochemical Model **Subtask:** Geochemical characteristics of key subsurface hydrogeologic units
OF-8	Sorption Parameters	Perform sorption experiments on uranium, strontium, plutonium, and americium using groundwater and core-cutting samples to determine adsorption constants (distribution coefficients and surface complexation parameters) from the Cerros del Rio basalt (perched groundwater zones) in Los Alamos Canyon and Mortandad Canyon.	**Task:** Develop Geochemical Model **Subtask:** Geochemical characteristics of key subsurface hydrogeologic units
OF-9	Pre-Bandelier Sedimentology	Characterize the components of the Puye Formation and Santa Fe Group to develop a representative description of grain size, shape, sorting, and mineralogy. The current descriptions based on drill cuttings are biased toward the larger grain sizes because the fines wash out while drilling. Collect samples from outcrops of these units to determine the relative proportion of the size components.	**Task:** Develop Hydrologic Model **Subtask:** Compile Hydraulic Characteristic Data 3) Hydrologic parameter estimation for Pajarito Plateau

Table 6-2 Planned Data Collection and Interpretation Activities

Task ID Number	Task Name	Task Description	Cross-Walk to Hydrogeologic Workplan (Table 3-1)
OF-10	Basalt Flow Geometry	Spatial refinement of the geometry of basalt flows, which are potential fast pathways, is uncertain. Use the airborne EM survey and surface mapping of Frijoles and Guaje Mountain (SE corner) quadrangles. Develop and consider multiple alternative geologic models and test them with flow model against water level data.	**Task:** Develop Geologic Model **Subtask:** Develop 3-dimensional database
OF-11	Range of measured permeability - small scale	Conduct pumping hydrologic tests in zones of interest. Slug tests may only test the filter pack materials.	**Task:** Develop Hydrologic Model **Subtask:** Water Quality Data 2) Evaluate water quality variations and vertical stratification
OF-12	Chemical stratification within the regional aquifer	Characterization wells completed with multiple screened intervals and sampling ports within the regional aquifer will be used to evaluate water quality variations and vertical stratification	**Task:** Develop Hydrologic Model **Subtask:** Water Quality Data 2) Evaluate water quality variations and vertical stratification
OF-13	Spring Flow and Quality Monitoring	Flow measurements and water quality analysis for springs in areas impacted by contamination, e.g., TA-16	**Task:** Develop Hydrologic Model **Subtask:** Inventory Springs Onsite
Analytical Activities			
A-1	Regional Aquifer Modeling - Facies Model & Aquifer Permeability	Review logs to see if anything is in logs related to permeability. Develop a method of logging to provide a correlation between textural deposits or depositional facies and permeability estimates. Incorporate hypotheses concerning fault zones, facies within sedimentary rocks, alternative realizations about structure of basalt flows, etc. quickly into 3-D Geologic Model so that they can be tested against water level data using flow modeling.	**Task:** Develop Geologic Model **Subtask:** Develop 3-dimensional database **Task:** Develop Hydrologic Model **Subtask:** Compile Hydraulic Characteristic Data 3)Hydrologic parameter estimation for Pajarito Plateau **Task:** Develop Hydrologic Model **Subtask:** Groundwater flow modeling using FEHM code
A-2	Groundwater Pathway Assessment	Rank contaminants of potential risk-significance to groundwater receptors on a site-wide basis. Synthesize information from contaminant sources and hydrogeologic data to assess transport times and pathways.	**Task:** Develop Hydrologic Model **Subtask:** Groundwater modeling using FEHM code
A-3	Regional Aquifer Modeling - Local Perturbations of Flow Field	Potential effects of fault zones with data from R-25, R-24, R-2 and R-4; link canyons models to regional aquifer model through the water table boundary condition, examine effects of local recharge	**Task:** Develop Hydrologic Model **Subtask:** Groundwater modeling using FEHM code
A-4	Regional Aquifer Modeling - Future Water Quality and Quantity	Incorporate new data into model calibration; define capture zones for water supply wells; assess potential future changes in water quality due to pumping; predict future water level declines	**Task:** Develop Hydrologic Model **Subtask:** Groundwater modeling using FEHM code

Table 6-2 Planned Data Collection and Interpretation Activities

Task ID Number	Task Name	Task Description	Cross-Walk to Hydrogeologic Workplan (Table 3-1)
A-5	Regional Aquifer Modeling - Support Monitoring Well Network Design	Incorporate all pertinent data into model calibration; calculate final sensitivity analyses to generate confidence intervals for all simulated flow directions and velocities for use in designing the monitoring well network.	**Task:** Develop Hydrologic Model **Subtask:** Groundwater modeling using FEHM code
A-6	Chloride and Stable Isotope Analysis	Determine recharge rates in core from boreholes in Potrillo Canyon, collected from the area where surface water disappears. Core is available for analysis.	**Task:** Develop Hydrologic Model **Subtask:** Compile Hydraulic Characteristic Data 2)Vadose Zone fluxes in Los Alamos mesas
A-7	Baseline Geochemistry	Finalize publication and make database available.	**Task:** Develop Geochemical Model **Subtask:** Hydrochemical and statistical evaluation of solute distributions
A-8	Geochemical Modeling	Understand the important processes occurring along flow paths using baseline water quality and characterization sampling data	**Task:** Develop Geochemical Model **Subtask:** Geochemical Modeling
A-9	Pajarito Plateau Water Balance	Refine plateau-wide water balance as part of regional aquifer modeling on an annual basis.	**Task:** Develop Hydrologic Model **Subtask:** Long-term water balance
A-10	Information Management	ER/ESH data exchange, system maintenance and administration, and project management to consolidate historical and newly collected water quality-related data	**Task:** Develop Hydrologic Model **Subtask:** Water Quality Data, Consolidate historical water quality database
A-11	Three-Dimensional Geologic Model	Maintain three-dimensional geologic model to produce structure contour, isopach, water table maps and to provide geologic data for hydrologic modeling; update annually with new data	**Task:** Develop Geologic Model **Subtask:** Develop 3-dimensional database **Subtask:** Perform comprehensive review of 3-dimensional stratigraphy
Project Management Activities			
PM-1	GIT Activities	Quarterly meetings, annual meetings, annual groundwater status report	
PM-2	EAG Activities	Semi-annual project reviews, semi-annual reports	
PM-3	Field Support Facility	Maintain field support facility and core facility	

Table 6-3 Summary of Status by Aggregates with Respect to Decisions and Data Necessary to Resolve Decisions

Decision	Aggregate 1: Los Alamos/ Pueblo	Aggregate 2: Canada del Buey/Pajarito	Aggregate 3: TA-49	Aggregate 4: Ancho/Indio/ Chaquehui	Aggregate 5: Canon del Valle	Aggregate 6: Water/ Potrillo/ Fence	Aggregate 7: Mortandad	Aggregate 8: Guaje/Bayo/ Rendija
Are there sources of sufficient magnitude to cause contamination of groundwater?	Yes ○	Yes ○	Yes ○	Yes ○	Yes ○	Yes ○	Yes ○	No ○
Are the alluvial sediments and uppermost subsurface water at contaminant concentrations > regulatory risk limit or risk level?	Yes ○	◠	⊘	**No** ○	Yes ○	◠	Yes ○	No ○
Is the intermediate perched groundwater at contaminant concentrations > regulatory limit or risk level?	Yes ○	◠	◠	**No** ○	Yes ○	◠	Yes ○	No ○
Is the regional aquifer as affected by the canyon systems by contaminant concentrations > regulatory limit or risk limit?	◠	◠	◠	No ○	◠	◠	◠	No ○
What are the pathways for exposure to contaminants from alluvial sediments and uppermost subsurface water?	◠	◠	⊘	◠	◠	◠	◠	No ○
Are there sufficient source terms to cause contamination if moved along the pathways in 1000 years?	◠	⊘	⊘	⊘	⊘	⊘	◠	No ○

○ Decision resolved; no further data collection necessary

◠ Decision not resolved, further data collection and analysis necessary

Table 7.2-1 shows the proposed regional aquifer boreholes, priority, and start dates from DP and ER baselines. Table 7.2-2 describes the status of the proposed regional aquifer boreholes. Note that both Tables 7.2-1 and 7.2-2 show only those wells to be completed in FY02 for which there is authorized funding as of December 2001.

Table 7.2-1 Proposed Regional Aquifer Boreholes, Priority, and Start Dates from DP and ER Baselines

Priority	Borehole	Funding Source	Current Start Date	FY00 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	Complete
7.	R-19	ER	Feb FY00	Complete
10.	R-22	ER	Sept FY00	Complete
12.	R-7	ER	May FY00	Complete
8.	R-5	NWT	Jul FY00	Complete
9.	R-28	NWT	TBD	-----
6.	R-27	ER	Apr FY04	-----
13.	R-1	NWT	Feb FY04	-----
11.	R-32	NWT	Jun FY02	-----
14.	R-18	ER	Apr FY03	-----
15.	R-8	NWT	Feb FY02	Started
16.	R-10	ER	May FY06	-----
17.	R-2	NWT	Apr FY04	-----
18.	R-3	ER	Dec FY03	-----
19.	R-20	NWT	Oct FY03	-----
20.	R-4	ER	Feb FY04	-----
21.	R-14	NWT	May FY02	-----
22.	R-13	ER	Nov FY04	Complete
23.	R-11	NWT	Sep FY04	-----
24.	R-17	ER	Jan FY06	-----
25.	R-6	NWT	Jun FY06	-----
26.	R-23	ER	Jul FY06	-----
27.	R-29	NWT	Jan FY05	-----
28.	R-16	NWT	Dec FY03	-----
29.	R-21	ER	Oct FY03	-----
30.	R-26	NWT	Mar FY05	-----
31.	R-24	NWT	Nov FY04	-----
32.	R-30	ER	Mar FY06	-----

Table 7.2-2 Status of Proposed Regional Aquifer Boreholes

Borehole	Original Start Date	Current Start Date	FY01 Status[a]	Funding Source	Status of Installed Boreholes/Rationale of Proposed Boreholes
R-9	FY98	FY98	Complete	ER	Borehole R-9 was installed at the eastern Laboratory boundary in Los Alamos Canyon, and 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).
R-12	FY98	FY98	Complete	ER	Borehole R-12 was installed at the eastern Laboratory boundary in Sandia Canyon, and completed as a monitoring well with three sampling zones. 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. 26% of the borehole was cored, due to the proximity to R-9, PM-1, and O-1, which provided stratigraphic information. 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 regional aquifer was encountered at 805 ft and saturation extends to borehole TD of 886 ft
R-25	FY98	FY98	Complete	NWT	Borehole R-25 was installed adjacent to MDA P in Aggregate 5, and completed with nine sampling zones. 10% core collection supports site-wide studies of the hydrogeologic framework in a largely uncharacterized area of the Laboratory. Saturated zones encountered include one perched zone almost 400-ft thick at 747 ft and the regional aquifer at 1286 ft with saturation to TD of 1942 ft. R-25 provides water quality data for the intermediate perched zone 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	Complete	ER	Borehole R-15 was installed and completed as a single completion well 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. One intermediate perched zone about 100-ft thick was encountered at 646 ft . The regional aquifer was encountered at 964 ft with saturation to borehole TD of 1107 ft. About 39% of the borehole was cored. 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.

Table 7.2-2 Status of Proposed Regional Aquifer Boreholes

Borehole	Original Start Date	Current Start Date	FY01 Status[a]	Funding Source	Status of Installed Boreholes/Rationale of Proposed Boreholes
R-31	FY01	FY99	Complete	NWT	Borehole R-31 was installed downgradient of open burning/open detonation sites in Aggregate 6 and upgradient of firing sites in Aggregate 4, and completed as a monitoring well with five zones. A possible 10-ft-thick lens of intermediate perched water was encountered at about 450 ft. The regional aquifer was encountered at a depth of 520 ft with saturation to borehole TD of 1103 ft. Well R-31 provides water quality data for perched water and the regional aquifer in an area of the Laboratory with little control.
R-19	FY01	FY00	Complete	ER	R-19 was installed 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 also constrains the location of the axis of the south-draining pre-Bandelier paleo-drainage that trends through this area.
R-7	FY98	FY00	Complete	ER	R-7 was drilled to a depth of 1097 ft and a well was constructed with two screens in perched groundwater and one screen in the regional aquifer 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. Geophysical logs indicate that partially to fully saturated conditions are present from a depth of 362 ft to the top of the regional aquifer at a depth of 903 ft. Preliminary borehole water samples suggest that no contaminants are present at the top of the regional aquifer in this location.
R-5	FY00	FY00	Complete	NWT	R-5 was drilled to a depth of 902 ft on the south side of lower Pueblo Canyon. R-5 is upgradient of 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 upgradient of O-1.

Table 7.2-2 Status of Proposed Regional Aquifer Boreholes

Borehole	Original Start Date	Current Start Date	FY01 Status[a]	Funding Source	Status of Installed Boreholes/Rationale of Proposed Boreholes
R-22	FY98	FY01	Complete	ER	Borehole R-22 was drilled to a depth of 1489 ft and a well with five screens was installed in the regional aquifer east of TA-54. Its chosen location east of TA-54 provides water-quality and water level data 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. No intermediate depth perched groundwater was detected during drilling.
R-28	FY01	TBD	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.
R-27	FY00	FY04	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-1	FY01	FY04	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 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.

Table 7.2-2 Status of Proposed Regional Aquifer Boreholes

Borehole	Original Start Date	Current Start Date	FY01 Status[a]	Funding Source	Status of Installed Boreholes/Rationale of Proposed Boreholes
R-32	FY01	FY02	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.
R-18	FY99	FY03	Planned	ER	R-18 is planned for installation above the confluence of Pajarito and Two Mile 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	Started	NWT	R-8 was partially drilled to a depth of 261 ft by the end of FY01. R-8 was drilled 0.6 mi east of the confluence of Los Alamos Canyon and DP Canyon. Los Alamos Canyon has a long history of facility releases with contaminants detected in alluvial groundwater (^{3}H, ^{90}Sr, and ^{137}Cs) and in an intermediate perched zone in the Guaje Pumice Bed (^{3}H). 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	FY06	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 ^{3}H. 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.

Table 7.2-2 Status of Proposed Regional Aquifer Boreholes

Borehole	Original Start Date	Current Start Date	FY01 Status[a]	Funding Source	Status of Installed Boreholes/Rationale of Proposed Boreholes
R-2	FY00	FY04	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.
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 wastewater 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 (^{3}H, ^{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, ^{3}H, 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.

Table 7.2-2 Status of Proposed Regional Aquifer Boreholes

Borehole	Original Start Date	Current Start Date	FY01 Status[a]	Funding Source	Status of Installed Boreholes/Rationale of Proposed Boreholes
R-4	FY01	FY04	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	FY02	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 ^{3}H, Pu, and NO_3 released from the Laboratory's liquid radioactive waste treatment plant at TA-50. Elevated activities of ^{3}H occur in core samples collected 100–200 ft below the canyon floor (Stoker et al. 1991). Sampling of TW-8 confirmed the presence of ^{3}H (89 pCi/l), ^{90}Sr (2.1 pCi/l), $^{239,240}Pu$ (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.
R-13	FY01	FY04	Well construct ed	ER	R-13, located in Mortandad Canyon at the eastern Laboratory boundary, was drilled to a depth of 1132 ft and a single screen well was installed to sample the top of the regional aquifer. R-13 was installed to provide water-quality and water-level data for potential intermediate perched zones and for the regional aquifer downgradient of 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).

Table 7.2-2 Status of Proposed Regional Aquifer Boreholes

Borehole	Original Start Date	Current Start Date	FY01 Status[a]	Funding Source	Status of Installed Boreholes/Rationale of Proposed Boreholes
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	FY06	Planned	ER	R-17 is planned for installation in Two Mile 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	FY06	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	FY06	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 7.2-2 Status of Proposed Regional Aquifer Boreholes

Borehole	Original Start Date	Current Start Date	FY01 Status[a]	Funding Source	Status of Installed Boreholes/Rationale of Proposed Boreholes
R-16	FY03	FY03	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	FY03	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.

Table 7.2-2 Status of Proposed Regional Aquifer Boreholes

Borehole	Original Start Date	Current Start Date	FY01 Status[a]	Funding Source	Status of Installed Boreholes/Rationale of Proposed Boreholes
R-24	FY02	FY04	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.
R-30	FY02	FY06	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.

7.2.1 FY02 Geologic Data Collection and Interpretation

Plans for geologic studies in FY02 include the collection of basic stratigraphic, lithologic, and petrologic data from regional aquifer and intermediate-depth wells being installed for the Hydrogeologic Workplan by the Groundwater Investigations Focus Area. The overall integration of these data into visualizations and models will be accomplished through 1) the ER database, 2) data in the FIMAD archives, 3) the 3-D Geologic Model, and 4) specific as-needed inputs for individual tasks.

This work will be used to develop improved conceptual models of site geology. Studies of subsurface geology and structure will be used to define key subsurface hydrogeologic units and their geochemical and hydrological characteristics. The results of this work will provide the information necessary to update the 3-D Geologic Model.

The geologic studies described here provide the framework for developing conceptual models of contaminant occurrence, transport, and exposure in groundwater (LANL, 1998). Occurrences of contamination are positioned within specific geologic units; the sorptive and permeable properties of units where contamination occurs are important parameters in transport determinations. Relations between geologic units, including discontinuities at their contacts, are important components for transport calculations and will be input to the 3-D Geologic Model. Ultimately, exposure calculations will depend on those geologic units where transport pathways intersect subaerial or stream discharge points, or where specific geologic units may be targeted for subsurface access (e.g., water supply wells).

Geologic studies of the site are necessary to make the conceptual model realistic and the numerical flow and transport codes defensible. Studies of samples from drill holes and from outcrop will be used to provide information of chemical and mineralogic nature that bears on hydrogeologic properties of the major geologic units at the site. In addition to sample studies, surface geophysical data will be acquired to aid in the three-dimensional reconstruction of occurrences, thickness, and structural relations between hydrogeologic units and groundwater bodies.

7.2.1.1 Data Obtained from Drilling and from Outcrop

The drill sites involved in this activity are located in areas with highly varied contaminant-migration concerns and/or in key areas for understanding the hydrogeologic setting of the laboratory. The site 3-D Geologic Model and the numerical flow and transport models for contaminant migration are strongly dependent on the information obtained from the current ER drilling program. Several anomalies in the 3-D Geologic Model, particularly in the treatment of the Puye Formation, basalts, and the Los Alamos aquifer, will be addressed by supplementing new information from drilling with evaluation of geologic units in outcrop. The links between the geologic units in the 3-D Geologic Model and their hydrologic properties can be better characterized by analysis of critical units on a field scale. To acquire the necessary understanding of site geology, data from drill cuttings will be supplemented by examination of outcrops of lavas, Puye sediments, and Santa Fe Group sediments. Regional gravity and magnetic survey work begun in FY01 will be supplemented by further data collection. All available gravity data will be reduced to provide three-dimensional information on basin structure and fault locations beneath the Laboratory.

Cuttings from yet unanalyzed FY01 and new FY02 boreholes will be analyzed and the data obtained will be evaluated and interpreted in order to construct a more accurate 3-D Geologic Model and to provide supporting information for hydrogeologic, geochemical, and modeling studies. Methods to be used in providing this information include petrography, electron microbeam analysis, X-ray diffraction, X-ray fluorescence, trace-element analysis, and radiometric dating. These methods will provide the information needed to identify stratigraphic units and to evaluate the history of water-rock geochemical processes (mineral alteration and chemical modification) that can be compared with modeled performance. Conceptual models will be revised and compared with the current 3-D Geologic Model as each new drill hole is completed. Data acquired through the geochemistry and hydrology tasks will be evaluated throughout this process and used to redirect or refocus the geologic studies as necessary.

7.2.1.2 3-D Geologic Model Input

This work includes generation and evaluation of contact surfaces, isopachs, and structures for the 3-D Geologic Model. This will include the provision of geologic information from new boreholes, updating and correction of geologic information from older boreholes, and quality assurance checks on the 3-D Geologic Model. The extent of clay alteration within pumiceous Puye sediments will provide one component of the model. In addition, percentages of differing subzones within the Cerros del Rio lavas (massive flow interiors, potentially transmissive breccia zones, and clay-filled breccia zones) will be added to the model. This information will help integrate laterally variable hydrogeologic properties for mapped units into the 3-D Geologic Model.

Studies of outcrop samples will be used to provide information that cannot be obtained from drill cuttings. One of the compromises made in collecting cuttings rather than core is the loss of fine-matrix data. The cost-effective solution to this compromise is to collect such information from outcrop. Data from matrix fines is important for understanding water-rock interactions. In addition, cuttings provide little or no information on fracture systems in key fracture-transmissive units (especially basalts) or on local-scale 3-D information needed to evaluate the role of structures (especially faults) and contacts.

7.2.1.3 Surface Geophysical Studies

Detailed gravity data can provide 3-D information on basin structure and, most importantly, the location of faults at depth. This information is vital to understanding the site hydrogeology and is difficult or impossible to obtain from drilling. Overflight electrical and magnetic data collected at the end of FY01 are providing a new site-wide view of properties that are important for understanding distributions of intermediate-range (to ~400 ft depth) saturation and of subsurface high-iron-content units (basaltic lavas). Gravity and magnetic data collected on the ground surface, particularly in the southeastern part of the Laboratory, will add detailed gravity information and finer scale and higher resolution magnetic information to the site-wide data. Integration with new information from drilling, particularly electrical and density data from borehole geophysics, will greatly improve the products of the surface geophysical studies.

7.2.2 FY02 Hydrologic Data Collection

In most years, hydrologic data collection is focused on testing the various wells projected for completion. However, few new wells are scheduled for FY02. Nonetheless, such activity will continue on a limited scale (if appropriate).

- When R-8 is complete, aquifer parameters shall be investigated by hydrologic testing, as at previous wells.
- If funding permits and R-14 is installed in FY02, it shall also be tested.

Further analysis of test data previously collected will also continue.

In a year when there is less field work, such as FY02, there is more time for processing and interpreting the other data that contribute to hydrologic characterization.

- Hydraulic heads will be extracted from the Westbay transducer data and vertical head profiles constructed for each Westbay-completed R well. Unfortunately, this has not been done to date as pulling/re-installing transducers in conjunction with an ambitious schedule of characterization sampling has fully consumed the time of personnel assigned to download and process the data.
- Hydrogeologic cross-sections will be constructed through selected key wells. This project should be fairly straightforward, using the 3-D Geologic Model and Hydrogeologic Atlas surfaces (including regional water table).
- Finally, several water quality maps will be prepared for inclusion in the Hydrogeologic Atlas. These will be compiled in consultation with the GIT Geochemistry subcommittee and tentatively may include

sheets for total-dissolved-solids content (possibly with Stiff diagrams), calcium/sodium ratio, and other selected constituents/parameters of concern.

- A new comprehensive Atlas report will also be prepared, not only describing these additional sheets, but also incorporating explanatory information presented in the previous documentation for the preliminary (Stone et al., 1999) and expanded (Stone et al., 2001) versions.

7.2.3 FY02 Geochemical Data Collection

Geochemical data collection activities planned for FY02 include analyzing samples from newly installed boreholes and wells and groundwater sampling of supply wells, test wells, and alluvial wells for surveillance purposes. Data collection activities consist of:

- Preparing geochemistry reports for R-9-9i, R-7, R-12, R-15, R-19, and R-22
- Collecting outcrop, core, and cuttings for geochemical-contaminant analyses of R-8, R-14, MCOBT-4.4, and MCOBT-8.5
- Collecting groundwater samples both during drilling and from newly completed wells to evaluate natural solute (inorganic-radionuclide) and contaminant distributions in perched zones and in the regional aquifer
- Collecting groundwater samples from alluvial wells in Pueblo Canyon, Los Alamos Canyon, Mortandad Canyon, and Cañon de Valle to evaluate water and contaminant balance, and estimate residence times and mixing of groundwater and surface water
- Collecting water quality samples from test wells and supply wells on and adjacent to the Pajarito Plateau as part of the annual environmental surveillance and compliance monitoring activities and special investigations
- Performing geochemical modeling using MINTEQA2 and PHREEQC2.2 to quantify aqueous speciation, mineral equilibrium, and adsorption reactions using groundwater and core samples collected from the completed wells and boreholes.

7.2.4 FY02 Vadose Zone and Regional Aquifer Modeling

Two types of modeling activities will be carried out in FY02: 1) ongoing model development and calibration and 2) model predictions of contaminant transport and analysis of their respective uncertainty. Most model development activities will directly support the characterization effort by providing input to guide the course of drilling and data collection, with a few activities also devoted to preparing the simulation tools for the model predictions task. The analyses of model predictions will be used to inform management of issues such as data sufficiency and quality with respect to key characterization and regulatory decisions that must be made in the future. The lists below summarize the ongoing modeling activities in these areas.

1) Model Development and Calibration:

Vadose Zone

- Develop infiltration map and characterize uncertainty in infiltration across the Plateau
- Interpret contaminant migration information from existing boreholes
- Complete development of GIS-based integration of the available site data and modeling results
- Link vadose zone and regional groundwater models

Regional Aquifer

- Incorporate new R-well data into model development/calibration
- Continue analyses to determine what lithologic structures are dominating heterogeneity within the sedimentary rocks
- Analyze the impact of heterogeneity on model calibration and model predictions

- Evaluate the impact of local recharge on regional aquifer hydrology
- Evaluate capture zones for water supply wells on the plateau

2) Model Predictions of Contaminant Transport:
- Develop parameter distributions for key uncertain parameter for use in analyses
- Develop source term information and quantify uncertainty
- Perform regional aquifer capture zone analyses
- Perform integrated vadose zone/regional aquifer Monte Carlo analyses of contaminant transport
- Analyze the propagation of uncertainty in the contaminant predictions from the potential sources to the potential recipients (pumping wells/rivers) through the integrated vadose zone/regional aquifer model
- Identify key uncertainties in the model requiring additional hydrogeologic characterization to decrease the prediction uncertainties

7.3 FY02 Information Management Activities

In FY02, a great deal of activity is planned for the WQDB. Data exchange with the ER Database has already begun. R-Well construction data is the first data set to be exchanged. Once the construction data is successfully exchanged, the associated chemistry data will be exchanged.

Also in FY02, data entry forms will be created to allow the web-based data entry of external verification and validation flags and reasons. Advanced sample planning, tracking, and chain of custody form generation features will also be developed. The import of water level data from legacy data sources and from R-wells is planned for FY02, and web-based GIS capabilities are planned for development in FY02. All of these activities are contingent upon receipt of sufficient funding.

8.0 REFERENCES

Allison, J. D., D. S. Brown, and K. J. Novo-Gradac, 1991. "MINTEQA2/PRODEFA2, A Geochemical Assessment Model for Environmental Systems: Version 3.0 User's Manual," EPA/600/3-91/021, Office of Research and Development, Athens, Georgia.

Bitner, K. A., B. Gallaher, and K. Mullen, 2001. "Review of Wildfire Effects on Chemical Water Quality," Los Alamos National Laboratory Report LA-13826-MS, Los Alamos, New Mexico

Blake, W. D., F. Goff, A. I. Adams, and D. Counce, 1995. "Environmental Geochemistry for Surface and Subsurface Waters in the Pajarito Plateau and Outlying Areas, New Mexico," Los Alamos National Laboratory Report LA-12912-MS, Los Alamos, New Mexico.

Broxton, D. E., R. Warren, D. Vaniman, B. Newman, A. Crowder, M. Everett, R. Gilkeson, P. Longmire, J. Marin, W. Stone, S. McLin, and D. Rogers, 2001a. "Characterization Well R-12 Completion Report," Los Alamos National Laboratory Report LA-13822, Los Alamos, New Mexico.

Broxton, D. E., R. Gilkeson, P. Longmire, J. Marin, R. Warren, D. Vaniman, A. Crowder, B. Newman, B. Lowry, D. Rogers, W. Stone, S. McLin, G. WoldeGabriel, and D. Wycoff, 2001b. "Characterization Well R-9 Completion Report," Los Alamos National Laboratory Report LA-13742, Los Alamos, New Mexico.

Broxton, D. E., R. Warren, R. Gilkeson, P. Longmire, D. Rogers, S. Johnson, W. Stone, B. Newman, M. Everett, D. Vaniman, S. McLin, J. Skalski, and D. Larson, 2001. "Characterization Well R-25 Completion Report," Draft, Los Alamos National Laboratory Report pending, Los Alamos, New Mexico.

Department of Energy, 1990, Order 5400.1. "General Environmental Protection Program," Washington DC.

Goff, F., Gardner, J. N., Baldridge, W. S., Hulen, J. B., Nielson, D. L., Vaniman, D., Heiken, G., Gungan, M. A., and Broxton, D., 1989, Volcanic and hydrothermal evolution of the valles caldera and the Jemez volcanic field, New Mexico Bureau of Mines and Mineral Resources memoir 46:381-434.

Ingersoll, R. V., Cavazza, W., Baldridge, W.S., and Shafiqullah, M., 1990. "Cenozoic sedimentation and paleotectonics of north-central New Mexico: Implications for initiation and evolution of the Rio Grande rift", Geological Society of America Bulletin, v. 102, pp. 1280-1296.

Izett, G. A., and J. D. Obadovich, 1994. "$^{30}Ar/^{39}Ar$ Age Constraints for the Jaramillo Normal Subchron and the Matuyama-Branhes Geomagnetic Boundary," Journal of Geophysical Research, Vol. 99, p 2925-2934.

Katzman, D., R. Ryti, and S. Reneau, 2001, Cerro Grande as a Source of Elevated Radionuclides and Metals: Geological Society of America, Rocky Mountain (53rd) and South-Central (35th) Sections, Albuquerque, NM, April 30-May 2, 2001.

Keating, E. and V. Vesselinov, 2001. "Annual Report on Regional Aquifer Modeling and Data Analysis," Draft, Los Alamos National Laboratory Report pending, Los Alamos, New Mexico.

Kendrick, B., January 1999. "Revised Summary Table," memorandum from B. Kendrick, TechLaw Inc., to P. Longmire, Los Alamos National Laboratory, Los Alamos, New Mexico.

Langmuir, D., 1997. *Aqueous Environmental Geochemistry,* Prentice-Hall, Inc., Upper Saddle River, New Jersey.

Los Alamos National Laboratory (LANL), 2001. "Environmental Surveillance and Compliance at Los Alamos during 2000," Los Alamos National Laboratory Report LA-13861-ENV, Los Alamos, New Mexico.

Los Alamos National Laboratory (LANL) 2000. "Environmental Surveillance and Compliance at Los Alamos during 1999," Los Alamos National Laboratory Report LA-13775-ENV, Los Alamos, New Mexico.

Los Alamos National Laboratory (LANL), 1998. "Hydrogeologic Workplan," Los Alamos National Laboratory Report LA-UR01-6511, Los Alamos, New Mexico.

Los Alamos National Laboratory (LANL), 1996. "Groundwater Protection Management Program Plan," Los Alamos, New Mexico.

Longmire, P., D. Counce, M. Dale, S. Chipera, and M. Snow, 2001a, Conceptual Model of Mineralogical and Hydrochemical Impacts From the Cerro Grande Fire, Los Alamos, New Mexico: 13th TIE Conference, Albuquerque, NM, November 13-15, 2001.

Longmire, P., Broxton, D. E., Stone, W., B. Newman, R. Gilkeson, J. Marin, D. Vaniman, D. Counce, D. Rogers, R. Hull, S. McLin, and R. Warren, 2001b. "Characterization Well R-15 Completion Report," Los Alamos National Laboratory Report LA-13749, Los Alamos, New Mexico.

Longmire, P., 2001c, MCOBT-4.4. Longmire email to D. Broxton, C. Nylander, and J. McCann dated October 1, 2001.

Longmire, P. A., S. Kung, J. M. Boak, A. I. Adams, F. Caporuscio, and R. N. Gray, 1996. "Aqueous Geochemistry of Upper Los Alamos Canyon, Los Alamos, New Mexico," in *New Mexico Geological Society Guidebook*, 47th Field Conference, Jemez Mountains Region, New Mexico, pp. 473–480.

McGraw, M., and P. Longmire, 2001, Status Report for Colloid Characterization (Draft), October 8, 2001.

Rogers, D. B., and Gallaher, B. M., 1995. "The Unsaturated Hydraulic Characteristics of the Bandelier Tuff", Los Alamos National Laboratory Report LA-12968-MS, Los Alamos, New Mexico.

Spangler, R. R., 1994. "Effect of Carbonate Dissolution on Carbon-14 Groundwater Ages," unpublished paper, Los Alamos National Laboratory, Los Alamos, New Mexico.

Stone, W. J., Cole, G., and Jones, M., 1999. Preliminary Hydrogeologic Atlas for Los Alamos National Laboratory, Los Alamos National Laboratory Report LA-UR-99-4619, Los Alamos, New Mexico

Stone, W. J., Cole, G., Carey, W., and Jones, M., 2001. Los Alamos National Laboratory Expanded Hydrogeologic Atlas. Los Alamos National Laboratory Report LA-UR-01-70, Los Alamos, New Mexico

Vaniman D. T., and Chipera S. J., 1996. "Paleotransport of lanthanides and strontium recorded in calcite compositions from tuffs at Yucca Mountain, Nevada, USA," Geochim. Cosmochim. Acta 60, 4417-4433.

APPENDIX A. WATER LEVEL AND PERMEABILITY DATA

Table A-1 Most recent water level data from wells in the vicinity of LANL. Some data from R-wells are preliminary.

	Well	Year	Water level	Top of Screen	Bottom of screen	Water level (m)	Figure 1
Test Wells	CDV-R-15-5	2001	6020	4672	4665	1835	
	CDV-R-15-6	2001	6026	4388	4381	1837	Y
	CDV-R-37-2	2001	6134	4945	4923	1870	Y
	R-12	1999	5695	5699	5661	1736	Y
	R-13	2001	5827	4869	4808	1777	Y
	R-15	2000	5856	4896	4836	1785	Y
	R-19-3	2000	5888	4717	4673	1795	Y
	R-19-6	2000	5932	4205	4198	1809	
	R-19-7	2000	5903	4071	4063	1800	
	R-22-1	2000	5756	4884	4842	1755	Y
	R-22-2	2000	5751	4804	4762	1753	
	R-22-3	2000	5708	4436	4429	1740	
	R-22-4	2000	5696	4307	4311	1736	
	R-25-5	1998	6224	4928	4918	1898	Y
	R-25-6	2000	6207	4801	4791	1892	
	R-25-7	2000	6181	4575	4565	1884	
	R-25-8	2000	6157	4361	4351	1877	
	R-31-2	2000	5853	5338	5307	1784	Y
	R-31-3	2000	5852	5186	5176	1784	
	R-31-4	2000	5854	5027	5017	1785	
	R-31-5	2000	5851	4844	4834	1784	
	R-5-3	2001	5788	5111	5068	1765	Y
	R-7-3	2001	5876	4980	4939	1792	Y
	R-8	2001	5837			1780	Y
	R-9	1998	5695	5012	4947	1736	Y
	DT-10	1998	5921	4836	4512	1805	Y
	DT-5A	1996	5950	4780	4130	1814	Y
	DT-9	1998	5917	4617	4417	1804	Y
	TW-1	1998	5837	5215	5205	1780	Y
	TW-2	1996	5848	5088	5048	1783	Y
	TW-3	1997	5810	5070	5010	1771	Y
	TW-4	1996	6066	4896	4866	1849	Y
	TW-8	1997	5884	4914	4784	1794	Y
Water Supply	G-1	1997	5705	5423	3725	1739	Y
	G-1A	1997	5709	5437	4196	1741	Y
	G-2	1997	5700	5419	3740	1738	Y
	G-3	1986	5764	5323	3979	1757	Y
	G-4	1997	5863	5437	3938	1788	Y
	G-5	1994	5858	5158	4348	1786	Y
	G-6	1997	5857	5287	3857	1786	Y

Table A-1 Most recent water level data from wells in the vicinity of LANL. Some data from R-wells are preliminary.

	Well	Year	Water level	Top of Screen	Bottom of screen	Water level (m)	Figure 1
Water Supply	LA-1	1990	5537	5477	4672	1688	Y
	LA-1B	1996	5646	5320	3952	1721	Y
	LA-2	1991	5525	5420	4660	1684	Y
	LA-3	1991	5560	5455	4695	1695	Y
	LA-4	1987	5706	4952	3742	1740	Y
	LA-5	1987	5671	5231	3931	1729	Y
	LA-6	1985	5678	5258	3900	1731	Y
	O-1	1990	5723	4706	3246	1745	
	O-4	1995	5863	4748	3267	1788	
	PM-1	1997	5737	4792	3258	1749	
	PM-2	1995	5847	4843	3567	1783	
	PM-3	1997	5859	4903	3327	1786	
	PM-4	1997	5827	4567	2973	1777	
	PM-5	1997	5840	4400	2768	1780	
Buckman Wellfield	Boon Doc	1994	5620			1713	
	Buckman 1	1998	5234	4985	4152	1596	
	Buckman 2	1998	5271	4971	3871	1607	
	Buckman 3	1998	5203	4823	3903	1586	
	Buckman 4	1998	5121	4921	3671	1561	
	Buckman 5	1998	5443	5197	4375	1659	
	Buckman 6	1998	5392	5208	4008	1644	
	Buckman 7	1997	4944	4744	3544	1507	
	Buckman 8	1997	5003	4803	3603	1525	
	Permit	1998	5886			1795	
	SF-1A	1999	6792	4875	4870	2071	
	SF-1B	1999	6689	5664	5659	2039	
	SF-1C	1999	6610	5941	5936	2015	
	SF-2A	1999	5511	3661	3651	1680	
	SF-2B	1999	5040	4238	4228	1537	
	SF-2C	1999	5316	4992	4982	1621	
	SF-3A	1999	5303	5029	5019	1617	
	SF-3B	1999	5468	5319	5309	1667	
	SF-3C	1999	5464	5424	5414	1666	
	SF-4A	1999	5323	5063	5053	1623	
	SF-4B	1999	5468	5358	5348	1667	
	SF-4C	1999	5459	5419	5409	1664	
	SF-5A	1988	5366	5086	5076	1636	
	SF-5C	1999	5451	5402	5392	1662	

Table A-2 Permeability data for wells on the Pajarito Plateau, and average linear velocity estimates

Stratigraphic unit	Well	Fraction [a]	Permeability		
			ft/day	Log(m^2)	Method
Tsf	O-1	0.99	0.6	-12.7	P
	LA-6	1	1.2	-12.4	P
	LA-5	1	0.4	-12.8	P
	LA-4	1	0.8	-12.5	P
	LA-3	1	0.4	-12.8	P
	LA-2	1	0.5	-12.7	P
	LA-1B	1	1.2	-12.4	P
	G-4	0.52	1.5	-12.3	P
	G-3	0.52	0.7	-12.6	P
	G-2	0.65	1.2	-12.4	P
	G-1A	0.53	1.2	-12.4	P
	G-1	0.59	0.9	-12.5	P
Tsfuv	DT-9	0.73	16.4	-11.2	P
	O-4	0.61	4	-11.8	P
	PM-4	0.6	3.2	-11.9	P
Tpf	CDV-R-15*	1	0.6	-12.7	G
	CDV-R-15-4	1	0.2	-13.1	G
	CDV-R-15-5	1	0.2	-13.1	G
	R-19*	1	0.3	-13.0	G
	CDV-R-15-5	1	0.2	-13.1	I
Tpp	CDV-R-15-6	1	0.7	-12.6	G
	R-7	1	0.1	-13.4	G
	R-19-6	1	1.4	-12.3	G
	R-19-7	1	0.6	-12.7	G
	R-15	1	3.3	-11.9	I
	R-19-6	1	17.5	-11.2	I
	R-19-7	1	19.7	-11.1	I
	CDV-R-15-6	1	0.1	-13.4	I
	TW-8	1	3.3	-11.9	P
Tpt	R-31-4	1	5.7	-11.7	I
	R-31-5	1	23.3	-11.1	I
	TW-3	1	16	-11.2	P
	TW-2	1	32.6	-10.9	P
	TW-1	1	0.5	-12.7	P
Tb	R-31-1	1(Tb4)	1.1	-12.4	I
	R-31-3	1(Tb4)	6.6	-11.6	I
	R-9i-1	1(Tb4)	37.5	-10.9	I
	R-9i-2	1(Tb4)	0.8	-12.5	I
	PM-5	.60 (Tb2)	0.7	-12.6	P
	G-5	.79 (Tb1)	1.2	-12.4	P
	DT-10	.63 (Tb4)	14.9	-11.3	P
Tt	TW-4	1	2.5	-12.0	P

[a] fraction of screened interval occupied by given hydrostratigraphic unit
* Indicates all data within Puye

This report has been reproduced directly from the best available copy. It is available electronically on the Web (http://www.doe.gov/bridge).

Copies are available for sale to U.S. Department of Energy employees and contractors from—

Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831
(865) 576-8401

Copies are available for sale to the public from—

National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22616
(800) 553-6847

Los Alamos
NATIONAL LABORATORY

Los Alamos NM 87545