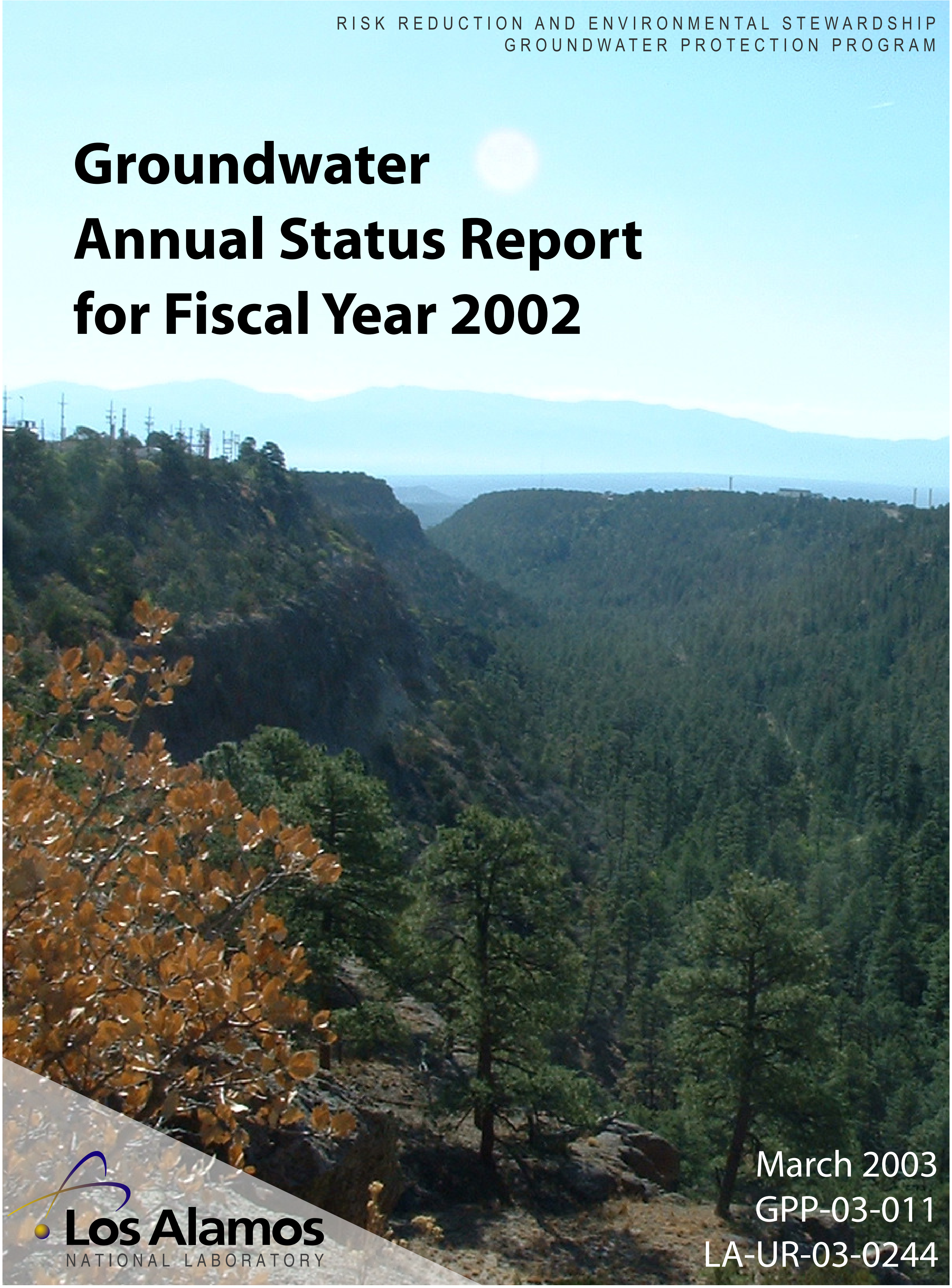
RISK REDUCTION AND ENVIRONMENTAL STEWARDSHIP
GROUNDWATER PROTECTION PROGRAM

Groundwater Annual Status Report for Fiscal Year 2002



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ABSTRACT

This is the sixth annual report intended to provide the US Department of Energy, the New Mexico Environment Department, and other interested stakeholders with a status of groundwater protection and management activities performed during fiscal year (FY) 2002. This report summarizes the data collected over the past 5 yr that have been integrated to revise the Los Alamos National Laboratory conceptual model of the hydrogeologic setting and to resolve the decisions that form the basis of the "Hydrogeologic Workplan." It also provides a projection of activities for FY2003.

In FY2002, field-based activities included well installation and characterization sampling. Six deep characterization wells were drilled, as required by the "Hydrogeologic Workplan." One characterization well, R-21, was started early in FY2003, and characterization sampling in eight of the completed wells was conducted.

Hydrologic modeling of the vadose zone has been undertaken to quantify key factors that influence the transport of contaminants and to assess uncertainties. In FY2002, a site-wide vadose zone model was constructed to predict the travel time from the ground surface to the water table of the regional aquifer. The two most important features required to estimate vadose travel times are the infiltration rate and the hydrologic conditions. The methodology and initial estimates of infiltration across the Pajarito Plateau were developed and are presented in this report. This infiltration serves as the upper flow boundary condition for the calculation of travel time. The time is computed assuming local one-dimensional (1-D) downward flow. The hydrogeologic layers used in the 1-D model are obtained from the three-dimensional geologic model of the site. Hydrologic properties are based on past laboratory measurements and data syntheses. A series of calculations were made across the plateau and the results were presented as maps of travel time. These results can be used to make preliminary assessments of the expected rate of movement of contaminants from the ground surface to the water table.

Data analysis activities regarding the regional aquifer included generation of a new water table map, which relies for the first time only on wells with short screens at or near the water table because the R-wells are sufficiently closely spaced. Historical data concerning all water supply wells on the plateau were compiled to support detailed analyses of capture zones for well fields supplying Los Alamos. These data, along with a new geologic model (FY2002), supplemented existing data used to support regional modeling applications. Further modeling accomplishments for the regional aquifer included calculations and reporting of capture zones for the Buckman well field, uncertainty analysis for simulated transport in the vicinity of Mortandad Canyon, and contaminant transport simulations.

1.0 INTRODUCTION

This is the sixth annual report intended to provide the US Department of Energy (DOE), the New Mexico Environment Department (NMED), and other interested stakeholders with a status of groundwater protection and management activities performed during fiscal year (FY) 2002. This report presents a summary of the data collected over the past 5 yr that have been integrated to revise the Los Alamos National Laboratory's (the Laboratory's) conceptual model of the hydrogeologic setting and to resolve the decisions that form the basis of the "Hydrogeologic Workplan" (LANL 1998, 59599). It also provides a projection of activities for FY03.

The current hydrogeologic characterization via the "Hydrogeologic Workplan" is based on regulatory requirements, specifically applied through Module VIII of the Laboratory's Hazardous Waste Operating Permit. The operating permit was preceded by groundwater monitoring waiver demonstrations submitted by the Laboratory in the 1980s and early 1990s. In May 1995, the NMED issued a letter to the Laboratory that indicated that there is insufficient information on the hydrogeologic setting upon which to base approval of the groundwater monitoring waiver demonstrations, and the waiver demonstrations were denied. By letter dated August 17, 1995 NMED required that a site-wide hydrogeologic characterization be completed that would satisfy both the RCRA operating permit and the HSWA module requirements (Section III. A. 1 of the HSWA portion of the RCRA permit requires that the hydrogeologic setting be characterized). It was these two regulatory compliance letters in 1995 that drove the development of the "Hydrogeologic Workplan." This document is intended as an addendum to the "Hydrogeologic Workplan" and is specifically written as a summary-level report. It relies on information incorporated by reference.

1.1 Background

This annual report results from commitments made in the Groundwater Protection Management Program Plan (GWPMPP) (LANL 1996, 70215) and the "Hydrogeologic Workplan" (LANL 1998, 59599). The Laboratory has had groundwater programs in place since 1945. The early programs focused on the need to develop a reliable water supply for the Laboratory and the community. Groundwater quality has been monitored through the environmental surveillance program using test wells, water supply wells, and springs. Since the early 1990s, there has been an increased emphasis on understanding the hydrogeologic environment to protect and manage the groundwater resource more effectively and from an updated scientific perspective.

The GWPMPP (approved by DOE in 1996) commits to submitting 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 safe manner. DOE Order 5400.1: "General Environmental Protection Program" establishes environmental protection requirements, authorities, and responsibilities for all DOE facilities (DOE 1988, 0075). 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" commits the Laboratory to prepare an annual report summarizing the activities of the previous FY and recommending activities for the current FY. 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. A critical step in developing an effective monitoring program and in managing the groundwater resource is to characterize the hydrogeologic setting beyond what has already been established by studies done over the last 50 yr.

While this annual report serves as the annual status report for both the GWPMPP and the “Hydrogeologic Workplan,” it also serves as a mechanism to update the scope of 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.

1.2 FY2002 Accomplishments Summary

This section provides a concise description of FY2002 groundwater accomplishments. The accomplishments listed below provide the sources of information for the descriptions in subsequent sections.

Field-Based Activities

- Completed six regional (R) “Hydrogeologic Workplan” wells: R-8, R-14, R-16, R-20, R-23, R-32
- Started drilling one “Hydrogeologic Workplan” well (R-21) early in FY2003
- Conducted characterization sampling at eight R-wells
- Conducted a pilot test of a new water sampling tool in R-20. The tool filters and collects a water sample in-line, without having to remove the drill string

Analysis and Interpretation Activities

- Completed capture zone analysis of the Buckman well field to evaluate potential for Laboratory impacts and presented capture-zone analysis at conferences and to interested groups
- Integrated well-construction and water-level information used for modeling into the Water Quality database (WQDB) (completed July 2002)
- Designed and constructed new numerical grid for the site-scale model, with a finer resolution to support the Groundwater Pathways Assessment Project
- Tested and evaluated alternative methodologies for coupling the basin- and site-scale groundwater flow models
- Compiled and summarized all hydrogeologic information concerning water supply wells on the Pajarito Plateau (including Guaje replacement [GR] wells)
- Analyzed the effect of horizontal anisotropy within the aquifer
- Developed canyon-focused recharge model that was integrated into the site-scale groundwater flow and contaminant transport model
- Conducted trend analyses for tritium, high-explosive (HE) compounds, and other chemicals in wells MCOBT-4.4, R-9, R-9i, R-12, R-15, R-19, R-22, and R-25
- Interpreted data for stable isotopes, metals, and major cations and anions in wells MCOBT-4.4, R-9, R-9i, R-12, R-15, R-19, and R-22 and boreholes MCOBT-4.4 and MCOBT-8.5
- Performed geochemical calculations for speciation (form of dissolved species), mineral equilibrium, and adsorption using geochemical analytical results collected from wells MCOBT-4.4, R-9, R-9i, R-12, R-15, R-19, and R-22
- Evaluated the breakdown of residual drilling fluids in wells R-9i, R-12, R-19, and R-22

Information Management

- Made available information on water levels for all regional aquifer wells at http://wqdbworld.lanl.gov
- Made available well construction data for R-wells in the Water Quality database (WQDB) at http://wqdbworld.lanl.gov
- Began working toward a comprehensive database for all groundwater data collected at the Laboratory

QA and Reports

- Published well completion reports for R-7, R-25, R-31, and CdV-R-15-3 (investigation well)
- Published geochemistry reports for R-9, R-9i, R-12, R-15, R-19, R-22, and R-7 (released in FY2003)
- Completed numerous QA assessments of field program

Project Management

- Completed a draft Groundwater Protection FY2003 Program Plan and Quality Assurance Project Management Plan
- Supported Laboratory efforts to conclude cost issues for R-25 and R-8
- Held bi-weekly Groundwater Investigation Team (GIT) meetings, three quarterly meetings, and an annual meeting
- Produced the groundwater annual status report for FY2001
- Developed two action plans in response to the External Advisory Group (EAG) recommendations

1.2.1 Field-Based Activities

In FY2002, field-based activities included well installation and characterization sampling. Six deep characterization wells were drilled, as required by the “Hydrogeologic Workplan” (LANL 1998, 59599). One characterization well, R-21, was started early in FY2003, and characterization was conducted sampling in eight of the completed wells.

1.2.1.1 Characterization Well Installation

The FY2002 characterization wells were drilled using air rotary in the vadose zone and rotary with stiff foam or bentonite mud in the saturated zone. Casing-advance with fluid-assist methods, used in drilling previous characterization wells, was employed only when swelling clays were encountered in the boreholes. Geologic core was collected in the upper vadose zone in each well, and geologic cuttings were collected at defined intervals during drilling operations and described to record the stratigraphy encountered. Geophysical logging was conducted in each well to enhance the understanding of the stratigraphy and rock characteristics. The six completed characterization wells include R-8 (Los Alamos Canyon), R-20, R-23, and R-32 (Pajarito Canyon), R-16 near the Rio Grande in White Rock, and R-14 (Mortandad Canyon). R-21 in Cañada del Buey near Technical Area (TA)-54 was started early in FY2003.

1.2.1.1.1 Well R-8

R-8 is located in Los Alamos Canyon east of the confluence of Los Alamos Canyon and DP Canyon. The primary purpose of this well is to determine regional aquifer water quality downgradient of releases in Los Alamos and DP Canyons. It also serves as a sentry well for water supply well Otowi (O)-4. Significant difficulties were encountered in drilling R-8, and the original borehole was abandoned. A second borehole, R-8a, was drilled 62 ft due east of R-8. All geologic and water samples were collected in R-8; no samples were collected in R-8a. The well was constructed in the borehole of R-8a. Drilling of R-8a began on January 9, 2002, and was completed on January 27, 2002. The samples and logs for R-8 are shown on Figure 1.2-1. The stratigraphy encountered in the borehole was 29 ft of alluvium at the surface overlying 64 ft of Bandelier Tuff (44 ft of Otowi Member and 20 ft of Guaje Pumice). The remainder of the borehole to total depth (TD) of 1022 ft is in the Puye Formation, interrupted by one section of Cerros del Rio basalt between 180 and 362 ft. The R-8 borehole was cored to a depth of 261 ft, into the Cerros del Rio basalt; no perched saturated zones were encountered in R-8 or R-8a. The static water level in the regional aquifer is 709 ft below ground surface (bgs).

Well construction and development were completed on February 14, 2002. Westbay sampling equipment was installed between February 21 and February 24, 2002. The R-8a well is completed with two screened intervals in the regional aquifer: one straddling the water table at a depth of 705–755 ft and one at a depth of 821 to 828 ft. One water sample from the R-8 borehole was collected at a depth of 822 ft. Tritium (with an activity of 15 pCi/L) was detected in the sample. The well construction, stratigraphic, and hydrologic information is summarized in Figure 1.2-1. The completion report for this well is expected to be complete by March 1, 2003.

1.2.1.1.2 Well R-14

Well R-14 is located within the Mortandad Canyon watershed in Ten Site Canyon, east of the former radioactive liquid waste and septic treatment facilities at TA-35. Drilling started on June 2, 2002, and was completed on July 2, 2002. The samples and logs for R-14 are shown in Figure 1.2-2. The stratigraphy encountered included a thick section of Bandelier Tuff (534 ft); both the Tshirege and Otowi Members are present. The Bandelier Tuff is underlain by Puye fanglomerate (534–620 ft) and then by dacitic lava flows (not basalt) from 620 to 768 ft. The underlying Puye Formation consists of fanglomerates from 768 to 1210 ft. Finally, the bottom of the borehole contains pumiceous sediments, provisionally assigned to the Puye Formation, from 1210 to1330 ft TD. The regional aquifer water level is at 1182 ft in the Puye Formation.

Well construction and development were conducted, and Westbay sampling equipment was installed to complete the well with two screened intervals in the regional aquifer: one near the water table at a depth of 1200 ft and one in a productive zone at a depth of 1286 ft. The well construction, stratigraphic, and hydrologic information is summarized in Figure 1.2-2. The completion report for this well is expected to be complete in March 2003.

Construction, Stratigraphic, and Hydrologic Information for Hydrogeologic Workplan Characterization Well R-8/8a Rev. B (04/15/02)

Location: TA-53, Los Alamos Canyon, near confluence with DP canyon.

Survey coordinates (brass marker in NW corner of R-8a cement pad):
x: 1641139 E y: 1772554 N (NAD 83)
z: 6544.7 ft asl (NGVD 29)
R-8 is 62 ft due east from R-8a at survey coordinates (center of cement plug):
x: 1641195 E y: 1772533 N (NAD 83)
z: 6542.9 ft asl (NGVD 29)

Drilling: air rotary core w/ wireline retrieval and fluid-assist air rotary reverse circulation with casing advance.
R-8 Start date: 09/25/01.
R-8 End date: 12/11/01.
R-8a Start date: 01/09/02.
R-8a End date: 01/27/02.

Borehole R-8 drilled to 1022 ft. bgs. (T.D.).
Borehole R-8a drilled to 880 ft. bgs. (T.D.).

Data collection:
Hydrologic properties:
Field Hydraulic Testing: Falling head test on R-8a screen #2.
Cores/cuttings submitted for geochemical and contaminant characterization: 156/6
Groundwater samples submitted for geochem and contaminant characterization: 1 (R-8)
Geologic properties:
Mineralogy, petrography, and chemistry: 11
Borehole logs from R-8:
Lithologic: 0-1022 ft.
Video (LANL tool): 0-850 ft. (well casing - R-8A)
Natural gamma (LANL tool): 0-30 ft. and 0-761 ft. (cased); 30-261 ft. and 761-768 ft. bgs. (open hole)
Induction (LANL tool): 0-30 ft. (cased); 30-261 ft. (open hole)
Schlumberger Logs: 0-761 ft. (cased); 761-764 ft. (open hole): Litho density, Spectral Gamma, Elemental Capture, Thermal/Epithermal Neutron, Natural Gamma.

Contaminants Detected in R-8 Water Sample:
Tritium at 15 pCi/l.

Well construction:
Drilling Completed (R-8a): 01/27/02.
Contract Geophysics (R-8): 11/13/01.
Well Constructed (R-8a): 01/28/02 - 02/01/02.
Well Developed (R-8a): 02/04/02 - 02/14/02.
Westbay Installed (R-8a): 02/21/02 - 02/24/02

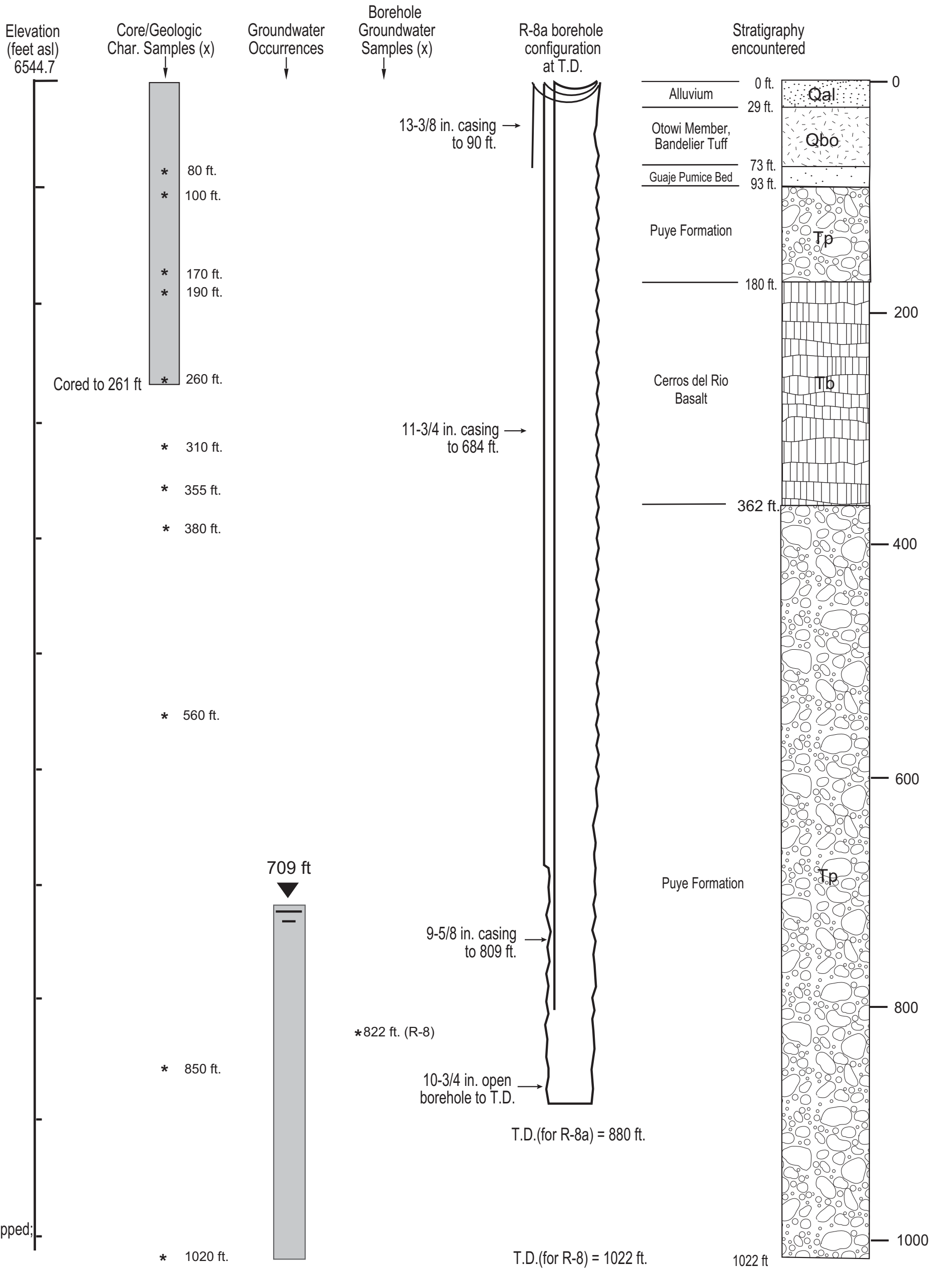
Casing: 4.5-in. I.D./5.0-in. O.D. stainless steel with external couplings.

Number of Screens: 2
4.5-in. I.D./5.56-in. O.D. pipe based, s.s. wire-wrapped; 0.010-in slotted.

Screen (perforated pipe interval):
Screen #1 - 705.3-755.7 ft. bgs.
Screen #2 - 821.3-828.0 ft. bgs.

Well development consisted of wire brushing, bailing, surging, swabbing, and pumping.

Groundwater occurrence was determined in R-8 by recognition of first water produced while drilling, by borehole geophysics, and by borehole video. Static water levels were determined after the R-8 borehole was rested.



Geologic contacts are from R-8 and were determined by examination of cuttings and interpretation of geophysical logs. Contacts may be refined by analysis of geologic samples by petrography and rock chemistry. No samples collected from R-8a borehole.

Figure 1.2-1. Regional aquifer well R-8 completion

Construction, Stratigraphic, and Hydrologic Information for Hydrogeologic Workplan Characterization Well R-14 Rev. 0 (1-10-03).

Location: In Ten Site Canyon, east of the former radioactive liquid waste and septic treatment facilities at TA-35 .

Survey coordinates (brass marker in NW corner of R-14 cement pad):
x: 1629855 E y: 1768953 N (NAD 83)
z: 7062.1 ft asl (NGVD 29)

Drilling: air rotary core w/ wireline retrieval, conventional mud drilling, casing advance.
R-14 Start date: 06/02/02.
R-14 End date: 07/02/02.

Borehole R-14 drilled to 1327 ft. bgs. (T.D.).

Data collection:
Hydrologic properties: Field hydraulic test:
Constant Rate Injection Test on screen #2
Cores/cuttings submitted for geochemical and contaminant characterization: (24)
Groundwater samples submitted for geochem and contaminant characterization: (2)
Geologic properties: (11)
Mineralogy, petrography, and chemistry.

Borehole logs from R-14:
Lithologic: 0-1327 ft.
Video (LANL tool): 0-923 ft. and 0-975 ft.
Natural gamma (LANL tool): 0-1068 ft. and 1046-1325 ft. bgs.
Schlumberger Logs: 0-12.2 ft (cased), 12.2-1068 ft (open hole): Litho density, Spectral Gamma, Elemental Capture, Thermal/Epithermal Neutron, Combinable Magnetic Resonance, and Natural Gamma.

Contaminants Detected in R-14 Water Samples: none

Well construction:
Drilling Completed: 07/02/02
Contract Geophysics: 06/19/02 - 06/20/02
Well Constructed : 07/04/02 - 07/11/02
Well Developed : 07/19/02 - 11/18/02
Westbay Installed : 11/19/02 - 11/25/02

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

Number of Screens: 2
4.5-in I.D. pipe based, s.s. wire-wrapped with 0.010-in slots.

Screen (perforated pipe interval):
Screen #1 - 1200.6-1233.2 ft. bgs.
Screen #2 - 1286.5-1293.1 ft. bgs.

Well development consisted of wire brushing, bailing, chemical treatments, surging, and pumping.

Groundwater occurrence was determined for R-14 by recognition of first water produced while drilling, by borehole geophysics, and by borehole video. Static water levels were determined after the R-14 borehole was rested.

Groundwater samples collected from packed off screen intervals after well development.

Geologic contacts for R-14 were determined by examination of cuttings and interpretation of borehole video and geophysical logs. Contacts and stratigraphy may be refined by petrographic, geochemical, or mineralogic analysis of geologic samples.

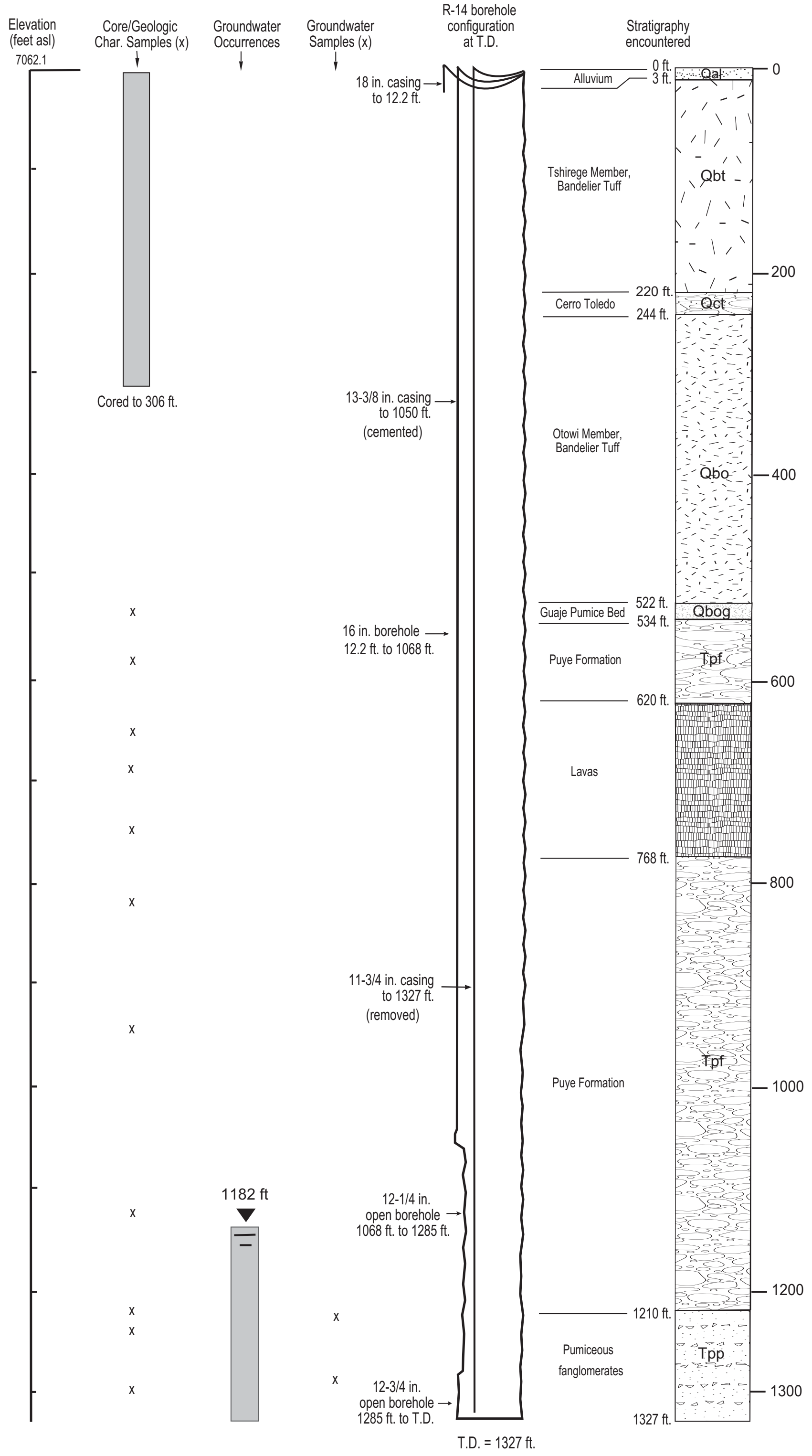


Figure 1.2-2. Regional aquifer well R-14 completion

1.2.1.1.3 Well R-16

Well R-16 is located above the Rio Grande near Overlook Park in White Rock. Drilling started on August 16, 2002, and was completed on September 13, 2002. The samples and logs for R-16 are shown in Figure 1.2-3. The stratigraphy encountered in R-16 was first the Bandelier Tuff, which was thicker than anticipated, consisting of about 79 ft of Otowi Member. Second, the Cerros del Rio basalts flows were encountered; they were thinner than expected, separated by interbedded materials including clay-rich lakebed sediments that caused drilling problems. The sediments were fossiliferous, similar to lakebed deposits exposed at several locations along the Rio Grande. Many of these lakebed sediments were deposited when Cerros del Rio basalts were erupted and dammed the river, creating lakes. Below the Cerros del Rio basalts was a sequence of alternating Totavi sediments and Puye fanglomerates from 377 to 728 ft. The borehole entered the Santa Fe Group at 728 ft and remained in Santa Fe Group to 1287 ft TD.

Based on the three dimensional (3-D) geologic model, the static water level for the regional aquifer was anticipated to be 783 ft. When the borehole reached within 100 ft of the anticipated depth of the regional aquifer, the driller had been instructed to stop if any influx of water was noted, signaled by sudden dispersal (liquification) of the foam. The first indication of water influx was at 867 ft; drilling stopped and the water level was measured. The water level rose to 621 ft, much higher than expected. There were clay-rich zones in the Santa Fe Group, so one possible explanation for the rise in water level is that the clays create confining zones. Similar conditions were encountered in Los Alamos Canyon (R-9). Well construction, development, and installation of Westbay sampling equipment were completed to provide a well with three screened intervals in the regional aquifer:

- screen 1: 863–871 ft,
- screen 2: 1015–1022 ft,
- screen 3: 1237–1245 ft.

The well construction, stratigraphic, and hydrologic information is summarized in Figure 1.2-3. The completion report for this well is expected to be complete in March 2003.

1.2.1.1.4 Well R-20

R-20 is located in Pajarito Canyon, east of TA-18 on the south side of Pajarito Road. Drilling started on August 4, 2002, and was completed on September 19, 2002. The samples and logs for R-20 are shown in Figure 1.2-4. The stratigraphy encountered in R-20 included a thick section of alluvium (0–68 ft) that was included a zone of saturation. The alluvium and alluvial saturation were cased off and not characterized. The alluvial system maybe studied in a future program focused on alluvium. Underlying the alluvium is Bandelier Tuff (68–392 ft), with both the Tshirege and Otowi Members present. The Cerros del Rio basalt occurs in two main thick sequences separated by a cinder deposit, all underlain by a zone of scoria. The full Cerros del Rio sequence extends from 392 to 932 ft. The Puye Formation is present from 932 to 1127 ft, above pumiceous deposits (1127–1240 ft) that maybe assigned to the Puye Formation pending further study. At the bottom of the borehole, the Santa Fe Group may be present from 1242 to 1365 ft (borehole TD).

No perched water was encountered in R-20. The static water level in the regional aquifer is at 837 ft. The well was constructed with three screened intervals; deeper screens were emplaced to coincide in part with screened interval in Pajarito Mesa (PM)-2:

- screen 1: 905–912 ft,
- screen 2: 1147–1155 ft, and
- screen 3: 1329–1337 ft.

Construction, Stratigraphic, and Hydrologic Information for Hydrogeologic Workplan Characterization Well R-16 Rev. 0 (1-14-03).

Location: West of the waste treatment ponds, north of Overlook Road in White Rock , N.M.

Survey coordinates (brass marker in NW corner of R-16 cement pad):
x: 1659284 E y: 1756711 N (NAD 83)
z: 6256.9 ft asl (NGVD 29)

Drilling: Conventional mud drilling, casing advance.
R-16 Start date: 08/16/02.
R-16 End date: 08/29/02.

Borehole R-16 drilled to 1287 ft. bgs. (T.D.).

Data collection:
- Hydrologic properties: Field hydraulic test:
  Constant Rate Injection Test on screen #2, screen #3, and screen #4
- Cores/cuttings submitted for geochemical and contaminant characterization: (0)
- Groundwater samples submitted for geochem and contaminant characterization: (3)
- Geologic properties: (16)
  Mineralogy, petrography, and chemistry
- Borehole logs from R-16:
  Lithologic: 0-867 ft. and 1047 ft.-1287 ft.
  Natural gamma (LANL tool): 0-729 ft. (cased), 729-1287 ft. (open hole).
  Schlumberger Logs: 0-729 ft. (cased), 729-1287 ft. (open hole): Array Induction, Combinable Magnetic Resonance, Micro Imager, Sonic, Caliper, Litho density, Spectral Gamma, Elemental Capture, Thermal/Epithermal Neutron, Natural Gamma.

Contaminants Detected in R-16 Water Samples: none.

Well construction:
- Drilling Completed: 08/29/02
- Contract Geophysics: 08/30/02 - 08/31/02
- Well Constructed : 08/31/02 - 09/07/02
- Well Developed : 09/14/02 - 12/04/02
- Westbay Installed : 12/6/02 - 12/10/02

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

Number of Screens: 4
4.5-in I.D. pipe based, s.s. wire-wrapped with 0.010-in slots.

Screen (perforated pipe interval):
- Screen #1 - 641.0 - 648.6 ft. bgs.
  (isolated behind stuck casing)
- Screen #2 - 863.4 - 870.9 ft. bgs.
- Screen #3 - 1014.8 - 1022.4 ft. bgs.
- Screen #4 - 1237.0 - 1244.6 ft. bgs.

Well development consisted of wire brushing, bailing, chemical treatments, surging, simultaneous jetting and pumping, and pumping.

Groundwater occurrence was determined for R-16 by recognition of first water produced while drilling, by borehole geophysics, and by borehole video. Static water levels were determined after the R-16 borehole was rested.

Groundwater samples collected from packed off screen intervals after well development.

Geologic contacts for R-16 were determined by examination of cuttings and interpretation of geophysical logs. Contacts may be refined by petrographic, geochemical, or mineralogic analysis of geologic samples.

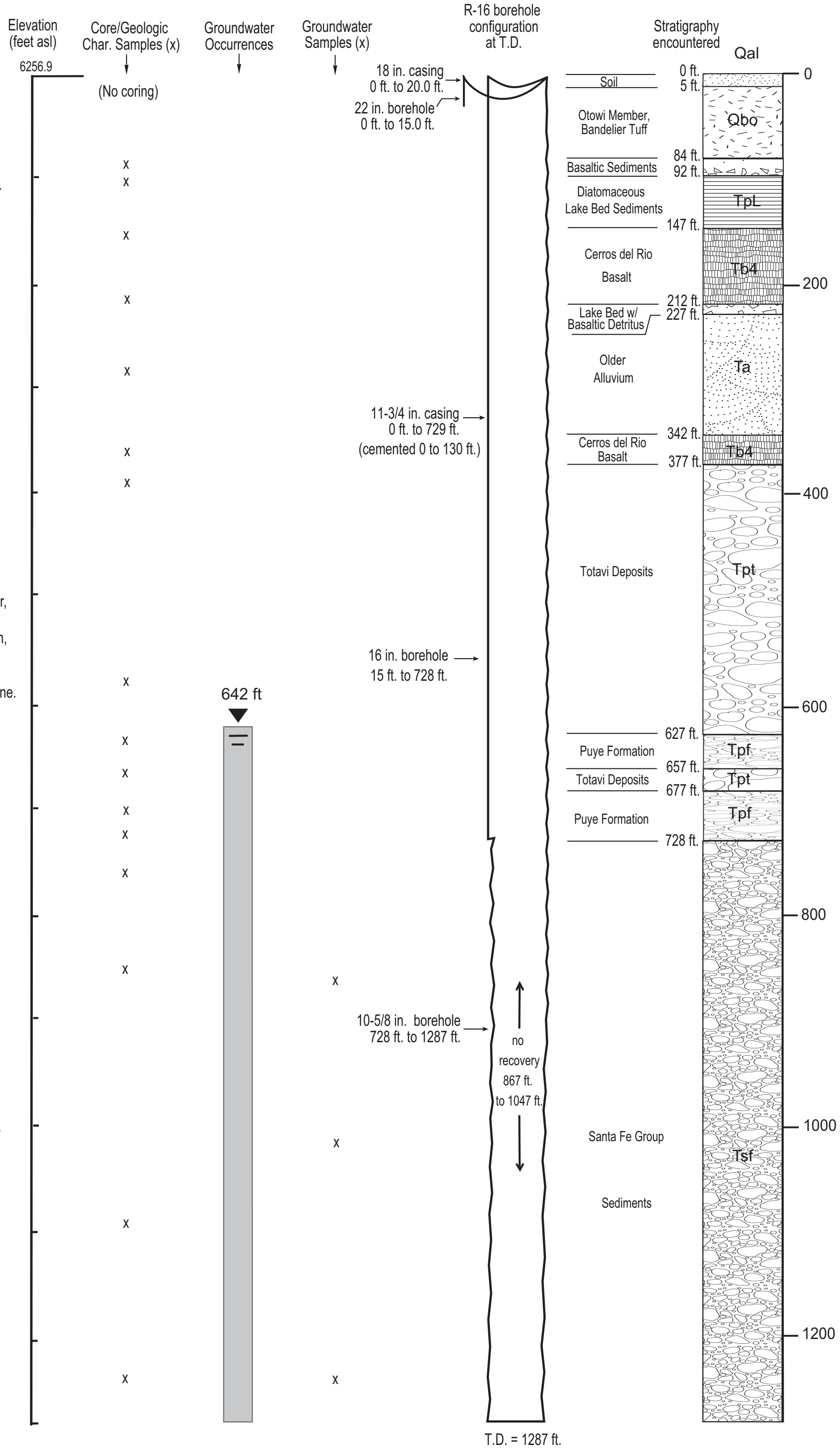


Figure 1.2-3. Regional aquifer well R-16 completion

Construction, Stratigraphic, and Hydrologic Information for Hydrogeologic Workplan Characterization Well R-20 Rev. 0 (1-16-03).

Location: East of TA-18 on the south side of Pajarito Rd., east of the stream channel.

Survey coordinates (brass marker in NW corner of R-20 cement pad): x: 1637835 E y: 1759695 N (NAD 83) z: 6694.3 ft asl (NGVD 29)

Drilling: Conventional mud drilling, casing advance; air rotary core w/ wireline retrival.
R-20 Start date: 08/15/02, end date: 09/06/02.
Coring start date: 10/16/02, end date: 10/19/02

Borehole R-20 drilled to 1365 ft. bgs. (T.D.).

Data collection:
- Hydrologic properties: Field hydraulic test:
  - Constant Rate Injection Test on screen #1, screen #2, and screen #3
- Cores/cuttings submitted for geochemical and contaminant characterization: (0)
- Groundwater samples submitted for geochemical and contaminant characterization: (3)
- Geologic properties: (12)
  - Mineralogy, petrography, and chemistry
- Borehole logs from R-20:
  - Lithologic: 0-490 ft. and 785 ft.-1365 ft.
  - Borehole Video (LANL tool): 82-785 ft. (open hole).
  - Natural gamma + Induction (LANL tool): 0-80.2 ft. (cased), 80.2 ft.-785 ft. (cased).
  - Schlumberger Logs: 0-80.2 ft. (cased), 80.2-785 ft. (open hole): Array Induction, Litho Density, Natural Gamma, Thermal/Epithermal Neutron,Caliper, Combinable Magnetic Resonance, and Elemental Capture Sonde.
  - Natural Gamma (LANL tool): 0-780 ft. (cased), 780-1365 ft. (open hole).
  - Schlumberger Logs: 0-780 ft. (cased), 780-1365 ft. (open hole): Thermal/Epithermal Neutron, Litho Density, Micro Imager, Array Induction, and Natural Gamma.

Contaminants Detected in R-20 Water Samples: none

Well construction:
- Drilling Completed: 09/06/02
- Contract Geophysics: 08/26/02; 09/06/02
- Well Constructed : 09/07/02-09/15/02
- Well Developed : 09/15/02-12/22/02
- Westbay Installed : 01/08/03-01/18/03

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 with 0.010-in slots.

Screen (perforated pipe interval):
- Screen #1 - 904.6 - 912.2 ft. bgs.
- Screen #2 - 1147.1 - 1154.7 ft. bgs.
- Screen #3 - 1328.8 - 1336.5 ft. bgs.

Well development consisted of wire brushing, bailing, chemical treatment, surging, and pumping.

Groundwater occurrence was determined for R-20 by recognition of first water produced while drilling, by borehole geophysics, and by borehole video. Static water levels were determined after the R-20 borehole was rested.

Groundwater samples collected from packed off screen intervals after well development.

Geologic contacts for R-20 were determined by examination of cuttings and interpretation of geophysical logs. Contacts may be refined by petrographic, geochemical, or mineralogic analysis of geologic samples.

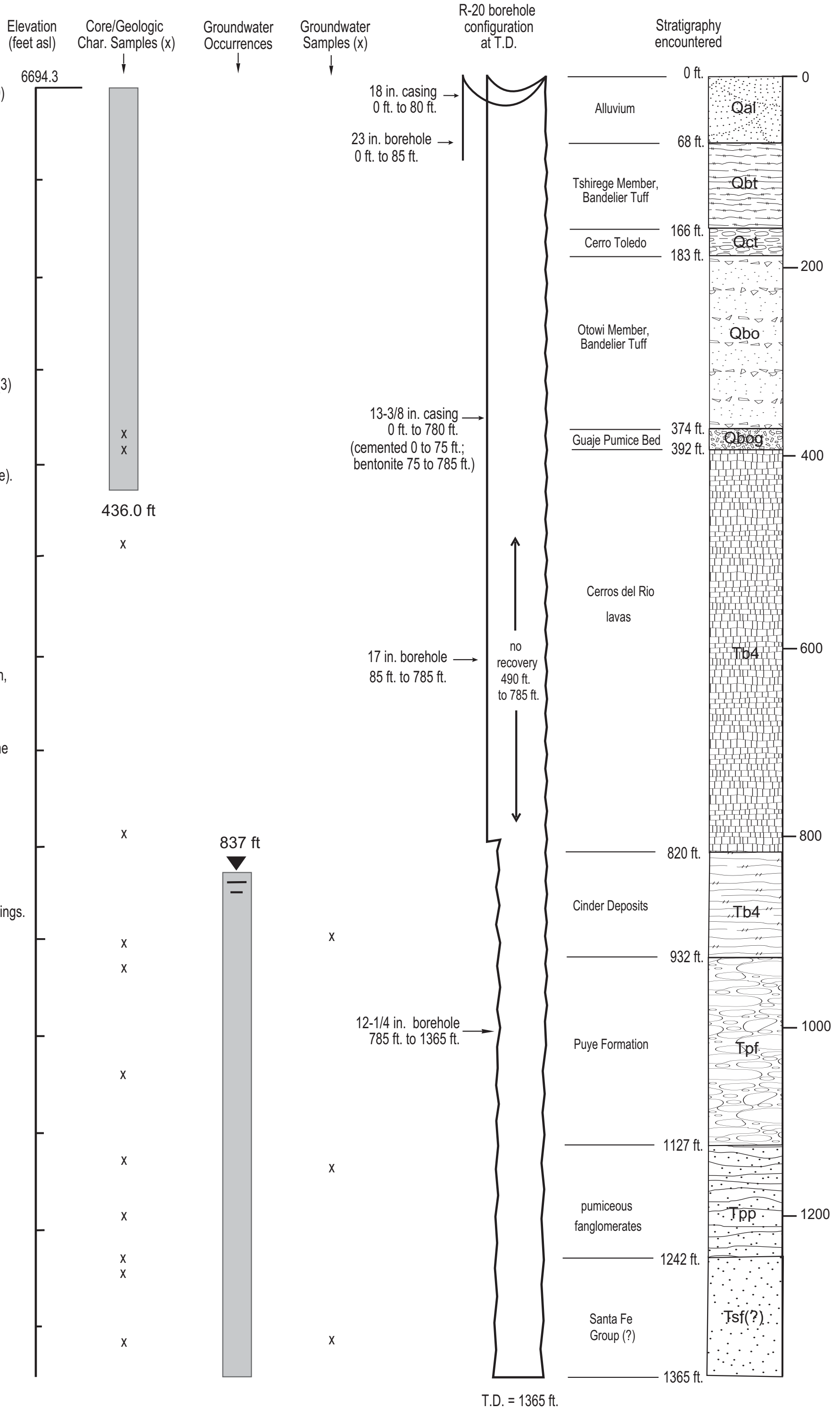


Figure 1.2-4. Regional aquifer well R-20 completion

The well construction, stratigraphic, and hydrologic information is summarized in Figure 1.2-4. The completion report for this well is expected to be complete in March 2003.

A tool for sampling water in the borehole was pilot tested in R-20. The EDM formation sampling and hydraulic testing (FAST) tool was developed to solve the problem of delineating water quality zones at well sites in order to provide good quality water supplies in rural villages. The FAST tool also can be adapted to perform aquifer-performance tests or drill-stem tests at selected depths. Patents (for the United States) have been filed on the new and improved FAST tool and worldwide patents are being filed. The complete report on the pilot test can be found at http://www.waterbank.com/Investment/FAST%20Tool.htm.

Two German drillers experienced in handling and operating the FAST tool were brought in to supervise the use of the tool. The installation and the operation of the FAST tool were straightforward at the R-20 monitoring well site. The FAST tool was added to the drill string directly above the bit. The FAST tool was deployed at 784 ft and drilling was begun in basalt using foam. This was the first time the tool had been used in rugged drilling of fractured basalt and it maintained its integrity. It also was the first time the tool had been used with foam. The Puye Formation drilled without difficulty to 913 ft with the FAST tool. With the bit at 933 ft, drilling was switched from foam to drilling fluid. An 0.75-in. airline was introduced into the drill string through a specially constructed head which allowed air-lifted water to exit into the mud pit along a return-flow channel dug into the soil. The fluid level in the drill string was about 230 ft when air-lifting began. The airline was lowered gradually to a depth of about 350 ft in stages as fluid was blown from the hole. The production rate was established at about 1 gal./ min at about 2100 hr on September 2, 2002. The discharge was stabilized to the satisfaction of Josef Grotendorst, who has used the FAST tool elsewhere for 10 yr. The test was blind because fluid levels behind the casing could not be measured.

Mechanically, the tool performed perfectly. When it was disassembled at the drill site it was clean internally and internal valves were free and functional. The reason for the failure to obtain a sample is not completely clear. The regional potentiometric surface was at 873 ft, based on later water-level measurements. The final pumping level in the drill string was probably about 380 ft. It was expected based on conventional science and Bernoulli's equation; if the airline had been below the expected regional potentiometric surface, water may have been produced if the upper Puye Formation had favorable transmissivity.

1.2.1.1.5 Well R-23

Well R-23 was drilled in Pajarito Canyon, just west of the State Highway 4/Pajarito Road intersection, on the south side of Pajarito Road. Drilling started on August 17, 2002, and was completed on October 3, 2002. The samples and logs for R-23 are shown in Figure 1.2-5. The stratigraphy encountered in R-23 was a thin section of saturated alluvium (0–10 ft); however the alluvium and alluvial saturation were cased off and not characterized. The alluvial system maybe studied in a future program focused on alluvium. The alluvium was overlying the Bandelier Tuff to a depth of 36 ft, consisting of 20 ft of Otowi Member ash flows and 6 ft of Guaje Pumice at the base. Underlying the Bandelier Tuff were Cerros del Rio lavas intercalated with sediments that included gravel zones, zones of alternating sands and clay beds (36–821 ft). This section of Cerros del Rio basalt was thinner than expected based on data from R-22. Below the basalts were sands (possibly the Santa Fe Group) from 821 ft to 926 ft TD. Contrary to expectation, no Puye Formation was encountered in R-23.

Construction, Stratigraphic, and Hydrologic Information for Hydrogeologic Workplan Characterization Well R-23 Rev. 0 (1-16-03).

Location: In Pajarito Canyon, just west of the N.M. 4 and Pajarito Road intersection; on the south side of Pajarito Road.

Survey coordinates (brass marker in NW corner of R-23 cement pad):
x: 1647914 E y: 1755165 N (NAD 83)
z: 6527.8 ft asl (NGVD 29)

Drilling: air rotary drilling, casing advance.
R-23 Start date: 8/17/02
R-23 End date: 9/27/02

Borehole R-23 drilled to 935.0 ft. bgs. (T.D.).

Data collection:
Hydrologic properties: Field hydraulic test:
Pump test
Cores/cuttings submitted for geochemical and contaminant characterization: (0)
Groundwater samples submitted for geochem and contaminant characterization: (1)
Geologic properties: (14)
Mineralogy, petrography, and chemistry
Borehole logs from R-23:
Lithologic: 0-935.0 ft.
Video (LANL tool): 0-599 ft. (cased) and 599-826.6 ft. (open hole).
Natural gamma (LANL tool): 0-599 ft. (cased) and 599-840 ft. (open hole).
Schlumberger Logs: 0-599 ft. (cased) and 599-828 ft. (open hole): Litho density, Thermal/Epithermal Neutron, Array Induction, Natural Gamma, Elemental Capture, and Combinable Magnetic Resonance.

Contaminants Detected in R-23 Water Sample: none

Well construction:
Drilling Completed: 09/27/02.
Contract Geophysics: 09/23-24/02.
Well Constructed : 09/27/02-10/02/02.
Well Developed : 10/08/02-pending
Dedicated Pump: 01/06/03-01/08/03

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

Number of Screens: 1
4.5-in I.D. pipe based, s.s. wire-wrapped with 0.010-in slots.

Screen (perforated pipe interval):
Screen #1 - 816.0 - 873.2 ft. bgs.

Well development consisted of wire brushing, bailing, surging, and pumping.

Groundwater occurrence was determined for R-23 by recognition of first water produced while drilling, by borehole geophysics, and by borehole video. Static water levels were determined after the R-23 borehole was rested.

Geologic contacts for R-23 were determined by examination of cuttings and interpretation of geophysical logs. Contacts may be refined by petrologic, geochemical, or mineralogic analysis of geologic samples.

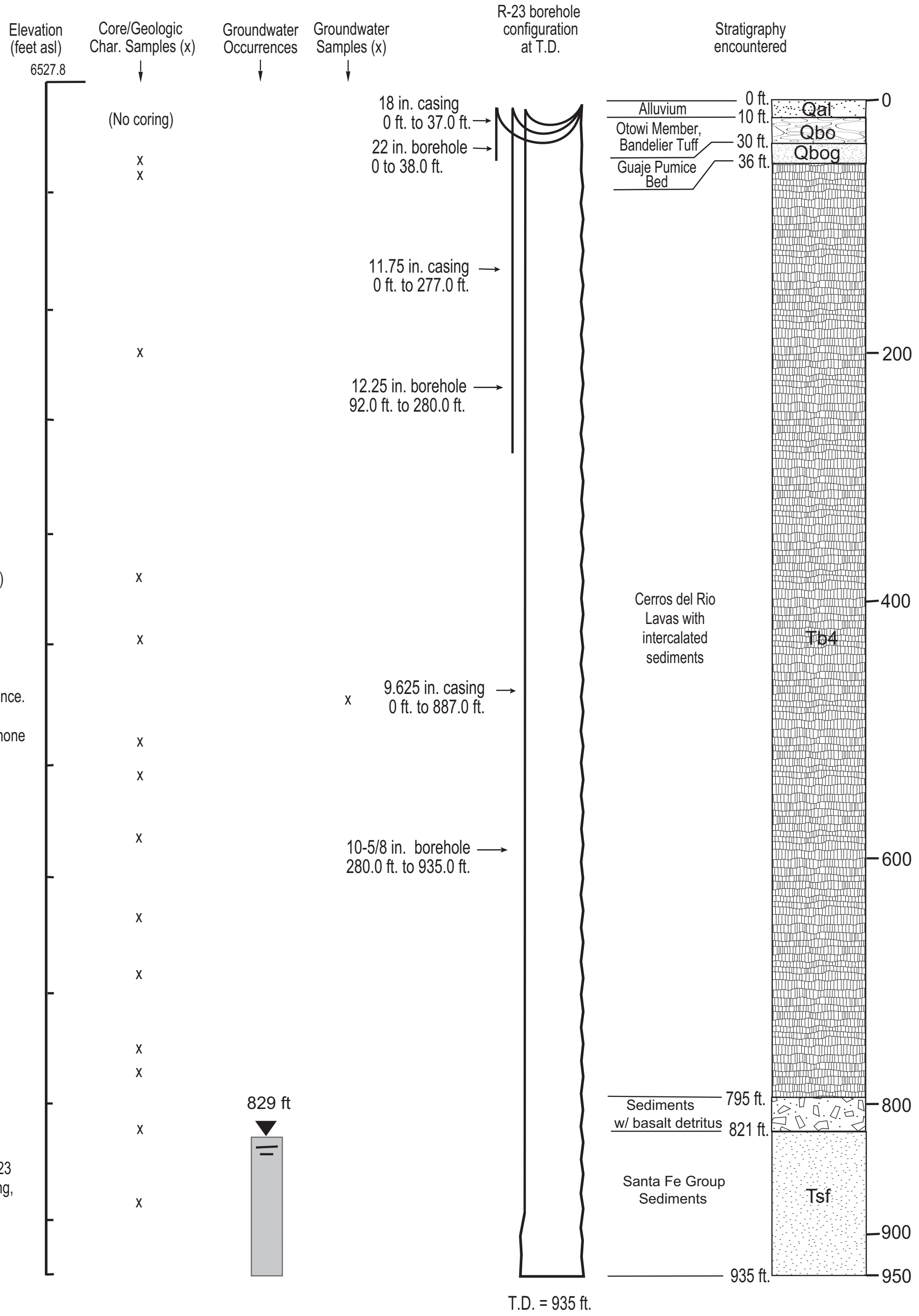


Figure 1.2-5. Regional aquifer well R-23 completion

The regional water table in R-23 was encountered at 829 ft, higher than expected (892 ft). Based on geophysical logging, perched water may be present. The well was constructed with one screened interval, from 816 to 873 ft, at the top of the regional aquifer water table. The well construction, stratigraphic, and hydrologic information is summarized in Figure 1.2-5. The completion report for this well is expected to be complete in March 2003.

1.2.1.1.6 Well R-32

Well R-32 is located in Pajarito Canyon, south of TA-54, on the north side of Pajarito Road. Drilling started on July 13, 2002, and was completed on August 7, 2002. The samples and logs for R-32 are shown in Figure 1.2-6. The stratigraphy encountered in R-32 was a thick section of saturated alluvium (0–47 ft) underlain by Bandelier Tuff (47–287 ft). The Otowi and Tshirege Members were present, separated by a 36-ft thickness of Cerro Toledo. The base of the Bandelier Tuff was marked by a 10-ft section of Guaje Pumice. The Cerros del Rio basalts were present beneath the Bandelier Tuff; they consist of basalt flows separated by rubble zones and zones of mixed scoria and sediments extending from 287 to 923 ft. A thin layer (8 ft) of Rio Grande deposits (Totavi Lentil) was encountered within the Cerros del Rio basalts, near the bottom of the borehole. No cuttings were recovered below the Cerros del Rio basalts, but drilling conditions and borehole logs indicate that the Puye Formation underlies the Cerros del Rio lavas from 923 ft to 1008 ft (borehole TD).

The regional water table in R-32 originally was encountered at 865 ft, the depth predicted by the 3-D geologic model. However, the water level rose to 715 ft before settling at 784 ft. The well was constructed with three screened intervals:

- screen 1: 867–874 ft,
- screen 2: 930–933 ft, and
- screen 3: 970–977 ft.

Well construction, stratigraphic, and hydrologic information is summarized in Figure 1.2-6. The completion report for this well is expected to be complete in March 2003.

1.2.1.2 Characterization Sampling

Characterization sampling consists of collecting four water samples from each screen in a well, generally on a quarterly basis. The samples are submitted for chemical analysis. After four characterization samples are analyzed, a geochemical report is prepared to present the data and provide evaluations and interpretations of the data. The regional well sampling status at the end of FY2002 was as follows:

- R-25, R-15, R-9, R-9i, R-12, R-31, R-19, R-22, R-7: four characterization sampling events have been completed and geochemical reports have been completed or are scheduled. These wells will be transferred to the RRES Division, Water Quality Group (RRES-WQH), which is responsible for custodial care of the wells and maintaining the monitoring network.
- R-5: The first characterization-sampling event has been completed.

Construction, Stratigraphic, and Hydrologic Information for Hydrogeologic Workplan Characterization Well R-32 Rev. 0 (1-13-03).

Location: In Pajarito Canyon, south of TA-54, along the north side of Pajarito Rd.

Survey coordinates (brass marker in NW corner of R-32 cement pad):
x: 1640798 E y: 1757730 N (NAD 83)
z: 6637.6 ft asl (NGVD 29)

Drilling: air rotary core w/ wireline retrieval, conventional mud drilling.
R-32 Start date: 07/13/02.
R-32 End date: 08/7/02.

Borehole R-32 drilled to 1008 ft. bgs. (T.D.).

Data collection:
Hydrologic properties: Field hydraulic test:
Constant Rate Injection Test on screen #1 and screen #3
Cores/cuttings submitted for geochemical and contaminant characterization: (13)
Groundwater samples submitted for geochem and contaminant characterization: (3)
Geologic properties: (7)
Mineralogy, petrography, and chemistry.
Borehole logs from R-32:
Lithologic: 0-915.5 ft.
Caliper (LANL): 0-1008 ft.
Video (LANL tool): 0-720 ft.
Natural gamma + Induction (LANL tool): 0-808 ft. and 0-1008 ft.
Schlumberger Logs: 0-54.5 ft. (cased), 54.5-808 ft. (open hole): Epithermal Neutron, Litho density, Induction, Combinable Magnetic Resonance, Elemental Capture, Spectral Gamma.

Contaminants Detected in R-32 Water Samples: none

Well construction:
Drilling Completed: 08/07/02
Contract Geophysics: 07/31/02
Well Constructed : 08/09/02 - 08/12/02
Well Developed : 8/18/02 - 11/10/02
Westbay Installed : 11/11/02 - 11/17/02

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 with 0.010-in slots.

Screen (perforated pipe interval):
Screen #1 - 867.5 - 875.2 ft. bgs.
Screen #2 - 931.8 - 934.9 ft. bgs.
Screen #3 - 972.9 - 980.6 ft. bgs.

Well development consisted of wire brushing, bailing, chemical treatments, surging, and pumping.

Groundwater occurrence was determined for R-32 by recognition of first water produced while drilling, by borehole geophysics, and by borehole video. Static water levels were determined after the R-32 borehole was rested.

Groundwater samples collected from packed off screen intervals after well development.

Geologic contacts for R-32 were determined by examination of cuttings and interpretation of geophysical logs. Contacts may be refined by petrographic, geochemical, or mineralogic analysis of geologic samples.

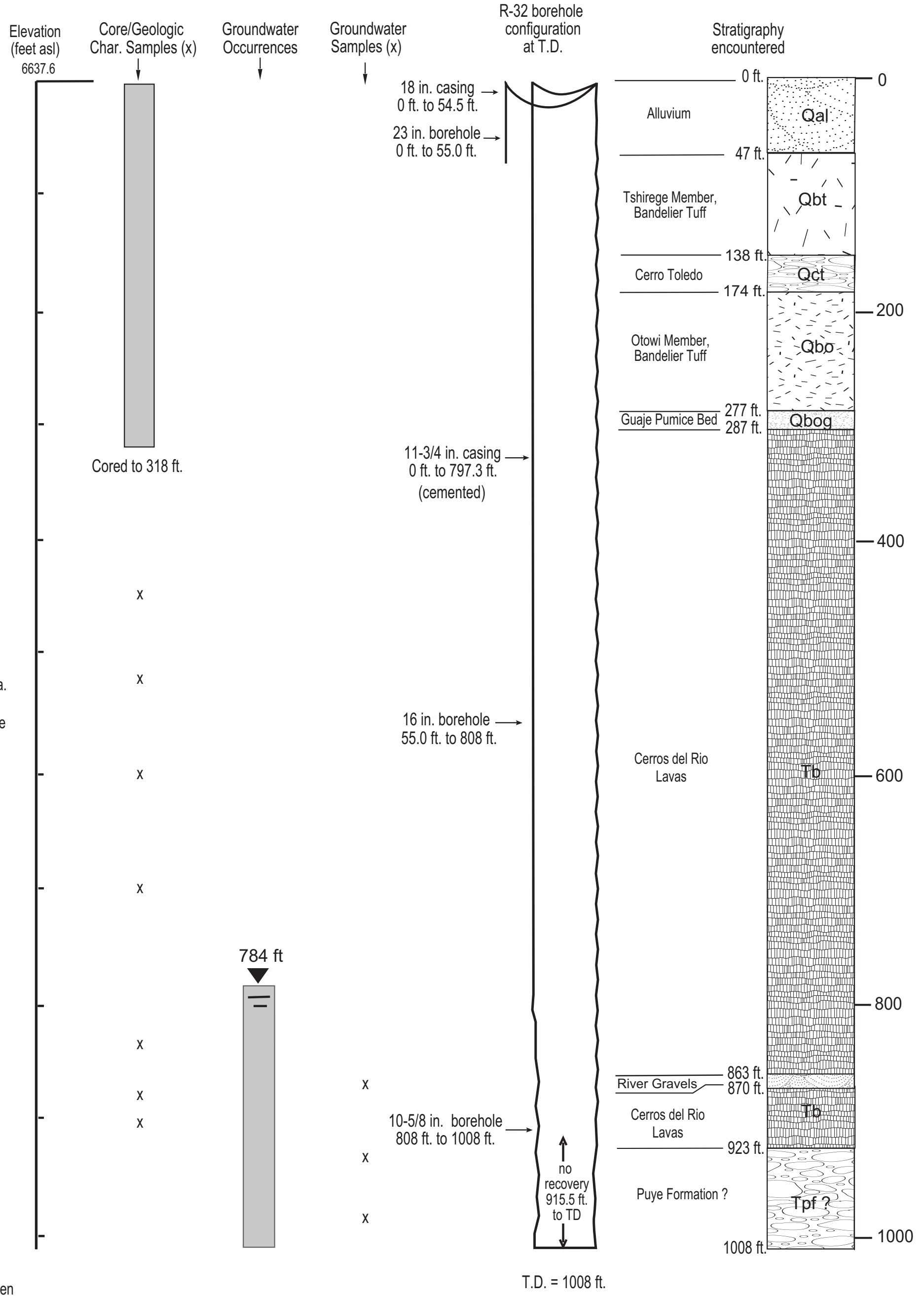


Figure 1.2-6. Regional aquifer well R-32 completion

1.2.2 Analysis and Interpretation Activities

Hydrologic modeling of the vadose zone has been undertaken to quantify key factors that influence the transport of contaminants and to assess uncertainties. In FY2002, a site-wide vadose zone model was constructed to predict travel time from the ground surface to the water table of the regional aquifer. The two most important features required to estimate vadose travel times are the infiltration rate and hydrologic conditions. The methodology and initial estimates of infiltration across the Pajarito Plateau were developed and are presented in this report. This infiltration serves as the upper flow boundary condition for the calculation of travel time. The time is computed assuming local 1-D downward flow. The hydrogeologic layers used in the 1-D model are obtained from the 3-D geologic site model. Hydrologic properties are based on past laboratory measurements and data syntheses. A series of calculations across the Plateau were made and the results presented as maps of travel time. These results can be used to make preliminary assessments of the expected rate of contaminant movement from the ground surface to the water table.

Data analysis activities regarding the regional aquifer included generation of a new water table map (presented in this report), which relies for the first time only on wells with short screens at or near the water table because the R-wells are sufficiently closely spaced. Historical data concerning all water supply wells on the plateau were compiled to support detailed analyses of capture zones for well fields that supply Los Alamos. These data, along with a new geologic model (FY2002), supplemented existing data used to support regional modeling applications. Much of the streamflow and head-data analyses that are used as part of model calibration were summarized in a report entitled "Overview of the Hydrogeology of the Española Basin" (Keating et al. 2002), which is currently in review for a peer-reviewed journal. In addition, the methodologies used in coupling basin- and site-scale models for the site and parameter estimation were summarized in a report that was published in *Groundwater* (Keating et al. 2003).

Modeling accomplishments for the regional aquifer included calculations and reporting of capture zones for the Buckman well field (Vesselinov and Keating 2002), uncertainty analysis for simulated transport in the vicinity of Mortandad Canyon (Vesselinov et al. 2002), and contaminant transport simulations in support of the Groundwater Pathways Assessment Project.

1.2.3 FY2002 Information Management

1.2.3.1 Hardware and Infrastructure

The WQDB continues to operate on servers located both behind and outside the Laboratory firewall and thus is open to the public. Sites can be found at the following URLs:

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

During the summer of 2002, the external database performance was improved by tuning the software. When funding permits, the database will be moved to a more robust server.

1.2.3.2 System Security

Following the attack against the United States on September 11, 2001, the Laboratory tightened its security requirements for website data distribution. As a result, certain WQDB data, such as maps and location information, were temporarily removed from the public website. To date, these restrictions remain in place. These data will be made available on the public website when security restrictions are eased.

1.2.3.3 Software

Additional web-based forms used to support data entry into the WQDB were developed FY2002. These forms allow users to produce chain of custody information and to review sample collection data for accuracy and completeness.

Water-level data are imported directly into the WQDB. Data for 34 wells from October 1992 through the present have been incorporated into the database.

Data from the Environmental Restoration (ER) Project, now the RRES–Remediation Program (R), have been merged with the WQDB, including well construction, sample, and analytical chemistry data. The process for these exchanges, including the ability to synchronize these data, is in progress.

Internal users have been trained to use the Oracle Discoverer software for data review and analysis. Templates for frequently used queries have been designed and stored in the WQDB, where users may execute them.

1.2.3.4 Data Import

In FY2002, analytical chemistry data continued to be loaded into the WQDB. Table 1.2-1 illustrates the data import effort during 2002:

Table 1.2-1
Data Import, 2002

Group	Stations	Samples	Results
2002 groundwater samples	79	812	29,792
2002 all ESH-18[a] samples	260	1582	65,480

[a] Now RRES-WQH.

These data are available internally and publicly via the WQDB websites usually 60 days after the samples are collected. The data are considered preliminary and are revised pending external verification and validation.

1.2.3.5 Reports

The WQDB public website now contains reports for well-construction diagrams, completion reports, borehole videos, and montages displaying geophysical data. In addition, water-level data may be displayed graphically.

1.2.4 QA and Reports

In FY2002, well completion reports were published for R-7, R-22, R-25, R-31, MCOBT-4.4, and 8.5. Geochemistry reports were published for R-7, R-9 and R-9i, R-12, R-15, R-19, and R-22. All eleven reports were published as Los Alamos National Laboratory reports.

- Ball, T.M., P. Longmire, D. Vaniman, W. Stone, D. Larssen, N. Clayton, and S. McLin, February 2002. “Characterization Well R-22 Completion Report,” LA-13893-MS, Los Alamos National Laboratory, Los Alamos, New Mexico.

- Vaniman, D., J. Marin, W. Stone, B. Newman, P. Longmire, N. Clayton, R. Lewis, R. Koch, S. McLin, G. WoldeGabriel, D. Counce, D. Rogers, R. Warren, E. Kluk, S. Chipera, D. Larssen, and W. Kopp, March 2002. “Characterization Well R-31 Completion Report,” LA-1390-MS, Los Alamos National Laboratory, Los Alamos, New Mexico.
- Broxton, D.E., R. Warren, P. Longmire, R. Gilkeson, S. Johnson, D. Rogers, W. Stone, B. Newman, M. Everett, D. Vaniman, S. McLin, J. Skalski, and D. Larssen, March 2002. “Characterization Well R-25 Completion Report,” LA-13909-MS, Los Alamos National Laboratory, Los Alamos, New Mexico.
- Stone, W., D. Vaniman, P. Longmire, D. Broxton, M. Everett, R. Lawrence, and D. Larssen, April 2002. “Characterization Well R-7 Completion Report,” LA-13932-MS, Los Alamos National Laboratory, Los Alamos, New Mexico.
- Broxton, D.E., D. Vaniman, P. Longmire, B. Newman, W. Stone, A. Crowder, P. Schuh, R. Lawrence, E. Everett, E. Tow, R. Warren, N. Clayton, D. Counce, E. Kluk, and D. Bergfeld, December 2002. “Characterization Well MCOBT-4.4 and Borehole MCOBT-8.5 Completion Report,” LA-13993-MS, Los Alamos, New Mexico.
- Longmire, P., March 2002, “Characterization Well R-15 Geochemistry Report,” LA-13896-MS, Los Alamos National Laboratory, Los Alamos, New Mexico.
- Longmire, P., April 2002, “Characterization Wells R-9 and R-9i Geochemistry Report,” LA-13927-MS, Los Alamos National Laboratory, Los Alamos, New Mexico.
- Longmire, P., June 2002, “Characterization Well R-12 Geochemistry Report,” LA-13952-MS, Los Alamos National Laboratory, Los Alamos, New Mexico.
- Longmire, P., June 2002, “Characterization Well R-19 Geochemistry Report,” LA-13964-MS, Los Alamos National Laboratory, Los Alamos, New Mexico.
- Longmire, P., September 2002, “Characterization Well R-22 Geochemistry Report,” LA-13986-MS, Los Alamos National Laboratory, Los Alamos, New Mexico.
- Longmire, P., December 2002, “Characterization Well R-7 Geochemistry Report,” LA-14004-MS, Los Alamos National Laboratory, Los Alamos, New Mexico.

Other related reports were also published in the summer of 2002:

- Stimac, J.A., D.E Broxton, E.C. Kluk, S.J. Chipera, J.R. Budahn, July 2002, “Stratigraphy of the Tuffs from Borehole 49-2-700-1 at Technical Area 49, Los Alamos National Laboratory, New Mexico,” LA-13969, Los Alamos National Laboratory, Los Alamos, New Mexico.
- Stone, W.J., and D.L. Newell, “Installation of the Monitoring Site at the Los Alamos Canyon Low-Head Weir,” LA-13970, Los Alamos National Laboratory, Los Alamos, New Mexico.

1.2.5 Project Management

Project management activities in FY2002 included maintaining scope, schedule, and costs and promoting communication. The cost and schedule for the “Hydrogeologic Workplan” activities are incorporated in the Groundwater Protection Program (GPP) baseline. A separate work-breakdown structure (WBS) is in place that defines scope, schedule, and cost for each project well. An integrated schedule incorporating all task activities and associated costs for drilling, installation, sampling, and data analysis for each well has been prepared.

In FY2002, bi-weekly GIT meetings were held to keep all participants informed about program activities and to provide a forum to discuss new data and analysis and future data collection. Three quarterly meetings and an annual meeting were held to exchange information with stakeholders. The results of the quarterly and annual meetings are summarized in Section 2.0.

1.3 Annual Report Organization

This report is organized to present the programmatic and technical activities that were accomplished during FY2002; programmatic activities are described in Section 2.0. A synthesis of data that have been collected and analyzed during the past 5 yr has resulted in a major revision to the hydrogeologic conceptual model. The resulting FY2002 hydrogeologic conceptual model is presented in Section 3.0. The hydrogeologic setting based on data collected is presented in Section 4.0. Section 5.0 describes the numerical simulation of groundwater flow in the vadose and saturated zones. Section 6.0 summarizes progress made toward resolving decisions (in the “Hydrogeologic Workplan”) by integrating data collected over the past 5 yr. Section 7.0 summarizes activities proposed for FY2003. Section 8.0 lists the references cited in this report.

2.0 PROGRAMMATIC ACTIVITIES

Programmatic activities are functions 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 bi-weekly to discuss the status of data collection and data interpretation activities.

The GIT holds three quarterly meetings and one annual meeting each FY. The purpose of these meetings is to communicate the status of program activities with stakeholders and to provide an opportunity to receive stakeholder input on 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. Section 2.2. summarizes the EAG semiannual reports and the action plans developed to respond to those reports.

2.1 Summary of FY2002 Meetings

Four meetings were held to discuss the FY2002 groundwater characterization activities. The participants of the meetings were Laboratory staff involved in the activities, DOE representatives, and representatives from the NMED bureaus of Hazardous Materials (HMB), Groundwater Quality, and DOE Oversight. Other interested stakeholders attending the meetings included representatives from San Ildefonso Pueblo, Santa Clara Pueblo, Los Alamos County, the New Mexico Attorney General, Northern New Mexico Citizens' Advisory Board, and Concerned Citizens for Nuclear Safety. The following sections summarize each meeting and points of agreement.

2.1.1 October 16–17, 2001, Quarterly Meeting

The notes from the October 16–17, 2001, quarterly meeting were issued by memorandum from Charles Nylander of the Laboratory's Water Quality and Hydrology Group (ESH-18) on December 17, 2001. The agenda included status reports from GIT subcommittees (information management, well construction, geochemistry, hydrology, and modeling); a review of the performance of the hydrogeologic characterization program; presentations on an approach to risk assessment; and presentation of the characterization program data quality objective (DQO) iteration. The following significant issues were discussed:

- completion of R-8 and R-13 and drilling and completion of R-14 and R-20.
- completion of three "Hydrogeologic Workplan" wells (R-22, R-7, R-5) and three investigation wells (MCOBT-8.5 and -4.4 and CdV-R-37-2). MCOBT-8.5 was dry so it was plugged and abandoned.
- drilling of two "Hydrogeologic Workplan" wells (R-13, R-8).
- description of the first order groundwater pathway assessment to rank contaminants of potential risk-significance to groundwater receptors on a site-wide basis. The assessment modeled contaminant movement across the plateau on a site-wide basis rather than on one specific area.
- proposed modification of the groundwater water analysis strategy that determines (1) when samples are representative of the predrilling groundwater conditions to minimize the cost by eliminating analyses for analytical suites not detected in two subsequent samples, (2) the cost

associated with analysis for both dissolved and total constituents in every sample, and (3) the analytical methods used.

- proposed revised hydrogeologic characterization program DQO iteration including
    - ? installing 15 regional aquifer wells,
    - ? conducting 13 other field-based activities: hydrologic testing, collecting groundwater for geochemical analyses, geologic mapping and sampling,
    - ? conducting 10 analytical activities including regional aquifer modeling, geochemical modeling, information management, and
    - ? conducting three project management activities.

2.1.2 January 30, 2002, Quarterly Meeting

The January 30, 2002, quarterly meeting is documented in notes issued by memorandum from Charles Nylander of the Laboratory's Water Quality and Hydrology Group (ESH-18) on March 19, 2002. The agenda included presentations on the integrated groundwater protection action plan, an interactive demonstration of the water quality database, possible perchlorate contamination, and the results of the DOE value engineering study. The following significant issues were discussed:

- Well R-13 in Mortandad Canyon was finished as a single completion well.
- Well completion reports for R-25, R-31, and R-22 are near completion; a completion report for R-7 is in progress.
- The integrated groundwater protection action plan has the goal of protecting groundwater users from known and potential releases. This plan is an integrated three-step approach: (1) objectively evaluate the existing groundwater monitoring program, (2) identify alternative actions to optimize the existing groundwater monitoring program, and (3) implement optimal actions and iterate continuously.
- Overview of water supply results for perchlorate:
    - ? Well O-1 appears to have perchlorate, possibly at 2 ppb.
    - ? No perchlorate detections were found in other water-supply wells based on data from the Babcock analytical laboratory.
    - ? Possibly 33% estimated J-flagged "detections" occurred in other water-supply wells based on General Engineering Laboratory (GEL) data; however, this conclusion does not consider the revised GEL method detection limit (MDL) of 4 ppb.
- The draft groundwater annual status report for FY2001 will be sent to NMED in February 2002.

2.1.3 April 10–12, 2002, Annual Meeting

The notes from the April 10–12, 2002, annual meeting were distributed by memorandum from Charles Nylander, RRES-DO, dated June 10, 2002. The agenda for the meeting included status reports from the GIT subcommittees: well construction, modeling, hydrology, geochemistry, and information management. There were technical presentations and posters on the following topics:

- status of Groundwater Protection Plan
- single-well testing of R-wells at the Laboratory

- regional aquifer modeling results with reference to the Buckman well field
- vadose zone geochemistry
- permeable reactive barrier in Mortandad Canyon
- incorporating uncertainty in the regional aquifer modeling
- groundwater pathways assessment
- well development survey
- WQDB and ERDB
- updated 3-D geologic model
- seismic hazards program results
- TA-16 high-resolution resistivity survey
- permeability of fault zones
- fracture characterization of the Bandelier Tuff in Cañon de Valle for seismic hazards and flow and transport analysis

The following significant issues were discussed at the April 10–12, 2002, annual meeting:

- Wells planned for FY2003 include three Defense Program (DP)-funded wells (R-2, R-11, R-24) and three EM-funded wells (R-4, R-24, R-27).
- Planned FY2003 nonfield activities include information management and strengthening ties between RRES-R Program (formerly the Environmental Restoration Project) (ERDB) and WQDB; continuing the groundwater pathway assessment into FY2003; modeling the regional aquifer; finalizing capture zone analysis and updating the geologic model; completing reports; and scheduling meetings.
- Drilling accomplishments include three "Hydrogeologic Workplan" wells (R-5, R-13, R-8/8a) and three investigation wells (MCOBT-8.5, MCOBT-4.4, CDV-R-37-2).
- Well completion reports for R-25, R-31, and R-22 were published. The well completion report for R-7 has been peer-reviewed and will be available in April 2002. The Laboratory has published two geochemical reports (R-15 and R-9i).
- A study is being conducted of the potential impact of Laboratory operations on the Buckman well field.
- A core team was formed to assess the current state of knowledge. Members are Beverly Ramsey (the Laboratory), Larry Goen (the Laboratory), James Bearzi (NMED), Greg Lewis (NMED), Corey Cruz (DOE), and Mat Johansen (DOE).

2.1.4 July 24, 2002, Quarterly Meeting

Notes from the July 24, 2002, quarterly meeting were distributed by memorandum from Charles Nylander, RRES-DO, dated September 23, 2002. The agenda for the meeting included status reports from the GIT subcommittees: well construction, modeling, hydrology, geochemistry, and information management. The Groundwater Protection Program, Groundwater Protection Core Team, and an FY2003 planning session with stakeholder participation were discussed. The following significant issues were discussed:

- FY2003 proposed work. With anticipated funding, DP will drill four wells (R-2, R-6, R-11, R-24) and EM two wells (R-4, R-18). With these wells, LA/Pueblo Canyon wells will be completed along with fault-related wells. Characterization sampling and analysis will be conducted in completed wells, and hydrologic testing will be done in new wells.
- The URL for the WQDB is http://wqdbworld.lanl.gov (external) and http://wqdb.lanl.gov (internal).
- Two wells have been completed (R-8, R-14), and four more wells will be installed by end of FY2003 (R-16, R-20, R-23, R-32). R-21, located near TA-54, will be installed early in FY2003 by DOE; the US Army Corps of Engineers (COE) will conduct drilling.
- The sampling activity for the quarter included completion of characterization sampling for eight wells (R-7, R-9, R-9i, R-12, R-15, R-19, R-22, R-25). Screening samples were collected at R-13 and MCOBT 4.4. Sampling rounds were completed for the CdV-wells (R-37-2, R-15-3).
- The well completion report for R-7 was completed. Two geochemistry reports (R-19, R-12) were completed.
- Groundwater Protection Program scope is larger than characterization efforts; it encompasses aspects of the overall concept of protecting groundwater. The program plan will be drafted by end of FY2003. The plan will capture how all aspects (including stewardship) are integrated to protect groundwater and to ensure proper funding.
- The core team, composed of the Laboratory, DOE, and NMED personnel, is designed to provide leadership and guidance to the GPP, to address criticisms regarding lack of management in the hydrogeologic characterization program, and to improve communication between the three management entities (the Laboratory, DOE, and NMED).

2.2 External Advisory Group Activities

The GIT formed an 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 who provide 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 and a Master of Arts in organizational management, with more than 25 yr experience . Dr. Charles served as chair of the EAG.
- Jack Powers, PE—Mr. Powers is a drilling consultant with more than 45 yr of worldwide professional drilling experience.
- Robert Powell, MS—Mr. Powell has a Master of Science in environmental science, with 25 yr of experience, and has published 33 groundwater-related documents. Mr. Powell has expertise in the area of low-flow groundwater sampling.
- Elizabeth Anderson, Ph.D.—Dr. Anderson has a doctorate in inorganic chemistry and more than 20 yr of experience in health and environmental science. Dr. Anderson is a nationally recognized expert on risk assessment and has established major national risk assessment programs at the US Environmental Protection Agency (EPA).
- David Schafer, MS—Mr. Schafer has 25 yr experience in computer modeling using numerical models, analytic element models, and proprietary analytical models he developed.

- Charles McLane, Ph.D.—Dr. McLane, the founder of McLane Environmental, has over 20 yr experience in hydrogeology, environmental investigation and remediation, and exposure and risk assessment.

The EAG met in conjunction with the quarterly meeting held October 16–17, 2001, and with the annual meeting on April 10–12, 2002, for semiannual reviews of activities proposed under the "Hydrogeologic Workplan." The EAG reports findings and observations based on the semiannual reviews. In response, the GIT develops an action plan that specifies how the recommendations of the EAG will be incorporated into the program. In FY2002, the following reports were completed:

- EAG semiannual report to the GIT, meeting dates 16–18 October 2001;
- GIT action plan for the EAG, October 2001 recommendations;
- EAG semiannual report to the GIT, meeting dates 9–12 April 2002; and
- GIT action plan for the EAG April recommendations.

At both EAG semiannual reviews, sessions were offered for stakeholders to discuss concerns about the program. The EAG is committed to holding similar sessions in conjunction with each semiannual review.

3.0 FY2002 HYDROGEOLOGIC CONCEPTUAL MODEL

The FY2002 hydrogeologic conceptual model describes current understanding of the hydrogeologic setting of the Pajarito Plateau. Section 3.1 describes mesa-related elements of the hydrogeologic conceptual model. Section 3.2 describes the elements related to alluvial groundwater. Section 3.3 addresses elements related to perched intermediate groundwater. Section 3.4 addresses 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 because of low rainfall, high evaporation, and efficient water use by vegetation. Atmospheric evaporation extends within mesas, drying the mesa interior and limiting downward movement of moisture. Moisture content of the tuff varies with recharge rate and with the textures of the lithologic units.
2. On 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 for 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 or the regional aquifer.
4. Mesa-top recharge under disturbed surface conditions is higher than under natural conditions. Increased recharge occurs when the soil is disturbed by compaction or during vegetation disturbance. Increased recharge also occurs 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 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 the 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 underlying Bandelier Tuff, Cerros del Rio basalts, or Puye Formation. Evapotranspiration (ET) and percolation into the underlying strata 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 generally originate on the Pajarito Plateau east of the Jemez Mountains.
3. In wet canyon bottoms, infiltration of surface water maintains shallow groundwater in the alluvium. Wet canyons generally have seasonal surface water flow, originate in the Jemez Mountains, or the surface water flow is maintained by effluent. Groundwater levels typically are highest in late spring from snowmelt runoff and in mid- to late summer from 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 highly permeable 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 sediments contain most of the adsorbing contaminants (such as plutonium). Only the mobile solutes (such as tritium, HE compounds, and anions) typically are found associated with alluvial groundwater, and these 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 originate 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 the 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. Intermediate perched zones are not continuous along the length of the canyon. Variations in stratigraphy and in 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 with limited eastward extent. 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 300–400 m bgs. The hydraulic gradient in the western portion of the aquifer is generally downward. Groundwater flow is east/southeast, toward the Rio Grande. The hydraulic gradient in the eastern portion of the aquifer near the Rio Grande is generally upward. Groundwater velocities vary spatially with a typical value of 10 m/yr. Local deviations in flow direction occur because of 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, west of the Pajarito Plateau. Recharge also occurs from leakage from mesas, from alluvial groundwater in canyon bottoms on the Pajarito Plateau, and from intermediate perched groundwater. 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 1000 to 6000 yr, although tritium activity indicates that a portion of the water is less than 50 yr old. Groundwater chemistry in many wells near the Rio Grande (high total dissolved solids [TDSs], 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, suggesting that old water (about 30,000 yr) 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

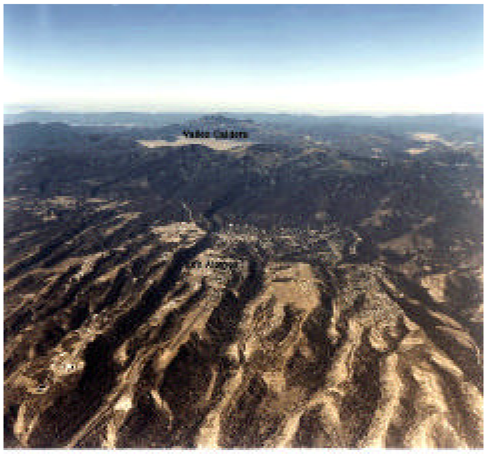
The following 11 elements reflect current understanding of the geochemistry of groundwater and are incorporated into the FY2002 geochemistry conceptual model.

1. Because of geochemical processes, the natural composition of groundwater can vary in 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 residence time exceeds reaction half-time (amount of time required for 50% of reactant A to form product B, assuming B is not present initially). 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 aluminum, 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 because the constituents readily adsorb onto clay- and silt-sized material.

5. In general, adsorption of radionuclides and inorganic species decrease at circumneutral 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 as a result of changes in solution speciation and mineralogy.
6. Activities of adsorbing radionuclides and inorganic species generally decrease downgradient along the groundwater flow path.
7. Non- and semisorbing 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 $SrCO_3$, $BaCO_3$, or $(Sr\text{-}Ba)SO_4$ 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 yr old, based on measurable tritium activities considerably above the cosmogenic baseline of 1 pCi/L.
11. Short-term increases in the concentrations of dissolved organic carbon (DOC), carbonate alkalinity, calcium, potassium, iron, manganese, and other solutes occurred in alluvial groundwater since the Cerro Grande fire. Oxidation and reduction reactions and carbonate complexation with metals influence aqueous speciation of redox-sensitive solutes. The concentrations of these solutes have returned to prefire conditions.

4.0 HYDROGEOLOGIC CHARACTERIZATION

4.1 Physical Setting



The Laboratory is located approximately 25 mi northwest of Santa Fe on the Pajarito Plateau, a dissected volcanic apron extending eastward from the Jemez Mountains. The Pajarito Plateau consists of a series of finger-like mesas separated by deep east-west oriented canyons cut by largely ephemeral streams. The plateau ranges in elevation from approximately 7800 ft on the flanks of the Jemez Mountain front to 6200 ft at their eastern termination at the Rio Grande.

4.1.1 Climate

The climate is a semiarid, temperate mountain climate (Bowen 1990, 6899). Annual precipitation is 18 in. Precipitation normally occurs as about 50% thundershowers in the summer and fall and 50% snow during the winter and early spring months. There are 58 thunderstorm days in an average year. Snowstorms with accumulations exceeding 4 in. are common, and the average annual snowfall is about 51 in.

Precipitation events vary in intensity and size. Thunderstorms can be localized and intense, resulting in overland flow in one area of the plateau while other areas remain dry. Snowfall is usually either plateau-wide or isolated to the Sierra de los Valles due to colder temperatures at higher elevations. Annual data collection shows that precipitation in the Los Alamos area is generally greatest in the Sierra de los Valles and decreases eastward across the plateau.

4.1.2 Surface Water

Most Los Alamos surface water occurs as ephemeral (flowing in response to precipitation), intermittent (flowing in response to availability of snowmelt or groundwater discharge), or interrupted (alternation of perennial, ephemeral, and intermittent stretches) streams in canyons cut into the Pajarito Plateau. Springs on the flanks of the Jemez Mountains, west of the Laboratory's western boundary, supply flow to the upper reaches of Cañon de Valle and in Guaje, Los Alamos, Pajarito, and Water Canyons (Purtymun and Rogers 2002). These springs discharge water perched in the Bandelier Tuff and Tschicoma Formation at rates from 2 to 135 gal./min (Abeele et al. 1981). The volume of flow from the springs maintains natural perennial reaches of varying lengths in each canyon.

4.1.3 Land Use

The federal government acquired all lands within Los Alamos County in 1942 and established the Laboratory in January 1943. Most townsite and Laboratory facilities were constructed on mesa tops, in areas previously cleared for agriculture. In the mid-1960s, the federal government either sold or transferred title to the areas beyond the current DOE boundary to various private interests, Los Alamos County, the US Forest Service, and the US Park Service.

Within DOE property, land uses include building sites, experimental areas, waste disposal locations, roads, and utility rights-of-way. Most of the land controlled by the Laboratory serves as a buffer zone for Laboratory activities, providing security and safety to the public, and as a reserve for future construction.

The Laboratory has produced a long-range site development plan (LANL 1996, 70215) that addresses the best possible future uses of available Laboratory lands.

4.2 Geologic Setting

Laboratory facilities are located almost entirely on mesas and within canyons that are erosional remnants of the Bandelier Tuff, which forms the southern Pajarito Plateau. The Bandelier Tuff consists of ash flows and minor airfall pyroclastic deposits with ages of 1.61 Ma (Otowi Member) and 1.22 Ma (Tshirege Member). Deeper units are poorly exposed at the surface but provide important components of the hydrogeologic system. Figure 4.2-1 summarizes current understanding of the geologic history at the Laboratory, extending to the beginning of the Miocene; earlier strata are not discussed because they are too deep to affect contaminant flow and transport.

4.2.1 Stratigraphy

The distribution of igneous and sedimentary units by age and in relative extent beneath west, central, and east portions of the Laboratory are indicated in Figure 4.2-1 and described in Table 4.2-1. For Miocene samples, individual data points are shown for ages of basalts (solid circles), intermediate lavas (gray circles), and rhyolites (open circles). Age data for younger samples are too numerous to list. Information about stratigraphic units older than about 5 Ma is limited to mapping areas peripheral to the Laboratory and samples from Laboratory boreholes because surface exposures of these units are rare in the vicinity of the Laboratory. The limited access to deeper units translates into increased uncertainty in the character and extent of deeper, older strata.

The oldest units represented in Figure 4.2-1 (early Miocene) are inferred from mapping near Saint Peter's Dome, southwest of the Laboratory (Goff et al. 1990, 21574) and from regional studies of the Rio Grande rift (Ingersoll et al. 1990). The oldest lava nearby, exposed within Santa Fe Group sediments south of Saint Peter's Dome, has a radiometric age of 25.3 Ma. Other thin (<15-ft-thick) basaltic flows have been dated at 20.7 Ma (south of Saint Peter's Dome) and 18.6 Ma (Medio Canyon). The earliest Santa Fe Group sediments in the area are >25 Ma in age and are also exposed near Saint Peter's Dome, where they are deposited unconformably on Eocene sediments of the Galisteo Formation (>37 Ma). Similar stratigraphic relations may occur beneath the Laboratory, but drilling has not been deep enough to test this possibility.

The oldest datable lithologies sampled by drilling beneath the Laboratory are basalts that represent a suite of lavas of 13.1–10.9 Ma, encountered by drilling in the central to northern and eastern portion of the Laboratory (Tb1 in Figure 4.2-1). One sample is a basalt within the Santa Fe Group dated at 12.0 Ma, from 2226-ft depth in the borehole for water supply well O-1. Another basalt of 10.9 Ma was collected at 2700-ft depth in the borehole for water supply well PM-5. The Tb1 basalts are comparable in age with basalts encountered to the north in the Guaje Replacement (GR)-series water supply wells of Guaje Canyon and in outcrop at Santa Clara Canyon. Tb1 basalts were erupted at the same time as rhyolites and basalts of the early Keres Group exposed to the southwest (rhyolite lava and intrusion in Sanchez Canyon and basalt of Capulin Canyon) (Goff et al. 1990, 21574).

Early- to middle-Miocene sedimentation is poorly characterized and is attributed entirely to the Santa Fe Group. Tectonic reconstructions of the early to middle Miocene (Ingersoll et al. 1990) suggest that sediment sources at this time could have been from the west (incipient Nacimiento block) as well as the east (Sangre de Cristos).

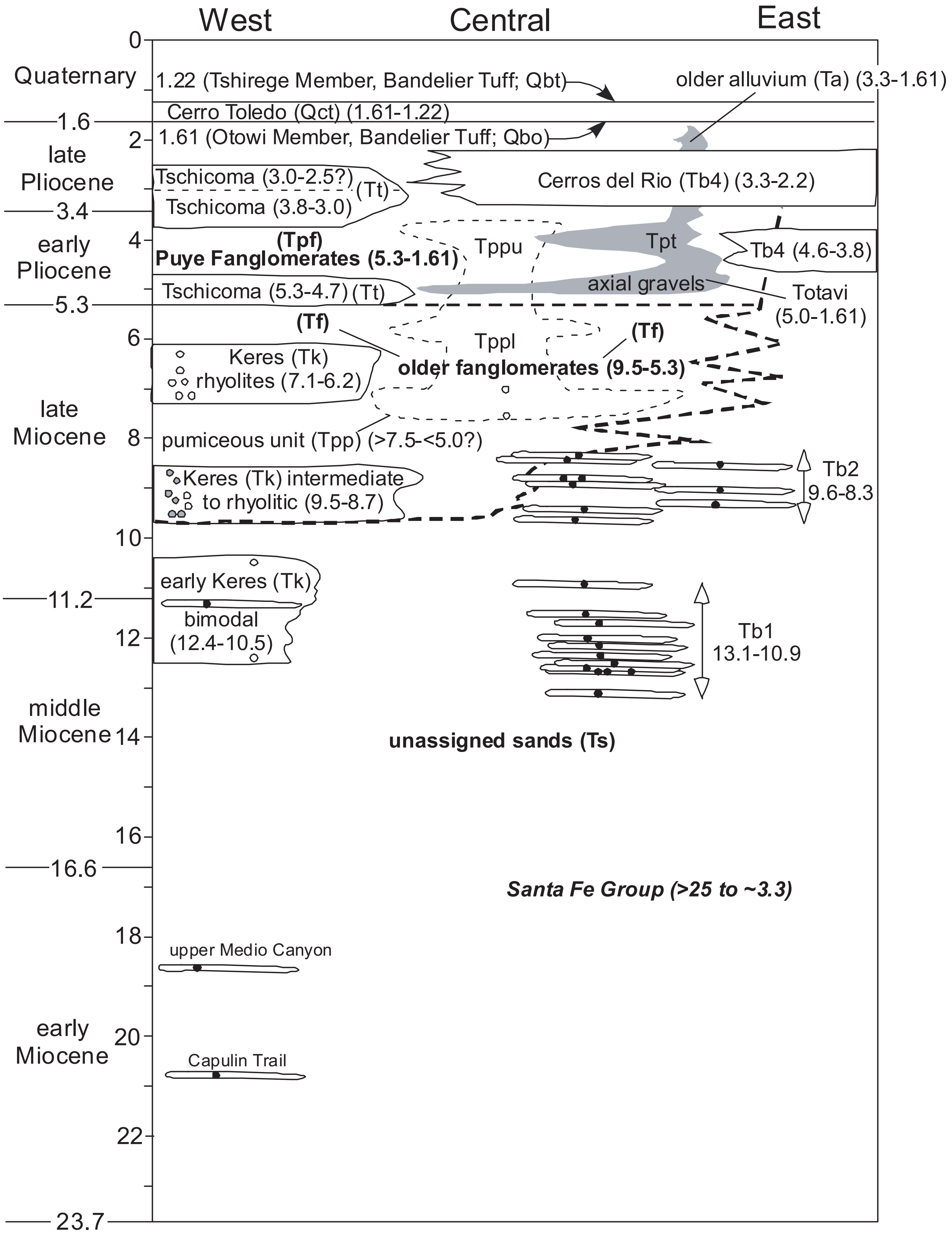


Figure 4.2-1. Stratigraphy of the Pajarito Plateau

Table 4.2-1
Stratigraphic Units in 3-D Geologic Model

Geologic Unit	Symbol	Description
Santa Fe Group sediments Intercalated basaltic lavas Keres Group volcanic rocks Unattributed fanglomerates and sands	Tsf Tb1 & Tb2 Tk Tf, Ts	In the vicinity of the Pajarito Plateau, the stratigraphy and geochronology of the Santa Fe Group (**Tsf**) is poorly understood because it is covered by a near-continuous blanket of younger deposits. Based on exposures near the Rio Grande, the Santa Fe Group beneath the Pajarito Plateau may include components of the Tesuque, Ancha, and/or Chamita Formations; these units are not differentiated in the 3-D geologic model, where they are treated as an unattributed sand unit **(Ts)**. This designation is used in lieu of Tsf because data from deep drilling at the Laboratory produce sands and gravels of dominantly volcanic rather than Precambrian metamorphic/granitic provenance, whereas recognition of Tsf in White Rock Canyon has been based on prominent presence of Precambrian sands (Dethier 1997, 49843). Incomplete evidence from earlier boreholes at the Laboratory suggests that some volcaniclastic units coarser than the typical Santa Fe Group sands and gravels occur above Ts, interspersed with sands of unknown provenance. These coarse-grained deposits are of unknown origin, possibly related to either local volcanic sources (Keres, **Tk**) or unknown distant volcanic or Precambrian sources. Because the hydrologic properties of these coarser deposits are likely to differ significantly from the underlying sands, they are mapped into the 3-D geologic model as unattributed Tertiary fanglomerates **(Tf)**. Two principal cycles of middle- to late-Miocene basaltic volcanism are included within the 3-D geologic model. These volcanic cycles produced lava flows in the age range of 13.1–10.9 Ma **(Tb1)** and 9.6–8.3 Ma **(Tb2)**. Both Tb1 and Tb2 are treated as units with a certain percentage (*x*) of lava flows between which there is a complementary percentage (*100-x*) of sediment. The percentages are based on relative thicknesses of lavas and intercalated sediments encountered in the boreholes.
Tschicoma Formation	Tt	The Tschicoma Formation of the Polvadera Group **(Tt)** makes up the highlands west of Los Alamos and crops out in the headwaters of the larger canyons that cut the Pajarito Plateau. The Tschicoma Formation consists of numerous thick lava flows derived from a series of volcanic domes of Pliocene age (Figure 4.2-1). Fragmental deposits of ash and lava debris occur in the distal parts of the formation. It has a variable thickness because of its thick wedge-shaped lava flows and is at least 2500 ft thick in the Sierra de los Valles. The Tschicoma Formation thins eastward beneath the Pajarito Plateau where it interfingers with its largely derivative deposit, the Puye Formation. The lower parts of the Tschicoma Formation may interfinger with the upper Santa Fe Group. Tschicoma Formation lava flows range in composition from andesite to low-silica rhyolite but are dominantly dacites. The rocks are mainly gray to purplish gray, but in places they are reddish brown. These flows display pronounced jointing and have bottoms commonly marked by blocky breccia. Lavas contain glassy and microcrystalline groundmass; the glass is partially devitrified, giving the rocks a stony appearance.

Table 4.2-1 (continued)

Geologic Unit	Symbol	Description
Unassigned pumiceous deposits	Tpp Tppl Tppu	Thick deposits of rhyolitic pumice occur in the central and northwest portion of the Laboratory, generally beneath pumice-poor fanglomerates of the Puye Formation. These pumiceous deposits were the deepest units encountered in boreholes CdV-R-15-3 and R-19, which reached TD without penetrating through the pumiceous deposits. Radiometric ages obtained on the upper- and lowermost pumice beds in R-19 were 7.0 and 7.5 Ma, respectively. No equivalent outcrops are known; therefore the unit is included in the 3-D geologic model as an unassigned Tertiary pumiceous deposit **(Tpp)**. Borehole R-7 penetrated a thick sequence of alternating pumiceous beds and dacitic (Tschicoma?) fanglomerates before reaching TD in deposits that appear to be axial gravels (Totavi, **Tpt**), indicating that some of these pumiceous beds postdate the initial spread of Totavi deposits across the Laboratory site at ~5 Ma. To construct an internally consistent 3-D geologic model, it has been necessary to subdivide the pumiceous deposits into lower **(Tppl)** and upper **(Tppu)** units, respectively below and above the initial horizon of Totavi deposition.
Puye Formation	Tpf Tpt Tpl	The Puye Formation is an apron of large alluvial fans that were shed eastward from the Jemez volcanic field into the Española basin, covering the Santa Fe Group rocks west of and along the Rio Grande. This formation crops out in eastern Los Alamos Canyon and in canyons to the north. Its estimated areal distribution is 518 mi^2 and its volume is approximately 3.6 mi^3. Its age is generally placed between 1.9 and 3.5 Ma, but it may be as young as 1.6 Ma and as old as 6.7 Ma because of its expected temporal and spatial association with eruption of the Tschicoma Formation. The dominant lithology of the Puye Formation is a fanglomerate **(Tpf)** consisting of subrounded dacitic and andesitic lava clasts in a sandy matrix. At least 25 ash beds of dacitic to rhyolitic composition are interbedded with the conglomerates and gravels (Turbeville et al. 1989, 21587), and basaltic ash and lacustrine layers are present along the eastern margins of this formation. In addition to the fanglomerates, Griggs (1964, 8795) originally included two other units, in ascending order: an axial facies (called the "Totavi Lentil" by Griggs, here designated as **Tpt**) and a lacustrine facies (here designated **Tpl**). The axial facies of the Puye Formation (also called "Totavi Lentil" or "Totavi Formation") overlies the Santa Fe Group and crops out at Totavi and in areas to the east in lower Los Alamos Canyon and in White Rock Canyon (Griggs 1964, 8795). It is approximately 50 ft thick under the eastern Pajarito Plateau but thickens in a northwest direction. It consists of coarse, poorly consolidated conglomerate containing cobbles and boulders of quartzite, granite, and pegmatite. It is a channel-fill deposit as opposed to an alluvial-fan deposit, which is characteristic of most of the overlying fanglomerate facies. The Tpl unit is of limited extent and is not used within the 3-D geologic model. The lakebed deposits (Tpl) include clays and sands deposited in episodes when flow along the Rio Grande was impeded; these deposits are rare at the Laboratory and occur principally in exposures along White Rock Canyon and in borehole R-16 at the eastern margin of the site.
Older Alluvium	Ta	The "older alluvium" consists of sand, gravel, and cobbles derived principally from the Sangre de Cristo Range. The older alluvium generally overlies Puye Formation deposits and may be intercalated between lava flows and other deposits of the Cerros del Rio. Older alluvium is generally restricted in extent and found only along White Rock Canyon and in boreholes in the eastern part of the Laboratory (e.g., R-9 and R-16).

Table 4.2-1 (continued)

Geologic Unit	Symbol	Description
Deposits of the Cerros del Rio volcanic field	Tb4	The basaltic rocks of the Cerros del Rio volcanic field **(Tb4)** crop out primarily along White Rock Canyon and occur in the subsurface below much of the Pajarito Plateau. The deposits include lava flows separated by interflow breccias, scoria, cinder, and ash. The lavas were erupted from numerous vents both east and west of the Rio Grande. In the vicinity of the Pajarito Plateau, these basalts form a north-south trending highland (now buried by the Bandelier Tuff) extending from the western edge of White Rock to the confluence of Los Alamos and Pueblo Canyons. These basalts are interbedded with the upper part of the fanglomerate facies of the Puye Formation. An extensive series of mafic alkalic basalts grading upward into more evolved tholeiitic basalts occurs beneath the northeastern part of the Laboratory, beneath Los Alamos, Sandia, and Mortandad Canyons. Elsewhere, the lateral extent of this lava series is variable, and it is difficult to determine widespread lava stratigraphy. As noted in Section 4.2.1, basalts predominate within the Cerros del Rio, but andesitic and thin dacitic lavas also occur. Throughout the southeastern portion of the Laboratory, the top of regional saturation is within the Cerros del Rio. Evidence from hydrologic testing at the Laboratory and data from other basalt aquifers (e.g., Whelan and Reed 1997) indicate that hydraulic conductivity in such lava series is quite heterogeneous. Breccia and scoria zones may be highly transmissive, compared with the poorly connected fracture transmission in most flow interiors. However, the lowest hydraulic conductivity generally occurs in clay-rich sediments between flows.
Bandelier Tuff and Cerro Toledo deposits	Qb Qct	The Bandelier Tuff **(Qb)** consists of the Otowi **(Qbo)** and Tshirege **(Qbt)** Members, which are stratigraphically separated in many places by tephra and volcaniclastic sediments of the Cerro Toledo interval. Bandelier Tuff was emplaced during two cataclysmic eruptions of the Valles caldera at 1.61 Ma **(Qbo)** and 1.22 Ma **(Qbt)**. The tuff is composed of pumice, minor rock fragments, and crystals in an ashy matrix. The Tshirege Member includes prominent cliff-forming subunits that are strongly consolidated due to compaction and welding at high temperatures within some cooling units after the tuff was emplaced. The Cerro Toledo interval **(Qct)** was deposited between eruptions of the two members of the Bandelier Tuff. Because Bandelier Tuff is the most prominent rock type on the Pajarito Plateau, its detailed stratigraphy and that of the included Cerro Toledo interval are of considerable importance and are included as separate units (Broxton and Reneau 1995, 49726).
Otowi Member and Guaje Pumice Bed	Qbo Qbog	The Otowi Member crops out in several canyons but is best exposed in Los Alamos Canyon and in canyons to the north. It consists of moderately consolidated (indurated), porous, nonwelded vitric tuff that forms gentle, colluvium-covered slopes along the base of many canyon walls. The predominant lithology consists of Otowi ash flows **(Qbo)**, but the Guaje Pumice Bed **(Qbog)** occurs at the base of the Otowi Member, making a significant and extensive marker horizons in many well boreholes. The Guaje Pumice Bed consists of well-bedded fall deposits containing well-sorted pumice fragments whose mean size varies between 0.8 and 1.6 in. The thickness of Qbog averages approximately 28 ft below most of the plateau with local areas of thickening and thinning. The Guaje Pumice Bed has greater porosity than the overlying ash flows, and in borehole logs it is marked by a greater abundance of pore-associated water, even in the vadose zone.

Table 4.2-1 (continued)

Geologic Unit	Symbol	Description
Cerro Toledo interval	Qct	The Cerro Toledo interval **(Qct)** is an informal name given to a sequence of volcaniclastic sediments and tephras of mixed volcanic and sedimentary provenance deposited in early Quaternary time between the Otowi and Tshirege eruptions. Although the Cerro Toledo is intercalated between the two members of the Bandelier Tuff, it is not considered part of that formation. The unit contains deposits of reworked equivalents of Cerro Toledo rhyolite tephra erupted from the Cerro Toledo and Rabbit Mountain rhyolite centers in the Sierra de los Valles, as well as intercalated and reworked volcaniclastic sediments. The occurrence of the Cerro Toledo interval is widespread; however, its thickness ranges from complete absence in eastern portions of the Laboratory to ~200 ft in the south-central part of the Laboratory. The pumice falls form porous and permeable horizons within the Cerro Toledo interval. Clast-supported gravel, cobble, and boulder deposits made up of porphyritic dacite derived from the Tschicoma Formation are interbedded with the tuffaceous rocks, and in some deposits, dacitic materials are volumetrically more important than rhyolitic detritus.
Tshirege Member	Qbt	The Tshirege Member **(Qbt)** is the most widely exposed bedrock unit of the Pajarito Plateau. It is a multiple-flow, compound cooling-unit, ash-and-pumice sheet that forms the prominent cliffs in most canyons. It also underlies canyon floors in all but the middle and lower reaches of Los Alamos Canyon and in canyons to the north. The Tshirege Member is generally >200 ft thick but exceeds 600 ft near the southern edge of the Laboratory. The Tshirege Member differs from the Otowi Member most notably in its generally greater degree of welding compaction and loss of glass to crystallization. The Tshirege Member can be divided into mappable subunits based on a combination of cooling-unit related density and porosity transitions, loss of glass to crystallization, and mineralogic or chemical transitions. Details of stratigraphic differentiation within the Bandelier Tuff can be found in Broxton and Reneau (1995, 49726) and Stimac et al. (2002, 73391). Borehole geophysical logs, particularly natural gamma and combined magnetic resonance, have proven to be particularly useful in recognizing some subunits of the Bandelier Tuff and separating the Cerro Toledo interval. The subunits of the Tshirege Member recognized in the 3-D geologic model are described as separate units.
Tsankawi Pumice Bed	(Qbtt)	The Tsankawi Pumice Bed forms the base of the Tshirege Member. Where exposed, it is commonly 20 to 30 in. thick. This pumice-fall deposit contains moderately well-sorted pumice lapilli in a crystal-rich matrix. Several thin ash beds are interbedded with the pumice-fall deposits.
Vitric nonwelded ash flows	Qbt 1g	The lowermost subunit of the thick ignimbrite sheet overlying the Tsankawi Pumice Bed consists of porous, nonwelded, and poorly sorted vitric ash flow tuffs (Qbt 1g). The "g" in this designation stands for "glass" because none of the glass in ash shards and pumices shows crystallization by devitrification or vapor-phase crystallization. This unit is poorly indurated but nonetheless forms steep cliffs because of a resistant bench near the top of the unit that forms a hard, protective cap over the softer underlying tuffs. A thin pumice-poor surge deposit commonly occurs at the base of this unit.

Table 4.2-1 (continued)

Geologic Unit	Symbol	Description
Vapor-phase altered nonwelded ash flows	Qbt 1v	Ash-flow unit Qbt 1v forms alternating cliff-like and sloping outcrops of porous, nonwelded, but crystallized tuffs. The "v" stands for vapor-phase crystallization, which together with crystallization from slow cooling (devitrification), has converted the glass in shards and pumices into microcrystalline aggregates. The base of this unit is a thin, horizontal zone of preferential weathering that marks the abrupt transition from glassy tuffs below to crystallized tuffs above. This feature forms a widespread mappable marker horizon (locally eroded in outcrop and hence termed the "vapor-phase notch") throughout the Pajarito Plateau, visible in many canyon walls. The lower part of Qbt 1v is orange-brown, resistant to weathering, and has distinctive columnar joints, forming a "colonnade tuff." A distinctive white band of alternating cliff- and slope-forming tuffs overlies the colonnade tuff. The tuffs of Qbt 1v are commonly nonwelded (pumices and shards retain their initial equant and have an open, porous structure).
Major welded interval	Qbt 2	Unit Qbt 2 is the most prominent cooling unit and forms a distinctive, medium brown, vertical cliff that stands out in marked contrast to slope-forming, lighter-colored tuffs above and below. A series of surge beds commonly mark its base in the eastern part of the Laboratory, and it displays the greatest degree of welding in the Tshirege Member. It is typically nonporous and has low-matrix permeability relative to the other units of the Tshirege Member. Vapor-phase crystallization of flattened shards and pumices is extensive in this unit.
Most pervasive upper cliff-forming interval	Qbt 3	Unit Qbt 3 is a nonwelded to moderately welded, vapor-phase altered tuff, which forms many of the upper cliffs in the mid- to lower reaches of canyons on the Pajarito Plateau. Its base consists of a purple-gray, unconsolidated, porous, and crystal-rich nonwelded tuff that overlies a broad, gently sloping bench developed on top of Qbt 2. This basal, nonwelded portion forms relatively soft outcrops that weather into low, rounded, white mounds, which contrast with the cliffs of partially welded tuff in the middle and upper portions of Qbt 3. In the western part of the Pajarito Plateau, Qbt 3 is further subdivided into Qbt 3, as described above, and Qbt 3t, a series of welded tuffs with chemical and petrologic features that are transitional between units Qbt 3 and Qbt 4. These subdivisions are not included in the 3-D geologic model.
Western mesa-capping unit	Qbt 4	Unit Qbt 4 is a partially welded to densely welded ignimbrite characterized by small, sparse pumices and numerous intercalated surge deposits. This unit crops out on the mesa tops in the western part of the Laboratory, but it is missing from mesa tops over the mid- to eastern Pajarito Plateau. It forms the bedrock unit in the canyon floors along the westernmost part of the Laboratory near the Sierra de los Valles. Devitrification and vapor-phase crystallization are typical in this unit, but thin zones of vitric ignimbrite occur within the upper part of the unit in the southwestern part of the Laboratory.

By about 9.5 Ma, pre-Puye fanglomerates ("older fanglomerates" of 9.5–5.3 Ma in Figure 4.2-1) appeared, containing detritus derived from large-scale Keres intermediate to rhyolitic volcanism to the southwest and west. The Keres volcanic centers may have cut off sediment sources from the west (Nacimiento block), but deposition of sands and gravels derived from the Sangre de Cristos in the east continued. A series of basaltic lavas, emplaced to the east (Tb2 in Figure 4.2-1), were erupted contemporaneously with the large-scale Keres Group intermediate to rhyolitic volcanism. The Tb2 basalts are equivalent in age and probably related to basalts exposed to the north in Bayo Canyon. Older fanglomerates and Santa Fe Group sands and gravels are intercalated between these lavas.

Beginning at some time prior to 7.5 Ma, rhyolite sources produced extensive pumiceous deposits that are encountered at drilling depths of about 700 to1800 ft and unknown maximum thickness. Radiometric ages of 7.0 and 7.5 Ma were measured on two samples from borehole R-19, which indicate that these deposits overlap in age with late-stage rhyolitic volcanism of the Keres Group to the southwest (intrusions and domes near Bland Canyon and the Peralta Tuff [Goff et al. 1990, 21574]). These rhyolitic sediments are part of a complex depositional system in the deepening southwestern portion of the Española basin during the late Miocene (Ingersoll et al. 1990).

Relationships between the southwestern rhyolites and the rhyolitic pumice deposits beneath the Laboratory are not known. The full age range of pumiceous deposits beneath the Laboratory remains undefined. The youngest pumiceous deposits may be no older than 5 Ma where they occur above axial stream gravels (probable ancestral Rio Grande deposits) in boreholes in Los Alamos Canyon. The oldest dated pumiceous deposits are late Miocene (7.5 Ma), and they are intercalated between fanglomerates derived from western Keres Group volcanic sources.

The prominent Sierra de los Valles highlands at the western margin of the Laboratory are remnants of Tschicoma volcanic constructs, which began to form in the early Pliocene (~5.3 Ma). The Tschicoma volcanic centers are characterized by large domes with viscous flank lavas up to several hundred feet thick. The Tschicoma volcanic sources provided detritus for the Puye Formation fanglomerates. The Puye Formation dominates the sedimentary history beneath the Laboratory from about 5.3 Ma until the 1.61-Ma eruption of the Otowi Member of the Bandelier Tuff. The proximal and active Tschicoma volcanic sources produced abundant volcaniclastic detritus that pushed the margins of Santa Fe Group deposition farther east.

Starting about 5 Ma, Totavi sediments were deposited in the Laboratory area. The Totavi (axial river gravels) marks the course of the ancestral Rio Grande, which first linked the Española basin with southern portions of the Rio Grande rift. The first appearance of Totavi with abundant quartzite cobbles from northern sources (Rio Mora, Truchas, Picuris, and Taos mountain ranges) marks the establishment of the through-flowing Rio Grande. The ancestral Rio Grande disrupted deposition of Santa Fe Group sands and gravels at the Laboratory site by acting as a barrier to movement of sediment from eastern sources to locations west of the river. Lateral shifting of the ancestral Rio Grande river channel between Tschicoma and Cerros del Rio volcanic barriers at the Laboratory site make the Totavi depositional system complex. Current models suggest widespread lateral migration of the river channel in the earliest Pliocene with a more easterly restriction of the channel at later times up to the present.

Cerros del Rio volcanism (largely basaltic) began to the east at 4.6–3.8 Ma with volcanic centers that fed relatively thin (tens of feet thick) and fluid lavas with interspersed breccia or scoria zones and near-vent accumulations of cinder. Although the Cerros del Rio is mostly basaltic, andesitic and thin dacitic lavas are also present. The age and compositional overlap between the Tschicoma and the Cerros del Rio make attribution of some lavas difficult, notably the "Tschicoma (3.0–2.5?)" lavas shown beneath the western part of the Laboratory in Figure 4.2-1. It is possible that Tschicoma and Cerros del Rio represent a single volcanic system, with eruption of Tschicoma magmas from the central magma chamber, while more basaltic lavas leaked from the eastern margins of the system to form Cerros del Rio eruptions. During and after the major episode of Cerros del Rio volcanism at 3.3–2.2 Ma throughout the eastern Laboratory site, stream gravels of older alluvium derived from mixed sources (including Sangre de Cristo granitic rocks) appear in the stratigraphic record.

The defining event in development of current Laboratory landscape was the eruption of two members of the Bandelier Tuff at 1.61 Ma (Otowi Member) and 1.22 Ma (Tshirege Member) to form the Pajarito Plateau. The 400,000-yr hiatus between Otowi and Tshirege eruptions included a separate erosional cycle with canyons up to 200 ft deep cut into soft, nonwelded ash flows of the Otowi Formation. Within these paleo-canyons Cerro Toledo ash and sediments were deposited. The number and orientations of these earlier canyons are not known, but orientations may be more southerly than the present canyon system. Stream incision after the eruption of the Tshirege Member created the canyons of the Pajarito Plateau, principally within the Tshirege Member. Erosion has been the principal geologic activity at the Laboratory site over the past 1.22 Ma yr.

4.2.2 3-D Geologic Model for the Laboratory

Temporal relations between stratigraphic units are summarized in Figure 4.2-1. Further subdivisions and the interrelationships of volcanic and sedimentary series were used for development of a 3-D model of geology at the Laboratory. The unit descriptions (Table 4.2-1) define the stratigraphic components that have been used to subdivide the 3-D space beneath the Laboratory, down to depths of approximately 3000 ft. The 3-D geologic model incorporates data from published maps (Goff 1990, 21574; Dethier 1997, 49843; Rogers 1995, 54419) as well as yet unpublished maps of the Puye (Dethier, in press) and Frijoles (Goff, in press) geologic quadrangles. For the central and western Laboratory site, the 3-D geologic model relies heavily on subsurface data from more than 30 deep wells. A major effort has been made to capture features of hydrogeologic significance, emphasizing characterization of those geologic features believed to be pertinent to groundwater flow. Units perceived to have hydrogeologic importance and that have heterogeneous physical characteristics that can be measured and correlated in three dimensions were subdivided. Figure 4.2-2 shows a simplified block view of the 3-D geologic model. Contact surfaces for the 3-D geologic model were generated by the following steps.

1. Creating a plot whose contours show structural offsets removed. Data-support included controls indicating the absence of the unit.
2. Hand-contouring of the surface based on the data and constrained by the conceptual model based on current interpretations of geologic history at the Laboratory (Section 4.2.1).
3. Machine gridding, with the hand-drawn contours, borehole control points, other quality (global positioning system [GPS] location) data as input, and a bias to fit the point data. The ANUDEM software (Hutchinson, 1996), as implemented by the ArcInfo geographic information system (GIS), was used to create topographically realistic grids.
4. Using various software (ArcInfo, Stratamodel) to insure appropriate melding of the full set of contact surfaces into a computationally consistent model.

Alternative models were created for several units of possible hydrogeologic importance providing the most likely (conceptually) and a worst-case (hydrogeologically) scenarios. Models were made for the basalts of Bayo Canyon (Tb2) and the Cerros del Rio basalts (Tb4), including spatially defined volumes that could be identified as either basalt or sediments during numerical groundwater-flow modeling processes.

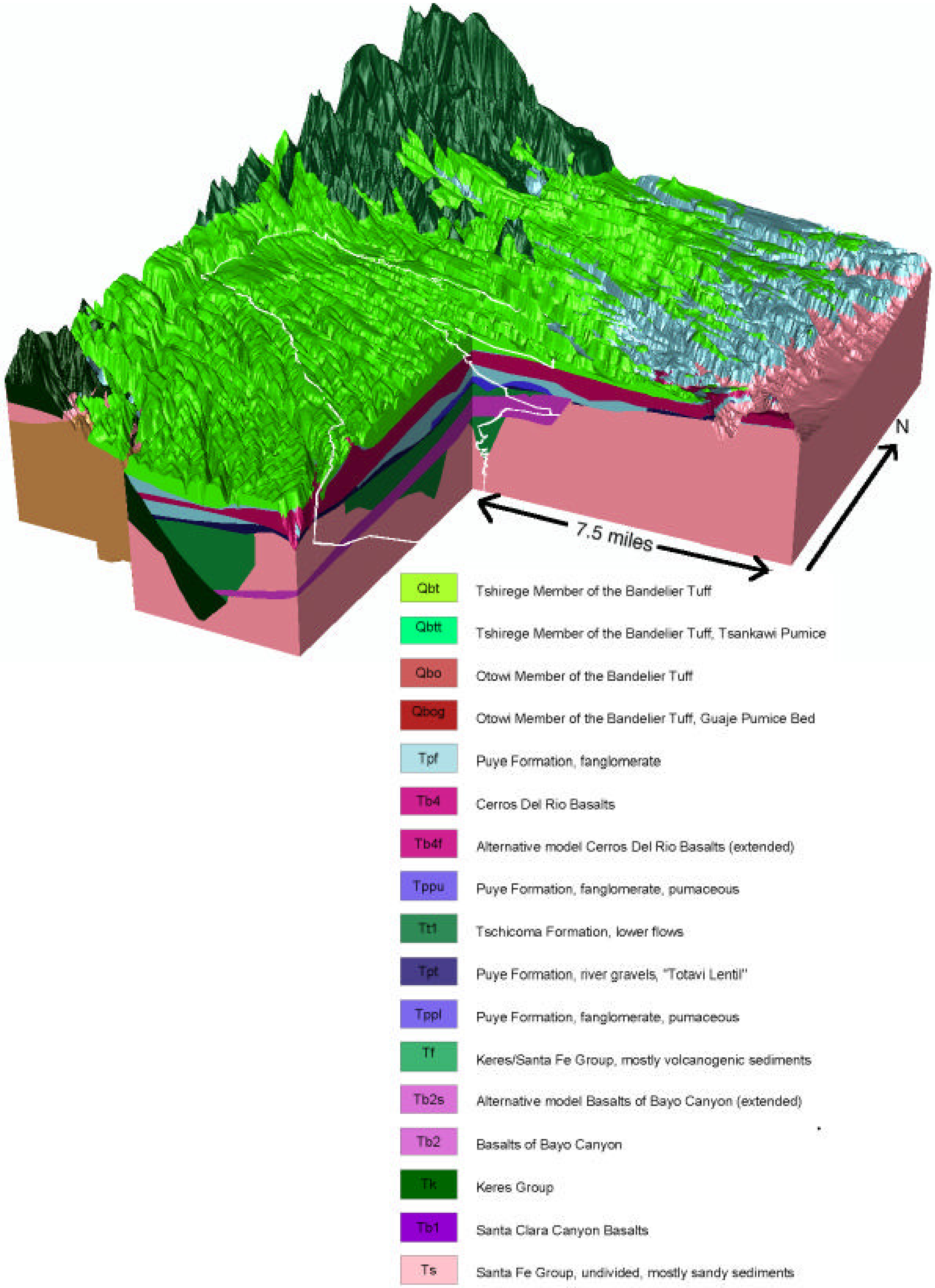


Figure 4.2-2. Simplified block view of Pajarito Plateau 3-D geologic model

Units perceived to have hydrogeologic importance and which had differentiable physical characteristics that could be measured and correlated in two dimensions (x, y) were assigned attributes for these characteristics within an x-y grid conforming to the x-y spatial extent of the unit. For example, the Cerros del Rio deposits (Tb4) consist of numerous flows and interzones that are difficult, if not impossible, to correlate between borehole observations. Although subunits for the multiple flows are not modeled, the percentages of flow interior, clay-filled breccia, and open breccia within the Tb4 interval are modeled as two-dimensional (2-D) distributed properties. These percentage measurements provided a 2-D distribution for each of these attributes within the range of (x, y) data support provided by the borehole locations. Two-dimensional, gridded attribute distributions were created for all basalt units and subunits of the Puye Formation (Tpp, Tpf), using splining or kriging. High hydraulic transmissivities are suspected where large thicknesses of Tb4 and high percentages of open breccia coincide. Further work on the distribution of hydrogeologic variability within Tb4 will be pursued.

4.2.3 Geologic Structure

The Laboratory is located on the Pajarito Plateau near the western margin of the Española basin of the Rio Grande rift. The Pajarito Fault system is the major border fault on the west side of the basin. This fault system has experienced Holocene movement and historic seismicity (Gardner and House 1987; Gardner et al. 1999, 63492; Gardner et al. 2001, 70106). Characterized by north-trending normal faults that intertwine along their traces, the Pajarito Fault system shows dominantly downeast movement and produces a series of prominent fault scarps west of the Laboratory. East of the major downeast faults is a zone of distributed, predominantly downwest structures extending more than 10,000 ft east of the major fault scarps. These antithetic structures reflect the extensional nature of the structural regime and reduce the amount of net (apparent) vertical throw by up to 40%. The net vertical throw on this fault system is over several hundred feet/million years in areas south and west of the Laboratory but decreases north of Los Alamos Canyon, where the fault system is less prominent.

In addition to the main traces of the Pajarito Fault system, other faults cut the Pajarito Plateau. The Rendija Canyon Fault is a normal fault trending north-south in the northwestern part of the plateau; it crosses Pueblo Canyon near its confluence with Acid Canyon and Los Alamos Canyon near TA-41 but does not have clear surface expression south of Sandia Canyon. The Guaje Mountain Fault parallels the Rendija Canyon Fault and is projected to cross Los Alamos Canyon near TA-2, although there is no clear offset of the Tshirege Member south of North Mesa. North of the Laboratory both these faults have downwest displacement and zones of gouge and breccia up to several meters wide, and they produce recognizable scarps with visible offset of stratigraphic horizons.

A structural block model has been developed that allows spatial reconstruction of the control data within the 3-D geologic model of the Laboratory for any time in the past. This structural block model was developed with assistance from the Seismic Hazards Project and is based on faults and offsets identified by Gardner and House (1987), Gardner et al. (1999, 63492; 2001, 70106), and Lewis et al. (2002). Each structural block defines a region that has a nonlinear offset relative to adjoining blocks. Based on offsets within the Tshirege Member of the Bandelier Tuff (1.22 Ma), a constant-rate offset model was developed for the major faults and fault zones back to 5 Ma. Prior to that time, major faulting is assumed to have occurred west of the site (Aldrich and Dethier 1990), although some pre-Bandelier faulting has occurred closer to the site as evidenced by fault traces within the Puye geologic quadrangle (Dethier, in press), field observations (WoldeGabriel and Warren, personal communication), and possible offsets in some of the modeled topographic surfaces for older units. Given the lack of quantifiable observations, additional offset prior to 5 Ma is not included in the current structural model.

Figure 4.2-3 identifies the maximum fault offsets within the site-wide structural model. These gridded offsets were applied when modeling units with an age of 5 Ma or older. Gridded offsets were subtracted from the elevations of the unit control points to allow contouring of "paleo" contact surfaces. Offsets then were added back to the final contact surface grids to reconstruct the current unit offsets. These fault offsets can be seen in various sections produced from the 3-D geologic model.

4.3 Hydrologic Setting

The hydrogeologic conceptual model for the Laboratory was described in Section 3.0. In the Los Alamos area, groundwater occurs in three modes: (1) water in shallow alluvium and underlying tuff in some of the larger canyons, (2) intermediate perched zone groundwater (a perched groundwater body above a less permeable layer and separated from the underlying aquifer by an unsaturated zone), and (3) the regional aquifer of the Los Alamos area.

4.3.1 Alluvial Groundwater

Alluvium as much as 100 ft thick has been deposited in the canyons of the Pajarito Plateau by intermittent and ephemeral streamflows. Alluvium in canyons that originate in the Jemez Mountains is generally composed of sands, gravels, pebbles, cobbles, and boulders derived from the Tschicoma Formation and from Bandelier Tuff on the flanks of the mountains. Alluvium in canyons that originate on the Pajarito Plateau is relatively fine-grained and consists of clays, silts, sands, and gravels derived from the Bandelier Tuff.

Ephemeral runoff in some canyons infiltrates the alluvium until downward movement is impeded by less-permeable underlying strata. The impeded downward movement results in a buildup of shallow alluvial groundwater. In some cases, relatively thin zones of shallow groundwater can be contained in the weathered tuff or some other geologic unit immediately underlying the alluvium. The horizontal and vertical extent of the alluvial groundwater is limited by depletion via ET and movement into the underlying rocks (Purtymun et al. 1977).

Lateral flow of alluvial groundwaters is down-canyon and easterly. Purtymun (1974, 5476) estimated that the velocity of alluvial groundwater flow ranges from about 60 ft/day in the upper reach of Mortandad Canyon to about 7 ft/day in the lower reach of the canyon. Purtymun (1974, 5476) determined field-scale hydraulic conductivity values for several zones of different texture within the Mortandad Canyon alluvium, which were identified in a study by Baltz et al. (1963, 8402). Chloride and tritium tracer measurements were used to estimate the hydraulic conductivities. The upper zone has a hydraulic conductivity of 1.6×10^{-3} m/s between MCO-5 and MCO-6. The lower zone has a hydraulic conductivity of 5.8×10^{-4} m/s between MCO-6 and MCO-7.5, and 8.8×10^{-5} m/s between MCO-7.5 and MCO-8. These estimates of alluvial sediment hydraulic properties are for Mortandad Canyon and their applicability to alluvium in other canyons will be the subject of future investigations.

4.3.2 Perched Intermediate Groundwater

The areas where intermediate perched zone groundwater has been encountered in wells are shown in Table 4.3-1. 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 wetter mesas than observed in drier mesas. In addition to spring discharge at mesa sides, saturated and unsaturated flow through mesas results in recharge to the underlying intermediate perched zones or the regional aquifer. In the western portion of the Laboratory, there is a large (300-ft-thick) intermediate perched zone within the lower Bandelier Tuff and the Puye Formation, approximately 700 ft below the mesa top.

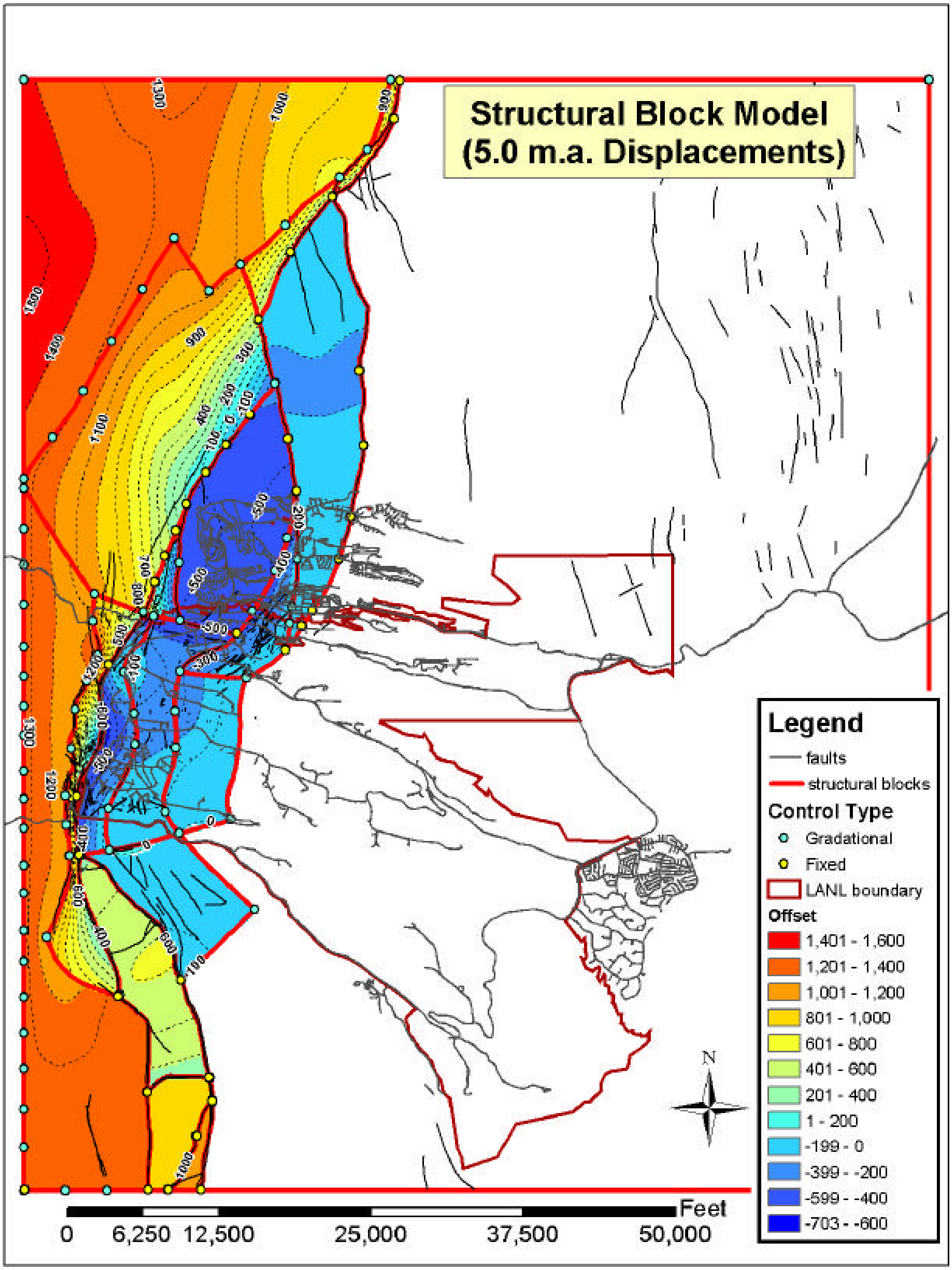


Figure 4.2-3. Structural block model for Pajarito Plateau

Table 4.3-1
Occurrences of Intermediate-Depth Perched Groundwater

Well	Perched Water Level Depth (ft)	Unit Containing Perched Saturation	Data Source
Pueblo Canyon			
TW-2A	120	Puye Formation	Purtymun 1995, 45344
O-1	183	Puye Formation	Purtymun 1995, 45344
TW-1A	180	Cerros del Rio basalt	Purtymun 1995, 45344
R-5	375	Cerros del Rio basalt	Well completion report expected to be completed by 3/30/03
Los Alamos Canyon			
H-19	(20-ft interval)	Guaje Pumice bed	LANL 1995, 50290
R-7	378	Guaje Pumice bed/Puye Formation	Stone 2002, 72717
LAO(A)	295	Guaje Pumice bed	LANL 1995, 50290
LADP-3	325	Guaje Pumice Bed	LANL 1995, 50290
O-4	253	Puye Formation	Purtymun 1995, 45344
R-9	137	Cerros del Rio basalt	Broxton et al. 2001, 71250
R-9	264	Cerros del Rio basalt	Broxton et al. 2001, 71250
R-9	524	Cerros del Rio basalt	Broxton et al. 2001, 71250
Sandia Canyon			
R-12	424	Cerros del Rio basalt	Broxton et al. 2001, 71252
PM-1	450	Cerros del Rio basalt	Purtymun 1995, 45344
Mortandad Canyon			
MCM-51	55	Tsankawi/Cerro Toledo	LANL 1997, 56835
MCM-5.9	105	Tsankawi/Cerro Toledo	LANL 1997, 56835
R-15	646	Cerros del Rio basalt	Longmire et al. 2000, 66602
MCOBT-4.4	493	Puye Formation	Broxton et al. 2002
Pajarito Canyon			
SHB-4	145	Cerro Toledo interval	LANL 1998, 59577
R-19	909	Puye Formation	Broxton 2001, 71253
54-1016	592	Cerros del Rio basalt	LANL 1998, 59577
Cañon de Valle			
R-25	747	Otowi Member	Broxton et al. 2002, 72640
Ancho Canyon			
R-31	440	Cerros del Rio basalt	Vaniman et al. 2002, 72615

The vertical and lateral extent of the perched zones, the nature and extent of the perching units, and the potential for migration of perched groundwater to the regional aquifer are not fully understood. However, based on data from wells that intersect intermediate perched groundwater, it appears that the perched saturated zones do not have significant vertical extent. Lateral movement of intermediate perched groundwater may occur if the dip of the perching horizon and the canyon orientation do not coincide. Most recharge for westside perched intermediate groundwater originates as underflow of groundwater from the Jemez Mountains, with some contribution from recharge through mesas and canyon bottoms. Discharge from intermediate perched zones occurs at springs or results in recharge to the underlying regional aquifer. Studies have shown that the intermediate perched zone groundwater in Pueblo Canyon is hydrologically connected to the stream in Pueblo Canyon (Abrahams and Purtymun 1966). This perched zone water discharges at the base of the basalt at Basalt Spring, located on San Ildefonso Pueblo land east of the Laboratory in lower Los Alamos Canyon. The estimated rate of movement of perched groundwater in this vicinity is about 60 ft/day, or about six months from recharge to discharge (Purtymun and Rogers 2002).

The direction and flux of water through the unsaturated zone have been examined in two studies. Rogers and Gallaher (1995, 55334) tabulated Bandelier Tuff core hydraulic properties from several boreholes at the Laboratory to estimate recharge rates beneath the Pajarito Plateau. Rogers et al. (1996, 55543) used hydraulic properties from seven boreholes that had sufficient data to evaluate movement of water in the vadose zone. The seven boreholes were from mesa-top and canyon-bottom locations, which represent two of the distinct hydrologic regimes on the Pajarito Plateau. Most head gradients determined for the boreholes were approximately unity, implying that flow is nearly steady state. One exception was found for boreholes at TA-54, Area G, where gradient reversals at depths of about 100 ft suggest evaporative drying may be occurring.

Infiltration rates for liquid water at the seven locations were approximated by Rogers et al. (1996, 55543), who used vertical head gradients and unsaturated hydraulic conductivity estimates in their calculations. As such, the apparent fluxes beneath mesa-top locations range from approximately 0.06 cm/yr beneath Area G to 245 cm/yr directly beneath the TA-53 surface impoundments. It is believed that high precipitation or surface disturbances (e.g., anthropogenic ponds) lead to higher fluxes beneath some mesas. Beneath Cañada del Buey and Potrillo Canyon, two typically dry canyons, the apparent canyon-bottom infiltration rates range from 0.4 to 8.3 cm/yr. Beneath Mortandad Canyon, the only relatively wet canyon for which data are currently available, canyon-bottom infiltration rates range from 1 to 10 cm/yr. Data from several wetter canyons have been interpreted to provide more comprehensive estimates. In Los Alamos Canyon, moisture profile measurements in canyon well LADP-3 were estimated to be consistent with infiltration rates of about 10 to 60 cm/yr. Similar estimation techniques for well R-15 in Mortandad Canyon yield estimates of on the order of 50 cm/yr. Such values are large enough that contaminants are predicted to travel through at least 100 m of Bandelier Tuff during the time of Laboratory operations. This result is consistent with the observations of relatively deep penetration of contaminants such as perchlorate ion in R-15.

4.3.3 Regional Aquifer

The groundwater hydrology of this site is influenced by many factors, including geologic setting, climate, topography, both natural and anthropogenic-derived surface water flows across the Pajarito Plateau, groundwater development (both locally and regionally), and regional flow directions.

In the saturated zone, the geologic framework can influence flow direction and velocity by influencing the spatial distribution of permeability and porosity. The geologic framework can influence solute transport by controlling the spatial distribution of chemically reactive minerals. Both permeability and porosity can be controlled by primary geologic processes (e.g., depositional facies, cooling fractures in basalt flows) and/or secondary processes such as diagenesis, pedogenesis, and rock/water interactions over geologic time.

4.3.3.1 Permeability

The geologic framework, as expressed in the site-wide 3-D geologic model, defines *35* units. Several methods were used to estimate permeability variations within and between a portion of these units. These methods, ordered in increasing spatial scale, are borehole geophysics (centimeters) and analysis of water-level responses to instantaneous injection in a single well (tens of meters), 1- to 10-day pump tests (10–100s of meters), and decades of pumping in wells across the plateau (1000s of meters). Results from the first three methods are presented in Table 4.3-2. For comparison, estimates for the Santa Fe Group collected in other parts of the Española Basin (Daniel B. Stephens & Associates, 1994) are included. These data are plotted in Figure 4.3-1, grouped according to the dominant rock type within the screened interval of the tested well. (For comparison, estimates for the Santa Fe Group from other locations in the basin are also shown. Rock types 11 to 1 are defined in Table 4.3-3.) Mean permeability values for six units ranged between $10^{-11.5}$ and 10^{-13} m^2; however, within-unit variability tends to be larger than between-unit variability. Very low permeability (less than 10^{-13} m^2) zones occurred within the Puye Formation, the Santa Fe Group, and Cerros del Rio basalts. The highest permeability estimate (greater than 10^{-11} m^2) was for a well completed within the Totavi Lentil. There is no apparent tendency for the three methods of estimating permeability to provide systematically different results.

Table 4.3-2
Hydraulic Conductivity Estimates

Dominant Rock Type	Well	Method	Hydraulic Conductivity (ft/day)	Permeability Log (m^2)	Source
Bayo Canyon Basalt	PM-5	Pump test	0.71	–12.6	1
Cerros del Rio	DT-10	Pump test	14.87	–11.3	1
Cerros del Rio	R-22-2	Injection	0.04	–13.8	2
Cerros del Rio	R-31-3	Injection	0.41	–12.8	2
Cerros del Rio	R-9i-1	Injection	4.87	–11.8	2
Cerros del Rio	R-9i-2	Injection	0.11	–13.4	2
Cerros del Rio	R-9i-1	Injection	3.88	–11.9	2
Cerros del Rio	R-9i-1	Pump test	4.75	–11.8	2
Older Basalt	G-5	Pump test	1.17	–12.4	1
Older Basalt	G-6	Pump test	0.90	–12.5	1
Older Basalt	GR-1	Pump test	0.50	–12.6	3
Older Basalt	GR-3	Pump test	1.30	–12.3	3
Older Basalt	R-22-4	Injection	0.54	–12.7	2
Older Basalt	R-22-4	Injection	0.72	–12.6	2
Tschicoma	CdV-R-37-3	Injection	7.01	–11.6	4
Tschicoma	CdV-R-37-4	Injection	11.36	–11.4	4
Tschicoma	TW-4	Pump test	2.55	–12.0	1
Puye	CdV-R-15 (all Puye)	Geophys	0.60	–12.7	5
Puye	R-19 (all Puye)	Geophys	0.30	–13.0	5
Puye (pumiceous & fang)	R-13	Pump test	13.70	–11.3	2
Puye (pumiceous & fang)	R-13	Pump test	21.40	–11.1	2
Puye fanglomerate	CdV-R-15-3-4	Geophys	0.20	–13.1	5

Table 4.3-2 (continued)

Dominant Rock Type	Well	Method	Hydraulic Conductivity (ft/day)	Permeability Log (m^2)	Source
Puye fanglomerate	CdV-R-15-3-5	Geophys	0.20	–13.1	5
Puye fanglomerate	CdV-R-15-3-5	Injection	0.25	–13.0	4
Puye fanglomerate	R-22-3	Injection	0.21	–13.1	2
Puye fanglomerate	R-22-5	Injection	0.27	–13.0	2
Puye pumiceous	TW-8	Pump test	3.35	–11.9	1
Puye pumiceous	CdV-R-15-3-6	Geophys	0.70	–12.6	5
Puye pumiceous	CdV-R-15-3-6	Injection	0.10	–13.4	4
Puye pumiceous	R-19-6	Geophys	1.40	–12.3	5
Puye pumiceous	R-19-6	Injection	1.10	–12.4	2
Puye pumiceous	R-19-7	Geophys	0.60	–12.7	5
Puye pumiceous	R-19-7	Injection	0.73	–12.6	2
Puye pumiceous	R-7	Geophys	0.10	–13.4	5
Totavi Lentil	R-31-4	Injection	1.23	–12.4	2
Totavi Lentil	R-31-5	Injection	0.75	–12.6	2
Totavi Lentil	TW-1	Pump test	0.54	–12.7	1
Totavi Lentil	TW-2	Pump test	32.29	–10.9	1
Totavi Lentil	TW-3	Pump test	16.08	–11.2	1
Santa Fe Group - fanglomerate	O-4	Pump test	4.02	–11.8	1
Santa Fe Group - sandy	DT-9	Pump test	16.35	–11.2	1
Santa Fe Group - sandy	G-1	Pump test	0.94	–12.5	1
Santa Fe Group - sandy	G-1A	Pump test	1.22	–12.4	1
Santa Fe Group - sandy	G-2	Pump test	1.22	–12.4	1
Santa Fe Group - sandy	G-3	Pump test	0.71	–12.6	1
Santa Fe Group - sandy	G-4	Pump test	1.51	–12.3	1
Santa Fe Group - sandy	GR-2	Pump test	0.60	–12.6	3
Santa Fe Group - sandy	GR-4	Pump test	0.70	–12.4	3
Santa Fe Group - sandy	LA-1B	Pump test	1.25	–12.3	1
Santa Fe Group - sandy	LA-2	Pump test	0.47	–12.8	1
Santa Fe Group - sandy	LA-3	Pump test	0.44	–12.8	1
Santa Fe Group - sandy	LA-4	Pump test	0.76	–12.6	1
Santa Fe Group - sandy	LA-5	Pump test	0.40	–12.8	1
Santa Fe Group - sandy	LA-6	Pump test	1.22	–12.4	1
Santa Fe Group - sandy	O-1	Pump test	0.63	–12.6	1
Santa Fe Group - sandy	PM-1	Pump test	4.15	–11.8	1
Santa Fe Group - sandy	PM-3	Pump test	23.99	–11.1	1
Santa Fe Group - sandy	PM-4	Pump test	3.22	–11.9	1

Table 4.3-2 (continued)

Dominant Rock Type	Well	Method	Hydraulic Conductivity (ft/day)	Permeability Log (m^2)	Source
Santa Fe Group - undifferentiated	Not reported in cited reference	Not reported in the cited reference	0.68	–12.6	6
Santa Fe Group - undifferentiated	Not reported in cited reference	Not reported in the cited reference	0.43	–12.8	6
Santa Fe Group - undifferentiated	Not reported in cited reference	Not reported in the cited reference	0.12	–13.4	6
Santa Fe Group - undifferentiated	Not reported in cited reference	Not reported in the cited reference	0.09	–13.5	6
Santa Fe Group - undifferentiated	Not reported in cited reference	Not reported in the cited reference	0.51	–12.7	6
Santa Fe Group - undifferentiated	Not reported in cited reference	Not reported in the cited reference	4.55	–11.8	6
Santa Fe Group - undifferentiated	Not reported in cited reference	Not reported in the cited reference	0.34	–12.9	6
Santa Fe Group - undifferentiated	Not reported in the cited reference	Not reported in the cited reference	0.66	–12.6	6
Santa Fe Group - undifferentiated	Not reported in cited reference	Not reported in the cited reference	0.12	–13.3	6
Santa Fe Group - undifferentiated	Not reported in cited reference	Not reported in the cited reference	2.41	–12.1	6
Santa Fe Group - undifferentiated	Not reported in cited reference	Not reported in the cited reference	14.39	–11.3	6
Santa Fe Group - undifferentiated	Not reported in cited reference	Not reported in the cited reference	0.91	–12.5	6
Santa Fe Group - undifferentiated	Not reported in cited reference	Not reported in the cited reference	0.08	–13.5	6
Santa Fe Group - undifferentiated	Not reported in cited reference	Not reported in the cited reference	0.12	–13.4	6
Santa Fe Group - undifferentiated	Not reported in cited reference	Not reported in the cited reference	0.13	–13.3	6

Note: (permeability (m^2) = hydraulic conductivity (ft/day) x 3.6 x 10^{-13}).

*Data sources:

1. Purtymun (1995, 45344).
2. Stone and McLin (in prep.).
3. John Shomaker and Associates (1999).
4. Fact Sheets for characterization wells.
5. Borehole geophysics logs prepared by Schlumberger, Inc.
6. Daniel B. Stephens & Associates (1994).

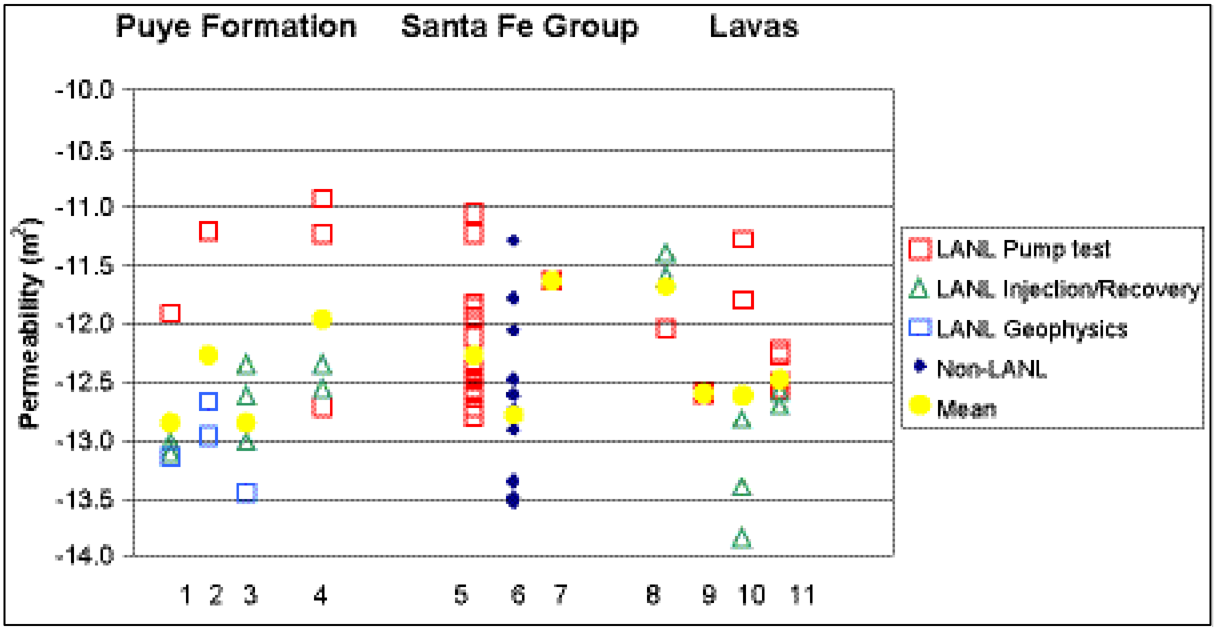


Figure 4.3-1. Permeability estimates for rock types on the Pajarito Plateau

Table 4.3-3
Rock Types Shown in Figure 4.3-1

1	Puye – fanglomerate (Tpf)	7	Santa Fe Group – fanglomerate (Tf)
2	Puye- undifferentiated	8	Tschicoma Formation (Tt)
3	Puye – pumiceous (Tpu, Tpl)	9	Bayo Canyon basalt (Tb2)
4	Totavi Lentil (Tpt)	10	Cerros del Rio basalt (Tb4)
5	Santa Fe Group – sandy (Ts)	11	Older basalts (Tb1)
6	Santa Fe Group - undifferentiated		

Note: Unit symbols are described in Table 4.2-1.

Analysis of large-scale temporal and spatial trends in water levels across the plateau (Keating et al. 2000) also suggests that there may be little difference between the mean effective permeability of the rock types present on the Pajarito Plateau. Large-scale (kilometers) aspects of the groundwater flow system, as evidenced by water-level data, appear to be controlled by the spatial distribution of recharge, topography, and pumping.

The three methods of estimating permeability (Figure 4.3-1) demonstrate that significant heterogeneity exists within the major rock types present within the saturated zone at the site. Model calibration results (Keating et al. 1999; Keating et al. 2000) supply further evidence. This heterogeneity may play an important role in local-scale flow directions and velocity. For simulating solute transport, statistical methods are appropriate for addressing this scale of heterogeneity. Both purely stochastic and geologic-based stochastic approaches, ascertained from site-specific geologic and hydrologic data, are described in Keating et al. (2000). These approaches can be applied for predictions of small-scale transport in a stochastic framework.

4.3.3.2 Porosity

There are two current sources of site-specific information about porosity. The first is borehole geophysics, which provides measurements at very small scales (centimeters). These have been summarized for the Puye Formation (LANL 1998, 59599). Mean values range from 0.01 to 0.2. Corresponding estimates of permeability are based on a theoretical relationship which predicts that permeability and porosity are correlated (see Figure 4.3-2, for R-19). Within the range of large-scale effective permeabilities measured at the site (see Figure 4.3-1, 10^{-12} to 10^{-14}, typical values of porosity are 0.1 to 0.3).

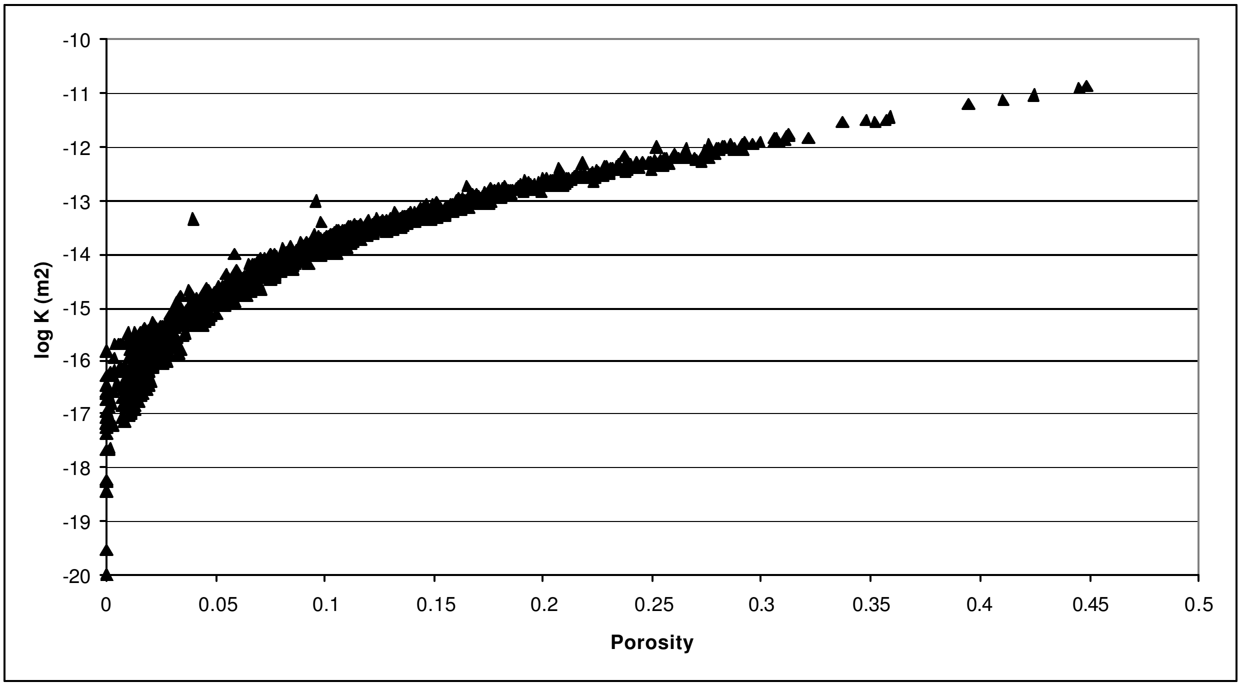


Figure 4.3-2. Estimates of porosity in well R-19 based on theoretical relationship that predicts permeability and porosity are correlated

The other source is carbon-14-based age estimates for groundwater. These data were originally collected by Spangler (Rogers et al. 1996, 55429) and have been since corrected for d^{13}C by Kwicklis (Keating et al. 2000). Age estimates provide constraints on the range of large-scale effective permeability and porosity possible for the aquifer. Simulations of carbon-14 suggest that waters sampled at wells on the plateau represent a mixture of waters of a wide range of ages. In flow and transport simulations, assuming values of porosity shown in Table 4.3-4, a reasonable agreement between measured and simulated mean groundwater age for most wells was achieved. Water sampled in wells near the Rio Grande, however, is much older than the model predicts. Possible reasons for this discrepancy are that the porosity values shown in Table 4.3-4 are too low or that the model misrepresents the mixing of young and old water near the river.

The porosity assumed for basalts (0.05) corresponds to measurements made at Idaho National Engineering and Environmental Laboratories and represents effective porosity of fractured rock. The degree to which fracture-flow occurs in basalts beneath the Laboratory is unknown.

Table 4.3-4
Porosity Estimates Literature-Derived

Parameter		Porosity [–]
Name	**Code**	
Precambrian	PC	0.02
Shallow Precambrian	Frac. PC	0.02
Paleozoic/Mesozoic	P/M	0.10
Pajarito Fault Zone	Paj. Fault	0.10
Tschicoma Formation	Tt	0.05
Tschicoma Formation—shallow	Frac. Tt	0.05
Cerros del Rio basalts	Tb	0.05
Puye—fanglomerate	Tpf	0.25
Puye—Totavi Lentil	Tpt	0.30
Chaquehui Formation	Tsfuv	0.30
Santa Fe Group	Ts	0.25
Ancha Formation	Ancha	0.25

Source: Keating et al. (2000).

4.3.3.3 Discharge

The primary discharge zone for the regional aquifer is the Rio Grande. Several studies have concluded that the reach of the Rio Grande between Otowi Bridge and Cochiti Reservoir has historically gained between 0.009 and 0.023 m^3/s/km (see Keating et al. 2002). The reach directly downstream of the Laboratory (between Otowi and Frijoles Canyon, 18.5 km) receives 0.17–0.43 m^3/sec total discharge from the aquifer. Assuming roughly 50% of the discharge to this reach is from the west (model results suggest this proportion could be even larger), total flux from the aquifer beneath the Laboratory to the Rio Grande would be 0.09–0.22 m^3/sec.

Groundwater also discharges to springs along White Rock Canyon, totaling ~0.091 m^3/sec (Purtymun 1966, 11789). It is unclear what proportion (if any) of this water is discharging from perched aquifers rather than from the regional system.

4.3.3.4 Recharge

The posited conceptual model of aquifer recharge is that the predominant proportion of recharge occurs at high elevations (greater than ~2200 m). Some recharge does occur at lower elevations along wet canyons. Very little recharge occurs at lower elevations along mesa tops. The body of evidence to support this conceptual model includes water budget studies and streamflow studies both on the Pajarito Plateau (Gray 1997, 58208; Keating et al. 1999) and in the eastern portion of the Española basin (Wasiolek 1995). Chloride mass balance studies both on the plateau (Newman 1996, 59118; Keating et al. 1999) and in the eastern portion of the basin (Anderholm 1994) confirmed the validity of the model. Finally, analysis of head gradients both on the Pajarito Plateau and in the larger basin (Keating et al. 1999; Keating et al. 2000; Keating et al. 2002) provides supporting evidence for the conceptual model.

Kwicklis (Keating et al. 1999) calculated that total streamflow losses across Laboratory property total ~0.009 m^3/sec. If all streamflow loss became aquifer recharge, this "canyon-focused" recharge would represent a maximum of 4% to 10% of the total flux through the aquifer beneath the Laboratory. Since chloride mass balance studies suggest that recharge rates through mesa tops within the Laboratory boundaries are extremely low, the remainder of aquifer recharge (at least 90–96%) must originate in relatively high elevations, west of the Laboratory. Simulations of flow and transport within the regional aquifer acknowledge that the ratio of high-elevation, diffuse recharge, and lower-elevation canyon-focused recharge is uncertain; therefore, the ratio is allowed to vary widely during analyses of model sensitivity. Examples of models used in sensitivity analyses are shown in Figure 5.1-3.

Oxygen isotopes can be used as an indicator of recharge elevations for groundwaters in regions where a strong relationship exists between elevation and oxygen isotope concentrations in precipitation. Such a relationship has been proposed by Vuataz and Goff (1986, 73687), but no precipitation data were presented. In a study of oxygen isotope concentrations in groundwater in the eastern portion of the basin, including the Buckman well field, Anderholm (1994) concluded that oxygen isotope data in groundwater were not useful tracers of flowpaths in this region.

4.3.3.5 Groundwater Development

The 50-yr history of production from wells on the Pajarito Plateau and the nearby Buckman well field is shown in Figure 4.3-3. The impact of pumping on water levels in the area has been variable; variations are controlled by rock types and production rates. The most dramatic declines have occurred in the Buckman well field (over 90 m). Declines up to 30 m have been observed in the Guaje and Los Alamos well fields. Relatively modest (less than 15 m) declines have occurred in the vicinity of Pajarito Mesa wells. Very little decline (less than 5 m) has occurred to the south (DT wells) and west (TW-4) of the water supply well fields.

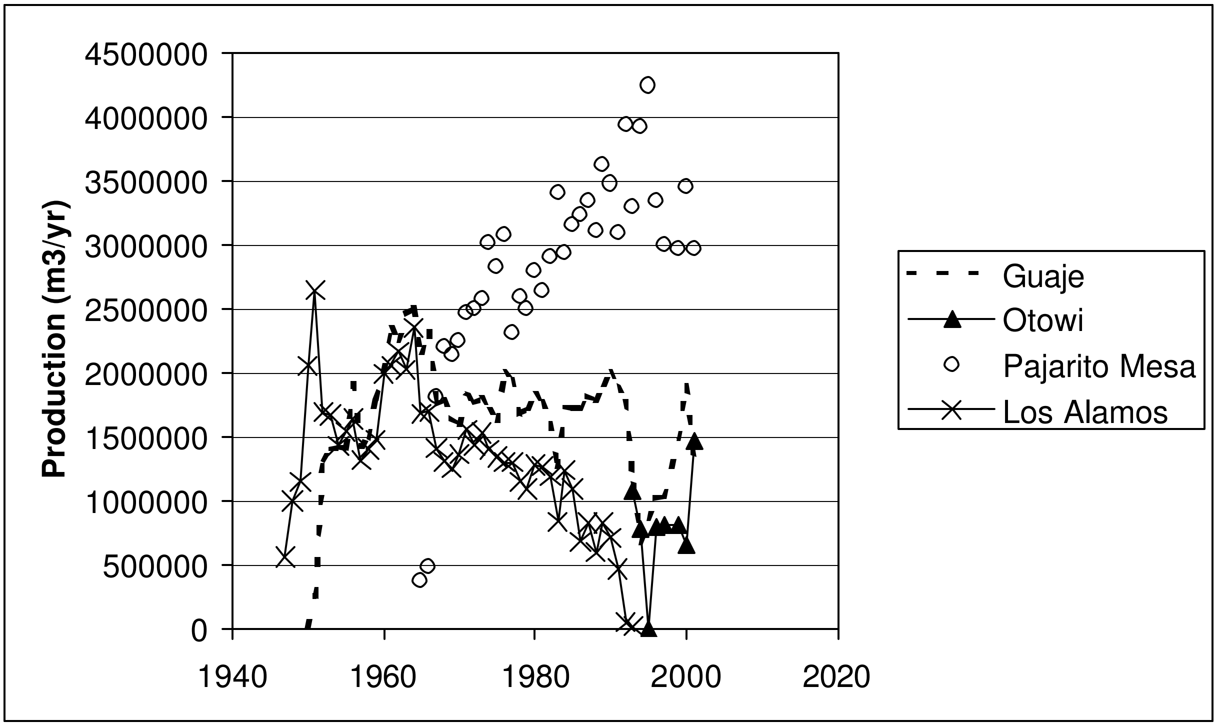
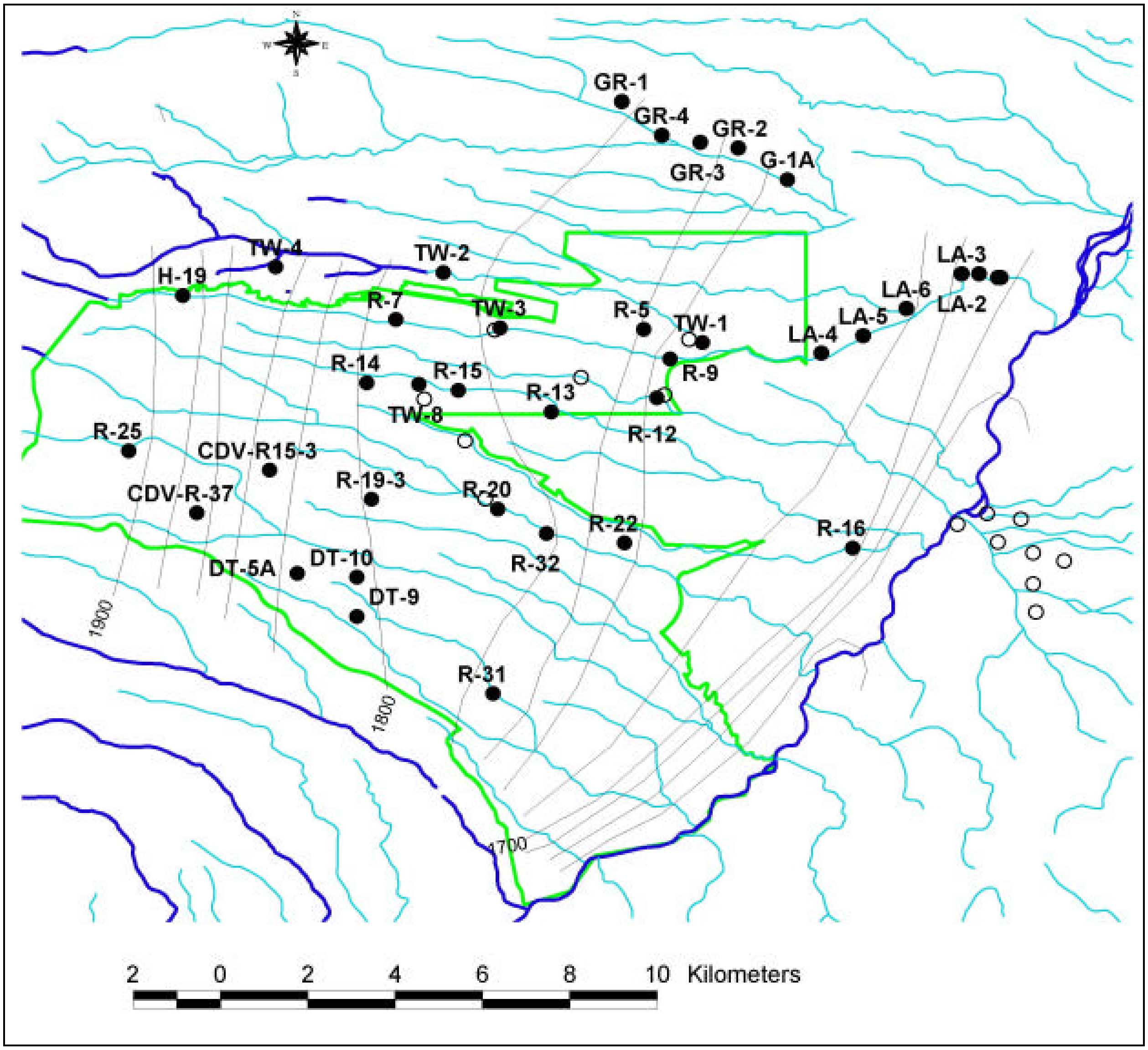


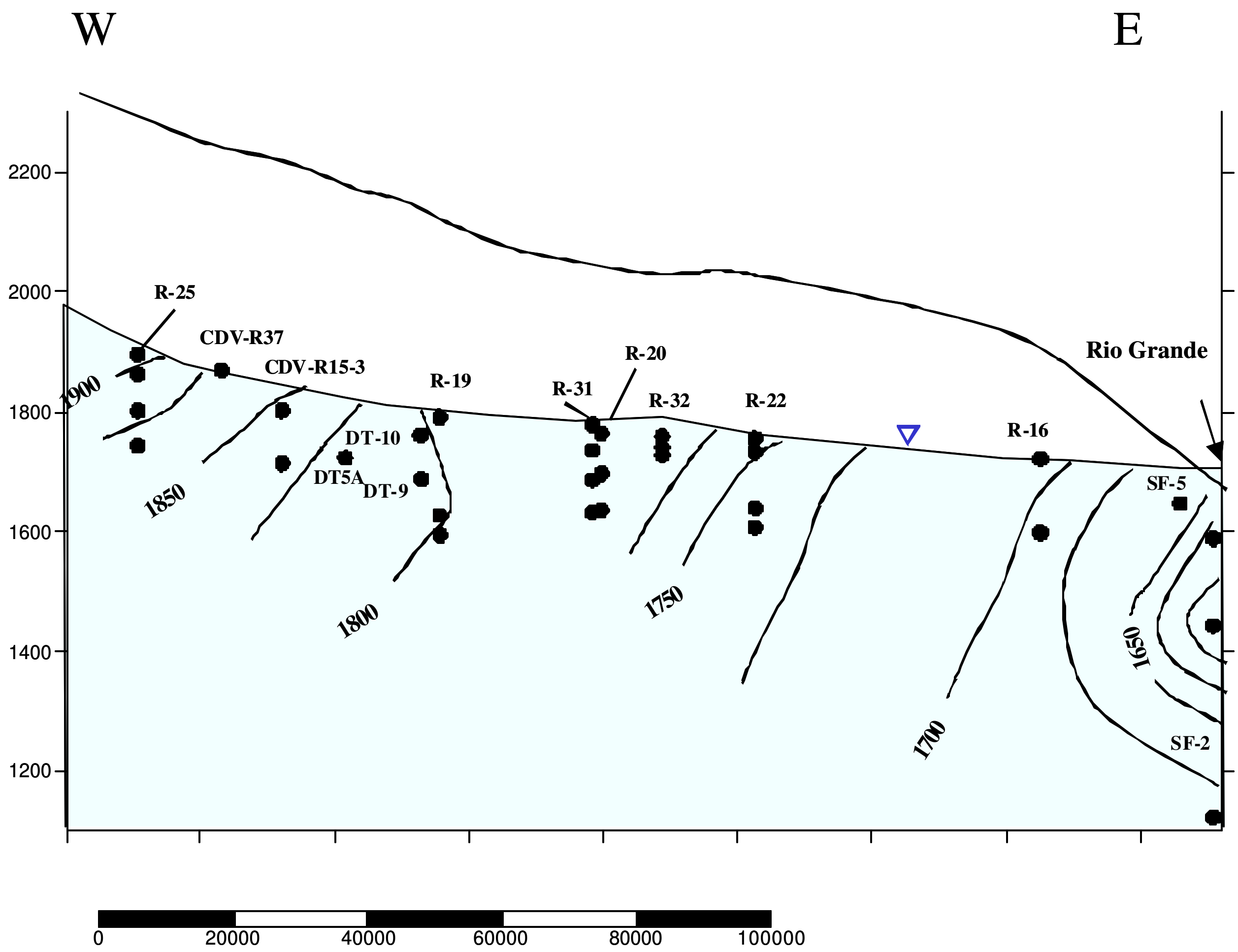
Figure 4.3-3. Production from wells on Pajarito Plateau and nearby Buckman well field

Figures 4.3-4 and 4.3-5 show the most recent contoured water-level data available for the plateau. Figure 4.3-4 represents the elevation of the water table primarily using data from wells screened at or near the water table. This figure is based on data shown in Table 4.3-5, some of which are very preliminary (R-wells drilled in the summer of 2002). The map of the water table suggests that the horizontal component of flow in the regional aquifer is predominately from west to the east, with perturbations in the center of the plateau that probably are caused by pumping. It is possible, however, that local flow directions may depart from regional flow directions. Local scale geochemical, geologic, and hydrologic data might be necessary to determine if such departures exist.



Contour interval = 20 m

Figure 4.3-4. **Water table map, using primarily data from wells with relatively short screens at or near water table**



Contour interval = 25 m

Figure 4.3-5. **East-west cross-section of head data from the regional aquifer, using wells in southern portion of the Laboratory**

Table 4.3-5
Water Table Elevations Beneath the Laboratory

Well		Date	Head		Source
			(ft)	(m)	
Water supply	G-1A	2001	5654	1723	LA County (2001)
	GR-1	2001	5884	1793	LA County (2001)
	GR-2	2001	5770	1759	LA County (2001)
	GR-3	2001	5800	1768	LA County (2001)
	GR-4	2000	5819	1774	LA County (2000)
	LA-1	1990	5537	1688	1995 water supply report
	LA-1B	1996	5646	1721	1995 water supply report
	LA-2	1991	5525	1684	1995 water supply report
	LA-3	1991	5560	1695	1995 water supply report

Table 4.3-5 (continued)

Well		Date	Head		Source
			(ft)	(m)	
Water supply	LA-4	1987	5706	1739	1995 water supply report
	LA-5	1987	5671	1729	1995 water supply report
	LA-6	1985	5678	1731	1995 water supply report
Characterization well	CdV-R-15-3-5	2001	6014	1833	Well completion report
	CdV-R-37-2	2001	6136	1869	Fact sheet
	R-12-3	2001	5697	1736	RRES-WQDB
	R-13	2001	5826	1776	Fact Sheet
	R-15	2000	5856	1785	Well completion report
	R-19-3	2000	5882	1793	Well completion report
	R-22-1	2000	5767	1758	Well completion report
	R-25-5	2001	6234	1900	RRES-WQDB
	R-31-2	2000	5833	1778	Well completion report
	R-5-3	2001	5788	1764	Fact Sheet
	R-7-3	2002	5882	1793	RRES-WQDB
	R-9	1998	5695	1736	Well completion report
	R-20-1	2003	5868	1789	Westbay
	R-14-1	2002	5885	1794	Westbay
	R-16-2	2002	5643	1720	Westbay
	R-32-1	2002	5860	1786	Westbay
Monitoring well	DT-10	1998	5922	1806	RRES-WQDB
	DT-5A	1996	5961	1817	RRES-WQDB
	DT-9	1998	5920	1805	RRES-WQDB
	TW-1	1998	5840	1781	RRES-WQDB
	TW-2	1996	5850	1784	RRES-WQDB
	TW-3	1997	5813	1772	RRES-WQDB
	TW-4	1996	6068	1850	RRES-WQDB
	TW-8	1997	5883	1794	RRES-WQDB
Other	H-19	1949	6228	1898	Purtymun 1995, 45344

Figure 4.3-5 shows a cross-section of head measurements, including all R-wells and test wells. This figure illustrates the vertical downward gradients present in the recharge area (to the west) and vertical upward gradients present in the discharge zone (to the east). Vertical downward gradients are present in many locations, including the vicinity of the Rio Grande (R-16). At this time, it is unclear whether these are local features caused by focused recharge or whether these are large-scale trends.

4.4 Geochemistry

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 basalt, and Santa Fe Group). Recharge to groundwater occurs within the Sierra de los Valles and on the Pajarito Plateau, based on distributions of stable isotopes (hydrogen and oxygen). Recharge water contains low TDS, typically less than 100 mg/L. The natural composition of groundwater can vary between and within these saturated zones because of geochemical processes, including precipitation/dissolution and adsorption/desorption reactions, age of the groundwater, and residence time. The residence time of groundwater is defined as the mass divided by flux, in which flux is mass/time. Groundwater residence times increase with depth and along flow paths within each aquifer type. The highest natural solute (dissolved) concentrations are associated with older groundwater within the regional aquifer.

Natural groundwater ranges from calcium-sodium-bicarbonate composition (Sierra de los Valles) to sodium-calcium-bicarbonate composition (White Rock Canyon springs) (Longmire 2002, 72614; Longmire 2002, 72713; Blake et al. 1995, 49931; ESP 2001, 71301). Silica is the second most abundant solute found in surface water and groundwater because of hydrolysis reactions taking place between soluble silica glass and water. Trace metals including barium, strontium, and uranium vary within the different saturated zones depending on the time and extent of water/rock interactions. Older groundwater within the regional aquifer tends to have higher concentrations of trace elements. Dissolved trace elements such as barium and strontium tend to correlate well with calcium and TDS.

DOC, in the form of humic and fulvic acids, is present in groundwater in concentrations typically <3 mgC/L. These acids occur as anions and can complex with calcium and magnesium. Higher DOC concentrations occur in alluvial groundwater where runoff through grasslands and forests occurs. Shortly after the Cerro Grande fire, increased concentrations of total organic carbon (TOC) were observed in surface water and alluvial groundwater within Pueblo Canyon, Los Alamos Canyon, Pajarito Canyon, and other watersheds. Since 2002, TOC concentrations have decreased in surface water but remain elevated in alluvial and perched-intermediate groundwater. TOC provides an excellent tracer for tracking movement of recent water (post-Cerro Grande fire) in the subsurface.

Groundwater impacted by Laboratory-derived effluent is characterized by elevated concentrations of major ions (calcium, magnesium, potassium, sodium, chloride, bicarbonate, nitrate, and sulfate); trace solutes (e.g., molybdenum, perchlorate, barium, boron, and uranium); HE compounds and other volatile organic compounds; and radionuclides (tritium, americium-241, cesium-137, plutonium isotopes, strontium-90, and uranium isotopes) (Longmire 2002, 73676; Longmire 2002, 72614; Longmire 2002, 72800; Longmire 2002, 72713; ESP 2001, 71301).

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 downgradient characterization wells (Longmire 2002, 72713; ESP 2001, 71301). Nonadsorbing contaminants (perchlorate, nitrate, RDX, and TNT) are the most mobile and travel the greatest distances along groundwater flow paths. In alluvial and intermediate perched groundwater, concentrations of some of these chemicals in groundwater above established maximum contaminant levels (MCLs) and recommended health and action levels are observed in some wells (MCOBT-4.4, R-25, and alluvial wells) (ESP 2001, 71301; Broxton et al. 2002, 72717). Perchlorate and RDX are persistent chemicals that are resistant to reductive breakdown to nontoxic forms in the environment.

Other contaminants including actinides, metals, and fission products are found within alluvial groundwater (Los Alamos Canyon, Pueblo Canyon, and Mortandad Canyon). These contaminants adsorb onto alluvial sediments and migrate at different rates through the subsurface. The largest masses of adsorbing contaminants, however, occur within alluvial groundwater systems.

A geochemical conceptual model is included in the regional aquifer modeling (Section 5.0). The geochemistry potentially contributes information regarding the source of recharge, rock/water interactions, groundwater flow velocities and directions, and the extent of groundwater mixing. In general, since water in the regional aquifer flows from high areas in the west towards the Rio Grande, the age of the water is also expected to increase from west to east. The concentration of major ions and trace elements in the groundwater correlates with the length of time groundwater is in contact with rock that hosts the aquifer, up to the point where groundwater reaches the saturation points of particular ions (e.g., silica). Therefore, beneath the Pajarito Plateau, the concentrations of major ions and trace elements that do not reach saturation are expected to increase with depth and from west to east across the Pajarito Plateau.

The concentrations of four chemicals (oxygen/hydrogen, carbon, tritium, and chloride) present in groundwater were analyzed as geochemical tracers because they do not interact with the aquifer rock and thus retain the signature of the recharge water and provide another line of evidence to further constrain the regional aquifer model, particularly in terms of recharge. Table 4.4-1 summarizes the analysis of these geochemical tracers. Geochemical tracers were incorporated into the numerical model by assigning concentration values at the nodes along the boundaries of the Española basin model. Along the upper recharge boundary, the values were based on elevation for those tracers that are elevation-sensitive (oxygen/hydrogen and chloride) and at prenuclear weapons testing levels for those radioactive tracers (carbon-14 and tritium). No chemical values were specified at no-flow and discharge boundaries. Relatively small amounts of water enter the regional aquifer as inflow along the northern boundary and from small areas adjacent to streams that recharge the regional aquifer (Chama River, Rio Grande, Rio Tesuque, and Santa Fe River). The geochemical values assigned to the nodes in these inflow areas were what would be expected based on research done in the area.

Table 4.4-1
Use of Geochemical Tracers in the Regional Aquifer Model

Chemical Species	Use of Information	Conclusions
Hydrogen and oxygen	Used to estimate recharge elevation. Oxygen has two isotopes (^{16}O and ^{18}O) and hydrogen has two natural isotopes (H and $H^{2;}$ see below for tritium, H^3). The higher the elevation of precipitation, the more there is of the lower-number isotope.	Groundwater at many springs and wells on the Pajarito Plateau and at springs near the Rio Grande contains a component of recharge from precipitation that fell at elevations lower than the precipitation that recharged springs in the Sierra de los Valles.
Carbon	Used to estimate the length of time that groundwater has been isolated from the atmosphere. When the carbon-14 is isolated from the atmosphere, it undergoes radioactive decay at a known rate.	Groundwater age increases rapidly towards the Rio Grande as water moves from recharge locations to discharge in the Rio Grande.
Tritium	Used to determine if younger water from the surface has been mixing with older water in the aquifer. Tritium in the water at greater than the expected concentration, based on very small amounts of natural tritium, indicates mixing of water less than 60 yr old with older water in the regional aquifer.	Based on tritium concentration, recent recharge is present in the regional aquifer in Pueblo Canyon (TW-1), Los Alamos Canyon (TW-3, LA-1A, LA-2), Mortandad Canyon (TW-8), and springs in White Rock Canyon.
Chloride	Used to estimate the amount of precipitation that reaches the regional aquifer. In the absence of anthropogenic and geothermal effects, the difference between chloride concentration in recharge and in the regional aquifer represents the amount of water removed by ET that occurs in the root zone.	Recharge is primarily in stream channels and does not occur beneath mesas. Models should include focused recharge in canyons and not diffuse recharge across mesas and canyons.

5.0 SIMULATION OF GROUNDWATER FLOW

Hydrologic modeling of the regional aquifer has focused on identifying groundwater flow directions and velocities, with quantitative estimation of uncertainties. Modeling results have been used to prioritize new data collections, to site regional aquifer characterization wells, and to predict the ultimate fate of contaminants introduced into the aquifer. In FY2002, the model was used to estimate zones of capture for the Buckman well field, to estimate the fate of potential contaminants beneath Mortandad Canyon, and to evaluate the impact of recently collected R-well data on conceptual and numerical models of deep groundwater flow.

Hydrologic modeling of the vadose zone has been undertaken to quantify key factors that influence the transport of contaminants and to assess uncertainties. The goals of this preliminary work are to identify potential regions at the Laboratory where deep migration of contaminants is possible and to guide future site characterization activities. In FY2002, a site-wide vadose zone model was constructed to predict the travel time from the ground surface to the water table of the regional aquifer. This section discusses the underlying assumptions, their validity, and the process for determining travel times. Transport of water and dissolved chemicals through the vadose zone beneath the Pajarito Plateau has been the subject of numerous laboratory and field investigations and numerical model development efforts (e.g., Rogers et al., 1996, 55429; Birdsell et al., 2000; Robinson et al., 2001).

Numerical groundwater models for the Española basin (basin-scale) and the Pajarito Plateau beneath Los Alamos National Laboratory (site-scale) were developed beginning in 1998 and have been continuously refined as new groundwater data are collected. The numeric model selected by the Laboratory is the Finite Element Heat and Mass (FEHM) computer code, a 3-D groundwater flow and transport code (Zyvoloski et al. 1996); computational grids were generated using LaGriT (Trease et al. 1996). The FEHM code was developed at the Laboratory for geothermal and environmental programs and has been supported by the High-Level Radioactive Waste Repository Program. It simulates the flow of water and air and the transport of heat or substances in water through saturated or partially saturated rock. It can simulate flow or transport in either two or three dimensions. It was selected because it has been tested rigorously and certified for use in radioactive waste disposal. This computer code is publicly available from Los Alamos National Laboratory.

5.1 Vadose Zone Groundwater Flow Modeling

Vadose-zone hydrology is a vast field of research; the basic processes are described in standard textbooks such as Freeze and Cherry (1979, 64057). The characterization and modeling of vadose zone systems require knowledge of the percolation rate and the hydrologic properties of rocks and soils under unsaturated conditions. A basic understanding has been acquired for the Bandelier Tuff underlying much of the Pajarito Plateau, and in the past that knowledge has been used to develop geometrically complex numerical models to investigate in detail the influence of dipping stratigraphy, rugged topography, and anthropogenic alterations to the natural system. Because of the complexity and computational demands of such models, each of these models covers only a small portion of the Laboratory property and thus provides only a local picture of the vadose-zone system. Presented below is a site-wide model designed as a first-order analysis of travel time through the vadose zone across the entire Pajarito Plateau.

A key input for such a model is the infiltration rate, known to depend on the local surface hydrologic conditions, topography, microclimatic conditions, evapotranspirative (ET) conditions, including vegetation type, and the presence or absence of impermeable layers such as thin clay layers within and at the base of the alluvium. The water that escapes ET and surface runoff is assumed to percolate through the remainder of the vadose zone to the regional aquifer, carrying with it any aqueous chemicals such as contaminants or dissolved minerals. This percolation rate is the direct input to the vadose zone numerical models. Although this rate undoubtedly changes with time as a result of storm transients, seasonal variations, and climatic variability, it is assumed that such effects are buffered by the hydrologic processes that redistribute water in the surface water, alluvial groundwater, and unsaturated rocks of the vadose zone, so that an equivalent constant percolation rate can be assigned. The methodology and initial estimates of infiltration across the Pajarito Plateau are presented below, followed by travel-time results.

Despite the potential complexities associated with vadose zone systems, many basic processes are amenable to characterization and numerical simulation. In Bandelier Tuff, when the percolation rate is lower than the saturated hydraulic conductivity (k_{sat})of the matrix rock, fluid saturation in the partially water-filled pores modulates itself to transmit the fluid under unit-gradient conditions associated with gravity-driven flow. Robinson et al. (2001), using numerical modeling of a field injection test in a vadose zone borehole at TA-50, showed that even if the tuff unit is fractured, fluid flow is likely within the matrix pores. When the percolation rate exceeds k_{sat}, some water must either be diverted laterally or flow rapidly through fractures. The distinction between fracture-dominated and matrix-dominated flow is most significant for contaminant transport, as illustrated by the following simplified calculations. For an infiltration rate of 1 mm/yr, typical of a mesa location, and volumetric water content of 0.1, downward pore water velocities will be on the order of 0.01 m/yr. Under these conditions, a nonsorbing contaminant front would take 10,000 yr to percolate through 100 m of unsaturated Bandelier Tuff. A similar calculation for a wet-canyon scenario (500 mm/yr, water content of 0.25) yields a transport velocity of 2 m/yr, or a travel time of 50 yr to traverse 100 m of Bandelier Tuff. If the hydrology were controlled by fractures, corresponding estimates would reduce the water contents to 10^{-3} or lower to account for the small fraction of the total rock volume that is taken up by the fracture void space. Travel time to traverse the same 100 m of Bandelier Tuff would be 100 yr for the mesas and 0.2 yr for the wet canyons. Therefore, the conceptual model for fluid flow and the percolation rate will control the travel-time estimates. The current conceptual model presented in this report is supported by field evidence cited above and posits that the relatively unfractured, high matrix-permeability Bandelier Tuff will exhibit matrix percolation and longer travel time than the basaltic rocks. The Puye Formation, another hydrogeologic unit present above the water table, is probably also matrix dominated, although the hydrology is complicated by its highly heterogeneous makeup and large permeability contrasts from mineral alteration.

Despite the inherently 3-D nature of vadose zone flow, an appropriate starting point for estimating travel time is to assume 1-D downward percolation of water and migration of contaminants. Intermediate perched groundwater observed in several wells across the Pajarito Plateau indicate the possibility of lateral diversion, but the influence of such groundwater on vadose zone travel time can be assessed in a bounding manner. To make the quantitative estimates of travel time, the FEHM computer code was used in the following manner. First, for the vertical stratigraphy predicted by the site geologic model, a 1-D grid was constructed with 10 numerical grid points within each layer. Hydrologic properties of each unit were assigned based on compilations performed in previous investigations (Tables 5.1-1 and 5.1-2), and the percolation rate was assigned based on the infiltration map presented in Figure 5.1-1. The calculation consisted of two steps: first, a steady state 1-D fluid flow calculation was executed to establish the fluid water content and water velocities through the stratigraphic column. Second, in a follow-on FEHM simulation, this steady state flow model was used to compute a travel time using a cell-based particle tracking technique described in Robinson and Bussod (2000). By performing the calculation at numerous locations across the Plateau, a site-wide description of vadose zone travel times could be obtained.

Table 5.1-1
Permeability and Porosity Values Used in Vadose Zone Simulations

Hydrogeologic Unit	Geologic Designation	Permeability (m^2)	Porosity
Unit 3, Tshirege Member	Qbt 3	1.01e-13	0.469
Unit 2, Tshirege Member	Qbt 2	7.48e-13	0.479
Vitric unit, Tshirege Member	Qbt 1v	1.96e-13	0.528
Glassy unit, Tshirege Member	Qbt 1g	3.68e-13	0.509
Basal Pumice unit, Tshirege Member	Qbtt	1.01e-12	0.473
Cerro Toledo interval	Qct	8.82e-13	0.473
Otowi Member	Qbof	7.25e-13	0.469
Guaje Pumice Bed	Qbog	1.53e-13	0.667
Cerros del Rio Basalt, Puye	Tb4	2.47e-12	0.3
Tschicoma basalt	Tt2	2.96e-13	0.3
Cerros del Rio basalt, Santa Fe Group	Tb3	2.96e-13	0.3
Puye Formation	Tpf	4.73e-12	0.25
Totavi Lentil	Tpt	4.73e-12	0.25
Santa Fe Group	Tsfuv	2.65e-13	0.25

Table 5.1-2
Unsaturated Hydrologic Parameter Values Used in the Vadose Zone Simulations

Hydrogeologic Unit	Geologic Designation	Van Genuchten a parameter, m^{-1}	Residual Moisture Content	Van Genuchten *n* parameter, unitless
Unit 3, Tshirege Member	Qbt 3	0.29	0.045	1.884
Unit 2, Tshirege Member	Qbt 2	0.66	0.032	2.09
Vitric unit, Tshirege Member	Qbt 1v	0.44	0.009	1.66
Glassy unit, Tshirege Member	Qbt 1g	2.22	0.018	1.592
Basal Pumice unit, Tshirege Member	Qbtt	1.52	0.01	1.506
Cerro Toledo interval	Qct	1.52	0.01	1.506
Otowi Member	Qbof	0.66	0.026	1.711
Guaje Pumice Bed	Qbog	0.081	0.01	4.026
Cerros del Rio basalt, Puye	Tb4	0.1	0.066	2.
Tschicoma basalt	Tt2	0.1	0.066	2.
Cerros del Rio basalt, Santa Fe Group	Tb3	0.1	0.066	2.
Puye Formation	Tpf	5.	0.01	2.68
Totavi Lentil	Tpt	5.	0.01	2.68
Santa Fe Group	Tsfuv	5.	0.01	2.68

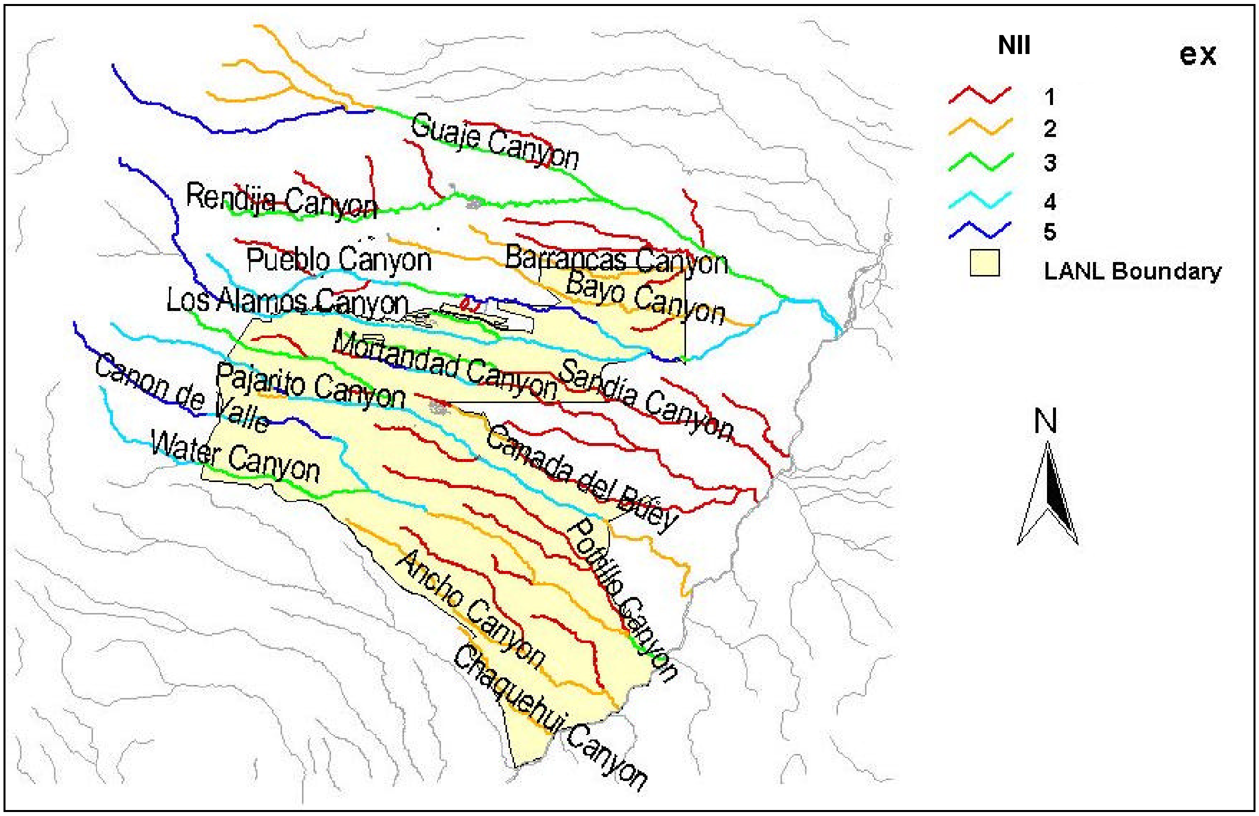


Figure 5.1-1. **Result of analysis to determine net infiltration index indicator parameter across Pajarito Plateau and surrounding study area region**

Because the goal of the present study is to provide a comprehensive set of predictions of travel times and pathways, a large number of individual model runs must be performed. To accomplish this goal, several time-consuming steps of the process were automated within a GIS-based data assembly and querying system. At a given location, a 1-D rendering of the vertical stratigraphy is used to generate a numerical grid for flow and transport calculations. The point distribution for the 1-D models was selected to provide a very fine-scale result within canyons (identified by a database of drainages recorded for the Pajarito Plateau) and a coarser resolution on the mesas. Regions corresponding to the drainages, where relatively large infiltration is applied, were converted to a high-resolution grid (cell size of 128 ft) with each point located in the center of the cell. On the mesas, a coarser point distribution of 512 ft was taken. Using this method, a total of 30,577 points across the plateau were identified for computing 1-D transport times.

Infiltration Estimation Results: Net infiltration is defined here as the percolating water that remains within the vadose zone beneath the root zone. A more complete site-wide study of net infiltration is underway (Kwicklis, in prep.). This study summarizes estimates of net infiltration determinations with a variety of estimation techniques, including the Darcy Law, chloride mass-balance, and water-balance methods. The study attempted to extrapolate these estimates to other areas for which estimates do not exist based on topography, soils, vegetation, and bedrock type. The groundwater assessment will be updated to include the detail from the site-wide net infiltration study.

Since net infiltration to the vadose zone beneath the plateau is assumed to occur mainly through canyons, the plateau is differentiated topographically as mesa or canyon. For the initial net infiltration map presented here, the mesa locations are all assigned the same fixed net infiltration rate. For the base-case study, this rate is 1 mm/yr. The map for canyon locations becomes more complex because the canyons are the main source of recharge across the plateau and because conditions in canyons across the plateau vary from wet to dry. For these reasons, a ranking scheme was developed to classify portions of canyons by a net infiltration index (NII) that describes the net infiltration rate.

The NII ranges in value from 1 to 5, with 1 representing the lowest and 5 representing the highest infiltration potential. The NII is based on a number of physical factors, as shown in Table 5.1-3.

- The location of the headwaters is the first factor because canyons that head in the mountains generally have a larger drainage area and receive more precipitation and run off than those that head on the plateau. Anthropogenic water sources within the canyons can also yield large surface flows that contribute similarly to headwaters located higher in the mountains. For this reason, anthropogenic sources were included with the first factor.
- The persistence of surface water in the canyon bottom is the next factor used to define the NII. Canyons with perennial streams are expected to generate higher net infiltration than those with ephemeral or intermittent streams.
- Observation of alluvial water is the final factor used to define the NII. Some canyons have alluvial aquifers of significant depth, while others have no alluvial water. Canyons with deeper alluvial aquifers receive a higher NII than those without.

Table 5.1-3
Determination of NII and Base-Case Net Infiltration Rates

NII	Headwater or Source	Surface Water	Alluvial Water	Base-Case Net Infiltration Estimate (mm/yr)
1	Plateau	Ephemeral or intermittent	Not saturated	1
2	Mountain or small anthropogenic source	Ephemeral or intermittent	Not saturated	10
2	Plateau	Ephemeral or intermittent	Sometimes saturated	10
2	Plateau	Perennial	Not saturated	10
3	Plateau or small anthropogenic source	Ephemeral or intermittent	Saturated	100
3	Mountain	Ephemeral or intermittent	Sometimes saturated	100
4	Plateau	Perennial	Saturated	300
4	Mountain or anthropogenic source	Ephemeral or intermittent	Saturated	300
5	Mountain or large anthropogenic source	Perennial	Saturated	1000

Factors contributing to the NII were used to define a preliminary set of indices that may be updated with site-specific observations and data and information gathered from the infiltration study currently underway. In some cases, factors such as persistent surface and alluvial waters may indicate an absence of vadose-zone infiltration rather than a higher net infiltration rate. Examples include the surface expression of springs or perching in the alluvium caused by a large contrast in hydraulic conductivity between the alluvium and underlying tuff. Despite these types of conditions, a higher NII in the wetter areas is assumed for this preliminary study so that possible fast paths can be identified. Once areas with potential fast paths are identified, more site-specific infiltration data can be gathered if any nearby potential sources exist.

Table 5.1-3 also includes the base-case net infiltration estimates for each NII used in the first-order groundwater assessment. These estimates show that approximately 3 orders of magnitude variation in net infiltration is expected between the driest and the wettest canyons. Different sets of net infiltration estimates are also included in the groundwater assessment.

The next step in generating the net infiltration map is assigning net infiltration indices of canyons or canyon stretches across the plateau. This task was accomplished by compiling information from the "Hydrogeologic Workplan" (LANL 1998, 59599) about the descriptive factors listed in Table 5.1-3. Major canyons from Guaje Canyon, located north of the Laboratory, to Chaquehui Canyon, located south of the Laboratory, were characterized with respect to the location of their headwaters, anthropogenic sources, and observations of surface and alluvial waters. In most cases, a canyon is split into sections because the hydrologic factors change downgradient of the canyon. The characteristics of these canyons or canyon stretches are shown in Table 5.1-4, with the resulting NII for each section. The NII is determined by comparing the characteristics in Table 5.1-4 to the net infiltration factors in Table 5.1-3.

Figure 5.1-1 shows the resulting NII map for the study area with respect to the Laboratory boundary. Canyons with no portion of their reach inside the site area, shown in gray, are not assigned an NII as part of this study because Laboratory-derived contaminants are not present in these canyons. The information after conversion to infiltration rates using the values in Table 5.1-3 was used as the upper water-flux boundary conditions for the series of 1-D vadose-zone flow and particle-tracking runs described in the next section.

Travel Time Modeling Results: A full-scale map of predicted travel times of a conservative nonsorbing solute in the vadose zone (from ground surface to the water table of the regional aquifer) is shown in Figure 5.1-2. Along each canyon with NII other than 1, travel times are predicted to be less than 1000 yr. On mesas, the predicted travel times are variable but for the most part are greater than 1000 yr, ranging from 1000 to 5000 yr on the eastern portions of the Laboratory to 20,000 to 30,000 yr in the western area. To a first approximation, travel times from mesa tops are controlled most strongly by the thickness of the tuff. Because the Bandelier Tuff is predicted to exhibit matrix-dominated flow, travel times on the mesas, all of which are assumed to have a percolation rate of 1 mm/yr, are dominated by slow percolation through these units. Other units between the ground surface and the water table are the basalt units, the Puye Formation, and the Tschicoma Formation. Each of these units is modeled with a low porosity to capture the conceptual model feature that assumes flow through these units could be controlled by fast pathways such as fractures or other heterogeneities. Therefore, most travel time to the water table is within the Bandelier Tuff, and the travel-time map is therefore dominated by the tuff thickness.

Table 5.1-4
Determination of NII

Canyon/ ArcView Identifier	Reach	Headwater (drainage <5 mi^2 unless noted)	Surface Water	Alluvial Water	Published Net Infiltration	Notes	NII
Pueblo (Pueb1)	From Headwaters to Guaje Mountain Fault	Mountains (drainage > 8 mi^2)	Ephemeral	Saturated		HWP* pp. 4–41, 4–42	4
Pueblo (Pueb2)	Below Guaje Mountain fault, above sewage treatment plant	Mountains	Ephemeral	May or may not be saturated		HWP pp. 4–41, 4–42	3
Pueblo (Pueb3)	Below sewage treatment plant to halfway across lab land	Mountains and anthropogenic source	Perennial	Saturated		HWP pp. 4–41, 4–42	5
Pueblo (Pueb4)	Half-way across Laboratory land to confluence with LA Canyon	Mountains	Intermittent	Saturated		HWP pp. 4–41, 4–42	4
Pueblo (Historic)	Mid- (below TA-45) and upper (old sewage) canyon	Mountains	Possible historic perennial flow	Possible historical saturated conditions	Previous effluent TA-45 (1951–1964); old sewage plant (pre-1963)		4 (historic)
Los Alamos (LA1)	West of the reservoir	Mountains (drainage >10 mi^2)	Perennial	Saturated		HWP pp. 4–48	5
Los Alamos (LA2)	East of reservoir to TA-2	Mountains	Continuous during snow melt (weeks to months); otherwise ephemeral	Saturated (thickness varies seasonally from several feet in winter to 25 ft in spring and summer)	(All LA Canyon estimates based on Gray 1997, 58208, Table 8) 714, 213, 566, 1076 mm/yr	HWP pp. 4–48	4
Los Alamos (LA3)	TA-2 to confluence of Pueblo Canyon	Mountains	Ephemeral	Saturated (same as above)	222, 408 mm/yr	HWP pp. 4–48	4
Los Alamos (LA4)	Confluence of Pueblo Canyon to LAO-4.5	Mountains	Perennial	Saturated	399 mm/yr	HWP pp. 4–48	5
Los Alamos (LA5)	LAO-4.5 to basalt spring	Mountains	Ephemeral	Not saturated	362 mm/yr	HWP pp. 4–48	3

Table 5.1-4 (continued)

Canyon/ ArcView Identifier	Reach	Headwaters (drainage <5 mi^2 unless noted)	Surface Water	Alluvial Water	Published Net Infiltration	Notes	NII
Los Alamos (LA6)	Lower Basalt Spring to Rio Grande	Mountains	Ephemeral	Saturated	325 mm/yr	HWP pp. 4–48	4
DP (DP)	All	Plateau	Ephemeral, except nearly continuous discharge near DP spring	Saturated conditions observed at wells LAUZ-1, LAUZ-2 (elsewhere ?)		HWP pp. 4–48	3
Sandia (San1)	Headwaters to TA-72	Plateau with small anthropogenic source	Ephemeral	Not characterized (likely saturated portions)	Surface water source is precipitation and treatment plant water (minimal snow melt)	HWP pp. 4–53	3
Sandia (San2)	Below TA-72	Plateau	Not present	Not characterized (eastern part near SCO-1 & SCO-2 dry since 1990)		HWP pp. 4–53	1
Cañada del Buey (CdB1)	All else	Plateau	Ephemeral (with snowmelt and thunderstorms)	Not saturated	<0 (Rogers et al.1996, 55543)	HWP pp. 4–59, 4–61	1
Cañada del Buey (CdB2)	Between CDBO-6 & CDBO-7	Plateau	Ephemeral (with snowmelt and thunderstorms)	Sometimes saturated within weathered tuff (near discharge of PM-4)		HWP pp. 4–61	2
Pajarito (Paj1)	West of Homestead Spring	Mountains (drainage >10 mi^2)	Occurs as springs above alluvium (1–15 gpm)	Saturated alluvium (perched to ~10 ft depth)		HWP pp. 4–61, 4–62	4
Pajarito (Paj2)	Several hundred yards near Homestead Spring	Mountains	Perennial	Saturated alluvium (perched to ~10 ft depth)		HWP pp. 4–61, 4–62	5
Pajarito (Paj3)	Below Homestead Spring to above Threemile Canyon	Mountains	Intermittent to ephemeral	Saturated alluvium (perched to ~10 ft depth)		HWP pp. 4–61, 4–62	4

Table 5.1-4 (continued)

Canyon/ ArcView Identifier	Reach	Headwaters (drainage <5 mi^2 unless noted)	Surface Water	Alluvial Water	Published Net Infiltration	Notes	NII
Pajarito (Paj4)	Threemile Canyon to Eastern Laboratory boundary	Mountains	Ephemeral	Saturated alluvium (perched to ~10 ft depth)		HWP pp. 4–61, 4–62	4
Pajarito (Paj5)	East of Laboratory boundary to Rio Grande	Mountains	(Not discussed) assumed ephemeral	Not saturated		HWP pp. 4–61, 4–62, 4–60	2
Ancho (Ancho)	All	Plateau	Ephemeral from precipitation (sometimes severe)	Little known (possible shallow perched zone)		HWP pp. 4–69	2
Chaquehui (Cheq1)	Headwaters to 0.5 mi from Rio Grande	Plateau	Ephemeral	Little known (however, observed infiltration into tuff at TA-33, tritium at 100–170 ft)		HWP pp. 4–74	2
Chaquehui (Cheq2)	0.5 mi from/to Rio Grande	Plateau	Perennial for short distance	Little known		HWP pp. 4–74	2
Cañon de Valle (CdV1)	Headwaters to Pajarito fault	Mountains	Perennial	Saturated		HWP pp. 4–78, 4–79	5
Cañon de Valle (CdV2)	Pajarito Fault to 260 Outfall	Mountains	Intermittent	Saturated		HWP pp. 4–78, 4–79	4
Cañon de Valle (CdV3)	260 Outfall to MDA P	Mountains and anthropogenic source	Perennial	Saturated		HWP pp. 4–78, 4–79	5
Cañon de Valle (CdV4)	MDA P to Water Canyon	Mountains	Intermittent	Saturated		HWP pp. 4–78, 4–79	4
Potrillo (Pot1)	Headwaters to POTM-wells	Plateau	Ephemeral (no significant snowmelt, discharge sink at POTM-wells)	Only saturated observance once at well POTM-2	0.01 cm/yr (Rogers et al. 1996, 55429)	HWP pp. 4–85	1

Table 5.1-4 (continued)

Canyon/ ArcView Identifier	Reach	Headwaters (drainage <5 mi^2 unless noted)	Surface Water	Alluvial Water	Published Net Infiltration	Notes	NII
Potrillo (Pot2)	POTM-wells to Water Canyon	Plateau	Rare	Not expected		HWP pp. 4–85	1
Fence (Fen1)	All	Plateau	Ephemeral (no significant snowmelt)	Little known, dry at State Highway 4		HWP pp. 4–86	1
Water (Wat1)	Headwaters to west of Laboratory boundary	Mountains	Mostly perennial	Assumed saturated		HWP pp. 4–87, 4–79	4
Water (Wat2)	Western Laboratory boundary to Cañon de Valle	Mountains	Unknown	Unknown		HWP pp. 4–87, 4–79	3
Water (Wat3)	Cañon de Valle to well DT-10	Mountains	Intermittent and ephemeral	Saturated		HWP pp. 4–87, 4–79	4
Water (Wat4)	DT-10 to spring 5AA	Mountains	ephemeral	Not saturated		HWP pp. 4–87, 4–79	2
Water (Wat5)	At spring 5AA	Mountains	Short perennial reach	Possibly saturated		HWP pp. 4–87, 4–79	4
Water (Wat6)	Beneath 5AA to Rio Grande	Mountains	Ephemeral	Not saturated		HWP pp. 4–87, 4–79	2
Mortandad (Mort1)	Headwaters to TA-50 outfall	Plateau	Ephemeral and intermittent	Not saturated	See HWP 4–92 for surface water loss estimates	HWP pp. 4–89, 4–91	1
Mortandad (Mort2)	Downstream from TA-50 wastewater treatment plant for about 1 mile	Plateau with large anthropogenic source	Perennial for about 1 mile	Saturated (~10 ft thick)	Dander (1998) 4500 mm/yr	HWP pp. 4–89, 4–91	5
Mortandad (Mort3)	Downstream from TA-50 wastewater treatment plant (from 1 mile downstream to 2 miles)	Plateau	Ephemeral	Saturated (~10 ft thick); approx from TA-50 to just above San Ildefonso land		HWP pp. 4–89, 4–91	4
Mortandad (Mort4)	From just above boundary with San Ildefonso land to the Rio Grande	Plateau	Ephemeral	Not saturated		HWP pp. 4–89, 4–91	1

Table 5.1-4 (continued)

Canyon/ ArcView Identifier	Reach	Headwaters (drainage <5 mi^2 unless noted)	Surface Water	Alluvial Water	Published Net Infiltration	Notes	NII
Guaje (Guaje1)	Upstream (near springs) to downstream from the Guaje Reservoir	Mountains	Perennial	Saturated		HWP pp. 4–95	5
Guaje (Guaje2)	Downstream from Guaje Reservoir to LA Canyon	Mountains	Intermittent	Possible seasonal saturation		HWP pp. 4–95	3
Rendija (Ren1)	All	Mountains	Ephemeral	Unknown			3
Barrancas (Barr1)	All	Plateau	Intermittent and ephemeral	Potentially saturated		HWP pp. 4–96, 4–97	2
Bayo (Bayo)		Plateau	Intermittent and ephemeral	Potentially saturated (90 boreholes in former TA-10 found no alluvial water)		HWP pp. 4–97	2
Threemile (Three)	All	Plateau	?	?	Assumed to be like Potrillo		1
Twomile (Two)	All	Mountain	Assumed ephemeral	Assumed saturated	HWP p. 4–60		3

*HWP = “Hydrogeologic Workplan” (LANL 1998, 59599).

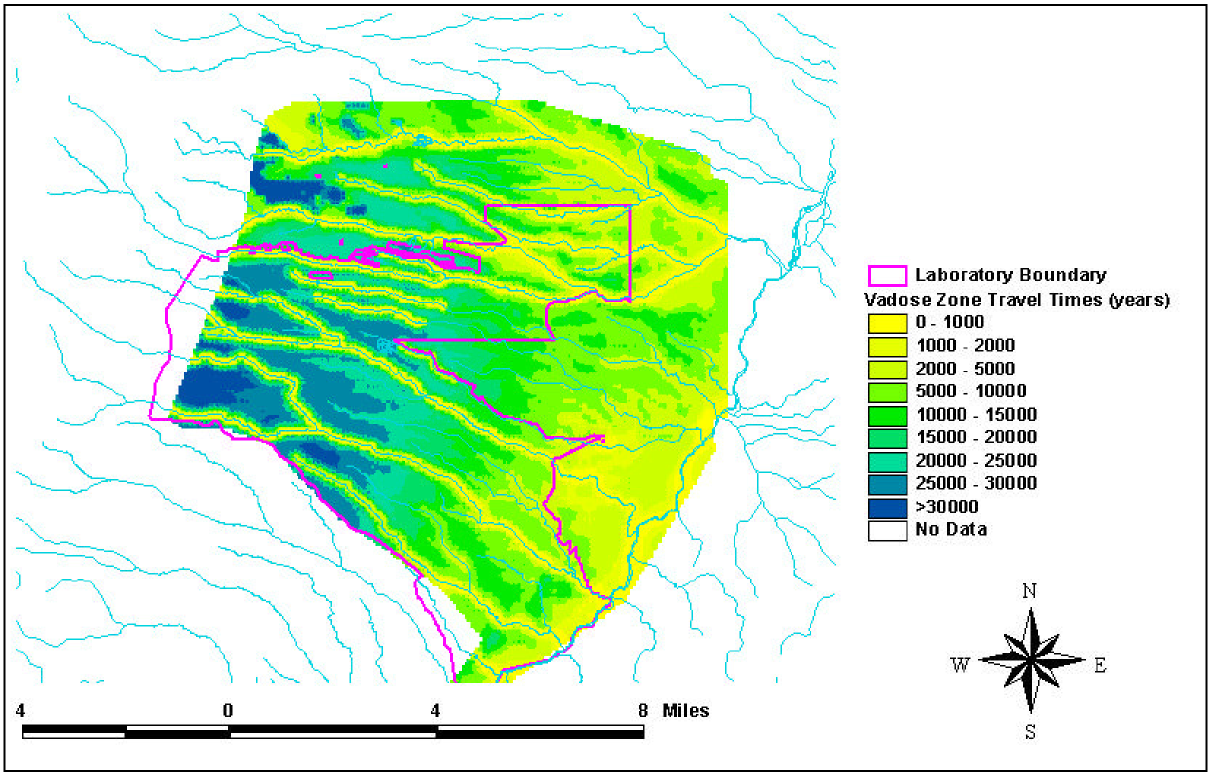


Figure 5.1-2. Predicted vadose zone travel times (yr) to water table: base case, full scale of travel times

Determining rapid travel time to the water table is important to determine if is in areas likely to have experienced Laboratory-derived groundwater contamination. Figure 5.1-3a shows the same model result presented in Figure 5.3-2, with the travel-time scale ranging from 0 to 100 yr (all points with values greater than 100 yr are shown in gray). According to the model, regions of relatively rapid travel times occur in the following canyons: Pajarito Canyon near White Rock, a portion of Cañon de Valle, Mortandad Canyon at the radioactive liquid waste treatment facility, middle and lower Los Alamos Canyon, large portions of Pueblo Canyon, and Guaje Canyon. In addition to the thickness of the Bandelier Tuff, the percolation rate in the canyon is a controlling parameter. Generally, travel times of less than 100 yr are predicted in the portions of canyons with NII values of 4 or 5 (300 mm/yr and 1000 mm/yr, respectively), especially in locations where the Bandelier Tuff is thin. Los Alamos and Pueblo Canyons have regions in which the predicted travel times are especially short (5 to 10 yr) because of a combination of thin or nonexistent Bandelier Tuff and high percolation rates.

The percolation rates associated with the qualitatively defined NII are uncertain and therefore must be varied to investigate the uncertainty in the model predictions. Figure 5.1-4a shows the same vadose zone travel time map as in Figure 5.1-3a but for the high-percolation flux scenario. Clearly, travel times are shorter at the same location in any particular canyon, and greater stretches of canyons are predicted to exhibit travel times to the regional aquifer of less than 100 yr. Specifically, in the high-flux scenario, most of Pajarito Canyon, much longer stretches of Mortandad and Los Alamos Canyons, Cañon de Valle/Water Canyons to the central portion of the Laboratory, and all of Pueblo Canyon in the vicinity of the Laboratory are predicted to have travel times that are less than 100 yr. This analysis highlights a key uncertainty in the model, namely the lack of precision in predicting the percolation rate from canyon bottoms. Because contaminants have been introduced into the groundwater in canyons, the percolation rate likely will be one of the key uncertainties that the site characterization should address, although characterization decisions await more definitive analyses and uncertainty quantification.

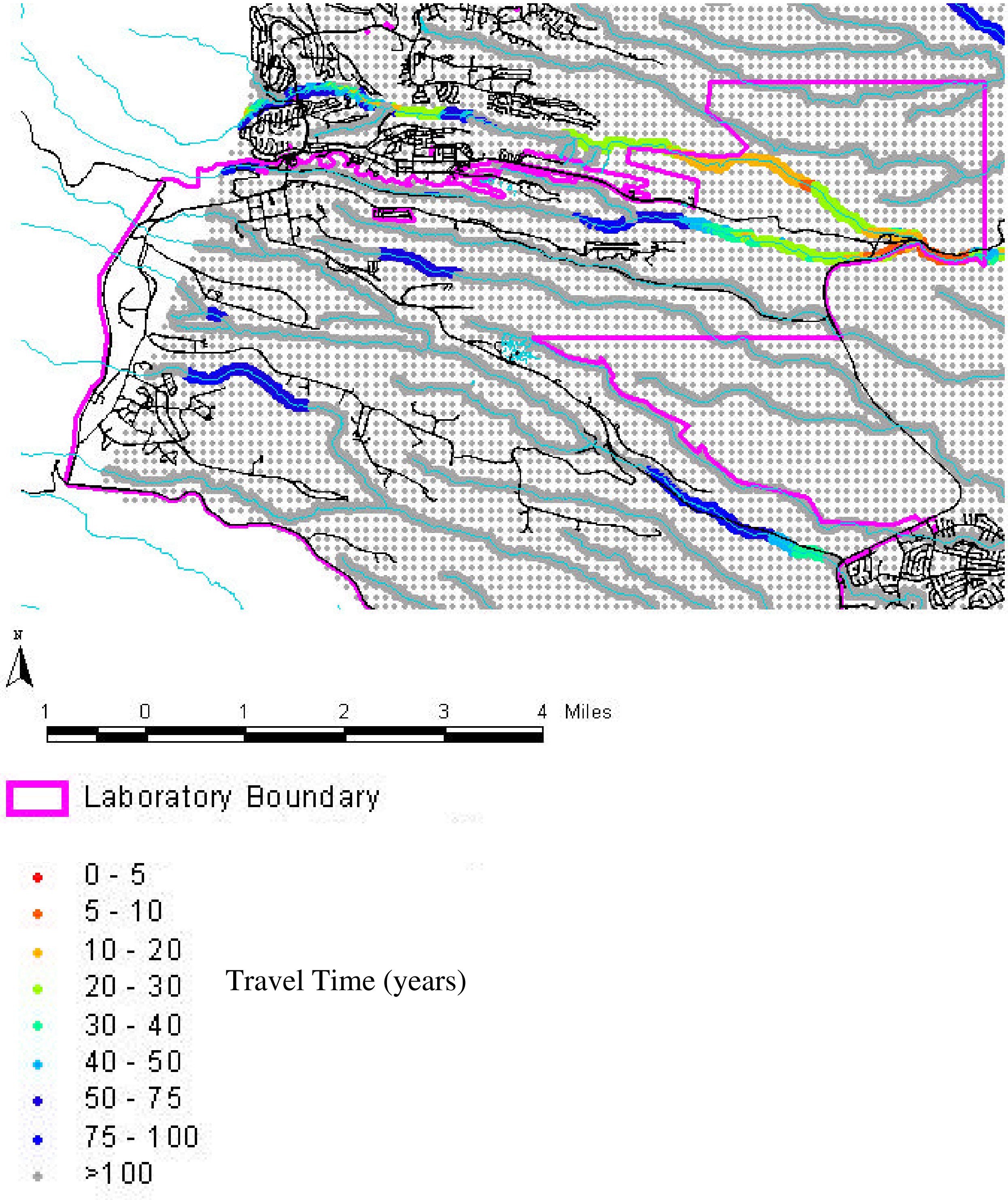


Figure 5.1-3a. **Predicted vadose zone travel times (yr) to the water table, showing only travel times of 100 yr or less. Base-case percolation scenario: 1-D transport to water table.**

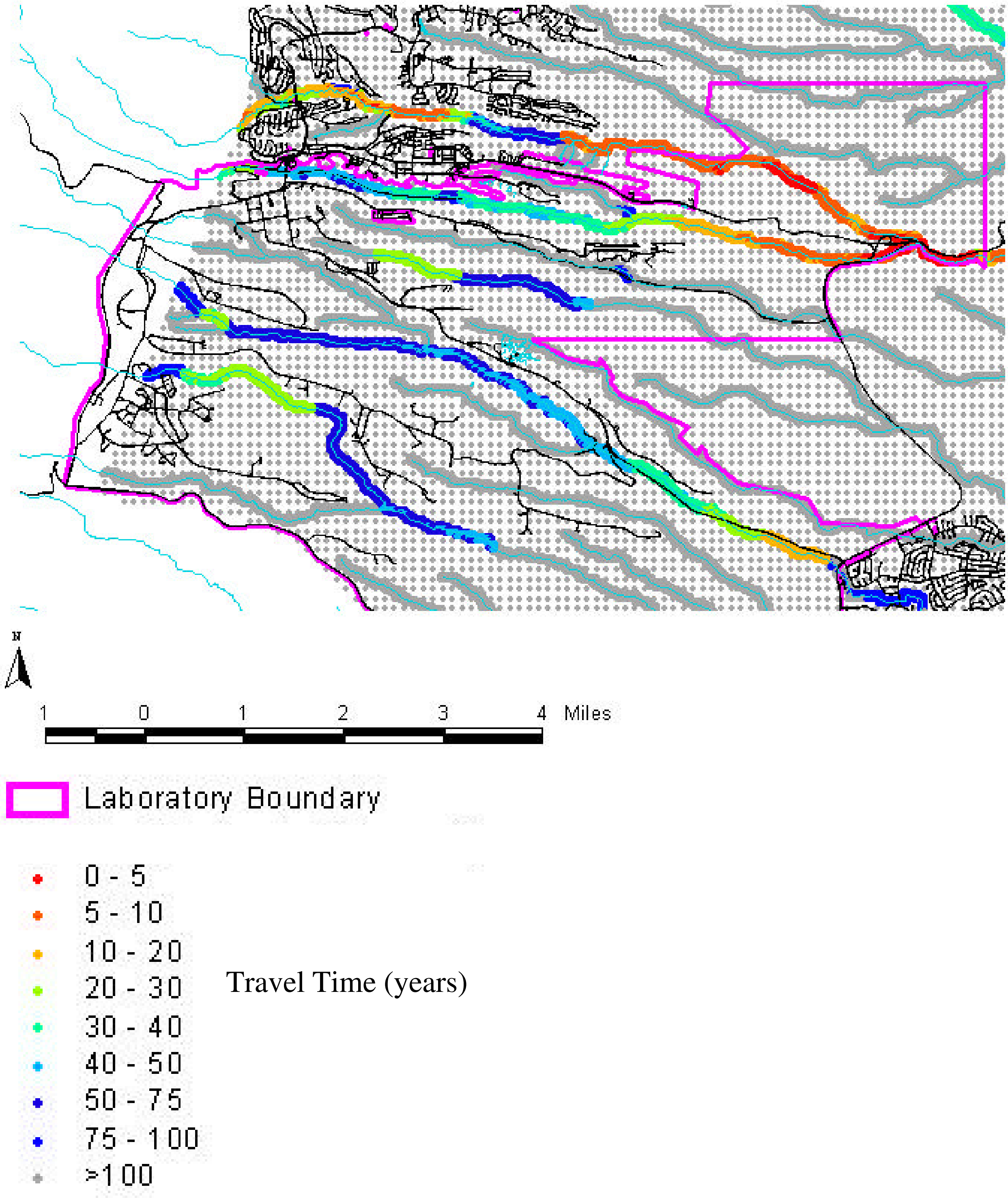


Figure 5.1-4a. Predicted vadose zone travel times (yr) to the water table, showing only travel times of 100 yr or less. High percolation flux scenario: 1-D transport to water table.

The 1-D, vertical transport model assumption is an approximation that may not be valid, given the presence of intermediate groundwater at various locations around the Laboratory. In general, zones of saturation have been identified directly beneath canyons, where infiltration rates are highest. Little or no evidence supports the supposition that connected groundwater pathways exist over large areal distances beneath mesas. Given the limitations of the data, the approach taken in the present study is to bracket the range of travel times to the water table that would be predicted assuming "end-member" conceptual models for the nature of flow within the intermediate groundwater regions. If the perched water represents a pool of water that drains in vertical flow through the perching layer, then the 1-D pathway approach presented above is an appropriate model. The other extreme is that the perched water could indicate a rapid lateral diversion along the top of the perching horizon. If the travel time from the perched water zone to the water table is assumed to be minimal, then the shortest overall possible travel time is estimated by computing the travel time from the surface to the perching horizon.

These calculations were performed after areas were identified within the canyons where intermediate groundwater is known to exist. All points in these identified areas were used to develop an alternate 1-D pathway from the surface to the perching horizon, thereby assuming immediate transport from this horizon to the regional aquifer. Figures 5.1-3b and 5.1-4b show the results of the travel-time simulations for the alternate perched water conceptual model for the two percolation scenarios. When these figures are compared to their counterparts for the 1-D downward flow (Figures 5.1-3a and 5.1-4a), the differences in travel time are quite subtle. The regions outlined as possessing vadose zone travel times of less than 100 yr remain approximately the same, and the travel times at the same location are minimally impacted by the perched water conceptual model. For example, for the base case percolation scenario, travel times are shorter by about 15 to 20 yr for the alternate perched water model than for the 1-D model; for the high-flux scenario, these differences are even smaller. To understand this result, it must be noted that in the 1-D model, transport from the ground surface to the water table is dominated by percolation through the matrix of the Bandelier Tuff. Therefore, terminating the transport pathway at the base of the tuff, as in the alternate perched water scenario, eliminates a relatively small portion of the total travel time to the regional aquifer. Despite this insensitivity of travel time, the arrival location is potentially quite different for the two cases.

5.2 Regional Aquifer Conceptual Model

The conceptual model for the Española basin-scale model and the Pajarito Plateau site-scale model include the following elements: boundaries of the model, the hydraulic gradient, aquifer properties, recharge, and discharge.

5.2.1 Regional Aquifer Model Boundaries

The northern and southern boundaries of the basin model were located according to structural transitions between the Española basin and neighboring basins where basin-fill sedimentary rocks are relatively thin (Figure 5.2-1). The eastern boundary corresponds to a topographic divide; the western boundary is a combination of topographic divides and the western margin of the Valles caldera. These lateral boundaries are assumed to be primarily no-flow, although in limited areas inter-basin flow is allowed to occur through specified head nodes (see Figure 5.2-2). Along the northern boundary, flow is allowed to occur through specified head nodes representing groundwater in the alluvium beneath the Rio Chama and Rio Grande and along the basin margin to the far north. Along the southern boundary, flow is also allowed through specified head nodes placed in a broad area beneath and adjacent to the Rio Grande. There is also outflow to the west of Valles Caldera along the Jemez Canyon.

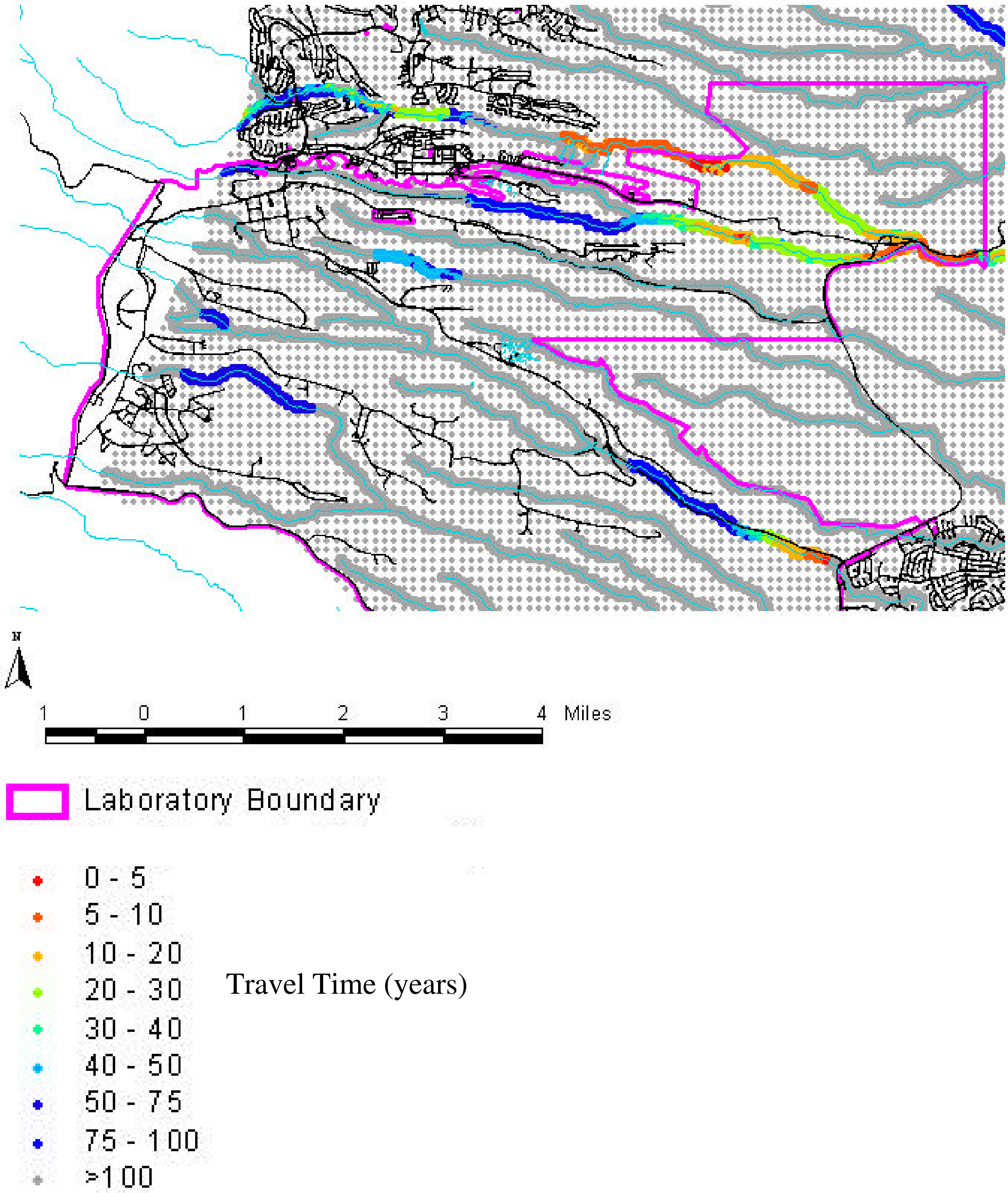


Figure 5.1-3b. Predicted vadose zone travel times (yr) to the water table, showing only travel times of 100 yr or less. Base-case percolation scenario: alternate perched water model.

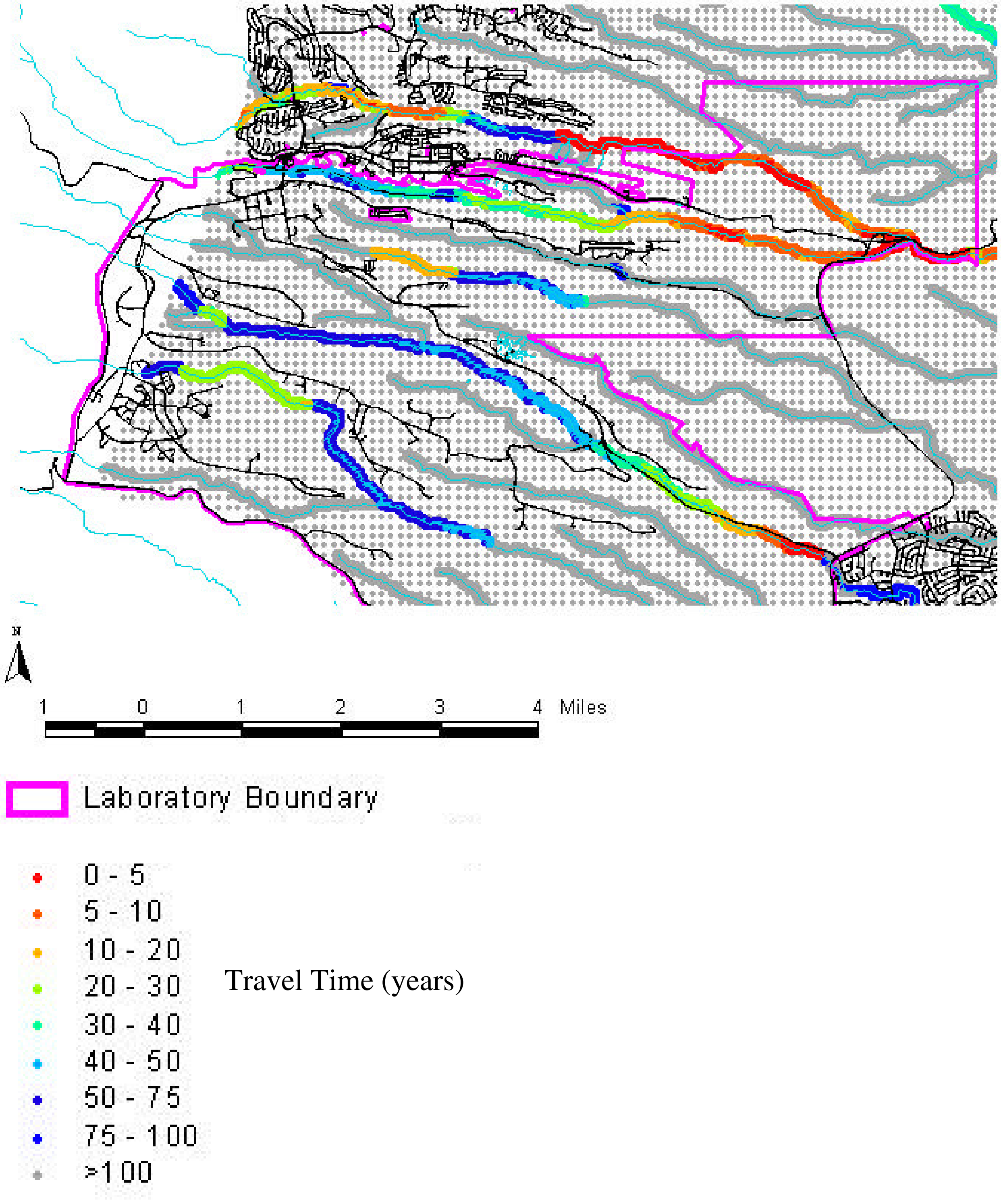


Figure 5.1-4b. **Predicted vadose zone travel times (yr) to the water table, showing only travel times of 100 yr or less. High percolation flux scenario: alternate perched water model.**

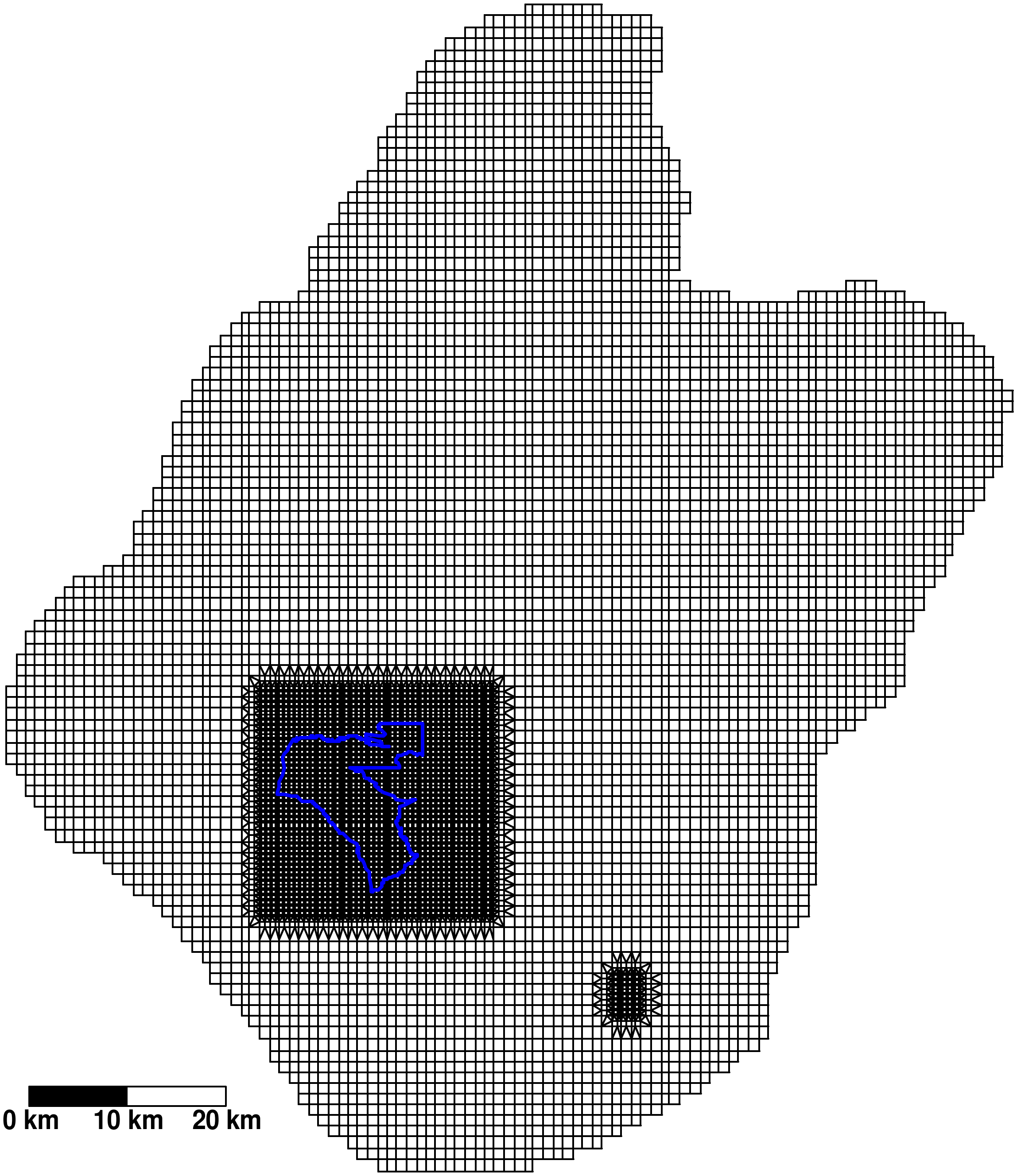


Figure 5.2-1. **Plan view of basin-scale grid**

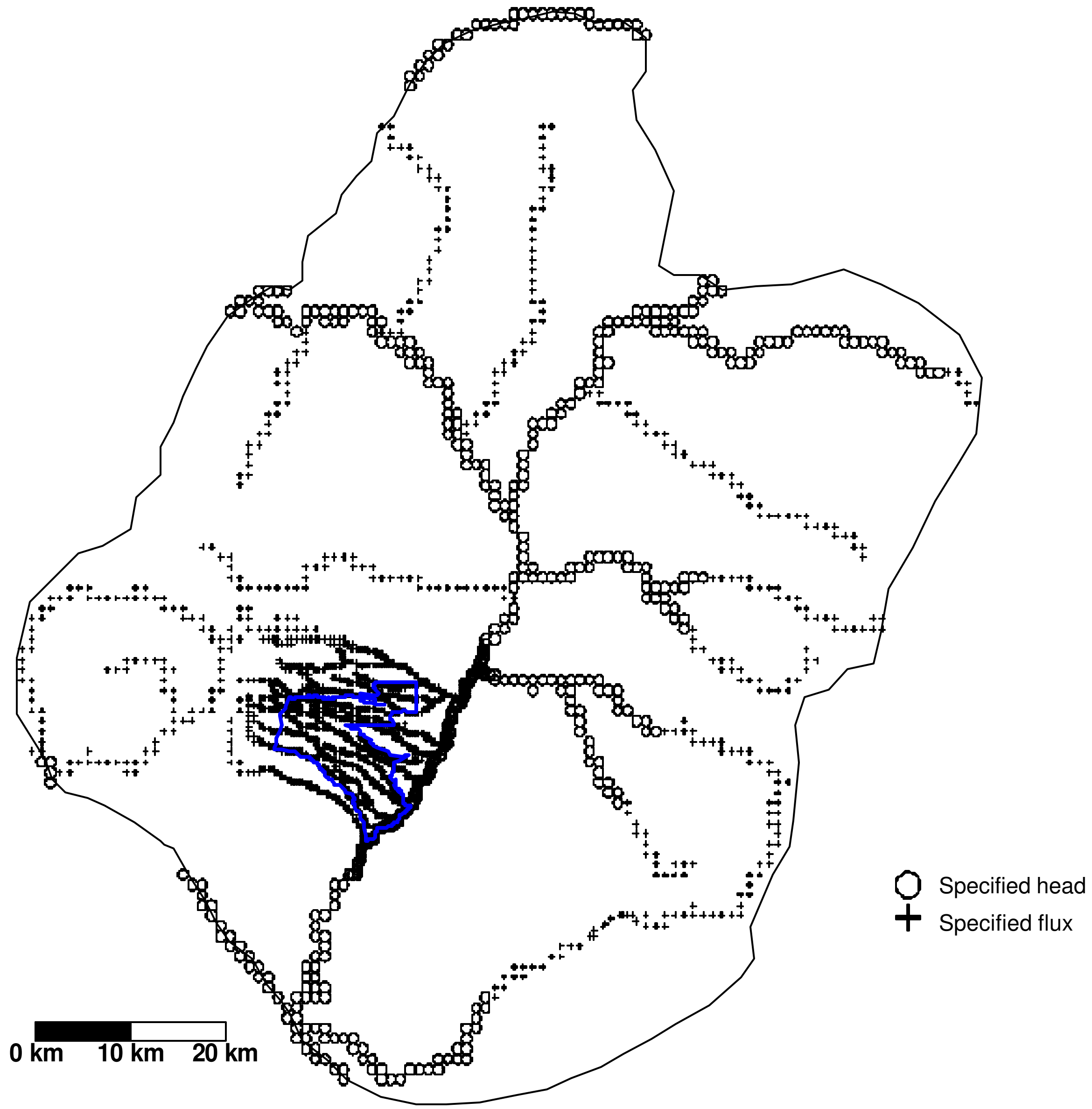


Figure 5.2-2. Boundary conditions along top surface of basin-scale model

The lateral boundaries for the site-scale model (see Figure 5.2-3) were chosen to coincide with the Rio Grande (to the west), the Santa Clara River (to the north), the Rio Frijoles (to the south), and the topographic divide defining the eastern rim of the Valles Caldera (to the west). The initial hypothesis is that little or no flow crosses these boundaries; testing this hypothesis is one objective of coupling the site- and basin-scale models. The calibrated basin-scale model was used to determine flux across these boundaries (and corresponding uncertainty). Analysis of fluxes across site-scale model boundaries suggested that “no-flow” is possible across all four lateral boundaries (predevelopment conditions); however, some degree of flow across all four boundaries is also possible, given the data available for basin-model calibration. The details of model coupling and the estimates of flux are described in Keating et al. (2003).

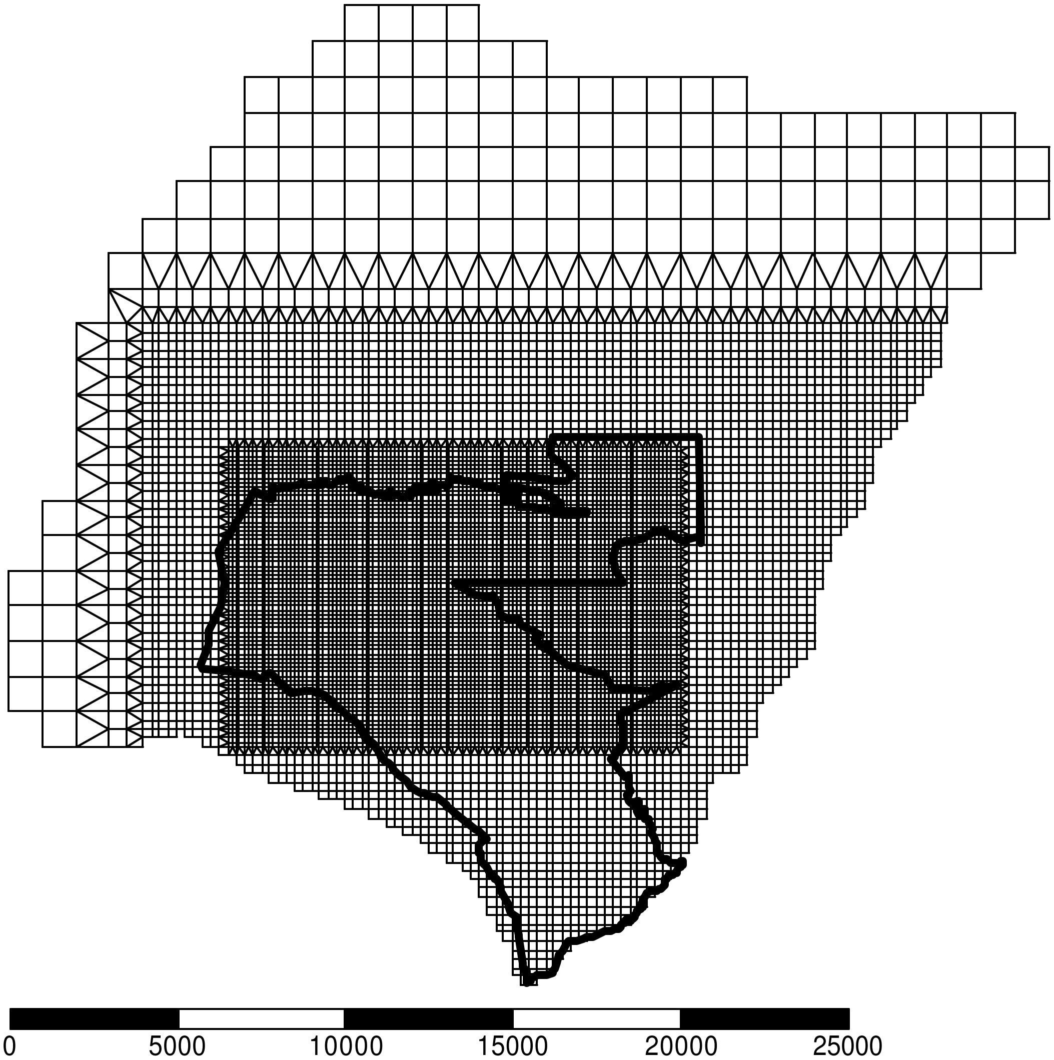


Figure 5.2-3. Plan view of site-scale grid

The upper surface of the numerical grid coincides with the water table. Along this surface, nodes are either no-flow, specified-flux (infiltration recharge), or specified-head (major rivers). Specified heads are applied to nodes simulating the major rivers (Rio Chama, Rio Grande, and the lower reaches of the Santa Fe, Santa Cruz, Embudo, and Pojoaque Rivers). Because data on riverbed hydraulic conductivity throughout the basin are lacking, it is assumed that no contrast occurs in the permeability between riverbeds and aquifer sediments. This simplification is not expected to impact flow and transport calculations on the plateau.

Specified flux nodes (recharge) are located in the upper reaches of major tributaries and the entire length of minor tributaries. The locations of these nodes and specified heads nodes are shown in Figures 5.2-2 and 5.2-4.

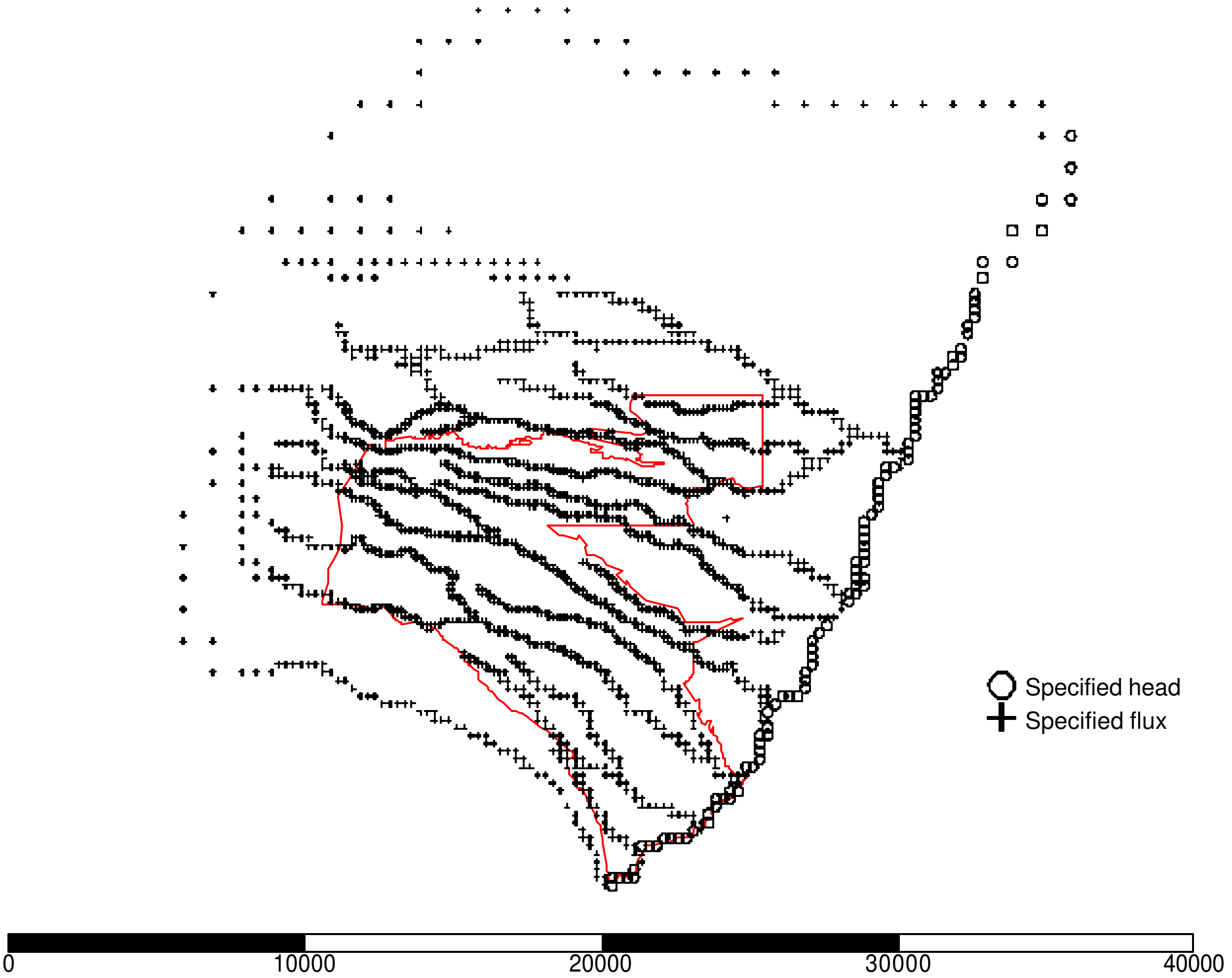


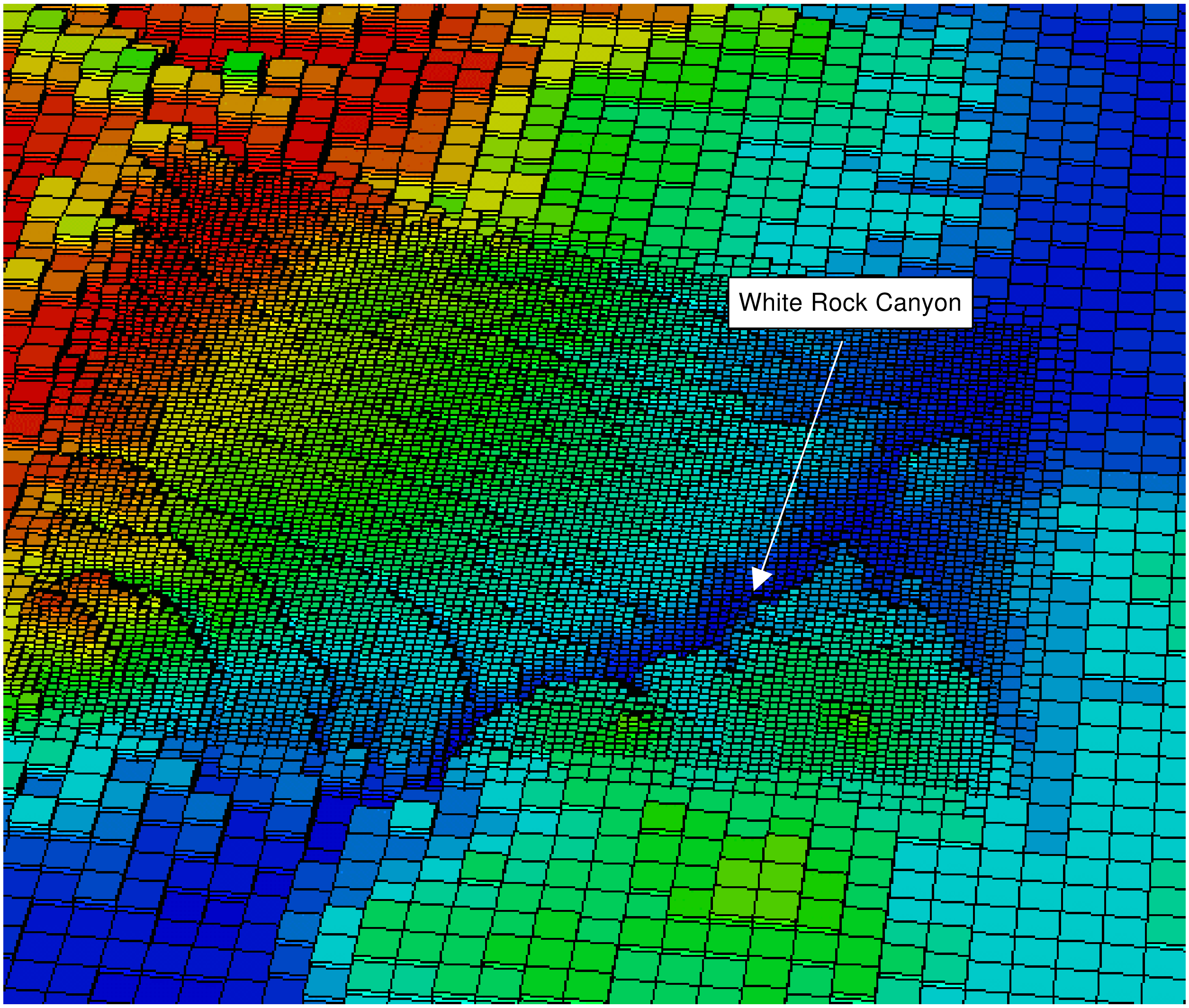
Figure 5.2-4. Boundary conditions along top surface of site-scale model

5.2.2 Regional Aquifer Model Grids

The computational grid for both the basin- and site-scale models are shown in Figures 5.2-1 and 5.2-3; grid characteristics are summarized in Table 5.2-1. The structure of the two models is identical, except for the increased vertical resolution of the site-scale model and the smaller lateral extent. In preparation for the groundwater pathways assessment calculations, a new numerical grid was developed for the site-scale model with an increased level of resolution (see Figures 5.2-3 and 5.2-5). The most finely resolved portion of the grid, beneath the Laboratory, has elements 125 m x 125 m x 12.5 m. This grid allows recalibrating the regional aquifer model using the FY2002 3-D geologic model to define hydrostratigraphic zonation. Included in the recalibration are a large amount of new R-well data and more recent production data from local well fields. The results of this calibration, as well as the impact on flow directions and capture zone delineation, are not yet available.

Table 5.2-1
Regional Aquifer Model Attributes and Calibration Data

	Basin-Scale	**Site-Scale**
Grid resolution		
Number of nodes	277,951 (91,872 within site-scale model region)	172,741
Number of tetrahedral elements	1,528,407	949,835
Number of calibration targets		
Pre-development flux estimates	7	0
Pre-development head measurements	81	26
Transient head measurements (measurements over time in specific wells since water development began in the basin)	76	66
Total	**164**	**92**
Number of estimated parameters (the initial number in parentheses)		
Recharge parameters	2 (3)	1 (3)
Hydrostratigraphic-unit permeabilities	18 (35)	10 (26)
Specific storage	1 (1)	1 (1)
Total	**21 (38)**	**12 (30)**



Colors correspond to ground surface elevations.

Figure 5.2-5. Zoned image of 2002 basin-grid, with additional level of refinement beneath the Laboratory

5.2.3 Regional Aquifer Recharge and Discharge

The conceptual model of recharge is formulated numerically as a blend of two distinct recharge models. The first is elevation-dependent diffuse recharge that is calculated according to an algebraic function of precipitation (see Keating et al. 1999; Keating et al. 2003). No diffuse recharge occurs below a specified elevation, Z_{min}. The second is canyon-focused recharge, where individual reaches of canyons within the Pajarito Plateau are assigned relative scores reflecting the degree to which they might provide water to the subsurface. Collectively, these two models and the algorithm that blends them together are characterized by four parameters that can be varied within calibration criteria to produce a wide variety of recharge scenarios for the purpose of uncertainty analysis. Figure 5.2-6 shows three examples of recharge rate distribution generated using this model, according to the parameters listed in Table 5.2-2. All three models apply the same amount of total recharge to the aquifer. Recent recharge studies generated as described in Section 5.1 will be used in future modeling analyses.

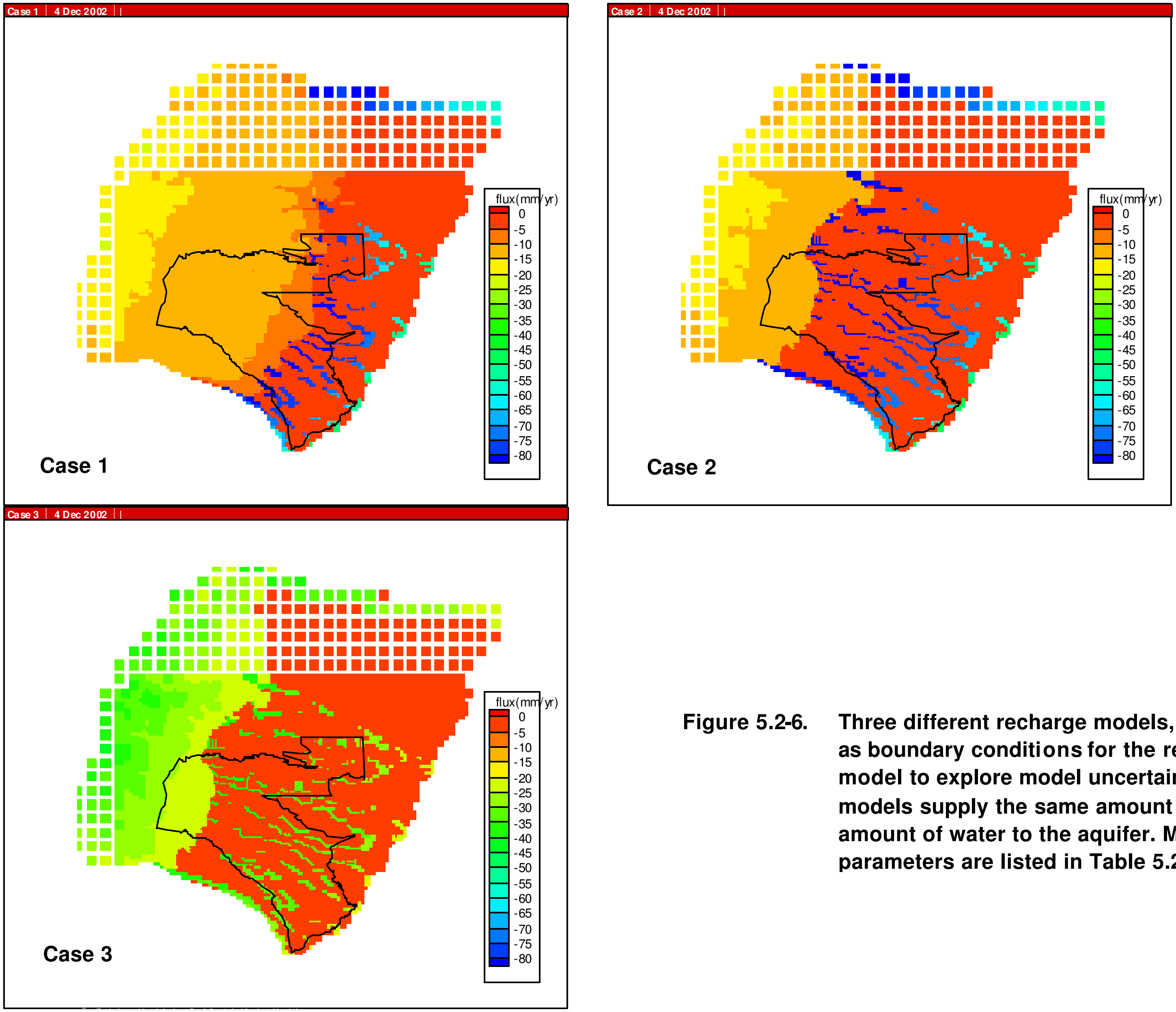


Figure 5.2-6. **Three different recharge models, used as boundary conditions for the regional model to explore model uncertainty. All models supply the same amount of total amount of water to the aquifer. Model parameters are listed in Table 5.2-2.**

Table 5.2-2
Example Recharge Cases Used in Regional Aquifer Model

	Case 1	Case 2	Case 3
Total recharge (kg/s)	200.3	200.3	200.3
Diffuse	122.3	70.6	145.2
Canyon-focused	78.0	129.7	55.1
Zmin (m)	2000	2200	2200

Note: See Figure 5.2-6.

One important model prediction is the amount of discharge from the aquifer to the Rio Grande. Model predictions are compared to estimates based on historical streamflow records (see Section 4.3.3.3). An example comparison is shown in Figure 5.3-1.

5.2.4 Regional Aquifer Definition of Hydrostratigraphic Zones

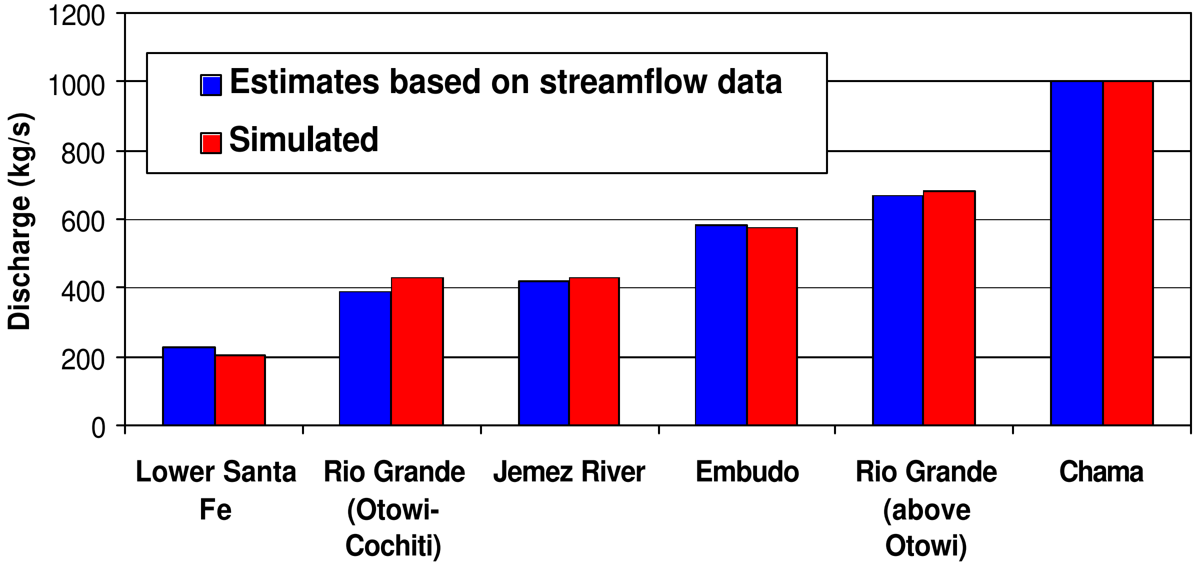
Two methods are used to define hydrostratigraphic zones, depending on the model application. For most purposes, the zones are defined according to stratigraphy incorporated in the 3-D geologic model. The hydrostratigraphic units for the regional scale model are described in Section 4.2. Each zone is assigned uniform properties (permeability, porosity). Although the units are assumed to be uniform, they can be anisotropic.

Stochastic representations of permeability variation within the Puye Formation were developed to address the problem of within-unit heterogeneity, as evidenced by permeability data shown in Figure 4.3-1. These methods could be applied to other units, if necessary. The representations include guassian random fields (Keating et al. 2000) and Markov-chain facies-based models; both approaches are predicated on site-specific data.

5.3 Regional Aquifer Model Calibration

The two primary datasets used for model calibration are (1) water levels (both predevelopment and transient) and (2) fluxes. The calibration datasets are summarized in Table 5.2-1. The water-level dataset for the plateau is derived from annual water supply reports, R-well completion reports, and the WQDB at http://wqdb.lanl.gov/. The flux calibration dataset is derived from streamflow data analysis (Keating et al. 2003).

The automated calibration software PEST (Doherty et al. 1994) is used to determine the set of model parameters (permeability for each zone and recharge model parameters) that provides the best agreement between simulated and observed heads and fluxes. Perhaps more importantly, PEST also provides an estimate of uncertainty for each of these parameters. These uncertainty estimates are critical to gauging the uncertainty of subsequent model predictions and to prioritizing data collection to reduce uncertainty. One important aspect of parameter estimation using PEST is the evaluation of model complexity. If PEST determines that a large number of parameters are insensitive (highly uncertain), the model may be overly complex relative to the data available (Hill 1998). In this case, either more data should be added or the model should be simplified. This principle was applied many times during the course of developing the model, primarily by reducing the number of hydrostratigraphic zones and recharge model parameters (Keating et al. 2000). A comparison of the initial number of model parameters and the simplified version is included in Table 5.2-1.



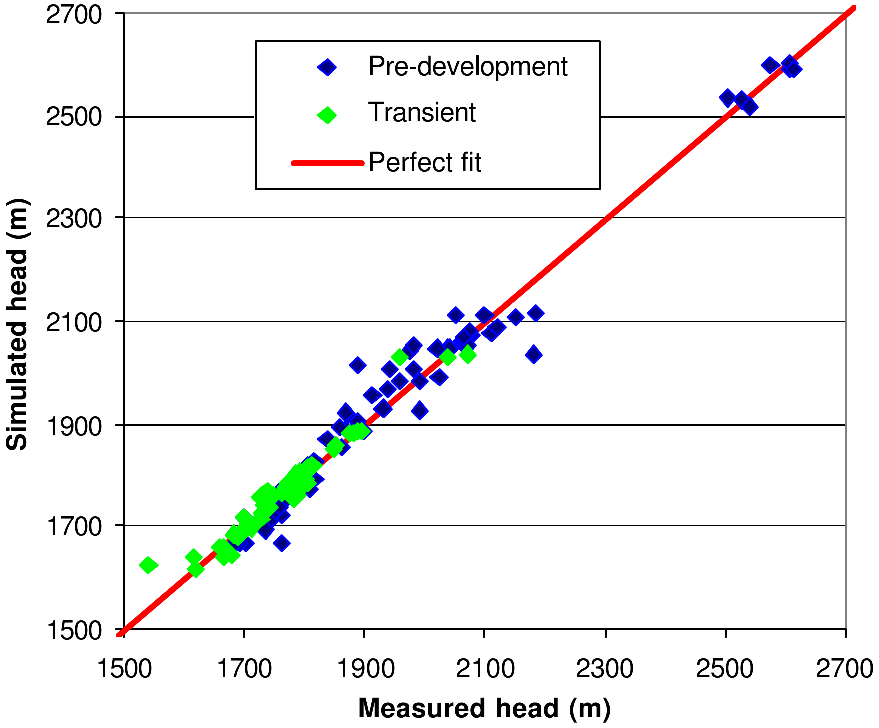


Figure 5.3-1. **Model calibration results from Vesselinov and Keating (2002)**

A few results from model calibration for this site are noteworthy. First, the transient head data are critical to reducing parameter uncertainty. Transient head data are compiled from water-supply wells. Each water-supply well is represented in the model as a series of vertical nodes, spanning the depth range of the screened interval for that well. For the Pajarito Plateau and Buckman well field, pumping data from 22 wells are included in the simulation. Total water withdrawn from these nodes is specified according to annual production data (see Figure 4.3-3). Flux from individual nodes is proportional to the permeability assigned to that node. During model calibration, as permeability values are adjusted for each zone, the apportionment of fluxes over the nodes associated with a given well is adjusted accordingly.

In a sense, water-level responses across the plateau to decades of pumping serve as a large-scale pump test that can be analyzed via model calibration. This analysis differs from conventional pump test analysis, which typically assumes 2-D flow in a homogeneous aquifer, because it is a fully 3-D analysis that incorporates site-specific information about aquifer heterogeneity. Because of the long-time scale (decades of water-level decline), the permeability estimates obtained during model calibration are expected to represent larger spatial scales (100s to 1000s of meters) than conventional pump test analysis.

Analyses of water-level data using PEST have consistently led to the conclusion that the large-scale effective permeability of the Santa Fe Group is lower than conventional pump test analyses indicate. There are three plausible reasons for this discrepancy:

1. Numerous north-south trending faults are present in the Santa Fe Group (Kelley 1978). If these faults behave as barriers to flow, the resulting large-scale effective permeability of the rock would be lower than that estimated at a single well (between fault zones).
2. The model significantly underestimates flux through the aquifer.
3. The saturated thickness of the aquifer is significantly overestimated.

While all three reasons seem plausible, only the first is realistic. The second reason would require that nearly 100% of the base flow to the Rio Grande flow originates from the west. This conceptual model is unrealistic based on current simulations, which predict that only about 50% of base flow to the Rio Grande originates from the west (Sierra de los Valles and Pajarito Plateau). Regarding the third reason, estimates of the saturated thickness of the aquifer are based on gravity data and published cross-sections for the basin and are considered as accurate as possible with existing data. No known data could be used to justify the third reason.

Therefore, the presence of low-permeability fault zones (reason 1) is the most plausible hypothesis at present, although all three hypotheses will continue to be considered.

Finally, in the calibrated models significant discrepancies occur between measured and simulated water levels in some wells. The most probable reason for these differences is the assumption that each hydrostratigraphic zone has uniform properties. Permeability data clearly demonstrate that the rocks are quite heterogeneous, and for this reason in any given unit the model will tend to underestimate water levels in some wells and overestimate water levels in others (mean error of zero). Development of stochastic and/or deterministic approaches to correctly model this heterogeneity and thus reduce errors in head predictions is ongoing.

An example of calibration results, shown in Figure 5.3-1, is taken from Vesselinov and Keating (2002). Departures from perfect agreement between simulated and measured heads are the result of either an overly simple recharge model or an overly simple permeability zonation in the aquifer. Since the recharge model is very flexible, most errors would result from overly simplified aquifer zonation.

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 adequate understanding of the hydrogeologic setting to design a monitoring network capable of detecting water quality threats to the regional aquifer. The “Hydrogeologic Workplan” provides an iterative process of learning from each activity, especially the wells that are installed, thus guiding the succeeding DQOs and the location and data collection of the succeeding wells. The interpretive process is equally as important as well installation and data collection, although the process 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. Iteration is done when sufficient new data and data interpretation have been accomplished to change the conceptual understanding. In FY2002, the data collection and modeling reached the level of maturity to allow a groundwater pathways assessment that will be the basis of the next major iteration on the DQOs. This section describes how the data and interpretation have informed the decisions made in the “Hydrogeologic Workplan.”

The groundwater protection decision flow diagram, developed for the “Hydrogeologic Workplan,” summarizes the decisions that must be made 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 individually in the Hydrogeologic Workplan. Resolution of these decisions for all aggregates will signal the successful completion of the hydrogeologic characterization program.

Table 6.0-1 summarizes the decisions in the “Hydrogeologic Workplan” for each aggregate, the data needed to resolve the decisions, and the proposed data-collection activities. Table 6.0-2 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 6.0-2 provides a cross-walk of non-well activities to the 1998 “Hydrogeologic Workplan.” Figure 6.0-1 shows the progress toward resolution of the decisions in all the aggregates.

In most aggregates, the first four decisions involving 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 involving identification of pathways and prediction of the potential for contamination in the future are unresolved.

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 proportion depending on the outline of the source. Similarly, the monitoring network design would be quite different depending upon anticipated shape of a plume. Thus, many of the proposed data collection activities are targeted at identifying the pathways and the factors affecting transport within the saturated zones. These activities are concentrated in wet canyons where contaminants were discharged and where contamination of saturated zones is anticipated.

Data collection in dry canyon systems and upgradient of the Laboratory focuses 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.

Table 6.0-1
Status of Aggregates with Respect to Decisions and Data Necessary to Resolve Decisions

Aggregate 1: Los Alamos/Pueblo Decision	Data Needs	Planned Data Collection (See Table 6.0-2 for descriptions)
Are there sources of sufficient magnitude to cause contamination of groundwater?		
Are the alluvial sediments and uppermost subsurface water at contaminant concentrations > regulatory risk limit or risk level?		
Is the intermediate perched groundwater at contaminant concentrations > regulatory limit or risk level?		
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 yr?	• 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 6.0-1 (continued)

Aggregate 2: **Cañada del Buey/Pajarito Decision**	**Data Needs**	**Planned Data Collection (see Table 6.0-2)**
Are there sources of sufficient magnitude to cause contamination of groundwater?		
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-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-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-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-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 yr?	• 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-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 6.0-1 (continued)

Aggregate 3: TA-49 Decision	Data Needs	Planned Data Collection (see Table 6.0-2)
Are there sources of sufficient magnitude to cause contamination of groundwater?		
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 geologic 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 yr?	• 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 6.0-1 (continued)

Aggregate 4: Ancho/Indio/Chaquehui Decision	Data Needs	Planned Data Collection (see Table 6.0-2)
Are there sources of sufficient magnitude to cause contamination of groundwater?		
Are the alluvial sediments and uppermost subsurface water at contaminant concentrations > regulatory risk limit or risk level?		
Is the intermediate perched groundwater at contaminant concentrations > regulatory limit or risk level?		
Is the regional aquifer as affected by the canyon systems by contaminant concentrations > regulatory limit or risk limit?		
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 yr?	• Range of measured permeability - large scale • Pre-Bandelier sedimentology • Effective porosity on a field scale • Head Data - horizontal Gradients and 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 6.0-1 (continued)

Aggregate 5: Cañon del Valle Decision	Data Needs	Planned Data Collection (see Table 6.0-2)
Are there sources of sufficient magnitude to cause contamination of groundwater?		
Are the alluvial sediments and uppermost subsurface water at contaminant concentrations > regulatory risk limit or risk level?		
Is the intermediate perched groundwater at contaminant concentrations > regulatory limit or risk level?		
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 yr?	• Range of measured permeability - large scale • Pre-Bandelier sedimentology • Effective porosity on a field scale • Head Data - horizontal gradients and 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 6.0-1 (continued)

Aggregate 6: Water/Potrillo/Fence Decision	Data Needs	Planned Data Collection (see Table 6.0-2)
Are there sources of sufficient magnitude to cause contamination of groundwater?		
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-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-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-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-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 yr?	• 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-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 6.0-1 (continued)

Aggregate 7: Mortandad Decision	Data Needs	Planned Data Collection (see Table 6.0-2)
Are there sources of sufficient magnitude to cause contamination of groundwater?		
Are the alluvial sediments and uppermost subsurface water at contaminant concentrations > regulatory risk limit or risk level?		
Is the intermediate perched groundwater at contaminant concentrations > regulatory limit or risk level?		
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-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-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 yr?	• Range of measured permeability - large scale • Pre-Bandelier sedimentology • Effective porosity on a field scale • Head Data - horizontal gradients and vertical gradients • Determination of 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 • 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 6.0-1 (continued)

Aggregate 8: Guaje/Bayo/Rendija Decision	Data Needs	Planned Data Collection (see Table 6.0-2)
Are there sources of sufficient magnitude to cause contamination of groundwater?		
Are the alluvial sediments and uppermost subsurface water at contaminant concentrations > regulatory risk limit or risk level?		
Is the intermediate perched groundwater at contaminant concentrations > regulatory limit or risk level?		
Is the regional aquifer as affected by the canyon systems by contaminant concentrations > regulatory limit or risk limit?		
What are the pathways for exposure to contaminants from alluvial sediments and uppermost subsurface water?		
Are there sufficient source terms to cause contamination if moved along the pathways in 1000 yr?		

Table 6.0-2

Planned Data Collection and Interpretation Activities

Task ID Number	Task Name	Task Description	Cross-Walk to "Hydrogeologic Workplan" (see Table 3-1)
Other Field (Non-Well) Activities			
OF-1	Spinner logs	Use spinner logs to determine the most productive zones in a well; logs 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	Conduct multiple well pump tests to determine medium - to large-scale permeability and 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	Test 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 Electromagnetic Survey	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 δ^{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

Table 6.0-2 (continued)

Task ID Number	Task Name	Task Description	Cross-Walk to "Hydrogeologic Workplan" (see Table 3-1)
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
OF-10	Basalt Flow Geometry	Use the airborne EM survey and surface mapping of Frijoles and Guaje Mountain (SE corner) quadrangles since spatial refinement of the geometry of basalt flows, which are potential fast pathways, is uncertain. Develop and consider multiple alternative geologic models and test them with flow model against water-level data.	**Task:** Develop geologic model **Subtask:** Develop 3-D 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	Use characterization wells completed with multiple screened intervals and sampling ports within the regional aquifer 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	Take flow measurements and water quality analysis for springs in areas impacted by contamination, e.g., TA-16.	**Task:** Develop hydrologic model **Subtask:** Inventory springs on-site
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-D 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

Table 6.0-2 (continued)

Task ID Number	Task Name	Task Description	Cross-Walk to "Hydrogeologic Workplan" (see Table 3-1)
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	Analyze 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
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 annually.	**Task:** Develop hydrologic model **Subtask:** Long-term water balance
A-10	Information management	Promote 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

Table 6.0-2 (continued)

Task ID Number	Task Name	Task Description	Cross-Walk to "Hydrogeologic Workplan" (see Table 3-1)
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-D database **Subtask:** Perform comprehensive review of 3-D stratigraphy
Project Management Activities			
PM-1	GIT activities	Conduct quarterly and annual meetings; compile annual groundwater status report.	
PM-2	EAG activities	Conduct semiannual project reviews and compile semiannual reports.	
PM-3	Field Support Facility	Maintain field support facility and core facility.	

Decision	Aggregate 1: Los Alamos/ Pueblo	Aggregate 2: Cañada del Buey/Pajarito	Aggregate 3: TA-49	Aggregate 4: Ancho/Indio/ Chaquehui	Aggregate 5: Cañon 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 yr?	◠	◠	⊘	⊘	⊘	⊘	◠	No ○

○ Decision resolved; no further data collection necessary.

◠ Decision not resolved, further data collection and analysis necessary.

⊘ Data have not been collected to resolve this decision

Figure 6.0-1. Summary of the progress toward resolution of decisions in all "Hydrogeologic Workplan" aggregates

6.1 FY2002 Observations Relative to Decisions

As detailed in Section 1.0, six regional aquifer wells were completed in FY2002. One well was drilled in Los Alamos Canyon, three in Pajarito Canyon near TA-54 (R-20, R-23, and R-32), one (R-14) in Ten Site Canyon, and one at the northern edge of White Rock (R-16). These wells were completed at the end of FY2002, so analysis and interpretation of the data are still in progress. However, work completed in FY2002 provides useful information to inform the decisions made in the "Hydrogeologic Workplan." First, characterization sampling of many R-wells was completed in FY2002 as documented in the geochemistry reports. Second, the regional aquifer model was applied to questions about travel path and travel time. Finally, the groundwater pathways assessment identifies areas where additional characterization data would be useful in reducing the uncertainty in risk estimates.

6.1.1 Geochemical Characterization

Figure 6.1-1 shows locations of wells where characterization sampling has been completed (R-9, R-9i, R-12, R-15, R-19, R-22) with other water supply wells for reference. Wells R-9 and R-15 are completed with single screens near the regional water table within Los Alamos Canyon and Mortandad Canyon, respectively. Wells R-12, R-19, and R-22 are completed with multiple screens in both perched systems (R-12, screens #1 and 2, and R-19, screen #1) and in the regional aquifer (R-12, screen #3; R-19, screens #2–7; and R-22, screens #1–5). Well R-9i is completed with two screens within a perched system (Cerros del Rio lavas) in Los Alamos Canyon. Sampling protocols at R-wells and analytical methods are described in the geochemistry reports (Longmire 2002, all).

"Detection" of a chemical in groundwater is defined as finding an analyte concentration that exceeds the MDL. Detection of a radionuclide in groundwater occurs if its activity is 3σ (three standard deviations) and the instrument's minimum detectable activity (MDA). The 3σ values for every radionuclide are contained in the ERDB and were included as part of data validation. A "nondetect" is defined as an analyte concentration that is recorded but is less than the MDL. The reporting limit (RL) is defined as the instrument quantitation limit.

Some variation in major ion chemistry in each well results from the breakdown of residual drilling fluid. Concentrations of alkalinity, sulfate, iron, manganese, and TOC fluctuated during characterization sampling because of oxidation and reduction reactions driven by the breakdown of residual drilling fluids. Concentrations of sulfate vary because of sulfate reduction and colloidal bentonite derived from bentonite annulus seals set above well screens (R-19, screen #7, and R-22, screen #3) (Longmire 2002, 73282; Longmire 2002, 73676). Natural sulfate occurs as an adsorbate (adsorbing anion) present on bentonite surfaces. The multiscreen wells are re-equilibrating with groundwater as residual drilling fluids dissociate and oxidize to inorganic carbon and as organic nitrogen is transformed to ammonium and nitrogen gas (denitrification). Additional sampling from multiscreen wells (R-12, R-19, R-22) will provide data on the kinetics of this re-equilibration process.

Aqueous Geochemistry

Wells R-9, R-9i, R-12, R-15, and R-22 are mainly characterized by calcium-sodium-bicarbonate and sodium-calcium-bicarbonate ionic compositions. Figures 6.1-2 and 6.1-3 show typical regional aquifer ionic composition. These wells generally show consistent concentrations of the major ions during characterization sampling; however, several screens in wells R-12, R-19, and R-22 show variations in major ion chemistry from the breakdown of residual drilling fluid (Longmire 2002, 72800; Longmire 2002, 73282; Longmire 2002, 73676).

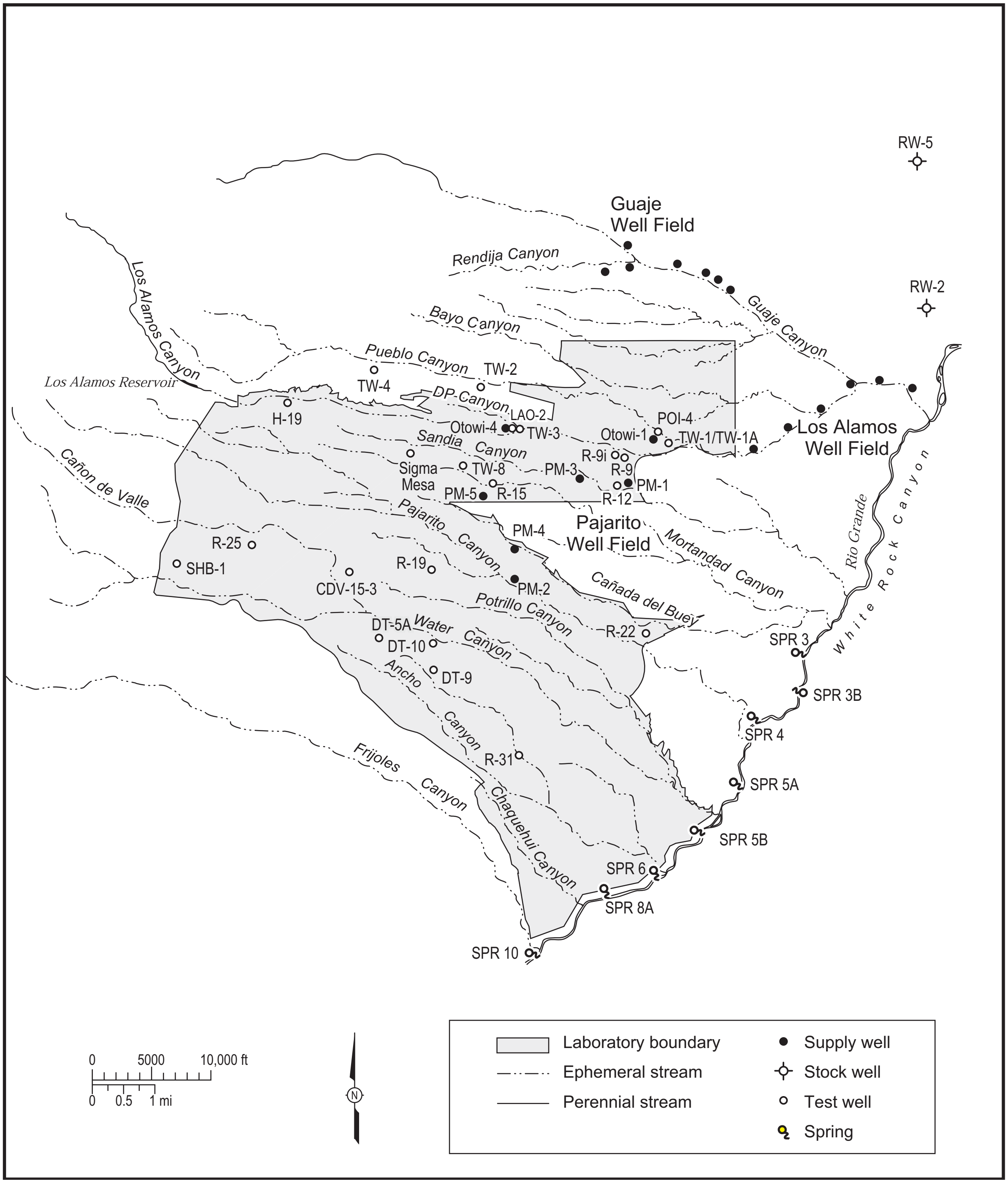


Figure 6.1-1. Locations of wells R-9, R-9i, R-12, R-15, R-19, and R-22, selected water supply wells, test wells, and springs near the Rio Grande

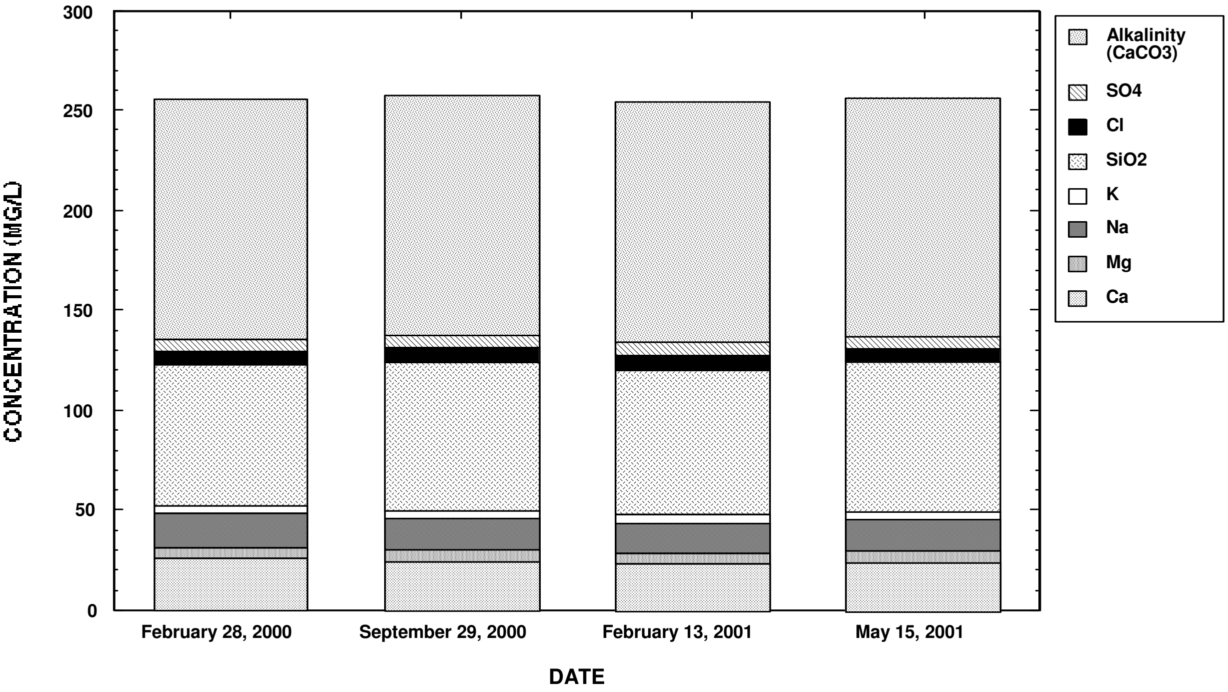


Figure 6.1-2. **Major ion chemistry for well R-9 (regional aquifer), upper Los Alamos Canyon**

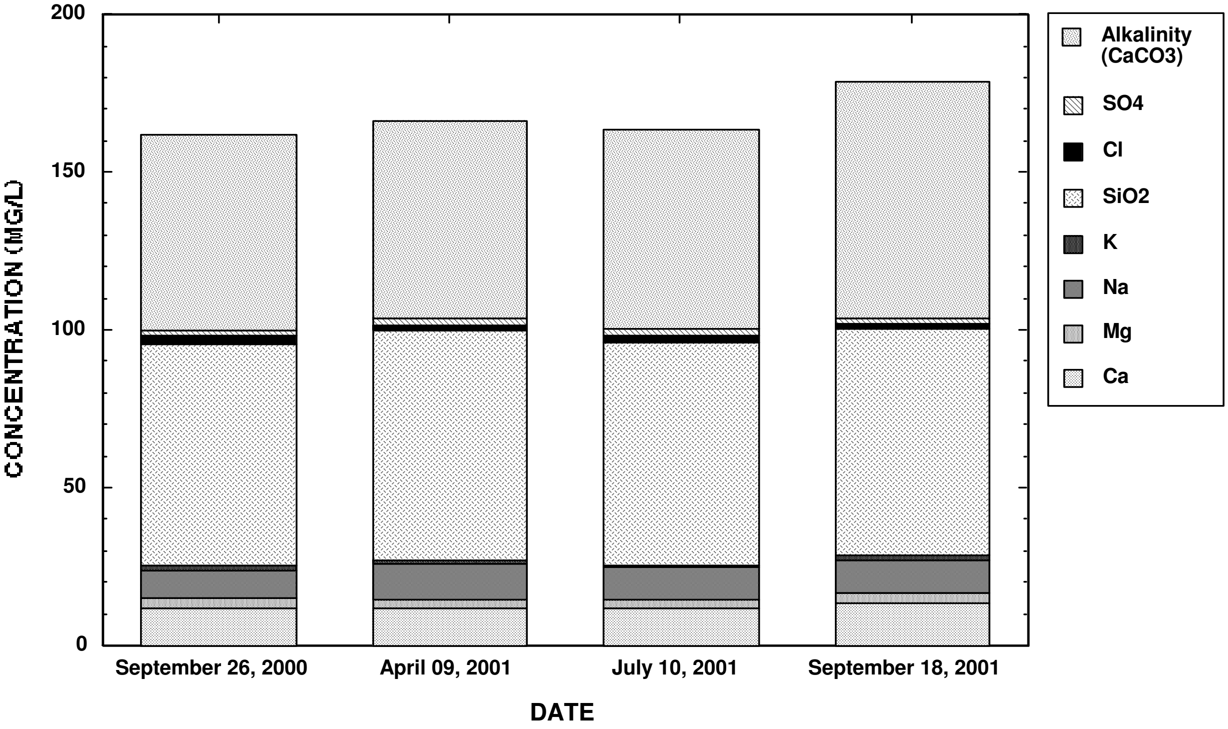


Figure 6.1-3. **Major ion chemistry for well R-19, regional aquifer (1190.5 ft)**

Trace Element Chemistry

Concentrations of trace elements in wells R-9, R-9i, R-12, R-15, R-19, and R-22 were within the low-to-moderate microgram/liter range and were generally less than their respective EPA and New Mexico Water Quality Control Commission (NMWQCC) standards. These include antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, lead, mercury, molybdenum, selenium, silver, strontium, thallium, uranium, vanadium, and zinc. Concentrations of natural iron, manganese, and/or nickel, however, exceeded their respective EPA standards in one or more screens at wells R-9i (nickel), R-12, R-19, and R-22. The EPA secondary standards (drinking water) for manganese and iron are 0.05 and 0.3 mg/L, respectively. Domestic water supply standards for manganese and iron established by the NMWQCC are 0.2 and 1 mg/L, respectively. Elevated concentrations of natural iron and manganese result from temporary reducing conditions enhanced by the breakdown or dissociation of residual drilling fluids.

The EPA primary standard for nickel is 0.1 mg/L. Concentrations of nickel at R-9i exceeded the MCL during the first sampling round, September 14–15, 2000, and during the second sampling round, February 20, 2001. Concentrations of nickel were below both the EPA and NMWQCC standards during the third sampling round, June 11–12, 2001, and during the fourth sampling round, September 5–6, 2001. Concentrations of dissolved nickel range from 0.039 to 0.140 mg/L in the upper perched zone and from 0.010 to 0.110 mg/L in the lower perched zone at well R-9i. Low concentrations of nickel (<0.020 mg/L) are typically observed at the Laboratory and around the Pajarito Plateau (ESP 2001, 71301). The NMWQCC standard for dissolved nickel is 0.2 mg/L, and the highest concentration of dissolved nickel at well R-9i was approximately 70% of the NMWQCC standard.

Nickel is a natural trace element found in olivine ($[Fe,Mg]_2SiO_4$), a common constituent of mafic rocks. This trace element has an average worldwide concentration of 160 ppm in mafic rocks (Krauskopf and Bird 1995, 71477). Concentration of nickel within the Cerros del Rio lavas (11 samples) at R-31 ranged from 35 to 154 ppm (Vaniman et al. 2002, 72615). Abundance of olivine ranged from 2.4 to 8.8 wt % in the Cerros del Rio basalt characterized at borehole R-9 (Broxton et al. 2001, 71250). One hypothesis for explaining the elevated nickel concentrations in well R-9i is that natural adsorbents such as $Fe(OH)_3$ and α-FeOOH present in the Cerros del Rio basalt dissolved because of the reducing conditions stabilized near the well screens, and nickel desorbed from the dissolving solids (Longmire 2002, 72713).

Adsorption/desorption calculations using the computer program MINTEQA2 (Allison et al. 1991, 49930) were performed to evaluate the release of nickel to the upper perched zone in well R-9i (Longmire 2002, 72713). These calculations are based on the hypothesis that hydrous ferric oxide (HFO) is a natural adsorbent present in the altered Cerros del Rio basalt, which has undergone reductive dissolution. Results of the adsorption/desorption calculations are provided in Table 6.1-1. Results of the MINTEQA2 calculations support the hypothesis that elevated natural iron and nickel at well R-9i result from the reductive dissolution of HFO followed by desorption of nickel.

Distribution of Tritium

Based on R-well characterization sampling, tritium is present in four areas: Los Alamos Canyon (R-9 and R-9i), Sandia Canyon (R-12), Mortandad Canyon (R-15), and the mesa top between Pajarito and Cañada del Buey (R-22). Distributions of tritium in wells within lower Los Alamos Canyon (R-9 and R-9i) and Sandia Canyon (R-12) are shown in Figures 6.1-4 and 6.1-5, respectively. In Los Alamos Canyon, activities of tritium generally increased in perched zone water (screens #1 and #2 in well R-9i) and are consistently low in well R-9 (regional aquifer). Dilution and/or mixing within well R-9i may account for the lower activities of tritium observed during the first sampling round conducted in September 2000. In Sandia Canyon, activities of tritium generally decreased in the perched system (screens #1 and #2) as well as in the regional aquifer (screen #3) at R-12.

Table 6.1-1
Results of Adsorption Calculations Using MINTEQA2 for Well R-9i, Upper Los Alamos Canyon

Parameter	Value	Surface Complex
Concentration of HFO (g/L)	0.0014	Not applicable
Specific surface area (m^2/g)	600	Not applicable
Ionic strength	0.003 molal	Not applicable
pH	8.04	Not applicable
Eh (calculated from Fe^{3+}/Fe^{2+} redox couple) (mV)	–78	Not applicable
Concentration of Ni molal (mg/L)	2.045E-06 (0.120)	Not applicable
Percentage Ni dissolved	97.8	Not applicable
Molality (mg/L)	1.999E-06 (0.118)	Not applicable
Percentage Ni adsorbed	2.2	Not applicable
Molality (mg/L)	4.563E-08 (0.002)	Not applicable
Percentage Ni adsorbed to strong binding site	1.0	$\equiv Fe\_{}^{s}OHNi^{2+}$
Molality of adsorbed complex (mg/L)	2.074E-08 (0.001)	$\equiv Fe\_{}^{s}OHNi^{2+}$
Percentage Ni adsorbed to weak binding site	1.2	$\equiv Fe\_{}^{w}ONi^{+}$
Molality of adsorbed complex (mg/L)	2.489E-08 (0.001)	$\equiv Fe\_{}^{w}ONi^{+}$
Speciation of dissolved and adsorbed Ni (%)	Ni^{2+} (3.0), $NiCO_3^0$ (93.2), $Ni(CO_3)_2^{2-}$ (1.1), $\equiv Fe\_{}^{s}OHNi^{2+}$ (1.0), $\equiv Fe\_{}^{w}ONi^{+}$ (1.2)	Not applicable

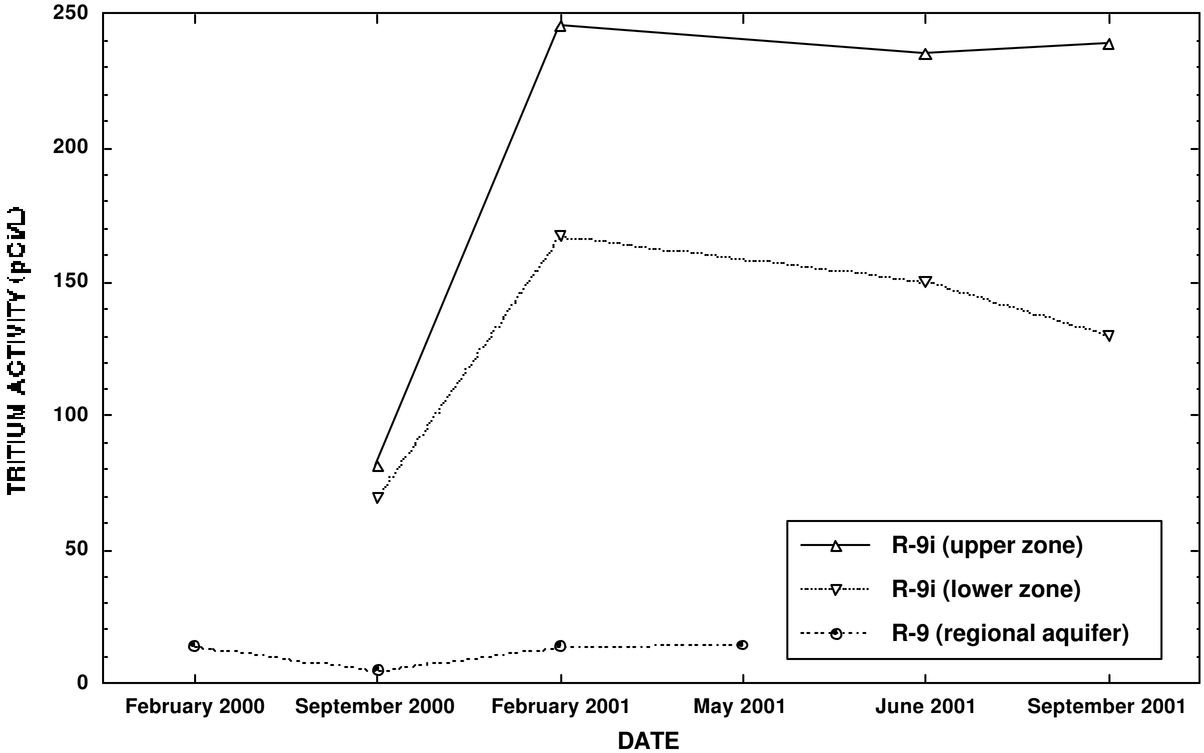


Figure 6.1-4. Tritium distribution in wells R-9 and R-9i during characterization sampling

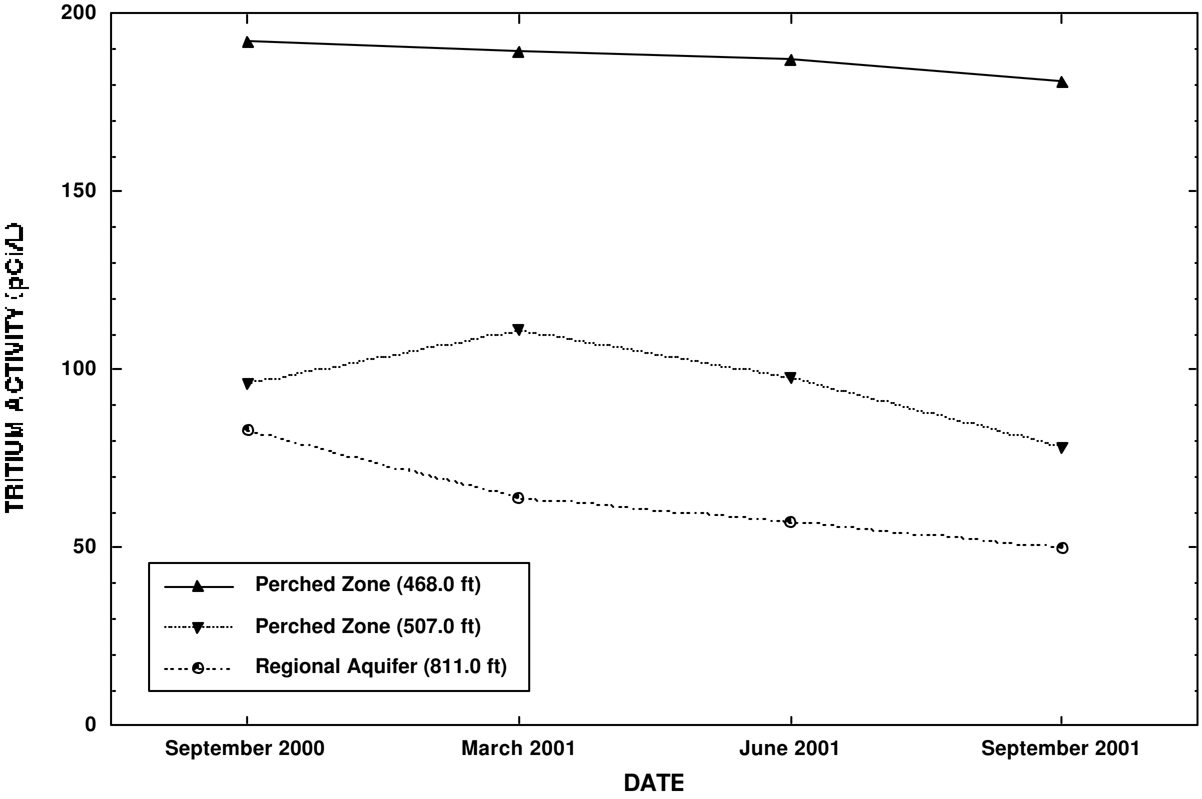


Figure 6.1-5. Tritium distribution in well R-12 during characterization sampling

Activities of tritium measured at well R-22 are shown in Figure 6.1-6 (Longmire 2002, 73676). Activities of tritium ranged from 2.01 to 2.87 pCi/L in screen #1 and from 3.54 to 18.45 pCi/L in screen #5 in well R-22 (Figure 6.1-6) (Longmire 2002, 73676). Possible sources of detectable tritium at well R-22 include atmospheric fallout and/or Laboratory discharges, subject to aqueous and vapor-phase movement entering the regional water table upgradient of the well. This hypothesis of upgradient recharge is consistent with measurements of higher tritium activities observed in screen #5, while it generally was not detected in screens #2, #3, and #4. The absence of tritium in screens #2, #3, and #4 suggests that the regional aquifer (from 947 to 1385 ft) has not received recharge in the past 50 yr, which predates the beginning of atmospheric nuclear testing. Perched zones were not encountered during the drilling of R-22, suggesting that vertical recharge through the vadose zone at the well site is unlikely. Other radionuclides including americium-241, cesium-137, plutonium isotopes, and strontium-90 were not detected in the R wells.

Distributions of Stable Isotopes

Average stable isotope ratios for several R-wells, supply wells, and springs are shown in Figure 6.1-7 (Longmire and Goff, in press). Wells R-5, R-9i, and R-12, drilled in Pueblo Canyon, Los Alamos Canyon, and Sandia Canyon, respectively, have screens set in perched zones within the Cerros del Rio lavas. Well R-25 was drilled in TA-16 and contains an upper saturated zone several hundred feet thick (Broxton et al. 2002, 72640). Perched groundwater samples collected from wells R-5, R-7, R-9i, R-12, and R-25 (Figure 6.1-7) show a significant spread of values (–85 to –70‰ δD and –12 to –10.5‰ δ^{18}O) that parallels both the world meteoric water line (MWL) and the Jemez Mountains meteoric water line (JMWL) (Vuataz and Goff 1986, 73687). Figure 6.1-7 indicates that the most likely source of recharge for the R-wells is from the Sierra de los Valles to the west.

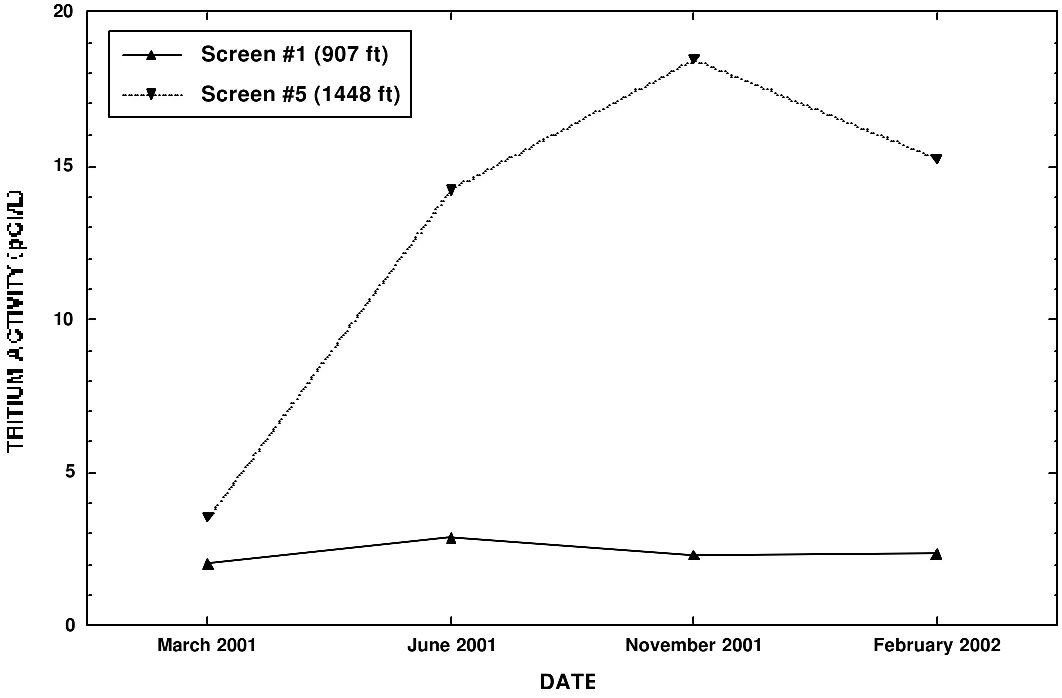


Figure 6.1-6. Tritium distribution in well R-22 during characterization sampling

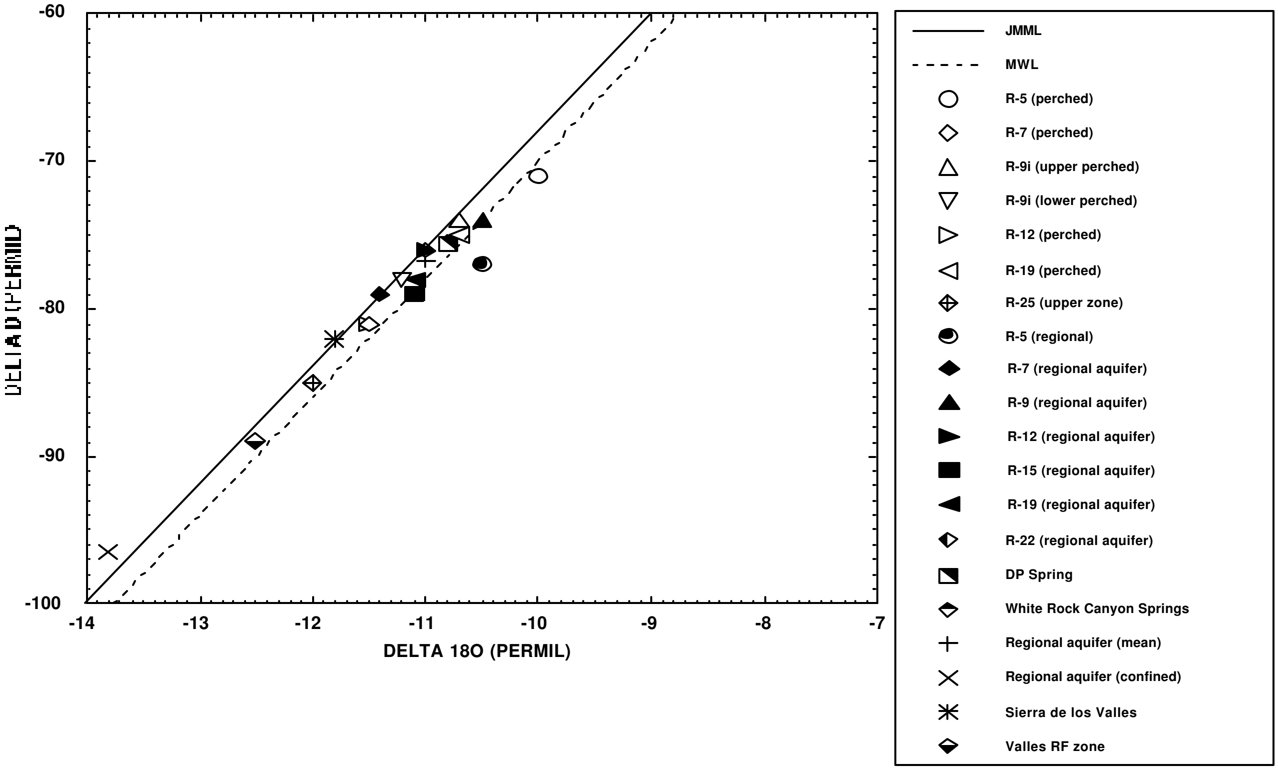


Figure 6.1-7. Average stable isotope results for wells R-5, R-7, R-9i, R-12, R-15, R-19, R-22, R-25, White Rock Canyon Springs, regional aquifer, DP Spring, Sierra de los Valles, Valles ring fracture zone, and confined aquifer

Figure 6.1-7 also shows the strong isotopic gradients observed in the Jemez Mountains region related to elevation differences; higher elevation sites have consistently more depleted isotope values (Clark and Fritz 1997, 59168). These data indicate that, on average, different water types in the Jemez Mountains and the Pajarito Plateau have isotope values greatly influenced by their average recharge elevations. Based on stable isotope ratios (δD and δ^{18}O) of groundwater, recharge to perched zones and the regional aquifer mainly occurs within the Sierra de los Valles and in wet canyons on the Pajarito Plateau (see Section 4.3.3.4 for discussion of recharge).

The one exception to this rule is the group of waters from the "confined aquifer" (regional aquifer) near San Ildefonso Pueblo (confined aquifer as originally defined by Purtymun and Johansen 1974, 11835; see also Blake et al. 1995, 49931). This groundwater discharges from wells and springs whose elevations are as low as those from White Rock Canyon springs, yet their average isotope values are exceptionally depleted (Goff and Sayer 1980, 73686). The "confined aquifer" groundwater is so completely different in isotopic composition that it is possibly recharged from entirely different high-elevation sources than other Jemez Mountains region waters. Goff and Sayer (1980, 73686) originally proposed that this source might be from the Sangre de Cristo Range east of the Pajarito Plateau. Another hypothesis for explaining these light isotopic ratios is that the "confined aquifer" contains older groundwater from the Pleistocene. The Pleistocene was characterized by colder climatic conditions, resulting in the ^{18}O and D depletion.

Summary of Geochemical Observations

Several features of the geochemical model have been validated, modified, or added as a result of FY2002 data collection and analysis (see Section 3.5). Additional knowledge has been gained about the perturbation of groundwater compositions by drilling and well construction materials and the subsequent re-equilibration of the groundwater system. These features are summarized below.

- Major ion chemistry of the regional aquifer varies from a calcium-sodium-bicarbonate to a sodium-calcium-bicarbonate ionic composition. TDS generally increase along groundwater flow paths in the regional aquifer.
- Several of the R-wells (multiscreen) are re-equilibrating with groundwater. The single screen wells have equilibrated with groundwater. Oxidation and reduction reactions are occurring in several wells that contain residual drilling fluid, resulting in elevated concentrations of alkalinity, iron, manganese, nickel, and DOC.
- Measurable activities of tritium observed in wells R-9, R-9i, R-12, R-15, and R-22 suggest that a component of groundwater is less than 60 yr old. Well R-19 does not contain tritium, and the age of groundwater at this well probably ranges between 3000 and 10,000 yr.
- Mobile (nonadsorbing) solutes, including tritium, nitrate, and perchlorate have migrated hundreds of feet within the subsurface within the past 60 yr. Concentrations and activities of these chemicals are below regulatory standards and/or health advisory limits within the regional aquifer at the R-wells.
- Based on stable isotope ratios (δD and δ^{18}O) of groundwater, recharge to perched zones and the regional aquifer occurs mainly in the Sierra de los Valles and in wet canyons on the Pajarito Plateau.

6.1.2 Regional Model Applications

In FY2000, the capture zones for the Buckman well field were estimated and communicated to numerous stakeholders in the region. Details of this study are available in Vesselinov and Keating (2002); a sample result is shown in Figure 6.1-8. A somewhat surprising aspect of this work was the prediction that some groundwater beneath the Laboratory may eventually be captured by the Buckman well field. Travel times from the regional aquifer beneath the Laboratory to Buckman are expected to be very long (thousands of years). In FY2003, these results will be updated using the FY2002 geologic model and robust estimates of model uncertainty.

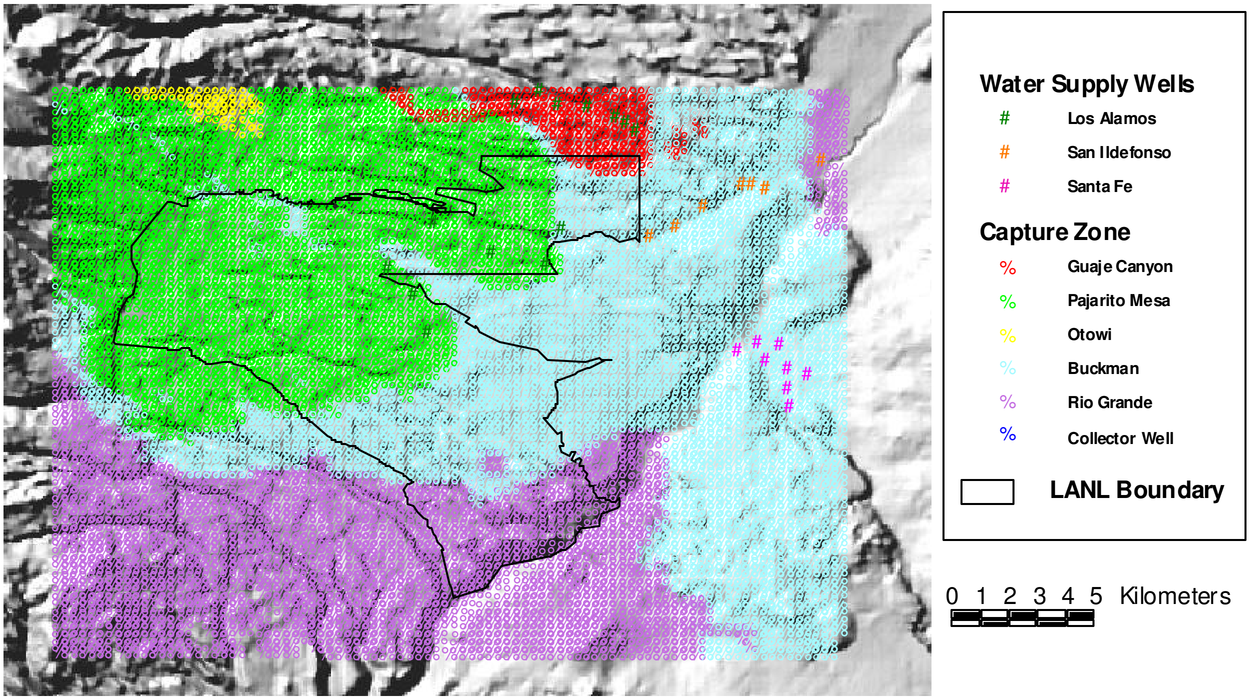


Figure 6.1-8. Estimated capture zones, Buckman well field

The regional aquifer model has also been applied to a detailed analysis of the capture zone of PM-5 and associated uncertainty. Releasing hypothetical particles into the aquifer at a location beneath Mortandad Canyon, the model predicted that 80% of the particle mass would be captured by PM-5. The rest would flow past the well (to the east) because of dispersion. A predictive analysis (Doherty et al. 1994) was applied to determine the uncertainty in this estimate of 80% capture. The results of the analysis showed that by changing recharge model parameters, the model could remain calibrated and predict either 0% capture (all mass traveling to the east) or 100% capture. Figure 6.1-9 illustrates this result, showing the character of the particle plume as it passes PM-5 (0% capture) and the two water table configurations producing the two different results. This analysis highlights the effect of local recharge on the water table configuration and the resulting impact on flow directions. This analysis will be updated using the FY2002 geologic model and more detailed site-specific information about recharge in Mortandad Canyon.

The regional aquifer model applications highlight the impact of uncertainty in modeling results and on decisions based on modeling results. The goal of the groundwater pathways assessment, which will be completed in FY2003, is to continue to identify the parameters that make a significant difference (e.g., local recharge) and to reduce uncertainty in those parameters.

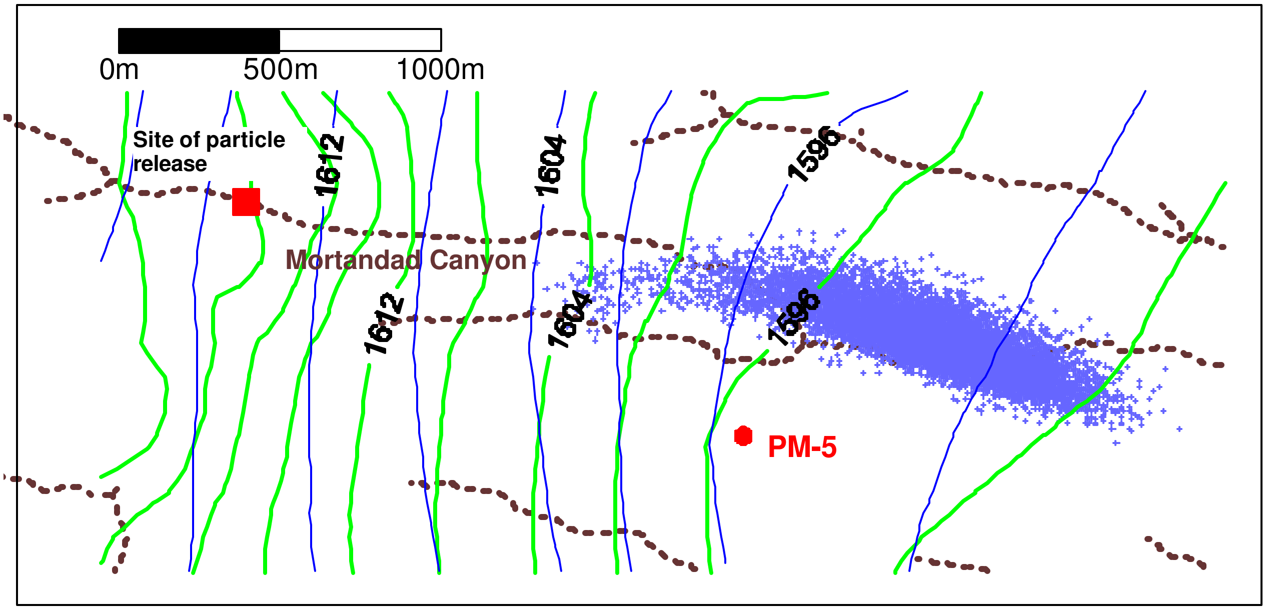


Figure 6.1-9. Hypothetical particle plume as it passes PM-5 caused by releasing hypothetical particles into aquifer, beneath Mortandad Canyon

7.0 FY2003 PLANNED ACTIVITIES

This section summarizes the project management, data collection, data interpretation, and data management activities planned for FY2003.

7.1 FY2003 Project Management Activities

The following are the project management activities for FY2003:

- 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.

7.2 FY2003 Data Collection, Analysis, and Interpretation Activities

The geologic, hydrologic, geochemical, and modeling activities planned for FY2003 are described in the following subsections. 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.

Geologic data collection and analysis activities for FY2003 will focus on the synthesis of data from drill holes R-5, R-8, R-14, R-16, R-20, R-21, R-23, and R-32. A key question to be addressed concerns the character and extent of the Cerros del Rio hydrogeologic unit from Pueblo to Los Alamos Canyons and into Mortandad Canyon. Of particular concern for revision of the 3-D geologic model is the relationship between basaltic components that are definitively attributed to the Cerros del Rio and the more evolved lavas of the central Laboratory that may be attributed to either the Cerros del Rio or the Tschicoma. Determining the sources of these lavas has a significant impact on how they are extended within the model. Borehole geophysical logging will be examined, along with the data from cuttings, to revise the distribution of transmissive and nontransmissive features (lava interiors, breccias, and clay/sediment horizons) within the Cerros del Rio. In addition, alteration of the pumiceous unit, an unassigned Tertiary pumiceous deposit, strongly affects its hydrologic properties, and the data from R-5 and R-8 will be used to better understand how this alteration should be represented in the 3-D geologic model. Available stratigraphic data from any new drilling, including boreholes beyond the scope of the "Hydrogeologic Workplan" (TA-50 drilling for replacement of the Chemistry Metallurgy Research Building and FY2003 facility-support drilling at TA-54), will be used to generate a new version of the 3-D geologic model (FY2003 model). As part of this effort, new detailed surfaces at TA-54 will be created to subdivide unit Qbt 1v, the vapor-phase altered nonwelded ash flows, for enhanced hydrogeologic modeling in the vicinity of Area G.

Table 7.2-1
Proposed Regional Aquifer Borehole Priority and Start Dates

Priority	Borehole	Funding Source	Start Date or Date Complete	FY2002 Drilling Status
1	R-9	ER	Sep 1997	Complete
2	R-12	ER	March 1998	Complete
3	R-25	NWT	Jul 1998	Complete
4	R-15	ER	June 1999	Complete
7	R-19	ER	Jan 2000	Complete
5	R-31	NWT	Feb 2000	Complete
10	R-22	ER	Sept 2000	Complete
12	R-7	ER	Dec 2000	Complete
8	R-5	NWT	May 2001	Complete
22	R-13	ER	Aug 2001	Complete
15	R-8	NWT	Feb 2002	Complete
21	R-14	NWT	July 2002	Complete
11	R-32	NWT	Aug 2002	Complete
19	R-20	NWT	Sept 2002	Complete
28	R-16	NWT	Sept 2002	Complete
26	R-23	ER	Oct 2002	Complete
29	R-21	ER	Dec 2002	Complete
17	R-2	NWT	Apr FY2004	Plan FY2003
20	R-4	ER	Feb FY2004	Plan FY2003
25	R-6	NWT	Jun FY2006	Plan FY2003
23	R-11	NWT	Sep FY2004	Plan FY2003
14	R-18	ER	Apr FY2003	Plan FY2003
30	R-26	NWT	Mar FY2005	Plan FY2003
6	R-27	ER	Apr FY2004	—
9	R-28	NWT	TBD	—
13	R-1	NWT	Feb FY2004	—
16	R-10	ER	May FY2006	—
18	R-3	ER	Dec FY2003	—
24	R-17	ER	Jan FY2006	—
27	R-29	NWT	Jan FY2005	—
31	R-24	NWT	Nov FY2004	—
32	R-30	ER	Mar FY2006	—

Table 7.2-2
Status of Proposed Regional Aquifer Boreholes

Borehole	Original Start Date	Current Start Date	FY2002 Status	Funding Source	Status of Installed Boreholes/ Rationale of Proposed Boreholes
R-9	FY98	FY98	Well complete (9/97)	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	Well complete (3/98)	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. Twenty-six percent of the borehole was cored because of its 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	Well complete (7/98)	NWT	Borehole R-25 was installed adjacent to MDA P in aggregate 5 and completed with nine sampling zones. Ten percent 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 farther 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	FY2000	FY98	Well complete (6/99)	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, which was completed in 1960.

Table 7.2-2 (continued)

Borehole	Original Start Date	Current Start Date	FY2002 Status	Funding Source	Status of Installed Boreholes/ Rationale of Proposed Boreholes
R-19	FY2001	FY2000	Well complete (1/00)	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-31	FY2001	FY99	Well complete (2/00)	NWT	Borehole R-31 was installed downgradient of open burning/open detonation sites in Aggregate 6 and upgradient of firing sites in aggregate 4. It was 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-22	FY98	FY2001	Well complete (9/00)	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 that released HE, radionuclides, organic solvents, and inorganic solutes. No intermediate depth perched groundwater was detected during drilling.
R-7	FY98	FY2000	Well complete (12/00)	ER	R-7 was drilled to a depth of 1097 ft and 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 close 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, which is 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 situated 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.

Table 7.2-2 (continued)

Borehole	Original Start Date	Current Start Date	FY2002 Status	Funding Source	Status of Installed Boreholes/ Rationale of Proposed Boreholes
R-5	FY2000	FY2000	Well complete (5/01)	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, 50285; 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.
R-13	FY2001	FY2004	Well complete (8/01)	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).
R-8	FY2000	FY2002	Well complete (2/02)	NWT	R-8 is located about 0.6 mi east of the confluence of Los Alamos Canyon and DP Canyon. The primary purpose of the well is to determine regional aquifer water quality downgradient of releases in Los Alamos and DP canyons. It also serves as a sentry well for PM-2. Significant difficulties were encountered in drilling R-8, and the original borehole was abandoned. A second borehole, R-8a, was drilled 62 ft due east of R-8. The R-8a well is completed with two screened intervals in the regional aquifer: one straddling the water table at a depth of 705–755 ft and one at a depth of 821–828 ft. One sample of water from the R-8 borehole was collected from a depth of 822 ft. Tritium with activity of 15 pCi/L was detected in the R-8 borehole water sample.
R-14	FY2002	FY2002	Well complete (7/02)	NWT	Well R-14 is located within the Mortandad Canyon watershed in Ten Site Canyon, east of the former radioactive liquid waste and septic treatment facilities at TA-35. Drilling started on June 2, 2002, and was completed on July 2, 2002. R-14 is completed with two screened intervals in the regional aquifer: one near the water table at a depth of 1200 ft and one in a productive zone at a depth of 1286 ft.
R-32	FY2001	FY2002	Well complete (8/02)	NWT	Well R-32 is located in Pajarito Canyon, south of TA-54, on the north side of Pajarito Road. Drilling started on July 13, 2002, and was completed on August 7, 2002. The original planned location for this well was west of Ancho Spring in lower Ancho Canyon. However, the location was changed in response to concerns about the potential for contaminant releases from TA-54. The well was constructed with three screened intervals, one at the top of water table and two deeper to measure pressure gradients: screen 1, 867–874 ft; screen 2, 930–933 ft; screen 3, 970–977 ft.

Table 7.2-2 (continued)

Borehole	Original Start Date	Current Start Date	FY2002 Status	Funding Source	Status of Installed Boreholes/ Rationale of Proposed Boreholes
R-20	FY2002	FY2003	Well complete (9/02)	NWT	R-20, water-supply protection well for PM-2, is located in Pajarito Canyon, east of TA-18 on the south side of Pajarito Road. Drilling started on August 4, 2002, and was completed on September 19, 2002. No perched water was encountered in R-20. The static water level in the regional aquifer is at 872 ft. The well was constructed with three screened intervals; the deeper screens were placed to coincide with screened intervals in PM-2: screen 1, 904–912 ft; screen 2, 1147–1154 ft; screen 3, 1328–1336 ft.
R-16	FY2003	FY2003	Well complete (9/02)	NWT	R-16 is located above the Rio Grande in Overlook Park in White Rock. Drilling started on August 16, 2002, and was completed on September 13, 2002. The primary purpose is to 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. The regional aquifer water level rose more than expected, possibly indicating artesian conditions similar to those encountered in Los Alamos Canyon (R-9). R-16 was completed with three screened intervals in the regional aquifer: screen 1, 863–871 ft; screen 2, 1015–1022 ft; and screen 3, 1237–1244 ft.
R-23	FY2002	FY2006	Well complete (10/02)	ER	Well R-23 was drilled in Pajarito Canyon, just west of the State Highway 4/Pajarito Road intersection, on the south side of Pajarito Road. Drilling started on August 17, 2002, and was completed on October 3, 2002. R-23 was originally planned to provide information downgradient of active firing sites in Potrillo Canyon. However, R-23 was relocated to Pajarito Canyon southeast of TA-54 to address concerns regarding potential releases from TA-54. The regional water table in R-23 was encountered at 817 ft, higher than predicted by the 3-D geologic model (892 ft). Geophysical logging indicates that perched water may be present. The well was constructed with one screened interval, from 816 to 873 ft, at the top of the regional aquifer water table.
R-21	FY2002	FY2003	Well complete (12/02)	ER	R-21 was installed to evaluate and monitor hydrologic and geochemical conditions in the regional aquifer beneath MDA L. Drilling started on November 1, 2002, and the well was completed in December 2002. The borehole was drilled to a total depth of 995 ft, and the well was completed with a single screen at the top of the regional aquifer.
R-2	FY2000	FY2003	Planned FY2003 (pending additional funding)	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 1950s. R-2 is situated 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, which was drilled by cable tool in 1950.

Table 7.2-2 (continued)

Borehole	Original Start Date	Current Start Date	FY2002 Status	Funding Source	Status of Installed Boreholes/ Rationale of Proposed Boreholes
R-4	FY2001	FY2003	Planned FY2003 (pending additional funding)	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 zones 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-6	FY2003	FY2003	Planned FY2003 (pending additional funding)	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-11	FY2003	FY2003	Planned FY2003 (pending additional funding)	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-18	FY99	FY2003	Planned FY2003 (pending additional funding)	ER	R-18 is planned for installation above the confluence of Pajarito and Twomile Canyons to provide information about intermediate perched zone groundwater, depth to the regional aquifer, and water quality of perched zones and the regional aquifer in the poorly characterized west-central part of the Laboratory. It is located downstream from Laboratory release sites at TA-8, TA-9, TA-14, TA-22, TA-40, and TA-69 but is in an area that has not been characterized for either groundwater or contaminants. The occurrence of surface flow through most of the year indicates perched alluvial groundwater is present in this part of Pajarito Canyon.

Table 7.2-2 (continued)

Borehole	Original Start Date	Current Start Date	FY2002 Status	Funding Source	Status of Installed Boreholes/ Rationale of Proposed Boreholes
R-26	FY2002	FY2003	Planned FY2003 (pending additional funding)	NWT	R-26 is planned for installation near the trace of the Pajarito Fault system near the southwest corner of the Laboratory. This borehole will provide water-quality and water-level data for perched systems and the regional aquifer on the downthrown block of the Pajarito Fault system. Numerous springs, including the large Water Canyon Gallery, issue from the Bandelier Tuff in Water Canyon. The location and occurrence of perched water and water-level data for the regional aquifer, when compared with similar data from R-24 and R-25 on the downthrown and upthrown blocks, respectively, will be used to evaluate the influence of the Pajarito Fault system on the regional piezometric surface and provide information about its role as a recharge zone. Water-quality data from intermediate perched zone and regional groundwater in R-26 will define background conditions in a large wet canyon upgradient from the Laboratory, and in particular for aggregate 5. These background geochemical data will be used to define potential impacts on groundwater from Laboratory facilities and to provide input data for geochemical and hydrological modeling of different groundwater systems.
R-27	FY2000	FY2004	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. HE 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 FY2000.
R-29	FY2003	FY2005	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.
R-17	FY2002	FY2006	Planned	ER	R-17 is planned for installation in Twomile Canyon, a major tributary to Pajarito Canyon, to provide information about intermediate perched zones, depth to the regional aquifer, and water quality of intermediate perched zones and the regional aquifer in the poorly characterized northwest part of the Laboratory. It is located downstream from Laboratory release sites at TA-3, TA-6, TA-58, TA-59, TA-62, and TA-69 but is in an area that has not been characterized for either groundwater or contaminants. R-17 will also provide upgradient water-quality information for aggregate 7.

Table 7.2-2 (continued)

Borehole	Original Start Date	Current Start Date	FY2002 Status	Funding Source	Status of Installed Boreholes/ Rationale of Proposed Boreholes
R-30	FY2002	FY2006	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.
R-3	FY99	TBD	Planned	ER	R-3 is planned for installation in upper Pueblo Canyon to provide water-quality information for potential intermediate perched zones and for the regional aquifer beneath upper Pueblo Canyon downgradient of former TA-45. In the past, natural surface water flow in Pueblo Canyon was augmented by Laboratory releases and by effluent from the former sewage waste-water treatment plant in upper Pueblo Canyon. Because of the augmented surface flow, upper Pueblo Canyon may have been a source of recharge to intermediate perched zones and the regional aquifer. The available data suggest that mobile contaminants associated with former TA-45 (^{3}H, ^{90}Sr, and NO_3) are present in a groundwater plume that extends at least 1.75 mi down Pueblo Canyon and perhaps farther. 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-10	FY2000	TBD	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, 55429; Davis et al. 1996, 55446) suggest that the gradient of the perching layer changes in the vicinity of R-7 and R-10, and water perched in this zone will move southward along the axis of a large pre-Bandelier paleo-drainage. R-10 is designed to investigate the southward extension of this perched system from the Los Alamos Canyon area.
R-1	FY2001	TBD	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, 54344) mid-Miocene high-permeability zone at the top of the Santa Fe Group, and this borehole could significantly extend the known northern limit of this important water-supply feature. This borehole is presently scheduled to be completed as a type 3 well, but the option is preserved to advance the boreholes for these wells to a TD 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 (continued)

Borehole	Original Start Date	Current Start Date	FY2002 Status	Funding Source	Status of Installed Boreholes/ Rationale of Proposed Boreholes
R-28	FY2001	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 potential release sites in aggregate 6, and it will provide information for optimizing the placement of monitoring wells in this part of the Laboratory.
R-24	FY2002	TBD	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.

FY2003 geochemical activities will focus on collecting geochemical data and information at MCOBT-4.4, R-5, R-8a, R-13, R-14, R-16, R-20, R-21, R-23, and R-32 to evaluate natural and contaminant distributions in perched zones and/or regional aquifer. These activities will enhance development of the geochemical conceptual model. In addition, these data will be analyzed using geochemical modeling codes MINTEQA2 and PHREEQC for quantifying the speciation, mineral reactions, and sorption of metals onto hydrous ferric oxide. This activity includes assembling a technically defensible sorption database for the Laboratory to use in geochemical and transport modeling for pathway assessment.

In FY2003 the background groundwater investigation for the Laboratory will be completed. The final report will detail natural distributions of inorganic and radionuclide solutes and DOC within the alluvium, perched volcanic zones, and the regional aquifer at 15 background sampling stations.

The groundwater pathways assessment will be completed in FY2003. Work completed up through FY2002 included developing multiple conceptual models, defining parameter distributions, and developing four coupled models: source term, vadose zone, regional aquifer, and risk model. As of the end of FY2002, many pieces of the groundwater pathways assessment were in place, or nearly in place, to start the assessment.

8.0 REFERENCES

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