Memorandum of Meeting or Phone Conversation

☑ Telephone ☐ Meeting	Time: 1137	Date: 01.03.12

Individuals Involved

Jennifer Fullam, NMED GWQB	☐ called ☑ was called by ☐ other:	Name: Bob Beers Affiliation: Contact DP: 1132 Site Name: Los Alamos Natl Laboratory Phone Number:

Subject: meeting / request for extension

Discussion: Beers left message for Fullam requesting to meet and discuss items needed for application and the status on the request for extension on the application

Conclusions:

Distribution:

Initialed JF

: 05294

Fullam Docs 030714 / caseloads / LANL / DP1132 TA-50 RLWTF / DP1132 Emails

Fullam, Jennifer, NMENV

From: Beers, Robert S <bbeers@lanl.gov>
Sent: Wednesday, January 18, 2012 3:27 PM
To: Fullam, Jennifer, NMENV
Cc: George, Robert, NMENV; Marshall, Clint, NMENV; Schoeppner, Jerry, NMENV; Turner, Gene E.; Saladen, Michael T
Subject: Request for a Short Time Extension_DP-1132 Discharge Permit Application
Attachments: DP-1132 RLWTF 45 day Extension Request.pdf

Jennifer,

Please find the attached request from the National Nuclear Security Administration (NNSA) and Los Alamos National Security, LLC (LANS) for a short time extension for specific items in Discharge Permit Application DP-1132.

A hard copy of this request is also being sent by postal mail.

Sincerely,

Bob Beers
Water Quality & RCRA Group
Los Alamos National Security, LLC

: 05299

Environmental Safety & Health
Environmental Protection Division
P.O. Box 1663, K491
Los Alamos, New Mexico 87545
(505) 665-6952FAX (505) 665-3811

National Nuclear Security Administration
Los Alamos Site Office, A316
3747 West Jemez Road
Los Alamos, New Mexico 87545
(505) 667-5794/FAX (505) 667-5948

Date: January 17, 2012
Refer To: ENV-DO-12-0001
LAUR: 12-10069

Mr. James H. Davis, Director
Resource Protection Division
New Mexico Environment Department
Harold Runnels Building
1190 St. Francis Drive
P.O. Box 5469
Santa Fe, NM 87502-5469

Dear Mr. Davis:

SUBJECT: REQUEST FOR CONSIDERATION OF SHORT TIME EXTENSION FOR SPECIFIC ITEMS FOR PERMIT APPLICATION DP-1132, RADIOACTIVE LIQUID WASTE TREATMENT FACILITY (RLWTF) AND ZERO LIQUID DISCHARGE EVAPORATIVE TANKS (ZLD)

On January 3, 2012, the National Nuclear Security Administration (NNSA) and Los Alamos National Security, LLC (LANS) for the Los Alamos National Laboratory received your response denying our request to extend the deadline to submit a Discharge Permit (DP) application for the RLWTF and the proposed Zero Liquid Discharge Evaporative Tanks (ZLD). This request followed your November 19, 2011 letter requiring NNSA/LANS to submit a comprehensive and up-to-date permit DP application by February 16, 2012 for RLWTF, and to include the ZLD tanks in this application. NNSA/LANS fully supports your intent to advance the permit process, and recognize that submittal of the updated permit application is the first step towards timely permit review and issuance. With this in mind, we have thoroughly reviewed the detailed list of 19 items and the additional information required by the permit application in your November 19, 2011 letter. Our review has concluded that with additional resources and significant effort, we can commit to deliver the majority of the requested items by February 16, 2012. However, for the following reasons, we respectfully request that you consider providing us a short 45-day extension until April 3, 2012 to submit the following limited items described below:

- Proposed processes for the operation, inspection and maintenance for the facility as it pertains to collection lines, treatment units and effluent storage disposal units

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- Procedures and corrective actions for addressing acute failures and long-term maintenance issues at the facility
- Proposed groundwater monitoring locations for ground water sources most likely to be impacted by intentional and unintentional discharges from the RLWTF. The proposal should identify geohydrology of the potentially impacted areas, existing monitoring well locations and construction.

The above technical documents pertain to existing procedures for RLWTF which will require significant review and coordination among differing groups at the facility. Procedures for the planned ZLD tanks have not been developed. Construction of the ZLD tanks is estimated for the summer of 2012. Procedures will be available prior to operation of the ZLD system. Further, as a practical matter, these procedures must undergo LANL's unique institutional security review which requires final procedures to be submitted for review at least a week prior to public release. Additionally, we discussed with NMED staff the challenges of traditional groundwater monitoring approaches for the RLWTF and ZLD tanks in the context of the Laboratory's complex hydrogeology, and understand that an alternate approach to groundwater monitoring should be presented in the DP application. Development of this approach for inclusion into the application will require additional resources and time. We are hopeful that the additional requested time will enable us to submit a complete permit application, and will facilitate permit review and timely permit issuance.

Thank you for your consideration of our request. If you need additional information, feel free to contact Robert Beers, LANS at (505) 667-7969 or Gene Turner, NNSA at (505) 667-5794 if you need additional information concerning the status of the Laboratory's corrective action activities.

Sincerely,

Alison Dorries
Division Leader
Environmental Protection Division
Los Alamos National Laboratory

Sincerely,

Gene E. Turner
Environmental Permitting Manager
Environmental Projects Office
Los Alamos Site Office
National Nuclear Security Administration

AD:MS:GET/lm

Cy: Hai Shen, LASO-EO, A316
Gene Turner, LASO-EO, A316
Steve Yanicak, LASO-GOV, M894
Carl A. Beard, PADOPS, A102
Michael T. Brandt, ADESH, K491
Alison Dorries, ENV-DO, K491
Scotty Jones, ENV-DO, K491

: 05301

Cy (continued):
Randy Johnson, ENV-ES, E500
Mike Saladen, ENV-RCRA, K490, (E-File)
Robert Beers, ENV-RCRA, K490
Robert C. Mason, TA-55-DO, E583
Clifford Kirkland, TA-55 RLW, E518
Chris Del Signore, TA-55-RLW, E518
Susan L. McMichael, LC-LESH, A187
Lisa Cummings, LASO-OC, A316
Jonathan M. Block, NMELC, Santa Fe, NM
Charles de Saillan, NMED, Santa Fe, NM
Taylor, Valdez, ENV-DO, K404, (E-File)
ENV-RCRA File, (12-0013) w/enc., M704
IRM-RMMSO, w/enc., A150

DP 1132 Blue Line MR JF

GROUND WATER
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Los Alamos
NATIONAL LABORATORY
EST. 1943

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Environmental Protection Division
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National Nuclear Security Administration
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Los Alamos, New Mexico 87545
(505) 667-5794/FAX (505) 667-5948

Date: January 24, 2012
Refer To: ENV-DO-12-0004
LAUR: 12-10137

Mr. Jerry Schoeppner, Acting Chief
Ground Water Quality Bureau
New Mexico Environment Department
Harold Runnels Building, Room N2250
1190 St. Francis Drive
P.O. Box 26110
Santa Fe, NM 87502

Dear Mr. Schoeppner:

SUBJECT: GROUNDWATER DISCHARGE PLAN (DP-1132) QUARTERLY REPORT, FOURTH QUARTER 2011, TA-50 RADIOACTIVE LIQUID WASTE TREATMENT FACILITY

This letter and tables are the fourth quarter 2011 Groundwater Discharge Plan (DP-1132) Report for the Technical Area (TA)-50 Radioactive Liquid Waste Treatment Facility (RLWTF) at Los Alamos National Laboratory. Since the first quarter of 1999, the US Department of Energy (DOE) and Los Alamos National Security, LLC (LANS) have provided your agency with voluntary quarterly reports containing analytical results from effluent and groundwater monitoring.

During the fourth quarter of 2011, no effluent was discharged by the TA-50 RLWTF through National Pollutant Discharge Elimination System (NPDES) Outfall 051to Mortandad Canyon; all effluent was evaporated on-site at the effluent evaporator.

Quarterly Monitoring Results, Mortandad Canyon Alluvial Groundwater Wells

Table 1.0 presents the analytical results from sampling conducted at Mortandad Canyon alluvial well MCO-7 during the fourth quarter of 2011. No nitrogen samples were collected from alluvial well MCO-7 because there was insufficient water in the well. Samples were submitted to General Engineering Laboratories (GEL), Charleston, SC, for analysis. All of the analytical results were below the New Mexico Water Quality Control Commission (NMWQCC) 3103 standards for nitrate-nitrogen (NO_3-N), fluoride (F), and total dissolved solids (TDS).

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Analytical results from the sampling of intermediate and regional aquifer wells in Mortandad Canyon can be accessed online at the Risk Analysis, Communication, Evaluation and Reduction (RACER) Web site (www.racernm.com).

TA-50 RLWTF Effluent Monitoring Results

Table 2.0 presents the analytical results from the weekly composite sampling of RLWTF effluent discharged through NPDES Outfall 051 to Mortandad Canyon. The final weekly composite (FWC) samples are flow-proportioned composite samples prepared from each tank of effluent discharged to Mortandad Canyon during a 7-day period. Samples are submitted to GEL for analysis. In addition, the TA-50 RLWTF analytical laboratory analyzes duplicate FWC samples as part of the Laboratory's compliance monitoring program. No FWC samples were collected during the fourth quarter of 2011 because no RLWTF effluent was discharged to Mortandad Canyon.

Table 3.0 presents the final monthly composite (FMC) sample results for NO_3-N, ClO_4, F, and TDS for the fourth quarter of 2011. No FMC samples were collected during the third quarter of 2011 because no effluent was discharged to Mortandad Canyon.

Please contact Bob Beers at (505) 667-7969 of the Water Quality and RCRA Group (ENV-RCRA) if you have questions concerning this report.

Sincerely,

Alison M. Dorries
Division Leader
Environmental Protection Division
Los Alamos National Security, LLC

Sincerely,

Peter Maggiore for Gene E. Turner

Gene E. Turner
Environmental Permitting Manager
Environmental Projects Office
Los Alamos Site Office
National Nuclear Security Administration

AMD:GET:BB/lm

Cy: Hai Shen, LASO-EO, A316
Gene Turner, LASO-EO, A316
Steve Yanicak, LASO-GOV, M894
Carl A. Beard, PADOPS, A102
Michael T. Brandt, ADESHQ, K491
Alison Dorries, ENV-DO, K491
Scotty Jones, ENV-DO, K491
Randy Johnson, ENV-ES, E500
Mike Saladen, ENV-RCRA, K490, (E-File)
Bob Beers, ENV-RCRA, K490
Robert C. Mason, TA55-DO, E583
Cliff Kirkland, TA-55 RLW, J910
Victor Salazar, TA-55 RLW, E518
Chris Del Signore, TA-55 RLW, E518
ENV-RCRA File (12-0029), M704
IRM-RMMSO, A150

: 05305

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Table 1.0. Mortandad Canyon Alluvial Well Sampling, 4th Quarter, 2011.

Sampling Location	Sample Field Prep (F/UF)[1]	Sample Date	Perchlorate (ug/L)	NO_3+NO_2-N (mg/L)	TKN[2] (mg/L)	NH3-N (mg/L)	TDS (mg/L)	F (mg/L)
MCO-3	F	11/8/2011	0.97	0.332	0.17	0.029J	200	0.27
MCO-4B	F	11/8/2011	6.8	0.855	0.22	<0.05	264	0.66
MCO-6	F	11/9/2011	4.8	1.24	0.10	<0.05	284	0.86
MCO-7	F	11/10/2011	7.7	dry	dry	dry	297	0.93
NM WQCC 3103 Groundwater Standards			***NA*** [2]	***10 mg/L*** [3]	***NA*** [2]	***NA*** [2]	***1000 mg/L***	***1.6 mg/L***

Notes:

[1]All samples filtered with the exception of TKN.

[2]NA means that there is no NM WQCC 3103 standard for this analyte.

[3]The NM WQCC 3103 Groundwater Standard is for NO_3-N.

J- means that the reported value is expected to be more uncertain than usual with a potential negative bias.

J+ means that the reported value is expected to be more uncertain than usual with a potential positive bias.

J means the reported value is greater than the Method Detection Limit (MDL) but less than the Reporting Limit (RL).

GROUND WATER
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Table 2.0. RLWTF Final Weekly Composite (FWC) Effluent Sampling, 4th Quarter, 2011.

			Analysis by RLWTF[1]		Analysis by General Engineering Laboratories, Inc.			
Monitoring Period	Sample Composite Date	Sample ID#	NO_3-N (mg/L)	NO_2-N (mg/L)	NO_3+NO_2-N (mg/L)	Perchlorate (ug/L)	Fluoride (mg/L)	TDS (mg/L)
October	10/3/11	No Discharge[2]	-----	-----	-----	-----	-----	-----
	10/10/11	No Discharge	-----	-----	-----	-----	-----	-----
	10/17/11	No Discharge	-----	-----	-----	-----	-----	-----
	10/24/11	No Discharge	-----	-----	-----	-----	-----	-----
	10/31/11							
November	11/7/11	No Discharge	-----	-----	-----	-----	-----	-----
	11/14/11	No Discharge	-----	-----	-----	-----	-----	-----
	11/21/11	No Discharge	-----	-----	-----	-----	-----	-----
	11/28/11	No Discharge	-----	-----	-----	-----	-----	-----
December	12/5/11	No Discharge	-----	-----	-----	-----	-----	-----
	12/12/11	No Discharge	-----	-----	-----	-----	-----	-----
	12/19/11	No Discharge	-----	-----	-----	-----	-----	-----
	12/26/11	No Discharge	-----	-----	-----	-----	-----	-----
4th Quarter 2011 Averages[3]			-----	-----	-----	-----	-----	-----
NMWQCC 3103 Groundwater Standards			***10 mg/L***	***NA[5]***	***10 mg/L[4]***	***NA[5]***	***1.6 mg/L***	***1000 mg/L***

Notes:

[1]Analysis by the TA-50 Radioactive Liquid Waste Treatment Facility's analytical laboratory.

[2]No Discharge means the RLWTF did not discharge effluent through NPDES Outfall 051 during the 7-day period preceding the composite date.

[3]4th quarter 2011 averages include the results from June 2011, if applicable.

[4]The NMWQCC Regulation 3103 groundwater standard is for nitrate (NO_3-N).

[5]NA means that there is no NMWQCC 3103 groundwater standard for this analyte.

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GROUND WATER
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Table 3.0. RLWTF Final Monthly Composite (FMC) Effluent Sampling, 4th Quarter, 2011.

Monitoring Period	RLWTF FMC Results[1]			
	NO_3-N (mg/L)	Perchlorate by IC[2] (ug/L)	TDS (mg/L)	F (mg/L)
October 2011	---- No Discharges ----			
November 2011	---- No Discharges ----			
December 2011	---- No Discharges ----			
NMWQCC 3103 Groundwater Standards	***10 mg/L***	***NA*** [3]	***1000 mg/L***	***1.6 mg/L***

Notes:

[1]Analysis by the TA-50 Radioactive Liquid Waste Treatment Facility's analytical laboratory.

[2]IC means EPA Method 314.0, perchlorate analysis by Ion Chromatography.

[3]NA means that there is no NM WQCC 3103 standard for this analyte.

1132 Blue File

NEW MEXICO
ENVIRONMENT DEPARTMENT

Resource Protection Division

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Cabinet Secretary
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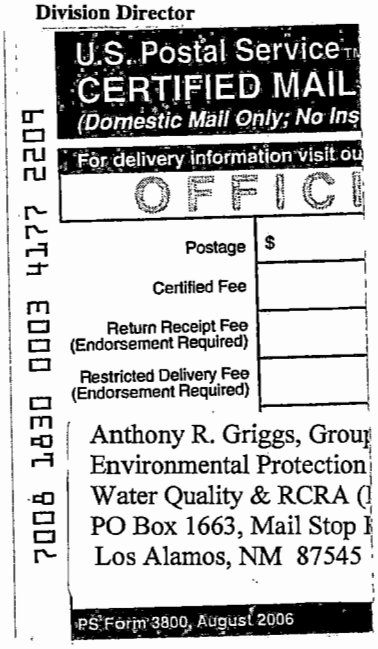
Division Director



CERTIFIED MAIL – RETURN RECEIPT REQUESTED

January 27, 2012

Anthony R. Grieggs, Group Leader
Environmental Protection Division
Water Quality & RCRA (ENV-RCRA)
P.O. Box 1663, Mail Stop K490
Los Alamos, NM 87545

RE: Approval of Time Extension to Submit Application, DP-1132, Radioactive Liquid Waste Treatment Facility (RLWTF)

Dear Mr. Grieggs:

On November 18, 2011, the New Mexico Environment Department (NMED) notified Los Alamos National Laboratory (LANL), by certified mail (copy enclosed), that a complete and current Discharge Permit application for the RLWTF was required to be submitted within 90 days (by February 16, 2012). On December 9, 2011, NMED received your request for a 90-day time extension to submit the required Discharge Permit application, which was denied on December 30, 2012. A request for a 45-day extension for submittal of certain portions of the application was submitted to NMED, via e-mail on January 18, 2012 (copy enclosed). LANL may not discharge to the Zero Liquid Discharge Evaporative Tanks prior to NMED's approval which may be delayed due to the timeframe in which a full application for the RLWTF is received and reviewed by NMED. **NMED hereby approves a 45-day extension (due by April 1, 2012) to submit the three elements specifically referenced in LANL's letter dated January 17, 2012. All other elements for the Discharge Permit application are required to be submitted to NMED by February 16, 2012.**

If you have any questions regarding this matter, please contact Clint Marshall, Program Manager of the Ground Water Pollution Prevention Section, at 505-827-0027 or Jennifer Fullam at 505-827-2909.

Sincerely,

James H. Davis, Ph.D.
Director, Resource Protection Division

JD:JF

enc: Letter from NMED to LANL requiring Discharge Permit application, dated November 18, 2011
E-mail (dated January 18, 2012) from Bob Beers, LANL, with attachment (dated January 17, 2012) requesting extension

cc: James Bearzi, NMED SWQB (w/o enclosures)
Richard Powell, NMED SWQB (w/o enclosures)
John Kieling, NMED HWB (w/o enclosures)
Steven Yanicak, NMED-DOE-Oversight Bureau (w/o enclosures)
Hai Shen, LASO-EO, Los Alamos National Laboratory, A316, Los Alamos, NM 87545 (w/o enclosures)
Gene Turner, LASO-EO, Los Alamos National Laboratory, A316, Los Alamos, NM 87545 (w/o enclosures)
Michael T. Brandt, ADESH, Los Alamos National Laboratory, K491, Los Alamos, NM 87545 (w/o enclosures)
Carl A. Beard, PADOPS, Los Alamos National Laboratory, A102, Los Alamos, NM 87545 (w/o enclosures)
J. Chris Cantwell, ADESHQ, Los Alamos National Laboratory, K491, Los Alamos, NM 87545 (w/o enclosures)
Randy Johnson, ENV-ES, Los Alamos National Laboratory, E500, Los Alamos, NM 87545 (w/o enclosures)
Michael Saladen ENV-RCRA, Los Alamos National Laboratory, K490, Los Alamos, NM 87545 (w/o enclosures)
Robert Mason, TA-55-DO, Los Alamos National Laboratory, E583, Los Alamos, NM 87545 (w/o enclosures)
Hugh McGovern, TA-55-RLW, Los Alamos National Laboratory, E518, Los Alamos, NM 87545 (w/o enclosures)
Pete Worland, TA-55-RLW, Los Alamos National Laboratory, E518, Los Alamos, NM 87545 (w/o enclosures)

Susan L. McMichael, LC-LESH, Los Alamos National Laboratory, A187, Los Alamos, NM 87545 (w/o enclosures)

Bob Beers, ENV-RCRA, Los Alamos National Laboratory, K490, Los Alamos NM, 87545 (w/ enclosures)

Jon Block, Staff Attorney, New Mexico Environmental Law Center, 1405 Luisa Street, Ste. 5, Santa Fe, NM 87505(w/ enclosures)

Joni Arends, Executive Director, Concerned Citizens for Nuclear Safety, 107 Cienega Street, Santa, Fe, NM 87501(w/ enclosures)

DP 1132 Blue Title

NEW MEXICO
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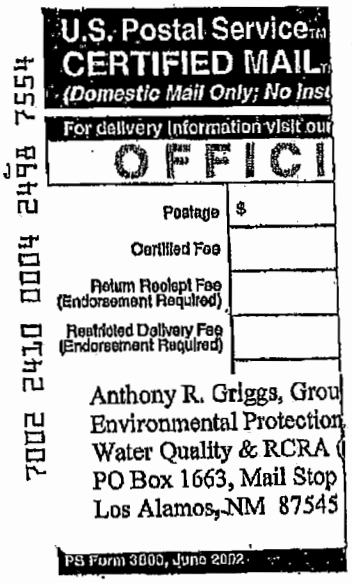

CERTIFIED MAIL – RETURN RECEIPT REQUESTED

November 18, 2011

Anthony R. Grieggs, Group Leader
Environmental Protection Division
Water Quality & RCRA (ENV-RCRA)
P.O. Box 1663, Mail Stop K490
Los Alamos, NM 87545

RE: Response to Notice of Intent to Discharge and Discharge Permit Required for Zero Liquid Discharge Tanks, AI 856: PRD20070004 and Updated Application Submittal Required for the Radioactive Liquid Waste Treatment Facility (RLWTF), DP-1132

Dear Mr. Grieggs:

The Ground Water Quality Bureau of the New Mexico Environment Department (NMED) received a Notice of Intent from Los Alamos National Laboratory (LANL) on November 8, 2007 for the facility referenced above. NMED responded in writing with a request for additional information which required LANL to submit 60% plans and specifications for the proposed structure, information pertaining to ground water which may be impacted should a release occur, operation and maintenance procedures for the tanks, information on the potential concentration of the wastestream due to evaporation, and seismic studies for the area in which the tanks are to be constructed. NMED received a response to the requested information from LANL on September 15, 2008 which provided most of the requested information and stated that plans and specifications would be submitted once available. NMED received the plans and specifications for the evaporative tanks on August 19, 2011 along with an addendum dated October 19, 2011. The notice describes LANL's intent to discharge up to 3.6 million gallons annually of treated effluent from the RLWTF to two evaporative concrete tanks equipped with synthetic liners and leak detection systems. The total operating volume of the tanks is approximately 754,036 gallons (100,800 cubic feet). The notice, along with the subsequent information submitted upon NMED's request, satisfies the requirements of Subsection A of 20.6.2.1201 New Mexico Administrative Code (NMAC) of the New Mexico Water Quality Control Commission (WQCC) Regulations, 20.6.2 NMAC. The proposed discharge is located within the boundaries of Los Alamos National Laboratory at

35°51'37"N, 106°16'57"W, approximately 2.5 miles southeast of Los Alamos in Section 23, Township 19N, Range 06E, Los Alamos County.

NMED has reviewed the information provided in accordance with Subsection D of 20.6.2.1201 NMAC and because the proposed evaporative tanks contain an effluent or leachate which may move directly or indirectly into ground water, NMED has determined that **a Discharge Permit is required for the proposed discharge.** NMED considers the proposed evaporative tanks to be a component of the RLWTF, therefore they must be included in the Discharge Permit for this facility.

Any appeal of this determination that a Discharge Permit is required must be made to the New Mexico WQCC within 30 days of receipt of this letter, in accordance with Subsection B of 20.6.2.3112 NMAC. A copy of the WQCC Regulations, 20.6.2 NMAC, is available at http://www.nmcpr.state.nm.us/nmac/_title20/T20C006.htm.

Upon further review of the file for the RLWTF, NMED has noted the following:

- An application for a Discharge Permit was submitted to NMED on April 16, 1996 for the discharge of 41,770 gallons per day of treated low level radioactive wastewater from the RLWTF to a tributary of Mortandad Canyon (referred to as Effluent Canyon).
- The application identified potential upgrades to the system which were to enhance the treatment process and provide alternate discharge capabilities for the facility.
- The treated effluent from the RLWTF is currently authorized to be discharged to an outfall (Outfall 051) under a United States Environmental Protection Agency (EPA) National Pollutant Discharge Elimination System (NPDES) Permit (NM0028355) last issued on August 1, 2007, and subsequently modified on July 17, 2007, May 13, 2011, and October 11, 2011.
- Numerous Notices of Planned Changes have been submitted to EPA for treatment system upgrades and facility changes under the NPDES Permit for Outfall 051. Copies of these notices were submitted to NMED on the following dates: April 21, 1998, March 18, 1999, April 3, 2000, June 13, 2000, May 7, 2002, March 14, 2003, April 18, 2003, January 12, 2004, May 14, 2007, May 6, 2008, August 19, 2010, September 16, 2010, and February 23, 2011.
- In addition to the Notices of Planned Changes, numerous notices concerning minor modifications to the facility have been submitted to NMED as addendums to the original Discharge Permit application. NMED received copies of these submissions which were dated March 23, 1999, December 8, 2000, November 8, 2007, August 25, 2010, September 27, 2010, December 15, 2010, and March 22, 2011.
- NMED has engaged in numerous meetings, inspections and written correspondence regarding the RLWTF in order to compile accurate information on the facility in preparation for drafting a Discharge Permit that will accurately reflect the activities conducted at the RLWTF.
- In September 2003, a draft of Discharge Permit DP-1132 was sent to LANL which was subsequently Public Noticed on April 18, 2005, beginning a 30-day comment period.
- On April 27, 2005, in response to multiple requests from interested parties, a second public comment period was granted on the proposed Discharge Permit (extending the comment period for approximately 90 days, until August 4, 2005).

- NMED received comments and requests for a public hearing regarding the draft Discharge Permit from both interested parties and LANL.
- Through continued discussions with LANL, correspondence, site inspections and the above referenced Notice of Intent, it has become apparent that the facility has significantly modified treatment processes, discharge volumes and locations of the discharge when compared to the original application submitted to NMED on August 16, 1996.
- As it pertains to any future Discharge Permits to be issued by the NMED Ground Water Quality Bureau (GWQB), this *facility* has been determined to include the central influent collection lines leading to the RLWTF, all components which are part of the wastewater treatment process and all locations where the treated wastewater is disposed, including all surface discharges as well as non-surface discharges such as evaporative tanks (as described in the above referenced Notice of Intent). This determination by the NMED-GWQB is based on information provided in the original application for a Discharge Permit along with subsequent information provided to NMED by LANL.

Given the extensive and fractured exchange of information concerning this facility, along with changes at the RLWTF that have occurred during the lengthy permitting process and planned future changes, NMED views LANL's August 16, 1996 Discharge Permit application to be inconsistent with the current and planned discharge activities associated with the RLWTF. **Therefore, NMED requires that LANL submit a comprehensive and up-to-date Discharge Permit application for the RLWTF within 90 days of the date of this letter (by February 16, 2011).**

When submitted, the application (copy enclosed) should be completed in its entirety and specifically address the following:

- The estimated volumes, sources (technical area and building) and wastestream characteristics of all influent wastewater that LANL receives, or intends to receive, at the RLWTF.
- A description of the conveyance methods used to transport wastewater to the RLWTF for each source.
- A description of waste characterization and metering systems used to determine influent wastestream characteristics and volumes entering the RLWTF.
- A description of the review and amendment process for LANL's internal Waste Acceptance Criteria (WAC) for all incoming wastewater received at the RLWTF. This should include LANL's process for ensuring the WAC relates to the current treatment technologies and processes.
- A description of operational procedures for receiving wastes from each generator.
- A schematic of the treatment process in its entirety for each wastestream (from collection to final disposal).
- Descriptions, locations, construction materials and sizing for each component of the treatment processes for each type of wastestream being treated at the RLWTF.
- Descriptions, locations and designs for all secondary storage and auxillary emergency units intended to receive, treat or store wastewater received at the facility.
- Proposed processes for the operation, inspection and maintenance for the facility as it pertains to the collection lines, treatment units and effluent storage disposal units.
- Procedures and corrective actions for addressing acute failures at the facility.
- Procedures and corrective actions for addressing long-term maintenance issues at the facility.

- Record drawings for all components of the facility, if available.
- Construction plans and specifications for all components of the facility which are under construction or are proposed for construction.
- A proposed effluent monitoring plan, identifying analytes and sample locations/frequency. The proposal should consider discharge frequencies, incoming waste characteristics and the constituents listed under 20.6.2.3103 NMAC and Subsection WW of 20.6.2.7 NMAC.
- Proposed flow and metering systems used to determine effluent discharge volumes for each of the discharge locations.
- Proposed ground water monitoring locations for ground water sources most likely to be impacted by intentional and unintentional discharges from the RLWTF. The proposal should identify geohydrology of the potentially impacted areas, existing monitoring well locations and construction.
- Actions which LANL would implement should partial or full closure of the facility occur.
- A scaled facility plan showing the facility's components including influent collection lines, storage units, major treatment units and disposal units.
- All other information sought in NMED's application for Discharge Permit Sections A through C. Please note that for the purposes of public notification, the "discharge site" as it relates to this facility encompasses the central collection system lines, the treatment and storage facilities and all discharge locations for the treated effluent.

When submitting the comprehensive and up-to-date Discharge Permit application, you must complete and submit three copies along with the $100 filing fee.

If you have any questions, please contact either Jennifer Fullam at (505) 827-2909 or Clint Marshall, Acting Program Manager of the Ground Water Pollution Prevention Section, at (505) 827-0027.

Sincerely,

James H. Davis, Ph.D.
Director, Resource Protection Division

JD:JF

Enc: Applying for a Discharge Permit: General Information
Discharge Permit Application

cc: Robert Italiano, District Manager, NMED District II (w/o enclosures)
NMED Santa Fe Field Office (w/o enclosures)
DP Required File (w/o enclosures)
James Bearzi, NMED SWQB (w/o enclosures)
Richard Powell, NMED SWQB (w/o enclosures)
John Kieling, NMED HWB (w/o enclosures)
Steven Yanicak, NMED-DOE-Oversight Bureau (w/o enclosures)

Hai Shen, LASO-EO, Los Alamos National Laboratory, A316, Los Alamos, NM 87545 (w/o enclosures)

Gene Turner, LASO-EO, Los Alamos National Laboratory, A316, Los Alamos, NM 87545 (w/o enclosures)

Eric Trujillo, LASO-NSM, Los Alamos National Laboratory, A316, Los Alamos, NM 87545 (w/o enclosures)

Carl A. Beard, PADOPS, Los Alamos National Laboratory, A102, Los Alamos, NM 87545 (w/o enclosures)

J. Chris Cantwell, ADESHQ, Los Alamos National Laboratory, K491, Los Alamos, NM 87545 (w/o enclosures)

Randy Johnson, ENV-ES, Los Alamos National Laboratory, E500, Los Alamos, NM 87545 (w/o enclosures)

Michael Saladen ENV-RCRA, Los Alamos National Laboratory, K490, Los Alamos, NM 87545 (w/o enclosures)

Robert Mason, TA-55-DO, Los Alamos National Laboratory, E583, Los Alamos, NM 87545 (w/o enclosures)

Hugh McGovern, TA-55-RLW, Los Alamos National Laboratory, E518, Los Alamos, NM 87545 (w/o enclosures)

Pete Worland, TA-55-RLW, Los Alamos National Laboratory, E518, Los Alamos, NM 87545 (w/o enclosures)

Keith Orr, PMF-FUNCT, Los Alamos National Laboratory, M984, Los Alamos, NM 87545 (w/o enclosures)

Roy Maestas, CM-STRS, Los Alamos National Laboratory, P299, Los Alamos, NM 87545 (w/o enclosures)

Joe Brophy, PMF-FUNCT Los Alamos National Laboratory, P137, Los Alamos, NM 87545 (w/o enclosures)

Ed Artiglia, ES-PE, Los Alamos National Laboratory, P137, Los Alamos, NM 87545 (w/o enclosures)

Bob Beers, ENV-RCRA, Los Alamos National Laboratory, K490, Los Alamos NM, 87545 (w/ enclosures)

Fullam, Jennifer, NMENV

From: Beers, Robert S [bbeers@lanl.gov]
Sent: Wednesday, January 18, 2012 3:27 PM
To: Fullam, Jennifer, NMENV
Cc: George, Robert, NMENV; Marshall, Clint, NMENV; Schoeppner, Jerry, NMENV; Turner, Gene E.; Saladen, Michael T
Subject: Request for a Short Time Extension_DP-1132 Discharge Permit Application
Attachments: DP-1132 RLWTF 45 day Extension Request.pdf

Jennifer,

Please find the attached request from the National Nuclear Security Administration (NNSA) and Los Alamos National Security, LLC (LANS) for a short time extension for specific items in Discharge Permit Application DP-1132.

A hard copy of this request is also being sent by postal mail.

Sincerely,

Bob Beers
Water Quality & RCRA Group
Los Alamos National Security, LLC

: 05318

Los Alamos
NATIONAL LABORATORY
EST. 1943

Environmental Safety & Health
Environmental Protection Division
P.O. Box 1663, K491
Los Alamos, New Mexico 87545
(505) 665-6952FAX (505) 665-3811

National Nuclear Security Administration
Los Alamos Site Office, A316
3747 West Jemez Road
Los Alamos, New Mexico 87545
(505) 667-5794/FAX (505) 667-5948

Date: January 17, 2012
Refer To: ENV-DO-12-0001
LAUR: 12-10069

Mr. James H. Davis, Director
Resource Protection Division
New Mexico Environment Department
Harold Runnels Building
1190 St. Francis Drive
P.O. Box 5469
Santa Fe, NM 87502-5469

Dear Mr. Davis:

SUBJECT: REQUEST FOR CONSIDERATION OF SHORT TIME EXTENSION FOR SPECIFIC ITEMS FOR PERMIT APPLICATION DP-1132, RADIOACTIVE LIQUID WASTE TREATMENT FACILITY (RLWTF) AND ZERO LIQUID DISCHARGE EVAPORATIVE TANKS (ZLD)

On January 3, 2012, the National Nuclear Security Administration (NNSA) and Los Alamos National Security, LLC (LANS) for the Los Alamos National Laboratory received your response denying our request to extend the deadline to submit a Discharge Permit (DP) application for the RLWTF and the proposed Zero Liquid Discharge Evaporative Tanks (ZLD). This request followed your November 19, 2011 letter requiring NNSA/LANS to submit a comprehensive and up-to-date permit DP application by February 16, 2012 for RLWTF, and to include the ZLD tanks in this application. NNSA/LANS fully supports your intent to advance the permit process, and recognize that submittal of the updated permit application is the first step towards timely permit review and issuance. With this in mind, we have thoroughly reviewed the detailed list of 19 items and the additional information required by the permit application in your November 19, 2011 letter. Our review has concluded that with additional resources and significant effort, we can commit to deliver the majority of the requested items by February 16, 2012. However, for the following reasons, we respectfully request that you consider providing us a short 45-day extension until April 3, 2012 to submit the following limited items described below:

- Proposed processes for the operation, inspection and maintenance for the facility as it pertains to collection lines, treatment units and effluent storage disposal units

05319

- Procedures and corrective actions for addressing acute failures and long-term maintenance issues at the facility
- Proposed groundwater monitoring locations for ground water sources most likely to be impacted by intentional and unintentional discharges from the RLWTF. The proposal should identify geohydrology of the potentially impacted areas, existing monitoring well locations and construction.

The above technical documents pertain to existing procedures for RLWTF which will require significant review and coordination among differing groups at the facility. Procedures for the planned ZLD tanks have not been developed. Construction of the ZLD tanks is estimated for the summer of 2012. Procedures will be available prior to operation of the ZLD system. Further, as a practical matter, these procedures must undergo LANL's unique institutional security review which requires final procedures to be submitted for review at least a week prior to public release. Additionally, we discussed with NMED staff the challenges of traditional groundwater monitoring approaches for the RLWTF and ZLD tanks in the context of the Laboratory's complex hydrogeology, and understand that an alternate approach to groundwater monitoring should be presented in the DP application. Development of this approach for inclusion into the application will require additional resources and time. We are hopeful that the additional requested time will enable us to submit a complete permit application, and will facilitate permit review and timely permit issuance.

Thank you for your consideration of our request. If you need additional information, feel free to contact Robert Beers, LANS at (505) 667-7969 or Gene Turner, NNSA at (505) 667-5794 if you need additional information concerning the status of the Laboratory's corrective action activities.

Sincerely,

Alison Dorries
Division Leader
Environmental Protection Division
Los Alamos National Laboratory

Sincerely,

Gene E. Turner
Environmental Permitting Manager
Environmental Projects Office
Los Alamos Site Office
National Nuclear Security Administration

AD:MS:GET/lm

Cy: Hai Shen, LASO-EO, A316
Gene Turner, LASO-EO, A316
Steve Yanicak, LASO-GOV, M894
Carl A. Beard, PADOPS, A102
Michael T. Brandt, ADESH, K491
Alison Dorries, ENV-DO, K491
Scotty Jones, ENV-DO, K491

05320

Cy (continued):
Randy Johnson, ENV-ES, E500
Mike Saladen, ENV-RCRA, K490, (E-File)
Robert Beers, ENV-RCRA, K490
Robert C. Mason, TA-55-DO, E583
Clifford Kirkland, TA-55 RLW, E518
Chris Del Signore, TA-55-RLW, E518
Susan L. McMichael, LC-LESH, A187
Lisa Cummings, LASO-OC, A316
Jonathan M. Block, NMELC, Santa Fe, NM
Charles de Saillan, NMED, Santa Fe, NM
Taylor, Valdez, ENV-DO, K404, (E-File)
ENV-RCRA File, (12-0013) w/enc., M704
IRM-RMMSO, w/enc., A150

Fullam, Jennifer, NMENV

From: Beers, Robert S [bbeers@lanl.gov]
Sent: Thursday, February 02, 2012 9:28 AM
To: Fullam, Jennifer, NMENV
Subject: RE: Request for a Meeting w/GWQB and HWB RE: R-28 DP Application

Thanks, see you then.

Bob

From: Fullam, Jennifer, NMENV [mailto:Jennifer.Fullam@state.nm.us]
Sent: Thursday, February 02, 2012 9:11 AM
To: Beers, Robert S
Subject: RE: Request for a Meeting w/GWQB and HWB RE: R-28 DP Application

Bob,

It looks like the 21st at 3:00 here in the Ground Water Bureau should work for everyone. Thanks.

Jennifer Fullam
Environmental Scientist
Ground Water Quality Bureau
New Mexico Environment Department
505.827.2909
jennifer.fullam@state.nm.us

From: Beers, Robert S [mailto:bbeers@lanl.gov]
Sent: Tuesday, January 31, 2012 3:22 PM
To: Fullam, Jennifer, NMENV
Cc: Saladen, Michael T; Cobrain, Dave, NMENV; Lynnes, Kathryn D; Turner, Gene E.; Maggiore, Peter; Lamb, Melanie J; Dorries, Alison M; Jones, Scotty Wayne; George, Victoria A; Grieggs, Anthony R
Subject: RE: Request for a Meeting w/GWQB and HWB RE: R-28 DP Application

Jennifer,

Sorry for the delay in getting back with.

If the date/time, *February 21, 2012 at 3:00pm,* is still available then that would be our preference.

Sincerely,

Bob Beers
Water Quality & RCRA Group
Los Alamos National Security, LLC
505-667-7969

From: Fullam, Jennifer, NMENV [mailto:Jennifer.Fullam@state.nm.us]
Sent: Thursday, January 26, 2012 8:22 AM
To: Beers, Robert S
Cc: Saladen, Michael T; Cobrain, Dave, NMENV
Subject: RE: Request for a Meeting w/GWQB and HWB RE: R-28 DP Application

05323

Bob,

It looks like late afternoon on the following dates would work the best for NMED-GWQB (and perhaps HWB).

February 21, 2012 at 3:00pm
February 23, 2012 at 2:00 pm
February 27, 2012 at 2:00 pm
February 28, 2012 at 3:00 pm

Let me know if any of these dates and times work for LANL. Thanks.

Jennifer Fullam
Environmental Scientist
Ground Water Quality Bureau
New Mexico Environment Department
505.827.2909
jennifer.fullam@state.nm.us

From: Beers, Robert S [mailto:bbeers@lanl.gov]
Sent: Tuesday, January 24, 2012 4:01 PM
To: Fullam, Jennifer, NMENV
Cc: Saladen, Michael T
Subject: Request for a Meeting w/GWQB and HWB RE: R-28 DP Application

Hi Jennifer,

We are in receipt of Mr. Davis' January 13, 2012, letter(attached) informing Los Alamos National Security, LLC (LANS) that the Discharge Permit application submitted on December 22, 2011, contains insufficient information for the NMED to proceed with the issuance of a Discharge Permit.

LANS and the US Department of Energy/National Nuclear Security Administration (NNSA) would like to meet with GWQB staff and HWB staff (Mr. Dave Cobrain) to discuss the NMED's request for supplemental information covering all potential temporary on-site treatment and discharge activities associated with contaminated groundwater which is intended to be land applied.

Would you please arrange a meeting at your Santa Fe office, at a time convenient for NMED attendees, during the weeks of either February 21-23 or February 27-March 1. Thank you.

Sincerely,

Bob Beers
Water Quality & RCRA Group
Los Alamos National Security, LLC
505-667-7969

New Mexico Environment Department
Ground Water Quality Bureau

Acknowledgement of Receipt

reviewer's initials ☐

I, Mannie Chávez hereby acknowledge receipt of

Check No. 251606, **dated** 2-06-12

received in the **amount of $** 100.00; or

cash received in the **amount of $** _____

from Los Alamos National Laboratory

Facility Name: Los Alamos National Laboratory

DP #: 1132 **AI ID:** _____

Activity ID Number: PRD_____

GWQB – Date of Receipt

GROUND WATER
FEB 16 2012
BUREAU

Administrative Fees

☒ $100.00 application filing fee

Permit Fees

☐ new facility

☐ renewal or renewal/modification

☐ modification fee = $_____

Other Fees

☐ $15.00 per poster:

poster(s)_____ x $15.00 = $_____

☐ $150.00 temporary permission

☐ Other: $_____

Explain: _____

Copy of Check (below): Hand - Delivered

THE FACE OF THIS CHECK IS PRINTED BLUE - THE BACK CONTAINS A SIMULATED WATERMARK

WELLS FARGO BANK OHIO, N.A.
115 Hospital Drive
Van Wert, Ohio 45891

LOS ALAMOS NATIONAL LABORATORY
PO BOX 1663, MS P240
LOS ALAMOS, NM 87545

251606

56-382
412

PLEASE CASH PROMPTLY
SUBJECT TO CANCELLATION
NINETY (90) DAYS AFTER DATE

MO DAY YR
02/06/12

PAY One Hundred and 00/100 Dollars

$ *******100.00

TO THE ORDER OF

NEW MEXICO ENVIRONMENTAL DEPT
GROUND WATER QUALITY BUREAU
PO BOX 5469
SANTA FE, NM 87502

Authorized Signature

⑈00251606⑈ ⑆041203824⑆ 9600078684⑈

: 05326

Fullam Docs / caseloads / LANL / LANL emails / 2011 Status Report

Fullam, Jennifer, NMENV

From: Fullam, Jennifer, NMENV
Sent: Friday, February 10, 2012 3:05 PM
To: Schoeppner, Jerry, NMENV
Cc: Marshall, Clint, NMENV
Subject: 2011 LANL Status Report
Attachments: LANL 2011 GWQB Status Report 021012.docx

Jerry,

Here is what I wrote up. Please verify it with Clint and/or Robert if you can. Thanks.

Jennifer Fullam
Environmental Scientist
Ground Water Quality Bureau
New Mexico Environment Department
505.827.2909
jennifer.fullam@state.nm.us

: 05328

Los Alamos National Laboratory has numerous operations in which discharges of wastewater to the environment occur. Although several regulatory agencies oversee activities at the Laboratory and the Ground Water Quality Bureau works in collaboration with other Federal and State agencies (as well as other Bureaus within NMED) to ensure appropriate regulatory oversight and reduce dual regulation where applicable. Because of the extent of LANL's operations under the U.S. Department of Energy, there is considerable public interest (and subsequently concern) as it pertains to environmental protection.

Unplanned and unauthorized releases into the environment are reported to NMED under 20.6.2.1203 NMAC to which NMED reviews and responds to corrective actions taken by LANL. In 2011, NMED responded to 30 reportable releases. For planned discharges, NMED responded to three Notices of Intent for proposed discharges at the facility during 2011. Two of the proposed discharges were determined to not require a Discharge Permit while one was determined to require a Discharge Permit based on the potential threat to ground water. LANL currently has four discharges which have been deemed to be under the authority of the WQCC regulations 20.6.2 NMAC and are in various stages of the permitting process. The status of each is as follows:

(DP-1132) Radioactive Liquid Waste Treatment Facility (RLWTF) - Given the extensive and fractured exchange of information concerning this facility, along with changes at the RLWTF that have occurred during the lengthy permitting process and LANL's planned future upgrades to the facility, NMED deemed the original Discharge Permit application (April 1996) to be inconsistent with the current and planned discharge activities associated with the RLWTF. NMED has required LANL submit a comprehensive and up-to-date Discharge Permit application for the RLWTF by February 16, 2011. NMED has been in negotiations with the Hazardous Waste Permit to which the Discharge Permit is a critical element of as it pertains to the regulatory oversight of the RLWTF.

(DP-857) Sanitary Waste Water System (SWWS)-NMED received an application for renewal and modification of the Discharge Permit in July 2010. The facility is the central domestic wastewater treatment system for domestic wastewater generated at the Laboratory and discharges to permitted NPDES outfalls or recirculates the treated effluent through other process control systems at the laboratory. The previous Discharge Permit for this facility expired on April 7, 2003 however; LANL has will continue operations under the expired permit until a new Discharge Permit is issued. NMED staff are working on the draft Discharge Permit which is anticipated to be sent out for public comment in 2012.

(DP-1589) Septic Tank/Leachfield Systems: LANL has numerous facilities which are not connected to the central SWWS and still discharge domestic wastewater to multiple treatment and disposal systems throughout the Laboratory. NMED has determined that these discharges are under the authority of the WQCC Regulations 20.6.2 NMAC and are required to be regulated under a Ground Water Discharge Permit. LANL submitted a Discharge Permit application in April 2006 and NMED has been in ongoing communication with LANL to obtain information on the extent of the systems in order to draft a Discharge Permit. There have been several updates and modifications from the original application to which NMED required an updated application be submitted. LANL submitted the an updated

application in 2010 to which NMED has been working on drafting a Discharge Permit. It is anticipated that a draft Discharge Permit will be sent out for public comment in 2012.

(DP-1793) On-site treatment of contaminated ground water- Upon review of a Notice of Intent submitted to NMED, for the on-site treatment and land application of contaminated ground water, NMED has determined that such processes and discharges are required to be regulated under a Ground Water Discharge Permit. LANL submitted a Discharge Permit application in December 2011 and NMED is currently in the process of acquiring additional information from LANL in order to draft a Discharge Permit.

Fullam, Jennifer, NMENV

From: Beers, Robert S <bbeers@lanl.gov>
Sent: Monday, February 13, 2012 3:19 PM
To: George, Robert, NMENV
Cc: Fullam, Jennifer, NMENV; Saladen, Michael T; Artiglia, Edward W
Subject: ZLD Evaporation Tank Liners

Hi Robert,

I apologize for the short notice. It was my intention to give you a longer lead.

The subcontractor installed the liner in the east Zero Liquid Discharge (ZLD) Solar Evaporation Tank last Friday. The liner (bottom pad and the 40 mil liner) for the west ZLD Solar Evaporation Tank is scheduled to be installed tomorrow, Tuesday, February 14. The inter membrane and the top liner (60 mil) will be installed later this week.

If you would like to visit the construction site, the following safety PPE are required:

- Construction boots
- Safety vest
- Safety glasses
- Hard hat

We can provide all PPE, as needed, except the construction boots.

Please let me know if you would like to conduct a site visit.

Sincerely,

Bob Beers
Water Quality & RCRA Group
Los Alamos National Security, LLC
505-667-7969

Fullam, Jennifer, NMENV

From: Beers, Robert S <bbeers@lanl.gov>
Sent: Tuesday, February 14, 2012 9:33 AM
To: George, Robert, NMENV
Cc: Fullam, Jennifer, NMENV; Saladen, Michael T; Artiglia, Edward W
Subject: RE: ZLD Evaporation Tank Liners

Robert,

Yes, we are documenting the liner installation with photographs.

Bob

From: George, Robert, NMENV [mailto:robert.george@state.nm.us]
Sent: Tuesday, February 14, 2012 8:15 AM
To: Beers, Robert S
Cc: Fullam, Jennifer, NMENV; Saladen, Michael T; Artiglia, Edward W; Knutson, Gerald, NMENV; Marshall, Clint, NMENV
Subject: RE: ZLD Evaporation Tank Liners

Bob,

Thanks for keeping us in the loop on this. It's unlikely that I will be able to get away for the next several weeks, but Jennifer and Jake were discussing the possibility of a trip up to see the liner installation. They will coordinate with you if they are available for a site inspection during the liner install, so please keep them both in the loop as thing unfold. If no one from NMED is able to make it up there, we would be appreciative if you could collect photographic documentation of the liner installation to include with the record drawings for the facility (I am assuming that this is already being done by the Lab for its own records). Let me know if you need anything from us in the short-term. Thanks again.

Robert J. George
Domestic Waste Team Leader
New Mexico Environment Department
Ground Water Quality Bureau
P.O. Box 5469
Santa Fe, New Mexico 87502-5469
(505) 476-3648

From: Beers, Robert S [mailto:bbeers@lanl.gov]
Sent: Tuesday, February 14, 2012 8:05 AM
To: George, Robert, NMENV
Cc: Fullam, Jennifer, NMENV; Saladen, Michael T; Artiglia, Edward W
Subject: FW: ZLD Evaporation Tank Liners

Robert,

The subcontractor installing the liner at the TA-52 ZLD Solar Evaporation Tanks has cancelled work for this week due to the forecast for snow.

I will keep you informed of their new schedule once it becomes available.

Please let me know if you have questions.

Sincerely,

Bob Beers
Water Quality & RCRA Group
Los Alamos National Security, LLC

From: Beers, Robert S
Sent: Monday, February 13, 2012 3:19 PM
To: George, Robert, NMENV
Cc: 'Fullam, Jennifer, NMENV'; Saladen, Michael T; Artiglia, Edward W
Subject: ZLD Evaporation Tank Liners

Hi Robert,

I apologize for the short notice. It was my intention to give you a longer lead.

The subcontractor installed the liner in the east Zero Liquid Discharge (ZLD) Solar Evaporation Tank last Friday. The liner (bottom pad and the 40 mil liner) for the west ZLD Solar Evaporation Tank is scheduled to be installed tomorrow, Tuesday, February 14. The inter membrane and the top liner (60 mil) will be installed later this week.

If you would like to visit the construction site, the following safety PPE are required:

- Construction boots
- Safety vest
- Safety glasses
- Hard hat

We can provide all PPE, as needed, except the construction boots.

Please let me know if you would like to conduct a site visit.

Sincerely,

Bob Beers
Water Quality & RCRA Group
Los Alamos National Security, LLC
505-667-7969

GROUND WATER
FEB 16 2012
BUREAU

Environmental Safety & Health
Environmental Protection Division
P.O. Box 1663, K491
Los Alamos, New Mexico 87545
(505) 665-6592/FAX (505) 665-3811

National Nuclear Security Administration
Los Alamos Site Office, A316
3747 West Jemez Road
Los Alamos, New Mexico 87545
(505) 667-5794/FAX (505) 667-5948

Date: February 14, 2012
Refer To: ENV-DO-12-0005
LAUR: 12-00672

Mr. Jerry Schoeppner, Acting Chief
Ground Water Quality Bureau
New Mexico Environment Department
Harold Runnels Building, Room N2261
1190 St. Francis Drive
P.O. Box 26110
Santa Fe, NM 87502

Dear Mr. Schoeppner:

SUBJECT: DISCHARGE PERMIT APPLICATION FOR THE TA-50 RADIOACTIVE LIQUID WASTE TREATMENT FACILITY AND THE TA-52 ZERO LIQUID DISCHARGE SOLAR EVAPORATION TANKS

The US Department of Energy and Los Alamos National Security, LLC (DOE/LANS) are in receipt of your November 18, 2011, letter (Appendix A) requiring a comprehensive and up-to-date application for the Technical Area (TA)-50 Radioactive Liquid Waste Treatment Facility (RLWTF) and the TA-52 Zero Liquid Discharge (ZLD) Solar Evaporation Tanks by February 16, 2012. Per your request, enclosed are three copies of the required Discharge Permit application and supporting documentation. Also enclosed is the $100.00 filing fee required by regulation.

In a December 7, 2011, letter (Appendix A) to the New Mexico Environment Department (NMED), DOE/LANS requested an additional 90 days to submit the required application. The referenced extension request was denied by the NMED in a December 30, 2011, response (Appendix A). On January 17, 2012, DOE/LANS submitted a request for a short 45-day extension to submit information on certain portions of the application. In a January 27, 2012, letter (Appendix A) the NMED granted the requested 45-day extension for certain portions of the Discharge Permit application pertaining to sections B-7, B-8, B-14, B-15, B-16, and B-18, as well as bullet items 9, 10, 11, and 16 from the November 18, 2011, letter. The information pertaining to these sections and bullets will be submitted under separate cover by April 2, 2012. LANL understands the restriction on discharges to the TA-52 ZLD Solar Evaporation Tanks prior to NMED approval.

: 05337

The US Department of Energy and Los Alamos National Security, LLC have initiated construction of the TA-52 ZLD Solar Evaporation Tanks. Construction is expected to be completed during 2012.

Please contact Bob Beers at (505) 667-7969 of the Water Quality and RCRA Group (ENV-RCRA) if you have questions.

Sincerely,

Alison M. Dorries
Division Leader
Environmental Protection Division
Los Alamos National Laboratory

Sincerely,

Gene E. Turner
Environmental Permitting Manager
Environmental Projects Division
Los Alamos Site Office
Department of Energy

AMD:GET:BB/lm

Enclosures: a/s

Cy: Joni Arends, Concerned Citizens for Nuclear Safety, Santa Fe, NM, w/enc.
Jonathan M. Block, New Mexico Environmental Law Center, Santa Fe, NM, w/enc.
James Bearzi, NMED/SWQB, Santa Fe, NM, w/enc.
John Kieling, NMED/HWB, Santa Fe, NM, w/enc.
Hai Shen, LASO-EO, w/enc., A316
Kevin W. Smith, LASO-OOM, w/o enc., A316
Gene Turner, LASO-EO, w/enc., A316
Steve Yanicak, LASO-GOV, w/enc., M894
Carl A. Beard, PADOPS, w/o enc., A102
Michael T. Brandt, ADESH, w/o enc., K491
Alison M. Dorries, ENV-DO, w/o enc., K491
Scotty Jones, ENV-DO, w/o enc., K491
Mike Saladen, ENV-RCRA, w/enc., K490
Bob Beers, ENV-RCRA, w/enc., K490, (w/o enc., 2010 ESR)
Bob Mason, TA-55 DO, w/o enc., E583
Cliff Kirkland, TA-55-RLW, w/enc., E505
Chris del Signore, TA-55-RLW, w/enc., E518
Victor Salazar, TA-55-RLW, w/o enc., E518
Randy Johnson, ENV-ES, w/enc., E500
Dianne Wilburn, ESHQ-DR, w/o enc., E503
ENV-RCRA File, (12-0038) w/enc., M704
IRM-RMMSO, (U1102277), w/enc., A150

GROUNDWATER DISCHARGE PERMIT DP-1132

APPLICATION FOR THE

TA-50 RADIOACTIVE LIQUID WASTE TREATMENT FACILITY (RLWTF)

and the

TA-52 ZERO LIQUID DISCHARGE SOLAR EVAPORATION TANKS

Submitted by

LOS ALAMOS NATIONAL SECURITY, LLC

And the

US DEPARTMENT OF ENERGY

FEBRUARY 2012

LA-UR-12-00672

ENV-DO-12-0005

Los Alamos
NATIONAL LABORATORY
EST. 1943

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TABLE OF CONTENTS

Requested Information

Table Addressing Requested Items from November 18, 2011 NMED Letter 1

Ground Water Discharge Permit Application

Part A 2

Part B 8

Part C 18

Appendix A – LANL/NMED Communications RE: DP-1132

Copies of the Following LANL/NMED Communications:

January 27, 2012, NMED Letter RE: Approval of Time Extension to Submit Application, DP-1132, Radioactive Liquid Waste Treatment Facility (RLWTF) 1

January 17, 2012, LANL Letter Subject: Request For Consideration of Short Time Extension For Specific Items For Permit Application DP-1132, Radioactive Liquid Waste Treatment Facility (RLWTF) And Zero Liquid Discharge Evaporative Tanks (ZLD) 5

December 30, 2011, NMED Letter RE: Denial Of Time Extension To Submit Application, DP-1132, Radioactive Liquid Waste Treatment Facility (RLWTF) 9

December 7, 2011, LANL Letter Subject: Request For An Extension To Submit An Updated Discharge Permit Application For The Radioactive Liquid Waste Treatment Facility (DP-1132) 19

November 18, 2011, NMED Letter RE: Response to Notice of Intent To Discharge 27

August 11, 2011, LANL Letter RE: Sixty Percent Design, Evaporation Tanks, TA-50 Radioactive Liquid Waste Treatment Facility 32

September 15, 2008, LANL Letter Subject: Request For Additional Information, DP-1132, Radioactive Liquid Waste Treatment Facility 41

June 11, 2008, NMED Letter RE: Request For Additional Information, DP-1132, Radioactive Liquid Waste Treatment Facility 49

November 1, 2007, LANL Letter Subject: Notice Of Intent To Discharge, Evaporation Tanks, TA-50 Radioactive Liquid Waste Treatment Facility 52

Appendix B – Process Diagrams and Description

Process Schematic – RLW-SD-PFD-001 1

RLWTF Treatment Units – Scaled Floor Plan 2

TA-50 RLWTF Units and Processes 3

Appendix C – NPDES Outfall #051

NPDES Permit No. NM0028355,. Outfall #051 1

Appendix D – Groundwater Quality

Groundwater Quality, Figures 1-12 1

: 05340

Appendix E – Well Logs

Well Logs

R-1 1

R-15 4

MCO-3 7

MCO-4B 10

MCO-6 12

MCO-7 15

MCOI-4 18

MCOI-5 21

MCOI-6 24

Appendix F – Geology

Soil Information

Soil Types 1

Geotechnical Investigations

TA-50 RLWTF 8

TA-50-0250 WMRM 11

TA-52 Zero Liquid Discharge Solar Evaporation Tanks 14

Plan and Map Views of Stratigraphic Units Beneath MDA C 21

Appendix G – Contingency Plan

Contingency Plan – to be submitted under separate cover by April 2, 2012 1

Appendix H – Closure Plan

Closure Plan 1

Appendix I – Referenced Documents

Compact Disc (CD) Containing the Following Documents 1

Los Alamos National Laboratory's Hydrogeologic Studies of the Pajarito Plateau: A Synthesis of Hydrogeologic Workplan Activities (1994-2004). LA-14263-MS.

2009 Hydrogeologic Site Altas. LAUR-09-3763.

Groundwater Level Status Report for 2010 Los Alamos National Laboratory. LA-14437-PR

Conceptual Models of Vadose Zone Flow and Transport Beneath The Pajarito Plateau, Los Alamos, New Mexico. Vadose Zone Journal, Vol. 4, August 2005

NRCS Soil Survey of Sandoval County Area, New Mexico, Parts of Los Alamos, Sandoval, and Rio Arriba Counties.

2006 Mortandad Canyon Investigation Report. LA-UR-06-6752.

2011 Interim Facility-Wide Groundwater Monitoring Plan, Revision 1. LA-UR-11-6958.

Compact Disc (CD) Containing the Following Document 2

Environmental Surveillance at Los Alamos During 2010. LA-14445-ENV.

: 05341

Appendix J - Maps

Map #1 - Location Map with Treatment Units, Lagoons, Tanks, Roads, Buildings, Supply Wells, Monitoring Wells, Canyons, Water Bodies, Property Boundaries, Other Permitted Discharges, and North Arrow 1

Map #2 - TA-50 RLWTF, RLW Collection System, NPDES Outfall #051, TA-52 ZLD Solar Evaporation Tanks, and 100-Year Flood Plain Map 2

Map #3 - LANL Soils Map 3

Map #4 - TA-50 Radioactive Liquid Waste Treatment Facility (RLWTF) Storm Drain System Map 4

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In response to the November 18, 2011 letter from NMED (See Appendix A), the requested items are addressed in the following locations:

1.	The estimated volumes, sources (technical area and building) and wastestream characteristics of all influent wastewater that LANL receives, or intends to receive, at the RLWTF.	A-8, A-10, B-1, Appendix B
2.	A description of the conveyance methods used to transport wastewater to the RLWTF for each source.	A-8, B-1, Appendix B
3.	A description of waste characterization and metering systems used to determine influent wastestream characteristics and volumes entering the RLWTF.	B-12
4.	A description of the review and amendment process for LANL's internal Waste Acceptance Criteria (WAC) for all incoming wastewater received at the RLWTF. This should include LANL's process for ensuring the WAC relates to the current treatment technologies and processes.	The amendment and review process for changes to LANL's Waste Acceptance Criteria (WAC) involves several reviews. A WAC facilitator distributes proposed WAC attachments to owners and reviewers, including regulatory Subject Matter Experts (SMEs). The facilitator will assist the owners to ensure that revisions are complete and that technical content is correct. Once revisions are agreed to, LANL's policy office conducts a final review, completes specific paperwork, and issues final WAC amendments. At RLWTF, the type of review will depend on the proposed WAC amendment, and can include review of the quality of treated wastewaters, revisions to state or federal discharge standards, the treatment process, including planned changes to process equipment, and administrative review.
5.	A description of operational procedures for receiving wastes from each generator.	Information falls under the granted time extension and will be submitted under separate cover by April 2, 2012.
6.	A schematic of the treatment process in its entirety for each wastestream (from collection to final disposal).	Appendix B
7.	Descriptions, locations, construction materials and sizing for each component of the treatment processes for each type of wastestream being treated at the RLWTF.	B-6, Appendix B
8.	Descriptions, locations and designs for all secondary storage and auxillary emergency units intended to receive, treat or store wastewater received at the facility.	B-6, Appendix B
9.	Proposed processes for the operation, inspection and maintenance for the facility as it pertains to the collection lines, treatment units and effluent storage disposal units.	Information falls under the granted time extension and will be submitted under separate cover by April 2, 2012.

10.	Procedures and corrective actions for addressing acute failures at the facility.	Information falls under the granted time extension and will be submitted under separate cover by April 2, 2012.
11.	Procedures and corrective actions for addressing long-term maintenance issues at the facility.	Information falls under the granted time extension and will be submitted under separate cover by April 2, 2012.
12.	Record drawings for all components of the facility, if available.	B-5
13.	Construction plans and specifications for all components of the facility which are under construction or are proposed for construction.	B-5
14.	A proposed effluent monitoring plan, identifying analytes and sample locations/frequency. The proposal should consider discharge frequencies, incoming waste characteristics and the constituents listed under 20.6.2.3103 NMAC and Subsection WW of20.6.2.7 NMAC.	B-13
15.	Proposed flow and metering systems used to determine effluent discharge volumes for each of the discharge locations.	B-12
16.	Proposed ground water monitoring locations for ground water sources most likely to be impacted by intentional and unintentional discharges from the RLWTF. The proposal should identify geohydrology of the potentially impacted areas, existing monitoring well locations and construction.	Information falls under the granted time extension and will be submitted under separate cover by April 2, 2012.
17.	Actions which LANL would implement should partial or full closure of the facility occur.	B-19
18.	A scaled facility plan showing the facility's components including influent collection lines, storage units, major treatment units and disposal units.	Appendix B
19.	All other information sought in NMED's application for Discharge Permit Sections A through C. Please note that for the purposes of public notification, the "discharge site" as it relates to this facility encompasses the central collection system lines, the treatment and storage facilities and all discharge locations for the treated effluent.	See Attached Application

LA-UR-12-00672
ENV-DO-12-0005

NEW MEXICO ENVIRONMENT DEPARTMENT
GROUND WATER QUALITY BUREAU

DISCHARGE PERMIT APPLICATION

GROUND WATER
FEB 16 2012
BUREAU

Type of Application. Check appropriate box.

- ☐ Application for new Discharge Permit -- new facility
- ☒ Application for new Discharge Permit -- existing (unpermitted) facility (DP-1132)
- ☐ Application for Discharge Permit Renewal
- ☐ Application for Discharge Permit Modification
  "Modification" is defined as a change to the permit requirements that result from a change in the location of the discharge, a significant increase in the quantity of the discharge, or a significant change in the quality of the discharge.
- ☐ Application for Discharge Permit Renewal and Modification

For an existing Discharge Permit, please indicate: DP Number _____ Expiration date _____

Checklist of Application Components.

☒ Part A: Administrative Completeness.	*Instructions for completing the application are included on the form itself and on Supplemental Instructions for Parts A and B.* *You may fill out the application manually, or a Microsoft Word version may be downloaded from www.nmenv.state.nm.us (Ground Water Quality) and filled out electronically.*
☒ Part B: Operational, Monitoring, Contingency and Closure Plans, with required attachments. *Choose appropriate option*: ☐ Septic Tank System ☒ General – Various Facility Types	
☒ Part C: Site Information, with required attachments.	
☒ $100 Filing Fee, payable to the New Mexico Environment Department. *Required from all applicants.* An additional fee will be assessed prior to permit issuance. Permit fees are listed in Section 20.6.2.3114 NMAC.	

Certification. Signature must be that of the person named in Item A-3 of Part A of the application.

I certify under penalty of law that I am knowledgeable about the information contained in this application. The information is, to the best of my knowledge and belief, true, accurate and complete.

Signature: _____ Date: 2/14/12

Printed Name/Title: Alison M. Dorries, Division Leader, ENV, Los Alamos National Security, LLC

Signature: _____ Date: 2/15/12

Printed Name/Title: Kevin W. Smith, Manager, Los Alamos Site Office, US Department of Energy

Send three complete copies of this application and the filing fee to:

Program Manager
Ground Water Pollution Prevention Section
New Mexico Environment Department
PO Box 5469
Santa Fe, NM 87502

LA-UR-12-00672
ENV-DO-12-0005

GROUND WATER
FEB 16 2012
BUREAU

GROUND WATER DISCHARGE PERMIT APPLICATION
PART A: ADMINISTRATIVE COMPLETENESS
All Facilities

A-1. Facility Information. See Supplemental Instructions to determine what constitutes the "facility." The physical location of the facility must be provided. If the facility does not have an address, the location can be described by road intersections, mile posts, or landmarks, as appropriate.

Facility Name	Los Alamos National Laboratory (LANL or the Laboratory)
Former Names (if any)	NA
Physical address/location *(mandatory)*	Los Alamos, New Mexico
	County Los Alamos
Mailing address	P.O. Box 1663 Mail Stop K491
	Los Alamos, NM 87545
Contact person	Alison M. Dorries
Title	Division Leader, Environmental Protection Division (ENV)
Telephone number(s)	505-665-6952
Fax number	505-665-3811 E-mail address adorries@lanl.gov

A-2. Type of Discharge and Type of Facility. See Supplemental Instructions.

Type of discharge: ☐ Domestic ☐ Agricultural ☒ Industrial ☐ Mining

Type of facility: The Radioactive Liquid Waste Treatment Facility (RLWTF) is a wastewater facility for the treatment of hazardous and radioactive liquid waste.

A-3. Applicant Information. The applicant is the person or entity (e.g., corporation, partnership, organization, municipality, etc.) legally responsible for the discharge and for complying with the terms of the Discharge Permit. If the applicant is an entity, then the name and title of a contact person must be provided. This application must be signed by the applicant or contact person named here.

Applicant Name	US Department of Energy (DOE)[1] Los Alamos National Security, LLC (LANS)[2]
Mailing address	[1]3747 West Jemez Road, Los Alamos, NM 87545 [2]P.O. Box 1663, MS K491, Los Alamos, NM 87545
Contact person	[1]Kevin W. Smith, Los Alamos Site Office, DOE [2]Alison M. Dorries, LANS
Title	[1]Manager [2]Division Leader
Telephone number(s)	[1](505) 667-5105 [2](505) 665-6952
Fax number	[1](505) 606-2004 [2](505) 665-3811
E-mail address	[1] kevin.smith@nnsa.doe.gov, [2] adorries@lanl.gov

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A-4. Consultant Information (if applicable). If the consultant is a company or organization, then the name and title of a contact person must be provided.

Consultant/Firm Name: NA

Mailing address:

Contact person:

Title:

Telephone number(s):

Fax number: E-mail address:

A-5. Permit Contact Information (if applicable). If someone other the applicant listed in Item A-3 or a consultant listed in Item A-4 is a primary contact for this application and/or facility, list here.

Permit Contact Name: Robert Beers

Title: Environmental Professional, Water Quality & RCRA Group, LANS

Mailing address: P.O. Box 1663, MS K490

Los Alamos, NM 87545

Telephone number(s): 505-667-7969

Fax number: 505-665-9344 E-mail address: bbeers@lanl.gov

A-6. Ownership.

The applicant owns (check as appropriate): ☒ the facility* ☐ some discharge sites ☐ all discharge sites

***Department of Energy (DOE) Facility**

If other parties own the facility or any of the discharge sites, attach their names and contact information.

A-7. Discharge Quantity.

Your Discharge Permit will specify a maximum discharge volume, which is typically expressed as the maximum number of gallons per day that may be treated and/or disposed of. Please indicate below the maximum discharge volume for your facility. You must show how it was determined in Part B of your application. For further explanation, see Supplemental Instructions for Part B.

Maximum discharge volume: 40,000 gallons per day

A-8. **Processing, Treatment, Storage and Disposal System.** Briefly describe how wastewater, sludge, etc. is processed, treated, stored, and/or disposed of at your facility. See Supplemental Instructions for examples of system components.

The Radioactive Liquid Waste Treatment Facility (RLWTF) consists of (a) an underground collection system that conveys water to Technical Area (TA) 50 from generators at LANL, (b) structures at TA-50, and (c) Zero Liquid Discharge Solar Evaporation Tanks at TA- 52. At Technical Area 50, Building 50-01 is the primary structure; it houses treatment equipment, process tanks, analytical laboratories, and offices. Adjacent TA-50 structures primarily provide for additional water storage: 50-02 (influent), 50-66 (influent), 50- 90 (influent), 50-248 (secondary waters), and 50-250 (emergency).

The RLWTF receives and treats radioactive liquid waste (RLW) from generators at Los Alamos National Laboratory. RLW includes small volumes, less than one percent of total influent, that are also characteristically hazardous for corrosivity, which are treated using elementary neutralization. The RLWTF has (1) a main treatment process for low-level RLW, (2) a process for treating transuranic RLW, and (3) a secondary treatment process for waste streams from both the low-level and transuranic processes.

1) The main treatment process consists of influent collection and storage, the treatment of low-level RLW, and the discharge of treated water to the environment. Treatment steps include clarification, filtration, ion exchange, and reverse osmosis. Discharge to the environment is via NPDES Outfall #051, solar evaporation at the TA-52 Zero Liquid Discharge (ZLD) Solar Evaporation Tanks, or mechanical evaporation at TA-50-257. Two secondary streams are generated by primary treatment, sludge and reverse osmosis concentrate; they are sent to the secondary treatment process.

2) Transuranic RLW treatment consists of influent collection and storage, treatment of the transuranic RLW, and sludge treatment. Treated water is not discharged; it either receives additional treatment (secondary reverse osmosis) or is sent to storage tanks in Building 50-248 for disposition as bottoms. Sludge from the treatment process is concentrated, solidified with cement, and shipped to the Waste Isolation Pilot Plant as a solid transuranic waste.

3) The secondary treatment process treats wastes from the primary and transuranic treatment lines. It consists of a rotary vacuum filter to treat sludge from the main treatment process, secondary reverse osmosis to treat reverse osmosis concentrate from the main process and/or effluent from the transuranic process, and a bottoms disposal step. Wastes from the secondary treatment process are disposed as low-level radioactive solid waste.

A-9. Discharge Locations. List the locations of your facility and of all components of your processing, treatment, storage and/or disposal system. Examples of components include septic tanks, lagoons, leachfields, irrigation sites, mine stockpiles, etc. Additional examples are listed in the Supplemental Instructions. Latitude and longitude are optional unless township, range and section are not available.

Components	Township	Range	Section(s)	Latitude	Longitude
RLWTF Mechanical Evaporator (50-257)	19N	6E	22	35° 51' 58.3"	-106° 17' 48.5"
NPDES Outfall #051 (NM0028355)	19N	6E	22	35° 51' 54"	-106° 17' 52"
TA-52 Zero Liquid Discharge Solar Evaporation Tanks (currently under construction)	19N	6E	22	35° 51' 36"	-106° 17' 12"

A-10. Discharge Quality.

Indicate the expected quality of the discharge -- wastewater, leachate, sludge, etc. -- generated, stored, treated, processed and/or discharged at your facility. List the contaminants of concern and the expected concentrations. *Not all facilities need to characterize influent quality.* See Supplemental Instructions for typical contaminants and additional guidance.

Effluent quality data is collected under two compliance monitoring programs. Each of these monitoring programs is discussed briefly below.

- **NPDES Compliance Effluent Monitoring** for the RLWTF's NPDES Outfall #051 in Mortandad Canyon is conducted in accordance with monitoring requirements of the Laboratory's NPDES Permit No. NM0028355. See Appendix C for a list of NPDES permit analytes and monitoring frequencies.

- **DP-1132 Voluntary Effluent Monitoring** has been conducted since the first quarter of 1999 for NO3-N, fluoride, TDS, and perchlorate. Flow-proportioned, weekly composite samples are prepared from each tank of effluent discharged to Mortandad Canyon during a 7-day period. Analytical results are reported to the NMED Ground Water Quality Bureau quarterly.

Based on the past 10 years of influent and effluent monitoring data the Laboratory has identified the potential contaminants of concern as shown in the table below. Contaminant concentrations listed in the table below are the average influent and effluent results from monitoring conducted during 2008, 2009, and 2010. No effluent was discharged to NPDES Outfall #051 during the second half of 2010, except for two discharges in November 2010, and all of 2011. As a result, no effluent data is available for 2011.

RLWTF Effluent Potential Contaminants of Concern.

Expected or Known Contaminants	Expected or Known Contaminants Indicate units: mg/L, CFU/100 ml, etc.	
	Incoming (Influent)	Final (Effluent)
Ammonia-N	9.6 mg/L	3.74 mg/L
Nitrate-N	12.9 mg/L	5.33 mg/L
Nitrite-N	0.45 mg/L	1.58 mg/L
Nitrate + Nitrite-N	NA	6.6 mg/L
Perchlorate	307 ug/L	0.78 ug/L
TKN	11.4 mg/L	4.6 mg/L
Benzo(a)pyrene	<MDL*	0.83 ug/L
Benzo(b)flouranthene	<MDL*	0.78 ug/L
pH [min/max]	3.1/8.5 su	7.0/7.5 su

*Less than the Method Detection Limit for influent utilizing analytical method SW-846:8270C with an analytical laboratory reported MDL of 1 ug/L.

For **new** septic tank systems, you may either fill out the chart above or simply check one of the following options:

☐ typical domestic wastewater

☐ low-strength domestic wastewater (large gray water component; e.g., laundromat, spa, etc.)

☐ high-strength domestic wastewater (low water use; e.g., RV park, low-flow toilets at campground, etc.)

A-11. Ground Water Conditions.

All applicants must provide the depth to and pre-discharge TDS concentration of the ground water that could be affected by the discharge. Refer to Supplemental Instructions for details on how to obtain these values.

Indicate the depth to the most shallow ground water beneath the discharge site. If there are multiple discharge sites, indicate the range of depths.	Indicate pre-discharge total dissolved solids (TDS) concentration of most shallow ground water beneath the discharge site. Attach copies of analyses.
Depth to water (feet): NPDES Outfall #051 - <1 foot to alluvial; 1262 feet to regional RLWTF – 1306 feet to regional ZLD – 1274 feet to regional	TDS (mg/L): NPDES Outfall #051 – 255 mg/L (alluvial) ZLD – 162 mg/L max (regional)
Reference: ☒ Measurement, nearby monitoring well ☐ Measurement, nearby supply well ☐ Well log from nearby well (attach copy) ☐ Office of the State Engineer http://www.ose.state.nm.us/	Reference: ☒ Analysis from upgradient monitoring well ☐ Analysis from on-site supply well ☐ Analysis from shallow nearby supply well ☐ Concentration provided in previous Discharge Permit application

☐ Report or study (give citation here and attach relevant portion): ☐ Other (describe):	☒ Report or study (give citation here and attach relevant portion): **R-15 information from Table S5-8 from the 2010 Environmental Surveillance at Los Alamos during 2010 attached in Appendix I** ☐ Other (describe):

A-12. Public Notice. See Supplemental Instructions.

a) The public notice packet including instructions and materials should be sent to:

☐ Applicant ☐ Consultant ☒ Other: Permit Contact (A-5)

b) Copies of the public notice packet (excluding sign) should be sent to:

☐ Applicant ☐ Consultant ☒ Other: Permit Contact (A-5)

c) The applicant is required to provide public notice of this application by placing a display ad in a newspaper of general circulation near the location of the proposed discharge. Indicate newspaper you intend to place the ad in:

Newspaper: Los Alamos Monitor

d) *For new or modification applications only:* The applicant must post a sign for 30 days in a conspicuous location at or near the facility, as approved by NMED. One sign must be posted for each 640 contiguous acres or less of the discharge site. An additional notice must be posted at an off-site location conspicuous to the public. Describe the locations below where you intend to post the notices. You may also attach sketches or photographs.

At or near facility: *2 by 3 feet in size*

The TA-50 RLWTF, TA-52 Zero Liquid Discharge Solar Evaporation Tanks, and NPDES Outfall #051 are all located in T19N, R6E, Section 22. The Radioactive Liquid Waste Collection System spans four additional Sections: 16, 17, 20, and 21. Accordingly, a sign will be posted at each of the following five locations:

1. Pecos Drive at the entrance to the TA-50 RLWTF (Section 22)
2. Pajarito Road at the entrance to the Vehicle Access Control Station (Section 21)
3. Intersection of Pajarito Road and Diamond Drive (Section 20)
4. Intersection of Embudo Road and Diamond Drive (Section 17)
5. Park & Ride bus stop at the intersection of Diamond Drive and West Jemez Road (Section 16)

Off-site location: *flyer size*

A flyer size notice will be posted at the LANL Public Reading Room at the J. Robert Oppenheimer Study Center and Research Library, located on West Jemez Road at Casa Grande, Los Alamos, NM

GROUND WATER DISCHARGE PERMIT APPLICATION
PART B: OPERATIONAL, MONITORING, CONTINGENCY AND CLOSURE PLANS
GENERAL FORM (VARIOUS FACILITY TYPES)

Operational Plan *[Section 20.6.2.3106.C, 3109.C NMAC]*

B-1. Source(s) of the Discharge. Describe what generates the wastewater, sludge or other discharges processed and/or disposed of at your facility. Identify all sources. Attach additional pages, if needed. See Supplemental Instructions.

The Radioactive Liquid Waste Treatment Facility receives influent from the following sources:

- Process water from radiochemistry laboratories, duct washing systems, radiological areas, boilers, and process areas. The annual average influent volume is 18,150 gallons per day.
- Cooling water from systems located in radiological areas. The annual average influent volume is 1,232 gallons per day.
- Storm and surface water (including samples) collected from sumps, manholes, and vaults. The daily influent volume varies and the annual average is 268 gallons per day.
- Environmental Restoration (ER) waste water generated by groundwater monitoring and sampling activities performed at LANL. The daily influent volume varies and the annual average is 50 gallons per day. Influent is accepted in 2,000 gallon batches.

B-2. Discharge Quantity. Describe the methods/calculations used to determine the maximum discharge volume listed in Item A-6 in Part A of your application. Attach additional pages, if needed. See Supplemental Instructions.

The maximum possible discharge from the RLWTF is 40,000 gallons per day as determined by the volume of the two effluent Frac tanks (20,000 gallons each) at RLWTF as discharges are conducted on a batch basis.

B-3. Site Map. Attach a site map showing the components of your proposed system and relevant surrounding features, clearly labeled, such as:

- treatment units
- lagoons
- tanks
- sumps
- manure separators
- land application fields
- domestic wastewater reuse areas
- pits
- stockpiles
- leachfields
- sludge drying beds
- roads
- buildings
- supply wells
- monitoring wells
- extraction/injection wells
- arroyos
- nearby water bodies such as ponds or canals
- property boundaries
- other permitted discharges
- required setbacks
- north arrow

If map is not to scale, mark distances on the map.

☒ Site map is attached.

See Appendix B for a scaled floor plan of the RLWTF treatment units. See Appendix J for Map #1 – Location Map and Map #2 – TA-50 RLWTF, RLW Collection System, NPDES Outfall #051, Zero Liquid Discharge Solar Evaporation Tanks, and 100-year Flood Plain.

B-4. Flood Protection. Describe the methods used to prevent flooding and run-off at the facility (tank protection, berms, diversion channels, etc.)

The RLWTF and TA-52 Zero Liquid Discharge Solar Evaporation Tanks, with the exception of the NPDES Outfall #051, are located outside of the 100-year flood plain, see Map #2 in Appendix J for the flood plains. The RLWTF is served by a functional storm water drain system consisting of a series of drainage swales and culverts that convey storm water around the facility as shown on Map #4 in Appendix J.

B-5. Plans and Specifications. For new facilities and for new components of existing systems, attach plans and specifications certified by a New Mexico registered professional engineer. *[Section 20.6.2.1202 NMAC]*

The RLWTF maintains facility drawings which include site, architectural, mechanical, electrical, instrumentation,structural and process details. Drawings include a facility as-built set (approximately 600 drawings)and process and instrumentation diagrams associated with low-level, transuranic and secondary treatment processes (approximately 60 drawings). See Appendix B for the RLWTF process schematic and a scaled floor plan of the RLWTF treatment units.

The drawings are available for review at TA-50 RLWTF. Arrangements for the review can be made with the Permit Contact Listed in A-5.

☐ Not applicable because no new facilities are proposed.

☐ Plans and specifications are attached.

☒ Plans and specifications were previously submitted.

Submittal date(s): **60% design package for the TA-52 Zero Liquid Discharge (ZLD) Solar Evaporation Tanks was submitted on August 11, 2011, ENV-RCRA-11-0136.**

B-6. Description of Components. Provide descriptive details of all components of your processing, treatment, storage and/or disposal system. Include all components listed under Item A-8 in Part A.

See Appendix B for a detailed list and description of major components at RLWTF, the process schematic, and for a scaled floor plan of the treatment units at RLWTF.

B-7. Operational Plan. Attach a detailed description of how you operate your processing, treatment, storage and/or disposal system.

Animal feeding operations: include stormwater management, nutrient management plans, method for mixing irrigation and wastewater.

Domestic wastewater treatment facilities: include pre-treatment, solids management, vegetation management for land application.

Facilities using reclaimed domestic wastewater above ground: include proposed water quality classification(s), effluent monitoring, setbacks, irrigation schedules, etc. that will result in protection of public health and the environment. Please refer to *NMED Ground Water Quality Bureau Guidance: Above-Ground Use of Reclaimed Domestic Wastewater* for further information. A copy of the guidance document is available on the NMED website www.nmenv.state.nm.us under "Ground Water Quality".

Per the January 27, 2012 NMED letter (See Appendix A) granting a 45-day extension, this item will be addressed and information will be submitted to NMED under separate cover by April 2, 2012.

☐ Operational plan is attached.

☐ Operational plan was previously submitted. Submittal date(s): _____

B-8. System Maintenance. Attach a description of the operations and maintenance procedures which ensure that your processing, treatment and disposal system functions properly; e.g., inspections, pumping schedules, equipment maintenance, etc.

Per the January 27, 2012 NMED letter (See Appendix A) granting a 45-day extension, this item will be addressed and information will be submitted to NMED under separate cover by April 2, 2012

☐ O & M procedures are attached.

☐ O & M procedures were previously submitted. Submittal date(s): _____

B-9. Backflow Prevention. If wastewater is used for land application or irrigation, describe methods used to protect wells from contamination by wastewater backflow. For new facilities or new systems at an existing facility, only air gap or reduced pressure valve assemblies are acceptable methods.

a) Clearly describe and/or sketch the location of air gaps or devices and attach specifications.

NA – effluent is not reused.

b) Describe how devices are maintained.

NA

B-10. Water Rights. Animal feeding operations which land apply wastewater must attach documentation of irrigation water rights for the proposed land application fields, sufficient to sustain the intended crop rotation.

☐ Water right documentation is attached.

☒ Not applicable.

B-11. Past Ground Water Monitoring Results. *This item applies only to existing facilities seeking renewal and/or modification of a Discharge Permit that required ground water monitoring.*

a) Attach a graph or a table showing all analytical results from ground water sampling at your facility. If preparing graphs, a separate graph should be developed for each constituent, except that nitrate and TKN may be shown on the same graph. Multiple wells may be shown on the same graph. See Supplemental Instructions for sample table and graph.

b) If the monitoring results indicate that ground water standards have been violated or that there is an upward trend approaching standards, attach a description of what actions you have taken or will take to address the elevated concentrations. Ground water standards are listed in Section 20.6.2.3103 NMAC. See the Supplemental Instructions for frequently referenced standards.

Groundwater beneath the Pajarito Plateau occurs in three modes, two of which are perched. Perched groundwater is a zone of saturation with limited extent that is retained above less permeable layers and is separated from underlying groundwater by unsaturated rock.

The three modes of groundwater occurrence are: (1) perched alluvial groundwater in canyon bottoms; (2) discontinuous zones of intermediate-depth perched groundwater whose location is controlled by availability of recharge and by subsurface changes in rock type and permeability; and (3) the regional aquifer beneath the Pajarito Plateau. The regional aquifer extends throughout the neighboring Española Basin.

Los Alamos National Laboratory routinely analyzes groundwater samples to monitor water quality beneath the Pajarito Plateau and the surrounding area. The Laboratory conducts groundwater monitoring and characterization programs to comply with the requirements of the Department of Energy (DOE) Orders and New Mexico and federal regulations. The objectives of the Laboratory's groundwater programs are to determine compliance with waste discharge requirements and to evaluate any impact of Laboratory activities on groundwater resources.

Most of the groundwater monitoring conducted during 2011 was carried out according to the 2011 Interim Facility-Wide Groundwater Monitoring Plan approved by the New Mexico Environment Department (NMED) under the Compliance Order on Consent (Consent Order). See Appendix I for the 2011 Interim Facility-Wide Groundwater Monitoring Plan. Additionally, voluntary quarterly groundwater

monitoring has been conducted continuously since 1999 at select alluvial wells in Mortandad Canyon to evaluate the impacts of effluent discharges from the RLWTF though NPDES Outfall #051.

Groundwater monitoring and associated investigations have shown a linkage between the shallow alluvial groundwater zone that first receives effluent from the RLWTF and underlying intermediate-depth (500 to 800 feet below ground surface) and regional (~1000 feet below ground surface) groundwater zones. The connection between these zones appears to occur in a relatively small area downstream of NPDES Outfall #051 (See Appendix I, 2006 Mortandad Canyon Investigation Report).

Monitoring-well data were compared to applicable standards for the period from 2000 to present for four alluvial wells, three intermediate-depth wells, and two regional wells. Time-series plots are provided as Figures 2 through 12 in Appendix D for contaminants that have shown exceedances of a standard for the period 2000 to present. The plots show decreasing concentrations over time for the alluvial wells indicating relatively rapid response to the improvements in the treatment process at RLWTF that were put in place in 2000. Plots for the intermediate-depth and regional wells are indicative of contamination that migrated to those zones likely over the scale of decades.

Chromium contamination in the deeper zones is likely attributable to the chromate that was used to treat cooling water at the power plant in Sandia Canyon until 1972; these earlier discharges are the source for hexavalent chromium concentrations discovered in intermediate groundwater and the regional aquifer beneath Sandia and Mortandad Canyons. Figure 1 in Appendix D shows that total chromium concentrations in the TA-50 RLWTF's effluent from 2001 to 2010 did not exceed the groundwater standard of 50 µg/L.

Additional detailed information on the quality of the alluvial, intermediate-depth, and regional groundwater can be found in Chapter 5 of the 2010 Environmental Surveillance Report (Appendix I)

Monitoring Plan *[Section 20.6.2.3107.A NMAC]*

B-12. Discharge Volumes. Describe how and where the monthly discharge volume at your facility will be. For all measuring devices, provide type, location, and units of measure including multipliers (e.g., gallons, gallons x 100, acre-ft, etc.) See Supplemental Instructions. Attach additional pages, if necessary.

Discharges of treated water to the environment are measured by the following methods:

- Low-level influent: Low-level RLW influent volumes are determined by daily water balance. The levels of process vessels and tanks are continuously monitored with information transmitted electronically to the RLWTF control room. Level changes are converted to volume

changes, which are summed daily. Influent is determined as the sum of tank volume changes plus volumes of water discharged to the environment and water removed as sludge. Tank level and other volume information is reviewed daily to assure activities and tank level changes agree with actual plant operations.

- Transuranic influent: Transuranic influent is received in batches from TA-55, with influent collected in either the acid tank or caustic tank in Building 50-66. Level probes for these tanks are linked electronically to the RLWTF control room. Operators monitor and record tank level changes during each influent batch transfer. Influent volumes are calculated from the difference between beginning and ending tank levels.

- Discharge to the environment by mechanical evaporation at 50-257: Treated water is fed to the evaporator from the effluent Frac tanks in Room 34B; water is typically fed continuously during the normal work week, including overnight. Volumes are read in gallons from a water meter on the evaporator feed line.

- Discharge to the environment by solar evaporation: Treated water is discharged to the TA-52 Zero Liquid Discharge Solar Evaporation Tanks from either of the effluent Frac tanks in Room 34B, or from TK38 in Room 38. Discharges occur in batches. The volume, in gallons, of each discharge is calculated from the change in tank level. If discharges are from the effluent Frac tanks, which are horizontal tanks, before- and after-discharge tank volumes are determined from a table that correlates tank level and volume of water in the tank. If discharges are from TK38, pre and post discharge tank volumes are read directly from markings on this translucent vertical tank.

- Discharge to the environment via NPDES Outfall #051: Treated water is discharged from either of the effluent Frac tanks in Room 34B, or from TK38 in Room 38. Discharges occur in batches. The volume, in gallons, of each discharge is calculated from the change in tank level. If discharges are from the effluent Frac tanks, which are horizontal tanks, before- and after-discharge tank volumes are determined from a table that correlates tank level and volume of water in the tank. If discharges are from TK38, pre and post discharge tank volumes are read directly from markings on this translucent vertical tank.

B-13. Discharge Quality Monitoring. Discharge Permits typically require that the discharge (treated wastewater, sludge, septage, etc.) be sampled on a regular basis. The frequency of sampling varies by type of facility, as do the contaminants of concern. Domestic and agricultural Discharge Permits typically require sampling for total Kjeldahl nitrogen (TKN), nitrate-nitrogen (NO_3-N), total dissolved solids (TDS) and chloride on a quarterly or semi-annual basis. *(continued on next page)*

If reclaimed domestic wastewater will be discharged for above ground uses, testing of the discharge for additional parameters is appropriate. Please refer to the *NMED Ground Water Quality Bureau Guidance: Above-Ground Use of Reclaimed Domestic Wastewater* for further information.

In the space below, provide a description or sketch of the sampling point(s) to be used for sampling the discharge at your facility.

The sampling point for effluent discharges from the North & South Frac Tanks is TA-50, Building 1, Room 34B.

The sampling point for effluent discharges from the TK38 tank is Room TA-50, Building 1, Room 38.

Optional: In the space below (or as an attachment), you may propose revisions or additions to the standard discharge quality monitoring requirements. If you do, provide the rationale for your proposal.

Proposed Monitoring Plan for Treated Effluent Discharged to Mortandad Canyon through NPDES Outfall #051.

LOCATION	PARAMETER	NOTES	FREQUENCY
Effluent Tank**	Batch Volume (gallons)	1	Per batch
Effluent Tank**	Total Nitrogen	1, 2	Quarterly
Effluent Tank**	Total Dissolved Solids	1	Quarterly
Effluent Tank**	Perchlorate	1	Quarterly
Effluent Tank**	Human Health Standards	1, 3	Annual
Effluent Tank**	Domestic Water Supply Standards	1, 4	Annual
Effluent Tank**	Irrigation Standards	1, 5	Annual
Effluent Tank**	Volatile & Semivolatile Organics	1, 6	Annual
Effluent Tank**	Radiochemistry	1, 7	Annual
Effluent Tank**	PCBs	1, 8	Annual

**North & South Frac Tanks or TK38

NOTES:

1. The Discharge Permit Sampling Points are: at the Frac tanks in Room 34B or at TA-50 Building 1, Room 38.
2. Total Nitrogen: TKN, Ammonia, NO3+NO2-N.
3. Human Health Standards (20.6.2.3103A): Ag, As, Ba, Cd, CN, Cr, F, Hg, NO3-N, Pb, Se, U.
4. Domestic Water Supply Standards (20.6.2.3103B): Cl, CU, Fe, Mn, SO4, Zn, TDS, pH.
5. Irrigation Standards (20.6.2.3103C): Al, B, Co, Mo, Ni.
6. Volatile & Semivolatile Organics (20.6.2.7WW, 20.6.2.3103) by EPA Methods 624 and 625.
7. Radiochemistry (20.6.2.3103A): Combined Ra-226 and Ra-228.
8. PCBs (20.6.2.3103A): EPA Method 608.

Proposed Monitoring Plan for Treated Effluent Discharged to the Zero Liquid Discharge Solar Evaporation Tanks at TA-52.

LOCATION	PARAMETER	NOTES	FREQUENCY
Effluent Tank**	Batch Volume (gallons)	1	Per batch
Effluent Tank**	Total Nitrogen	1, 2	Quarterly
Effluent Tank**	Total Dissolved Solids	1	Quarterly
Effluent Tank**	Perchlorate	1	Quarterly
Effluent Tank**	Human Health Standards	1, 3	Annual
Effluent Tank**	Domestic Water Supply Standards	1, 4	Annual
Effluent Tank**	Irrigation Standards	1, 5	Annual
Effluent Tank**	Volatile & Semivolatile Organics	1, 6	Annual
Effluent Tank**	Radiochemistry	1, 7	Annual
Effluent Tank**	PCBs	1, 8	Annual

**North & South Frac Tanks or TK38

NOTES:

1. The Discharge Permit Sampling Points are: at the Frac tanks in Room 34B or at TA-50 Building 1, Room 38.
2. Total Nitrogen: TKN, Ammonia, NO3+NO2-N.
3. Human Health Standards (20.6.2.3103A): Ag, As, Ba, Cd, CN, Cr, F, Hg, NO3-N, Pb, Se, U.
4. Domestic Water Supply Standards (20.6.2.3103B): Cl, CU, Fe, Mn, SO4, Zn, TDS, pH.
5. Irrigation Standards (20.6.2.3103C): Al, B, Co, Mo, Ni.
6. Volatile & Semivolatile Organics (20.6.2.7WW, 20.6.2.3103) by EPA Methods 624 and 625.
7. Radiochemistry (20.6.2.3103A): Combined Ra-226 and Ra-228.
8. PCBs (20.6.2.3103A): EPA Method 608.

B-14. Ground Water Quality Monitoring. Discharge Permits typically require that ground water samples be collected quarterly from properly constructed monitoring wells located downgradient from discharge locations. The samples must be analyzed for contaminants of concern. For most domestic and agricultural Discharge Permits, the typical contaminants of concern are total Kjeldahl nitrogen (TKN), nitrate-nitrogen (NO_3-N), total dissolved solids (TDS) and chloride.

Optional: In the space below (or as an attachment), you may propose revisions or additions to the standard ground water monitoring requirements. If you do, provide the rationale for your proposal.

Per the January 27, 2012 NMED letter (See Appendix A) granting a 45-day extension, this item will be addressed and information will be submitted to NMED under separate cover by April 2, 2012.

For existing facilities:

Indicate number of existing monitoring wells: 9

Attach copies of monitoring well logs.

☒ Well logs attached. **See Appendix E.**

☐ Well logs cannot be located.

☐ Well logs previously submitted. Submittal date(s): _____

Attach copy of monitoring well survey (typically not applicable if fewer than 3 monitoring wells).

☒ Survey attached. **See Appendix J for Map #1 – Location Map.**

☐ No survey has been conducted.

☐ Survey previously submitted. Submittal date(s): _____

B-15. Other Monitoring. In addition to discharge volumes, discharge quality monitoring and ground water sampling, Discharge Permits typically require the following monitoring, depending on the type of facility:

- inspection and pumping of septic tanks, grease tanks, lift stations
- inspection of leachfields
- inspection of lagoons
- process testing for treatment plants
- land application data sheets (LADS)
- tracking of chemical fertilizer applications to land application areas
- soil sampling (agricultural and selected other facilities land applying wastewater)
- harvested plant material testing (agricultural facilities)

Optional: In the space below (or as an attachment), you may propose revisions or additions to the other standard monitoring requirements for your type of facility. If you do, provide the rationale for your proposal.

Per the January 27, 2012 NMED letter (See Appendix A) granting a 45-day extension, this item will be addressed and information will be submitted to NMED under separate cover by April 2, 2012.

Contingency Plan *[Section 20.6.2.3107.A.10 NMAC]*

B-16. System Failure. Describe your contingency plan in the event there is a failure of your wastewater or discharge system (e.g., wastewater back-up, pump failure, pipe breaks, tank overflow, leachfield failure, saturated fields etc.)

Per the January 27, 2012 NMED letter (See Appendix A) granting a 45-day extension, this item will be addressed and information will be submitted to NMED under separate cover by April 2, 2012.

B-17. Contingency Leachfield Location. *This item applies only if your disposal system includes a leachfield.* Identify a location on your site map (Item B-3) for a contingency leachfield in the event that your leachfield must be replaced. If no land is available for a contingency leachfield at an existing facility, describe how you will address a failed leachfield. New facilities must provide for a contingency leachfield location.

NA

B-18. Other Contingencies. Discharge Permits typically contain standard contingencies to address:

- exceeding wastewater quality limits
- violation of ground water or surface water standards
- spills or illegal releases of wastewater
- migration of soil nitrogen
- loading nitrogen above limit

Propose additional contingency plans, if appropriate:

Per the January 27, 2012 NMED letter (See Appendix A) granting a 45-day extension, this item will be addressed and information will be submitted to NMED under separate cover by April 2, 2012.

Closure Plan *[Section 20.6.2.3107(A)11 NMAC]*

B-19. Facility Closure and Post-Closure Monitoring. Discharge Permits contain standard requirements to address the closure of part or all of your discharge system, as follows:

- cap or plug lines to prevent the flow of wastewater to treatment or disposal system
- empty and remove or backfill tanks
- empty lagoons, perforate or remove liners, re-grade to surface topography
- appropriately dispose of solids
- regrade and cover stockpiles at mine facilities
- continue ground water monitoring for at least two years, longer as appropriate
- enact contingency plans if ground water standards are violated
- financial assurance may be required.

Propose additional closure plans in the space below or as an attachment, if appropriate:

See Appendix H for Closure Plan.

Please Note: You must also complete Part C of the application.

GROUND WATER DISCHARGE PERMIT APPLICATION
PART C: SITE INFORMATION
All Facilities

C-1. Area Map. Attach a current area map showing roads and clearly mark the location of your facility.

See Appendix J for Map #1 – Location Map.

C-2. Directions to Site. Provide driving directions to the site from the nearest town or, if located in a town, from an easily identifiable location.

From Santa Fe, NM, take US-285 north to Pojoaque, NM. Take NM-502 west towards Los Alamos, NM. Because access to the RLWTF Facility requires entry through one of the Los Alamos National Laboratory's Pajarito Corridor Vehicle Access Portals, visitors without a LANL badge must be escorted to the project site. Visits to the project site may be coordinated through the point of contact listed in A-5 of this application.

C-3. Topographic Map. Attach a copy of the appropriate US Geological Survey topographic map. You may provide just the relevant portion. USGS maps are available at many outdoor equipment stores or bookstores, from the USGS at www.usgs.gov or 1-888-ASKUSGS, and from commercial websites.

On the map clearly indicate the location of your facility. Also identify the approximate locations of all wells within 1,000 feet of your discharge locations. The Office of the State Engineer has a searchable database of supply wells on its website at www.ose.state.nm.us.

☒ USGS map attached with facility location and neighboring wells marked. **See Appendix J for Map #1 – Location Map.**

C-4. Flood Potential. Attach a copy of the latest Federal Emergency Management Agency (FEMA) flood map with your facility's location clearly marked, to the best of your ability. Information about how to obtain this map, formally known as a Flood Insurance Rate Map (FIRM) is available at www.fema.gov, insurance agencies or county government offices. A site specific analysis may be substituted.

☒ FEMA map or site-specific analysis attached. **See Appendix J for Map #2 which includes the 100-year flood plain coverage.**

☐ Previously submitted and still up-to-date. Submittal date(s): _____

C-5. Soils. Attach either:

a) A copy of the appropriate Natural Resource Conservation Service (NRCS) soil survey map, with your site clearly identified to the best of your ability. Include the descriptive information for soils associated with the discharge locations. To obtain the map, contact your local NRCS office – there is one in every county.

b) A site-specific assessment showing the soils classifications. This is preferred over the more generalized NRCS surveys.

☒ NRCS soil survey or site-specific assessment attached.

- **See soil type descriptions in Appendix F.**
- **See Appendix J for LANL Soils Map #3.**
- **See Appendix I for NRCS Soil Survey of Sandoval County Area, New Mexico, Parts of Los Alamos, Sandoval, and Rio Arriba Counties.**

☐ Previously submitted. Submittal date(s): _____

C-6. Geology. Provide information on the geology beneath the site by attaching relevant portions of geologic reports, well logs for on-site or nearby wells, or site specific assessments. A variety of geology publications and resources are available from the New Mexico Bureau of Geology and Mineral Resources at http://geoinfo.nmt.edu or 505-835-5420 (Socorro). Well logs are available from the New Mexico State Engineer's Office at http://www.ose.state.nm.us/.

☒ Geologic report attached. ☐ Well log(s) attached.

See Appendix F for bore hole locations and bore hole information for the following areas:

- **TA-50 RLWTF.**
- **TA-50-0250 (WMRM)**
- **Zero Liquid Discharge Solar Evaporation Tanks at TA-52**

See Appendix F for the Plan and Map Views of Stratigraphic Units Beneath MDA C.

☐ Geologic information previously submitted. Submittal date(s): _____

C-7. Ground Water Hydrology. Ground water hydrology refers to the occurrence, distribution, movement and chemistry of ground water. The ground water hydrology at your site will determine in large part whether your discharge will adversely affect ground water quality. You may need to present detailed information in order to "demonstrate that the Discharge Permit will not result in concentrations in excess of the standards of Section 20.6.2.3103 NMAC or the presence of any toxic pollutant." (20.2.3106.C.7 NMAC)

At a minimum, provide information below on the direction of ground water flow. Ground water may not flow in the same direction as water on the surface of the ground. A monitoring well survey is one of the best methods to determine the direction of ground water flow at a particular site. Such surveys are routinely required for many Discharge Permit locations.

If a survey is not available, check with well drillers, the city water department, staff at the Office of the State Engineer, environmental consultants or other knowledgeable persons in your area. In addition, relevant reports have been published for some areas. See the OSE website at www.ose.state.nm.us or the NMBGMR website at http://geoinfo.nmt.edu.

Direction of ground water flow: Southeast.

If ground water flow shifts seasonally, describe here: NA

Reference:

☐ On-site well survey attached. ☐ Previously submitted. Submittal date(s): _____

☐ Nearby well survey attached. ☐ Previously submitted. Submittal date(s): _____

☒ Other. Specify: **See Appendix I for (CD) containing the following LANL reports:**

1. **2009 Hydrogeologic Site Atlas. LAUR-09-3763.**
2. **Groundwater Level Status Report for 2010 Los Alamos National Laboratory. LA-14437-PR.**
3. **Los Alamos National Laboratory's Hydrogeologic Studies of the Pajarito Plateau: A Synthesis of Hydrogeologic Workplan Activities (1994-2004). LA-14263-MS.**
4. **Conceptual Models of Vadose Zone Flow and Transport Beneath the Pajarito Plateau, Los Alamos, New Mexico. Vadose Zone Journal.**
5. **2006 Mortandad Canyon Investigation Report. LA-UR-06-6752.**
6. **2011 Interim Facility-Wide Groundwater Monitoring Plan, Revision 1. LA-UR-11-6958.**

☐ Relevant portion attached.

☐ Previously submitted. Submittal date(s): _____

Attach any additional information available about ground water hydrology at the site.

C-8. Other Permitted Discharge Locations. If applicable, list other locations of wastewater or stormwater discharges on your site that are not described in this application and indicate what permits apply to them. Examples include discharges from small septic systems (covered by Liquid Waste Permits, discharges to surface waters under a NPDES permit, a discharge covered by a separate Discharge Permit, etc. Be sure these other discharge locations are identified on the site map required in Item B-3.

Discharge Type	Permit Identification
RLWTF (this application)	NPDES Permit No. NM028355 Outfall #051; GW Discharge Permit Application DP-1132
SWWS Plant	NPDES Permit No. NM028355 Outfall 13S; GW Discharge Permit DP-857
HEWTF	NPDES Permit No. NM028355 Outfall 05A055
Cooling Towers (7)	NPDES Permit No. NM028355 Outfalls 03A022, 03A027, 03A048, 03A113, 03A158, 03A160, 03A181
Power Plant	NPDES Permit No. NM028355 Outfall 001
Septic Systems (12)	GW Discharge Permit Application DP-1589
Stormwater from SWMUs	NPDES Individual Stormwater Permit NM0030759
Stormwater from Construction Sites	NPDES Stormwater Construction General Permit Program
Stormwater from Industrial Facilities	NPDES Stormwater Multi-Sector General Permit Program NMR05A734, NMR05A735

C-9. Other Information. Describe below or attach any additional information to demonstrate that your proposed discharge plan will be protective of ground water quality, public health and property.

APPENDIX A

LANL/NMED COMMUNICATIONS RE: DP-1132

TABLE OF CONTENTS

COPIES OF THE FOLLOWING LANL/NMED COMMUNICATIONS:

1. JANUARY 27, 2012, NMED LETTER RE: APPROVAL OF TIME EXTENSION TO SUBMIT APPLICATION, DP-1132, RADIOACTIVE LIQUID WASTE TREATMENT FACILITY (RLWTF)
2. JANUARY 17, 2012, LANL LETTER SUBJECT: REQUEST FOR CONSIDERATION OF SHORT TIME EXTENSION FOR SPECIFIC ITEMS FOR PERMIT APPLICATION DP-1132, RADIOACTIVE LIQUID WASTE TREATMENT FACILITY (RLWTF) AND ZERO LIQUID DISCHARGE EVAPORATIVE TANKS (ZLD)
3. DECEMBER 30, 2011, NMED LETTER RE: DENIAL OF TIME EXTENSION TO SUBMIT APPLICATION, DP-1132, RADIOACTIVE LIQUID WASTE TREATMENT FACILITY (RLWTF)
4. DECEMBER 7, 2011, LANL LETTER SUBJECT: REQUEST FOR AN EXTENSION TO SUBMIT AN UPDATED DISCHARGE PERMIT APPLICATION FOR THE RADIOACTIVE LIQUID WASTE TREATMENT FACILITY (DP-1132)
5. NOVEMBER 18, 2011, NMED LETTER RE: RESPONSE TO NOTICE OF INTENT TO DISCHARGE
6. AUGUST 11, 2011, LANL LETTER RE: SIXTY PERCENT DESIGN, EVAPORATION TANKS, TA-50 RADIOACTIVE LIQUID WASTE TREATMENT FACILITY
7. SEPTEMBER 15, 2008, LANL LETTER SUBJECT: REQUEST FOR ADDITIONAL INFORMATION, DP-1132, RADIOACTIVE LIQUID WASTE TREATMENT FACILITY
8. JUNE 11, 2008, NMED LETTER RE: REQUEST FOR ADDITIONAL INFORMATION, DP-1132, RADIOACTIVE LIQUID WASTE TREATMENT FACILITY
9. NOVEMBER 1, 2007, LANL LETTER SUBJECT: NOTICE OF INTENT TO DISCHARGE, EVAPORATION TANKS, TA-50 RADIOACTIVE LIQUID WASTE TREATMENT FACILITY

January 27, 2012, NMED Letter RE: Approval of Time Extension to Submit Application, DP-1132, Radioactive Liquid Waste Treatment Facility (RLWTF)

NEW MEXICO
ENVIRONMENT DEPARTMENT

Resource Protection Division

Harold Runnels Building
1190 Saint Francis Drive (87505)
P.O. Box 5469, Santa Fe, NM 87502-5469
Phone (505) 827-0419 Fax (505) 827-0310
www.nmenv.state.nm.us

SUSANA MARTINEZ
Governor
JOHN A. SANCHEZ
Lieutenant Governor

DAVE MARTIN
Cabinet Secretary
BUTCH TONGATE
Deputy Secretary
JAMES H. DAVIS, Ph.D.
Division Director

CERTIFIED MAIL – RETURN RECEIPT REQUESTED

January 27, 2012

Anthony R. Grieggs, Group Leader
Environmental Protection Division
Water Quality & RCRA (ENV-RCRA)
P.O. Box 1663, Mail Stop K490
Los Alamos, NM 87545

RE: Approval of Time Extension to Submit Application, DP-1132, Radioactive Liquid Waste Treatment Facility (RLWTF)

Dear Mr. Grieggs:

On November 18, 2011, the New Mexico Environment Department (NMED) notified Los Alamos National Laboratory (LANL), by certified mail (copy enclosed), that a complete and current Discharge Permit application for the RLWTF was required to be submitted within 90 days (by February 16, 2012). On December 9, 2011, NMED received your request for a 90-day time extension to submit the required Discharge Permit application, which was denied on December 30, 2012. A request for a 45-day extension for submittal of certain portions of the application was submitted to NMED, via e-mail on January 18, 2012 (copy enclosed). LANL may not discharge to the Zero Liquid Discharge Evaporative Tanks prior to NMED's approval which may be delayed due to the timeframe in which a full application for the RLWTF is received and reviewed by NMED. **NMED hereby approves a 45-day extension (due by April 1, 2012) to submit the three elements specifically referenced in LANL's letter dated January 17, 2012. All other elements for the Discharge Permit application are required to be submitted to NMED by February 16, 2012.**

If you have any questions regarding this matter, please contact Clint Marshall, Program Manager of the Ground Water Pollution Prevention Section, at 505-827-0027 or Jennifer Fullam at 505-827-2909.

Sincerely,

James H. Davis, Ph.D.
Director, Resource Protection Division

JD:JF

enc: Letter from NMED to LANL requiring Discharge Permit application, dated November 18, 2011
E-mail (dated January 18, 2012) from Bob Beers, LANL, with attachment (dated January 17, 2012) requesting extension

cc: James Bearzi, NMED SWQB (w/o enclosures)
Richard Powell, NMED SWQB (w/o enclosures)
John Kieling, NMED HWB (w/o enclosures)
Steven Yanicak, NMED-DOE-Oversight Bureau (w/o enclosures)
Hai Shen, LASO-EO, Los Alamos National Laboratory, A316, Los Alamos, NM 87545 (w/o enclosures)
Gene Turner, LASO-EO, Los Alamos National Laboratory, A316, Los Alamos, NM 87545 (w/o enclosures)
Michael T. Brandt, ADESH, Los Alamos National Laboratory, K491, Los Alamos, NM 87545 (w/o enclosures)
Carl A. Beard, PADOPS, Los Alamos National Laboratory, A102, Los Alamos, NM 87545 (w/o enclosures)
J. Chris Cantwell, ADESHQ, Los Alamos National Laboratory, K491, Los Alamos, NM 87545 (w/o enclosures)
Randy Johnson, ENV-ES, Los Alamos National Laboratory, E500, Los Alamos, NM 87545 (w/o enclosures)
Michael Saladen ENV-RCRA, Los Alamos National Laboratory, K490, Los Alamos, NM 87545 (w/o enclosures)
Robert Mason, TA-55-DO, Los Alamos National Laboratory, E583, Los Alamos, NM 87545 (w/o enclosures)
Hugh McGovern, TA-55-RLW, Los Alamos National Laboratory, E518, Los Alamos, NM 87545 (w/o enclosures)
Pete Worland, TA-55-RLW, Los Alamos National Laboratory, E518, Los Alamos, NM 87545 (w/o enclosures)

Susan L. McMichael, LC-LESH, Los Alamos National Laboratory, A187, Los Alamos, NM 87545 (w/o enclosures)

Bob Beers, ENV-RCRA, Los Alamos National Laboratory, K490, Los Alamos NM, 87545 (w/ enclosures)

Jon Block, Staff Attorney, New Mexico Environmental Law Center, 1405 Luisa Street, Ste. 5, Santa Fe, NM 87505(w/ enclosures)

Joni Arends, Executive Director, Concerned Citizens for Nuclear Safety, 107 Cienega Street, Santa, Fe, NM 87501(w/ enclosures)

January 17, 2012, LANL Letter Subject: Request For Consideration of Short Time Extension For Specific Items For Permit Application DP-1132, Radioactive Liquid Waste Treatment Facility (RLWTF) And Zero Liquid Discharge Evaporative Tanks (ZLD)

Environmental Safety & Health
Environmental Protection Division
P.O. Box 1663, K491
Los Alamos, New Mexico 87545
(505) 665-6952FAX (505) 665-3811

National Nuclear Security Administration
Los Alamos Site Office, A316
3747 West Jemez Road
Los Alamos, New Mexico 87545
(505) 667-5794/FAX (505) 667-5948

Date: January 17, 2012
Refer To: ENV-DO-12-0001
LAUR: 12-10069

Mr. James H. Davis, Director
Resource Protection Division
New Mexico Environment Department
Harold Runnels Building
1190 St. Francis Drive
P.O. Box 5469
Santa Fe, NM 87502-5469

Dear Mr. Davis:

SUBJECT: REQUEST FOR CONSIDERATION OF SHORT TIME EXTENSION FOR SPECIFIC ITEMS FOR PERMIT APPLICATION DP-1132, RADIOACTIVE LIQUID WASTE TREATMENT FACILITY (RLWTF) AND ZERO LIQUID DISCHARGE EVAPORATIVE TANKS (ZLD)

On January 3, 2012, the National Nuclear Security Administration (NNSA) and Los Alamos National Security, LLC (LANS) for the Los Alamos National Laboratory received your response denying our request to extend the deadline to submit a Discharge Permit (DP) application for the RLWTF and the proposed Zero Liquid Discharge Evaporative Tanks (ZLD). This request followed your November 19, 2011 letter requiring NNSA/LANS to submit a comprehensive and up-to-date permit DP application by February 16, 2012 for RLWTF, and to include the ZLD tanks in this application. NNSA/LANS fully supports your intent to advance the permit process, and recognize that submittal of the updated permit application is the first step towards timely permit review and issuance. With this in mind, we have thoroughly reviewed the detailed list of 19 items and the additional information required by the permit application in your November 19, 2011 letter. Our review has concluded that with additional resources and significant effort, we can commit to deliver the majority of the requested items by February 16, 2012. However, for the following reasons, we respectfully request that you consider providing us a short 45-day extension until April 3, 2012 to submit the following limited items described below:

- Proposed processes for the operation, inspection and maintenance for the facility as it pertains to collection lines, treatment units and effluent storage disposal units

05372

- Procedures and corrective actions for addressing acute failures and long-term maintenance issues at the facility
- Proposed groundwater monitoring locations for ground water sources most likely to be impacted by intentional and unintentional discharges from the RLWTF. The proposal should identify geohydrology of the potentially impacted areas, existing monitoring well locations and construction.

The above technical documents pertain to existing procedures for RLWTF which will require significant review and coordination among differing groups at the facility. Procedures for the planned ZLD tanks have not been developed. Construction of the ZLD tanks is estimated for the summer of 2012. Procedures will be available prior to operation of the ZLD system. Further, as a practical matter, these procedures must undergo LANL's unique institutional security review which requires final procedures to be submitted for review at least a week prior to public release. Additionally, we discussed with NMED staff the challenges of traditional groundwater monitoring approaches for the RLWTF and ZLD tanks in the context of the Laboratory's complex hydrogeology, and understand that an alternate approach to groundwater monitoring should be presented in the DP application. Development of this approach for inclusion into the application will require additional resources and time. We are hopeful that the additional requested time will enable us to submit a complete permit application, and will facilitate permit review and timely permit issuance.

Thank you for your consideration of our request. If you need additional information, feel free to contact Robert Beers, LANS at (505) 667-7969 or Gene Turner, NNSA at (505) 667-5794 if you need additional information concerning the status of the Laboratory's corrective action activities.

Sincerely,

Alison Dorries
Division Leader
Environmental Protection Division
Los Alamos National Laboratory

Sincerely,

Gene E. Turner
Environmental Permitting Manager
Environmental Projects Office
Los Alamos Site Office
National Nuclear Security Administration

AD:MS:GET/lm

Cy: Hai Shen, LASO-EO, A316
Gene Turner, LASO-EO, A316
Steve Yanicak, LASO-GOV, M894
Carl A. Beard, PADOPS, A102
Michael T. Brandt, ADESH, K491
Alison Dorries, ENV-DO, K491
Scotty Jones, ENV-DO, K491

Cy (continued):
Randy Johnson, ENV-ES, E500
Mike Saladen, ENV-RCRA, K490, (E-File)
Robert Beers, ENV-RCRA, K490
Robert C. Mason, TA-55-DO, E583
Clifford Kirkland, TA-55 RLW, E518
Chris Del Signore, TA-55-RLW, E518
Susan L. McMichael, LC-LESH, A187
Lisa Cummings, LASO-OC, A316
Jonathan M. Block, NMELC, Santa Fe, NM
Charles de Saillan, NMED, Santa Fe, NM
Taylor, Valdez, ENV-DO, K404, (E-File)
ENV-RCRA File, (12-0013) w/enc., M704
IRM-RMMSO, w/enc., A150

December 30, 2011, NMED Letter RE: Denial Of Time Extension To Submit Application, DP-1132, Radioactive Liquid Waste Treatment Facility (RLWTF)

NEW MEXICO
ENVIRONMENT DEPARTMENT

Resource Protection Division

Harold Runnels Building
1190 Saint Francis Drive (87505)
PO Box 5469, Santa Fe, NM 87502-5469
Phone (505) 827-2855 Fax (505) 827-2836
www.nmenv.state.nm.us
James H. Davis, Ph.D.

SUSANNA MARTINEZ
Governor
JOHN A. SANCHEZ
Lieutenant Governor

DAVE MARTIN
Cabinet Secretary
BUTCH TONGATE
Deputy Secretary
JAMES H. DAVIS, Ph.D.
Division Director

CERTIFIED MAIL – RETURN RECEIPT REQUESTED

December 30, 2011

Anthony R. Grieggs, Group Leader
Environmental Protection Division
Water Quality & RCRA (ENV-RCRA)
P.O. Box 1663, Mail Stop K490
Los Alamos, NM 87545

RE: Denial of Time Extension to Submit Application, DP-1132, Radioactive Liquid Waste Treatment Facility (RLWTF)

Dear Mr. Grieggs:

On November 18, 2011, the New Mexico Environment Department (NMED) notified Los Alamos National Laboratory (LANL), by certified mail (copy enclosed), that a complete and current Discharge Permit application for the RLWTF was required to be submitted within 90 days (by February 16, 2011). On December 9, 2011, NMED received your request for a time extension to complete the required Discharge Permit application (copy enclosed). NMED is determined to advance the permitting process in a timely manner. With that in mind, an extension of the deadline for the submission of an application would only prolong and perhaps inhibit the facility's ability to implement and discharge to the proposed Zero Liquid Discharge Evaporative Tanks (ZLD). **NMED therefore denies the time extension for submission of the Discharge Permit application.**

In order to effectively and efficiently process the Discharge Permit application, NMED provided a list of elements which should be included in the submittal. Mr. Robert Beers, with Los Alamos National Laboratory, has requested a meeting with NMED to discuss the specific elements in NMED's November 18, 2011 letter to ensure the application is submitted in its entirety and to prevent further delays in the permitting process. NMED remains committed to working with LANL to clarify the specific elements that must be addressed in the application and is planning to meet with LANL staff within the first two weeks of January. It is anticipated that the outcome of the technical discussion will provide constructive information which will advance the application process.

If you have any questions regarding this matter, please contact Clint Marshall, Acting Program Manager of the Ground Water Pollution Prevention Section, at 505-827-0027 or Jennifer Fullam at 505-827-2909.

Sincerely,

James H. Davis, Ph.D.
Director, Resource Protection Division

JD:JF

enc: Letter from NMED to LANL requiring Discharge Permit application, dated November 18, 2011
Letter from LANL to NMED requesting extension, dated December 9, 2011, NMED

cc: James Bearzi, NMED SWQB (w/o enclosures)
Richard Powell, NMED SWQB (w/o enclosures)
John Kieling, NMED HWB (w/o enclosures)
Steven Yanicak, NMED-DOE-Oversight Bureau (w/o enclosures)
Hai Shen, LASO-EO, Los Alamos National Laboratory, A316, Los Alamos, NM 87545 (w/o enclosures)
Gene Turner, LASO-EO, Los Alamos National Laboratory, A316, Los Alamos, NM 87545 (w/o enclosures)
Michael T. Brandt, ADESH, Los Alamos National Laboratory, K491, Los Alamos, NM 87545 (w/o enclosures)
Carl A. Beard, PADOPS, Los Alamos National Laboratory, A102, Los Alamos, NM 87545 (w/o enclosures)
J. Chris Cantwell, ADESHQ, Los Alamos National Laboratory, K491, Los Alamos, NM 87545 (w/o enclosures)
Randy Johnson, ENV-ES, Los Alamos National Laboratory, E500, Los Alamos, NM 87545 (w/o enclosures)
Michael Saladen ENV-RCRA, Los Alamos National Laboratory, K490, Los Alamos, NM 87545 (w/o enclosures)
Robert Mason, TA-55-DO, Los Alamos National Laboratory, E583, Los Alamos, NM 87545 (w/o enclosures)
Hugh McGovern, TA-55-RLW, Los Alamos National Laboratory, E518, Los Alamos, NM 87545 (w/o enclosures)
Pete Worland, TA-55-RLW, Los Alamos National Laboratory, E518, Los Alamos, NM 87545 (w/o enclosures)
Susan L. McMichael, LC-LESH, Los Alamos National Laboratory, A187, Los Alamos, NM 87545 (w/o enclosures)
Bob Beers, ENV-RCRA, Los Alamos National Laboratory, K490, Los Alamos NM, 87545 (w/ enclosures)

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RESOURCE PROTECTION DIVISION

Los Alamos
NATIONAL LABORATORY
EST 1943

Environmental Protection Division
Water Quality & RCRA Group (ENV-RCRA)
P.O. Box 1663, Mail Stop M704
Los Alamos, New Mexico 87545
(505) 667-0666/FAX: (505) 667-5224

Date: December 7, 2011
Refer To: ENV-RCRA-11-0270
LAUR: 11-12157

Mr. James H. Davis, Director
Resource Protection Division
New Mexico Environment Department
Harold Runnels Building
1190 St. Francis Drive
P.O. Box 5469
Santa Fe, NM 87502-5469

Dear Mr. Davis:

SUBJECT: REQUEST FOR AN EXTENSION TO SUBMIT AN UPDATED DISCHARGE PERMIT APPLICATION FOR THE RADIOACTIVE LIQUID WASTE TREATMENT FACILITY (DP-1132)

The US Department of Energy and Los Alamos National Security, LLC (DOE/LANS) are in receipt of your November 18, 2011, letter (Enclosure 1) requiring a comprehensive and up-to-date Discharge Permit application for the Radioactive Liquid Waste Treatment Facility (RLWTF) within 90 days of the letter's date (by February 16, 2012). For reasons explained below, DOE/LANS request an additional 90 days to prepare a Discharge Permit application for the RLWTF.

DOE/LANS have appreciated working with you and your staff on this matter. The goal is to submit a new Discharge Permit application for the RLWTF that is complete and satisfactory at the time of submittal. Addressing each of the 19 bullets listed in the above-referenced letter will require a significant level of effort by DOE/LANS technical staff. Further, the administrative record identified in the letter will need to be carefully reviewed, and supplemented as appropriate. Meetings between our respective representatives will be needed to ensure the information provided is responsive and focused correctly. For these reasons and because the Laboratory is closed during the holiday season, DOE/LANS respectfully request an extension of the application deadline to May 16, 2012.

Please contact Bob Beers at (505) 667-7969 if you have questions regarding this request.

Sincerely,

A R Grieggs

Anthony R. Grieggs
Group Leader
Water Quality & RCRA Group

Enclosures: a/s.

Cy: ✓Hai Shen, LASO-EO, A316
✓Gene Turner, LASO-EO, A316
✓Steve Yanicak, LASO-GOV, M894
✓Carl A. Beard, PADOPS, A102
✓Michael T. Brandt, ADESH, K491
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✓Robert C. Mason, TA55-DO, E583
✓Hugh McGovern, TA-55 RLW, E518
✓Pete Worland, TA-55-RLW, E518
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JAMES H. DAVIS, Ph.D.
Division Director

CERTIFIED MAIL – RETURN RECEIPT REQUESTED

November 18, 2011

U1102277

Anthony R. Grieggs, Group Leader
Environmental Protection Division
Water Quality & RCRA (ENV-RCRA)
P.O. Box 1663, Mail Stop K490
Los Alamos, NM 87545

RE: Response to Notice of Intent to Discharge and Discharge Permit Required for Zero Liquid Discharge Tanks, AI 856: PRD20070004 and Updated Application Submittal Required for the Radioactive Liquid Waste Treatment Facility (RLWTF), DP-1132

Dear Mr. Grieggs:

The Ground Water Quality Bureau of the New Mexico Environment Department (NMED) received a Notice of Intent from Los Alamos National Laboratory (LANL) on November 8, 2007 for the facility referenced above. NMED responded in writing with a request for additional information which required LANL to submit 60% plans and specifications for the proposed structure, information pertaining to ground water which may be impacted should a release occur, operation and maintenance procedures for the tanks, information on the potential concentration of the wastestream due to evaporation, and seismic studies for the area in which the tanks are to be constructed. NMED received a response to the requested information from LANL on September 15, 2008 which provided most of the requested information and stated that plans and specifications would be submitted once available. NMED received the plans and specifications for the evaporative tanks on August 19, 2011 along with an addendum dated October 19, 2011. The notice describes LANL's intent to discharge up to 3.6 million gallons annually of treated effluent from the RLWTF to two evaporative concrete tanks equipped with synthetic liners and leak detection systems. The total operating volume of the tanks is approximately 754,036 gallons (100,800 cubic feet). The notice, along with the subsequent information submitted upon NMED's request, satisfies the requirements of Subsection A of 20.6.2.1201 New Mexico Administrative Code (NMAC) of the New Mexico Water Quality Control Commission (WQCC) Regulations, 20.6.2 NMAC. The proposed discharge is located within the boundaries of Los Alamos National Laboratory at

35°51'37"N, 106°16'57"W, approximately 2.5 miles southeast of Los Alamos in Section 23, Township 19N, Range 06E, Los Alamos County.

NMED has reviewed the information provided in accordance with Subsection D of 20.6.2.1201 NMAC and because the proposed evaporative tanks contain an effluent or leachate which may move directly or indirectly into ground water, NMED has determined that **a Discharge Permit is required for the proposed discharge.** NMED considers the proposed evaporative tanks to be a component of the RLWTF, therefore they must be included in the Discharge Permit for this facility.

Any appeal of this determination that a Discharge Permit is required must be made to the New Mexico WQCC within 30 days of receipt of this letter, in accordance with Subsection B of 20.6.2.3112 NMAC. A copy of the WQCC Regulations, 20.6.2 NMAC, is available at http://www.nmcpr.state.nm.us/nmac/_title20/T20C006.htm.

Upon further review of the file for the RLWTF, NMED has noted the following:

- An application for a Discharge Permit was submitted to NMED on April 16, 1996 for the discharge of 41,770 gallons per day of treated low level radioactive wastewater from the RLWTF to a tributary of Mortandad Canyon (referred to as Effluent Canyon).
- The application identified potential upgrades to the system which were to enhance the treatment process and provide alternate discharge capabilities for the facility.
- The treated effluent from the RLWTF is currently authorized to be discharged to an outfall (Outfall 051) under a United States Environmental Protection Agency (EPA) National Pollutant Discharge Elimination System (NPDES) Permit (NM0028355) last issued on August 1, 2007, and subsequently modified on July 17, 2007, May 13, 2011, and October 11, 2011.
- Numerous Notices of Planned Changes have been submitted to EPA for treatment system upgrades and facility changes under the NPDES Permit for Outfall 051. Copies of these notices were submitted to NMED on the following dates: April 21, 1998, March 18, 1999, April 3, 2000, June 13, 2000, May 7, 2002, March 14, 2003, April 18, 2003, January 12, 2004, May 14, 2007, May 6, 2008, August 19, 2010, September 16, 2010, and February 23, 2011.
- In addition to the Notices of Planned Changes, numerous notices concerning minor modifications to the facility have been submitted to NMED as addendums to the original Discharge Permit application. NMED received copies of these submissions which were dated March 23, 1999, December 8, 2000, November 8, 2007, August 25, 2010, September 27, 2010, December 15, 2010, and March 22, 2011.
- NMED has engaged in numerous meetings, inspections and written correspondence regarding the RLWTF in order to compile accurate information on the facility in preparation for drafting a Discharge Permit that will accurately reflect the activities conducted at the RLWTF.
- In September 2003, a draft of Discharge Permit DP-1132 was sent to LANL which was subsequently Public Noticed on April 18, 2005, beginning a 30-day comment period.
- On April 27, 2005, in response to multiple requests from interested parties, a second public comment period was granted on the proposed Discharge Permit (extending the comment period for approximately 90 days, until August 4, 2005).

- NMED received comments and requests for a public hearing regarding the draft Discharge Permit from both interested parties and LANL.
- Through continued discussions with LANL, correspondence, site inspections and the above referenced Notice of Intent, it has become apparent that the facility has significantly modified treatment processes, discharge volumes and locations of the discharge when compared to the original application submitted to NMED on August 16, 1996.
- As it pertains to any future Discharge Permits to be issued by the NMED Ground Water Quality Bureau (GWQB), this *facility* has been determined to include the central influent collection lines leading to the RLWTF, all components which are part of the wastewater treatment process and all locations where the treated wastewater is disposed, including all surface discharges as well as non-surface discharges such as evaporative tanks (as described in the above referenced Notice of Intent). This determination by the NMED-GWQB is based on information provided in the original application for a Discharge Permit along with subsequent information provided to NMED by LANL.

Given the extensive and fractured exchange of information concerning this facility, along with changes at the RLWTF that have occurred during the lengthy permitting process and planned future changes, NMED views LANL's August 16, 1996 Discharge Permit application to be inconsistent with the current and planned discharge activities associated with the RLWTF. **Therefore, NMED requires that LANL submit a comprehensive and up-to-date Discharge Permit application for the RLWTF within 90 days of the date of this letter (by February 16, 2011).**

When submitted, the application (copy enclosed) should be completed in its entirety and specifically address the following:

- The estimated volumes, sources (technical area and building) and wastestream characteristics of all influent wastewater that LANL receives, or intends to receive, at the RLWTF.
- A description of the conveyance methods used to transport wastewater to the RLWTF for each source.
- A description of waste characterization and metering systems used to determine influent wastestream characteristics and volumes entering the RLWTF.
- A description of the review and amendment process for LANL's internal Waste Acceptance Criteria (WAC) for all incoming wastewater received at the RLWTF. This should include LANL's process for ensuring the WAC relates to the current treatment technologies and processes.
- A description of operational procedures for receiving wastes from each generator.
- A schematic of the treatment process in its entirety for each wastestream (from collection to final disposal).
- Descriptions, locations, construction materials and sizing for each component of the treatment processes for each type of wastestream being treated at the RLWTF.
- Descriptions, locations and designs for all secondary storage and auxillary emergency units intended to receive, treat or store wastewater received at the facility.
- Proposed processes for the operation, inspection and maintenance for the facility as it pertains to the collection lines, treatment units and effluent storage disposal units.
- Procedures and corrective actions for addressing acute failures at the facility.
- Procedures and corrective actions for addressing long-term maintenance issues at the facility.

- Record drawings for all components of the facility, if available.
- Construction plans and specifications for all components of the facility which are under construction or are proposed for construction.
- A proposed effluent monitoring plan, identifying analytes and sample locations/frequency. The proposal should consider discharge frequencies, incoming waste characteristics and the constituents listed under 20.6.2.3103 NMAC and Subsection WW of 20.6.2.7 NMAC.
- Proposed flow and metering systems used to determine effluent discharge volumes for each of the discharge locations.
- Proposed ground water monitoring locations for ground water sources most likely to be impacted by intentional and unintentional discharges from the RLWTF. The proposal should identify geohydrology of the potentially impacted areas, existing monitoring well locations and construction.
- Actions which LANL would implement should partial or full closure of the facility occur.
- A scaled facility plan showing the facility's components including influent collection lines, storage units, major treatment units and disposal units.
- All other information sought in NMED's application for Discharge Permit Sections A through C. Please note that for the purposes of public notification, the "discharge site" as it relates to this facility encompasses the central collection system lines, the treatment and storage facilities and all discharge locations for the treated effluent.

When submitting the comprehensive and up-to-date Discharge Permit application, you must complete and submit three copies along with the $100 filing fee.

If you have any questions, please contact either Jennifer Fullam at (505) 827-2909 or Clint Marshall, Acting Program Manager of the Ground Water Pollution Prevention Section, at (505) 827-0027.

Sincerely,

James H. Davis, Ph.D.
Director, Resource Protection Division

JD:JF

Enc: Applying for a Discharge Permit: General Information
Discharge Permit Application

cc: Robert Italiano, District Manager, NMED District II (w/o enclosures)
NMED Santa Fe Field Office (w/o enclosures)
DP Required File (w/o enclosures)
James Bearzi, NMED SWQB (w/o enclosures)
Richard Powell, NMED SWQB (w/o enclosures)
John Kieling, NMED HWB (w/o enclosures)
Steven Yanicak, NMED-DOE-Oversight Bureau (w/o enclosures)

Hai Shen, LASO-EO, Los Alamos National Laboratory, A316, Los Alamos, NM 87545 (w/o enclosures)

Gene Turner, LASO-EO, Los Alamos National Laboratory, A316, Los Alamos, NM 87545 (w/o enclosures)

Eric Trujillo, LASO-NSM, Los Alamos National Laboratory, A316, Los Alamos, NM 87545 (w/o enclosures)

Carl A. Beard, PADOPS, Los Alamos National Laboratory, A102, Los Alamos, NM 87545 (w/o enclosures)

J. Chris Cantwell, ADESHQ, Los Alamos National Laboratory, K491, Los Alamos, NM 87545 (w/o enclosures)

Randy Johnson, ENV-ES, Los Alamos National Laboratory, E500, Los Alamos, NM 87545 (w/o enclosures)

Michael Saladen ENV-RCRA, Los Alamos National Laboratory, K490, Los Alamos, NM 87545 (w/o enclosures)

Robert Mason, TA-55-DO, Los Alamos National Laboratory, E583, Los Alamos, NM 87545 (w/o enclosures)

Hugh McGovern, TA-55-RLW, Los Alamos National Laboratory, E518, Los Alamos, NM 87545 (w/o enclosures)

Pete Worland, TA-55-RLW, Los Alamos National Laboratory, E518, Los Alamos, NM 87545 (w/o enclosures)

Keith Orr, PMF-FUNCT, Los Alamos National Laboratory, M984, Los Alamos, NM 87545 (w/o enclosures)

Roy Maestas, CM-STRS, Los Alamos National Laboratory, P299, Los Alamos, NM 87545 (w/o enclosures)

Joe Brophy, PMF-FUNCT Los Alamos National Laboratory, P137, Los Alamos, NM 87545 (w/o enclosures)

Ed Artiglia, ES-PE, Los Alamos National Laboratory, P137, Los Alamos, NM 87545 (w/o enclosures)

Bob Beers, ENV-RCRA, Los Alamos National Laboratory, K490, Los Alamos NM, 87545 (w/ enclosures)

December 7, 2011, LANL Letter Subject: Request For An Extension To Submit An Updated Discharge Permit Application For The Radioactive Liquid Waste Treatment Facility (DP-1132)

Los Alamos
NATIONAL LABORATORY
EST. 1943

Environmental Protection Division
Water Quality & RCRA Group (ENV-RCRA)
P.O. Box 1663, Mail Stop M704
Los Alamos, New Mexico 87545
(505) 667-0666/FAX: (505) 667-5224

Date: December 7, 2011
Refer To: ENV-RCRA-11-0270
LAUR: 11-12157

Mr. James H. Davis, Director
Resource Protection Division
New Mexico Environment Department
Harold Runnels Building
1190 St. Francis Drive
P.O. Box 5469
Santa Fe, NM 87502-5469

Dear Mr. Davis:

SUBJECT: REQUEST FOR AN EXTENSION TO SUBMIT AN UPDATED DISCHARGE PERMIT APPLICATION FOR THE RADIOACTIVE LIQUID WASTE TREATMENT FACILITY (DP-1132)

The US Department of Energy and Los Alamos National Security, LLC (DOE/LANS) are in receipt of your November 18, 2011, letter (Enclosure 1) requiring a comprehensive and up-to-date Discharge Permit application for the Radioactive Liquid Waste Treatment Facility (RLWTF) within 90 days of the letter's date (by February 16, 2012). For reasons explained below, DOE/LANS request an additional 90 days to prepare a Discharge Permit application for the RLWTF.

DOE/LANS have appreciated working with you and your staff on this matter. The goal is to submit a new Discharge Permit application for the RLWTF that is complete and satisfactory at the time of submittal. Addressing each of the 19 bullets listed in the above-referenced letter will require a significant level of effort by DOE/LANS technical staff. Further, the administrative record identified in the letter will need to be carefully reviewed, and supplemented as appropriate. Meetings between our respective representatives will be needed to ensure the information provided is responsive and focused correctly. For these reasons and because the Laboratory is closed during the holiday season, DOE/LANS respectfully request an extension of the application deadline to May 16, 2012.

Please contact Bob Beers at (505) 667-7969 if you have questions regarding this request.

Sincerely,

A R Grieggs

Anthony R. Grieggs
Group Leader
Water Quality & RCRA Group

Enclosures: a/s

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Gene Turner, LASO-EO, A316
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NEW MEXICO
ENVIRONMENT DEPARTMENT

Resource Protection Division

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Division Director

CERTIFIED MAIL – RETURN RECEIPT REQUESTED

November 18, 2011

U1102277
IRM RMMSO Record Copy

Anthony R. Grieggs, Group Leader
Environmental Protection Division
Water Quality & RCRA (ENV-RCRA)
P.O. Box 1663, Mail Stop K490
Los Alamos, NM 87545

RE: Response to Notice of Intent to Discharge and Discharge Permit Required for Zero Liquid Discharge Tanks, AI 856: PRD20070004 and Updated Application Submittal Required for the Radioactive Liquid Waste Treatment Facility (RLWTF), DP-1132

Dear Mr. Grieggs:

The Ground Water Quality Bureau of the New Mexico Environment Department (NMED) received a Notice of Intent from Los Alamos National Laboratory (LANL) on November 8, 2007 for the facility referenced above. NMED responded in writing with a request for additional information which required LANL to submit 60% plans and specifications for the proposed structure, information pertaining to ground water which may be impacted should a release occur, operation and maintenance procedures for the tanks, information on the potential concentration of the wastestream due to evaporation, and seismic studies for the area in which the tanks are to be constructed. NMED received a response to the requested information from LANL on September 15, 2008 which provided most of the requested information and stated that plans and specifications would be submitted once available. NMED received the plans and specifications for the evaporative tanks on August 19, 2011 along with an addendum dated October 19, 2011. The notice describes LANL's intent to discharge up to 3.6 million gallons annually of treated effluent from the RLWTF to two evaporative concrete tanks equipped with synthetic liners and leak detection systems. The total operating volume of the tanks is approximately 754,036 gallons (100,800 cubic feet). The notice, along with the subsequent information submitted upon NMED's request, satisfies the requirements of Subsection A of 20.6.2.1201 New Mexico Administrative Code (NMAC) of the New Mexico Water Quality Control Commission (WQCC) Regulations, 20.6.2 NMAC. The proposed discharge is located within the boundaries of Los Alamos National Laboratory at

35°51'37"N, 106°16'57"W, approximately 2.5 miles southeast of Los Alamos in Section 23, Township 19N, Range 06E, Los Alamos County.

NMED has reviewed the information provided in accordance with Subsection D of 20.6.2.1201 NMAC and because the proposed evaporative tanks contain an effluent or leachate which may move directly or indirectly into ground water, NMED has determined that **a Discharge Permit is required for the proposed discharge.** NMED considers the proposed evaporative tanks to be a component of the RLWTF, therefore they must be included in the Discharge Permit for this facility.

Any appeal of this determination that a Discharge Permit is required must be made to the New Mexico WQCC within 30 days of receipt of this letter, in accordance with Subsection B of 20.6.2.3112 NMAC. A copy of the WQCC Regulations, 20.6.2 NMAC, is available at http://www.nmcpr.state.nm.us/nmac/_title20/T20C006.htm.

Upon further review of the file for the RLWTF, NMED has noted the following:

- An application for a Discharge Permit was submitted to NMED on April 16, 1996 for the discharge of 41,770 gallons per day of treated low level radioactive wastewater from the RLWTF to a tributary of Mortandad Canyon (referred to as Effluent Canyon).
- The application identified potential upgrades to the system which were to enhance the treatment process and provide alternate discharge capabilities for the facility.
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- Numerous Notices of Planned Changes have been submitted to EPA for treatment system upgrades and facility changes under the NPDES Permit for Outfall 051. Copies of these notices were submitted to NMED on the following dates: April 21, 1998, March 18, 1999, April 3, 2000, June 13, 2000, May 7, 2002, March 14, 2003, April 18, 2003, January 12, 2004, May 14, 2007, May 6, 2008, August 19, 2010, September 16, 2010, and February 23, 2011.
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- Through continued discussions with LANL, correspondence, site inspections and the above referenced Notice of Intent, it has become apparent that the facility has significantly modified treatment processes, discharge volumes and locations of the discharge when compared to the original application submitted to NMED on August 16, 1996.
- As it pertains to any future Discharge Permits to be issued by the NMED Ground Water Quality Bureau (GWQB), this *facility* has been determined to include the central influent collection lines leading to the RLWTF, all components which are part of the wastewater treatment process and all locations where the treated wastewater is disposed, including all surface discharges as well as non-surface discharges such as evaporative tanks (as described in the above referenced Notice of Intent). This determination by the NMED-GWQB is based on information provided in the original application for a Discharge Permit along with subsequent information provided to NMED by LANL.

Given the extensive and fractured exchange of information concerning this facility, along with changes at the RLWTF that have occurred during the lengthy permitting process and planned future changes, NMED views LANL's August 16, 1996 Discharge Permit application to be inconsistent with the current and planned discharge activities associated with the RLWTF. **Therefore, NMED requires that LANL submit a comprehensive and up-to-date Discharge Permit application for the RLWTF within 90 days of the date of this letter (by February 16, 2011).**

When submitted, the application (copy enclosed) should be completed in its entirety and specifically address the following:

- The estimated volumes, sources (technical area and building) and wastestream characteristics of all influent wastewater that LANL receives, or intends to receive, at the RLWTF.
- A description of the conveyance methods used to transport wastewater to the RLWTF for each source.
- A description of waste characterization and metering systems used to determine influent wastestream characteristics and volumes entering the RLWTF.
- A description of the review and amendment process for LANL's internal Waste Acceptance Criteria (WAC) for all incoming wastewater received at the RLWTF. This should include LANL's process for ensuring the WAC relates to the current treatment technologies and processes.
- A description of operational procedures for receiving wastes from each generator.
- A schematic of the treatment process in its entirety for each wastestream (from collection to final disposal).
- Descriptions, locations, construction materials and sizing for each component of the treatment processes for each type of wastestream being treated at the RLWTF.
- Descriptions, locations and designs for all secondary storage and auxillary emergency units intended to receive, treat or store wastewater received at the facility.
- Proposed processes for the operation, inspection and maintenance for the facility as it pertains to the collection lines, treatment units and effluent storage disposal units.
- Procedures and corrective actions for addressing acute failures at the facility.
- Procedures and corrective actions for addressing long-term maintenance issues at the facility.

- Record drawings for all components of the facility, if available.
- Construction plans and specifications for all components of the facility which are under construction or are proposed for construction.
- A proposed effluent monitoring plan, identifying analytes and sample locations/frequency. The proposal should consider discharge frequencies, incoming waste characteristics and the constituents listed under 20.6.2.3103 NMAC and Subsection WW of 20.6.2.7 NMAC.
- Proposed flow and metering systems used to determine effluent discharge volumes for each of the discharge locations.
- Proposed ground water monitoring locations for ground water sources most likely to be impacted by intentional and unintentional discharges from the RLWTF. The proposal should identify geohydrology of the potentially impacted areas, existing monitoring well locations and construction.
- Actions which LANL would implement should partial or full closure of the facility occur.
- A scaled facility plan showing the facility's components including influent collection lines, storage units, major treatment units and disposal units.
- All other information sought in NMED's application for Discharge Permit Sections A through C. Please note that for the purposes of public notification, the "discharge site" as it relates to this facility encompasses the central collection system lines, the treatment and storage facilities and all discharge locations for the treated effluent.

When submitting the comprehensive and up-to-date Discharge Permit application, you must complete and submit three copies along with the $100 filing fee.

If you have any questions, please contact either Jennifer Fullam at (505) 827-2909 or Clint Marshall, Acting Program Manager of the Ground Water Pollution Prevention Section, at (505) 827-0027.

Sincerely,

James H. Davis, Ph.D.
Director, Resource Protection Division

JD:JF

Enc: Applying for a Discharge Permit: General Information
Discharge Permit Application

cc: Robert Italiano, District Manager, NMED District II (w/o enclosures)
NMED Santa Fe Field Office (w/o enclosures)
DP Required File (w/o enclosures)
James Bearzi, NMED SWQB (w/o enclosures)
Richard Powell, NMED SWQB (w/o enclosures)
John Kieling, NMED HWB (w/o enclosures)
Steven Yanicak, NMED-DOE-Oversight Bureau (w/o enclosures)

Hai Shen, LASO-EO, Los Alamos National Laboratory, A316, Los Alamos, NM 87545 (w/o enclosures)

Gene Turner, LASO-EO, Los Alamos National Laboratory, A316, Los Alamos, NM 87545 (w/o enclosures)

Eric Trujillo, LASO-NSM, Los Alamos National Laboratory, A316, Los Alamos, NM 87545 (w/o enclosures)

Carl A. Beard, PADOPS, Los Alamos National Laboratory, A102, Los Alamos, NM 87545 (w/o enclosures)

J. Chris Cantwell, ADESHQ, Los Alamos National Laboratory, K491, Los Alamos, NM 87545 (w/o enclosures)

Randy Johnson, ENV-ES, Los Alamos National Laboratory, E500, Los Alamos, NM 87545 (w/o enclosures)

Michael Saladen ENV-RCRA, Los Alamos National Laboratory, K490, Los Alamos, NM 87545 (w/o enclosures)

Robert Mason, TA-55-DO, Los Alamos National Laboratory, E583, Los Alamos, NM 87545 (w/o enclosures)

Hugh McGovern, TA-55-RLW, Los Alamos National Laboratory, E518, Los Alamos, NM 87545 (w/o enclosures)

Pete Worland, TA-55-RLW, Los Alamos National Laboratory, E518, Los Alamos, NM 87545 (w/o enclosures)

Keith Orr, PMF-FUNCT, Los Alamos National Laboratory, M984, Los Alamos, NM 87545 (w/o enclosures)

Roy Maestas, CM-STRS, Los Alamos National Laboratory, P299, Los Alamos, NM 87545 (w/o enclosures)

Joe Brophy, PMF-FUNCT Los Alamos National Laboratory, P137, Los Alamos, NM 87545 (w/o enclosures)

Ed Artiglia, ES-PE, Los Alamos National Laboratory, P137, Los Alamos, NM 87545 (w/o enclosures)

Bob Beers, ENV-RCRA, Los Alamos National Laboratory, K490, Los Alamos NM, 87545 (w/ enclosures)

External Correspondence Traveler

Los Alamos NATIONAL LABORATORY EST. 1943

Document Identification				
ESH&Q. #:		Enclosures:	Attachments:	LAUR No.
ENV-Group:	ENV-RCRA	Yes: ☐	Yes: ☐	11-12157
Doc. #:	11-0270	No: ☐	No: ☐	
Is this a response to an action item		Yes: ☐	No: ☐	
Email ☐ Memo ☐ Letter ☐		Document Date:	12/02/2011	
		Due Date:	N/A	

To:	Jim Davis
Subject:	Request for an Extension to Submit an Updated Discharge Permit Application for the Radioactive Liquid Waste Treatment Facility (DP-1132)
Action:	
Background / Issues	On November 18, 2011, the NMED requested a new Discharge Permit application from LANL for the TA-50 RLWTF. The NMED asked for the application within 90 days of the date of the letter; accordingly, the application deadline is February 16, 2012. Due to the complexity and scope of the application, and the upcoming holiday season, it will be difficult for LANL to submit a complete application by February 16, 2012. The attached letter is a request for a 90-day extension until May 16, 2012.

			Date
From (Ghost Writer)	Bob Beers	RBB	12/8/11
Author	Anthony R. Greiggs	ARG	12/8/11
Group Leader	Anthony R. Grieggs		
Deputy Group Leader	Tina Marie Sandoval	—	
Division Leader	Dennis L. Hjeresen	N/A	
ADC Review			
DUSA / SAFE-7			
LC-LESH Review	Susan McMichael	SMM 12/8/11 8:45	
Coordinated with Facility or Program	Hugh McGovern Gene Turner — verbal OK, Mike Saladen	12/2/11 @ 2:45 PSG 12/8/11	
Comments:	By COB 12/9/11		

Hand Deliver: ☑ **Express Mail:** ☐ **FedEX:** ☐ **CRRR:** ☐ **Regular Mail Service:** ☐

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Distribution to IRM-RMMSO, A150:		**Date:** 12/8/11	
Time: 9:20	**Date:** 12/8/11	EFile sent to WD Team	

November 18, 2011, NMED Letter RE: Response to Notice of Intent To Discharge

NEW MEXICO
ENVIRONMENT DEPARTMENT

Resource Protection Division

Harold Runnels Building
1190 Saint Francis Drive (87505)
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James H. Davis, Ph.D.

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Lieutenant Governor

DAVE MARTIN
Cabinet Secretary
BUTCH TONGATE
Deputy Secretary
JAMES H. DAVIS, Ph.D.
Division Director

CERTIFIED MAIL – RETURN RECEIPT REQUESTED

November 18, 2011

U1102277
IRM RMMSO Record Copy

Anthony R. Grieggs, Group Leader
Environmental Protection Division
Water Quality & RCRA (ENV-RCRA)
P.O. Box 1663, Mail Stop K490
Los Alamos, NM 87545

RE: Response to Notice of Intent to Discharge and Discharge Permit Required for Zero Liquid Discharge Tanks, AI 856: PRD20070004 and Updated Application Submittal Required for the Radioactive Liquid Waste Treatment Facility (RLWTF), DP-1132

Dear Mr. Grieggs:

The Ground Water Quality Bureau of the New Mexico Environment Department (NMED) received a Notice of Intent from Los Alamos National Laboratory (LANL) on November 8, 2007 for the facility referenced above. NMED responded in writing with a request for additional information which required LANL to submit 60% plans and specifications for the proposed structure, information pertaining to ground water which may be impacted should a release occur, operation and maintenance procedures for the tanks, information on the potential concentration of the wastestream due to evaporation, and seismic studies for the area in which the tanks are to be constructed. NMED received a response to the requested information from LANL on September 15, 2008 which provided most of the requested information and stated that plans and specifications would be submitted once available. NMED received the plans and specifications for the evaporative tanks on August 19, 2011 along with an addendum dated October 19, 2011. The notice describes LANL's intent to discharge up to 3.6 million gallons annually of treated effluent from the RLWTF to two evaporative concrete tanks equipped with synthetic liners and leak detection systems. The total operating volume of the tanks is approximately 754,036 gallons (100,800 cubic feet). The notice, along with the subsequent information submitted upon NMED's request, satisfies the requirements of Subsection A of 20.6.2.1201 New Mexico Administrative Code (NMAC) of the New Mexico Water Quality Control Commission (WQCC) Regulations, 20.6.2 NMAC. The proposed discharge is located within the boundaries of Los Alamos National Laboratory at

35°51'37"N, 106°16'57"W, approximately 2.5 miles southeast of Los Alamos in Section 23, Township 19N, Range 06E, Los Alamos County.

NMED has reviewed the information provided in accordance with Subsection D of 20.6.2.1201 NMAC and because the proposed evaporative tanks contain an effluent or leachate which may move directly or indirectly into ground water, NMED has determined that **a Discharge Permit is required for the proposed discharge.** NMED considers the proposed evaporative tanks to be a component of the RLWTF, therefore they must be included in the Discharge Permit for this facility.

Any appeal of this determination that a Discharge Permit is required must be made to the New Mexico WQCC within 30 days of receipt of this letter, in accordance with Subsection B of 20.6.2.3112 NMAC. A copy of the WQCC Regulations, 20.6.2 NMAC, is available at http://www.nmcpr.state.nm.us/nmac/_title20/T20C006.htm.

Upon further review of the file for the RLWTF, NMED has noted the following:

- An application for a Discharge Permit was submitted to NMED on April 16, 1996 for the discharge of 41,770 gallons per day of treated low level radioactive wastewater from the RLWTF to a tributary of Mortandad Canyon (referred to as Effluent Canyon).
- The application identified potential upgrades to the system which were to enhance the treatment process and provide alternate discharge capabilities for the facility.
- The treated effluent from the RLWTF is currently authorized to be discharged to an outfall (Outfall 051) under a United States Environmental Protection Agency (EPA) National Pollutant Discharge Elimination System (NPDES) Permit (NM0028355) last issued on August 1, 2007, and subsequently modified on July 17, 2007, May 13, 2011, and October 11, 2011.
- Numerous Notices of Planned Changes have been submitted to EPA for treatment system upgrades and facility changes under the NPDES Permit for Outfall 051. Copies of these notices were submitted to NMED on the following dates: April 21, 1998, March 18, 1999, April 3, 2000, June 13, 2000, May 7, 2002, March 14, 2003, April 18, 2003, January 12, 2004, May 14, 2007, May 6, 2008, August 19, 2010, September 16, 2010, and February 23, 2011.
- In addition to the Notices of Planned Changes, numerous notices concerning minor modifications to the facility have been submitted to NMED as addendums to the original Discharge Permit application. NMED received copies of these submissions which were dated March 23, 1999, December 8, 2000, November 8, 2007, August 25, 2010, September 27, 2010, December 15, 2010, and March 22, 2011.
- NMED has engaged in numerous meetings, inspections and written correspondence regarding the RLWTF in order to compile accurate information on the facility in preparation for drafting a Discharge Permit that will accurately reflect the activities conducted at the RLWTF.
- In September 2003, a draft of Discharge Permit DP-1132 was sent to LANL which was subsequently Public Noticed on April 18, 2005, beginning a 30-day comment period.
- On April 27, 2005, in response to multiple requests from interested parties, a second public comment period was granted on the proposed Discharge Permit (extending the comment period for approximately 90 days, until August 4, 2005).

- NMED received comments and requests for a public hearing regarding the draft Discharge Permit from both interested parties and LANL.
- Through continued discussions with LANL, correspondence, site inspections and the above referenced Notice of Intent, it has become apparent that the facility has significantly modified treatment processes, discharge volumes and locations of the discharge when compared to the original application submitted to NMED on August 16, 1996.
- As it pertains to any future Discharge Permits to be issued by the NMED Ground Water Quality Bureau (GWQB), this *facility* has been determined to include the central influent collection lines leading to the RLWTF, all components which are part of the wastewater treatment process and all locations where the treated wastewater is disposed, including all surface discharges as well as non-surface discharges such as evaporative tanks (as described in the above referenced Notice of Intent). This determination by the NMED-GWQB is based on information provided in the original application for a Discharge Permit along with subsequent information provided to NMED by LANL.

Given the extensive and fractured exchange of information concerning this facility, along with changes at the RLWTF that have occurred during the lengthy permitting process and planned future changes, NMED views LANL's August 16, 1996 Discharge Permit application to be inconsistent with the current and planned discharge activities associated with the RLWTF. **Therefore, NMED requires that LANL submit a comprehensive and up-to-date Discharge Permit application for the RLWTF within 90 days of the date of this letter (by February 16, 2011).**

When submitted, the application (copy enclosed) should be completed in its entirety and specifically address the following:

- The estimated volumes, sources (technical area and building) and wastestream characteristics of all influent wastewater that LANL receives, or intends to receive, at the RLWTF.
- A description of the conveyance methods used to transport wastewater to the RLWTF for each source.
- A description of waste characterization and metering systems used to determine influent wastestream characteristics and volumes entering the RLWTF.
- A description of the review and amendment process for LANL's internal Waste Acceptance Criteria (WAC) for all incoming wastewater received at the RLWTF. This should include LANL's process for ensuring the WAC relates to the current treatment technologies and processes.
- A description of operational procedures for receiving wastes from each generator.
- A schematic of the treatment process in its entirety for each wastestream (from collection to final disposal).
- Descriptions, locations, construction materials and sizing for each component of the treatment processes for each type of wastestream being treated at the RLWTF.
- Descriptions, locations and designs for all secondary storage and auxillary emergency units intended to receive, treat or store wastewater received at the facility.
- Proposed processes for the operation, inspection and maintenance for the facility as it pertains to the collection lines, treatment units and effluent storage disposal units.
- Procedures and corrective actions for addressing acute failures at the facility.
- Procedures and corrective actions for addressing long-term maintenance issues at the facility.

- Record drawings for all components of the facility, if available.
- Construction plans and specifications for all components of the facility which are under construction or are proposed for construction.
- A proposed effluent monitoring plan, identifying analytes and sample locations/frequency. The proposal should consider discharge frequencies, incoming waste characteristics and the constituents listed under 20.6.2.3103 NMAC and Subsection WW of 20.6.2.7 NMAC.
- Proposed flow and metering systems used to determine effluent discharge volumes for each of the discharge locations.
- Proposed ground water monitoring locations for ground water sources most likely to be impacted by intentional and unintentional discharges from the RLWTF. The proposal should identify geohydrology of the potentially impacted areas, existing monitoring well locations and construction.
- Actions which LANL would implement should partial or full closure of the facility occur.
- A scaled facility plan showing the facility's components including influent collection lines, storage units, major treatment units and disposal units.
- All other information sought in NMED's application for Discharge Permit Sections A through C. Please note that for the purposes of public notification, the "discharge site" as it relates to this facility encompasses the central collection system lines, the treatment and storage facilities and all discharge locations for the treated effluent.

When submitting the comprehensive and up-to-date Discharge Permit application, you must complete and submit three copies along with the $100 filing fee.

If you have any questions, please contact either Jennifer Fullam at (505) 827-2909 or Clint Marshall, Acting Program Manager of the Ground Water Pollution Prevention Section, at (505) 827-0027.

Sincerely,

James H. Davis, Ph.D.
Director, Resource Protection Division

JD:JF

Enc: Applying for a Discharge Permit: General Information
Discharge Permit Application

cc: Robert Italiano, District Manager, NMED District II (w/o enclosures)
NMED Santa Fe Field Office (w/o enclosures)
DP Required File (w/o enclosures)
James Bearzi, NMED SWQB (w/o enclosures)
Richard Powell, NMED SWQB (w/o enclosures)
John Kieling, NMED HWB (w/o enclosures)
Steven Yanicak, NMED-DOE-Oversight Bureau (w/o enclosures)

August 11, 2011, LANL Letter RE: Sixty Percent Design, Evaporation Tanks, TA-50 Radioactive Liquid Waste Treatment Facility

Los Alamos
NATIONAL LABORATORY
EST. 1943

Environmental Protection Division
Water Quality & RCRA Group (ENV-RCRA)
P.O. Box 1663, K490
Los Alamos, New Mexico 87545
(505) 667-0666/FAX (505) 667-5224

National Nuclear Security Administration
Los Alamos Site Office, A316
3747 West Jemez Road
Los Alamos, New Mexico 87545
(505) 667-5794/FAX (505) 667-5948

Date: August 11, 2011
Refer To: ENV-RCRA-11-0136
LAUR: 11-11041

Mr. Jerry Schoeppner, Acting Chief
Ground Water Quality Bureau
New Mexico Environment Department
Harold Runnels Building, Room N2250
1190 St. Francis Drive
P.O. Box 26110
Santa Fe, NM 87502

Dear Mr. Schoeppner:

SUBJECT: SIXTY PERCENT DESIGN, EVAPORATION TANKS, TA- 50 RADIOACTIVE LIQUID WASTE TREATMENT FACILITY

In November 2007, Los Alamos National Laboratory (the Laboratory) submitted a notice of intent (NOI) to the New Mexico Environment Department (NMED) to discharge treated effluent from the Technical Area 50 (TA-50) Radioactive Liquid Waste Treatment Facility (RLWTF) to three proposed aboveground evaporation tanks. On June 11, 2008, the NMED replied to the Laboratory's NOI with a request for additional information on six items (Enclosure 1). In the Laboratory's September 15, 2008, reply (Enclosure 2), all six items were addressed except for item 1, listed below:

1. *Submit 60% complete plans and specifications of the facility. Include detailed information regarding the construction of the evaporation tanks.*

The lack of project funding over the past several years has delayed design and construction of the evaporation tanks. The 60% design package was finally completed on July 28, 2011, and is now available for your review. Enclosure 3 contains a compact disc (CD) with the 60% complete plans and specifications for the construction of two (2) aboveground evaporation tanks. The third tank originally proposed has been dropped from the design. The mesa top location at TA-52 has not changed.

Given the design (concrete walls and floor with two synthetic liners and leak detection alarms) and the depth to groundwater (1260 ft), no reasonable potential exists that liquid in the evaporation tanks will move directly or indirectly into groundwater. Therefore, the evaporation tanks are not subject to the permitting requirement of 20.6.2.3104 and 3106 NMAC. Further, even if discharges to the evaporation tanks were considered a discharge subject to the permitting requirements of 20.6.2.3104 and 3106 NMAC, the effluent meets all of the listed numerical standards of 20.6.2.3103 NMAC, has a total nitrogen concentration of 10 mg/L or less, does not contain any toxic pollutant, and is therefore exempt from the permitting requirements under 20.6.2.3105.A NMAC.

Because of the accelerated design and construction schedule for this project, the Laboratory respectfully requests that the NMED review the enclosed plans and specifications and determine that no discharge permit is required. At your request and convenience, Laboratory engineers familiar with the enclosed design are available to meet with you and your staff to answer questions.

Please contact Bob Beers at (505) 667-7969 of the Water Quality and RCRA Group (ENV-RCRA) if you have questions.

Sincerely,

Anthony R. Grieggs
Group Leader
Water Quality & RCRA Group
Los Alamos National Laboratory

Sincerely,

Gene E. Turner
Environmental Permitting Manager
Environmental Projects Office
Los Alamos Site Office
National Nuclear Security Administration

ARG:GET:BB/lm

Enclosures: a/s

Cy: Hai Shen, LASO-EO, w/o enc., A316
Gene Turner, LASO-EO, w/o enc., A316
Eric Trujillo, LASO-NSM, w/o enc., A316
Steve Yanicak, LASO-GOV, w/o enc., M894
Carl A. Beard, PADOPS, w/o enc., A102
J. Chris Cantwell, ADESHQ, w/o enc., K491
Randy Johnson, ENV-ES, w/o enc., E500
Mike Saladen, ENV-RCRA, w/o enc., K490, (E-File)
Robert Mason, TA-55-DO, w/o enc., E583
Hugh McGovern, TA-55 RLW, w/o enc., E518
Pete Worland, TA-55-RLW, w/o enc., E518
Keith Orr, PMF-FUNCT, w/o enc., M984

Cy (continued):
Roy Maestas, CM-STRS, w/o enc., P299
Joe Brophy, PMF-FUNCT, w/o enc., P137
Ed Artiglia, ES-PE, w/o enc., P137
ENV-RCRA File, w/enc., K490
IRM-RMMSO, w/enc., A150

NEW MEXICO
ENVIRONMENT DEPARTMENT

Ground Water Quality Bureau

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RON CURRY
Secretary
JON GOLDSTEIN
Deputy Secretary

CERTIFIED MAIL – RETURN RECEIPT REQUESTED

June 11, 2008

Anthony R. Grieggs, Group Leader
Environmental Protection Division
Water Quality & RCRA (ENV-RCRA)
P.O. Box 1663, Mail Stop K490
Los Alamos, NM 87545

RE: Request for Additional Information, DP-1132, Radioactive Liquid Waste Treatment Facility

Dear Mr. Grieggs:

The New Mexico Environment Department (NMED) received a ground water Discharge Permit application from you on April 16, 1996 for the above referenced facility and a Notice of Intent for the discharge of effluent water to evaporative tanks (zero liquid discharge facility) on November 8, 2007. The application proposes the discharge of up to 3.6 million gallons per year of industrial wastewater.

NMED has reviewed the Notice of Intent in accordance with the New Mexico Water Quality Control Commission Regulations (20.6.2 NMAC). The following additional information is necessary in order for NMED to determine if the zero liquid discharge facility will require a New Mexico Environment Department Ground Water Discharge Permit:

1. Submit 60% complete plans and specifications of the facility. Include detailed information regarding the construction of the evaporation tanks.

2. Submit information regarding ground water near the facility that is most likely to be impacted should a release occur. This should include the most shallow aquifers located down gradient of the facility prior to the Rio Grande.

3. Submit procedures for the operation and maintenance of the evaporation tanks. Please include estimated cleaning timelines and methodologies.

4. Submit information on the concentration of waste in the tanks due to evaporation.

5. Submit seismic studies conducted in accordance to 40 CFR § 264.18 (a)

Following submission of the requested additional information, NMED will act upon your Notice of Intent to discharge. Your cooperation is appreciated. If you have any questions, you may reach me at (505) 827-2909.

Sincerely,

Jennifer Fullam
Environmental Scientist
Ground Water Pollution Prevention Section

cc: James Bearzi, NMED Hazardous Waste Bureau
John Young, NMED Hazardous Waste Bureau
Marcy Leavitt, NMED SWQB
Ralph Ford-Schmidt, NMED-DOE Oversight Bureau
Bob Beers, Environmental Protection Division, Water Quality & RCRA Ground , P.O. Box 1663, Mail Stop K490, Los Alamos, New Mexico 87545
Mike Saladen, ENV-RCRA, Los Alamos National Laboratory, K490, Los Alamos, NM 87545 (W/O enclosure)

Los Alamos
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Environmental Protection Division
Water Quality & RCRA (ENV-RCRA)
P.O. Box 1663, Mail Stop K490
Los Alamos, New Mexico 87545
(505) 667-7969/FAX: (505) 665-9344

Date: September 15, 2008
Refer To: ENV-RCRA-08-169
LA-UR: 08-04520

Ms. Jennifer Fullam
Ground Water Pollution Prevention Section
Ground Water Quality Bureau
New Mexico Environment Department
Harold Runnels Building, Room N2261
1190 St. Francis Drive
P.O. Box 26110
Santa Fe, NM 87502

Dear Ms. Fullam:

SUBJECT: REQUEST FOR ADDITIONAL INFORMATION, DP-1132, RADIOACTIVE LIQUID WASTE TREATMENT FACILITY

I have received your June 11, 2008, letter (Enclosure 1) requesting additional information for Los Alamos National Laboratory's November 8, 2007, Notice of Intent (NOI) for the discharge of treated effluent from the TA-50 Radioactive Liquid Waste Treatment Facility (RLWTF) to proposed evaporation tanks. I have listed each of your requests below, along with the Laboratory's response.

1. *Submit 60% complete plans and specifications of the facility. Include detailed information regarding the construction of the evaporation tanks.*

As the Laboratory indicated in the November 8, 2007, NOI, detailed plans and specifications for the evaporation tanks will be submitted to your agency once they become available. To date, no contract has been signed by the Laboratory for the final design of the evaporation tanks.

2. *Submit information regarding ground water near the facility that is most likely to be impacted should a release occur. This should include the most shallow aquifers located down gradient of the facility prior to the Rio Grande.*

The proposed site is a mesa top location at Technical Area (TA)-52. The approximate elevation of the proposed site is 7160 ft above mean sea level (MSL). Two regional aquifer wells are located within approximately 1500 ft of the proposed site: Los Alamos County water supply well PM-5 (7095 ft above MSL), and the Laboratory's regional aquifer monitoring well R-14 (7062 ft above MSL).

The static water level at both PM-5 and R-14 is approximately 5900 ft above MSL; this places the depth of the regional aquifer at the proposed project site at approximately 1260 ft below ground surface (bgs). No perched zone of saturation was encountered during drilling at R-14 (*Hydrologic Tests at Characterization Well R-14*, LA-14107MS, August 2004). In 2008, a new regional aquifer monitoring well will be installed on the mesa top in the vicinity of the evaporation tanks. The well, R-46, will be sited downgradient of Material Disposal Area (MDA) C and upgradient of water supply well PM-5 to ensure the safety of the supplied water.

Given the depth to ground water at the proposed project site (1260 ft bgs), the potential for impact to groundwater, should a release occur, is low. The nearest shallow aquifer (alluvial) is in Mortandad Canyon, approximately one mile away via the Ten Site Canyon watercourse. The depth to alluvial ground water in Mortandad Canyon at the Ten Site Canyon confluence is approximately 40 ft.

3. *Submit procedures for the operation and maintenance of the evaporation tanks. Please include estimated cleaning timelines and methodologies.*

In accordance with Laboratory requirements, a Standard Operating Procedure (SOP) will be prepared before the evaporation tanks are placed into service. The SOP will provide detailed instructions for the operation and maintenance of the facility. A copy of the SOP will be submitted to your agency once it is available for release.

4. *Submit information on the concentration of waste in the tanks due to evaporation.*

Treated effluent discharged to the evaporation tanks from the TA-50 RLWTF will have a composition of approximately 99.95 percent water and 0.05 percent solids; product from the reverse osmosis (RO) treatment unit has, on average, a Total Dissolved Solids (TDS) concentration of less than 500 mg/L (0.05 percent solids). Airborne dust and dirt blowing into the tanks will be the primary source of solids. When solids are removed from the tank, they will be characterized and managed in accordance with the applicable waste management requirements.

5. *Submit seismic studies conducted in accordance with 40 CFR § 264.18 (a).*

Conducting seismic studies in accordance to 40 CFR § 264.18 (a) is not a requirement of the New Mexico Water Quality Control Commission (NM WQCC) regulations. The proposed evaporation tanks will receive treated effluent from the TA-50 RLWTF. The tanks are therefore exempt from RCRA requirements as part of a Clean Water Act (CWA) wastewater treatment facility permitted by the Environmental Protection Agency (EPA) under NPDES Permit No. NM0028355. The specifications package that you will receive as part of the project's final design (see request #1) will include the seismic standards used in the engineering design of the evaporation tanks.

Please contact Bob Beers (505-667-7969) if you have any questions or need any additional information.

Sincerely,

A R Grieggs

Anthony R. Grieggs, Group Leader
Water Quality & RCRA Group (ENV-RCRA)

BB/lm

Enclosure: a/s

Cy: William Olson, NMED/GWQB, w/enc, Santa Fe, NM
Robert George, NMED/GWQB, w/enc, Santa Fe, NM
Glenn Saums, NMED/SWQB, w/enc, Santa Fe, NM
James Bearzi, NMED/HWB, w/enc, Santa Fe, NM
Steve Yanicak, NMED/OB/LASO, w/enc, J993
Hai Shen, LASO/EO, w/enc, A316
Gene Turner, LASO/EO, w/enc, A316
Michael Mallory, PADOPS, w/enc, A102
Richard S. Watkins, ADESHQ, w/enc, K491
Susan G. Stiger, ADEP, w/enc, M991
Mike Saladen, ENV-RCRA, w/enc, K490
Bob Beers, ENV-RCRA, w/enc, K490
Peter J. Rice, STO-DO, w/enc, E518
Craig Douglass, RLW, w/enc, E518
Pete Worland, EWMO-RLW, w/enc, E518
Edward Artiglia, ES-PE, w/enc, P137
Phil Wardwell, LC-LESH, w/enc, A187
Ellen Louderbough, LC-LESH, w/enc, A187
Keith R. Orr, PP-WEP, w/enc, P137
ENV-DO File, w/enc., J978
ENV-RCRA, File, w/enc., K490
IRM-RMMSO, w/enc., A150

September 15, 2008, LANL Letter Subject: Request For Additional Information, DP-1132, Radioactive Liquid Waste Treatment Facility

Los Alamos
NATIONAL LABORATORY
EST. 1943

Environmental Protection Division
Water Quality & RCRA (ENV-RCRA)
P.O. Box 1663, Mail Stop K490
Los Alamos, New Mexico 87545
(505) 667-7969/FAX: (505) 665-9344

Date: September 15, 2008
Refer To: ENV-RCRA-08-169
LA-UR: 08-04520

Ms. Jennifer Fullam
Ground Water Pollution Prevention Section
Ground Water Quality Bureau
New Mexico Environment Department
Harold Runnels Building, Room N2261
1190 St. Francis Drive
P.O. Box 26110
Santa Fe, NM 87502

Dear Ms. Fullam:

SUBJECT: REQUEST FOR ADDITIONAL INFORMATION, DP-1132, RADIOACTIVE LIQUID WASTE TREATMENT FACILITY

I have received your June 11, 2008, letter (Enclosure 1) requesting additional information for Los Alamos National Laboratory's November 8, 2007, Notice of Intent (NOI) for the discharge of treated effluent from the TA-50 Radioactive Liquid Waste Treatment Facility (RLWTF) to proposed evaporation tanks. I have listed each of your requests below, along with the Laboratory's response.

1. *Submit 60% complete plans and specifications of the facility. Include detailed information regarding the construction of the evaporation tanks.*

As the Laboratory indicated in the November 8, 2007, NOI, detailed plans and specifications for the evaporation tanks will be submitted to your agency once they become available. To date, no contract has been signed by the Laboratory for the final design of the evaporation tanks.

2. *Submit information regarding ground water near the facility that is most likely to be impacted should a release occur. This should include the most shallow aquifers located down gradient of the facility prior to the Rio Grande.*

The proposed site is a mesa top location at Technical Area (TA)-52. The approximate elevation of the proposed site is 7160 ft above mean sea level (MSL). Two regional aquifer wells are located within approximately 1500 ft of the proposed site: Los Alamos County water supply well PM-5 (7095 ft above MSL), and the Laboratory's regional aquifer monitoring well R-14 (7062 ft above MSL).

The static water level at both PM-5 and R-14 is approximately 5900 ft above MSL; this places the depth of the regional aquifer at the proposed project site at approximately 1260 ft below ground surface (bgs). No perched zone of saturation was encountered during drilling at R-14 (*Hydrologic Tests at Characterization Well R-14*, LA-14107MS, August 2004). In 2008, a new regional aquifer monitoring well will be installed on the mesa top in the vicinity of the evaporation tanks. The well, R-46, will be sited downgradient of Material Disposal Area (MDA) C and upgradient of water supply well PM-5 to ensure the safety of the supplied water.

Given the depth to ground water at the proposed project site (1260 ft bgs), the potential for impact to groundwater, should a release occur, is low. The nearest shallow aquifer (alluvial) is in Mortandad Canyon, approximately one mile away via the Ten Site Canyon watercourse. The depth to alluvial ground water in Mortandad Canyon at the Ten Site Canyon confluence is approximately 40 ft.

3. *Submit procedures for the operation and maintenance of the evaporation tanks. Please include estimated cleaning timelines and methodologies.*

In accordance with Laboratory requirements, a Standard Operating Procedure (SOP) will be prepared before the evaporation tanks are placed into service. The SOP will provide detailed instructions for the operation and maintenance of the facility. A copy of the SOP will be submitted to your agency once it is available for release.

4. *Submit information on the concentration of waste in the tanks due to evaporation.*

Treated effluent discharged to the evaporation tanks from the TA-50 RLWTF will have a composition of approximately 99.95 percent water and 0.05 percent solids; product from the reverse osmosis (RO) treatment unit has, on average, a Total Dissolved Solids (TDS) concentration of less than 500 mg/L (0.05 percent solids). Airborne dust and dirt blowing into the tanks will be the primary source of solids. When solids are removed from the tank, they will be characterized and managed in accordance with the applicable waste management requirements.

5. *Submit seismic studies conducted in accordance with 40 CFR § 264.18 (a).*

Conducting seismic studies in accordance to 40 CFR § 264.18 (a) is not a requirement of the New Mexico Water Quality Control Commission (NM WQCC) regulations. The proposed evaporation tanks will receive treated effluent from the TA-50 RLWTF. The tanks are therefore exempt from RCRA requirements as part of a Clean Water Act (CWA) wastewater treatment facility permitted by the Environmental Protection Agency (EPA) under NPDES Permit No. NM0028355. The specifications package that you will receive as part of the project's final design (see request #1) will include the seismic standards used in the engineering design of the evaporation tanks.

: 05410

Please contact Bob Beers (505-667-7969) if you have any questions or need any additional information.

Sincerely,

A R Grieggs

Anthony R. Grieggs, Group Leader
Water Quality & RCRA Group (ENV-RCRA)

BB/lm

Enclosure: a/s

Cy: William Olson, NMED/GWQB, w/enc, Santa Fe, NM
Robert George, NMED/GWQB, w/enc, Santa Fe, NM
Glenn Saums, NMED/SWQB, w/enc, Santa Fe, NM
James Bearzi, NMED/HWB, w/enc, Santa Fe, NM
Steve Yanicak, NMED/OB/LASO, w/enc, J993
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Bob Beers, ENV-RCRA, w/enc, K490
Peter J. Rice, STO-DO, w/enc, E518
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Keith R. Orr, PP-WEP, w/enc, P137
ENV-DO File, w/enc., J978
ENV-RCRA, File, w/enc., K490
IRM-RMMSO, w/enc., A150

ENCLOSURE 1

: 05412

NEW MEXICO
ENVIRONMENT DEPARTMENT

Ground Water Quality Bureau

1190 St. Francis Drive
P.O. Box 26110, Santa Fe, NM 87502
Phone (505) 827-2918 Fax (505) 827-2965
www.nmenv.state.nm.us

BILL RICHARDSON
Governor
DIANE DENISH
Lieutenant Governor

RON CURRY
Secretary
JON GOLDSTEIN
Deputy Secretary

CERTIFIED MAIL – RETURN RECEIPT REQUESTED

June 11, 2008

Anthony R. Grieggs, Group Leader
Environmental Protection Division
Water Quality & RCRA (ENV-RCRA)
P.O. Box 1663, Mail Stop K490
Los Alamos, NM 87545

RE: Request for Additional Information, DP-1132, Radioactive Liquid Waste Treatment Facility

Dear Mr. Grieggs:

The New Mexico Environment Department (NMED) received a ground water Discharge Permit application from you on April 16, 1996 for the above referenced facility and a Notice of Intent for the discharge of effluent water to evaporative tanks (zero liquid discharge facility) on November 8, 2007. The application proposes the discharge of up to 3.6 million gallons per year of industrial wastewater.

NMED has reviewed the Notice of Intent in accordance with the New Mexico Water Quality Control Commission Regulations (20.6.2 NMAC). The following additional information is necessary in order for NMED to determine if the zero liquid discharge facility will require a New Mexico Environment Department Ground Water Discharge Permit:

1. Submit 60% complete plans and specifications of the facility. Include detailed information regarding the construction of the evaporation tanks.

2. Submit information regarding ground water near the facility that is most likely to be impacted should a release occur. This should include the most shallow aquifers located down gradient of the facility prior to the Rio Grande.

3. Submit procedures for the operation and maintenance of the evaporation tanks. Please include estimated cleaning timelines and methodologies.

4. Submit information on the concentration of waste in the tanks due to evaporation.

5. Submit seismic studies conducted in accordance to 40 CFR § 264.18 (a)

Following submission of the requested additional information, NMED will act upon your Notice of Intent to discharge. Your cooperation is appreciated. If you have any questions, you may reach me at (505) 827-2909.

Sincerely,

Jennifer Fullam
Environmental Scientist
Ground Water Pollution Prevention Section

cc: James Bearzi, NMED Hazardous Waste Bureau
John Young, NMED Hazardous Waste Bureau
Marcy Leavitt, NMED SWQB
Ralph Ford-Schmidt, NMED-DOE Oversight Bureau
Bob Beers, Environmental Protection Division, Water Quality & RCRA Ground , P.O. Box 1663, Mail Stop K490, Los Alamos, New Mexico 87545
Mike Saladen, ENV-RCRA, Los Alamos National Laboratory, K490, Los Alamos, NM 87545 (W/O enclosure)

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4. Submit information on the concentration of waste in the tanks due to evaporation.

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Sincerely,

Jennifer Fullam
Environmental Scientist
Ground Water Pollution Prevention Section

cc: James Bearzi, NMED Hazardous Waste Bureau
John Young, NMED Hazardous Waste Bureau
Marcy Leavitt, NMED SWQB
Ralph Ford-Schmidt, NMED-DOE Oversight Bureau
Bob Beers, Environmental Protection Division, Water Quality & RCRA Ground , P.O. Box 1663, Mail Stop K490, Los Alamos, New Mexico 87545
Mike Saladen, ENV-RCRA, Los Alamos National Laboratory, K490, Los Alamos, NM 87545 (W/O enclosure)

June 11, 2008, NMED Letter RE: Request For Additional Information, DP-1132, Radioactive Liquid Waste Treatment Facility

NEW MEXICO
ENVIRONMENT DEPARTMENT

Ground Water Quality Bureau

1190 St. Francis Drive
P.O. Box 26110, Santa Fe, NM 87502
Phone (505) 827-2918 Fax (505) 827-2965
www.nmenv.state.nm.us

BILL RICHARDSON
Governor
DIANE DENISH
Lieutenant Governor

RON CURRY
Secretary
JON GOLDSTEIN
Deputy Secretary

GW_00118

CERTIFIED MAIL – RETURN RECEIPT REQUESTED

June 11, 2008

Anthony R. Grieggs, Group Leader
Environmental Protection Division
Water Quality & RCRA (ENV-RCRA)
P.O. Box 1663, Mail Stop K490
Los Alamos, NM 87545

RE: Request for Additional Information, DP-1132, Radioactive Liquid Waste Treatment Facility

Dear Mr. Grieggs:

The New Mexico Environment Department (NMED) received a ground water Discharge Permit application from you on April 16, 1996 for the above referenced facility and a Notice of Intent for the discharge of effluent water to evaporative tanks (zero liquid discharge facility) on November 8, 2007. The application proposes the discharge of up to 3.6 million gallons per year of industrial wastewater.

NMED has reviewed the Notice of Intent in accordance with the New Mexico Water Quality Control Commission Regulations (20.6.2 NMAC). The following additional information is necessary in order for NMED to determine if the zero liquid discharge facility will require a New Mexico Environment Department Ground Water Discharge Permit:

1. Submit 60% complete plans and specifications of the facility. Include detailed information regarding the construction of the evaporation tanks.

2. Submit information regarding ground water near the facility that is most likely to be impacted should a release occur. This should include the most shallow aquifers located down gradient of the facility prior to the Rio Grande.

3. Submit procedures for the operation and maintenance of the evaporation tanks. Please include estimated cleaning timelines and methodologies.

4. Submit information on the concentration of waste in the tanks due to evaporation.

5. Submit seismic studies conducted in accordance to 40 CFR § 264.18 (a)

Following submission of the requested additional information, NMED will act upon your Notice of Intent to discharge. Your cooperation is appreciated. If you have any questions, you may reach me at (505) 827-2909.

Sincerely,

Jennifer Fullam
Environmental Scientist
Ground Water Pollution Prevention Section

cc: James Bearzi, NMED Hazardous Waste Bureau
John Young, NMED Hazardous Waste Bureau
Marcy Leavitt, NMED SWQB
Ralph Ford-Schmidt, NMED-DOE Oversight Bureau
Bob Beers, Environmental Protection Division, Water Quality & RCRA Ground , P.O. Box 1663, Mail Stop K490, Los Alamos, New Mexico 87545
Mike Saladen, ENV-RCRA, Los Alamos National Laboratory, K490, Los Alamos, NM 87545 (W/O enclosure)

November 1, 2007, LANL Letter Subject: Notice Of Intent To Discharge, Evaporation Tanks, TA-50 Radioactive Liquid Waste Treatment Facility

GW_00185

Los Alamos
NATIONAL LABORATORY
EST.1943

Environmental Protection Division
Water Quality & RCRA (ENV-RCRA)
P.O. Box 1663, Mail Stop K490
Los Alamos, New Mexico 87545
(505) 667-0666/FAX: (505) 667-5224

Date: November 1, 2007
Refer To: ENV-RCRA: 07-184
LA-UR: 07-4794

Mr. William C. Olson
Ground Water Quality Bureau
New Mexico Environment Department
P.O. Box 26110
Santa Fe, NM 87502-6110

Mr. James Bearzi
Hazardous Waste Bureau
New Mexico Environment Department
2905 Rodeo Park Drive East, Bldg. 1
Santa Fe, NM 87505-6313

SUBJECT: NOTICE OF INTENT TO DISCHARGE, EVAPORATION TANKS, TA-50 RADIOACTIVE LIQUID WASTE TREATMENT FACILITY

Dear Mr. Olson and Mr. Bearzi:

This letter and enclosures constitute a Notice of Intent (NOI) to discharge pursuant to 20.6.2.1201 NMAC regarding Los Alamos National Laboratory's (Laboratory) plan to construct three evaporation tanks. The above-ground tanks would receive part or all of the treated effluent from the Laboratory's TA-50 Radioactive Liquid Waste Treatment Facility (RLWTF). The evaporation of treated effluent at these tanks would significantly reduce or, at times, eliminate discharges at NPDES Outfall 051. The RLWTF discharge is into Mortandad Canyon, pursuant to NPDES Permit NM0028355. It is the Laboratory's view that a groundwater discharge permit will not be required for this project because there is no reasonable probability or likelihood that liquid contained in the evaporation tanks will move into groundwater, either through a leak or by overflow. Additional information is presented below and in the following enclosures:

- Enclosure 1.0 is a completed NMED-Ground Water Quality Bureau NOI form.
- Enclosure 2.0 is a preliminary location map.
- Enclosure 3.0, per your agency's request, is the Laboratory's analysis of the applicability of the Wastewater Treatment Unit (WWTU) exemption under the federal RCRA regulations for those facilities regulated under the federal CWA.
- Enclosure 4.0 is EPA FAXBACK #13526, January 16, 1992.
- Enclosure 5.0 is Federal Register Vol. 61, No. 68, *Land Disposal Restrictions Phase III—Decharacterization Wastewaters, Carbamate Wastes, and Spent Potliners* (40 CFR Parts 148, 268, 271, and 403); specifically relevant to this NOI are pages 15569 to 15574 containing land disposal restrictions applicable to zero dischargers.

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Enclosure 4.0 states that the primary reason of the wastewater treatment exemption is to avoid imposing duplicative requirements pursuant to both a NPDES permit and a RCRA permit for the same unit. The FAXBACK also defines the requirements that must be met for the WWTU exemption to apply.

Enclosure 5.0 is an EPA preamble dealing with Land Disposal Restrictions, which we are providing in response to questions from Steve Pullen. Any material removed from the evaporation tanks during cleaning will be characterized and managed appropriately. Further, Section III.A. of the Federal Register in Enclosure 5.0 states that land disposal treatment standards apply only to the following types of facilities:

"(1) facilities treating formerly characteristic wastes in surface impoundments whose ultimate discharge is subject to regulation under either section 402 or 307 of the CWA." The ZLD evaporation tanks at LANL will meet the definition of a tank or tank system in 40 CFR §260.10, they are not surface impoundments; thus, the tanks are not within the first type of facility to which land disposal requirements apply.

"(2) permitted and unpermitted zero dischargers engaging in treatment that is equivalent to that of the CWA-regulated facilities (see 40 CFR 268.37(a) defining CWA-equivalent treatment), including facilities treating formerly characteristic waste in tanks prior to release on the land for such purposes as irrigation or land treatment." The proposed ZLD tanks will not release effluent on the land for such purposes as irrigation or land treatment. In addition, the proposed ZLD tanks will not conduct treatment that meets the description of CWA-equivalent treatment[1], therefore, land disposal regulations do not apply to the evaporation tanks under these criteria either. This Federal Register further clarifies that the treatment standards do not apply to facilities that discharge to navigable water or POTWs or that manage decharacterized waste in treatment systems without surface impoundments.

Conceptual Tank Design

Each of the three evaporation tanks will have an area of approximately 0.7 to 1.0 acres providing a total evaporation area of 2.1 to 3.0 acres. The total depth of each basin will be approximately 4 ft. Multiple modeling scenarios using conservative input parameters show that the actual operating depth will range from approximately 1.4 to 2.2 ft depending upon the volume of effluent discharged to the tanks, precipitation, and the final tank sizes selected; these operating depths will provide a minimum freeboard of approximately 1.8 ft. The tanks will be constructed with reinforced-concrete walls and floors, and with the water surface open to the atmosphere. The concrete tanks will be sealed with a curing compound and all joints will be watertight. A liner system will be installed in each concrete tank consisting of primary and secondary geomembrane liners separated by a geosynthetic drainage material for leak detection. The wall of the tanks will be self-supporting. Depth to regional groundwater at the project site is approximately 1260 ft.

[1] CWA-equivalent treatment means biological treatment for organics, alkaline chlorination or ferrous sulfate precipitation of cyanide, precipitation/sedimentation for metals, reduction of hexavalent chromium, or other treatment technology that can be demonstrated to perform equally or greater than these technologies.

Quality of Effluent

All effluent discharged to the evaporation tanks will be fully treated by RLWTF treatment operations and will comply with all applicable NPDES permit limits and all of the listed numerical standards of 20.6.2.3103 NMAC. Effluent discharged to the evaporation tanks will receive the same level of treatment and will be of equal quality to that effluent discharged to Mortandad Canyon at NPDES Outfall 051. The quality of the RLWTF's effluent is routinely reported to the NMED through the following documents:

1. NPDES Monthly Discharge Monitoring Reports (DMRs) submitted to NMED, Surface Water Quality Bureau;
2. RLWTF Annual Operating Reports submitted to the NMED, Ground Water Quality Bureau (the 2006 RLWTF Annual Report was submitted on June 11, 2007; ENV-RCRA: 07-0135, LA-UR-07-3447); and
3. DP-1132 quarterly monitoring reports submitted to the NMED, Ground Water Quality Bureau.

For the reasons indicated above, no groundwater permit is required. As explained above, there is no reasonable probability that liquid in the evaporation tanks will move directly or indirectly into groundwater [*See* Amended Final Order, In the Matter of: No Discharge Plan Required McKinley Paper Co. (July 13, 1993) (determining no discharge permit required for discharges to closed-loop, zero discharge system comprised of U-drains, lift stations and piping)]. Further, even if the discharges to the tanks were considered a discharge subject to the permitting requirements of 20.6.2.3104 NMAC, as discussed above, the effluent meets all of the listed numerical standards of 20.6.2.3103 NMAC, has a total nitrogen concentration of 10 mg/L or less, does not contain any toxic pollutant, and is therefore exempt from the permitting requirements under 20.2.3105.A NMAC.

We are sending this NOI well in advance of beginning construction as we want to complete all regulatory requirements in a timely fashion. Detailed plans and specifications will be submitted to your agency once they become available.

This letter is not intended to fully answer to the information requested in the October 26, 2007, letter from James Bearzi to Donald L. Winchell and Richard S. Watkins regarding the exemption status of the TA-50 RLWTF. The response to that letter will be forthcoming under separate cover.

We look forward to receiving your response to this NOI and position paper. Please contact Bob Beers (505-667-7969) if you have any questions or need any additional information.

Sincerely,

A. R. Grieggs

Anthony R. Grieggs
Group Leader
Water Quality & RCRA (ENV-RCRA) Group
ARG:BB/lm

ARG:BB/lm

Enclosures: a/s

Cy: Tracy Hughes, NMED OGC, Santa Fe, NM
Marcy Leavitt, NMED SWQB, Santa Fe, NM
George Schuman, NMED GWQB, Santa Fe, NM
Robert George, NMED GWQB, Santa Fe, NM
Jake Knutson, NMED GWQB, Santa Fe, NM
John Young, NMED HWB, Santa Fe, NM
Steve Pullen, NMED HWB, Santa Fe, NM
Dave Cobrain, NMED HWB, Santa Fe, NM
Lisa Cummings, NNSA/LASO, MS A316
George Rael, LASO/EO, MS A316
Gene Turner, LASO/EO, MS A316
Michael B. Mallory, PADOPS, MS A102
Richard S. Watkins, ADESHQ, MS K491
Tori George, ENV-DO, MS J978
Mike Saladen, ENV-RCRA, MS K490
Bob Beers, ENV-RCRA, MS K490
Holly Wheeler-Benson, ENV-RCRA, MS K490
Marc Bailey, ENV-RCRA, MS K490
Pete Worland, EWMO-RLW, MS E518
Ed Artiglia, PE-DO, MS E554
Craig Douglas, RLW, MS E0518
Phil Wardwell, LC-LESH, MS A187
ADESHQ Files, MS K491
LC Fileroom, MS A187
LC/LESH File, MS A187
ENV-RCRA File, MS K490
IRM-RMMSO, MS A150

ENCLOSURE 1.0

New Mexico Environment Department
Ground Water Quality Bureau

Ground Water Quality Bureau – Pollution Prevention Section Notice of Intent

1. Name and Address of person making discharge:

Los Alamos National Laboratory
Attn: Bob Beers
P.O. Box 1663, Mail Stop K490
Los Alamos, NM 87545

Phone: 505-667-7969 (office)
505-665-9344 (fax)

2. Location of discharge (give township, range, section, ¼ section, miles from closest town and street address, if applicable):

Los Alamos National Laboratory
Technical Area (TA)-52. See Enclosure 2.0.
35° 51' 37"N, 106° 16' 57"W (NAD27), USGS Frijoles (NM) Quadrangle

3. Type of operation generating the discharge:

Treated effluent evaporation tanks (3)

4. Description of the source of the discharge:

Treated effluent from TA-50 RLWTF treatment unit operations

5. Estimated concentration of contaminants in the discharge:

Effluent quality is documented in the following reports submitted to the NMED in 2006-07:

- NPDES Monthly Discharge Monitoring Reports (DMRs) submitted to NMED, Surface Water Quality Bureau,
- RLWTF Annual Operating Reports submitted to the NMED, Ground Water Quality Bureau (the 2006 RLWTF Annual Report was submitted on June 11, 2007; ENV-RCRA: 07-0135, LA-UR-07-3447), and
- DP-1132 quarterly monitoring reports submitted to the NMED, Ground Water Quality Bureau.

6. Means of the discharge (to a lagoon, watercourse, septic tank/leachfield, etc.):

Treated effluent will be transferred from the TA-50 RLWTF to the evaporation tanks via a pipeline.

7. Estimated daily flow rate of the discharge:

Evaporation Tanks Design Basis: 13.6 million liters per year (3.6 million gallons per year).

8. Estimated depth to ground water:

Approximately 1260 ft to regional ground water.

Signature: A R Grieggs **Title:** Group Leader

Printed name: Anthony R. Grieggs **Date:** 11/2/07

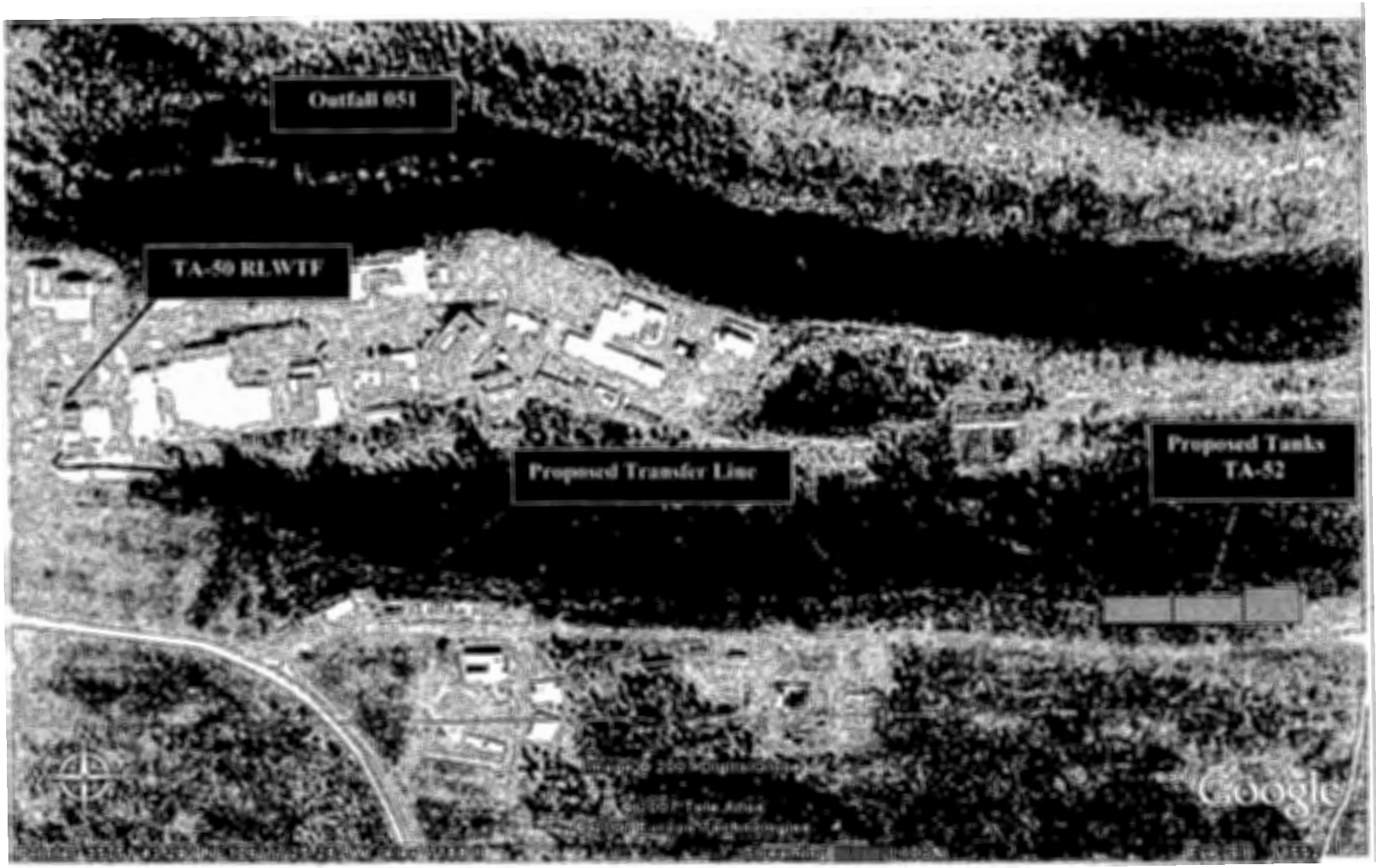
Providing additional information such as maps, plans and specifications, laboratory analyses, and/or a detailed description of the discharge will help NMED to process this NOI in a more timely manner. Please return this form to:

NMED Ground Water Quality Bureau
P.O. Box 26110
Santa Fe, New Mexico 87502

Telephone: 505-827-2900
Fax: 505-827-2965

ENC URE 2.0

NPDES PERMIT NO. NM0028355
Proposed RLWTF Effluent Evaporation Tanks
LA-UR-07-4794



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ENCLOSURE 3.0

Position Paper

TA-50 RLWTF Zero Liquid Discharge Evaporation Tanks

Under Los Alamos National Laboratory's NPDES Permit No. NM0028355, the TA-50 Radioactive Liquid Waste Treatment Facility (RLWTF) discharges treated effluent from Outfall 051 to Mortandad Canyon. Permit conditions, including effluent limitations and monitoring requirements, for Outfall 051 can be viewed online at http://www.lanl.gov/environment/h2o/docs/NM0028355_LANL_NPDES2007.pdf. The proposed change to the RLWTF includes the addition of three concrete evaporation tanks to receive treated effluent, so that the discharge from Outfall 051 is significantly reduced or eliminated. Reducing or eliminating the amount of water discharge from Outfall 051 will, in turn, reduce the potential for the migration of legacy contaminants in Mortandad Canyon by reducing surface flow.

The evaporation tanks will be an integral part of the RLWTF which is a wastewater treatment facility regulated under the Clean Water Act (CWA). Therefore, a RCRA permit is not required for this project. The Environmental Protection Agency (EPA) provided some discussion in 53 FR 34080 (September 2, 1988) which states that: "the wastewater treatment unit exemption is intended to cover only tank systems that are part of a wastewater treatment facility that (1) produces a treated wastewater effluent which is discharged into surface waters or into a POTW sewer system and therefore is subject to the NPDES or pretreatment requirements of the Clean Water Act, or (2) produces no treated wastewater effluent as a direct result of such requirements."

Further guidance relative to zero discharge facilities is provided in Enclosure 4.0, EPA FAXBACK # 13526, January 16, 1992.

Federal RCRA regulations, adopted by reference by the EIB (20.4.1 NMAC), provide that a RCRA permit is not required for wastewater treatment units (WWTUs). Further, 40 CFR 270.1(c)(2), states that "The following persons are among those not required to obtain a RCRA permit: . . . (v) Owners and operators of . . wastewater treatment units as defined in 40 CFR 260.10." The definition of a WWTU in 40 CFR 260.10 contains three requirements. The RLWTF meets these three requirements as follows:

First, RLWTF and its associated evaporation tanks (once constructed) are "part of a wastewater facility that is subject to regulation under . . . Section 402 . . . of the Clean Water Act." The RLWTF is currently subject to regulation under Section 402 of the federal Clean Water Act, as Outfall 51 of NPDES Permit No. NM0028355.

Second, the RLWTF receives and treats or stores influent that is a hazardous waste, in that it may contain corrosive characteristic (D002) mixed wastewater. This influent will be treated before it is discharged to the evaporation tanks.

Third, the structure containing the wastewater must meet the definition of a "tank" or "tank system" in 40 CFR 260.10. A "tank" is defined as "a stationary device, designed to contain an accumulation of hazardous waste which is constructed primarily of non-earthen materials (e.g., wood, concrete, steel, plastic) which provide structural support." As noted above, the evaporation tanks will be constructed of concrete; the concrete walls will provide structural support to contain the liquid inside. A "tank system" includes the associated ancillary equipment of a tank; for example, the sump.

ENCLOSURE 4.0

FAXBACK #13526

EXEMPTION FROM PERMITTING REQUIREMENTS FOR WASTE WATER TREATMENT UNITS
PPC 9522.1992(01)

United States Environmental Protection Agency
Washington, D.C. 20460
Office of Solid Waste and Emergency Response

January 16, 1992

Mr. Thomas W. Cervino, P.E.
Colonial Pipeline Company
Lenox Towers
3390 Peachtree Road, N.E.
Atlanta, Georgia 30326

Dear Mr. Cervino:

This letter is in response to your August 9, 1991 correspondence requesting a clarification of the conditions under which waste water treatment units qualify for an exemption from RCRA permitting requirements. In your letter you explained that Colonial Pipeline Company has several locations that generate waste waters that are hazardous under the toxicity characteristic, and you asked whether a RCRA permit would be required for a new treatment unit that you are considering.

The primary reason for the waste water treatment exemption is to avoid imposing duplicative requirements pursuant to both a NPDES permit and a RCRA permit for the same unit. As you are aware, in order for a unit to qualify for this exemption contained in 40 CFR_264.1(g)(6), it must:

(1) Be part of a waste water treatment facility that is subject to regulation under either Section 402 or 307(b) of the Clean Water Act;

(2) Receive, treat, or store influent waste water; or generate, accumulate, treat, or store a waste water treatment sludge; and,

(3) Meet the definition of tank or tank system in 40 CFR _260.10.

The main question that you raised concerns the first criteria: i.e., which units are considered subject to the Clean Water Act. As you are aware, the Agency provided some discussion of this requirement in 53 FR 34080 (September 2, 1988) which states that:

"the wastewater treatment unit exemption is intended to cover only tank systems that are part of a wastewater treatment facility that (1) produces a treated wastewater effluent which is discharged into surface waters or into a POTW sewer system and therefore is subject to the NPDES or pretreatment requirements of the Clean Water Act, or (2) produces no treated wastewater effluent as a direct result of such requirements."

It is important to note that it is not necessary that the Clean Water Act permits actually be issued for the units to be eligible for the RCRA exemption; it is sufficient that the facility be subject to the requirements of the Clean Water Act.

Based on a review of the information provided, EPA has determined that any of the treatment systems (including the proposed treatment unit) at the Colonial Pipeline facilities which are currently permitted, were ever permitted, or should have been permitted under NPDES, all meet the first test of the Section 264.1(g)(6) exemption. The key issue is whether the treatment system ever had a discharge to surface water, and thus was ever permitted (or should have been permitted) under NPDES. If there was never a discharge to surface waters, then the exemption criteria is not satisfied. You also mentioned that some of your facilities employ wastewater treatment systems which are regulated in accordance with other applicable state laws, rules, and regulations. Without more specific information regarding these state requirements and permits, EPA cannot address whether these facilities would qualify for the exemption. However, as discussed above, the exemption in the federal regulations would only be available if the state requirements stem from the identified sections of the Clean Water Act.

With regard to the question of a "zero discharge" facility, EPA would like to clarify the difference between a facility that produces no treated wastewater as a direct result of Clean Water Act requirements and units that are not required to obtain an NPDES permit because they do not discharge treated effluent. In the first case, the facility would have had a surface water discharge at one time, but has since eliminated the discharge as a result of, or by exceeding, NPDES or pretreatment requirements. Such facility would qualify for the waste water treatment unit exemption under RCRA. In the second case, the facility never had a surface water discharge, and therefore was never subject to NPDES permitting or Clean Water Act requirements (53 FR 34080). The RCRA exemption is not available in these cases. (We should point out that the language you referred to on page 2 of the May 22, 1984 memo on zero discharge has been further refined and clarified by recent program policies and interpretations.)

There is another management option that my staff has discussed with you on the phone. That approach would be to treat your waste water in tank units pursuant to the generator accumulation exemption of 40 CFR _262.34. This provision allows generators of hazardous wastes to treat or store such wastes in tanks or containers for short periods of time (i.e., 90 days) without obtaining a RCRA permit, provided that all the conditions of _262.34 are met, including compliance with specified tank or container standards in 40 CFR Part 265. In many cases air strippers may be considered tank units under RCRA and might be eligible for this exemption. Of course, as long as the treated waste water meets a hazardous waste listing description or exhibits a hazardous waste characteristic it must

continue to be managed as a hazardous waste.

If you have facility-specific questions, please contact individual in the appropriate EPA Regional Offices. For Region III (Philadelphia), contact Ms. Susan Sciarratia at (215) 597-7259 and for Region IV (Atlanta), contact Ms. Beth Antley at (404) 347-3433. Should you have further questions about this letter, please contact Glenn Strahs of my staff at (202) 260-4782.

Sincerely,
Sylvia K. Lowrance, Director
Office of Solid Waste

cc: Kathy Nam, OGC; EPA RCRA Branch Chiefs, Regions I-X; Barbara Simcoe, ASTSWMO

Enclosure 5.0

Monday
April 8, 1996

Federal Register

Part II

Environmental Protection Agency

40 CFR Part 148, et al.
Land Disposal Restrictions Phase III; Final Rule and Partial Withdrawal and Amendment of Final Rule

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I. Background

A. Summary of the Statutory Requirements of the 1984 Hazardous and Solid Waste Amendments, and Requirements of the 1993 Consent Decree With the Environmental Defense Fund

The Hazardous and Solid Waste Amendments (HSWA) to the Resource Conservation and Recovery Act (RCRA), enacted on November 8, 1984, largely prohibit the land disposal of untreated hazardous wastes that do not meet treatment standards established by EPA under section 3004(m). Once a hazardous waste is prohibited, the statute provides only two options for legal land disposal: meet the treatment standard for the waste prior to land disposal, or dispose of the waste in a land disposal unit that has been found to satisfy the statutory no migration test. A no migration unit is one from which there will be no migration of hazardous constituents for as long as the waste remains hazardous. RCRA sections 3004 (d), (e), (f), (g)(5).

The amendments also require the Agency to set levels or methods of treatment, if any, which substantially diminish the toxicity of the waste or substantially reduce the likelihood of migration of hazardous constituents from the waste so that short term and long term threats to human health and the environment are minimized. RCRA section 3004(m)(1). To date, the Agency has implemented this provision by establishing treatment standards for chemical constituents in hazardous wastes based on the performance of the best demonstrated available technology (BDAT) to treat the waste. EPA may establish treatment standards as specified technologies, as constituent concentration levels in treatment residuals, or both. When treatment standards are set as levels, the regulated community may use any technology not otherwise prohibited (such as impermissible dilution) to treat the waste.

It should be noted that the Agency has proposed risk-based exit levels—levels at which wastes are no longer considered hazardous for purposes of RCRA subtitle C—for the majority of hazardous constituents found in listed hazardous wastes in the Hazardous Waste Identification Rule (HWIR) (60 FR 66344, December 21, 1995). Wastes meeting these levels either before or after treatment consequently could be disposed in units not subject to RCRA hazardous waste management requirements (e.g., landfills without subtitle C permits). A consent decree approved by the U.S. District Court for the District of Columbia requires EPA to finalize the HWIR exit levels by December 15, 1996. In the same notice, the Agency proposed to allow the exit levels for some constituents to serve as alternative, risk-based LDR treatment standards satisfying the "minimize threat" standard of section 3004(m). Where these risk-based levels are higher (less restrictive) than current BDAT treatment standards, they will effectively supersede the BDAT requirements. See *Hazardous Waste Treatment Council* v. *EPA*, 886 F.2d 355, 362–63 (D.C. Cir. 1989).

EPA was required to promulgate land disposal prohibitions and treatment standards by May 8, 1990 for all wastes that were either listed or identified as hazardous at the time of the 1984 amendments (RCRA sections 3004 (d), (e), and (g)(5)), a task EPA completed within the statutory timeframe. EPA also required to promulgate prohibit. and treatment standards for wastes identified or listed as hazardous after the date of the 1984 amendments within six months after the listing or identification takes effect (RCRA section 3004(g)(4)).

The Agency did not meet this latter statutory deadline for all of the wastes identified or listed after the 1984 amendments. As a result, a suit was filed by the Environmental Defense Fund (EDF). EPA and EDF signed a consent decree that establishes a schedule for adopting prohibitions and treatment standards for newly identified and listed wastes. (*EDF* v. *Reilly*, Cir. No. 89–0598, D.D.C.). EPA also entered into a settlement agreement with the environmental petitioners in *Chemical Waste Management* v. *EPA*, 976 F.2d 2 (D.C. Cir. 1992), cert. denied 113 S. Ct. 1961 (1993) regarding the procedural effect of the mandate entered in that case. This settlement calls for EPA to take action to implement the portions of the opinion dealing with centralized management of wastewaters that initially exhibit a hazardous waste characteristic within specified timeframes.

Today's rule fulfills several provisi of the settlement agreement and proposed consent decree. First, the rule amends the treatment standards for initially characteristic wastewaters managed in centralized wastewater management systems containing land disposal units. Three specific fact patterns are covered by the rule: (1) Where the wastewaters are ultimately discharged and are subject to limitations or standards established under the Clean Water Act (CWA) and the treatment system preceding discharge includes a surface impoundment; (2) where a facility with initially characteristic wastes treats those wastes with CWA-equivalent treatment but ultimately uses a form of land disposal (such as spray irrigation) that is not regulated under the CWA as the final means of disposing of the treated wastewaters; and (3) the initially characteristic wastes are injected into Class 1 non-hazardous deep wells subject to regulation under the Safe Drinking Water Act (SDWA). In all cases, the wastewaters no longer exhibit a characteristic at the point of land disposal. The amended treatment standards require treatment that destroys, immobilizes, or removes the hazardous constituents present in the initially characteristic wastewaters (referred to as "underlying hazardous

setting out circumstances where such responses are exempt from RCRA permitting requirements.) During the development of the proposed Military Munitions Rule: Hazardous Waste Identification and Management; Explosives Emergencies; Redefinition of On-site proposed rule (60 FR 56468, November 8, 1995), the Department of Defense, the military services, and other Federal agencies raised concerns that LDR requirements requiring treatment of underlying hazardous constituents might impede the most effective emergency responses involving these materials. If a responding team had to determine LDR applicability before deactivating an explosive subject to an emergency response, the response could be significantly delayed or complicated. Furthermore, concern about LDR applicability might discourage the team from responding at all. This discussion serves as EPA's initial response to these comments.

EPA agrees that the primary goal in emergency responses to explosives is the safe and prompt elimination of immediate threats to human life and property, and the Agency would be concerned if LDR or other regulatory requirements complicated these responses. The issue is too important and potentially complicated to resolve in today's rule. Therefore, EPA is temporarily deferring final action while it considers this issue further.

In deferring action for this limited class of reactive wastes, EPA notes that emergency responses present issues different from routine management of reactive wastes, where there is no competing consideration of need for immediate action to prevent an imminent threat. In non-emergency response management situations, as discussed earlier, the Agency believes these wastes can be fully treated to minimize both short and long-term threats posed by land disposal of wastes.[1] EPA also is amending the treatment standards for wastes exhibiting the toxicity characteristic to include standards for underlying hazardous constituents.

Toxic wastes can also contain underlying hazardous constituents in the same potentially harmful concentrations as ICR wastes. 60 FR at 11706. Today's final rule consequently conforms standards for toxic characteristic hazardous wastes to assure treatment of underlying hazardous constituents as well, when such constituents are present at levels exceeding the minimize threat level (as established either by the current technology-based standards or, if risk-based levels are established, exceeding a risk-based level.) Thus, the prohibitions and standards in today's rule will apply to ignitable, corrosive, reactive and toxic characteristic wastes, as just discussed.

II. Miscellaneous Issues for Which EPA Is Not Finalizing an Approach in This Final Rule

A. Treatment Standards for Organobromine Wastes

Organobromine wastes are not yet listed as hazardous. EPA anticipates making a final listing determination in a future rulemaking.

Although EPA proposed treatment standards for organobromine wastes, it clearly would be putting the cart before the horse to promulgate treatment standards in advance of a determination of whether the wastes are hazardous. The Agency intends to establish treatment standards for organobromine wastes should these wastes are listed in the future.

B. Potential Prohibition of Nonamenable Wastes From Land-Based Biological Treatment Systems

The proposed rule contained an extensive discussion of whether certain wastes should be prohibited from placement in biological treatment surface impoundments because they are not amenable to biological treatment. To allow more time to gather comments, the Agency has decided to address this issue in the LDR Phase IV rule, which was proposed on August 22, 1995 (60 FR 43654) and is scheduled to be finalized in June of 1996.

C. Certain Sections of Completing Universal Treatment Standards

The LDR Phase III proposed rule included a section on the completion of universal treatment standards (60 FR at 11727, March 2, 1995). Possible nonwastewater universal treatment standards (UTS) for eleven constituents were discussed in the proposal, and comments and data were solicited. In general, commenters felt more data should be gathered before EPA proposes nonwastewater standards for these constituents, and EPA agrees. EPA had also solicited comment and data on extending certain universal treatment standards to fill gaps in the § 268.40 table of universal treatment standards where "NA" appeared for either the wastewater or nonwastewater form of a regulated hazardous constituent. Commenters were opposed to this, stating that it would be arbitrary to add a standard to a waste code where before there was none without supporting data. The Agency again agrees. Therefore, EPA is not taking final action at this time.

D. Prohibition of Hazardous Waste as Fill Material

EPA proposed to prohibit use of hazardous waste as fill material. 60 FR at 11732. Because issues raised in the proposal are related to those in a number of other pending rulemakings, including the Hazardous Waste Identification Rule, and the proposed rule relating to land-based uses of hazardous waste K061 (59 FR 67256 (Dec. 29, 1994)), EPA is not taking final action on the proposal at this time.

E. Point of Generation

The Agency discussed possible changes that could be made to the "point of generation"—or point at which LDR requirements attach to a hazardous waste (see 60 FR 11717, March 2, 1995). The Agency is still considering the options discussed in the proposal and potentially other options not discussed. The Agency will reopen the point of generation issue for further comment, and is intending to finalize an option in a future rulemaking.

F. Prohibition on Using Iron Filings to Stabilize Spent Foundry Sand

The Agency proposed designating the practice of adding iron dust/filings to spent foundry sand as impermissible dilution (60 FR 11731, March 2, 1995). The Agency is gathering data on the stability of the chemical bond formed between the iron and lead in the spent foundry sand. After the Agency analyzes these data, as well as further studies the public comments on this issue, it may take final action on the proposal.

III. End-of-Pipe Equivalence: Treatment Standards for Clean Water Act (CWA) and CWA-Equivalent Wastewater Treatment Systems

A. Types of Facilities to Which Treatment Standards Apply

As explained above, the D.C. Circuit established a standard of so-called end-of-pipe equivalence, allowing CWA treatment systems with surface impoundments to dilute characteristic wastes before land disposal in those impoundments without violating LDR requirements, provided the treatment system destroys, immobilizes, or removes an equivalent amount of hazardous constituent as if the characteristic waste were treated separately to meet RCRA standards. EPA

[1] EPA also notes that it is not reopening the issue of open burning/open detonation of reactive wastes. In 1986, EPA determined that such activities are not a form of land disposal. See 51 FR at 40580 (Nov. 7, 1986).

characteristic waste containing metal and organic underlying hazardous constituents and the waste was treated sequentially by means not involving impermissible dilution, there could be different compliance points for the metal and organic hazardous constituents.

EPA notes, however, that if alternative points of compliance are utilized, enforcement would normally be pursuant to RCRA, not the Clean Water Act. This is by necessity, since CWA permits (or, for indirect dischargers, control mechanisms) would not normally apply to effluent quality before final discharge. See further discussion on means of implementing today's standards below in this preamble.

C. Why CWA Limitations and Standards Can Also Be RCRA Treatment Standards

As explained above, when a hazardous constituent is already subject to a CWA industry category or Water Quality Criteria-based limitation, or a case-by-case industrial POTW limitation or standard, the Agency believes (and the final rule provides) that the CWA limitations and standards satisfy RCRA section 3004(m) requirements and consequently become the RCRA treatment standard for purposes of demonstrating equivalent treatment. EPA believes that this is an obvious and effective means of integrating CWA and RCRA requirements, in accord with the court's objective. 976 F. 2d at 22; RCRA section 1006(b). This approach was generally supported by commenters as a reasonable means of satisfying the court's mandate and the underlying policy of integration of the two statutes.

Several commenters, however, argued that CWA limitations and standards could not be equivalent to RCRA because such standards can reflect (among other things) "the cost of achieving such effluent reduction", and "the age of equipment and facilities involved". CWA section 304(b)(2)(B) (factors to be considered in determining Best Available Technology). EPA disagrees. While it is true that technology-based standards developed to address toxic pollutants from various industrial categories are developed after consideration of levels that can be achieved through application of the best available technology economically achievable, the CWA limitations and standards nevertheless represent the best evaluation of what technically advanced wastewater treatment is capable of achieving for a particular industry's (or, in some cases, particular plant's) wastewater. Although there is no requirement that a particular treatment technology must be used to achieve the facility's limits, it is expected that plants utilizing BAT will have treated their effluent so that there are substantial reductions in concentration and mass of hazardous constituents. As the Agency has stated many times, EPA believes that section 3004(m) is satisfied by treatment that substantially destroys, immobilizes, and removes the hazardous constituents that are present in the waste, notwithstanding that minor amounts of hazardous constituents remain after treatment. Put another way, the statute does not require that every conceivable threat posed by land disposal be eliminated by treatment. 55 FR at 6641 and n. 1 (Feb. 26, 1990); 56 FR at 12355 (March 25, 1991); 57 FR 37259 (August 18, 1992); 55 FR at 22596 (June 1, 1990). In fact, the legislative history states explicitly that the treatment standards are not to be technology forcing, but rather are to utilize the available effective treatment technologies. 130 Cong. Rec. S. 1978 (daily ed. July 25, 1984) (statement of Sen. Chaffee); 56 FR at 12355. That is precisely what EPA has done here.

Second, with specific regard to use of CWA limitations, EPA notes that virtually all of the current LDR treatment standards for wastewaters are already drawn from CWA limitations and standards. See 55 FR at 22601 (wastewater standards for U and P wastes and F039, which essentially became the universal treatment standards, were transferred from treatment data from CWA programs), and see also the Final BDAT Background Document for U and P Wastes and Multi-Source Leachate (F039) Volume C (documenting that most of existing RCRA wastewater standards were transferred from CWA limitations and standards). Moreover, the technologies that are often used to achieve CWA limitations and standards are, in most cases, the same technologies upon which the RCRA Universal Treatment Standards are based. As EPA has already stated, "because most treatment technologies cannot be so precisely calibrated as to achieve, for example, 3.5 ppm rather than 2.7 ppm, the likely result is that the same amount of treatment will occur." 59 FR at 47989 (Sept. 19, 1994). Since frequently the same technologies are used to treat wastewaters, EPA expects the degree of treatment to be comparable.

EPA also emphasizes that RCRA section 1006(b) requires EPA (among other things) to integrate provisions of RCRA and the CWA when implementing RCRA, and to avoid duplication to the maximum extent possible with CWA requirements. The Agency feels it is accomplishing this requirement by allowing a constituent specific, CWA treatment standard to satisfy RCRA 3004(m). The Agency reiterates that a technology-based CWA limitation or standard for a hazardous constituent satisfies RCRA because such a limitation or standard directly reflects the capability of BAT technologies to treat a specific industry's or facility's wastewater, whereas the RCRA UTS for wastewaters were developed by transferring performance data from various industries, and thus EPA need not make that same transfer when industry-specific (or plant-specific) wastewater treatment data is available.

A water-quality based limitation would also satisfy RCRA section 3004(m). A CWA water quality-based limitation must be at least as stringent as the limitations required to implement an existing technology-based standard. (See CWA section 301(b)(1)(c).) Even where there is no existing BAT limitation for a toxic or nonconventional pollutant, a permit writer must determine whether BAT would be more stringent than the applicable water quality-based limitation, and again, must apply the more stringent of the two potential limitations. (40 CFR 125.3(c)(2).)

If a facility has received a Fundamentally Different Factors (FDF) variance, the limitations established by that variance also satisfy RCRA requirements. Limitations established by the FDF variance process are technology-based standards reflecting facility-specific circumstances, and hence can appropriately be viewed as BDAT as well, just as with RCRA treatability variance standards. See 51 FR at 40605 (Nov. 7, 1986).

EPA also believes that there are adequate constraints in the CWA implementing rules to prevent these end-of-pipe standards from being achieved by means of simple dilution. First, many of the effluent limitation guidelines and standards regulate the mass of pollutants discharged, and thus directly regulate not only the concentration of pollutant discharged but the degree of wastewater flow as well. Even where rules are concentration-based, NPDES permit writers can set requirements which preclude excessive water use, and EPA has so instructed permit writers. (See 58 FR 66151, December 17, 1993, encouraging permit writers to estimate reasonable rate of flow per facility and factor that flow limit into the permit.) These permit conditions can take the form of best management practices,

2. Where Permits Do Not Contain a Limitation for a Hazardous Constituent

If the CWA permit either does not contain a limitation for the pollutant or does not regulate the pollutant through an indicator, or in cases when this rule becomes effective before the reissuance of a facility's permit, the RCRA universal treatment standards would apply as they do for any other RCRA hazardous wastestream. In this situation, the owner or operator of a facility has several choices. The owner/operator could do nothing, in which case the hazardous constituent would be subject to the UTS. These standards would be implemented by rule, and thus would not be embodied in a CWA permit. Enforcement consequently would be solely under RCRA. As noted earlier, the point of compliance could, but need not be, at the end-of-pipe point of discharge.

In the alternative, a facility could seek amendment of its NPDES permit pursuant to § 122.62(a)(3), requesting that the applicable permitting authority modify the permit at reissuance, or sooner, to add limits for the underlying hazardous constituents reflecting BAT for that pollutant at the facility.[3] Assuming proper design and operation of the wastewater treatment technology, a permit writer in such a case could modify the permit to add a limitation for the pollutant based on Best Professional Judgement reflecting actual BAT treatment (40 CFR 125.3(c)). Modification requests would be processed pursuant to the procedures found at § 124.5. The modified permit limitation would be a CWA requirement and enforceable solely under that statute, but would be deemed by the Agency to satisfy RCRA 3004(m), so that meeting UTS per se would not be required.

A final alternative is for the facility to seek a RCRA treatability variance. EPA is amending the grounds for granting such a variance to include situations where a facility is treating decharacterized wastes by treatment identified as BAT or NSPS (New Source Performance Standards), the technology is designed and operated properly, but is not achieving the UTS (see § 268.44(a)).

3. Indirect Dischargers

The same alternatives exist for indirect dischargers. If an underlying hazardous constituent is regulated by a categorical PSES, PSNS, or by a local limit in a control mechanism reflecting PSES or PSNS—level treatment, then that standard satisfies both RCRA and the CWA. In addition, if there is no pretreatment standard (i.e., PSES/PSNS) for an underlying hazardous constituent, because the Agency determined that there was no pass through, then section 3004(m) is satisfied and the RCRA standard for that underlying hazardous constituents does not apply.

If an underlying hazardous constituent is not regulated nationally by a PSES or PSNS, or by a local limit, it becomes subject to the UTS for that constituent. That UTS would be enforced as a RCRA standard. However, in cases where an underlying hazardous constituent is not already subject to categorical PSES, categorical PSNS, or to a local limit in a control mechanism reflecting PSES or PSNS-level treatment, water quality, or pass through, the control mechanism between the indirect discharger and the applicable control authority would have to be modified in order to avoid application of the UTS by rule. EPA is amending § 403.5(c)(1) and § 403.5(c)(2) of the pretreatment rules to specifically authorize control authorities to make such determinations.

The final option is for a facility to obtain a RCRA treatability variance. Thus, the amendment to the treatability variance rules also applies to indirect dischargers properly operating technology identified as the basis for their PSES or their PSNS standard.

4. Zero Dischargers Performing CWA-Equivalent Treatment

The implementation options for zero dischargers performing CWA-equivalent treatment are similar. Some of these facilities may have CWA permits authorizing specified levels of discharge. If these permit limitations apply to underlying hazardous constituents present in the RCRA-prohibited portion of the discharge, the CWA permit limit satisfies RCRA as well. The facility also could seek to amend the CWA permit to add limitations for the hazardous constituent. Enforcement then would be exclusively pursuant to the CWA.

If the zero discharger has no CWA permit, or the permit does not contain limitations for underlying hazardous constituents and is not amended to do so, then the facility would have to meet the RCRA UTS or an alternative standard established by treatability variance either at the point of discharge[4] or at an earlier point of its choosing (assuming, of course, that a valid demonstration of bona fide treatment can be made at an earlier point).

5. Implementation When CWA Standards and Limitations Will Not Be the Exclusive Standard

If the facility treats to UTS and does not modify its CWA permit or control mechanism to include a CWA standard/limitation for an underlying hazardous constituent, EPA is finalizing minimal recordkeeping requirements, under RCRA authority. Generators can use their knowledge to identify the underlying hazardous constituents reasonably expected to be present at the point of generation of the ICRT wastes which are not covered by a CWA limitation or standard and hence must be treated to meet UTS (assuming no permit modification). EPA is requiring that this information be kept on-site in files at the facility. The facility will then monitor compliance with the UTS standard for each of these constituents at the point of ultimate discharge or alternative compliance point, on a quarterly basis, and results of this monitoring must be kept in the facility's on-site files. An exceedence of the RCRA UTS standard must be documented in the facility's on site records.

These same requirements apply to facilities without NPDES permits documenting compliance as zero dischargers with CWA-equivalent treatment who are affected by this rule. The absence of a permit necessitates some alternative means of documenting compliance, and the scheme outlined above seems to be the least burdensome scheme which would still provide a reasonable means of enforcing this rule.

6. RCRA Controls Over Point Source Discharges and Domestic Sewage

Both RCRA and the implementing regulations provide that point source discharges and domestic sewage (including mixtures of domestic sewage with other wastes) are not subject to

[3] EPA is interpreting the language in § 122.62(a)(2) to indicate that the D.C. Circuit's opinion in the Third Third case is new information warranting reopening a permit.

[4] The point of compliance for a zero discharger choosing the point of discharge as a compliance point would be at the point of ultimate disposal. For those zero dischargers who discharge to a dry river bed (common in the western U.S.) not considered a "water of the U.S." under the CWA, the point of compliance would be at the end-of-pipe. For those zero dischargers who spray irrigate, or otherwise place the wastewaters on the land after treatment in the surface impoundment, the point of compliance would be at the point just prior to the land placement. Furthermore, zero dischargers treating wastewaters in a tank system followed by spray irrigation or another form of land placement are also subject to this rule. For those zero dischargers who use evaporation ponds, the point of compliance is before the wastewater enters the surface impoundment, as this is the ultimate disposal point.

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would be the trigger level for the LDR prohibition, EPA has recently proposed risk-based hazardous constituent concentration levels which would implement the "minimize threat" requirement in section 3004(m), and would cap the technology-based treatment standards whenever the technology-based standards are lower (60 FR 66344, December 21, 1995). The *de minimis* feature of today's rule further addresses situations where EPA believes that prohibitions need not apply due to the low concentrations and volumes of hazardous constituents in the decharacterized portion of the injectate.

B. Compliance Options for Class I Nonhazardous Wells

In the proposed rule, the Agency indicated that facilities could segregate their hazardous wastes, and treat just that volume of the total waste stream to UTS levels in order to conform to the treatment requirement. A number of commenters maintained that the Agency oversimplified this approach and that such segregation was impractical from both a technical and economic standpoint. EPA acknowledges that many facilities may not practically be able to segregate streams. These facilities may utilize of other LDR compliance options as discussed below.

One option would be to apply for an exemption from treatment standards via the no-migration petition variance. EPA is promulgating a clarifying revision to 40 CFR 148.20 which allows facilities to seek a no-migration variance for their Class I nonhazardous wells, and has long indicated that this compliance option is available (see pp. 25–27, Supplemental Information Report prepared for the Notice of Data Availability, January 19, 1993, 58 FR 4972). If these facilities demonstrate to EPA that their formerly characteristic wastes (including any hazardous constituents) will not migrate out of the injection zone for 10,000 years, or no longer pose a threat to human health and the environment because the wastes are attenuated, transformed, or immobilized by natural processes, then they may continue to inject without further treatment.

A significant number of commenters responded to the proposed rule's discussion on the Agency's position on granting no-migration petitions. Comments included that petitions were a too costly option, took too much time to be processed, generic petitions for Class I non-hazardous wells should be granted, and existing no-migration exemptions should not require modification to include Phase III wastes. These comments, among others, will be discussed in detail in the "Response to Comments" background document for this rule, but basically many had partial merit.

First, although the Agency has estimated earlier that the average petition costs an operator $343,000, several individual petition reviews have far exceeded that amount. The Agency will examine the possibility of revising petition cost data in future LDR rules. Second, although a petition may take up to 3 years to process, the Agency (as noted above) indicated as early as 1992 (after the Third Third opinion) that it would begin review of Class I nonhazardous injection well no-migration petitions if submitted (58 FR 4972, January 19, 1993). Although time and resource restraints on the Agency are real, the Agency will continue to work with affected Class I operators in order to facilitate the no-migration petition review process. Third, although EPA has established a reasonable knowledge base on the review process for Class I hazardous facilities, it cannot automatically infer that all Class I nonhazardous facilities will successfully make a no-migration demonstration. Well site geology, hydrogeology, abandoned well area of review, and the specific characteristics of the injectate and receiving formation are site specific factors which, as a factual matter, must be evaluated individually in order to demonstrate "to a reasonable degree of certainty" (RCRA section 3004(g)(5)) that the no migration standard has been satisfied. See Supplemental Report to Notice of Data Availability, January 19, 1993, at 25–26 9. It must be remembered that not every Class I injection well applying for the variance has been able to make the demonstration, and that one salutary effect of the no migration process has been to identify certain (albeit a limited number of) wells that would not be capable of adequately containing injectate over the long term.

EPA agrees completely with commenters, however, that wells that already have approved no migration exemptions are not affected by the Third Third opinion and thus are not affected by land disposal restrictions affecting decharacterized wastes. (In fact, EPA does not read the proposal to suggest otherwise.) Absent a change in the waste being injected, there is no reason to reopen no migration determinations that have already evaluated the entire injected waste stream. 57 FR at 31963 (July 20, 1992).

EPA is also promulgating additional means for Class I nonhazardous facilities to comply with the LDR requirements. Revisions to 40 CFR 148.1(c)(1) and 148.4 will allow Class I nonhazardous owners and operators to apply for a case-by-case extension of t capacity variance for up to one year (renewable for up to an additional year) in order to acquire or construct alternative treatment capacity. Based on experience, EPA believes that the availability of the case-by-case extension coupled with national capacity variance(s) should allow operators more than adequate time to acquire alternative treatment or complete the no-migration petition process. Two other options include the pollution prevention option and the de minimis volume exclusion.

C. Pollution Prevention Compliance Option

The final rule provides an alternative means of obtaining the reductions in mass loadings of hazardous constituents mandated by the Third Third opinion. Under this alternative, mass reductions can be achieved by removing hazardous constituents from any of the wastestreams that are going to be injected, and these reductions in mass loadings can be accomplished by means of source reduction (i.e. equipment or technology modifications, process or procedure modifications, reformulation or redesign of products, substitution o raw materials, and improvements in housekeeping, maintenance, training, or inventory control), recycling, or conventional treatment. As an example, if a facility can make process changes that reduce the mass of cadmium by the same amount that would be removed if the prohibited wastestream was treated to satisfy UTS, the facility would satisfy LDR requirements. The facility could also remove cadmium from any of the streams (prohibited or non-prohibited) which are going to be injected, or could find a means of recycling some portion of the injectate to reduce injected mass loadings of cadmium. In all cases, the result would be that the mass loading of hazardous constituents into the injection unit would be reduced by the same amount as it would be reduced by treatment of the prohibited, characteristic portion of the injectate. 976 F. 2d at 23 n. 8; see also *Specialty Steel Inst.* v. *EPA*, 27 F. 3d 642, 649 (D.C. Cir. 1994) (treatment standards that result in lower volume of waste to be disposed—precisely what the alternative standard here can achieve—are a permissible means of complying with RCRA section 3004 (m)).

Commenters further requested that this alternative be available on a hazardous constituent by hazardous constituent basis. EPA agrees that this is

present in the characteristic wastes at concentrations less than 10 times UTS at the point of generation, then the wastes are not prohibited from injection in a Class I non-hazardous deepwell (assuming the injectate is not hazardous at the point of injection). The Agency continues to believe that under these circumstances, the relatively small decharacterized hazardous waste streams would not appreciably alter the risks posed by the injection practice.

Generally, the proposed approach was well received. Some commenters stated, however, that the *de minimis* volume exemption, as proposed, would allow excessively large volumes of routinely generated characteristic wastes to go untreated to disposal in deep wells, while others believe that the specific quantifying parameters are overly restrictive. The Agency analyzed potential risks associated with concentrations of 5 contaminants detected in Class I facility waste streams at 10, 20, and 50 times UTS. (This analysis was conducted in conjunction with revising the Regulatory Impact Analysis For Underground Injected Wastes for this rule. See 60 FR 11715.) In brief, risk estimates for 4 geologic settings and 2 well malfunction scenarios were found to be below levels of regulatory concern at 10 and 20 times UTS. However, at 50 times UTS, risk estimates for cancer and hazard index were above regulatory concern for a waste stream containing carbon tetrachloride, assuming an abandoned borehole failure within 500 feet of the injection well. Taking into account the statutorily enumerated "long-term uncertainties associated with land disposal" (RCRA section 3004(d)(1)(A)), EPA believes the 10 × UTS level to be well within the zone of reasonable values it could select as *de minimis*. The one percent volumetric requirement is consistent with other longstanding *de minimis* exemptions for wastewater management systems in the subtitle C rules (see § 261.3(a)(2)(iv) (A) and (E)), and would normally cap the total volume of characteristic injectate at approximately 1100 gallons per day, given average Class I UIC non-hazardous injection rates.

At a rate of 1100 gallons per day, 10×UTS for carbon tetrachloride would mean a mass loading of approximately 165 mg of the constituents being injected each day. Mass loadings for the other hazardous constituents would similarly be modest. EPA again believes that these small mass loadings would have *de minimis* effect on the risk potential posed by the injection practice and consequently should be exempted from the prohibition.

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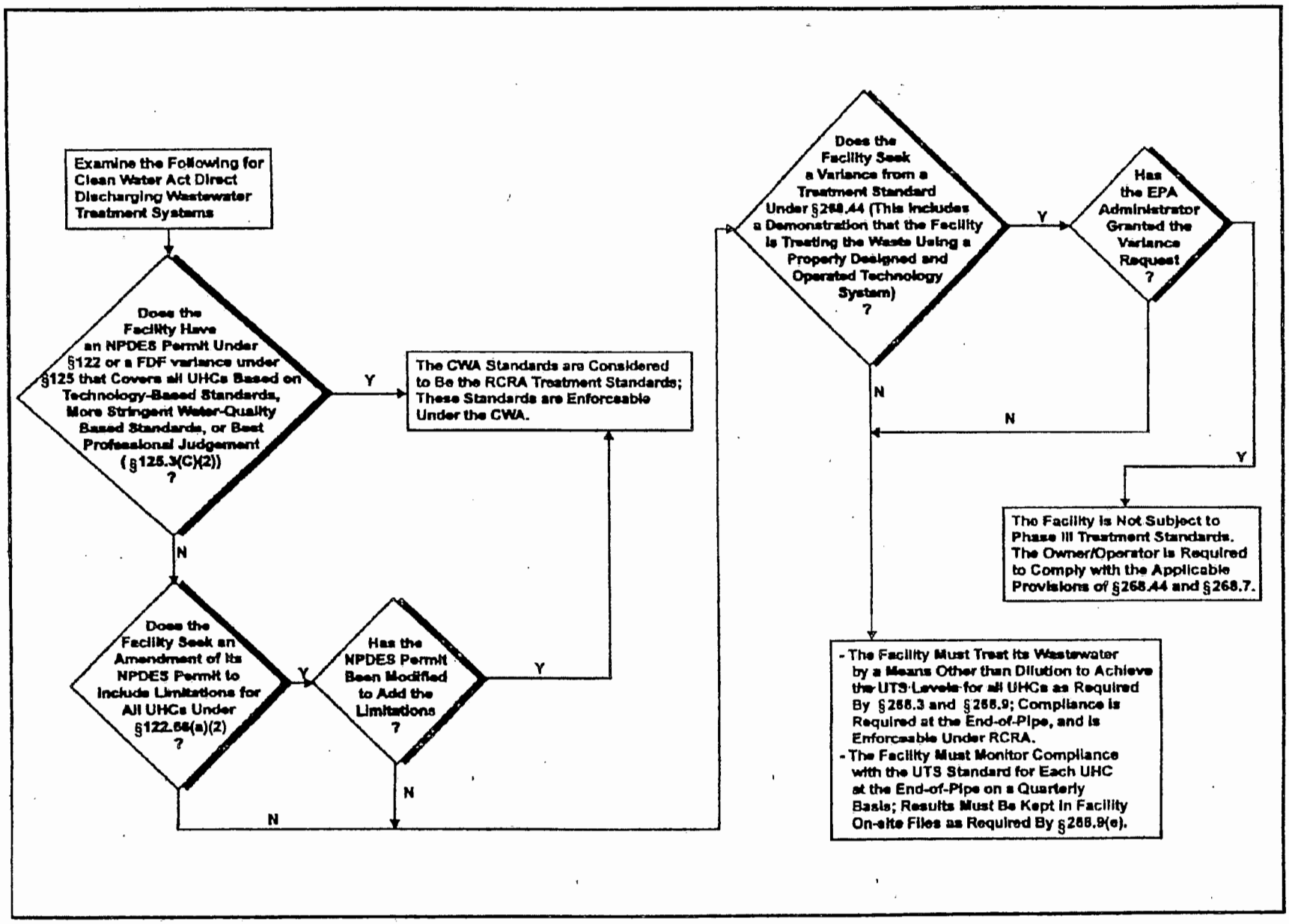

Figure 2. Applicability Criteria and Treatment Standards for Decharacterized Wastes Managed in Clean Water Act Direct Discharging Wastewater Treatment Systems

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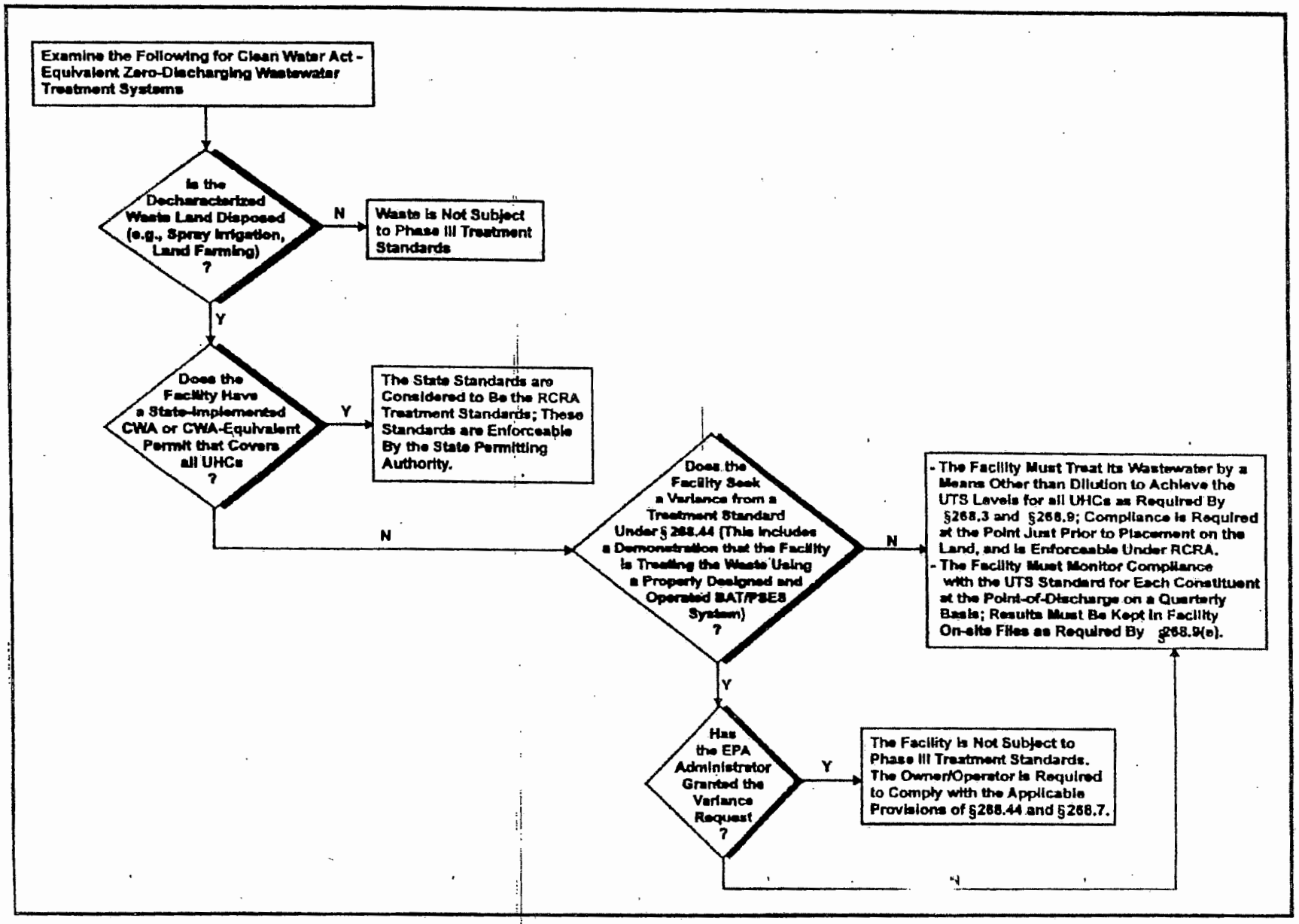

Figure 4. Applicability Criteria and Treatment Standards for Decharacterized Wastes Managed in Clean Water Act - Equivalent Zero-Discharging Wastewater Treatment Systems

V. Treatment Standards for Newly Listed Wastes

A. Carbamates

Hazardous Wastes From Specific Sources (K Waste Codes)

K156—Organic waste (including heavy ends, still bottoms, light ends, spent solvents, filtrates, and decantates) from the production of carbamates and carbamoyl oximes.
K157—Wastewaters (including scrubber waters, condenser waters, washwaters, and separation waters) from the production of carbamates and carbamoyl oximes.
K158—Bag house dust, and filter/separation solids from the production of carbamates and carbamoyl oximes.
K159—Organics from the treatment of thiocarbamate wastes.
K160—Solids (including filter wastes, separation solids, and spent catalysts) from the production of thiocarbamates and solids from the treatment of thiocarbamate wastes.
K161—Purification solids (including filtration, evaporation, and centrifugation solids), baghouse dust, and floor sweepings from the production of dithiocarbamate acids and their salts. (This listing does not include K125 or K126.)

Acute Hazardous Wastes (P Waste Codes)

P203 Aldicarb sulfone
P127 Carbofuran
P189 Carbosulfan
P202 m-Cumenyl methylcarbamate
P191 Dimetilan
P198 Formetanate hydrochloride
P197 Formparanate
P192 Isolan
P196 Manganese dimethyldithiocarbamate
P199 Methiocarb
P190 Metolcarb
P128 Mexacarbate
P194 Oxamyl
P204 Physostigmine
P188 Physostigmine salicylate
P201 Promecarb
P185 Tirpate
P205 Ziram

Toxic Hazardous Wastes

U394 A2213
U280 Barban
U278 Bendiocarb
U364 Bendiocarb phenol
U271 Benomyl
U400 Bis(pentamethylene)thiuram tetrasulfide
U392 Butylate
U279 Carbaryl
U372 Carbendazim
U367 Carbofuran phenol
U393 Copper dimethyldithiocarbamate
U386 Cycloate
U366 Dazomet
U395 Diethylene glycol, dicarbamate
U403 Disulfiram
U390 EPTC
U407 Ethyl Ziram
U396 Ferbam
U375 3-Iodo-2-propynyl n-butylcarbamate
U384 Metam Sodium
U365 Molinate
U391 Pebulate
U383 Potassium dimethyl dithiocarbamate
U378 Potassium n-hydroxymethyl-n-methyldithiocarbamate
U377 Potassium n-methyldithiocarbamate
U373 Propham
U411 Propoxur
U387 Prosulfocarb
U376 Selenium, tetrakis (dimethyldithiocarbamate)
U379 Sodium dibutyldithiocarbamate
U381 Sodium diethyldithiocarbamate
U382 Sodium dimethyldithiocarbamate
U277 Sulfallate
U402 Tetrabutylthiuram disulfide
U401 Tetramethylthiuram monosulfide
U410 Thiodicarb
U409 Thiophanate-methyl
U389 Triallate
U404 Triethylamine
U385 Vernolate

EPA is promulgating the treatment standards that were proposed for wastes from the carbamate industry specified above.

The preamble of the proposed rule described the basis for these treatment standards in greater detail (60 FR 11720). For background information on waste characterization data, data gathering efforts, and applicable technologies, see the Best Demonstrated Available Technology (BDAT) Background Document for Newly Listed or Identified Wastes from the Production of Carbamates.

The concentration-based treatment standards being promulgated today for carbamate wastewaters and nonwastewaters are at UTS levels for certain constituents, and at newly-established levels for other constituents that are today being added to the UTS list. The UTS standards have already been promulgated for 21 of the constituents of concern (16 organic constituents and 5 metals). The Agency is promulgating new UTS for 42 constituents associated with carbamate wastes. Forty of these constituents are chemicals produced by the carbamate industry which may be grouped into the following categories: carbamates and carbamate intermediates, carbamoyl oximes, thiocarbamates, and dithiocarbamates. Please refer to the Background Document for definitions of these chemical groups and the categorization of these 40 chemicals. The other 2 constituents for which new UTS are being promulgated (triethylamine, and o-phenylene diamine) are not carbamate products, but are hazardous constituents present at levels of regulatory concern in carbamate wastes.

One commenter requested clarification on the applicability of the carbamate treatment standards, stating that the summary section of the proposed treatment standards said that treatment standards were being proposed for certain hazardous wastes "including those from the production of carbamate pesticides", whereas the section of the rule that directly addressed carbamate wastes referred to carbamates without the pesticide limitation. EPA points out in response that the final listing rule which defined the new waste codes does not limit the definition to pesticides only. The treatment standards being promulgated apply to all wastes which fit the definitions of the waste codes established in the final listing rule.

One commenter stated that EPA exceeded its authority under RCRA section 3004 and violated the Administrative Procedure Act by preparing the proposed treatment standards and sending this rule to OMB well before the final listing had been promulgated. EPA points out that the proposed treatment standards were actually published after publication of the final listing rule. The proposed treatment standards were modified to conform with the changes that appeared in the final listing; thus, treatment standards were only proposed for those carbamate wastes whose listing had been promulgated in final form. Proposed standards for wastes whose listings were not finalized were eliminated from the proposed treatment standards rule. Given the statutory requirement described above (i.e., the requirement to finalize LDR treatment standards six months after the listing is finalized), Congress must have envisioned that the two rulemaking activities would occur in close proximity.

One commenter had several objections to the proposed standards for thiocarbamate wastes, stating that 1) nonwastewater standards should not have been based on detection limits compiled from sampling and analysis performed as part of the listing process

sources under section 112, but that determination need not be part of the present rulemaking.

2. Comments Received on Regulated Constituents

EPA requested comment on regulating the phthalates: bis (2-ethylhexyl) phthalate, di-n-butyl phthalate and di-n-octyl phthalate. These constituents have seemingly been detected in the untreated potliner and the treated residue; however, EPA believes that their presence may simply be due to lab contamination. Commenters overwhelmingly requested that these phthalates not be regulated. The Agency agrees and is not including any phthalates in the list of regulated constituents for K088.

A number of commenters requested that benzo(a)pyrene be used as a surrogate for analyzing organics. The commenters were concerned that analytical costs for other PAHs would be excessive. EPA is not convinced that analyzing benzo(a)pyrene would be sufficient for determining proper treatment of all organics. The concentration of one constituent does not always reflect the concentration of similar constituents in a waste. Surrogate analyses assume that all PAHs are present at similar concentrations which may or may not be true. Because of the variability of concentrations found in K088 wastes, benzo(a)pyrene may not be present while other PAHs may be present. Analyzing only for benzo(a)pyrene or any other potential surrogate does not ensure the treatment to UTS concentrations of other PAHs. In addition, the Agency believes that since all of the PAHs are analyzed by a single method the cost increase for additional PAHs should not be significant. Therefore, the Agency does not believe the organic constituents monitored in K088 wastes should be limited to a surrogate indicator. EPA is allowing, however, flexibility in the waste analysis plans developed by the companies with their permit writers to analyze only for those constituents expected to be present in the generated K088.

The Agency proposed to regulate fluoride in K088. While fluoride is not a "hazardous constituent", i.e., listed in Appendix VIII of part 261, it is present in very high concentrations in K088 and is capable of causing substantial harm in the form of groundwater degradation, adverse ecological effects and potential adverse human health effects. The Agency's view thus is that, unless fluoride in this waste is treated, the legal standard in section 3004(m) would not be satisfied. That is, treatment would not "substantially diminish the toxicity of the waste * * * so that short-term and long-term threats to human health and the environment are minimized." RCRA section 3004(m)(1). In addition, as discussed in the proposed rule, EPA reads the language in section 3004 (d)(1), (e)(1), and (g)(5) to require that land disposal may still be prohibited after treatment of hazardous constituents if the waste might still pose substantial hazards due to presence of other constituents or properties. 56 FR at 41168 (August 19, 1991); *NRDC* v. *EPA*, 907 F. 2d 1146, 1171–72 (D.C. Cir. 1990) (dissenting opinion). These hazards could be posed due to lack of treatment of other constituents in the waste, in this case, fluoride.

The Agency requested comment on whether fluoride should be added to Appendix VIII, as well. The overwhelming response of the commenters is that fluoride should not be added to Appendix VIII. The Agency agrees that fluoride does not pose the same risks in other wastes because it does not occur in such high concentrations. Furthermore, adding fluoride to Appendix VIII has associated potential analytical costs which would be unwarranted. Therefore, even though the Agency is regulating fluoride in K088, it is not adding it to Appendix VIII at this time.

3. Comments Received on Data

Several comments were received regarding EPA's use of data on K088. One comment in particular suggested that EPA ignored relevant data gathered by the Aluminum Association. The Agency did not ignore these data. They were submitted after the proposal and are currently in the docket for this final rule. The Agency has reviewed these data and found that they do not support any changes to the proposed treatment standards that are being finalized in this rule. This issue is discussed in greater detail in the Response to Comments background document.

4. Comments Received on Technical Basis for BDAT

There were a number of comments submitted on the technical basis for the numerical treatment standards. As described in the preamble to the proposed rule, most of the treatment standards are taken from the universal treatment standards (UTS) (59 FR 47988, September 19, 1994) which were developed for each constituent by evaluating all existing Agency data from various technologies. The exception to the UTS for K088 constituents is the fluoride treatment standard, which was taken from the Reynolds delisting petition. While K088 is a unique waste, available data indicate that these UTS levels can be routinely achieved.

There seemed to be some confusion in that some commenters believed that EPA was proposing a required technology for the treatment of K088. This is not the case. The longstanding position of the Agency is when numerical treatment levels are established under the LDR program, any treatment technology (other than impermissible dilution) can be used to achieve those levels.

Additional K088 comments along with EPA's responses are provided in the Response to Comments Background Document located in the docket for this rule.

VI. Improvements to the Existing Land Disposal Restrictions Program

A. Completion of Universal Treatment Standards

1. Addition of Constituents to Table 268.48

As discussed in the section on carbamate wastes, EPA is today adding 42 new constituents to the table of universal treatment standards (Table 268.48), for which treatment standards are being promulgated today.

2. Wastewater Standard for 1,4-Dioxane

EPA proposed on March 2, 1995 (60 FR 11702), to establish a wastewater treatment standard for 1,4-dioxane. 1,4-Dioxane was the only UTS constituent for which EPA had promulgated a nonwastewater treatment standard but not a wastewater standard. At that time, the Agency proposed a wastewater UTS for 1,4-dioxane of 0.22 mg/l. This proposed standard was based on the maximum daily limit for 1,4-dioxane that had been developed as part of the proposed effluent guidelines for the pharmaceutical industry (60 FR 21592, May 2, 1995). This standard was based on a transfer of distillation performance data from methanol to 1,4-dioxane.

Today, the Agency is promulgating a revised treatment standard for wastewater forms of 1,4-dioxane based on 5 data points. This data was submitted by one of the commenters and represents actual treatment of wastewaters containing 1,4-dioxane. The Agency prefers to use actual treatment data in lieu of a data transfer whenever possible. These data show that wastewaters containing between 2265–7365 mg/l of 1,4-dioxane can be treated by distillation to levels between 3–7 mg/l, representing a 99.9% removal rate for the dioxane. As a result of this data submittal, the Agency is today promulgating a UTS of 12.0 mg/l for 1,4-

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a Statement of Policy which clarified this point (59 FR 27546–27547). Today the Agency is codifying and quantifying these principles.

As discussed in the proposed rule, impermissible dilution may occur when wastes not amenable to treatment by a certain method (i.e., treated very ineffectively by that treatment method) are nevertheless 'treated' by that method (55 FR 22666, June 1, 1990; 52 FR at 25778–25779, July 8, 1987). Today's rule provides a general distinction between "adequate treatment" and potential violations of the dilution prohibition.

1. Inorganic Metal-Bearing Wastes

The Agency has evaluated the hazardous wastes and has determined that 43 of the RCRA listed wastes (as set forth in 40 CFR part 261) typically appear to be inorganic hazardous wastes that do not contain organics, or contain only insignificant amounts of organics, and are not regulated for organics. BDAT for these inorganic, metal-bearing listed wastes is metal recovery or stabilization. Thus, impermissible dilution may result when these wastes are combusted. When an inorganic metal-bearing hazardous waste with insignificant concentrations of organics is placed in a combustion unit, legitimate treatment for purposes of LDR ordinarily is not occurring. No treatment of the inorganic component occurs during combustion, and therefore, metals are not destroyed, removed, or immobilized. Since there are no significant concentrations of organic compounds in inorganic metal-bearing hazardous wastes, it cannot be maintained that the waste is being properly or effectively treated via combustion (i.e., thermally treated or otherwise destroyed, removed, or immobilized). For this reason, combustion of inorganic wastes is not a "metho[d] of treatment * * * which substantially diminish[es] the toxicity of the waste or substantially reduce[s] the likelihood of migration of hazardous constituents from the waste * * *" (RCRA § 3004(m)) and so is not a permissible method of treatment under that provision.

In terms of the dilution prohibition, if combustion is allowed as a method to achieve a treatment standard for these wastes, metals in these wastes will be dispersed to the ambient air and will be diluted by being mixed in with combustion ash from other waste streams. Adequate treatment (stabilization or metal recovery to meet LDR treatment standards) has not been performed and dilution has occurred. It is also inappropriate to regard eventual stabilizing of such combustion ash as providing adequate treatment for purposes of the LDRs. Simply meeting the numerical BDAT standards for the ash fails to account for metals in the original waste stream that were emitted to the air and for reductions achieved by dilution with other materials in the ash. (In most cases, of course, the metal-bearing wastes will have been mixed with other wastes before combustion, which mixing itself could be viewed as impermissible dilution).

These inorganic, metal-bearing hazardous wastes should be—and are usually—treated by metal recovery or stabilization technologies. These technologies remove hazardous constituents through recovery in products, or through immobilization, and are therefore permissible BDAT treatment methods.

There are eight characteristic metal wastes; however, only wastes that exhibit the TC as measured by both the TCLP and the EP for D004–D011 are presently prohibited (see 55 FR 22660–22662, June 1, 1990). EPA recently proposed prohibition and treatment standards for wastes identified as hazardous solely because they exhibit the TC (60 FR at 43682, August, 22, 1995). Characteristic wastes, of course, cannot be generically characterized as easily as listed wastes because they can be generated from many different types of processes. For example, although some characteristic metal wastes do not contain organics or cyanide or contain only insignificant amounts, others may have organics or cyanide present which justify combustion, such as a used oil exhibiting the TC characteristic for a metal. Thus, it is difficult to say which D004–D011 wastes would be impermissibly diluted when combusted, beyond stating that as a general matter, impermissible dilution would occur if the D004–D011 waste does not have significant organic or cyanide content but is nevertheless combusted.

An "inorganic metal-bearing waste" is one for which EPA has established treatment standards for metal hazardous constituents, and which does not otherwise contain significant organic or cyanide content. The table being promulgated in 40 CFR part 268, Appendix XI is the list of waste codes for which EPA regulates only metals that are affected by this rule.

2. Inorganic Metal-Bearing Wastes Not Prohibited Under the LDR Dilution Prohibition

Combustion of the following inorganic metal-bearing wastes is not prohibited under the LDR dilution prohibition: (1) wastes that, at the point of generation, or after any bona fide treatment such as cyanide destruction prior to combustion, contain hazardou organic constituents or cyanide at leve. exceeding the constituent-specific treatment standard for UTS; (2) organic, debris-like materials (e.g., wood, paper, plastic, or cloth) contaminated with an inorganic metal-bearing hazardous waste; (3) wastes that, at point of generation, have reasonable heating value such as greater than or equal to 5000 Btu/lb (see 48 FR 11157, March 16, 1983); (4) wastes co-generated with wastes that specify combustion as a required method of treatment; (5) wastes, including soil, subject to Federal and/or State requirements necessitating reduction of organics (including biological agents); and (6) wastes with greater than 1% Total Organic Carbon (TOC).

Several commenters want EPA to add additional criteria. One commenter recommended adding a seventh criterion, i.e., combustion that results in a significant reduction in volume. Several commenters recommended adding a seventh criterion to allow combustion of lab packs. The Agency is not persuaded that a seventh criterion is necessary. It has determined that volume reduction is not a sufficient reason to allow the combustion of inorganic metal-bearing wastes because metals are neither destroyed nor immobilized, and it is possible that a significant amount of metal is being transferred to another media. As for lab packs, in the Phase II final rule (59 FR 47982, September 19, 1994), the Agency specifically addressed lab pack issues when it revised 268 Appendix IV to specify those wastes that are prohibited from inclusion in lab packs destined for combustion. Today's dilution prohibition does not supersede the streamlined treatment standards promulgated in the Phase II final rule. Therefore, metal-bearing inorganic wastes may be included in a lab pack unless it is prohibited under the list of wastes in 268 Appendix IV.

3. Cyanide-Bearing Wastes

A commenter questioned why EPA allows the presence of cyanide to justify combustion when there are adequate alternative treatment methods for that waste constituent. This approach was adopted because cyanide is destroyed—i.e., effectively treated and not diluted—by combustion. Existing LDR rules, in many cases, identify combustion as an appropriate BDAT for destruction of cyanide-bearing wastes. See, e.g., treatment standards for F009, F010, an. F011. The LDR Phase III proposal solicited comments on whether the

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Land Disposal Restrictions Rulemaking, also found in the docket for today's rule.

In general, EPA's capacity analysis methodologies focus on the amount of waste to be restricted from land disposal that is currently managed in land-based units and that will require alternative treatment as a result of the LDRs. The quantity of wastes that are not managed in land-based units (e.g., wastewaters managed only in RCRA exempt tanks, with direct discharge to a POTW) is not included in the quantities requiring alternative treatment as a result of the LDRs. Also, wastes that do not require alternative treatment (e.g., those that are currently treated using an appropriate treatment technology) are not included in these quantity estimates.

EPA's decisions on whether to grant a national capacity variance are based on the availability of alternative treatment or recovery technologies. Consequently, the methodology focuses on deriving estimates of the quantities of waste that will require either commercial treatment or the construction of new on-site treatment systems as a result of the LDRs—quantities of waste that will be treated adequately either on site in existing systems or off site by facilities owned by the same company as the generator (i.e., captive facilities) are omitted from the required capacity estimates.

B. Capacity Analysis Results Summary

For the decharacterized ICR and TC wastes managed in CWA, CWA-equivalent, and Class I injection well systems, EPA estimates that between 85 and 500 million tons per year (estimated at end-of-pipe) will be affected as a result of today's rule. EPA believes that many affected facilities need time to build treatment capacity for these wastes, as wastewater volumes generally make off-site treatment impractical. Thus, EPA has determined that sufficient alternative treatment capacity is not available, and today is granting a two-year national capacity variance for decharacterized wastewaters.

Commenters to the rule generally supported EPA's decision to grant a national capacity variance for decharacterized wastes managed in CWA, CWA-equivalent, and Class I injection well systems. Numerous other comments were received on issues such as those associated with the definition of point of generation for ICR and TC wastewaters and the applicability of today's rule to wastewater management units other than surface impoundments, such as stormwater impoundments, sumps, sewers, and trenches. The Response to Capacity-Related Comments Received on the Phase III Land Disposal Restrictions Rulemaking background document provides a detailed discussion of the capacity-related comments on decharacterized wastewaters and EPA's response to them.

To assess the quantity of D003 wastes that could be affected by the rule other than those wastes managed in CWA and CWA-equivalent systems, EPA extracted information from the 1993 Biennial Reporting System (BRS) on the generation and management of D003 wastes. According to the BRS, approximately 2.2 million tons of D003 wastewaters are currently deepwell injected, 650 tons of D003 nonwastewaters are managed through land application, and 17,600 tons of D003 nonwastewaters are managed in "other" disposal units (not specified in the BRS). These wastes may require additional treatment in order to meet the LDRs. In addition, some D003 waste that may be affected by the rule may not be reported in the BRS, because these wastes may not be considered hazardous by the generator once they have been decharacterized. Although EPA believes that in general there is adequate treatment capacity for these wastes, such capacity may not be immediately available. Therefore, EPA is granting a 90-day capacity variance for D003 wastes that are impacted by the rule and are not managed in CWA and CWA-equivalent systems in order to allow facilities time to determine whether their wastes are affected by this rule, and identify and locate alternative treatment capacity if necessary.

EPA estimates that approximately 105,000—130,000 tons of newly listed wastes included in today's rule will require alternative treatment. In particular, approximately 4,500 tons of carbamate wastes (K156–K161, P127, P128, P185, P188–P192, P194, P196–P199, P201–P205, U271, U277–U280, U364–U367, U372, U373, U375–U379, U381–U387, U389–U396, U400–U404, U407, U409–U411) will require alternative treatment. In addition, 100,000—125,000 tons (not including contaminated media) of spent aluminum potliners (K088) will require alternative treatment capacity.

EPA received a number of comments on its capacity analysis for K088 wastes. Most commenters disagreed with EPA's proposal not to grant a capacity variance for K088 wastes. Specifically, these commenters believe that EPA overestimated the quantity of available capacity and underestimated the quantity of required capacity. In performing the capacity analysis for the final rule, EPA considered all of the issues raised by the commenters and reexamined its estimates of both available and required capacity. EPA found that adequate treatment capacity does exist for K088 wastes, although the amount of treatment capacity appears to be just adequate to accommodate demand. However, some of the facilities capable of treating these wastes may require pretreatment such as grinding or crushing prior to accepting the waste. In order to allow facilities generating K088 adequate time to work out logistics such as transportation, pretreatment capacity, and contracting for treatment capacity, EPA has decided to grant a nine-month national capacity variance for these wastes—the time at which EPA estimates existing treatment capacity will be available as a practical matter. A detailed discussion of the final capacity analysis is provided in the Background Document for Capacity Analysis for Land Disposal Restrictions, Phase III—Decharacterized Wastewaters, Carbamate Wastes, and Spent Potliners and EPA's responses to the individual comments on the K088 capacity analysis are provided in the Response to Capacity-Related Comments Received on the Phase III Land Disposal Restrictions Rulemaking, both of which are in the docket for today's rule.

EPA has determined that there is adequate alternative treatment capacity available for the 4,500 tons of carbamate wastes generated each year and is therefore not granting a national capacity variance for these wastes.

The quantities of radioactive wastes mixed with wastes included in today's rule are generated primarily by the U.S. Department of Energy (DOE). EPA estimates that 820 tons of high-level waste and 360 tons of mixed low-level waste that may be affected by this proposal will be generated annually by DOE. In addition, there are currently 7,000 tons of high-level waste, 10 tons of mixed transuranic waste, and 2,700 tons of mixed low-level waste in storage that may be affected by this rule. DOE currently faces treatment capacity shortfalls for high-level wastes and mixed transuranic wastes. Although DOE does have some available treatment capacity for mixed low-level wastes, most of this capacity is limited to treatment of wastewaters with less than one percent total suspended solids and is not readily adaptable for other waste forms. DOE has indicated that it will generally give treatment priority to mixed wastes that are already restricted under previous LDR rules. Therefore, EPA is granting a two-year national capacity variance to radioactive wastes mixed with the hazardous wastes affected by today's rule. Commenters to the proposed rule supported EPA's

be neither more or less stringent since the technology basis of the standards has not changed. Accordingly, EPA will not implement the amendments to the UTS in today's LDR Phase III rule for those states with LDR authorization.

Because today's rule is promulgated pursuant to HSWA, a State submitting a program modification may apply to receive interim or final authorization under RCRA section 3006(g)(2) or 3006(b), respectively, on the basis of requirements that are substantially equivalent or equivalent to EPA's. The procedures and schedule for State program modifications for final authorization are described in 40 CFR 271.21. It should be noted that all HSWA interim authorizations will expire January 1, 2003. (See § 271.24 and 57 FR 60132, December 18, 1992.)

Section 271.21(e)(2) requires that States with final authorization must modify their programs to reflect Federal program changes and to subsequently submit the modification to EPA for approval. The deadline by which the State would have to modify its program to adopt these regulations is specified in § 271.21(e). This deadline can be extended in certain cases (see § 271.21(e)(3)). Once EPA approves the modification, the State requirements become Subtitle C RCRA requirements.

States with authorized RCRA programs may already have requirements similar to those in today's rule. These State regulations have not been assessed against the Federal regulations being proposed today to determine whether they meet the tests for authorization. Thus, a State is not authorized to implement these requirements in lieu of EPA until the State program modifications are approved. Of course, states with existing standards could continue to administer and enforce their standards as a matter of State law. In implementing the Federal program, EPA will work with States under agreements to minimize duplication of efforts. In most cases, EPA expects that it will be able to defer to the States in their efforts to implement their programs rather than take separate actions under Federal authority.

States that submit official applications for final authorization less than 12 months after the effective date of these regulations are not required to include standards equivalent to these regulations in their application. However, the State must modify its program by the deadline set forth in § 271.21(e). States that submit official applications for final authorization 12 months after the effective date of these regulations must include standards equivalent to these regulations in their application. The requirements a State must meet when submitting its final authorization application are set forth in 40 CFR 271.3.

IX. Regulatory Requirements

A. Regulatory Impact Analysis Pursuant to Executive Order 12866

Executive Order No. 12866 requires agencies to determine whether a regulatory action is "significant." The Order defines a "significant" regulatory action as one that "is likely to result in a rule that may: (1) have an annual effect on the economy of $100 million or more or adversely affect, in a material way, the economy, a sector of the economy, productivity, competition, jobs, the environment, public health or safety, or State, local, or tribal governments or communities; (2) create serious inconsistency or otherwise interfere with an action taken or planned by another agency; (3) materially alter the budgetary impact of entitlements, grants, user fees, or loan programs or the rights and obligations of recipients; or (4) raise novel legal or policy issues arising out of legal mandates, the President's priorities, or the principles set forth in the Executive Order."

The Agency estimated the costs of today's rule to determine if it is a significant regulation as defined by the Executive Order. The analysis considers compliance cost and economic impacts for both characteristic wastes and newly listed wastes affected by this rule. For characteristic wastes, the potential cost impacts of this rule depend on whether facilities' current wastewater treatment systems will meet the UTS levels or if additional treatment will be required. If current treatments are adequate, facilities will only incur administrative costs to have their permits revised as well as on-going monitoring costs. In general, the Agency expects that facilities will seek permit modifications, treatability variances, or certification of adequate POTW treatment because these compliance options can be implemented at much lower cost than the option requiring treatment to UTS levels. EPA estimates the total annualized costs of the rule for these wastes would range from approximately $197,000 to $598,000, of which $154,000 to $425,000 would be incurred at the 28 to 73 potentially affected facilities in the organic chemical industry, and approximately $43,000 to $173,000 would be incurred at the 8 to 30 potentially affected facilities in the petroleum refining industry. However, at the high end, if current wastewater treatment systems need to be augmented with additional treatment steps, the incremental compliance costs for today's rule could be as high as $1 million per affected facility. The Agency does not have adequate data to estimate how many, if any, facilities may require modification to their treatment facilities. The Agency did conduct a sensitivity analysis, considering the costs of the rule under two scenarios: (1) Assuming that 80 percent of the facilities comply with the rule by obtaining permit modifications and 20 percent comply by treating their wastes, and, (2) assuming that 60 percent comply by obtaining permit modifications and 40 percent comply by treating their wastes. Based on the first scenario, the estimated annualized costs of the rule would range from $6.6 million to $18.2 million. Based on the second scenario, the estimated annualized costs would range from $12.9 million to $35.7 million. For newly listed wastes, the costs are substantially higher and will be incurred each year. These costs range from approximately $11.9 million to $47.3 million and are attributable to thermal treatment of aluminum potliner wastes (K088). Therefore, today's rule may be considered an economically significant rule. Because today's rule is significant, the Agency analyzed the costs, economic impacts, and benefits.

This section of the preamble for today's rule provides a discussion of the methodology used for estimating the costs, economic impacts and the benefits attributable to today's rule, followed by a presentation of the cost, economic impact and benefit results. More detailed discussions of the methodology and results may be found in the background document, "Regulatory Impact Analysis of the Land Disposal Restrictions Final Rule for the LDR Phase III Newly Listed and Identified Wastes," which has been placed in the docket for today's rule.

1. Methodology Section

In today's rule, the Agency is establishing treatment standards for the following wastes: end-of-pipe standards for ignitable, corrosive, and reactive (ICR) wastewaters managed in CWA, CWA-equivalent systems, and UIC wells; Toxicity Characteristic pesticide (D012–17) and organic (D018–43) wastewaters managed in CWA, CWA-equivalent systems, and UIC wells; and newly listed wastes from two industries—spent aluminum potliners and carbamates.

a. Methodology for Estimating the Affected Universe. In determining the costs, economic impacts, and benefits associated with today's rule, the Agency

newly listed carbamate wastes are expected to be minimal.

i. Estimation of Pollutant Loadings Reductions. An incremental approach was used to estimate reductions in pollutant loadings. For the baseline scenario, contaminant concentrations were based upon data or estimates of current effluent discharge concentration levels. For the post-regulatory scenario, concentration levels were assumed to equal UTS levels.

ii. Estimation of Reductions in Exceedances of Health-Based Levels. The methods used for evaluating the benefits associated with cancer and noncancer risk reductions resulting from the rule entail comparing constituent concentration levels to health-based standards to evaluate whether implementation of the rule reduces concentration levels below levels that pose risk to human health.

To estimate benefits from cancer risk reductions resulting from the rule, a simple screening analysis was performed. This analysis compared contaminant concentrations for the baseline and post-regulatory scenario to health-based levels for carcinogens. Further analysis may be undertaken to quantify benefits associated with facility/ wastestream combinations identified in the contaminant concentration comparisons.

Benefits associated with reductions in non-cancer exceedances are estimated based upon comparisons of contaminant concentration levels in effluent discharges of the affected wastestreams to the reference health levels. These benefits are expressed in terms of the number of exceedances of health-based levels under the baseline scenario compared to the number of exceedances under the rule.

iii. Qualitative Description of the Potential Benefits. A qualitative assessment of potential benefits likely to result from the rule is used where data are limited. The Agency acknowledges limited data availability in developing waste volumes affected, constituents, concentrations, cost estimates, economic impacts, and benefits estimates for the LDR Phase III rulemaking. The Agency continues to request comment from industry regarding constituents, concentrations, waste volumes, and current management practices.

2. Results

a. Volume Results. The Agency has estimated the volumes of formerly characteristic wastes potentially affected by today's rule to total in the range of 33.5 to 500 million metric tons. The Agency requests comment on waste volumes affected by the LDR Phase III rule. For newly listed wastes, the analyses supporting the listing determination showed about 4,500 metric tons of carbamate wastes and 118,000 metric tons of spent aluminum potliners are potentially affected by this rule.

b. Cost Results. For characteristic wastes, the potential cost impacts of this rule depend on whether facilities' current wastewater treatment systems will meet the UTS levels or if additional treatment will be required. If current treatments are adequate, facilities will only incur administrative costs to have their permits revised. EPA estimates the total annualized costs of the rule for these wastes would range from approximately $197,000 to $598,000, of which $154,000 to $425,000 would be incurred at the 28 to 73 potentially affected facilities in the organic chemical industry, and approximately $43,000 to $173,000 would be incurred at the 8 to 30 potentially affected facilities in the petroleum refining industry. However, at the high end, if current wastewater treatment systems need to be augmented with additional treatment steps, the incremental compliance costs could be as high as $1 million per affected facility. The Agency does not have adequate data to estimate how many, if any, facilities may require modification to their treatment facilities. The Agency continues to request comment and data on how often additional treatment may be required. For newly listed wastes, the costs are substantially higher and will be incurred each year. These costs range from approximately $11.9 million to $47.3 million and are attributable to thermal treatment of aluminum potliner wastes (K088). The Agency requests comment on where industry falls within this range.

c. Economic Impact Results. The Agency has estimated the economic impacts of today's rule to represent less than one percent of historic pollution control and operating costs for the organic chemical and petroleum refining industries. However, for those facilities that may need to treat to UTS to comply with today's rule, costs could be more significant. The estimated compliance costs for treating newly listed spent aluminum potliners represents 40 percent of pollution control operating costs for aluminum reducers; however, treatment costs represent only one percent of total historic operating costs.

d. Benefit Estimate Results. The Agency expects facilities to comply with the LDRs through permit modifications. As a result, the Agency has estimated the benefits associated with today's rule to be small. Assuming facilities comply with the rule by treating their affected wastestreams, loadings reductions estimates range between 1,527 to 21,322 metric tons per year at 129 to 291 facilities (direct and indirect dischargers) involving 175 to 647 constituent/wastestream combinations. Ninety-eight percent of the reductions occur at organic chemicals facilities, with the remainder occurring at petroleum refiners. Estimated loadings reductions for direct dischargers range between 36 and 267 tons per year, representing between 0.03 and 0.2 percent of total Toxic Release Inventory (TRI) chemical loadings to surface waters. For indirect dischargers, estimated loadings reductions range between 1,491 and 21,055 metric tons per year, representing between 0.8 and 11.0 percent of total TRI chemical loadings transferred to POTWs. Based upon the results of the screening and more detailed risk assessments, the estimated baseline risks associated with nine to twenty wastestreams (out of the 155 to 404 constituent/wastestream combinations potentially affected by the rule) exceed 10^{-6} under baseline conditions and three to six wastestreams with noncancer risk levels exceeding reference doses. These 12 to 26 wastestreams contain one of five constituents: aniline (9 to 19 wastestreams), acrylamide (0 to 1 wastestream), pyridine (2 waststreams), barium compounds (1 wastestream), and acetonitrile (0 to 2 wastestreams). For these 12 to 26 wastestreams, EPA conducted a more detailed risk assessment, using site-specific data. Results of the more detailed risk assessment indicate that the benefits from the rule are small. EPA identified four wastestreams potentially posing cancer risk exceeding the threshold risk levels. Three wastestreams pose baseline cancer risk ranging from 1×10^{-5} to 1×10^{-4} (due to exposure to aniline) which potentially would be reduced to between 8×10^{-8} and 3×10^{-6} under the LDR Phase III rule. A fourth wastestream containing acrylamide poses baseline cancer risk at a level of 2×10^{-3}. The rule is estimated to reduce this risk to between 2×10^{-4} and 4×10^{-36}. All four of these wastestreams are discharged to POTWs; if POTW treatment removes these constituents from the wastewater prior to discharge to surface water and/or if no drinking water intake is located downstream from the POTW's outfall, baseline risks will be lower. The Agency expects facilities to comply with the LDRs through permit modifications;

from $3.67 million per year for all facilities incurring only petition costs to $132.62 million per year for all facilities incurring both petition and treatment costs. Based on past EPA experience, there is little probability that all facilities will arrive at each of these possible outcomes. However, this indicated range provides an extreme lower and upper bound estimate for national compliance costs purposes.

The benefits to human health and the environment in the RIA are generally defined as reduced human health risk resulting from fewer instances of ground water contamination. In general, potential health risks from Class I injection wells are extremely low.

EPA conducted a quantitative assessment of the potential human health risks associated with two well malfunction scenarios. EPA developed a methodology described in the RIA to measure health risks of five Phase III contaminants: benzene, carbon tetrachloride, chloroform, phenol, and toluene. The results of these analyses show that most of the cancer risks calculated are below the 1×10^{-4} to 1×10^{-6} risk range generally used by EPA to regulate exposure to carcinogens. Virtually all of the non-cancer risks are below a hazard index (HI) of 1, which represents a ratio used to compare the relative health risks posed by contaminants. Therefore, these cancer and non-cancer risks calculated are below any levels of regulatory concern. Only two cancer risk estimates in the high end scenarios, those calculated for benzene and carbon tetrachloride, slightly exceeded the risk range to regulate exposure to carcinogens. Only one hazard index calculated for carbon tetrachloride exceeded EPA's level of concern of a ratio greater than 1. However, these results were derived from a scenario where an abandoned borehole (i.e. the "failure pathway") was in very close proximity to the injection well, substantial pumping of a drinking water well was occurring, and the local geology was typical of the highly transmissive East Gulf Coast Region. The assumptions used in deriving these results were based on conservative, upper-bound estimates, therefore the cancer and non-cancer risks represent worst-case estimates. Considering the limitations imposed by the failure scenarios, and the documented low probability of Class I failures, the overall risks from failure of Class I injection wells would be below regulatory concern.

There also is a potential qualitative benefit to the no-migration process for Class I nonhazardous wells. It is possible that the process would uncover certain wells that cannot satisfy the no-migration standard and indeed may not be suitable for Class I injection in any case. This proved to be true for Class I hazardous wells. However, notwithstanding this potential benefit, as noted in the early part of this preamble, the Agency does not regard this regulatory effort as deserving of the priority afforded it, due to the litigation-driven schedule and the D.C. Circuit's mandate, and would not be undertaking the effort at this time were it not for that mandate and schedule.

The economic analysis of LDR Phase III compliance costs suggests that publicly traded companies probably will not be significantly affected. The limited data available for privately-held companies suggests, however, that they may face significant costs due to the proportionally larger expenses they may face due to the LDR Phase III rule.

C. Regulatory Flexibility Analysis

Pursuant to the Regulatory Flexibility Act of 1980, 5 U.S.C. 601 et seq., when an agency publishes a notice of rulemaking, for a rule that will have a significant effect on a substantial number of small entities, the agency must prepare and make available for public comment a regulatory flexibility analysis that considers the effect of the rule on small entities (i.e.: small businesses, small organizations, and small governmental jurisdictions). Under the Agency's Revised Guidelines for Implementing The Regulatory Flexibility Act, dated May 4, 1992, the Agency committed to considering regulatory alternatives in rulemakings when there were any economic impacts estimated on any small entities. (See RCRA sections 3004 (d), (e), and (g)(5), which apply uniformly to all hazardous wastes.) Previous guidance required regulatory alternatives to be examined only when significant economic effects were estimated on a substantial number of small entities.

In assessing the regulatory approach for dealing with small entities in today's rule, for both surface disposal of wastes, the Agency considered two factors. First, data on potentially affected small entities are unavailable. Second, due to the statutory requirements of the RCRA LDR program, no legal avenues exist for the Agency to provide relief from the LDR's for small entities. The only relief available for small entities is the existing small quantity generator provisions and conditionally exempt small quantity generator exemptions found in 40 CFR 262.11–12, and 261.5, respectively. These exemptions basically prescribe 100 kilograms (kg) per calendar month generation of hazardous waste as the limit below which one is exempted from complying with the RCRA standards.

Given these two factors, the Agency was unable to frame a series of small entity options from which to select the lowest cost approach; rather, the Agency was legally bound to regulate the land disposal of the hazardous wastes covered in today's rule without regard to the size of the entity being regulated.

The Agency has, however, included an exemption covering injection facilities where the decharacterized portion of the injectate is minimal in absolute terms, as a percentage of the total injectate, and in hazardous constituent mass loadings. This *de minimis* exemption provides a measure of relief to both small and larger entities satisfying its terms.

D. Paperwork Reduction Act

The information collection requirements in this rule have been submitted for approval to the Office of Management and Budget (OMB) under the Paperwork Reduction Act, 44 U.S.C. 3501 *et seq.* Four Information Collection Request (ICR) documents have been prepared by EPA, as follows. OSWER ICR No. 1442.12 would amend the existing ICR approved under OMB Control No. 2050–0085 the additional information requirements for the Underground Injection Control (UIC) Program were submitted to OMB under ICR No. 0370.14; this will amend the existing UIC approval under OMB Control No. 2040–0042. OSWER ICR No. 1442.12 and UIC ICR No. 0370.14 have not been approved by OMB and the information collection requirements in those ICRs are not enforceable until OMB approves them. EPA will publish a document in the Federal Register when OMB approves the information collection requirements. Until EPA publishes a document displaying the valid OMB control number, persons are not required to respond to collections of information in these two ICRs. Two amendments to National Pollutant Discharge Elimination System (NPDES) ICRs were approved at proposal. These are ICR 0229.10 for the Discharge Monitoring Report, approved under OMB Control No. 2040–0004, and ICR 0226.11 for NPDES Applications, approved under OMB Control No. 2040–0086.

Copies of these ICRs may be obtained from Sandy Farmer, OPPE Regulatory Information Division; U.S. Environmental Protection Agency (2136); 401 M St., S.W.; Washington, D.C. 20460 or by calling (202) 260–274 Include the ICR numbers in any reques The information requirements for the

constituents as would be removed by treating the characteristic hazardous wastestream pursuant to the treatment standards in 40 CFR 268.48. This mass reduction can come from:

(1) Treating nonhazardous portions of the injectate;

(2) Recycling before ultimate injection; or

(3) Engaging in pollution prevention practices (such as equipment or technology modifications, substitution of raw materials, and improvements in housekeeping, maintenance, training, or inventory control).

(B) The compliance alternative in paragraph (d)(2)(iii)(A) of this section is demonstrated by comparing the injected baseline (determined by multiplying the volume/day of characteristically hazardous waste generated and injected) times the concentration of hazardous constituents before the treatment/recycling/pollution prevention measure, with the mass allowance obtained by multiplying the volume/day of a hazardous constituent generated and injected times the universal treatment standard for that constituent. The baseline cannot include practices initiated before the year 1990. (Recordkeeping requirements for this alternative are found at 40 CFR 268.9(d)(3).)

3. Section 148.3 is revised to read as follows:

§ 148.3 Dilution prohibited as a substitute for treatment.

(a) The provisions of 40 CFR 268.3 shall apply to owners or operators of Class I wells used to inject a waste which is hazardous at the point of generation whether or not the waste is hazardous at the point of injection.

(b) Owners or operators of Class I nonhazardous waste injection wells which inject waste formerly exhibiting a hazardous characteristic which has been removed by dilution, may address underlying hazardous constituents by treating the hazardous waste, obtaining an exemption pursuant to a petition filed under § 148.20, or complying with the provisions set forth in 40 CFR 268.9.

4. Section 148.4 is revised to read as follows:

§ 148.4 Procedures for case-by-case extensions to an effective date.

The owner or operator of a Class I hazardous or nonhazardous waste injection well may submit an application to the Administrator for an extension of the effective date of any applicable prohibition established under subpart B of this part according to the procedures of 40 CFR 268.5.

5. Section 148.18 is added to subpart B to read as follows:

§ 148.18 Waste specific prohibitions—Newly Identified Wastes.

(a) On July 8, 1996, the wastes specified in 40 CFR 261.32 as EPA Hazardous waste numbers K156–K161, P127, P128, P185, P188–P192, P194, P196–P199, P201–P205, U271, U277–U280, U364–U367, U372, U373, U375–U379, U381–387, U389–U396, U400–U404, U407, and U409–U411 are prohibited from underground injection.

(b) On January 8, 1997, the wastes specified in 40 CFR 261.32 as EPA Hazardous waste number K088 is prohibited from underground injection.

(c) On April 8, 1998, the wastes specified in 40 CFR part 261 as EPA Hazardous waste numbers D018–043, and Mixed TC/Radioactive wastes, are prohibited from underground injection.

(d) On April 8, 1998, the wastes specified in 40 CFR part 261 as EPA Hazardous waste numbers D001–D003 are prohibited from underground injection.

6. Section 148.20 is amended by revising paragraph (a) introductory text to read as follows:

§ 148.20 Petitions to allow injection of a waste prohibited under subpart B.

(a) Any person seeking an exemption from a prohibition under subpart B of this part for the injection of a restricted hazardous waste, including a hazardous waste exhibiting a characteristic and containing underlying hazardous constituents at the point of generation, but no longer exhibiting a characteristic when injected into a Class I injection well or wells, shall submit a petition to the Director demonstrating that, to a reasonable degree of certainty, there will be no migration of hazardous constituents from the injection zone for as long as the waste remains hazardous. This demonstration requires a showing that:

* * * * *

PART 268—LAND DISPOSAL RESTRICTIONS

7. The authority citation for part 268 continues to read as follows:

Authority: 42 U.S.C. 6905, 6912(a), 6921, and 6924.

Subpart A—General

8. Section 268.1 is amended in paragraph (e)(3) by removing the period at the end of the paragraph and adding "; or" in its place, by revising paragraph (e)(4) and by removing paragraph (e)(5) to read as follows:

§ 268.1 Purpose, scope and applicability.

* * * * *

(e) * * *

(4) *De minimis* losses of characteristic wastes to wastewaters are not considered to be prohibited wastes and are defined as:

(i) Losses from normal material handling operations (e.g. spills from the unloading or transfer of materials from bins or other containers, leaks from pipes, valves or other devices used to transfer materials); minor leaks of process equipment, storage tanks or containers; leaks from well-maintained pump packings and seals; sample purgings; and relief device discharges; discharges from safety showers and rinsing and cleaning of personal safety equipment; rinsate from empty containers or from containers that are rendered empty by that rinsing; and laboratory wastes not exceeding one per cent of the total flow of wastewater into the facility's headworks on an annual basis, or with a combined annualized average concentration not exceeding one part per million in the headworks of the facility's wastewater treatment or pretreatment facility; or

(ii) Decharacterized wastes which are injected into Class I nonhazardous wells which wastes combined volume is less than one per cent of the total flow at the wellhead on an annualized basis, is no greater than 10,000 gallons per day, and in which any underlying hazardous constituents in the characteristic wastes are present at the point of generation at levels less than ten times the treatment standards found at § 268.48.

* * * * *

9. Section 268.2 is amended by revising paragraphs (f) and (i), and by adding paragraphs (j), (k), and (l) to read as follows:

§ 268.2 Definitions applicable in this part.

* * * * *

(f) *Wastewaters* are wastes that contain less than 1% by weight total organic carbon (TOC) and less than 1% by weight total suspended solids (TSS).

* * * * *

(i) *Underlying hazardous constituent* means any constituent listed in § 268.48, Table UTS—Universal Treatment Standards, except fluoride, vanadium, and zinc, which can reasonably be expected to be present at the point of generation of the hazardous waste, at a concentration above the constituent-specific UTS treatment standards.

(j) *Inorganic metal-bearing waste* is one for which EPA has established treatment standards for metal hazardous constituents, and which does not otherwise contain significant organic or cyanide content as described in § 268.3(b)(1), and is specifically listed in appendix XI of this part.

significant penalties for submitting a false certification, including the possibility of fine and imprisonment.

* * * * *

§ 268.8 [Removed and reserved]

12. Section 268.8 is removed and reserved.

13. Section 268.9 is amended by revising paragraphs (a), (d) introductory text, (d)(1)(i), and (d)(1)(ii), and by adding paragraphs (d)(3), (e), (f), and (g) to read as follows:

§ 268.9 Special rules regarding wastes that exhibit a characteristic.

(a) The initial generator of a solid waste must determine each EPA Hazardous Waste Number (waste code) applicable to the waste in order to determine the applicable treatment standards under subpart D of this part. For purposes of this part 268, the waste will carry the waste code for any applicable listing under 40 CFR part 261, subpart D. In addition, the waste will carry one or more of the waste codes under 40 CFR part 261, subpart C, where the waste exhibits a characteristic, except in the case when the treatment standard for the waste code listed in 40 CFR part 261, subpart D operates in lieu of the standard for the waste code under 40 CFR part 261, subpart C, as specified in paragraph (b) of this section. If the generator determines that his waste displays a hazardous characteristic (and the waste is not a D004—D011 waste, a High TOC D001, or is not treated by CMBST, or RORGS of § 268.42, Table 1), the generator must determine what underlying hazardous constituents (as defined in § 268.2), are reasonably expected to be present above the universal treatment standards found in § 268.48.

* * * * *

(d) Wastes that exhibit a characteristic are also subject to § 268.7 requirements, except that once the waste is no longer hazardous, a one-time notification and certification must be placed in the generators or treaters files and sent to the EPA region or authorized state, except for those facilities discussed in paragraph (f) of this section. The notification and certification that is placed in the generators or treaters files must be updated if the process or operation generating the waste changes and/or if the Subtitle D facility receiving the waste changes. However, the generator or treater need only notify the EPA region or an authorized state on an annual basis if such changes occur. Such notification and certification should be sent to the EPA region or authorized state by the end of the calendar year, but no later than December 31.

(1) * * *

(i) For characteristic wastes other than those managed on site in a wastewater treatment system subject to the Clean Water Act (CWA), zero-dischargers engaged in CWA-equivalent treatment, or Class I nonhazardous injection wells, the name and address of the Subtitle D facility receiving the waste shipment; and

(ii) For all characteristic wastes, a description of the waste as initially generated, including the applicable EPA Hazardous Waste Number(s), treatability group(s), and underlying hazardous constituents.

* * * * *

(3) For characteristic wastes whose ultimate disposal will be into a Class I nonhazardous injection well, and compliance with the treatment standards found in § 268.48 for underlying hazardous constituents is achieved through pollution prevention that meets the criteria set out at 40 CFR 148.1(d), the following information must also be included:

(i) A description of the pollution prevention mechanism and when it was implemented if already complete;

(ii) The mass of each underlying hazardous constituent before pollution prevention;

(iii) The mass of each underlying hazardous constituent that must be removed, adjusted to reflect variations in mass due to normal operating conditions; and

(iv) The mass reduction of each underlying hazardous constituent that is achieved.

(e) For decharacterized wastes managed on-site in a wastewater treatment system subject to the Clean Water Act (CWA) or zero-dischargers engaged in CWA-equivalent treatment, compliance with the treatment standards found at § 268.48 must be monitored quarterly, unless the treatment is aggressive biological treatment, in which case compliance must be monitored annually. Monitoring results must be kept in on-site files for 5 years.

(f) For decharacterized wastes managed on-site in a wastewater treatment system subject to the Clean Water Act (CWA) for which all underlying hazardous constituents (as defined in § 268.2), are addressed by a CWA permit, this compliance must be documented and this documentation must be kept in on-site files.

(g) For characteristic wastes whose ultimate disposal will be into a Class I nonhazardous injection well which qualifies for the *de minimis* exclusion described in § 268.1, information supporting that qualification must be kept in on-site files.

§§ 268.10–268.12 [Removed and Reserved]

14. Sections 268.10 through 268.12 are removed and reserved.

15. Section 268.39 is added to subpart C to read as follows:

§ 268.39 Waste specific prohibitions—End-of-pipe CWA, CWA-equivalent, and Class I nonhazardous injection well treatment standards; spent aluminum potliners; and carbamate wastes.

(a) On July 8, 1996, the wastes specified in 40 CFR 261.32 as EPA Hazardous Waste numbers K156–K161; and in 40 CFR 261.33 as EPA Hazardous Waste numbers P127, P128, P185, P188–P192, P194, P196–P199, P201–P205, U271, U277–U280, U364–U367, U372, U373, U375–U379, U381–U387, U389–U396, U400–U404, U407, and U409–U411 are prohibited from land disposal. In addition, soil and debris contaminated with these wastes are prohibited from land disposal.

(b) On July 8, 1996 the wastes identified in 40 CFR 261.23 as D003 that are managed in systems other than those whose discharge is regulated under the Clean Water Act (CWA), or that inject in Class I deep wells regulated under the Safe Drinking Water Act (SDWA), or that are zero dischargers that engage in CWA-equivalent treatment before ultimate land disposal, are prohibited from land disposal. This prohibition does not apply to unexploded ordnance and other explosive devices which have been the subject of an emergency response (such D003 wastes are prohibited unless they meet the treatment standard of DEACT before land disposal (see § 268.40)).

(c) On July 8, 1996, the wastes specified in 40 CFR 261.32 as EPA Hazardous Waste number K088 are prohibited from land disposal. In addition, soil and debris contaminated with these wastes are prohibited from land disposal.

(d) On April 8, 1998, decharacterized wastes managed in surface impoundments whose discharge is regulated under the Clean Water Act (CWA), or decharacterized wastes managed by zero dischargers in surface impoundments or tanks that engage in CWA-equivalent treatment before ultimate land disposal are prohibited from land disposal. The following are exceptions to this requirement.

(1) Surface impoundments which are permitted under subtitle C of RCRA;

(2) Storm water impoundments as defined in § 268.2;

TREATMENT STANDARDS FOR HAZARDOUS WASTES

(Note: NA means not applicable.)

Waste code	Waste description and treatment/regulatory subcategory[1]	Regulated hazardous constituent		Wastewaters	Nonwastewaters
		Common name	CAS[2] No.	Concentration in mg/l[3]; or technology code[4]	Concentration in mg/kg[5] unless noted as "mg/l TCLP"; or technology code
D001	Ignitable Characteristic Wastes, except for the § 261.21(a)(1) High TOC Subcategory.	NA	NA	DEACT and meet § 268.48 standards; or RORGS; or CMBST[6]	DEACT and meet § 268.48 standards; or RORGS; or CMBST[6]
	High TOC Ignitable Characteristic Liquids Subcategory based on 40 CFR 261.21(a)(1)—Greater than or equal to 10% total organic carbon. (Note: This subcategory consists of nonwastewaters only).	NA	NA	NA	RORGS; or CMBST
D002	Corrosive Characteristic Wastes.	NA	NA	DEACT and meet § 268.48 standards[6]	DEACT and meet § 268.48 standards[6]
D002, D004, D005, D006, D007, D008, D009, D010, D011.	Radioactive high level wastes generated during the reprocessing of fuel rods. (Note: This subcategory consists of nonwastewaters only).	Corrosivity (pH)	NA	NA	HLVIT
		Arsenic	7440–38–2	NA	HLVIT
		Barium	7440–39–3	NA	HLVIT
		Cadmium	7440–43–9	NA	HLVIT
		Chromium (Total)	7440–47–3	NA	HLVIT
		Lead	7439–92–1	NA	HLVIT
		Mercury	7439–97–6	NA	HLVIT
		Selenium	7782–49–2	NA	HLVIT
		Silver	7440–22–4	NA	HLVIT
D003	Reactive Sulfides Subcategory based on 261.23(a)(5).	NA	NA	DEACT and meet § 268.48 standards[6]	DEACT and meet § 268.48 standards[6]
	Explosives Subcategory based on 261.23(a) (6), (7) and (8).	NA	NA	DEACT and meet § 268.48 standards[6]	DEACT and meet § 268.48 standards[6]
	Unexploded ordnance and other explosive devices which have been the subject of an emergency response.	NA	NA	DEACT	DEACT
	Other Reactives Subcategory based on 261.23(a)(1).	NA	NA	DEACT and meet § 268.48 standards[6]	DEACT and meet § 268.48 standards[6]
	Water Reactive Subcategory based on 261.23(a)(2), (3), and (4). (Note: This subcategory consists of nonwastewaters only).	NA	NA	NA	DEACT and meet § 268.48 standards[6]
	Reactive Cyanides Subcategory based on 261.23(a)(5).	Cyanides (Total)[7]	57–12–5	Reserved	590
		Cyanides (Amendable)[7]	57–12–5	0.86	30
D004	Wastes that exhibit, or are expected to exhibit, the characteristic of toxicity for arsenic based on the extraction procedure (EP) in SW846 Methods 1310.	Arsenic	7440–38–2	5.0	5.0 mg/l EP

95150

D009	Nonwastewaters that exhibit, or are expected to exhibit, the characteristic of toxicity for mercury based on the extraction procedure (EP) in SW846 Method 1310; and contain greater than or equal to 260 mg/kg total mercury that also contain organics and are not incinerator residues. (High Mercury-Organic Subcategory.).	Mercury	7439–97–6	NA	IMERC; OR RMERC
	Nonwastewaters that exhibit, or are expected to exhibit, the characteristic of toxicity for mercury based on the extraction procedure (EP) in SW846 Method 1310; and contain greater than or equal to 260 mg/kg total mercury that are inorganic, including incinerator residues and residues from RMERC. (High Mercury-Inorganic Subcategory.).	Mercury	7439–97–6	NA	RMERC
	Nonwastewaters that exhibit, or are expected to exhibit, the characteristic of toxicity for mercury based on the extraction procedure (EP) in SW846 Method 1310; and contain less than 260 mg/kg total mercury. (Low Mercury Subcategory.).	Mercury	7439–97–6	NA	0.20 mg/l TCLP
	All D009 wastewaters	Mercury	7439–97–6	0.20	NA
	Elemental mercury contaminated with radioactive materials. (Note: This subcategory consists of nonwastewaters only.).	Mercury	7439–97–6	NA	AMLGM
	Hydraulic oil contaminated with Mercury Radioactive Materials Subcategory. (Note: This subcategory consists of nonwastewaters only.).	Mercury	7439–97–6	NA	IMERC
D010	Wastes that exhibit, or are expected to exhibit, the characteristic of toxicity for selenium based on the extraction procedure (EP) in SW846 Method 1310.	Selenium	7782–49–2	1.0	5.7 mg/l TCLP
D011	Wastes that exhibit, or are expected to exhibit, the characteristic of toxicity for silver based on the extraction procedure (EP) in SW846 Method 1310.	Silver	7440–22–4	5.0	5.0 mg/l TCLP
D012	Wastes that are TC for Endrin based on the TCLP in SW846 Method 1311.	Endrin	72–20–8	BIODG; or CMBST[a]	0.13 and meet § 268.48 standards[a]
		Endrin aldehyde	7421–93–4	BIODG; or CMBST[a]	0.13 and meet § 268.48 standards[a]
D013	Wastes that are TC for Lindane based on the TCLP in SW846 Method 1311.).	alpha-BHC	319–84–6	CARBN; or CMBST[a]	0.066 and meet § 268.48 standards[a]
		beta–BHC	319–85–7	CARBN; or CMBST[a]	0.066 and meet § 268.48 standards[a]
		delta-BHC	319–86–8	CARBN; or CMBST[a]	0.066 and meet § 268.48 standards[a]
		gamma-BHC (Lindane)	58–89–9	CARBN; or CMBST[a]	0.066 and meet § 268.48 standards[a]
D014	Wastes that are TC for Methoxychlor based on the TCLP in SW846 Method 1311.	Methoxychlor	72–43–5	WETOX or CMBST[a]	0.18 and meet § 268.48 standards[a]

D030	Wastes that are TC for 2,4-Dinitrotoluene based on the TCLP in SW846 Method 1311.	2,4-Dinitrotoluene	121–14–2	0.32 and meet § 268.48 standards [8]	140 and meet § 268.48 standards [8]
D031	Wastes that are TC for Heptachlor based on the TCLP in SW846 Method 1311.	Heptachlor	76–44–8	0.0012 and meet § 268.48 standards [8]	0.066 and meet § 268.48 standards [8]
		Heptachlor epoxide	1024–57–3	0.016 and meet § 268.48 standards [8]	0.066 and meet § 268.48 standards [8]
D032	Wastes that are TC for Hexachlorobenzene based on the TCLP in SW846 Method 1311.	Hexachlorobenzene	118–74–1	0.055 and meet § 268.48 standards [8]	10 and meet § 268.48 standards [8]
D033	Wastes that are TC for Hexachlorobutadiene based on the TCLP in SW846 Method 1311.	Hexachlorobutadiene	87–68–3	0.055 and meet § 268.48 standards [8]	5.6 and meet § 268.48 standards [8]
D034	Wastes that are TC for Hexachloroethane based on the TCLP in SW846 Method 1311.	Hexachloroethane	67–72–1	0.055 and meet § 268.48 standards [8]	30 and meet § 268.48 standards [8]
D035	Wastes that are TC for Methyl ethyl ketone based on the TCLP in SW846 Method 1311.	Methyl ethyl ketone	78–93–3	0.28 and meet § 268.48 standards [8]	36 and meet § 268.48 standards [8]
D036	Wastes that are TC for Nitrobenzene based on the TCLP in SW846 Method 1311.	Nitrobenzene	98–95–3	0.068 and meet § 268.48 standards [8]	14 and meet § 268.48 standards [8]
D037	Wastes that are TC for Pentachlorophenol based on the TCLP in SW846 Method 1311.	Pentachlorophenol	87–86–5	0.089 and meet § 268.48 standards [8]	7.4 and meet § 268.48 standards [8]
D038	Wastes that are TC for Pyridine based on the TCLP in SW846 Method 1311.	Pyridine	110–86–1	0.014 and meet § 268.48 standards [8]	16 and meet § 268.48 standards [8]
D039	Wastes that are TC for Tetrachloroethylene based on the TCLP in SW846 Method 1311.	Tetrachloroethylene	127–18–4	0.056 and meet § 268.48 standards [8]	6.0 and meet § 268.48 standards [8]
D040	Wastes that are TC for Trichloroethylene based on the TCLP in SW846 Method 1311.	Trichloroethylene	79–01–6	0.054 and meet § 268.48 standards [8]	6.0 and meet § 268.48 standards [8]
D041	Wastes that are TC for 2,4,5-Trichlorophenol based on the TCLP in SW846 Method 1311.	2,4,5-Trichlorophenol	95–95–4	0.18 and meet § 268.48 standards [8]	7.4 and meet § 268.48 standards [8]
D042	Wastes that are TC for 2,4,6-Trichlorophenol based on the TCLP in SW846 Method 1311.	2,4,6-Trichlorophenol	88–06–2	0.035 and meet § 268.48 standards [8]	7.4 and meet § 268.48 standards [8]
D043	Wastes that are TC for Vinyl chloride based on the TCLP in SW846 Method 1311.	Vinyl chloride	75–01–4	0.27 and meet § 268.48 standards [8]	6.0 and meet § 268.48 standards [8]

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		1,1,2-Trichloro-1,2,2-trifluoroethane.	76–13–1	0.057	30
		Trichloroethylene	79–01–6	0.054	6.0
		Trichloromonofluoromethane	75–69–4	0.020	30
		Xylenes-mixed isomers (sum of o-, m-, and p-xylene concentrations.	1330–20–7	0.32	30
	F003 and/or F005 solvent wastes that contain any combination of one or more of the following three solvents as the only listed F001–5 solvents: carbon disulfide, cyclohexanone, and/or methanol. (formerly 268.41(c)).	Carbon disulfide	75–15–0	3.8	4.8 mg/1 TCLP
		Cyclohexanone	108–94–1	0.36	0.75 mg/l TCLP
		Methanol	67–56–1	5.6	0.75 mg/l TCLP
	F005 solvent waste containing 2-Nitropropane as the only listed F001–5 solvent..	2-Nitropropane	79–46–9	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
	F005 solvent waste containing 2—Ethoxyethanol as the only listed F001–5 solvent..	2-Ethoxyethanol	110–80–5	BIODG; or CMBST	CMBST
F006	Wastewater treatment sludges from electroplating operations except from the following processes: (1) Sulfuric acid anodizing of aluminum; (2) tin plating on carbon steel; (3) zinc plating (segregated basis) on carbon steel; (4) aluminum or zinc-aluminum plating on carbon steel; (5) cleaning/stripping associated with tin, zinc and aluminum plating on carbon steel; and (6) chemical etching and milling of aluminum..	Cadmium	7440–43–9	0.69	0.19 mg/l TCLP
		Chromium (Total)	7440–47–3	2.77	0.86 mg/l TCLP
		Cyanides (Total)[7]	57–12–5	1.2	590
		Cyanides (Amendable)[7]	57–12–5	0.86	30
		Lead	7439–92–1	0.69	0.37 mg/l TCLP
		Nickel	7440–02–0	3.98	5.0 mg/l TCLP
		Silver	7440–22–4	0.43	0.30 mg/l TCLP
F007	Spent cyanide plating bath solutions from electroplating operations.	Cadmium	7440–43–9	0.69	0.19 mg/1 TCLP
		Chromium (Total)	7440–47–3	2.77	0.86 mg/l TCLP
		Cyanides (Total)[7]	57–12–5	1.2	590
		Cyanides (Amenable)[7]	57–12–5	0.86	30
		Lead	7439–92–1	0.69	0.37 mg/l TCLP
		Nickel	7440–02–0	3.98	5.0 mg/l TCLP
		Silver	7440–22–4	NA	0.30 mg/l TCLP
F008	Plating bath residues from the bottom of plating baths from electroplating operations where cyanides are used in the process.	Cadmium	7440–43–9	NA	0.19 mg/l TCLP
		Chromium (Total)	7440–47–3	2.77	0.86 mg/l TCLP
		Cyanides (Total)[7]	57–12–5	1.2	590
		Cyanides (Amenable)[7]	57–12–5	0.86	30
		Lead	7439–92–1	0.69	0.37 mg/l TCLP
		Nickel	7440–02–0	3.98	5.0 mg/l TCLP
		Silver	7440–22–4	NA	0.30 mg/l TCLP
F009	Spent stripping and cleaning bath solutions from electroplating operations where cyanides are used in the process.	Cadmium	7440–43–9	NA	0.19 mg/l TCLP
		Chromium (Total)	7440–47–3	2.77	0.86 mg/l TCLP
		Cyanides (Total)[7]	57–12–5	1.2	590
		Cyanides (Amenable)[7]	57–12–5	0.86	30
		Lead	7439–92–1	0.69	0.37 mg/l TCLP
		Nickel	7440–02–0	3.98	5.0 mg/l TCLP
		Silver	7440–22–4	NA	0.30 [illegible]LP

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F020, F021, F022, F023, F026	Wastes (except wastewater and spent carbon from hydrogen chloride purification) from the production or manufacturing use (as a reactant, chemical intermediate, or component in a formulating process) of: (1) tri- or tetrachlorophenol, or of intermediates used to produce their pesticide derivatives, excluding wastes from the production of Hexachlorophene from highly purified 2,4,5-trichlorophenol (F020); (2) pentachlorophenol, or of intermediates used to produce its derivatives (i.e., F021); (3) tetra-, penta-, or hexachlorobenzenes under alkaline conditions (i.e., F022); and from the production of materials on equipment previously used for the production or manufacturing use (as a reactant, chemical intermediate, or component in a formulating process) of: (1) tri- or tetrachlorophenols, excluding wastes from equipment used only for the production of Hexachlorophene from highly purified 2,4,5-trichlorophenol (F023); (2) tetra-, penta-, or hexachlorobenzenes under alkaline conditions (i.e., F026).	HxCDDs (All Hexachlorodibenzo-p-dioxins).	NA	0.000063	0.001
		HxCDFs (All Hexachlorodibenzofurans).	NA	0.000063	0.001
		PeCDDs (All Pentachlorodibenzo-p-dioxins).	NA	0.000063	0.001
		PeCDFs (All Pentachlorodibenzofurans).	NA	0.000035	0.001
		Pentachlorophenol	87-86-5	0.089	7.4
		TCDDs (All Tetrachlorodibenzo-p-dioxins).	NA	0.000063	0.001
		TCDFs (All Tetrachlorodibenzofurans).	NA	0.000063	0.001
		2,4,5-Trichlorophenol	95-95-4	0.18	7.4
		2,4,6-Trichlorophenol	88-06-2	0.035	7.4
		2,3,4,6-Tetrachlorophenol	58-90-2	0.030	7.4
F024	Process wastes, including but not limited to, distillation residues, heavy ends, tars, and reactor clean-out wastes, from the production of certain chlorinated aliphatic hydrocarbons by free radical catalyzed processes. These chlorinated aliphatic hydrocarbons are those having carbon chain lengths ranging from one to and including five, with varying amounts and positions of chlorine substitution. (This listing does not include wastewaters, wastewater treatment sludges, spent catalysts, and wastes listed in § 261.31 or § 261.32.).	All F024 wastes	NA	CMBST	CMBST
		2-Chloro-1,3-butadiene	126-99-8	0.057	0.28
		3-Chloropropylene	107-05-1	0.036	30
		1,1-Dichloroethane	75-34-3	0.059	6.0
		1,2-Dichloroethane	107-06-2	0.21	6.0
		1,2-Dichloropropane	78-87-5	0.85	18
		cis-1,3-Dichloropropylene	10061-01-5	0.036	18
		trans-1,3-Dichloropropylene	10061-02-6	0.036	18
		bis(2-Ethylhexyl) phthalate	117-81-7	0.28	28
		Hexachloroethane	67-72-1	0.055	30
		Chromium (Total)	7440-47-3	2.77	0.86 mg/l TCLP

		TCDDs (All Tetrachlorodibenzo-p-dioxins).	NA	0.28	28
		TCDFs (All Tetracholorodibenzofurans).	NA	0.059	3.4
		2,4,5-Trichlorophenol	95–95–4	0.057	28
		2,4,6-Trichlorophenol	88–06–2	0.057	10
		2,3,4,6-Tetrachlorophenol	58–90–2	0.059	NA
F028	Residues resulting from the incineration or thermal treatment of soil contaminated with EPA Hazardous Wastes Nos. F020, F021, F023, F026, and F027.	HxCDDs (All Hexachlorodibenzo-p-dioxins).	NA	0.059	5.6
		HxCDFs (All Hexachlorodibenzofurans).	NA	0.059	5.6
		PeCDDs (All Pentachlorodibenzo-p-dioxins).	NA	0.039	6.2
		PeCDFs (All Pentachlorodibenzofurans).	NA	0.067	8.2
		Pentachlorophenol	87–86–5	0.080	10
		TCDDs (All Tetrachlorodibenzo-p-dioxins).	NA	0.32	30
		TCDFs (All Tetrachlorodibenzofurans).	NA	2.77	0.86 mg/l TCLP
		2,4,5-Trichlorophenol	95–95–4	1.2	590
		2,4,6-Trichlorophenol	88–06–2	0.69	NA
		2,3,4,6-Tetrachlorophenol	58–90–2	3.98	5.0 mg/l TCLP
F037	Petroleum refinery primary oil/water/solids separation sludge—Any sludge generated from the gravitational separation of oil/water/solids during the storage or treatment of process wastewaters and oily cooling wastewaters from petroleum refineries. Such sludges include, but are not limited to, those generated in: oil/water/solids separators; tanks and impoundments; ditches and other conveyances; sumps; and stormwater units receiving dry weather flow. Sludge generated in stormwater units that do not receive dry weather flow, sludges generated from non-contact once-through cooling waters segregated for treatment from other process or oil cooling waters, sludges generated in aggressive biological treatment units as defined in §261.31(b)(2) (including sludges generated in one or more additional units after wastewaters have been treated in aggressive biological treatment units) and K051 wastes are not included in this listing.	Acenaphthene	83–32–9	0.059	NA
		Anthracene	120–12–7	0.059	3.4
		Benzene	71–43–2	0.14	10
		Benz(a)anthracene	56–55–3	0.059	3.4
		Benzo(a)pyrene	50–32–8	0.061	3.4
		bis(2-Ethylhexyl) phthalate	117–81–7	0.28	28
		Chrysene	218–01–9	0.059	3.4
		Di-n-butyl phthalate	84–74–2	0.057	28
		Ethylbenzene	100–41–4	0.057	10
		Fluorene	86–73–7	0.059	NA
		Naphthalene	91–20–3	0.059	5.6
		Phenanthrene	85–01–8	0.059	5.6
		Phenol	108–95–2	0.039	6.2
		Pyrene	129–00–0	0.067	

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F039	Leachate (liquids that have percolated through land disposed wastes) resulting from the disposal of more than one restricted waste classified as hazardous under subpart D of this part. (Leachate resulting from the disposal of one or more of the following EPA Hazardous Wastes and no other Hazardous Wastes retains its EPA Hazardous Waste Number(s): F020, F021, F022, F026, F027, and/or F028.).	Acenaphthylene	208–96–8	0.059	3.4
		Acenaphthene	83–32–9	0.059	3.4
		Acetone	67–64–1	0.28	160
		Acetonitrile	75–05–8	5.6	38
		Acetophenone	96–86–2	0.010	9.7
		2-Acetylaminofluorene	53–96–3	0.059	140
		Acrolein	107–02–8	0.29	NA
		Acrylonitrile	107–13–1	0.24	84
		Aldrin	309–00–2	0.021	0.066
		4-Aminobiphenyl	92–67–1	0.13	NA
		Aniline	62–53–3	0.81	14
		Anthracene	120–12–7	0.059	3.4
		Aramite	140–57–8	0.36	NA
		alpha-BHC	319–84–6	0.00014	0.066
		beta-BHC	319–85–7	0.00014	0.066
		delta-BHC	319–86–8	0.023	0.066
		gamma-BHC	58–89–9	0.0017	0.066
		Benzene	71–43–2	0.14	10
		Benz(a)anthracene	56–55–3	0.059	3.4
		Benzo(b)fluoranthene (difficult to distinguish from benzo(k)fluoranthene.	205–99–2	0.11	6.8
		Benzo(b)fluoranthene (difficult to distinguish from benzo(k)fluoranthene.	207–08–9	0.11	6.8
		Benzo(g,h,i)perylene	191–24–2	0.0055	1.8
		Benzo(a)pyrene	50–32–8	0.061	3.4
		Bromodichloromethane	75–27–4	0.35	15
		Methyl bromide (Bromomethane)	74–83–9	0.11	15
		4-Bromophenyl phenyl ether	101–55–3	0.055	15
		n-Butyl alcohol	71–36–3	5.6	2.6
		Butyl benzyl phthalate	85–68–7	0.017	28
		2-sec-Butyl-4,6-dinitrophenol (Dinoseb).	88–85–7	0.066	2.5
		Carbon disulfide	75–15–0	3.8	4.8 mg/l TCLP
		Carbon tetrachloride	56–23–5	0.057	6.0
		Chlordane (alpha and gamma isomers).	57–74–9	0.0033	0.26
		p-Chloroaniline	106–47–8	0.46	16
		Chlorobenzene	108–90–7	0.057	6.0
		Chlorobenzilate	510–15–6	0.10	NA
		2-Chloro-1,3-butadiene	126–99–8	0.057	0.28
		Chlorodibromomethane	124–48–1	0.057	15
		Chloroethane	75–00–3	0.27	6.0
		bis(2-Chloroethoxy)methane	111–91–1	0.036	7.2
		bis(2-Chloroethyl)ether	111–44–4	0.033	6.0
		Chloroform	67–66–3	0.046	6.0
		bis(2-Chloroisopropyl)ether	39638–32–9	0.055	7.2
		p-Chloro-m-cresol	59–50–7	0.018	14
		Chloromethane (Methyl chlorida)	74–87–3	0.19	30
		2-Chloronaphthalene	91–58–7	0.055	5.6

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1,4-Dioxane	123–91–1	0.22	170
Diphenylamine (difficult to distinguish from diphenylnitrosamine).	122–39–4	0.92	13
Diphenylnitrosamine (difficult to distinguish from diphenylamine).	86–30–6	0.92	13
1,2-Diphenylhydrazine	122–66–7	0.087	1.5
Disulfoton	298–04–4	0.017	6.2
Endosulfan I	939–98–8	0.023	0.066
Endosulfan II	33213–6–5	0.029	0.13
Endosulfan sulfate	1–31–07–8	0.029	0.13
Endrin	72–20–8	0.0028	0.13
Endrin aldehyde	7421–93–4	0.025	0.13
Ethyl acetate	141–78–6	0.34	33
Ethyl cyanide (Propanenitrile)	107–12–0	0.24	360
Ethyl benzene	100–41–4	0.057	10
Ethyl ether	60–29–7	0.12	160
bis(2-Ethylhexyl) phthalate	117–81–7	0.28	28
Ethyl methacrylate	97–63–2	0.14	160
Ethylene oxide	75–21–8	0.12	NA
Famphur	52–85–7	0.017	15
Fluoranthene	206–44–0	0.068	3.4
Fluorene	86–73–7	0.059	3.4
Heptachlor	76–44–8	0.0012	0.066
Heptachlor epoxide	1024–57–3	0.016	0.066
Hexachlorobenzene	118–74–1	0.055	10
Hexachlorobutadiene	87–68–3	0.055	5.6
Hexachlorocyclopentadiene	77–47–4	0.057	2.4
HxCDDs (All Hexachlorodibenzo-p-dioxins).	NA	0.000063	0.001
HxCDFs (All Hexachlorodibenzofurans).	NA	0.000063	0.001
Hexachloroethane	67–72–1	0.055	30
Hexachloropropylene	1888–71–7	0.035	30
Indeno (1,2,3-c,d) pyrene	193–39–5	0.0055	3.4
Iodomethane	74–88–4	0.19	65
Isobutyl alcohol	78–83–1	5.6	170
Isodrin	465–73–6	0.021	0.066
Isosafrole	120–58–1	0.081	2.6
Kepone	143–50–8	0.0011	0.13
Methacrylonitrile	126–98–7	0.24	84
Methanol	67–56–1	5.6	0.75 mg/l TCLP
Methapyrilene	91–80–5	0.081	1.5
Methoxychlor	72–43–5	0.25	0.18
3-Methylcholanthrene	56–49–5	0.0055	15
4,4-Methylene bis(2-chloroaniline)	101–14–4	0.50	30
Methylene chloride	75–09–2	0.089	30
Methyl ethyl ketone	78–93–3	0.28	36
Methyl isobutyl ketone	108–10–1	0.14	33
Methyl methacrylate	80–62–6	0.14	160
Methyl methansulfonate	66–27–3	0.018	NA
Methyl parathion	298–00–0	0.014	4.6
Naphthalene	91–20–3	0.059	5.6
2-Naphthylamine	91–59–8	0.52	NA
p-Nitroaniline	100–01–6	0.028	28
Nitrobenzene	98–95–3	0.068	14
5-Nitro-o-toluidine	99–55–8	0.32	28
p-Nitrophenol	100–02–7	0.12	29
N-Nitrosodiethylamine	55–18–5	0.40	28
N–Nitrosodimethylamine	62–75–9	0.40	

		tris(2,3-Dibromopropyl) phosphate	126–72–7	0.11	0.10
		Vinyl chloride	75–01–4	0.27	6.0
		Xylenes-mixed isomers (sum of o-, m-, and p-xylene concentrations).	1330–20–7	0.32	30
		Antimony	7440–36–0	1.9	2 1 mg/l TCLP
		Arsenic	7440–38–2	1.4	5.0 mg/l TCLP
		Barium	7440–39–3	1.2	7.6 mg/l TCLP
		Beryllium	7440–41–7	0.82	0.014 mg/l TCLP
		Cadmium	7440–43–9	0.69	0.19 mg/l TCLP
		Chromium (Total)	7440–47–3	2.77	0.86 mg/l TCLP
		Cyanides (Total)[7]	57–12–5	1.2	590
		Cyanides (Amenable)[7]	57–12–5	0.86	30
		Fluoride	16964–48–8	35	48
		Lead	7439–92–1	0.69	0.37 mg/l TCLP
		Mercury	7439–97–6	0.15	0.025 mg/l TCLP
		Nickel	7440–02–0	3.98	5.0 mg/l TCLP
		Selenium	7782–49–2	0.82	0.16 mg/l TCLP
		Silver	7440–22–4	0.43	0.30 mg/l TCLP
		Sulfide	8496–25–8	14	NA
		Thallium	7440–28–0	1.4	0.078 mg/l TCLP
		Vanadium	7440–62–2	4.3	0.23
K001	Bottom sediment sludge from the treatment of wastewaters from wood preserving processes that use creosote and/or pentachlorophenol..	Naphthalene	91–20–3	0.059	5.6
		Pentachlorophenol	87–86–5	0.089	7.4
		Phenanthrene	85–01–8	0.059	5.6
		Pyrene	129–00–0	0.067	8.2
		Toluene	108–88–3	0.080	10
		Xylenes-mixed isomers (sum of o-, m-, and p-xylene concentrations).	1330–20–7	0.32	30
K002	Wastewater treatment sludge from the production of chrome yellow and orange pigments.	Lead	7439–92–1	0.69	0.37 mg/l TCLP
		Chromium (Total)	7440–47–3	2.77	0.86 mg/l TCLP
K003	Wastewater treatment sludge from the production of molybdate orange pigments.	Lead	7439–92–1	0.69	0.37 mg/l TCLP
		Chromium (Total)	7440–47–3	2.77	0.86 mg/l TCLP
K004	Wastewater treatment sludge from the production of zinc yellow pigments.	Lead	7439–92–1	0.69	0.37 mg/l TCLP
		Chromium (Total)	7440–47–3	2.77	0.86 mg/l TCLP
K005	Wastewater treatment sludge from the production of chrome green pigments.	Lead	7439–92–1	0.69	0.37 mg/l TCLP
		Chromium (Total)	7440–47–3	2.77	0.86 mg/l TCLP
K006	Wastewater treatment sludge from the production of chrome oxide green pigments (anhydrous).	Lead	7439–92–1	0.69	0.37 mg/l TCLP
		Cyanides (Total)[7]	57–12–5	1.2	590
		Chromium (Total)	7440–47–3	2.77	0.86 mg/l TCLP
	Wastewater treatment sludge from the production of chrome oxide green pigments (hydrated).	Lead	7439–92–1	0.69	NA
		Chromium (Total)	7440–47–3	2.77	0.86 mg/l TCLP
K007	Wastewater treatment sludge from the production of iron blue pigments.	Lead	7439–92–1	0.69	0.37 mg/l TCLP
		Chromium (Total)	7440–47–3	2.77	0.86 mg/l TCLP
K008	Oven residue from the production of chrome oxide green.	Lead	7439–92–1	0.69	0.37 mg/l TCLP
		Cyanides (Total)[7]	57–12–5	1.2	590
		Chromium (Total)	7440–47–3	2.77	0.86 mg/l
		Lead	7439–92–1	0.69	0.37 mg/l TCLP

		1,1-Dichloroethane	75–34–3	0.059	6.0
		1,2-Dichloroethane	107–06–2	0.21	6.0
		Hexachlorobenzene	118–74–1	0.055	10
		Hexachlorobutadiene	87–68–3	0.055	5.6
		Hexachloroethane	67–72–1	0.055	30
		Pentachloroethane	76–01–7	NA	6.0
		1,1,1-Trichloroethane	71–55–6	0.054	6.0
K019	Heavy ends from the distillation of ethylene dichloride in ethylene dichloride production..	bis(2-Chloroethyl)ether	111–44–4	0.033	6.0
		Chlorobenzene	108–90–7	0.057	6.0
		Chloroform	68–66–3	0.046	6.0
		p-Dichlorobenzene	106–46–7	0.090	NA
		1,2-Dichloroethane	107–06–2	0.21	6.0
		Fluorene	86–73–7	0.059	NA
		Hexachloroethane	67–72–1	0.055	30
		Naphthalene	91–20–3	0.059	5.6
		Phenanthrene	85–01–8	0.059	5.6
		1,2,4,5-Tetrachlorobenzene	95–94–3	0.055	NA
		Tetrachloroethylene	127–18–4	0.056	6.0
		1,2,4-Trichlorobenzene	120–82–1	0.055	19
		1,1,1-Trichloroethane	71–55–6	0.054	6.0
K020	Heavy ends from the distillation of vinyl chloride in vinyl chloride monomer production.	1,2-Dichloroethane	107–06–2	0.21	6.0
		1,1,2,2-Tetrachloroethane	79–34–6	0.057	6.0
		Tetrachloroethylene	127–18–4	0.056	6.0
K021	Aqueous spent antimony catalyst waste from fluoromethanes production.	Carbon tetrachloride	56–23–5	0.057	6.0
		Chloroform	67–66–3	0.046	6.0
		Antimony	7440–36–0	1.9	2.1 mg/l TCLP
K022	Distillation bottom tars from the production of phenol/acetone from cumene.	Toluene	108–88–3	0.080	10
		Acetophenone	96–86–2	0.010	9.7
		Diphenylamine (difficult to distinguish from diphenylnitrosamine).	122–39–4	0.92	13
		Diphenylnitrosamine (difficult to distinguish from diphenylamine).	86–30–6	0.92	13
		Phenol	108–95–2	0.039	6.2
		Chromium (Total)	7440–47–3	2.77	0.86 mg/l TCLP
		Nickel	7440–02–0	3.98	5.0 mg/l TCLP
K023	Distillation light ends from the production of phthalic anhydride from naphthalene.	Phthalic anhydride (measured as Phthalic acid or Terephthalic acid).	100–21–0	0.055	28
		Phthalic anhydride (measured as Phthalic acid or Terephthalic acid).	85–44–9	0.055	28
K024	Distillation bottoms from the production of phthalic anhydride from naphthalene.	Phthalic anhydride (measured as Phthalic acid or Terephthalic acid).	100–21–0	0.055	28
		Phthalic anhydride (measured as Phthalic acid or Terephthalic acid).	85–44–9	0.055	28
K025	Distillation bottoms from the production of nitrobenzene by the nitration of benzene.	NA	NA	LLEXT fb SSTRP fb CARBN; or CMBST	CMBST
K026	Stripping still tails from the production of methyl ethyl pyridines.	NA	NA	CMBST	CMBST
K027	Centrifuge and distillation residues from toluene diisocyanate production.	NA	NA	CARBN; or CMBST	CMBST

6515

K035	Wastewater treatment sludges generated in the production of creosote.	Acenaphthene	83–32–9	NA	3.4
		Anthracene	120–12–7	NA	3.4
		Benz(a)anthracene	56–55–3	0.059	3.4
		Benzo(a)pyrene	50–32–8	0.061	3.4
		Chrysene	218–01–9	0.059	3.4
		o-Cresol	95–48–7	0.11	5.6
		m-Cresol (difficult to distinguish from p-cresol).	108–39–4	0.77	5.6
		p-Cresol (difficult to distinguish from m-cresol).	106–44–5	0.77	5.6
		Dibenz(a,h)anthracene	53–70–3	NA	8.2
		Fluoranthene	206–44–0	0.068	3.4
		Fluorene	86–73–7	NA	3.4
		Indeno(1,2,3-cd)pyrene	193–39–5	NA	3.4
		Naphthalene	91–20–3	0.059	5.6
		Phenanthrene	85–01–8	0.059	5.6
		Phenol	108–95–2	0.039	6.2
		Pyrene	129–00–0	0.067	8.2
K036	Still bottoms from toluene reclamation distillation in the production of disulfoton.	Disulfoton	298–04–4	0.017	6.2
K037	Wastewater treatment sludges from the production of disulfoton.	Disulfoton	298–04–4	0.017	6.2
K038	Wastewater from the washing and stripping of phorate production.	Toluene	108–88–3	0.080	10
		Phorate	298–02–2	0.021	4.6
K039	Filter cake from the filtration of diethylphosphorodithioc acid in the production of phorate.	NA	NA	CARBN, or CMBST	CMBST
K040	Wastewater treatment sludge from the production of phorate.	Phorate	298–02–2	0.021	4.6
K041	Wastewater treatment sludge from the production of toxaphene.	Toxaphene	8001–35–2	0.0095	2.6
K042	Heavy ends or distillation residues from the distillation of tetrachlorobenzene in the production of 2,4,5-T.	o-Dichlorobenzene	95–50–1	0.088	6.0
		p-Dichlorobenzene	106–46–7	0.090	6.0
		Pentachlorobenzene	608–93–5	0.055	10
		1,2,4,5-Tetrachlorobenzene	95–94–3	0.055	14
		1,2,4-Trichlorobenzene	120–82–1	0.055	19
K043	2,6-Dichlorophenol waste from the production of 2,4-D.	2,4-Dichlorophenol	120–83–2	0.044	14
		2,6-Dichlorophenol	187–65–0	0.044	14
		2,4,5-Trichlorophenol	95–95–4	0.18	7.4
		2,4,6-Trichlorophenol	88–06–2	0.035	7.4
		2,3,4,6-Tetrachlorophenol	58–90–2	0.030	7.4
		Pentachlorophenol	87–86–5	0.089	7.4
		Tetrachloroethylene	127–18–4	0.056	6.0
		HxCDDs (All Hexachlorodibenzo-p-dioxins).	NA	0.000063	0.001
		HxCDFs (All Hexachlorodibenzofurans).	NA	0.000063	0.001
		PeCDDs (All Pentachlorodibenzo-p-dioxins).	NA	0.000063	0.001
		PeCDFs (All Pentachlorodibenzofurans).	NA	0.000035	0.001
		TCDDs (All Tetrachlorodibenzo-p-dioxins).	NA	0.000063	0.001

K050	Heat exchanger bundle cleaning sludge from the petroleum refining industry.	Cyanides (Total)[7]	57–12–5	1.2	590
		Chromium (Total)	7440–47–3	2.77	0.86 mg/l TCLP
		Lead	7439–92–1	0.69	NA
		Nickel	7440–02–0	NA	5.0 mg/l TCLP
		Benzo(a)pyrene	50–32–8	0.061	3.4
		Phenol	108–95–2	0.039	6.2
K051	API separator sludge from the petroleum refining industry.	Cyanides (Total)[7]	57–12–5	1.2	590
		Chromium (Total)	7440–47–3	2.77	0.86 mg/l TCLP
		Lead	7439–92–1	0.69	NA
		Nickel	7440–02–0	NA	5.0 mg/l TCLP
		Acenaphthene	83–32–9	0.059	NA
		Anthracene	120–12–7	0.059	3.4
		Benz(a)anthracene	56–55–3	0.059	3.4
		Benzene	71–43–2	0.14	10
		Benzo(a)pyrene	50–32–8	0.061	3.4
		bis(2-Ethylhexyl) phthalate	117–81–7	0.28	28
		Chrysene	2218–01–9	0.059	3.4
		Di-n-butyl phthalate	105–67–9	0.057	28
		Ethylbenzene	100–41–4	0.057	10
		Fluorene	86–73–7	0.059	NA
		Naphthalene	91–20–3	0.059	5.6
		Phenanthrene	85–01–8	0.059	5.6
		Phenol	108–95–2	0.039	6.2
		Pyrene	129–00–0	0.067	8.2
		Toluene	108–88–3	0.08	10
		Xylenes-mixed isomers (sum of o-, m-, and p-xylene concentrations).	1330–20–7	0.32	30
K052	Tank bottoms (leaded) from the petroleum refining industry.	Cyanides (Total)[7]	57–12–5	1.2	590
		Chromium (Total)	7440–47–3	2.77	0.86 mg/l TCLP
		Lead	7439–92–1	0.69	NA
		Nickel	7440–02–0	NA	5.0 mg/l TCLP
		Benzene	71–43–2	0.14	10
		Benzo(a)pyrene	50–32–8	0.061	3.4
		o-Cresol	95–48–7	0.11	5.6
		m-Cresol (difficult to distinguish from p-cresol).	108–39–4	0.77	5.6
		p-Cresol (difficult to distinguish from m-cresol).	106–44–5	0.77	5.6
		2,4-Dimethylphenol	105–67–9	0.036	NA
		Ethylbenzene	100–41–4	0.057	10
		Naphthalene	91–20–3	0.059	5.6
		Phenanthrene	85–01–8	0.059	5.6
		Phenol	108–95–2	0.039	6.2
		Toluene	108–88–3	0.08	10
		Xylenes-mixed isomers (sum of o-, m-, and p-xylene concentrations).	1330–20–7	0.32	30
K060	Ammonia still lime sludge from coking operations ...	Chromium (Total)	7440–47–3	2.77	0.86 mg/l TCLP
		Cyanides (Total)[7]	57–12–5	1.2	590
		Lead	7439–92–1	0.69	NA
		Nickel	7440–02–0	NA	5.0 mg/l TCLP
		Benzene	71–43–2	0.14	10
		Benzo(a)pyrene	50–32–8	0.061	3.4
		Naphthalene	91–20–3	0.059	5.6
		Phenol	108–95–2	0.039	2

		Diphenylamine (difficult to distinguish from diphenylnitrosamine).	122–39–4	0.92	13
		Diphenylnitrosamine (difficult to distinguish from diphenylamine).	86–30–6	0.92	13
		Nitrobenzene	98–95–3	0.068	14
		Phenol	108–95–2	0.039	6.2
K084	Wastewater treatment sludges generated during the production of veterinary pharmaceuticals from arsenic or organo-arsenic compounds.	Nickel	7440–02–0	3.98	5.0 mg/l TCLP
		Arsenic	7440–38–2	1.4	5.0 mg/l TCLP
K085	Distillation or fractionation column bottoms from the production of chlorobenzenes.	Benzene	71–43–2	0.14	10
		Chlorobenzene	108–90–7	0.057	6.0
		m-Dichlorobenzene	541–73–1	0.036	6.0
		o-Dichlorobenzene	95–50–1	0.088	6.0
		p-Dichlorobenzene	106–46–7	0.090	6.0
		Hexachlorobenzene	118–74–1	0.055	10
		Total PCBs (sum of all PCB isomers, or all Aroclors).	1336–36–3	0.10	10
		Pentachlorobenzene	608–93–5	0.055	10
		1,2,4,5-Tetrachlorobenzene	95–94–3	0.055	14
		1,2,4-Trichlorobenzene	120–82–1	0.055	19
K086	Solvent wastes and sludges, caustic washes and sludges, or water washes and sludges from cleaning tubs and equipment used in the formulation of ink from pigments, driers, soaps, and stabilizers containing chromium and lead.	Acetone	67–64–1	0.28	160
		Acetophenone	96–86–2	0.010	9.7
		bis(2-Ethylhexyl phthalate	117–81–7	0.28	28
		n-Butyl alcohol	71–36–3	5.6	2.6
		Butylbenzyl phthalate	85–68–7	0.017	28
		Cyclohexanone	108–94–1	0.36	NA
		o-Dichlorobenzene	95–50–1	0.088	6.0
		Diethyl phthalate	84–66–2	0.20	28
		Dimethyl phthalate	131–11–3	0.047	28
		Di-n-butyl phthalate	84–74–2	0.057	28
		Di-n-octyl phthalate	117–84–0	0.017	28
		Ethyl acetate	141–78–6	0.34	33
		Ethylbenzene	100–41–4	0.057	10
		Menthanol	67–56–1	5.6	NA
		Methyl ethyl ketone	78–93–3	0.28	36
		Methyl isobutyl ketone	108–10–1	0.14	33
		Methylene chloride	75–09–2	0.089	30
		Naphthalene	91–20–3	0.059	5.6
		Nitrobenzene	98–95–3	0.068	14
		Toluene	108–88–3	0.080	10
		1,1,1-Trichloroethane	71–55–6	0.054	6.0
		Trichloroethylene	79–01–6	0.054	6.0
		Xylenes-mixed isomers (sum of o-,m-, and p-xylene concentrations).	1330–20–7	0.32	30
		Chromium (Total)	7440–47–3	2.77	0.86 mg/l TCLP
		Cyanides (Total)[7]	57–12–5	1.2	590
		Lead	7439–92–1	0.69	0.37 mg/l TCLP
K087	Decanter tank tar sludge from coking operations	Acenaphthylene	208–96–8	0.059	3.4
		Benzene	71–43–2	0.14	10
		Chrysene	218–01–9	0.059	3.4
		Fluoranthene	206–44–0	0.068	3.4
		Indeno(1,2,3-cd)pyrene	193–39–5	0.0055	3.4

K095	Distillation bottoms from the production of 1,1,1-trichloroethane.	Hexachloroethane	67–72–1	0.055	30
		Pentachloroethane	76–01–7	0.055	6.0
		1,1,1,2-Tetrachloroethane	630–20–6	0.057	6.0
		1,1,2,2-Tetrachloroethane	79–34–6	0.057	6.0
		Tetrachloroethylene	127–18–4	0.056	6.0
		1,1,2-Trichloroethane	79–00–5	0.054	6.0
		Trichloroethylene	79–01–6	0.054	6.0
K096	Heavy ends from the heavy ends column from the production of 1,1,1-trichloroethane.	m-Dichlorobenzene	541–73–1	0.036	6.0
		Pentachloroethane	76–01–7	0.055	6.0
		1,1,1,2-Tetrachloroethane	630–20–6	0.057	6.0
		1,1,2,2-Tetrachloroethane	79–34–6	0.057	6.0
		Tetrachloroethylene	127–18–4	0.056	6.0
		1,2,4-Trichlorobenzene	120–82–1	0.055	19
		1,1,2-Trichloroethane	79–00–5	0.054	6.0
		Trichloroethylene	79–01–6	0.054	6.0
K097	Vacuum stripper discharge from the chlordane chlorinator in the production of chlordane.	Chlordane (alpha and gamma isomers).	57–74–9	0.0033	0.26
		Heptachlor	76–44–8	0.0012	0.066
		Heptachlor epoxide	1024–57–3	0.016	0.066
		Hexachlorocyclopentadiene	77–47–4	0.057	2.4
K098	Untreated process wastewater from the production of toxaphene.	Toxaphene	8001–35–2	0.0095	2.6
K099	Untreated wastewater from the production of 2,4-D	2,4-Dichlorophenoxyacetic acid	94–75–7	0.72	10
		HxCDDs (All Hexachlorodibenzo-p-dioxins).	NA	0.000063	0.001
		HxCDFs (All Hexachlorodibenzofurans).	NA	0.000063	0.001
		PeCDDs (All Pentachlorodibenzo-p-dioxins).	NA	0.000063	0.001
		PeCDFs (All Pentachlorodibenzofurans).	NA	0.000035	0.001
		TCDDs (All Tetrachlorodibenzo-p-dioxins).	NA	0.000063	0.001
		TCDFs (All Tetrachlorodibenzofurans).	NA	0.000063	0.001
K100	Waste leaching solution from acid leaching of emission control dust/sludge from secondary lead smelting.	Cadmium	7440–43–9	0.69	0.19 mg/l TCLP
		Chromium (Total)	7440–47–3	2.77	0.86 mg/l TCLP
		Lead	7439–92–1	0.69	0.37 mg/l TCLP
K101	Distillation tar residues from the distillation of aniline-based compounds in the production of veterinary pharmaceuticals from arsenic or organo-arsenic compounds.	o-Nitroaniline	88–74–4	0.27	14
		Arsenic	7440–38–2	1.4	5.0 mg/l TCLP
		Cadmium	7440–43–9	0.69	NA
		Lead	7439–92–1	0.69	NA
		Mercury	7439–97–6	0.15	NA
K102	Residue from the use of activated carbon for decolorization in the production of veterinary pharmaceuticals from arsenic or organo-arsenic compounds.	o-Nitrophenol	88–75–5	0.028	13
		Arsenic	7440–38–2	1.4	5.0 mg/l TCLP
		Cadmium	7440–43–9	0.69	NA
		Lead	7439–92–1	0.69	NA
		Mercury	7439–97–6	0.15	

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K110	Condensed column overheads from intermediate separation from the production of 1,1-dimethyhydrazine (UDMH) from carboxylic acid hydrazides.	NA	NA	CMBST; or CHOXD fb CARBN; or BIODG fb CARBN	CMBST
K111	Product washwaters from the production of dinitrotoluene via nitration of toluene.	2,4-Dinitrotoluene	121–1–2	0.32	140
		2,6-Dinitrotoluene	606–20–2	0.55	28
K112	Reaction by-product water from the drying column in the production of toluenediamine via hydrogenation of dinitrotoluene.	NA	NA	CMBST; or CHOXD fb CARBN; or BIODG fb CARBN	CMBST
K113	Condensed liquid light ends from the purification of toluenediamine in the production of toluenediamine via hydrogenation of dinitrotoluene.	NA	NA	CARBN; or CMBST	CMBST
K114	Vicinals from the purification of toluenediamine in the production of toluenediamine via hydrogenation of dinitrotoluene.	NA	NA	CARBN; or CMBST	CMBST
K115	Heavy ends from the purification of toluenediamine in the production of toluenediamine via hydrogenation of dinitrotoluene.	Nickel	7440–02–0	3.98	5.0 mg/l TCLP
		NA	NA	CARBN; or CMBST	CMBST
K116	Organic condensate from the solvent recovery column in the production of toluene diisocyanate via phosgenation of toluenediamine.	NA	NA	CARBN; or CMBST	CMBST
K117	Wastewater from the reactor vent gas scrubber in the production of ethylene dibromide via bromination of ethene.	Methyl bromide (Bromomethane)	74–83–9	0.11	15
		Chloroform	67–66–3	0.046	6.0
		Ethylene dibromide (1,2-Dibromoethane).	106–93–4	0.028	15
K118	Spent absorbent solids from purification of ethylene dibromide in the production of ethylene dibromide via bromination of ethene.	Methyl bromide (Bromomethane)	74–83–9	0.11	15
		Chloroform	67–66–3	0.046	6.0
		Ethylene dibromide (1,2-Dibromoethane).	106–93–4	0.028	15
K123	Process wastewater (including supernates, filtrates, and washwaters) from the production of ethylenebisdithiocarbamic acid and its salts.	NA	NA	CMBST; or CHOXD fb (BIODG or CARBN)	CMBST
K124	Reactor vent scrubber water from the production of ethylenebisdithiocarbamic acid and its salts.	NA	NA	CMBST; or CHOXD fb (BIODG or CARBN)	CMBST
K125	Filtration, evaporation, and centrifugation solids from the production of ethylenebisdithiocarbamic acid and its salts.	NA	NA	CMBST; or CHOXD fb (BIODG or CARBN)	CMBST
K126	Baghouse dust and floor sweepings in milling and packaging operations from the production or formulation of ethylenebisdithiocarbamic acid and its salts.	NA	NA	CMBST; or CHOXD fb (BIODG or CARBN)	CMBST
K131	Wastewater from the reactor and spent sulfuric acid from the acid dryer from the production of methyl bromide.	Methyl bromide (Bromomethane)	74–83–9	0.11	15

		Benzo(a)pyrene	50–32–8	0.061	3.4
		Benzo(b)fluoranthene (difficult to distinguish from benzo(k) fluoranthene).	205–99–2	0.11	6.8
		Benzo(k)fluoranthene (difficult to distinguish from benzo(b)fluoranthene).	207–08–9	0.11	6.8
		Benzene	71–43–2	0.14	10
		Chrysene	218–01–9	0.059	3.4
K144	Wastewater sump residues from light oil refining, including, but not limited to, intercepting or contamination sump sludges from the recovery of coke by-products produced from coal.	Benz(a)anthracene	56–55–3	0.059	3.4
		Benzo(a)pyrene	50–32–8	0.061	3.4
		Benzo(b)fluoranthene (difficult to distinguish from benzo(k)fluoranthene).	205–99–2	0.11	6.8
		Benzo(k)fluoranthene (difficult to distinguish from benzo(b)fluoranthene).	207–08–9	0.11	6.8
		Chrysene	218–01–9	0.059	3.4
		Dibenz(a,h)anthracene	53–70–3	0.055	8.2
K145	Residues from naphthalene collection and recovery operations from the recovery of coke by-products produced from coal.	Benzene	71–43–2	0.14	10
		Benz(a)anthracene	56–55–3	0.059	3.4
		Benzo(a)pyrene	50–32–8	0.061	3.4
		Chrysene	218–01–9	0.059	3.4
		Dibenz(a,h)anthracene	53–70–3	0.055	8.2
		Naphthalene	91–20–3	0.059	5.6
K147	Tar storage tank residues from coal tar refining	Benzene	71–43–2	0.14	10
		Benz(a)anthracene	56–55–3	0.059	3.4
		Benzo(a)pyrene	50–32–8	0.061	3.4
		Benzo(b)fluoranthene (difficult to distinguish from benzo(k)fluoranthene).	205–99–2	0.11	6.8
		Benzo(k)fluoranthene (difficult to distinguish from benzo(b)fluoranthene).	207–08–9	0.11	6.8
		Chrysene	218–01–9	0.059	3.4
		Dibenz(a,h)anthracene	53–70–3	0.055	8.2
		Indeno(1,2,3-cd)pyrene	193–39–5	0.0055	3.4
K148	Residues from coal tar distillation, including, but not limited to, still bottoms.	Benz(a)anthracene	56–55–3	0.059	3.4
		Benzo(a)pyrene	50–32–8	0.061	3.4
		Benzo(b)fluoranthene (difficult to distinguish from benzo(k)fluoranthene).	205–99–2	0.11	6.8
		Benzo(k)fluoranthene (difficult to distinguish from benzo(b)fluoranthene).	207–08–9	0.11	6.8
		Chrysene	218–01–9	0.059	3.4
		Dibenz(a,h)anthracene	53–70–3	0.055	8.2
		Indeno(1,2,3-cd)pyrene	193–39–5	0.0055	3.4

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K157	Wastewaters (including scrubber waters, condenser waters, washwaters, and separation waters) from the production of carbamates and carbamoyl oximes.	Toluene	108–88–3	0.080	10
		Triethylamine	121–44–8	0.081	1.5
		Xylenes (total)	1330–20–7	0.32	30
		Acetone	67–64–1	0.28	160
		Carbon tetrachloride	56–23–5	0.057	6.0
		Chloroform	67–66–3	0.046	6.0
		Chloromethane	74–87–3	0.19	30
		Methanol	67–56–1	5.6	0.75 mg/l TCLP
		Methomyl	16752–77–5	0.028	0.14
		Methylene chloride	75–09–2	0.089	30
		Methyl ethyl ketone	78–93–3	0.28	36
		Methyl isobutyl ketone	108–10–1	0.14	33
		o-Phenylenediamine	95–54–5	0.056	5.6
		Pyridine	110–86–1	0.014	16
		Triethylamine	121–44–8	0.081	1.5
K158	Bag house dusts and filter/separation solids from the production of carbamates and carbamoyl oximes.	Benomyl	17804–35–2	0.056	1.4
		Benzene	71–43–2	0.14	10
		Carbenzadim	10605–21–7	0.056	1.4
		Carbofuran	1563–66–2	0.006	0.14
		Carbosulfan	55285–14–8	0.028	1.4
		Chloroform	67–66–3	0.046	6.0
		Hexane	110–54–3	0.611	10
		Methanol	67–56–1	5.6	0.75 mg/l TCLP
		Methylene chloride	75–09–2	0.089	30
		Phenol	108–95–2	0.039	6.2
		Xylenes (total)	1330–20–7	0.32	30
K159	Organics from the treatment of thiocarbamate wastes.	Benzene	71–43–2	0.14	10
		Butylate	2008–41–5	0.003	1.5
		EPTC (Eptam)	759–94–4	0.003	1.4
		Molinate	2212–67–1	0.003	1.4
		Pebulate	1114–71–2	0.003	1.4
		Thiocarbamate, N.O.S.	NA	0.003	1.4
		Vernolate	1929–77–7	0.003	1.4
K160	Solids (including filter wastes, separation solids, and spent catalysts) from the production of thiocarbamates and solids from the treatment of thiocarbamate wastes.	Butylate	2008–41–5	0.003	1.5
		EPTC (Eptam)	759–94–4	0.003	1.4
		Molinate	2212–67–1	0.003	1.4
		Pebulate	1114–71–2	0.003	1.4
		Thiocarbamate, N.O.S.	NA	0.003	1.4
		Toluene	108–88–3	0.080	10
		Vernolate	1929–77–7	0.003	1.4
		Xylenes (total)	1330–20–7	0.32	30
K161	Purification solids (including filtration, evaporation, and centrifugation solids), baghouse dust and floor sweepings from the production of dithiocarbamate acids and their salts.	Antimony	7440–36–0	1.9	2.1 mg/l TCLP
		Carbon disulfide	75–15–0	3.8	4.8 mg/l TCLP
		Dithiocarbamates, total	NA	0.028	28
		Lead	7439–92–1	0.69	0.37 mg/l TCLP
		Nickel	7440–02–0	3.98	5.0 mg/l TCLP
		Selenium	7782–49–2	0.82	016 mg/l TCLP
		Xylenes (total)	1330–20–7	0.32	30
P001	Warfarin, & salts, when present at concentrations greater than 0.3%.	Warfarin	81–81–2	(WETOX or CHOXD) fb CARBN; or CBMST	CMBST

P020	2-sec-Butyl-4,6-dinitrophenol (Dinoseb)	2-sec-Butyl-4,6-dinitrophenol (Dinoseb).	88–85–7	0.066	2.5
P021	Calcium cyanide	Cyanides (Total)[7]	57–12–5	1.2	590
		Cyanides (Amenable)[7]	57–12–5	0.86	30
P022	Carbon disulfide	Carbon disulfide	75–15–0	3.8	CMBST
		Carbon disulfide; alternate[6] standard for nonwastewaters only.	75–15–0	NA	4.8 mg/l TCLP
P023	Choloracetaldehyde	Choloracetaldehyde	107–20–0	(WETOX or CHOXD) fb CARBN; or CBMST	CMBST
P024	p-Chloroaniline	p-Chloroaniline	106–47–8	0.46	16
P026	1-(o-Cholorphenyl)thiourea	1-(o-Cholorphenyl)thiourea	5344–82–1	(WETOX or CHOXD) fb CARBN; or CBMST	CMBST
P027	3-Chloropropionitrile	3-Chloropropionitrile	542–76–7	(WETOX or CHOXD) fb CARBN; or CBMST	CMBST
P028	Benzyl chloride	Benzyl chloride	100–44–7	(WETOX or CHOXD) fb CARBN; or CBMST	CMBST
P029	Copper cyanide	Cyanides (Total)[7]	57–12–5	1.2	590
		Cyanides (Amenable)[7]	57–12–5	0.86	30
P030	Cyanides (soluble salts and complexes)	Cyanides (Total)[7]	57–12–5	1.2	590
		Cyanides (Amenable)[7]	57–12–5	0.86	30
P031	Cyanogen	Cyanogen	460–19–5	CHOXD; WETOX; or CMBST	CHOXD; WETOX; or CMBST
P033	Cyanogen chloride	Cyanogen chloride	506–77–4	CHOXD; WETOX; or CMBST	CHOXD; WETOX; or CMBST
P034	2-Cyclohexly-4,6-dinitrophenol	2-Cyclohexly-4,6-dinitrophenol	131–89–5	(WETOX or CHOXD) fb CARBN; or CBMST	CMBST
P036	Dichlorophenylarsine	Arsenic	7440–38–2	1.4	5.0 mg/l TCLP
P037	Dieldrin	Dieldrin	60–57–1	0.017	0.13
P038	Diethylarsine	Arsenic	7440–38–2	1.4	50 mg/l TCLP
P039	Disulfoton	Disulfoton	298–04–4	0.017	6.2
P040	0,0-Diethyl O-pyrazinyl phosphorothioate	0,0-Diethyl O-pyrazinyl phosphorothioate.	297–97–2	CARBN; or CMBST	CMBST
P041	Diethyl-p-nitrophenyl phosphate	Diethyl-p-nitrophenyl phosphate	311–45–5	CARBN; or CMBST	CMBST
P042	Epinephrine	Epinephrine	51–43–4	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
P043	Diisopropylfluorophosphate (DFP)	Diisopropylfluorophosphate (DFP)	55–91–4	CARBN; or CMBST	CMBST
P044	Dimethoate	Dimethoate	60–51–5	CARBN; or CMBST	CMBST
P045	Thiofanox	Thiofanox	39196–18–4	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST

	Mercury fulminate nonwastewaters that are either incinerator residues or are residues from RMERC; and contain greater than or equal to 260 mg/kg total mercury.	Mercury	7339–97–6	NA	RMERC
	Mercury fulminate nonwastewaters that are residues from RMERC and contain less than 260 mg/kg total mercury.	Mercury	7439–97–6	NA	0.20 mg/l TCLP
	Mercury fulminate nonwastewaters that are incinerator residues and contain less than 260 mg/kg total mercury.	Mercury	7439–97–6	NA	0.025 mg/l TCLP
	All mercury fulminate wastewaters	Mercury	7439–97–6	0.15	NA
P066	Methomyl	Methomyl	16752–77–5	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
P067	2-Methyl-aziridine	2-Methyl-aziridine	75–55–8	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
P068	Methyl hydrazine	Methyl hydrazine	60–34–4	CHOXD; CHRED; CARBN; BIODG; or CMBST	CHOXD; CHRED; or CMBST
P069	2-Methyllactonitrile	2-Methyllactonitrile	75–86–5	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
P070	Aldicarb	Aldicarb	116–06–3	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
P071	Methyl parathion	Methyl parathion	298–00–0	0.014	4.6
P072	1-Naphthyl–2–thiourea	1-Naphthyl–2–thiourea	86–88–4	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
P073	Nickel carbonyl	Nickel	7440–02–0	3.98	5.0 mg/l TCLP
P074	Nickel-cyanide	Cyanides (Total)[7]	57–12–5	1.2	590
		Cyanides (Total)[7]	57–12–5	0.86	30
		Nickel	7440–02–0	3.98	5.0 mg/l TCLP
P075	Nicotine and salts	Nicotine and salts	54–11–5	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
P076	Nitric oxide	Nitric oxide	10102–43–9	ADGAS	ADGAS
P077	p-Nitroaniline	p-Nitroaniline	100–01–6	0.028	28
P078	Nitrogen dioxide	Nitrogen dioxide	10102–44–0	ADGAS	ADGAS
P081	Nitroglycerin	Nitroglycerin	55–63–0	CHOXD; CHRED; CARBN; BIODG; or CMBST	CHOXD; CHRED; or CMBST
P082	N-Nitrosodimethylamine	N-Nitrosodimethylamine	62–75–9	0.40	2.3
P084	N-Nitrosomethylvinylamine	N-Nitrosomethylvinylamine	4549–40–0	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
P085	Octamethylpyrophosphoramide	Octamethylpyrophosphoramide	152–16–9	CARBN; OR CMBST	CMBST
P087	Osmium tectroxide	Osmium tectroxide	20816–12–0	RMETL; or RTHRM	RMETL; or RTHRM

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P0105	Sodium azide	Sodium azide	26628–22–8	CHOXD; CHRED; CARBN; BIODG; or CMBST	CHOXD; CHRED; or CMBST
P0106	Sodium cyanide	Cyanides (Total)[7]	57–12–5	1.2	590
		Cyanides (Amenable)[7]	57–12–5	0.86	30
P0108	Strychnine and salts	Strychnine and salts	57–24–9	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
P109	Tetraethyldithiopyrophosphate	Tetraethyldithiopyrophosphate	3689–24–5	CARBN; or CMBST	CMBST
P110	Tetraethyl lead	Lead	7439–92–1	0.69	0.37 mg/l TCLP
P111	Tetraethylpyrophosphate	Tetraethylpyrophosphate	107–49–3	CARBN; or CMBST	CMBST
P112	Tetranitromethane	Tetranitromethane	509–14–8	CHOXD; CHRED; CARBN; BIODG; or CMBST	CHOXD; CHRED; or CMBST
P113	Thallic oxide	Thallium (measured in wastewaters only).	7440–28–0	1.4	RTHRM; or STABL
P114	Thallium selenite	Selenium	7782–49–2	0.82	0.16 mg/l TCLP
P115	Thallium (I) sulfate	Thallium (measured in wastewaters only).	7440–28–0	1.4	RTHRM; or STABL
P116	Thiosemicarbazide	Thiosemicarbazide	79–19–6	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
P118	Trichloromethanethiol	Trichloromethanethiol	75–70–7	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
P119	Ammonium vanadate	Vanadium (measured in wastewaters only).	7440–62–2	4.3	STABL
P120	Vandium pentoxide	Vanadium (measured in wastewaters only).	7440–62–2	4.3	STABL
P121	Zinc cyanide	Cyanides (Total)[7]	57–12–5	1.2	590
		Cyanides (Amenable)[7]	57–12–5	0.86	30
P122	Zinc phosphide Zn_3P_2, when present at concentrations greater than 10%.	Zinc Phosphide	1314–84–7	CHOXD; CHRED; or CMBST	CHOXD; CHRED; or CMBST
P123	Toxaphene	Toxaphene	8001–35–2	0.0095	2.6
P127	Carbofuran	Carbofuran	1563–66–2	0.006	0.14
P128	Mexacarbate	Mexacarbate	315–18–4	0.056	1.4
P185	Tirpate	Tirpate	26419–73–8	0.056	0.28
P187	Bendiocarb	Bendiocarb	22781–23–3	0.056	1.4
P188	Physostigmine salicylate	Physostigmine salicylate	57–64–7	0.056	1.4
P189	Carbosulfan	Carbosulfan	55285–14–8	0.028	1.4
P190	Metolcarb	Metolcarb	1129–41–5	0.056	1.4
P191	Dimetilan	Dimetilan	644–64–4	0.056	1.4
P192	Isolan	Isolan	119–38–0	0.056	1.4
P193	Thiophanate-methyl	Thiophanate-methyl	23564–05–8	0.056	1.4
P194	Oxamyl	Oxamyl	23135–22–0	0.056	0.28
P195	Thiodicarb	Thiodicarb	59669–26–0	0.019	1.4
P196	Dithiocarbamates (total)	Dithiocarbamates (total)	NA	0.028	28
P197	Formparanate	Formparanate	17702–57–7	0.056	1.4
P198	Formetanate hydrochloride	Formetanate hydrochloride	23422–53–9	0.056	1.4
P199	Methiocarb.	Methiocarb	2032–65–7	0.056	1.4
P200	Propoxur	Propoxur	114–26–1	0.056	1.4
P201	Promecarb	Promecarb	2631–37–0	0.056	1.4
P202	Hercules AC–5727	Hercules AC–5727	64–00–6	0.056	

U017	Benzal chloride	Benzal chloride	98–87–3	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U018	Benz(a)anthracene	Benz(a)anthracene	56–55–3	0.059	3.4
U019	Benzene	Benzene	71–43–2	0.14	10
U020	Benzenesulfonyl chloride	Benzenesulfonyl chloride	98–09–9	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U021	Benzidine	Benzidine	92–87–5	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U022	Benzo(a)pyrene	Benzo(a)pyrene	50–32–8	0.061	3.4
U023	Benzotrichloride	Benzotrichloride	98–07–7	CHOXD; CHRED; CARBN; BIODG; or CMBST	CHOXD; CHRED; or CMBST
U024	bis(2-Chloroethoxy)methane	bis(2-Chloroethoxy)methane	111–91–1	0.036	7.2
U025	bis(2-Chloroethyl)ether	bis(2-Chloroethyl)ether	111–44–4	0.033	6.0
U026	Chlornaphazine	Chlornaphazine	494–03–1	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U027	bis(2-Chloroisopropyl)ether	bis(2-Chloroisopropyl)ether	39638–32–9	(WETOX or CHOXD) fb CARBN; or CMBST	7.2
U028	bis(2-Ethylhexyl) phthalate	bis(2-Ethylhexyl) phthalate	117–81–7	0.28	28
U029	Methyl bromide (Bromomethane)	Methyl bromide (Bromomethane)	74–83–9	0.11	15
U030	4-Bromophenyl phenyl ether	4-Bromophenyl phenyl ether	101–55–3	0.055	15
U031	n-Butyl alcohol	n-Butyl alcohol	71–36–3	5.6	2.6
U032	Calcium chromate	Chromium (Total)	7440–47–3	2.77	0.86 mg/l TCLP
U033	Carbon oxyfluoride	Carbon oxyfluoride	353–50–4	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U034	Trichloroacetaldehyde (Chloral)	Trichloroacetaldehyde (Chloral)	75–87–6	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U035	Chlorambucil	Chlorambucil	305–03–3	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U036	Chlordane	Chlordane (alpha and gamma isomers).	57–74–9	0.0033	0.26
U037	Chlorobenzene	Chlorobenzene	108–90–7	0.057	6.0
U038	Chlorobenzilate	Chlorobenzilate	510–15–6	0.10	CMBEST
U039	p-Chloro-m-cresol	p-Chloro-m-cresol	59–50–7	0.018	14
U041	Epichlorohydrin (1-Chloro-2,3-epoxypropane)	Epichlorohydrin (1-Chloro-2,3-epoxypropane).	106–89–8	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U042	2-Chloroethyl vinyl ether	2-Chloroethyl vinyl ether	110–75–8	0.062	CMBST
U043	Vinyl chloride	Vinyl chloride	75–01–4	0.27	6.0
U044	Chloroform	Chloroform	67–66–3	0.046	6.0
U045	Chloromethane (Methyl chloride)	Chloromethane (Methyl chloride)	74–87–3	0.19	30

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U017	Benzal chloride	Benzal chloride	98–87–3	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U018	Benz(a)anthracene	Benz(a)anthracene	56–55–3	0.059	3.4
U019	Benzene	Benzene	71–43–2	0.14	10
U020	Benzenesulfonyl chloride	Benzenesulfonyl chloride	98–09–9	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U021	Benzidine	Benzidine	92–87–5	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U022	Benzo(a)pyrene	Benzo(a)pyrene	50–32–8	0.061	3.4
U023	Benzotrichloride	Benzotrichloride	98–07–7	CHOXD; CHRED; CARBN; BIODG; or CMBST	CHOXD; CHRED; or CMBST
U024	bis(2-Chloroethoxy)methane	bis(2-Chloroethoxy)methane	111–91–1	0.036	7.2
U025	bis(2-Chloroethyl)ether	bis(2-Chloroethyl)ether	111–44–4	0.033	6.0
U026	Chlornaphazine	Chlornaphazine	494–03–1	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U027	bis(2-Chloroisopropyl)ether	bis(2-Chloroisopropyl)ether	39638–32–9	(WETOX or CHOXD) fb CARBN; or CMBST	7.2
U028	bis(2-Ethylhexyl) phthalate	bis(2-Ethylhexyl) phthalate	117–81–7	0.28	28
U029	Methyl bromide (Bromomethane)	Methyl bromide (Bromomethane)	74–83–9	0.11	15
U030	4-Bromophenyl phenyl ether	4-Bromophenyl phenyl ether	101–55–3	0.055	15
U031	n-Butyl alcohol	n-Butyl alcohol	71–36–3	5.6	2.6
U032	Calcium chromate	Chromium (Total)	7440–47–3	2.77	0.86 mg/l TCLP
U033	Carbon oxyfluoride	Carbon oxyfluoride	353–50–4	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U034	Trichloroacetaldehyde (Chloral)	Trichloroacetaldehyde (Chloral)	75–87–6	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U035	Chlorambucil	Chlorambucil	305–03–3	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U036	Chlordane	Chlordane (alpha and gamma isomers).	57–74–9	0.0033	0.26
U037	Chlorobenzene	Chlorobenzene	108–90–7	0.057	6.0
U038	Chlorobenzilate	Chlorobenzilate	510–15–6	0.10	CMBEST
U039	p-Chloro-m-cresol	p-Chloro-m-cresol	59–50–7	0.018	14
U041	Epichlorohydrin (1-Chloro-2,3-epoxypropane)	Epichlorohydrin (1-Chloro-2,3-epoxypropane).	106–89–8	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U042	2-Chloroethyl vinyl ether	2-Chloroethyl vinyl ether	110–75–8	0.062	CMBST
U043	Vinyl chloride	Vinyl chloride	75–01–4	0.27	6.0
U044	Chloroform	Chloroform	67–66–3	0.046	6.0
U045	Chloromethane (Methyl chloride)	Chloromethane (Methyl chloride)	74–87–3	0.19	30

U059	Daunomycin	Daunomycin	20830–81–3	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U060	DDD	o,p'-DDD	53–19–0	0.023	0.087
		p,p'-DDD	72–54–8	0.023	0.087
U061	DDT	o,p'-DDT	789–02–6	0.0039	0.087
		p,p'-DDT	50–29–3	0.0039	0.087
		o,p'-DDD	53–19–0	0.023	0.087
		p,p'-DDD	72–54–8	0.023	0.087
		o,p'-DDE	3424–82–6	0.031	0.087
		p,p'-DDE	72–55–9	0.031	0.087
U062	Diallate	Diallate	2303–16–4	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U063	Dibenz(a,h)anthracene	Dibenz(a,h)anthracene	53–70–3	0.055	8.2
U064	Dibenz(a,i)pyrene	Dibenz(a,i)pyrene	189–55–9	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U066	1,2-Dibromo-3-chloropropane	1,2-Dibromo-3-chloropropane	96–12–8	0.11	15
U067	Ethylene dibromide (1,2-Dibromoethane)	Ethylene dibromide (1,2-Dibromoethane).	106–93–4	0.028	15
U068	Dibromomethane	Dibromomethane	74–95–3	0.11	15
U069	Di-n-butyl phthalate	Di-n-butyl phthalate	84–74–2	0.057	28
U070	o-Dichlorobenzene	o-Dichlorobenzene	95–50–1	0.088	6.0
U071	m-Dichlorobenzene	m-Dichlorobenzene	541–73–1	0.036	6.0
U072	p-Dichlorobenzene	p-Dichlorobenzene	106–46–7	0.090	6.0
U073	3,3'-Dichlorobenzidine	3,3'-Dichlorobenzidine	91–94–1	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U074	1,4-Dichloro-2-butene	cis-1,4-Dichloro-2-butene	1476–11–5	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
		trans-1,4-Dichloro-2-butene	764–41–0	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U075	Dichlorodifluoromethane	Dichlorodifluoromethane	75–71–8	0.23	7.2
U076	1,1-Dichloroethane	1,1-Dichloroethane	75–34–3	0.059	6.0
U077	1,2-Dichloroethane	1,2-Dichloroethane	107–06–2	0.21	6.0
U078	1,1-Dichloroethylene	1,1-Dichloroethylene	75–35–4	0.025	6.0
U079	1,2-Dichloroethylene	trans-1,2-Dichloroethylene	156–60–5	0.054	30
U080	Methylene chloride	Methylene chloride	75–09–2	0.089	30
U081	2,4-Dichlorophenol	2,4-Dichlorophenol	120–83–2	0.044	14
U082	2,6-Dichlorophenol	2,6-Dichlorophenol	87–65–0	0.044	14
U083	1,2-Dichloropropane	1,2-Dichloropropane	78–87–5	0.85	18
U084	1,3-Dichloroproplyene	cis-1,3-Dichloroproplyene	10061–01–5	0.036	18
		trans-1,3-Dichloroproplyene	10061–02–6	0.036	18
U085	1,2:3,4-Diepoxybutane	1,2:3,4-Diepoxybutane	1464–53–5	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST

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U099	1,2-Dimethylhydrazine	1,2-Dimethylhydrazine	540–73–8	CHOXD; CHRED; CARBN; BIODG; or CMBST	CHOXD; CHRED; or CMBST
U101	2,4-Dimethylphenol	2,4-Dimethylphenol	105–67–9	0.036	CHOXD; CHRED; or CMBST
U102	Dimethyl phthalate	Dimethyl phthalate	131–11–3	0.047	14
U103	Dimethyl sulfate	Dimethyl sulfate	77–78–1	CHOXD; CHRED; CARBN; BIODG; or CMBST	28
U105	2,4-Dinitrotoluene	2,4-Dinitrotoluene	121–14–2	0.32	CHOXD; CHRED; or CMBST
U106	2,6-Dinitrotoluene	2,6-Dinitrotoluene	606–20–2	0.55	140
U108	1,4-Dioxane	1,4-Dioxane	123–91–1	(WETOX or CHOXD) fb CARBN; or CMBST	28
		1,4-Dioxane; alternate[6] standard for nonwastewaters only.	123–91–1	NA	CMBST
U109	1,2-Diphenylhydrazine	1,2-Diphenylhydrazine	122–66–7	CHOXD; CHRED; CARBN; BIODG; or CMBST	170
		1,2-Diphenylhydrazine; alternate[6] standard for wastewaters only.	122–66–7	0.087	CHOXD; CHRED; or CMBST
U110	Dipropylamine	Dipropylamine	142–84–7	(WETOX or CHOXD) fb CARBN; or CMBST	NA
U111	Di-n-propylnitrosamine	Di-n-propylnitrosamine	621–64–7	0.40	CMBST
U112	Ethyl acetate	Ethyl acetate	141–78–6	0.34	14
U113	Ethyl acrylate	Ethyl acrylate	140–88–5	(WETOX or CHOXD) fb CARBN; or CMBST	33
U114	Ethylenebisdithiocarbamic acid salts and esters	Ethylenebisdithiocarbamic acid	111–54–6	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U115	Ethylene oxide	Ethylene oxide	75–21–8	(WETOX or CHOXD) fb CARBN; or CMBST	CHOXD; or CMBST
		Ethylene oxide; alternate[6] standard for wastewaters only.	75–21–8	0.12	NA
U116	Ethylene thiourea	Ethylene thiourea	96–45–7	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U117	Ethyl ether	Ethyl ether	60–29–7	0.12	160
U118	Ethyl methacrylate	Ethyl methacrylate	97–63–2	0.14	160
U119	Ethyl methane sulfonate	Ethyl methane sulfonate	62–50–0	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U120	Fluoranthene	Fluoranthene	206–44–0	0.068	3.4
U121	Trichloromonofluoromethane	Trichloromonofluoromethane	75–69–4	0.020	30

U143	Lasiocarpine	Lasiocarpine	303–34–4	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U144	Lead acetate	Lead	7439–92–1	0.69	0.37 mg/l TCLP
U145	Lead phosphate	Lead	7439–92–1	0.69	0.37 mg/l TCLP
U146	Lead subacetate	Lead	7439–92–1	0.69	0.37 mg/l TCLP
U147	Maleic anhydride	Maleic anhydride	108–31–6	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U148	Maleic hydrazide	Maleic hydrazide	123–33–1	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U149	Malononitrile	Malononitrile	109–77–3	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U150	Melphalan	Melphalan	148–82–3	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U151	U151 (mercury) nonwastewaters that contain greater than or equal to 260 mg/kg total mercury.	Mercury	7439–97–6	NA	RMERC
	U151 (mercury) nonwastewaters that contain less than 260 mg/kg total mercury and that are residues from RMERC only.	Mercury	7439–97–6	NA	0.20 mg/l TCLP
	U151 (mercury) nonwastewaters that contain less than 260 mg/kg total mercury and that are not residues from RMERC.	Mercury	7439–97–6	NA	0.025 mg/l TCLP
	All U151 (mercury) wastewaters	Mercury	7439–97–6	0.15	NA
	Elemental Mercury Contaminated with Radioactive materials.	Mercury	7439–97–6	NA	AMLGM
U152	Methacrylonitrile	Methacrylonitrile	126–98–7	0.24	84
U153	Methanethiol	Methanethiol	74–93–1	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U154	Methanol	Methanol	67–56–1	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
		Methanol, alternate[6] set of standards for both wastewaters and nonwastewaters.	67–56–1	5.6	0.75 mg/l TCLP
U155	Methapyrilene	Methapyrilene	91–80–5	0.081	1.5
U156	Methyl chlorocarbonate	Methyl chlorocarbonate	79–22–1	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U157	3-Methylcholanthrene	3-Methylcholanthrene	56–49–5	0.0055	15
U158	4,4'-Methylene bis(2-chloroaniline)	4,4'-Methylene bis(2-chloroaniline)	101–14–4	0.50	30
U159	Methyl ethyl ketone	Methyl ethyl ketone	78–93–3	0.28	36
U160	Methyl ethyl ketone peroxide	Methyl ethyl ketone peroxide	1338–23–4	CHOXD; CHRED; CARBN; BIODG; OR CMBST	CHOXD; CHRED; OR CMBST

U182	Paraldehyde	Paraldehyde	123–63–7	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U183	Pentachlorobenzene	Pentachlorobenzene	608–93–5	0.055	10
U184	Pentachloroethane	Pentachloroethane	76–01–7	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
		Pentachloroethane; alternate[6] standards for both wastewaters and nonwastewaters.	76–01–7	0.055	6.0
U185	Pentachloronitrobenzene	Pentachloronitrobenzene	82–68–8	0.055	4.8
U186	1,3-Pentadiene	1,3-Pentadiene	504–60–9	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U187	Phenacetin	Phenacetin	62–44–2	0.081	16
U188	Phenol	Phenol	108–95–2	0.039	6.2
U189	Phosphorus sulfide	Phosphorus sulfide	1314–80–3	CHOXD, CHRED, or CMBST	CHOXD, CHRED, or CMBST
U190	Phthalic anhydride (measured as Phthalic acid or Terephthalic acid).	Phthalic anhydride (measured as Phthalic acid or Terephthalic acid).	100–21–0	0.055	28
		Phthalic anhydride	85–44–9	0.055	28
U191	2-Picoline	2-Picoline	109–06–8	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U192	Pronamide	Pronamide	23950–58–5	0.093	1.5
U193	1,3-Propane sultone	1,3-Propane sultone	1120–71–4	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U194	n-Propylamine	n-Propylamine	107–10–8	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U196	Pyridine	Pyridine	110–86–1	0.014	16
U197	p-Benzoquinone	p-Benzoquinone	106–51–4	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U200	Reserpine	Reserpine	50–55–5	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U201	Resorcinol	Resorcinol	108–46–3	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U202	Saccharin and salts	Saccharin	81–07–2	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U203	Safrole	Safrole	94–59–7	0.081	22
U204	Selenium dioxide	Selenium	7782–49–2	0.82	0.16 mg/l TCLP
U205	Selenium sulfide	Selenium	7782–49–2	0.82	0.16 1 TCLP

U235	tris-(2,3-Dibromoprophyl)-phosphate	tris-(2,3-Dibromoprophyl)-phosphate.	126–72–7	0.11	0.10
U236	Trypan Blue	Trypan Blue	72–57–1	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U237	Uracil mustard	Uracil mustard	66–75–1	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U238	Urethane (Ethyl carbamate)	Urethane (Ethyl carbamate)	51–79–6	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U239	Xylenes	Xylenes-mixed isomers (sum of o-, m-, and p-xylene concentrations).	1330–20–7	0.32	30
U240	2,4-D (2,4-Dichlorophenoxyacetic acid)	2,4–D (2,4-Dichlorophenoxyacetic acid).	94–75–7	0.72	10
	2,4-D (2,4-Dichlorophenoxyacetic acid) salts and esters.		NA	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U243	Hexachloropropylene	Hexachloropropylene	1888–71–7	0.035	30
U244	Thiram	Thiram	137–26–8	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U246	Cyanogen bromide	Cyanogen bromide	506–68–3	CHOXD; WETOX; or CMBST	CHOXD, WETOX; or CMBST
U247	Methoxychlor	Methoxychlor	72–43–5	0.25	0.18
U248	Warfarin, & salts, when present at concentrations of 0.3% or less.	Warfarin	81–81–2	(WETOX or CHOXD) fb CARBN; or CMBST	CMBST
U249	Zinc phosphide, Zn_3P_2, when present at concentrations of 10% or less.	Zinc Phosphide	1314–84–7	CHOXD; CHRED; or CMBST	CHOXD; CHRED; or CMBST
U271	Benomyl	Benomyl	17804–35–2	0.056	1.4
U277	Sulfallate	Sulfallate	95–06–7	0.056	1.4
U279	Carbaryl	Carbaryl	63–25–2	0.006	0.14
U280	Barban	Barban	101–27–9	0.056	1.4
U328	o-Toluidine	o-Toluidine	95–53–4	CMBST; or CHOXD fb (BIODG or CARBN); or BIODG fb CARBN.	CMBST
U353	p-Toluidine	p-Toluidine	106–49–0	CMBST; or CHOXD fb (BIODG or CARBN); or BIODG fb CARBN.	CMBST
U359	2-Ethoxyethanol	2-Ethoxyethanol	110–80–5	CMBST; or CHOXD fb (BIODG or CARBN); or BIODG fb CARBN	CMBST

U399	Dithiocarbamates (total)	Dithiocarbamates (total)	NA	0.028	28
	Nickel	Nickel	7440–02–0	3.98	5.0 mg/l TCLP
U400	Dithiocarbamates (total)	Dithiocarbamates (total)	NA	0.028	28
U401	Dithiocarbamates (total)	Dithiocarbamates (total)	NA	0.028	28
U402	Dithiocarbamates (total)	Dithiocarbamates (total)	NA	0.028	28
U403	Dithiocarbamates (total)	Dithiocarbamates (total)	NA	0.028	28
U404	Triethylamine	Triethylamine	121–44–8	0.081	1.5
U405	Dithiocarbamates (total)	Dithiocarbamates (total)	NA	0.028	28
U406	Dithiocarbamates (total)	Dithiocarbamates (total)	NA	0.028	28
U407	Dithiocarbamates (total)	Dithiocarbamates (total)	NA	0.028	28
U408	2,4,6-Tribromophenol	2,4,6-Tribromophenol	118–79–6	0.035	7.4

Notes to Table:

[1] The waste descriptions provided in this table do not replace waste descriptions in 40 CFR part 261. Descriptions of Treatment/Regulatory Subcategories are provided, as needed, to distinguish betweenapplicability of different standards.

[2] CAS means Chemical Abstract Services. When the waste code and/or regulated constituents are described as a combination of a chemical with it's salts and/or esters, the CAS number is given for the parent compound only.

[3] Concentration standards for wastewaters are expressed in mg/l and are based on analysis of composite samples.

[4] All treatment standards expressed as a Technology Code or combination of Technology Codes are explained in detail in 40 CFR 268.42 Table 1—Technology Codes and Descriptions of Technology-Based Standards.

[5] Except for Metals (EP or TCLP) and Cyanides (Total and Amenable) the nonwastewater treatment standards expressed as a concentration were established, in part, based upon incineration in units operated in accordance with the technical requirements of 40 CFR Part 264, Subpart O, or Part 265, Subpart O, or based upon combustion in fuel substitution units operating in accordance with applicable technical requirements. A facility may comply with these treatment standards according to provisions in 40 CFR 268.40(d). All concentration standards for nonwastewaters are based on analysis of grab samples.

[6] Where an alternate treatment standard or set of alternate standards has been indicated, a facility may comply with this alternate standard, but only for the Treatment/Regulatory Subcategory or physical form (i.e., wastewater and/or nonwastewater) specified for that alternate standard.

[7] Both Cyanides (Total) and Cyanides (Amenable) for nonwastewaters are to be analyzed using Method 9010 or 9012, found in "Test Methods for Evaluating Solid Waste, Physical/Chemical Methods", EPA Publication SW–846, as incorporated by reference in 40 CFR 260.11, with a sample size of 10 grams and a distillation time of one hour and 15 minutes.

[8] As an alternative to these standards, the underlying hazardous constituents in the waste must meet a CWA limitation, which can include a toxic pollutant indicator for the constituent; Pretreatment Standards for Existing Sources; Pretreatment Standards for New Sources; local limitations based upon a pass-through determination; or a Fundamentally Different Factors variance under 40 CFR 125.30–125.32.

UNIVERSAL TREATMENT STANDARDS—Continued

[Note: NA means not applicable.]

Regulated constituent/common name	CAS[1] number	Wastewater standard	Nonwastewater standard
		Concentration in mg/l[2]	Concentration in mg/kg[3] unless noted as "mg/l TCLP"
alpha-BHC	319-84-6	0.00014	0.066
beta-BHC	319-85-7	0.00014	0.066
delta-BHC	319-86-8	0.023	0.066
gamma-BHC	58-89-9	0.0017	0.066
Bromodichloromethane	75-27-4	0.35	15
Bromomethane/Methyl bromide	74-83-9	0.11	15
4-Bromophenyl phenyl ether	101-55-3	0.055	15
n-Butyl alcohol	71-36-3	5.6	2.6
Butyl benzyl phthalate	85-68-7	0.017	28
Butylate	2008-41-5	0.003	1.4
2-sec-Butyl-4,6-dinitrophenol/Dinoseb	88-85-7	0.066	2.5
Carbaryl	63-25-2	0.006	0.14
Carbenzadim	10605-21-7	0.056	1.4
Carbofuran	1563-66-2	0.006	0.14
Carbofuran phenol	1563-38-8	0.056	1.4
Carbon disulfide	75-15-0	3.8	4.8 mg/l TCLP
Carbon tetrachloride	56-23-5	0.057	6.0
Carbosulfan	55285-14-8	0.028	1.4
Chlordane (alpha and gamma isomers)	57-74-9	0.0033	0.26
p-Chloroaniline	106-47-8	0.46	16
Chlorobenzene	108-90-7	0.057	6.0
Chlorobenzilate	510-15-6	0.10	NA
2-Chloro-1,3-butadiene	126-99-8	0.057	0.28
Chlorodibromomethane	124-48-1	0.057	15
Chloroethane	75-00-3	0.27	6.0
bis(2-Chloroethoxy)methane	111-91-1	0.036	7.2
bis(2-Chloroethyl)ether	111-44-4	0.033	6.0
2-Chloroethyl vinyl ether	110-75-8	0.062	NA
Chloroform	67-66-3	0.046	6.0
bis(2-Chloroisopropyl)ether	39638-32-9	0.055	7.2
p-Chloro-m-cresol	59-50-7	0.018	14
Chloromethane/Methyl chloride	74-87-3	0.19	30
2-Chloronaphthalene	91-58-7	0.055	5.6
2-Chlorophenol	95-57-8	0.044	5.7
3-Chloropropylene	107-05-1	0.036	30
Chrysene	218-01-9	0.059	3.4
o-Cresol	95-48-7	0.11	5.6
m-Cresol (difficult to distinguish from p-cresol)	108-39-4	0.77	5.6
p-Cresol (difficult to distinguish from m-cresol)	106-44-5	0.77	5.6
m-Cumenyl methylcarbamate	64-00-6	0.056	1.4
Cycloate	1134-23-2	0.003	1.4
Cyclohexanone	108-94-1	0.36	0.75 mg/l TCLP
o,p'-DDD	53-19-0	0.023	0.087
p,p'-DDD	72-54-8	0.023	0.087
o,p'-DDE	3424-82-6	0.031	0.087
p,p'-DDE	72-55-9	0.031	0.087
o,p'-DDT	789-02-6	0.0039	0.087
p,p'-DDT	50-29-3	0.0039	0.087
Dibenz(a,h)anthracene	53-70-3	0.055	8.2
Dibenz(a,e)pyrene	192-65-4	0.061	NA
1,2-Dibromo-3-chloropropane	96-12-8	0.11	15
1,2-Dibromoethane/Ethylene dibromide	106-93-4	0.028	15
Dibromomethane	74-95-3	0.11	15
m-Dichlorobenzene	541-73-1	0.036	6.0
o-Dichlorobenzene	95-50-1	0.088	6.0
p-Dichlorobenzene	106-46-7	0.090	6.0
Dichlorodifluoromethane	75-71-8	0.23	7.2
1,1-Dichloroethane	75-34-3	0.059	6.0
1,2-Dichloroethane	107-06-2	0.21	6.0
1,1-Dichloroethylene	75-35-4	0.025	6.0
trans-1,2-Dichloroethylene	156-60-5	0.054	30
2,4-Dichlorophenol	120-83-2	0.044	14
2,6-Dichlorophenol	87-65-0	0.044	14
2,4-Dichlorophenoxyacetic acid/2,4-D	94-75-7	0.72	10
1,2-Dichloropropane	78-87-5	0.85	18

UNIVERSAL TREATMENT STANDARDS—Continued

[Note: NA means not applicable.]

Regulated constituent/common name	CAS[1] number	Wastewater standard	Nonwastewater standard
		Concentration in mg/l[2]	Concentration in mg/kg[3] unless noted as "mg/l TCLP"
Methyl isobutyl ketone	108-10-1	0.14	33
Methyl methacrylate	80-62-6	0.14	160
Methyl methansulfonate	66-27-3	0.018	NA
Methyl parathion	298-00-0	0.014	4.6
3-Methylcholanthrene	56-49-5	0.0055	15
4,4-Methylene bis(2-chloroaniline	101-14-4	0.50	30
Methylene chloride	75-09-2	0.089	30
Metolcarb	1129-41-5	0.056	1.4
Mexacarbate	315-18-4	0.056	1.4
Molinate	2212-67-1	0.003	1.4
Naphthalene	91-20-3	0.059	5.6
2-Naphthylamine	91-59-8	0.52	NA
o-Nitroaniline	88-74-4	0.27	14
p-Nitroaniline	100-01-6	0.028	28
Nitrobenzene	98-95-3	0.068	14
5-Nitro-o-toluidine	99-55-8	0.32	28
o-Nitrophenol	88-75-5	0.028	13
p-Nitrophenol	100-02-7	0.12	29
N-Nitrosodiethylamine	55-18-5	0.40	28
N-Nitrosodimethylamine	62-75-9	0.40	2.3
N-Nitroso-di-n-butylamine	924-16-3	0.40	17
N-Nitrosomethylethylamine	10595-95-6	0.40	2.3
N-Nitrosomorpholine	59-89-2	0.40	2.3
N-Nitrosopiperidine	100-75-4	0.013	35
N-Nitrosopyrrolidine	930-55-2	0.013	35
Oxamyl	23135-22-0	0.056	0.28
Parathion	56-38-2	0.014	4.6
Total PCBs (sum of all PCB isomers, or all Aroclors)	1336-36-3	0.10	10
Pebulate	1114-71-2	0.003	1.4
Pentachlorobenzene	608-93-5	0.055	10
PeCDDs (All Pentachlorodibenzo-p-dioxins)	NA	0.000063	0.001
PeCDFs (All Pentachlorodibenzofurans)	NA	0.000035	0.001
Pentachloroethane	76-01-7	0.055	6.0
Pentachloronitrobenzene	82-68-8	0.055	4.8
Pentachlorophenol	87-86-5	0.089	7.4
Phenacetin	62-44-2	0.081	16
Phenanthrene	85-01-8	0.059	5.6
Phenol	108-95-2	0.039	6.2
o-Phenylenediamine	95-54-5	0.056	5.6
Phorate	298-02-2	0.021	4.6
Phthalic acid	100-21-0	0.055	28
Phthalic anhydride	85-44-9	0.055	28
Physostigmine	57-47-6	0.056	1.4
Physostigmine salicylate	57-64-7	0.056	1.4
Promecarb	2631-37-0	0.056	1.4
Pronamide	23950-58-5	0.093	1.5
Propham	122-42-9	0.056	1.4
Propoxur	114-26-1	0.056	1.4
Prosulfocarb	52888-80-9	0.003	1.4
Pyrene	129-00-0	0.067	8.2
Pyridine	110-86-1	0.014	16
Safrole	94-59-7	0.081	22
Silvex/2,4,5-TP	93-72-1	0.72	7.9
1,2,4,5-Tetrachlorobenzene	95-94-3	0.055	14
TCDDs (All Tetrachlorodibenzo-p-dioxins)	NA	0.000063	0.001
TCDFs (All Tetrachlorodibenzofurans)	NA	0.000063	0.001
1,1,1,2-Tetrachloroethane	630-20-6	0.057	6.0
1,1,2,2-Tetrachloroethane	79-34-5	0.057	6.0
Tetrachloroethylene	127-18-4	0.056	6.0
2,3,4,6-Tetrachlorophenol	58-90-2	0.030	7.4
Thiodicarb	59669-26-0	0.019	1.4
Thiophanate-methyl	23564-05-8	0.056	1.4
Tirpate	26419-73-8	0.056	0.28
Toluene	108-88-3	0.080	10
Toxaphene	8001-35-2	0.0095	2.6

APPENDIX XI TO PART 268—METAL BEARING WASTES PROHIBITED FROM DILUTION IN A COMBUSTION UNIT ACCORDING TO 40 CFR 268.3(c) [1]—Continued

Waste code	Waste description
F006	Wastewater treatment sludges from electroplating operations except from the following processes: (1) sulfuric acid anodizing of aluminum; (2) tin plating carbon steel; (3) zinc plating (segregated basis) on carbon steel; (4) aluminum or zinc-plating on carbon steel; (5) cleaning/stripping associated with tin, zinc and aluminum plating on carbon steel; and (6) chemical etching and milling of aluminum.
F007	Spent cyanide plating bath solutions from electroplating operations.
F008	Plating bath residues from the bottom of plating baths from electroplating operations where cyanides are used in the process.
F009	Spent stripping and cleaning bath solutions from electroplating operations where cyanides are used in the process.
F010	Quenching bath residues from oil baths from metal treating operations where cyanides are used in the process.
F011	Spent cyanide solutions from salt bath pot cleaning from metal heat treating operations.
F012	Quenching waste water treatment sludges from metal heat treating operations where cyanides are used in the process.
F019	Wastewater treatment sludges from the chemical conversion coating of aluminum except from zirconium phosphating in aluminum car washing when such phosphating is an exclusive conversion coating process.
K002	Wastewater treatment sludge from the production of chrome yellow and orange pigments.
K003	Wastewater treatment sludge from the production of molybdate orange pigments.
K004	Wastewater treatment sludge from the production of zinc yellow pigments.
K005	Wastewater treatment sludge from the production of chrome green pigments.
K006	Wastewater treatment sludge from the production of chrome oxide green pigments (anhydrous and hydrated).
K007	Wastewater treatment sludge from the production of iron blue pigments.
K008	Oven residue from the production of chrome oxide green pigments.
K061	Emission control dust/sludge from the primary production of steel in electric furnaces.
K069	Emission control dust/sludge from secondary lead smelting.
K071	Brine purification muds from the mercury cell processes in chlorine production, where separately prepurified brine is not used.
K100	Waste leaching solution from acid leaching of emission control dust/sludge from secondary lead smelting.
K106	Sludges from the mercury cell processes for making chlorine.
P010	Arsenic acid H_3AsO_4
P011	Arsenic oxide As_2O_5
P012	Arsenic trioxide
P013	Barium cyanide
P015	Beryllium
P029	Copper cyanide Cu(CN)
P074	Nickel cyanide $Ni(CN)_2$
P087	Osmium tetroxide
P099	Potassium silver cyanide
P104	Silver cyanide
P113	Thallic oxide
P114	Thallium (I) selenite
P115	Thallium (I) sulfate
P119	Ammonium vanadate
P120	Vanadium oxide V_2O_5
P121	Zinc cyanide.
U032	Calcium chromate.
U145	Lead phosphate.
U151	Mercury.
U204	Selenious acid.
U205	Selenium disulfide.
U216	Thallium (I) chloride.
U217	Thallium (I) nitrate.

[1] A combustion unit is defined as any thermal technology subject to 40 CFR part 264, subpart O; Part 265, subpart O; and/or 266, subpart H.

PART 271—REQUIREMENTS FOR AUTHORIZATION OF STATE HAZARDOUS WASTE PROGRAMS

21. The authority citation for part 271 continues to read as follows:

Authority: 42 U.S.C. 6905, 6912(a) and 6926.

Subpart A—Requirements for Final Authorization

22. Section 271.1(j) is amended by adding the following entries to Table 1 in chronological order by date of publication in the Federal Register, and by adding the following entries to Table 2 in chronological order by effective date in the Federal Register to read as follows:

§ 271.1 Purpose and scope.

* * * * *

(j) * * *

APPENDIX B

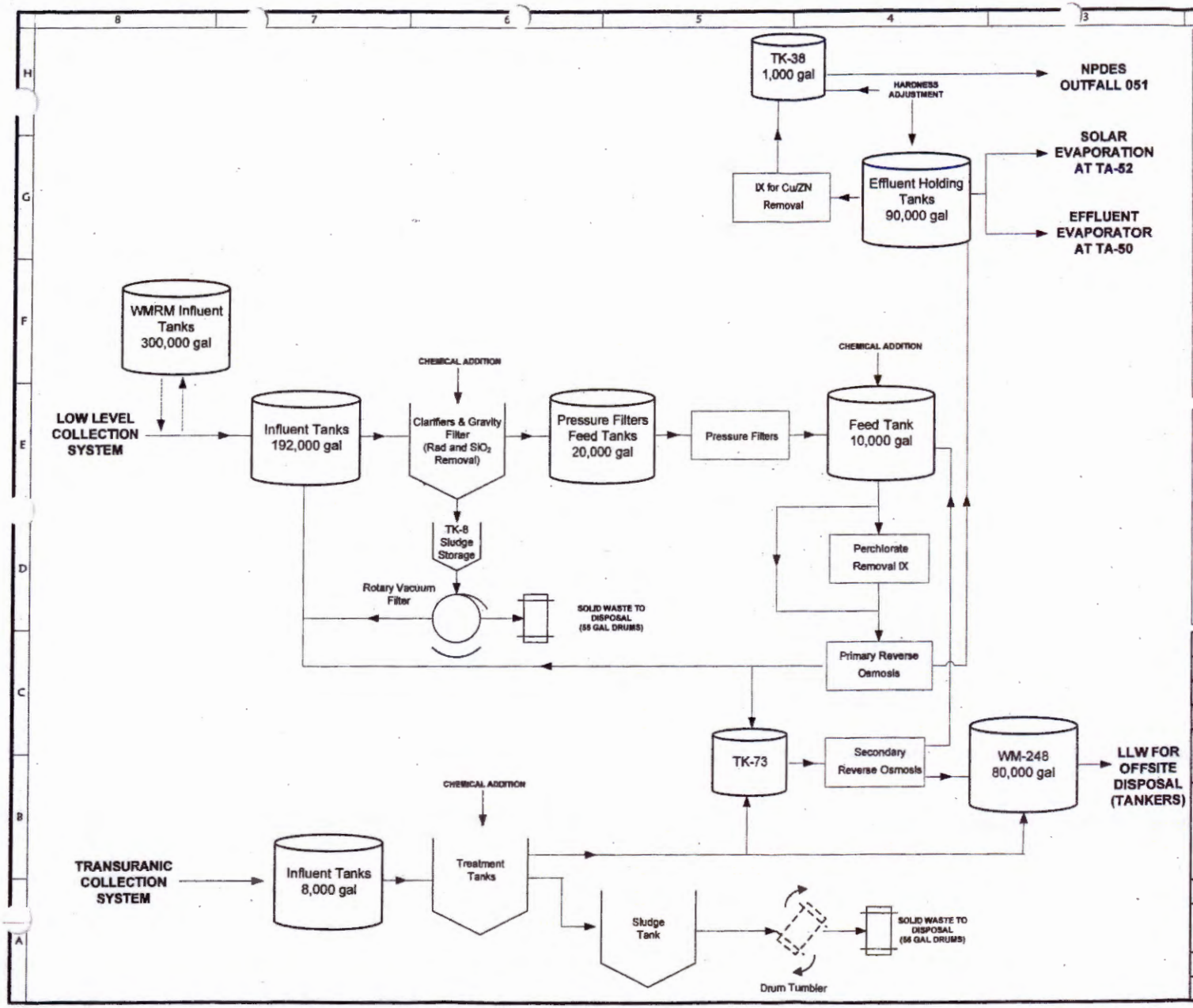
PROCESS DIAGRAMS AND DESCRIPTION

TABLE OF CONTENTS

1. PROCESS SCHEMATIC – RLW-SD-PFD-001
2. RLWTF TREATMENT UNITS – SCALED FLOOR PLAN
3. TA-50 RLWTF UNITS AND PROCESSES

PROCESS SCHEMATIC

RLW-SD-PFD-001



General Notes

LA-UR-12-00672
ENV-DO-12-0005

NOTES:

THIS PROCESS SCHEMATIC DEPICTS TYPICAL FLOW PATHS WHEN TREATING WATER AT THE TA50 RLWTF. ACTUAL TREATMENT MAY VARY DEPENDING UPON WATER QUALITY. FOR EXAMPLE, WATER FROM THE CLARIFIER MAY BE SENT TO EITHER THE GRAVITY FILTER OR THE PRESSURE FILTERS, THUS BYPASSING A SET OF FILTERS. OR PERMEATE FROM THE SECONDARY RO UNIT MAY BE SENT TO EFFLUENT HOLDING TANKS RATHER THAN TO THE PERCHLORATE FEED TANK.

No.	Date	Class Rev	ADC	Description	DFT	CHK	CSE SME	APP
3								
2	01/11/2012	2	U	CHANGES FROM DISCHARGE PERMIT MTNG	JCR	JCDS	RLS	RLS
1	10/31/2011	1	U	CHANGES FROM WQH – RLW MTNG	JCR	JCDS	RLS	RLS

ENGINEERING STANDARDS PROGRAM
Radioactive Liquid Waste Treatment Facility (RLWTF)

PROCESS SCHEMATIC
NPDES OUTFALL 051

DRAFTER	J. Rutznavarro
CHECKER	J.C Del Signore
CSE / SME	R. Swickley
Date	01/11/2012

SUBMITTED
RLWTF SM: R. Swickley

APPROVED FOR RELEASE
RLWTF DAR: R. Swickley

Los Alamos National Laboratory
Los Alamos, NM 87545

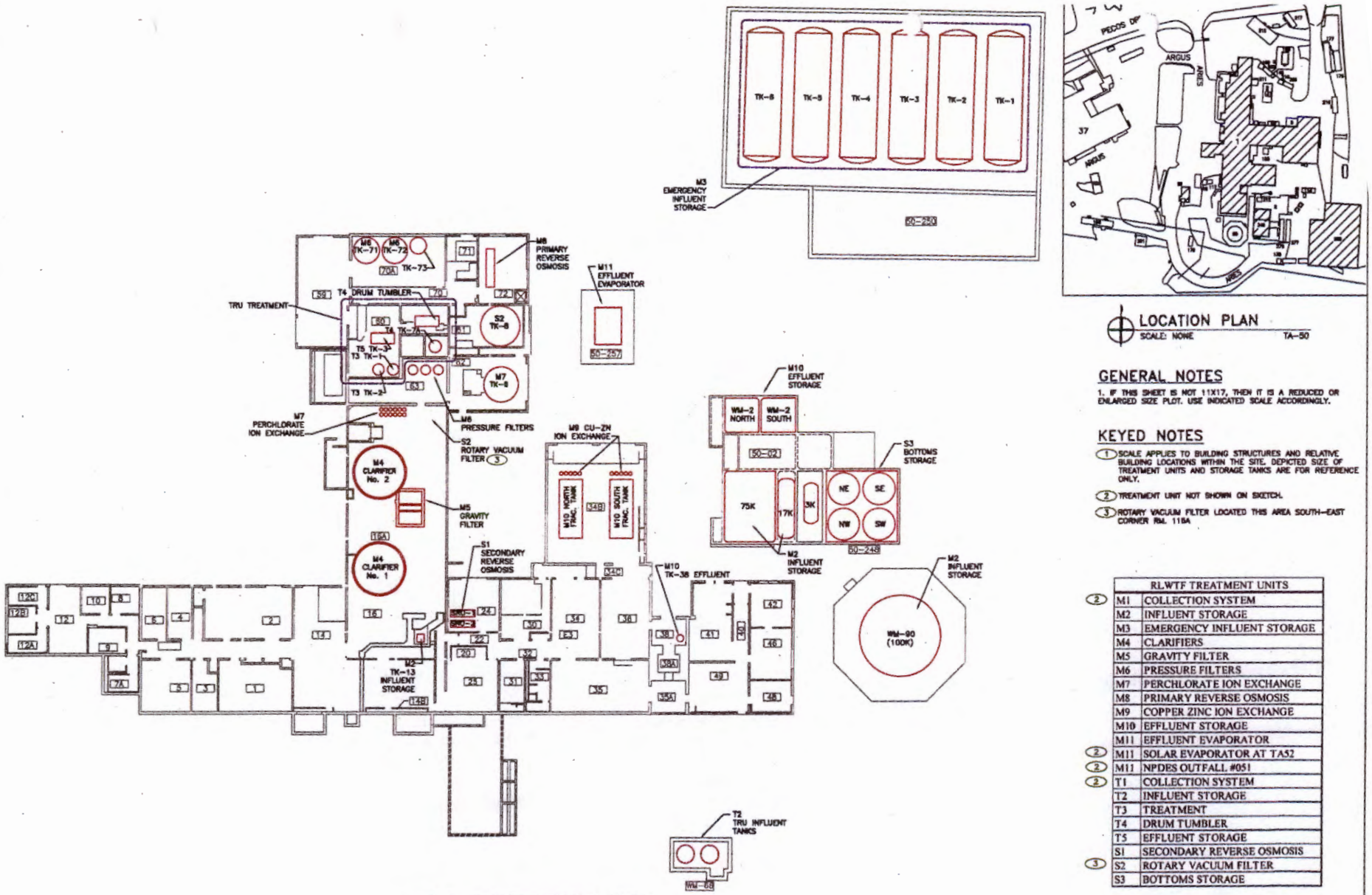
RLWTF-SD-PFD-001
1 OF 1

CLASSIFICATION: UNCLASSIFIED
ADC: JC DelSignore
DATE: 1-12-12
PROJECT ID: N/A
REV: 2

05483

RLWTF TREATMENT UNITS

SCALED FLOOR PLAN



LOCATION PLAN
SCALE: NONE
TA-50

GENERAL NOTES

1. IF THIS SHEET IS NOT 11X17, THEN IT IS A REDUCED OR ENLARGED SIZE PLOT. USE INDICATED SCALE ACCORDINGLY.

KEYED NOTES

(1) SCALE APPLIES TO BUILDING STRUCTURES AND RELATIVE BUILDING LOCATIONS WITHIN THE SITE. DEPICTED SIZE OF TREATMENT UNITS AND STORAGE TANKS ARE FOR REFERENCE ONLY.

(2) TREATMENT UNIT NOT SHOWN ON SKETCH.

(3) ROTARY VACUUM FILTER LOCATED THIS AREA SOUTH-EAST CORNER RM. 118A

	RLWTF TREATMENT UNITS	
(2)	M1	COLLECTION SYSTEM
	M2	INFLUENT STORAGE
	M3	EMERGENCY INFLUENT STORAGE
	M4	CLARIFIERS
	M5	GRAVITY FILTER
	M6	PRESSURE FILTERS
	M7	PERCHLORATE ION EXCHANGE
	M8	PRIMARY REVERSE OSMOSIS
	M9	COPPER ZINC ION EXCHANGE
	M10	EFFLUENT STORAGE
	M11	EFFLUENT EVAPORATOR
(2)	M11	SOLAR EVAPORATOR AT TA52
(2)	M11	NPDES OUTFALL #051
(2)	T1	COLLECTION SYSTEM
	T2	INFLUENT STORAGE
	T3	TREATMENT
	T4	DRUM TUMBLER
	T5	EFFLUENT STORAGE
	S1	SECONDARY REVERSE OSMOSIS
(3)	S2	ROTARY VACUUM FILTER
	S3	BOTTOMS STORAGE

LA-UR-12-00672
ENV-DO-12-0005

05485

TA-50 RLWTF UNITS AND PROCESSES

The Radioactive Liquid Waste Treatment Facility (RLWTF) consists of: (a) an underground collection system that conveys water to Technical Area (TA) 50 from generators at LANL, (b) structures at TA-50, and (c) the Zero Liquid Discharge Solar Evaporation Tanks at TA-52. At TA- 50, Building 50-01 is the primary structure; it houses treatment equipment, process tanks, analytical laboratories, and offices. Adjacent TA-50 structures primarily provide for additional water storage: 50-02 (influent), 50-66 (influent), 50-90 (influent), 50-248 (secondary waters), and 50-250 (emergency).

The RLWTF receives and treats radioactive liquid waste (RLW) from generators at Los Alamos National Laboratory. RLW includes small volumes, less than one percent of total influent, that are also characteristically hazardous for corrosivity, which are treated using elementary neutralization. The RLWTF has (1) a main treatment process for low-level RLW, (2) a process for treating transuranic RLW, and (3) a secondary treatment process for waste streams from both the low-level and transuranic processes. The units within each of these process lines are summarized in Table 1 and described in the paragraphs that follow. Table 2 provides additional information for each unit operation, including location, treatment and storage vessels, construction materials, and sizes.

Table 1: Summary of RLWTF Treatment Units

Unit Operation	Location
Main Treatment:	
M1 Collection System	TA-03, 35, 48, 50, 55, 59
M2 Influent Storage	50-02, 50-90
M3 Emergency Influent Storage	50-250
M4 Clarifiers	50-01
M5 Gravity Filter	50-01
M6 Pressure Filters	50-01
M7 Perchlorate Ion Exchange	50-01
M8 Primary Reverse Osmosis	50-01
M9 Polishing Ion Exchange	50-01
M10 Effluent Storage	50-01, 50-02
M11 Effluent Evaporator	50-257
M11 Zero Liquid Discharge Solar Evaporation Tanks	TA-52
M11 NPDES Outfall #051	Mortandad Canyon
Transuranic:	
T1 Collection System	TA-50, TA-55
T2 Influent Storage	50-66
T3 Treatment	50-01
T4 Drum Tumbling	50-01
T5 Effluent Storage	50-01
Secondary Treatment:	
S1 Secondary Reverse Osmosis	50-01
S2 Rotary Vacuum Filter	50-01
S3 Bottoms Disposal	50-248

05487

MAIN TREATMENT PROCESS

The main treatment process consists of influent collection and storage, the treatment of low-level RLW, and the discharge of treated water to the environment. Treatment steps include clarification, filtration, ion exchange, and reverse osmosis. Discharge to the environment is via NPDES Outfall #051, solar evaporation at the TA-52 Zero Liquid Discharge (ZLD) Solar Evaporation Tanks, or mechanical evaporation at TA-50-257. Two secondary streams are generated by primary treatment, sludge and reverse osmosis concentrate; they are sent to the secondary treatment process.

M1. Radioactive Liquid Waste Collection System

The majority of RLW is transferred by direct pipeline between generator facilities and the RLWTF. The remaining RLW, typically less than 1,000 gallons per month, is transferred from small generators via truck. The pipeline system, installed in 1982, connects the TA-50 RLWTF to buildings in six TAs using approximately four miles of underground piping. Piping is essentially an underground pipeline within a pipeline. Primary piping is six- or eight-inch-diameter polyethylene encased within 10- or 12-inch polyethylene secondary piping. The primary piping transitions to stainless steel in each of the 62 underground valve stations (also referred to as vaults), then back to polyethylene. Underground vaults are equipped with leak detection sensors that are linked electronically to the RLWTF control room.

M2. Influent Storage

Influent flows from vault 50-72 through the neutralization tank (TK-13) in Room 16 of TA-50-01, and then beneath the RLWTF into the influent tanks at building 50-02. There are two influent tanks, an in-ground concrete vessel with a capacity of 75,000 gallons, and a 17,000-galllon steel vessel set within a below-grade concrete containment vault. Influent may also be stored in Structure 50-90, which is an above-ground steel vessel with secondary containment and a capacity of 100,000 gallons. Low-level influent may be subjected to pH adjustment and/or oxidation. Typically, sodium hydroxide (25% solution) is used to adjust the influent pH; chemicals such as sodium permanganate may be used for oxidation. These two steps may be carried out in the neutralization tank, or the chemicals may be added directly to the influent tanks.

M3. Emergency Influent Storage

Building 50-250, the Waste Management and Risk Mitigation (WMRM) facility, is located about 50 meters southeast of Building 50-01. WMRM houses six emergency influent storage tanks with a capacity of 50,000 gallons each. Low-level influent can be shunted to these fiberglass tanks at vault 50-72, upstream

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of the 17K and 75K influent storage tanks. WMRM is a steel frame structure designed to withstand seismic, wind, and snow load criteria. The concrete basement houses the six storage tanks, and acts as secondary containment. Tanks would receive influent by gravity flow from WM-72.

M4. Clarifiers

The clarifier acts as the workhorse of the Main Treatment Plant, removing insoluble constituents, including more than 90% of the radioactivity. There are two concrete clarifiers. Each is 20 feet in diameter with a working volume of about 20,000 gallons, and each is designed to operate at 120 gallons per minute. Influent and chemicals enter from above through a flash mixer into a center well. (Chemicals such as ferric sulfate and magnesium sulfate are added at the clarifier, to promote particle growth and to adjust pH.) Contaminants precipitate as sludge, which settles to the bottom of the clarifier. Treated waters flow to the bottom of the center well, rise in the outer portion of the clarifier, and overflow to the gravity filter. Sludge is periodically removed to TK8 for subsequent treatment in the rotary vacuum filter.

M5. Gravity Filter

The dual media gravity filter is used to remove suspended solids in overflow water from the clarifier. The gravity filter contains two filtration cells of 45 square feet each. The filter bed consists of layers of anthracite, sand, and gravel resting on an underdrain grate. Water flows by gravity into the top and exits at the bottom of the bed. Backwashing is needed periodically to remove solids and to reconstitute the bed. When properly maintained and operated, the gravity filter removes particles down to 10 microns in size. The gravity filter is sized to process up to 250 gallons of water per minute.

M6. Pressure Filters

Three pressure media filters, which operate in parallel or singly, can be used to remove suspended solids in water from either the clarifier or the gravity filter. Water is pumped from two feed tanks, TK71 and TK72, through the media in an enclosed steel vessel at a pressure of about 30 psig. Feed tanks are above-grade, carbon-steel vessels, ~10,000 gallons each. Pressure filters are 30 inches in diameter and ~five feet high, and are constructed of carbon steel lined with plasite (an epoxy). The media in the pressure filter consists of coarse and fine sized particles of sand, garnet, coal, and gravel. Backwashing is needed periodically to remove solids and to reconstitute the bed. Each filter can process up to 50 gallons per minute.

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M7. Perchlorate Ion Exchange

Ion-exchange columns located in Room 16 are used to remove perchlorates. Six of the 12 fiberglass reinforced plastic (FRP) ion exchange vessels are typically in service. Vessels range in size to nine cubic feet of ion exchange resin, and can treat up to 60 gallons of water per minute. The columns are installed downstream of TK9, and prior to treatment by the Reverse Osmosis. TK9 is a 9000-gallon, carbon-steel, above-grade vessel located in Room 61. Resins are not re-generated. Instead, columns are drained of water, then disposed as solid radioactive waste.

M8. Primary Reverse Osmosis

The Reverse Osmosis unit removes soluble contaminants, and produces a high quality effluent that approaches and sometimes meets EPA primary drinking water standards. The Reverse Osmosis unit uses commercially available high-rejection membranes, typically rated at nominal NaCl rejection of 90-99%. The unit has three 8-inch-diameter pressure vessels, and operates at pressures of about 400 psig. Each pressure vessel contains four membranes in series; each membrane is 40 inches in length. The Reverse Osmosis is a two-stage membrane unit; the third pressure vessel receives reject from the first two. Feed may first be pH-adjusted at the perchlorate ion exchange feed tank, TK-9. Permeate is sent to storage tanks in Room 34B; concentrate is either recycled to the 75K influent storage tank, or is processed through the secondary Reverse Osmosis unit. The primary Reverse Osmosis has a capacity up to 60 gallons per minute.

M9. Copper-Zinc Ion Exchange

NPDES Permit effluent limits for the discharge of treated water to NPDES Outfall #051 in Mortandad Canyon became more restrictive on 08-01-2010. As a result of acute aquatic life water quality standards being applied to ephemeral streams, discharge limits for copper and zinc were decreased to levels more than 2,000 times lower than EPA's secondary drinking water standards. In order to meet these new effluent limits, an ion exchange system was installed to polish permeate from the primary Reverse Osmosis unit. The system consists of two banks; each bank has five 3.5-cubic foot fiberglass. The ion exchange system draws water from one of the Frac tanks that holds Reverse Osmosis permeate, pumps the water through one, or if needed, both ion exchange banks, and then into TK38. Resins are not re-generated. Instead, columns are drained of water, then disposed as solid radioactive waste.

: 05490

M10. Effluent Storage

Five tanks are available for the storage of treated water. Two Frac tanks (north tank and south tank) receive permeate from the primary reverse osmosis unit. Frac tanks are horizontal carbon steel tanks located in Room 34B; each has a capacity of ~20,000 gallons. Water that receives post-Reverse Osmosis treatment (i.e., copper-zinc ion exchange) is collected in a 1000-gallon tank, TK38 in Room 38, constructed of high-density polyethylene. Two additional storage tanks (WM2-N and WM2-S) are located in Building 50-02. These are below-grade concrete tanks with a nominal capacity of 25,000 gallons each.

M11. Discharge of Treated Water to the Environment

11a. Discharge Via Mechanical Evaporation at TA-50-257

Treated water may be discharged to the environment via a thermal evaporator located outside Room 34 of Building 50-01. Water is heated using natural gas in a 4.5 million Btu/hr low NOx gas burner that can evaporate up to 400 gallons of water per hour. The unit is constructed of stainless steel, and has received a No Permit Required Determination from the NMED Air Quality Bureau.

11b. Discharge Via Zero Liquid Discharge Solar Evaporation Tanks at TA52

Zero-Liquid-Discharge Solar Evaporation Tanks for solar evaporation of treated water are currently being constructed. The tanks are located on a site of approximately one acre, about two-thirds of a mile from the TA-50 RLWTF within TA-52 at LANL. The Zero Liquid Discharge Solar Evaporation Tanks have concrete walls approximately four feet high, and have a double liner with leak detection; each is approximately 70' x 250' in size, with a usable capacity of about 380,000 gallons. The pump house has the capability of returning the contents of the tanks to the TA-50 RLWTF for storage and retreatment, if necessary. Approximately 3500 feet of high-density polyethylene (HDPE) transfer piping connect the Zero Liquid Discharge Solar Evaporation Tanks and the TA-50 RLWTF.

11c. Discharge Via NPDES Outfall #051

Treated water that meets NPDES and DOE discharge standards can be discharged to the environment via NPDES Permitted Outfall #051 in Mortandad Canyon. Water is pumped to the outfall through approximately 1400 feet of three-inch-diameter, carbon steel pipe. NPDES samples are collected at TA-50 while water is discharging to the canyon.

: 05491

TRANSURANIC TREATMENT PROCESS

Transuranic RLW treatment consists of influent collection and storage, treatment of the transuranic RLW, and sludge treatment. Treated water is not discharged; it either receives additional treatment (secondary reverse osmosis) or is sent to storage tanks in Building 50-248 for disposition as bottoms. Sludge from the treatment process is concentrated, solidified with cement, and shipped to the Waste Isolation Pilot Plant as a solid transuranic waste.

T1. Transuranic Collection System

The transuranic collection system runs from Building 55-04 through below-grade, double-contained transfer lines, through a valve pit and vault at 50-201, and into influent storage tanks at Building 50-66. One transfer line is dedicated for acid waste, and a second for caustic waste. Both are two-inch-diameter pipes. The acid waste lines are constructed of polyvinylidene fluoride (PVDF); the caustic lines are constructed of polypropylene (PP).

TRU wastewater is not freely drained to the RLWTF. Instead, TA55 and RLWTF personnel coordinate batch wastewater transfers in advance. Once a transfer is coordinated, a batch of known volume, typically less than 100 gallons, is discharged through the system by gravity to the TRU influent storage tanks in Building 50-66. Transuranic influent is not trucked.

T2. Transuranic Influent Storage

Two influent storage tanks are located in Building 50-66, one for acid waste (~3900 gallons) and the other for caustic waste (~3000 gallons). Each tank has enough capacity to hold more than two years of transuranic influent. Both tanks are cylindrical, cone-bottomed tanks, and each has a mixer, a HEPA-filtered vent. The sump in Building 50-66 has a leak detector that is linked to the RLWTF control room.

T3. Transuranic Treatment

Acid waste is pumped from Building 50-66 into TK1 in Room 60. The acid waste is neutralized by mixing it with liquid sodium hydroxide (nominal 25%). Chemicals (ferric sulfate or polymer) may be added to promote particle growth. Solids that form in the neutralized waste settle, and are then pumped to the sludge tank, TK-7A. Clear liquid is pumped through a pressure filter into a receiving tank, TK3.

: 05492

Caustic waste is pumped from Building 50-66 to Tank TK1 in Room 60, and then into the sludge-settling tank, TK-7A. The treated caustic waste is allowed to stand in the tank, which allows most of the solid particles to deposit on the bottom of the tank as sludge. In order to facilitate particle growth, TK-7A may be seeded with sludge left over from the previous treatment campaign. Chemicals (lime, ferric sulfate, or polymer) may also be added to TK-7A for this purpose.

T4. Transuranic Sludge

Sludge collects in TK-7A, a 900-gallon carbon-steel tank in Room 60. Excess water is decanted from TK-7A, then transferred to the effluent storage tank, TK3. The sludge itself is added to cement and sodium silicate, then tumbled and allowed to cure. After curing, drums of cemented sludge are transported to TA-54 to await shipment to and disposal at the Waste Isolation Pilot Plant as a solid transuranic waste.

T5. Transuranic Effluent

Effluent from the transuranic treatment process is collected in TK3 in Room 60, a 1000-gallon, horizontal fiberglass tank. Having been treated, effluent is no longer transuranic waste. The effluent either receives additional treatment (secondary reverse osmosis) or is sent to storage tanks in Building 50-248 for disposition as bottoms.

: 05493

SECONDARY TREATMENT PROCESSES

The secondary treatment process treats wastes from the primary and transuranic treatment lines. It consists of a rotary vacuum filter to treat sludge from main process, secondary reverse osmosis to treat reverse osmosis concentrate from the main process and/or effluent from the transuranic process, and a bottoms disposal step. Wastes from the secondary treatment process are disposed as low-level radioactive solid waste.

S1. Secondary Reverse Osmosis

These two Reverse Osmosis units, each with a capacity of up to five gallons per minute, recover much of the concentrate from the primary Reverse Osmosis unit, thereby reducing the volume of bottoms that must be disposed of. Effluent from the transuranic process may also be treated. Secondary Reverse Osmosis units use commercially available high-rejection membranes, typically rated at nominal NaCl rejection of 90-99%. The units have two 4-inch-diameter pressure vessels, and operate at pressures of about 300 psig. Each pressure vessel has a single membrane 40 inches in length. They are two-stage membrane units; the second pressure vessel receives reject from the first. Concentrate from the primary Reverse Osmosis unit is collected in TK73 (3700 gallons, lined steel), then fed to a smaller feed tank (300 gallons, polyethylene) in Room 24, adjacent to the secondary Reverse Osmosis units. Permeate is sent to the feed tank for the perchlorate ion exchange system (TK9), for re-treatment through the MTP. Reject is sent to storage tanks in Building 50-248 to await shipment as bottoms.

S2. Rotary Vacuum Filter

Solids that settle to the bottom of the MTP clarifier are separated from water and then disposed as low-level radioactive solid waste. This sludge treatment operation includes the TK8 storage tank (capacity of 8,000 gallons) in Room 61 and the rotary vacuum filter in Room 116. Low-level sludge contains more than 90% of the radioactivity present in low-level influent; it does not contain hazardous chemical constituents above RCRA limits, and is not a mixed waste.

S3. Bottoms Disposal

RLWTF bottoms are shipped to a commercial waste treatment facility using a commercial tanker truck; shipments typically range from 4,000 to 5,000 gallons each. The commercial waste treatment facility processes bottoms to a solid form, and disposes of the solids as low-level radioactive waste at a Department of Energy or commercial disposal site.

: 05494

Table 2: Vessel Information for RLWTF Treatment Units

Unit Operation	Vessel	Capacity (gallons)	Material	Above (A) Below (B)	Secondary Containment	Note
Main Treatment:						
M1 Collection System	Piping	----	Polyethylene	B	Polyethylene	
	Vaults (62)	----	Concrete	B	----	x
M2 Influent Storage	TK13	400	Stainless Steel	B	Concrete	
	17K tank	17,000	Steel	B	Concrete	
	75K tank	75,000	Concrete	B	----	
	100K tank	100,000	Steel	A	Concrete	
M3 Emergency Influent Storage	WMRM tanks (6)	50,000	Fiberglass	B	Concrete	z
M4 Clarifiers	Clarifiers (2)	26,000	Concrete	A	Concrete	v, z
M5 Gravity Filter	Gravity Filter	7,000	Concrete	A	Concrete	v
M6 Pressure Filters	Filters (3)	100	Lined Steel	A	Concrete-w	z
	TK71, TK72	10,000	Steel	A	Concrete-w	z
M7 Perchlorate Ion Exchange	Ion Exchange Vessels(12)	50	Fiberglass	A	Concrete-w	z
	TK09	10,000	Steel	A	Concrete-w	
M8 Primary Reverse Osmosis	RO Vessel	40	Steel	A	Concrete-w	
M9 Polishing Ion Exchange	Ion Exchange Columns (10)	200	Fiberglass	A	Concrete-w	
M10 Effluent Storage	N. Frac, S. Frac	20,000	Steel	A	Concrete-w	z
	TK-38	1,000	HDPE	A	Concrete-w	
	WM2-N, WM2-S	25,000	Concrete	B	----	z
M11 Effluent Evaporator	----	1,200	Stainless Steel	A	Hypalon, Asphalt	
M11 Solar Evaporation at TA-52	E. Tank, W. Tank	380,000	HDPE	A	HDPE, Concrete	z
M12 NPDES Outfall #051	----	----	----	B	----	y

Notes:

v: Two concrete bottom slabs, with compacted tuff between.

w: Floor of Building 50-01, with floor drains, provides secondary containment.

x: Vaults provide secondary containment.

y: Pipe is below grade; the outfall is at the surface.

z: Capacity is for each vessel.

Table 2: Vessel Information for RLWTF Treatment Units (Continued)

Unit Operation	Vessel	Capacity (gallons)	Material	Above (A) Below (B)	Secondary Containment	Note
Transuranic:						
T1 Collection System	Piping	----	PVDF , PP	B	PVDF, PP	
T2 Influent Storage	Acid Tank	3,900	Steel	B	Concrete	
	Caustic Tank	3,000	Steel	B	Concrete	
T3 Treatment	TK1	900	Steel	A	Concrete-w	
	TK2	800	Fiberglass	A	Concrete-w	
T4 Drum Tumbling	TK-7A	900	Steel	A	Concrete-w	
T5 Effluent Storage	TK3	1,000	Fiberglass	A	Concrete-w	
Secondary Treatment:						
S1 Secondary Reverse Osmosis	RO Vessel	10	Fiberglass	A	Concrete-w	
	TK2401	300	Polyethylene	A	Concrete-w	
	TK73	3,700	Steel	A	Concrete-w	
S2 Rotary Vacuum Filter	Rotary Vacuum Filter	900	Stainless Steel	A	Concrete-w	
	TK8	8,000	Steel	A	Concrete-w	
S3 Bottoms Storage	TK-NE, SE, SW, NW	20,000	Steel	A	Concrete	z

Notes:

w: Floor of Building 50-01, with floor drains, provides secondary containment.

Z: Capacity is for each vessel.

APPENDIX C

NPDES OUTFALL #051

TABLE OF CONTENTS

1. NPDES Permit No. NM0028355, Outfall #051.

NPDES PERMIT No. NM0028355

OUTFALL #051

Region 6
1445 Ross Avenue
Dallas, Texas 75202-2733

NPDES Permit No. NM0028355

AUTHORIZATION TO DISCHARGE UNDER THE NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM

In compliance with the provisions of the Clean Water Act, as amended, (33 U.S.C. 1251 et. seq; the "Act"),

Los Alamos National Security, LLC
Management Contractor for Operations
Los Alamos, New Mexico 87544

and

U.S. Department of Energy
Los Alamos Area Office
Los Alamos, New Mexico 87544

are authorized to discharge from a facility located at Los Alamos,

to receiving waters named: Perennial portion of Sandia Canyon in Waterbody Segment No. 20.6.4.126, and Mortandad Canyon, Canada del Buey, Los Alamos Canyon, ephemeral portion of Sandia Canyon, Ten Site Canyon, Canon de Valle, and Water Canyon, in Waterbody Segment No. 20.6.4.128 of the Rio Grande Basin,

in accordance with this cover page and the effluent limitations, monitoring requirements, and other conditions set forth in Parts I [Requirements for NPDES Permits - 36 pages], II [Other Conditions - 22 pages], III [Standard Conditions for NPDES Permits - 8 pages], and IV [Sewage Sludge Requirements - 18 pages] hereof.

This permit supersedes and replaces NPDES Permit No. NM0028355 issued December 29, 2000.

This permit shall become effective on August 1, 2007

This permit and the authorization to discharge shall expire at midnight, July 31, 2012

Issued on June 8, 2007

Miguel I. Flores
Director
Water Quality Protection Division (6WQ)

Prepared by

Isaac Chen
Environmental Engineer
NPDES Permits Branch (6WQ-P)

OUTFALL 051 - Radioactive Liquid Waste Treatment Facility (TA-50)
Discharge Type: Intermittent
Latitude 35E51'54"N, Longitude 106E17'52"W

During the period beginning the effective date of the permit and lasting through the expiration date of the permit (unless otherwise noted),

the permittee is authorized to discharge treated radioactive liquid waste to Mortandad Canyon in segment number 20.6.4.128 of the Rio Grande Basin.

Such discharges shall be limited and monitored by the permittee as specified below:

PARAMETERS/STORET CODES	DISCHARGE LIMITATIONS/REPORTING REQUIREMENTS			
	QUANTITY/LOADING (LBS/DAY UNLESS STATED)		QUALITY/CONCENTRATION (mg/L UNLESS STATED)	
	MONTHLY AVG	DAILY MAX	MONTHLY AVG	DAILY MAX
Flow STORET: 50050	Report	Report	****	****
Chemical Oxygen Demand STORET: 00340	****	****	125	125
Total Suspended Solids STORET: 00530	****	****	30	45
Total Toxic Organics (*1) STORET: 78141	****	****	1.0	1.0
Ra 226+228 STORET: 11503	****	****	30 pCi/l	30 pCi/l
Total Chromium STORET: 01034	****	****	1.34	2.68
Total Lead STORET: 01051	****	****	0.423	0.524
Total Cadmium (*2) STORET: 01027	****	****	Report	Report
Total Mercury (*2) STORET: 71900	****	****	Report	Report
Total Nickel (*2) STORET: 01067	****	****	Report	Report
Total Copper (*3) STORET: 01042	****	****	Report	Report

Total Copper (*3) STORET: 01042	****	****	0.14 ug/l	0.2 ug/l
Total Zinc (*3) STORET: 01092	****	****	Report	Report
Total Zinc (*3) STORET: 01092	****	****	2.2 ug/l	3.3 ug/l
Total Residual Chlorine (*4) STORET: 50060	****	****	****	0.011
Total Selenium STORET: 01147	****	****	Report	Report
Perchlorate STORET: 61209	****	****	Report	Report
pH (Standard Units) STORET: 00400	Ranges from 6.0 to 9.0			
Total PCBs STORET: 39516	****	****	Report	Report

PARAMETERS/STORET CODES	MONITORING REQUIREMENTS	
	FREQUENCY OF ANALYSIS	SAMPLE TYPE
Flow	Continuous	Record
Chemical Oxygen Demand	1/Month	Grab
Total Suspended Solids	1/Month	Grab
Total Toxic Organics	1/Month	Grab
Tritium	1/Year	Grab
Ra 226+228	1/Year	Grab
Total Chromium	1/Year	Grab
Total Lead	1/Year	Grab
Total Cadmium	1/Year	Grab
Total Mercury	1/Year	Grab
Total Nickel	1/Year	Grab
Total Copper	1/Month	Grab
Total Zinc	1/Month	Grab
Total Residual Chlorine	1/Week	Grab
Total Selenium	1/Year	Grab
Perchlorate	1/Year	Grab
Total PCBs	1/Year	Grab
pH (Standard Units)	1/Week	Grab

EFFLUENT CHARACTERISTIC	DISCHARGE MONITORING	
	30-Day Avg Min.	48-Hr. Min.

Whole Effluent Toxicity Testing (48 Hr. Static Renewal)		
Daphnia pulex	Report	Report

EFFLUENT CHARACTERISTIC	MONITORING REQUIREMENTS	
	Frequency	Type
Whole Effluent Toxicity Testing (48 Hr. Static Renewal)		
Daphnia pulex	1/3 Months (*5)	3-hr Composite

SAMPLING LOCATION(S) AND OTHER REQUIREMENTS

SAMPLING LOCATION(S)
Samples taken in compliance with the monitoring requirements specified above shall be taken at the following location(s): following the final treatment and prior to or at the point of discharge from TA-50-1 treatment plant (approximately at Latitude 35E51'54"N, Longitude 106E17'52"W)

NO DISCHARGE REPORTING
If there is no discharge event at this outfall during the sampling month, place an "X" in the NO DISCHARGE box located in the upper right corner of the preprinted Discharge Monitoring Report.

FLOATING SOLIDS, OIL AND GREASE
There shall be no discharge of oils, scum, grease and other floating materials that would cause the formation of a visible sheen or visible deposits on the bottom or shoreline, or would damage or impair the normal growth, function or reproduction of human, animal, plant or aquatic life.

FLOW MEASUREMENTS
"Estimate" flow measurements shall not be subject to the accuracy provisions established at Part III.C.6. The daily flow value may be estimated using best engineering judgment.

FOOTNOTES

*1 The limits and monitoring for Total Toxic Organics do not include 2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD), Pesticides, or Polychlorinated biphenyls

*2 Annual sample shall be taken for five (5) years until the expiration date.

*3 During the period beginning the effective date of the permit and lasting through three (3) years from the effective date, the concentration of total copper and total zinc shall the reported in the DMRs. During the period beginning the three years from the effective date through the expiration date of the permit, the discharge must meet the effluent limitations.

*4 The effluent limitation for TRC is the instantaneous maximum and cannot be averaged for reporting purposes.

*5 Sampling frequency 1/3 Months for the 1st year of the permit. If the test passes, reduce the frequency to 1/6 Months for year 2 through year 5 of the permit. If any test fails, return frequency to 1/3 Months for remainder of the permit. Critical dilution 100%, and the dilution series are 32%, 42%, 56%, 75%, 100%. Also, see Part II, Section I. Whole Effluent Toxicity (48-hour Acute Testing).

Section B. Clean Water Act Requirements

Law: Federal Water Pollution Control Act (Clean Water Act)

As used in this part, the term "total toxic organics" (TTO) means the sum of the concentrations of each of the following toxic organic compounds found in the discharge at a concentration greater than ten (10) micrograms per liter:

- Acenaphthene
- Acrolein
- Acrylonitrile
- Benzene
- Benzidine
- Carbon tetrachloride (tetrachloromethane)
- Chlorobenzene
- 1,2,4-Trichlorobenzene
- Hexachlorobenzene
- 1,2-Dichloroethane
- 1,1,1-Trichloroethane
- Hexachloroethane
- 1,1-Dichloroethane
- 1,1,2-Trichloroethane
- 1,1,2,2-Tetrachlorophenol
- Chloroethane
- Bis (2-chloroethyl) ether
- 2-Chloroethyl vinyl ether (mixed)
- 2-Chloronaphthalene
- 2,4,6-Trichlorophenol
- Parachlorometa cresol
- Chloroform (trichloromethane)
- 2-Chlorophenol
- 1,2-Dichlorobenzene
- 1,3-Dichlorobenzene
- 1,4-Dichlorobenzene
- 3,3-Dichlorobenzidine
- 1,1-Dichloroethylene
- 1,2-Trans-dichloroethylene
- 2,4-Dichlorophenol
- 1,2-Dichloropropane
- 1,3-Dichloropropylene (1,3-dichloropropene)
- 2,4-Dimethylphenol
- 2,4-Dinitrotoluene
- 2,6-Dinitrotoluene
- 1,2-Diphenylhydrazine
- Ethyl benzene
- Fluoranthene
- 4-Chlorophenyl phenyl ether
- 4-Bromophenyl phenyl ether
- Bis (2-chloroisopropyl) ether

Section B. Clean Water Act Requirements

Law: Federal Water Pollution Control Act (Clean Water Act)

- Bis (2-chloroethoxy) methane
- Methylene chloride (dichloromethane)
- Methyl chloride (chloromethane)
- Methyl bromide (bromomethane)
- Bromoform (tribromomethane)
- Dichlorobromomethane
- Chlorodibromomethane
- Hexachlorobutadiene
- Hexachlorocyclopentadiene
- Isophorone
- Naphthalene
- Nitrobenzene
- 2-Nitrophenol
- 4-Nitrophenol
- 2,4-Dinitrophenol
- 4,6-Dinitro-o-cresol
- N-nitrosodimethylamine
- N-nitrosodiphenylamine
- N-nitrosodi-n-propylamine
- Pentachlorophenol
- Phenol
- Bis (2-ethylhexyl) phthalate
- Butyl Benzyl Phthalate
- Di-n-butyl phthalate
- Di-n-octyl phthalate
- Diethyl phthalate
- Dimethyl phthalate
- 1,2-Benzanthracene (benzo(a)anthracene)
- Benzo(a)pyrene (3,4-benzopyrene)
- 3,4-Benzofluoranthene (benzo(b)fluoranthene)
- 11,12-Benzofluoranthene (benzo(k)fluoranthene)
- Chrysene
- Acenaphthylene
- 1,12-Benzoperylene (benzo(ghi)perylene)
- Fluorene
- Phenanthrene
- 1,2,5,6-Dibenzanthracene (dibenzo(a,h)anthracene)
- Indeno(1,2,3-cd) pyrene (2,3-o-phenylene pyrene)
- Pyrene
- Tetrachloroethylene
- Toluene
- Trichloroethylene
- Vinyl chloride (chloroethylene)
- Aldrin
- Dieldrin

Section B. Clean Water Act Requirements

Law: Federal Water Pollution Control Act (Clean Water Act)

- Chlordane (technical mixture and metabolites)
- 4,4-DDT
- 4,4-DDE (p,p-DDX)
- 4,4-DDD (p,p-TDE)
- Alpha-endosulfan
- Beta-endosulfan
- Endosulfan sulfate
- Endrin
- Endrin aldehyde
- Heptachlor
- Heptachlor epoxide (BHC-hexachlorocyclohexane)
- Alpha-BHC
- Beta-BHC
- Gamma-BHC
- Delta-BHC (PCB-polychlorinated biphenyls)
- PCB-1242 (Arochlor 1242)
- PCB-1254 (Arochlor 1254)
- PCB-1221 (Arochlor 1221)
- PCB-1232 (Arochlor 1232)
- PCB-1248 (Arochlor 1248)
- PCB-1260 (Arochlor 1260)
- PCB-1016 (Arochlor 1016)
- Toxaphene
- 2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD)

APPENDIX D

GROUNDWATER QUALITY

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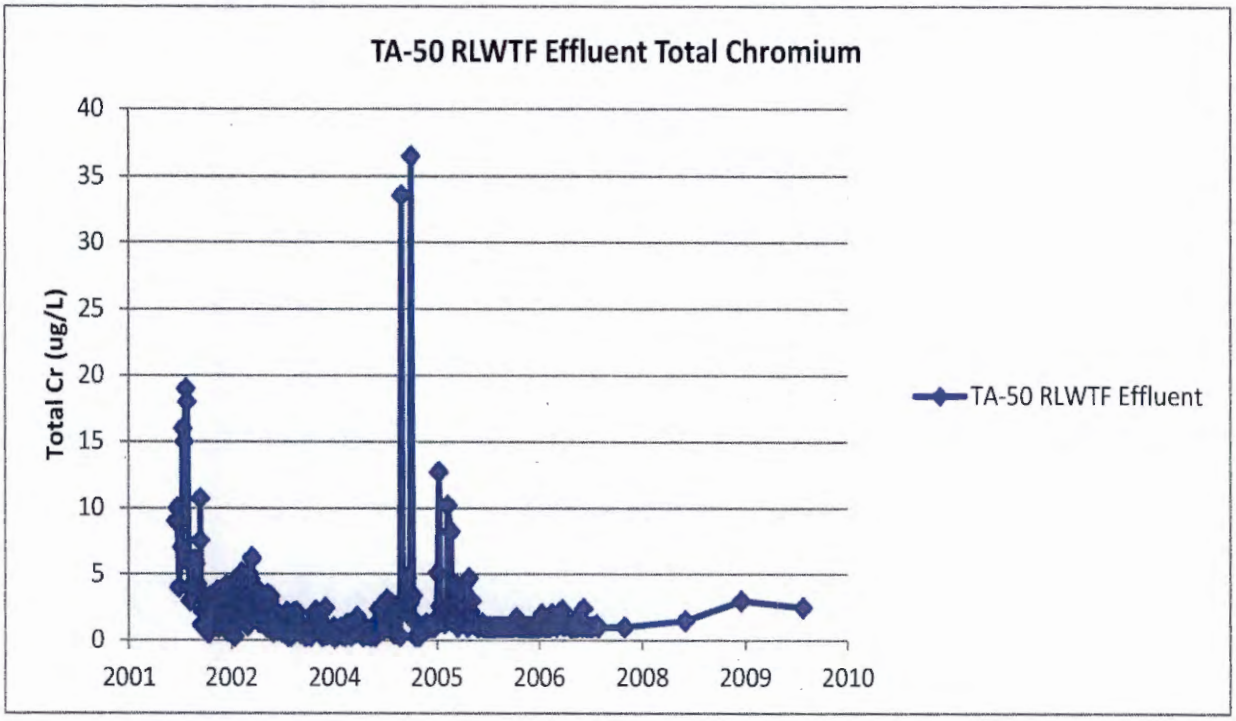
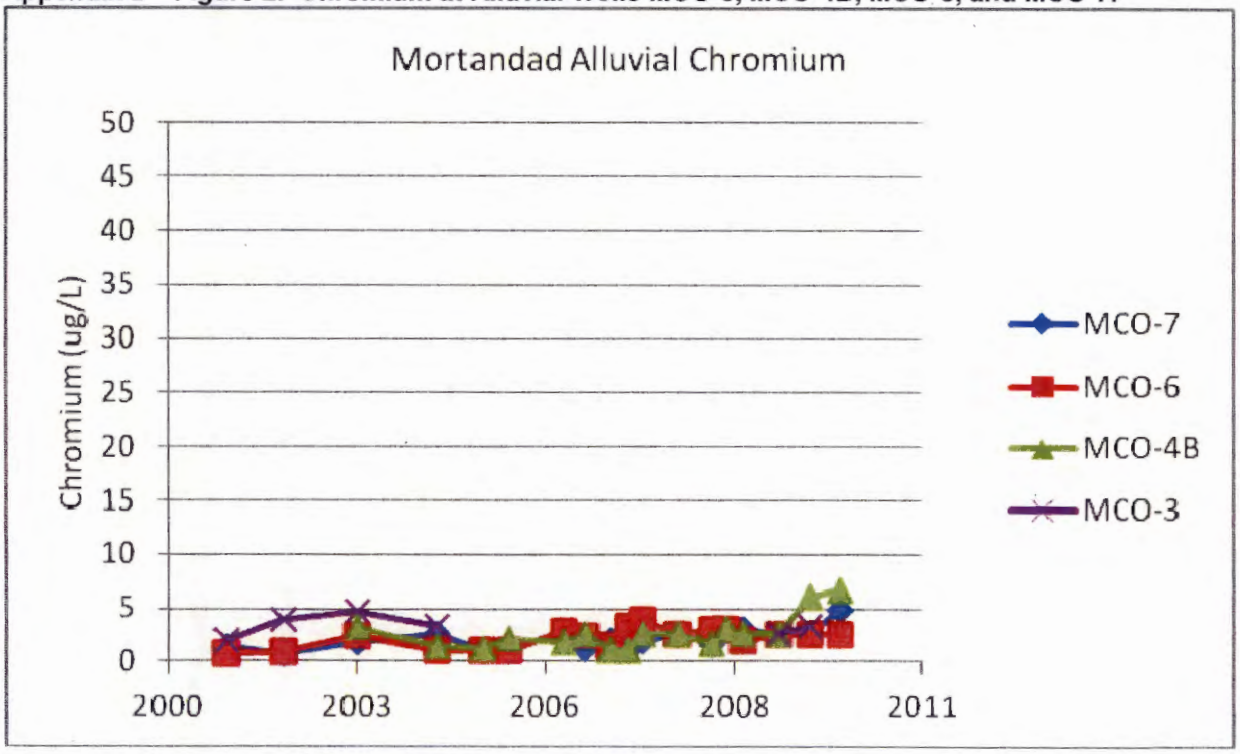
1. GROUNDWATER QUALITY, FIGURES 1-12, PAGES 1-6.

GROUNDWATER QUALITY FIGURES 1 – 12

Appendix D - Figure 1. TA-50 RLWTF Effluent Total Chromium from 2001 to 2010.



Appendix D - Figure 2. Chromium at Alluvial Wells MCO-3, MCO-4B, MCO-6, and MCO-7.



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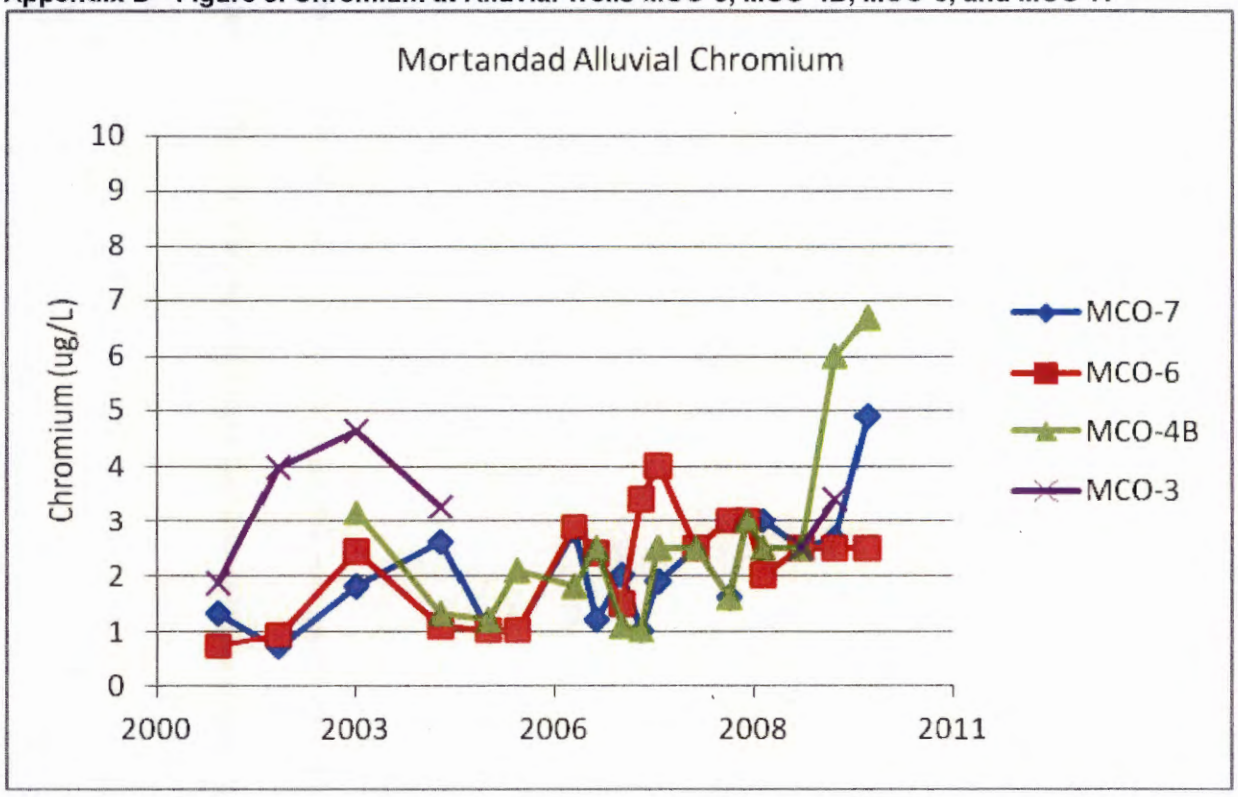
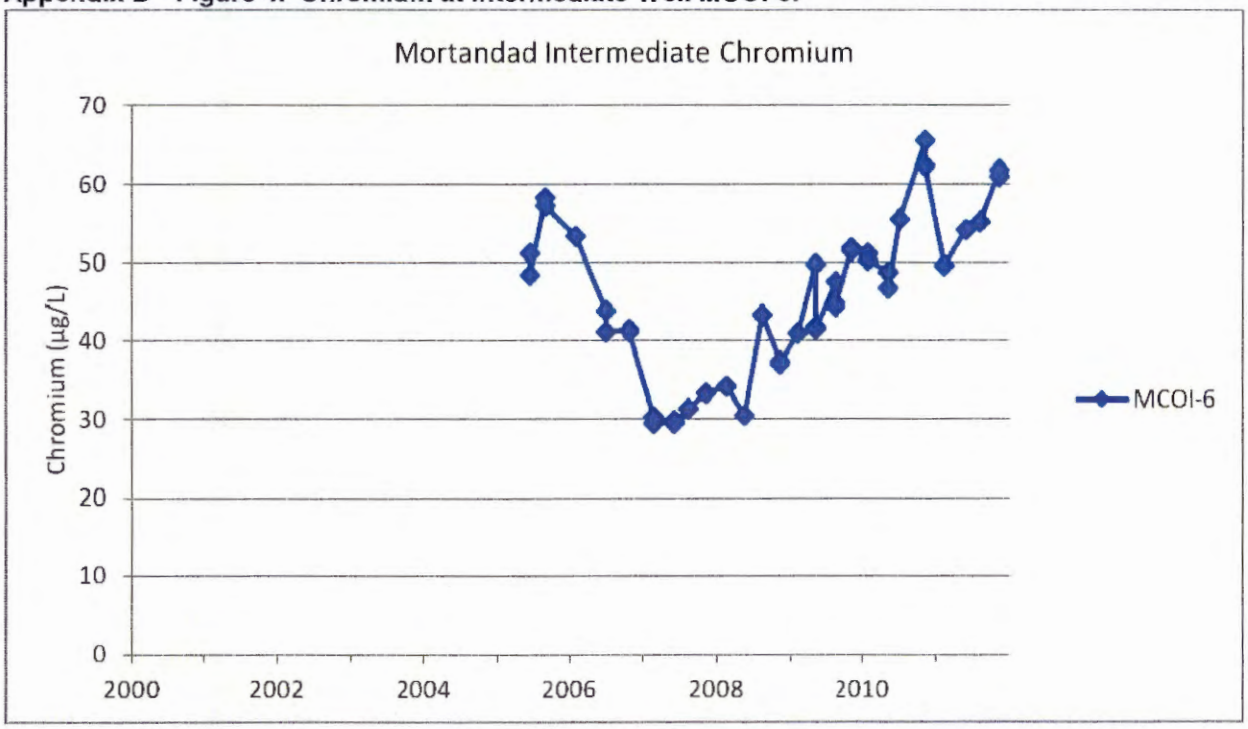
Appendix D - Figure 3. Chromium at Alluvial Wells MCO-3, MCO-4B, MCO-6, and MCO-7.

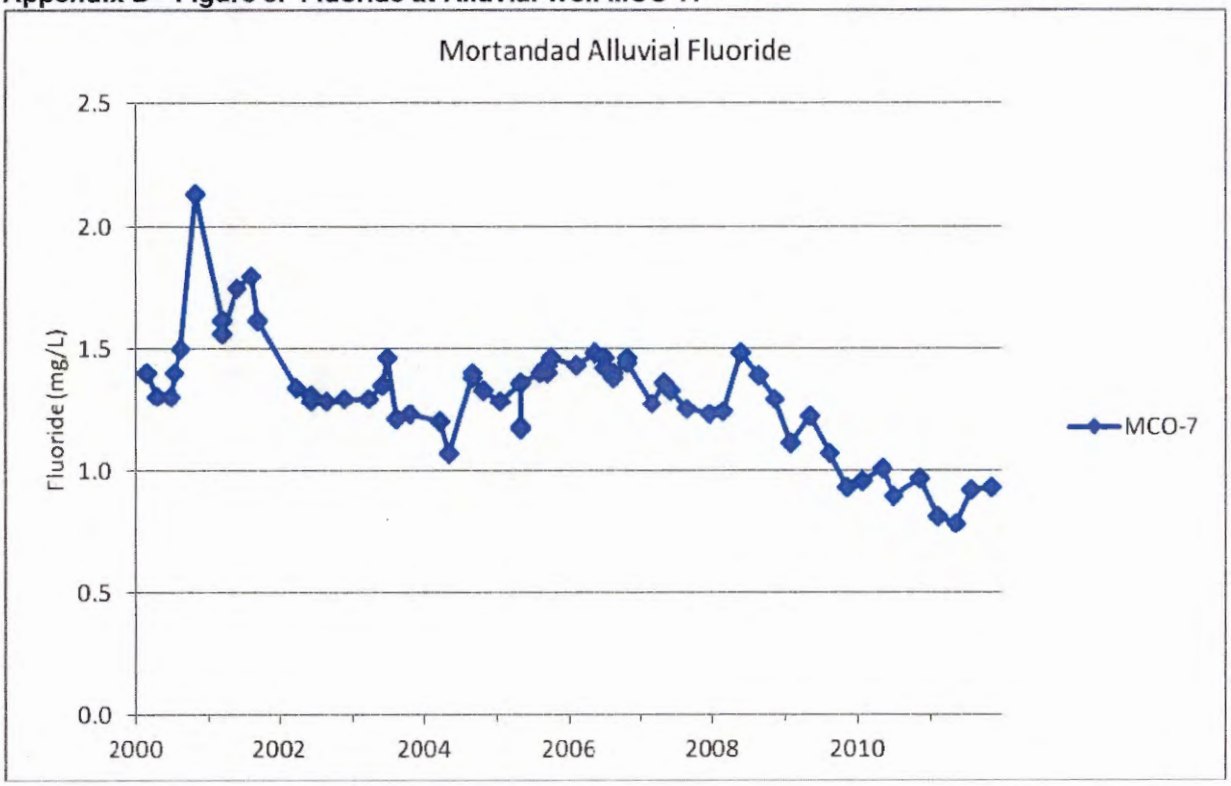


Appendix D - Figure 4. Chromium at Intermediate Well MCOI-6.

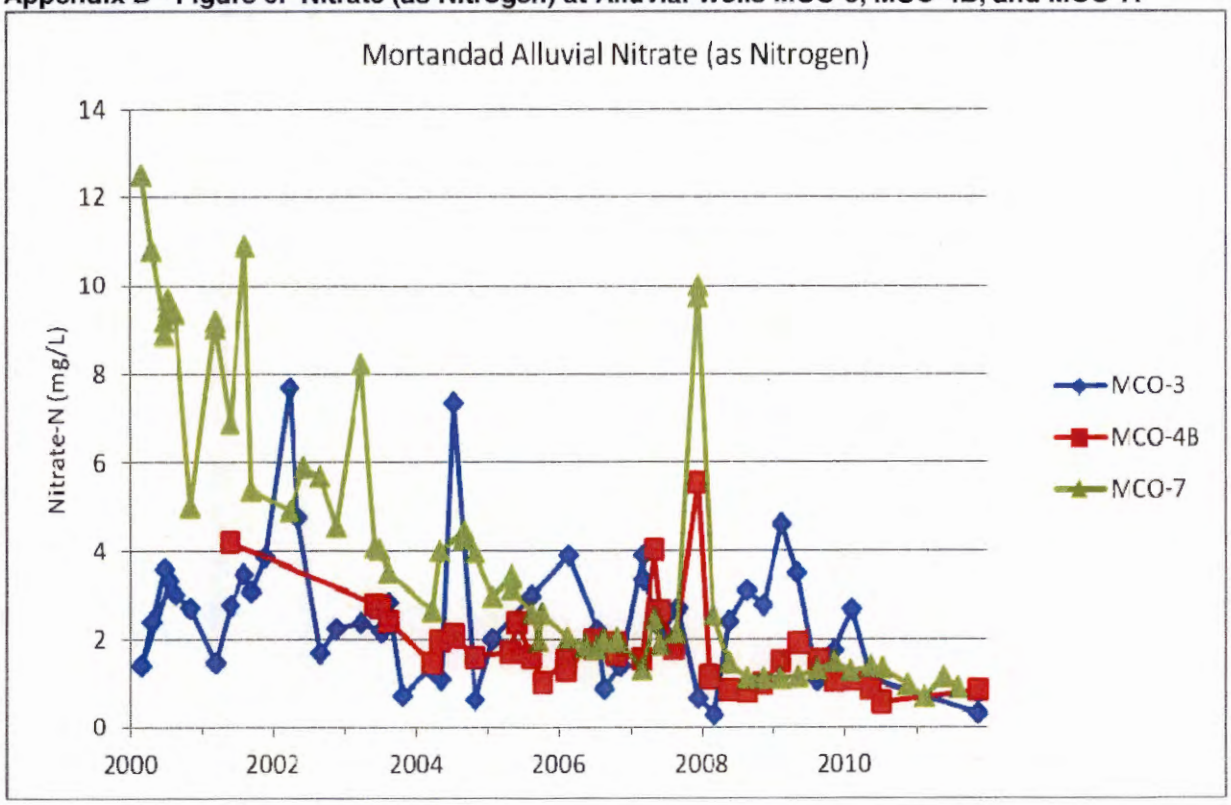


: 05510

Appendix D - Figure 5. Fluoride at Alluvial Well MCO-7.



Appendix D - Figure 6. Nitrate (as Nitrogen) at Alluvial Wells MCO-3, MCO-4B, and MCO-7.



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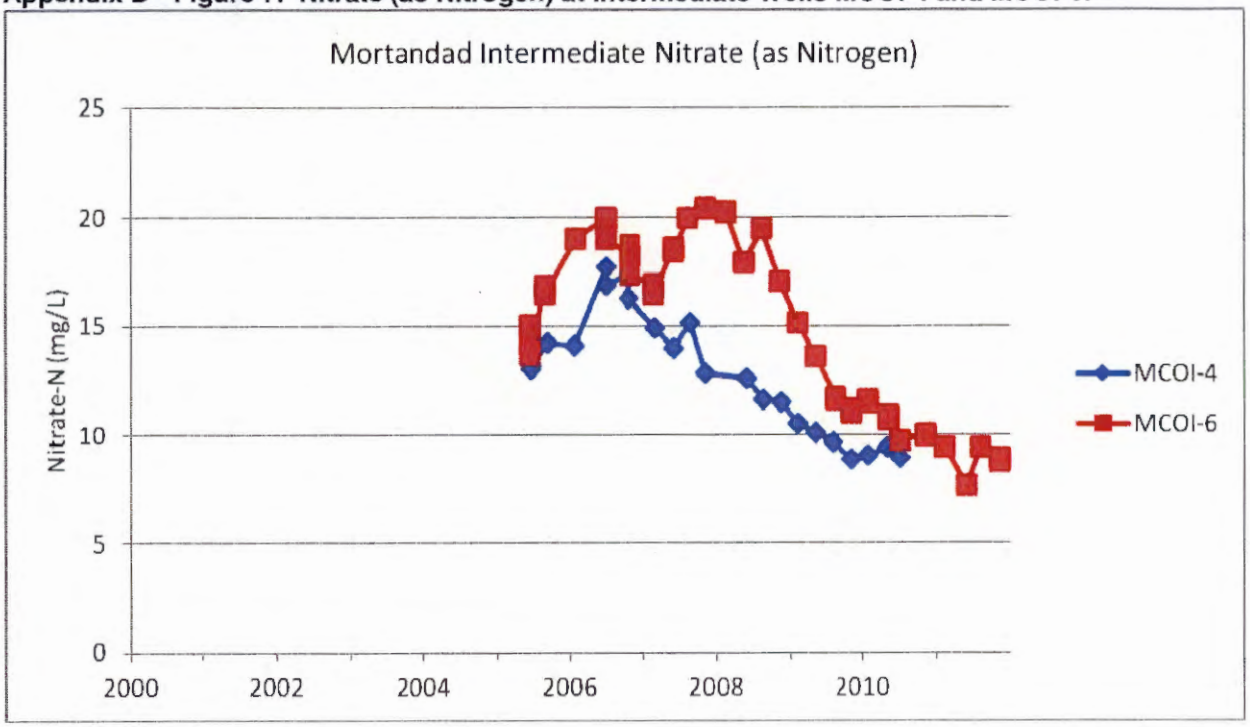
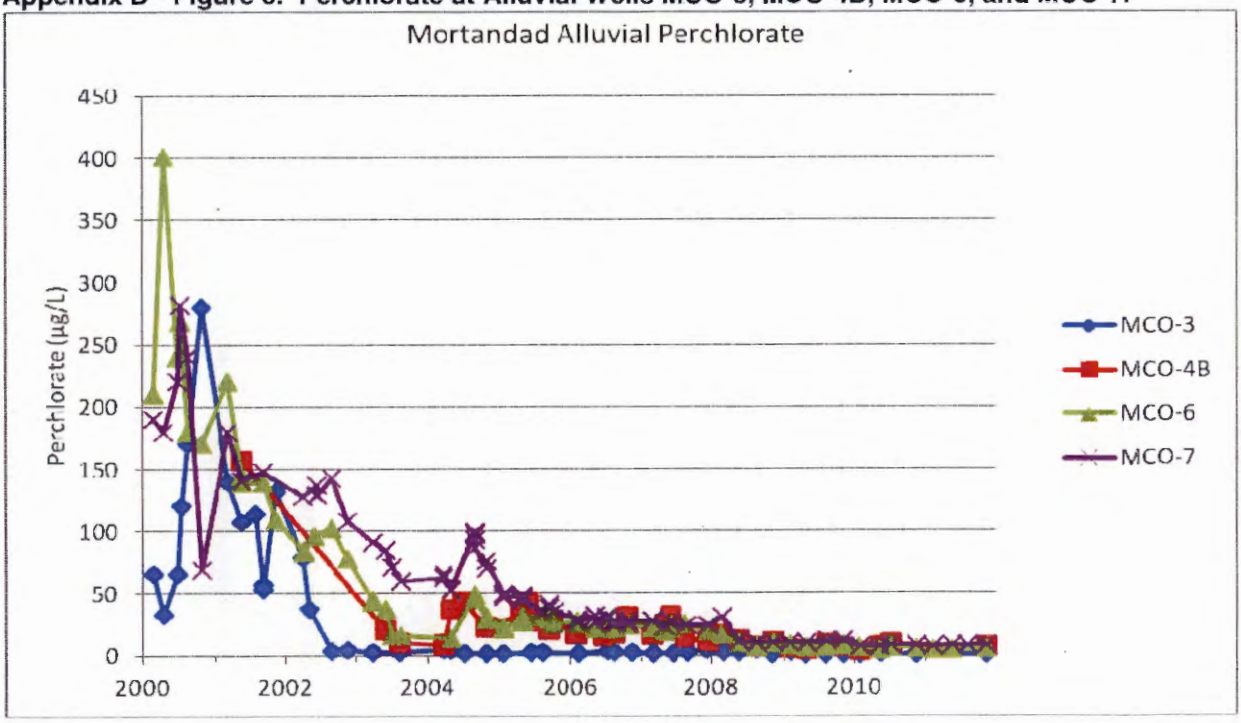
Appendix D - Figure 7. Nitrate (as Nitrogen) at Intermediate Wells MCOI-4 and MCOI-6.



Appendix D - Figure 8. Perchlorate at Alluvial Wells MCO-3, MCO-4B, MCO-6, and MCO-7.



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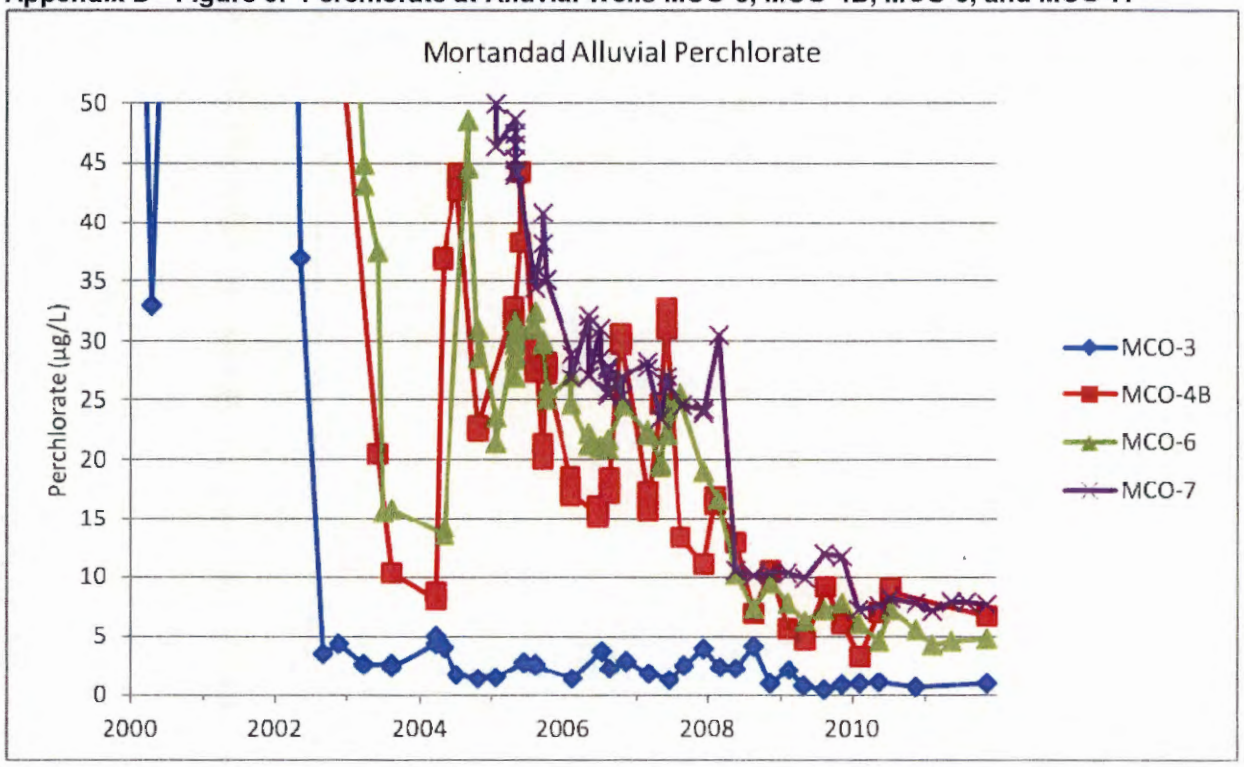
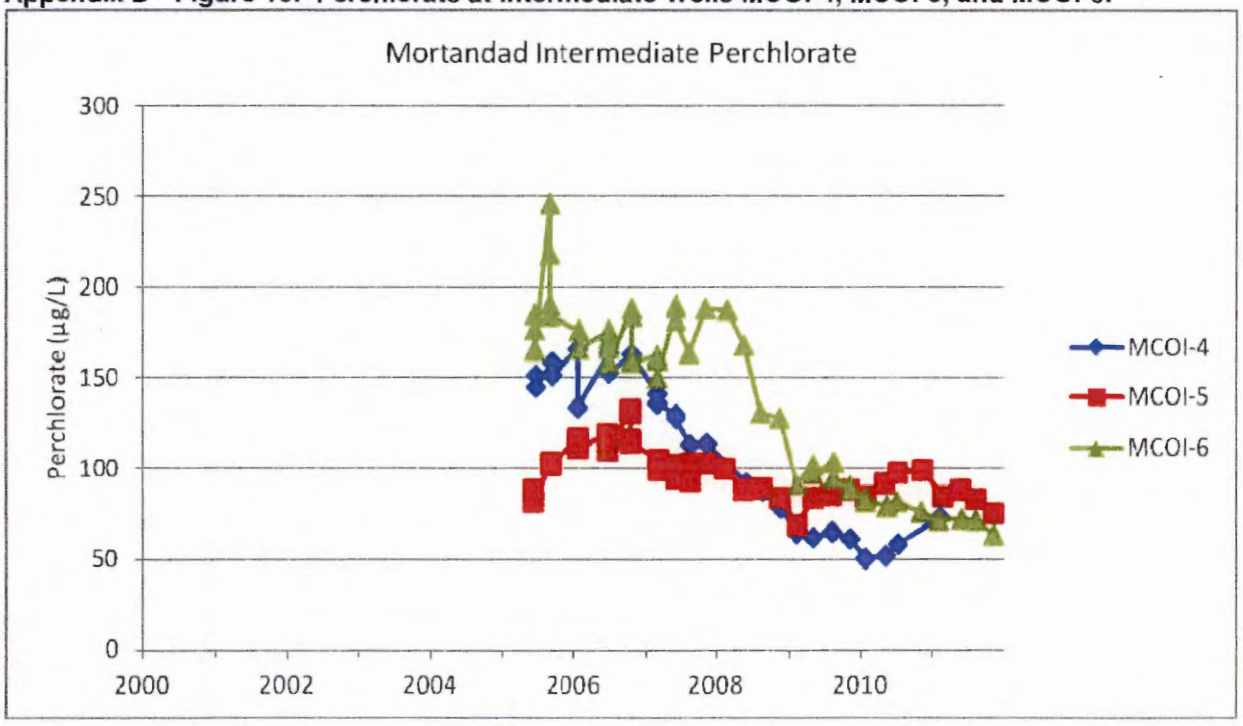
Appendix D - Figure 9. Perchlorate at Alluvial Wells MCO-3, MCO-4B, MCO-6, and MCO-7.

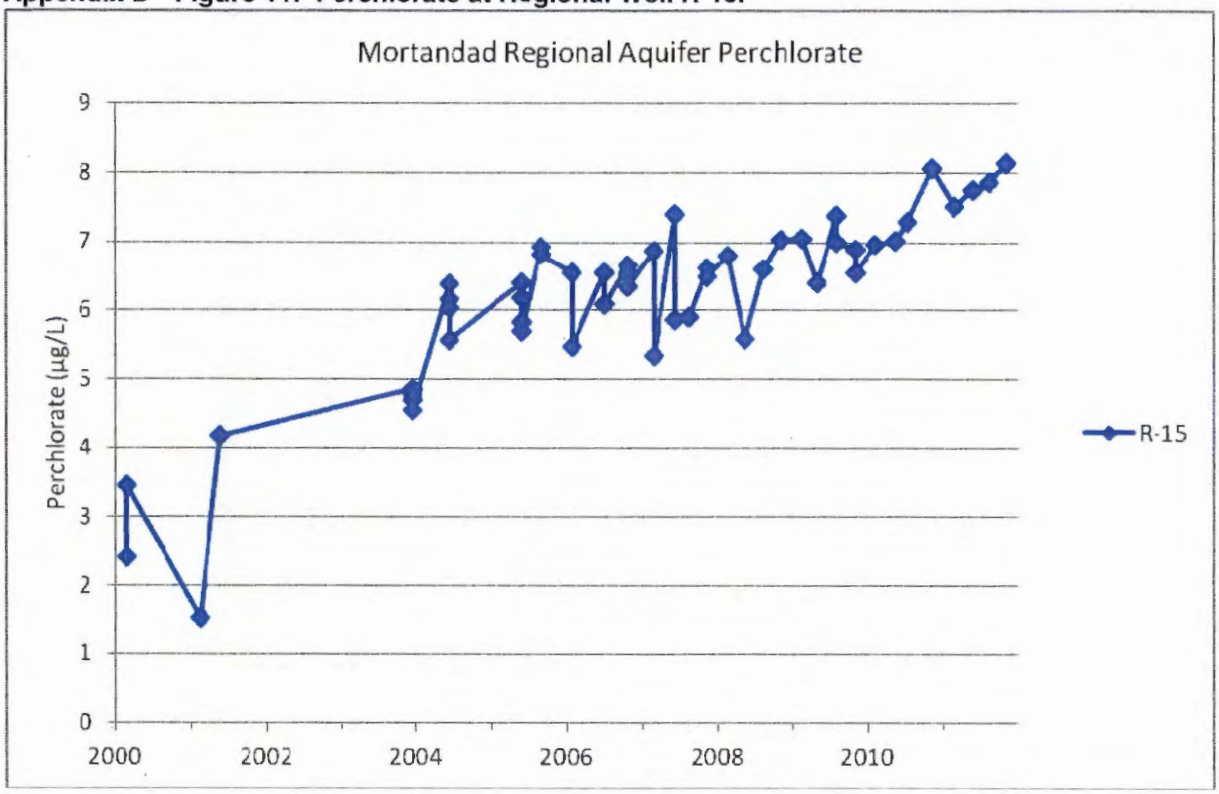


Appendix D - Figure 10. Perchlorate at Intermediate Wells MCOI-4, MCOI-5, and MCOI-6.

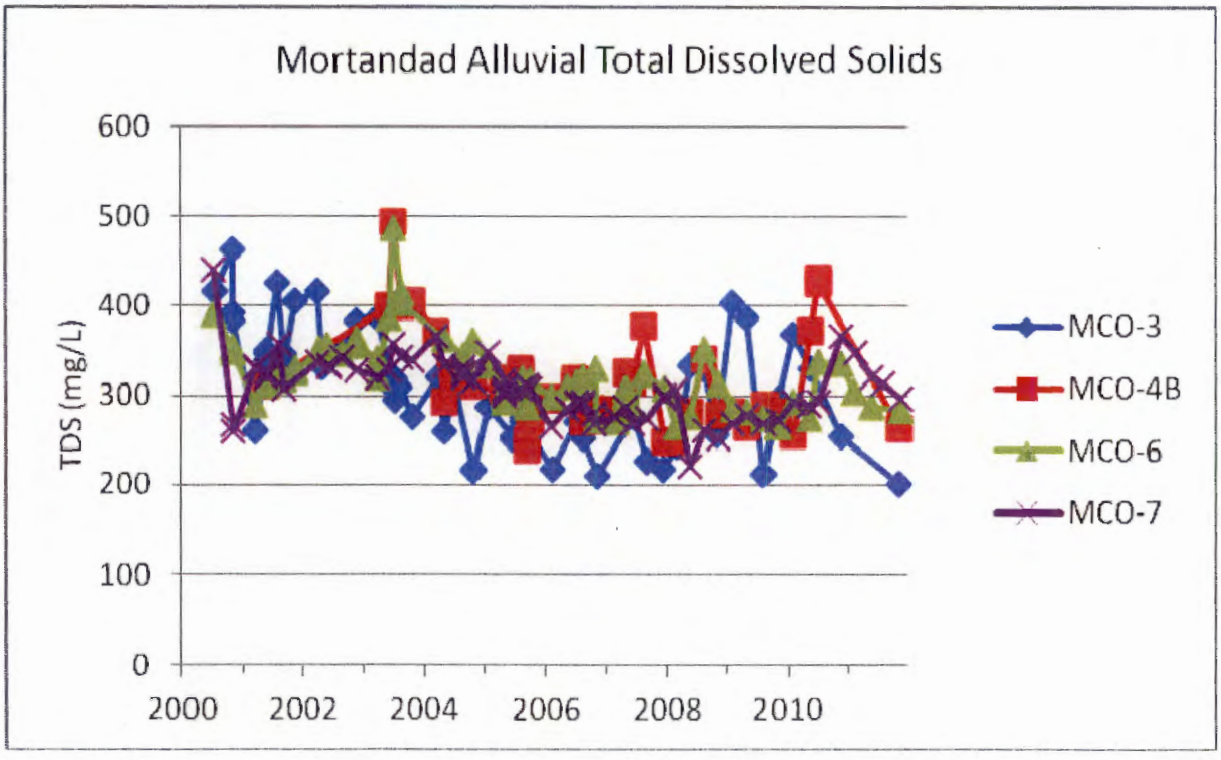


05513

Appendix D - Figure 11. Perchlorate at Regional Well R-15.



Appendix D - Figure 12. Total Dissolved Solids at Alluvial Wells MCO-3, MCO-4B, MCO-6, and MCO-7.



05514

APPENDIX E

WELL LOGS

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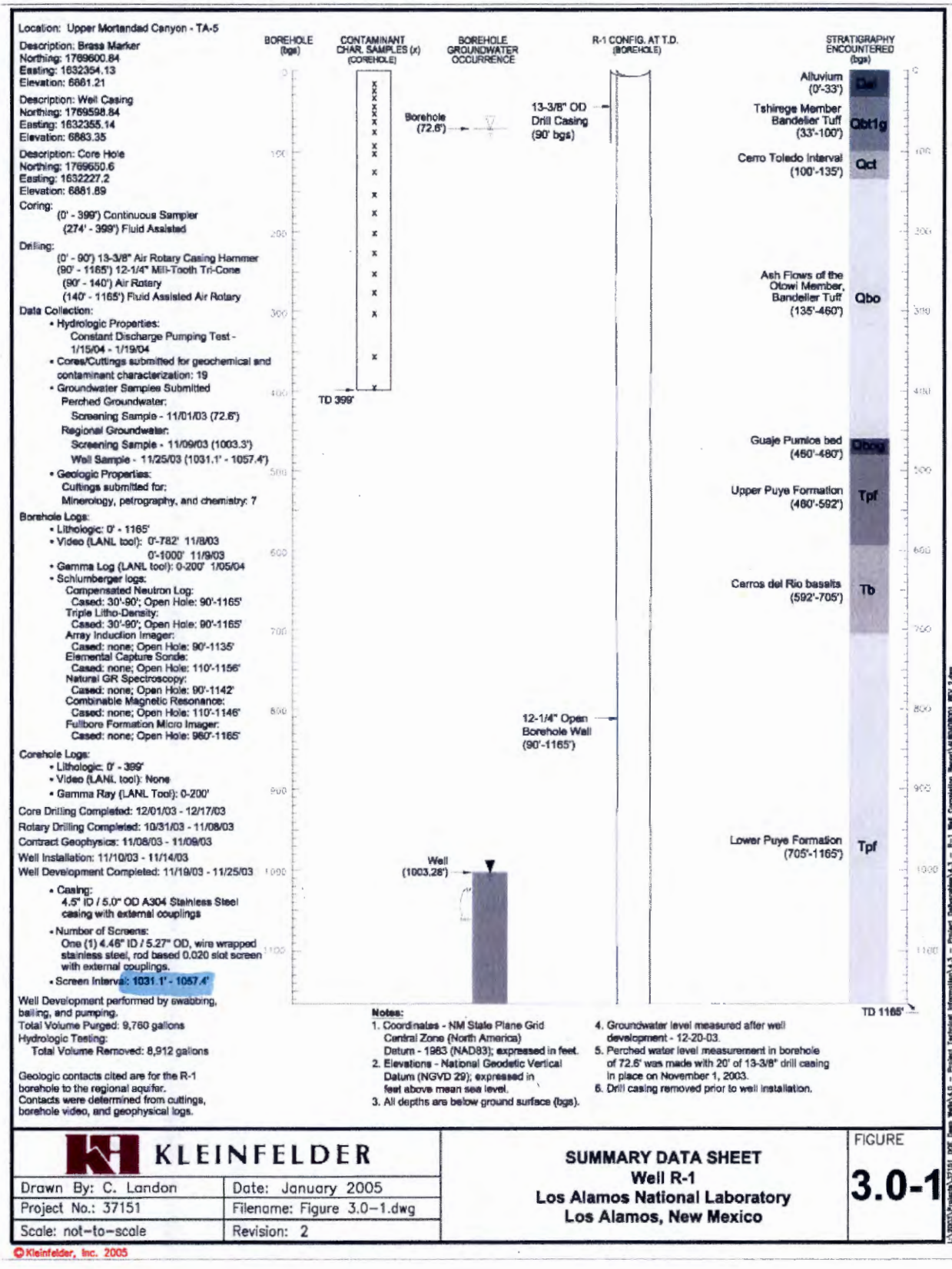
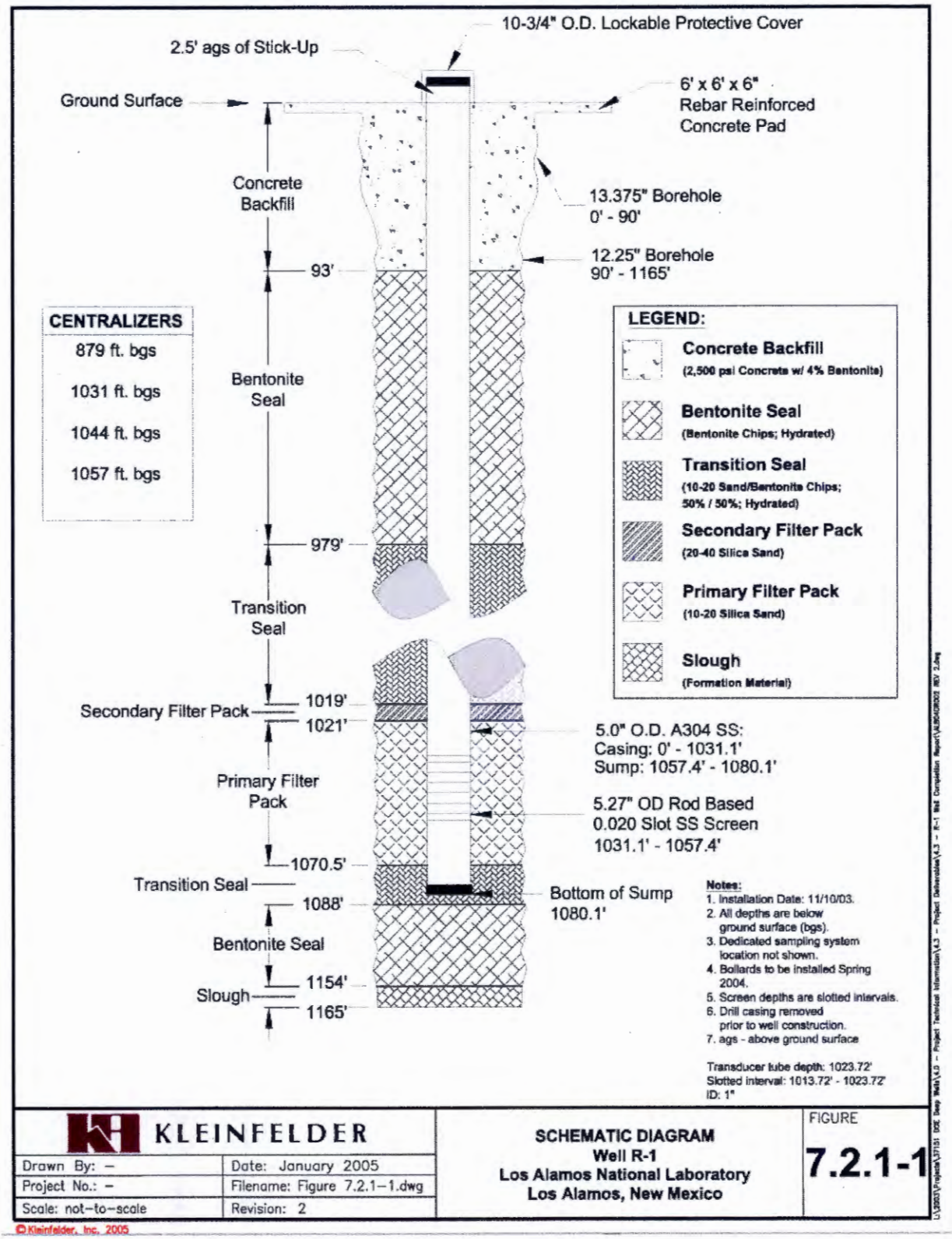
1. Well logs
   - R-1
   - R-15
   - MCO-3
   - MCO-4B
   - MCO-6
   - MCO-7
   - MCOI-4
   - MCOI-5
   - MCOI-6

R-1 WELL



R-1 Well Fact Sheet

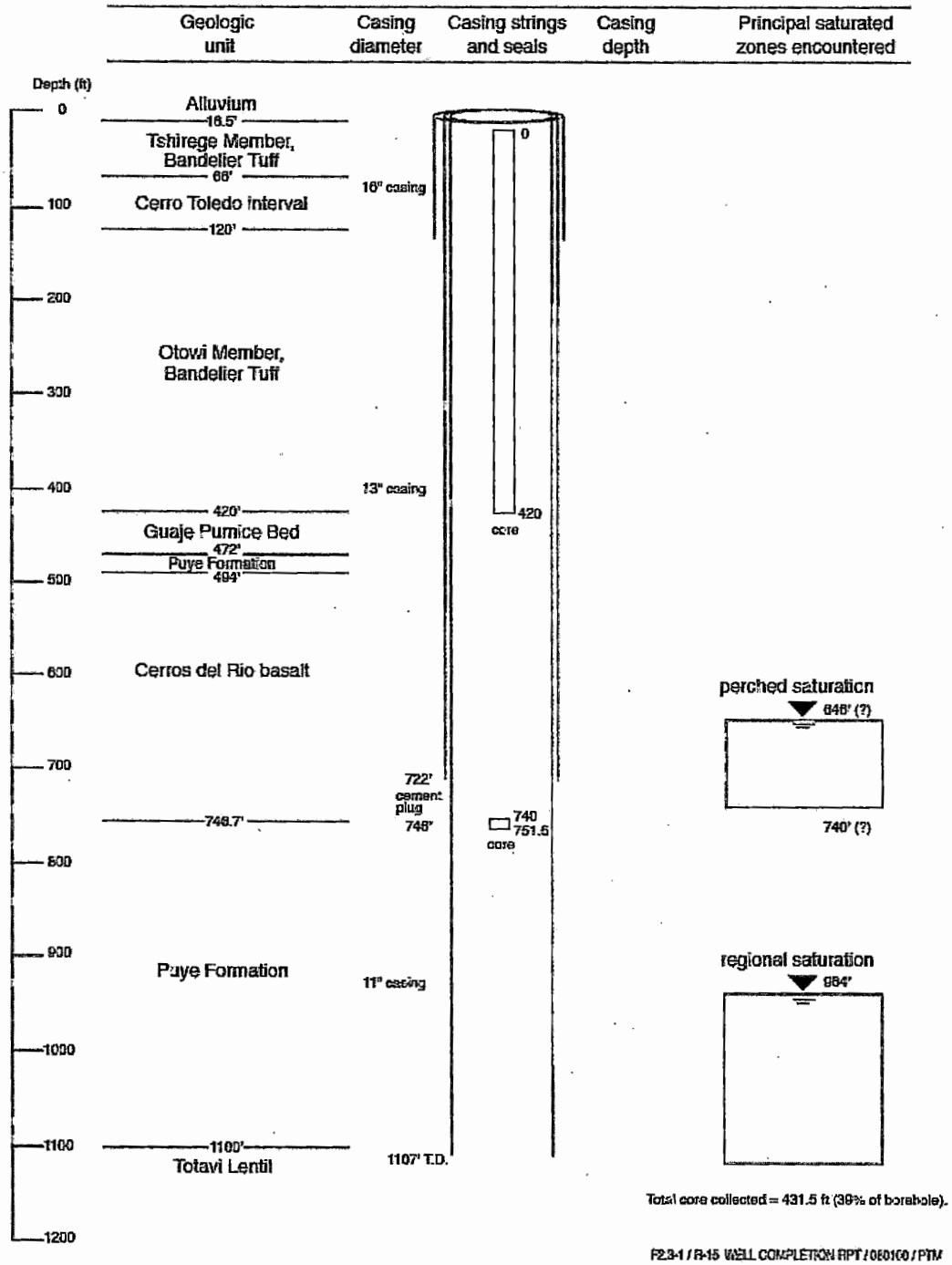
05517



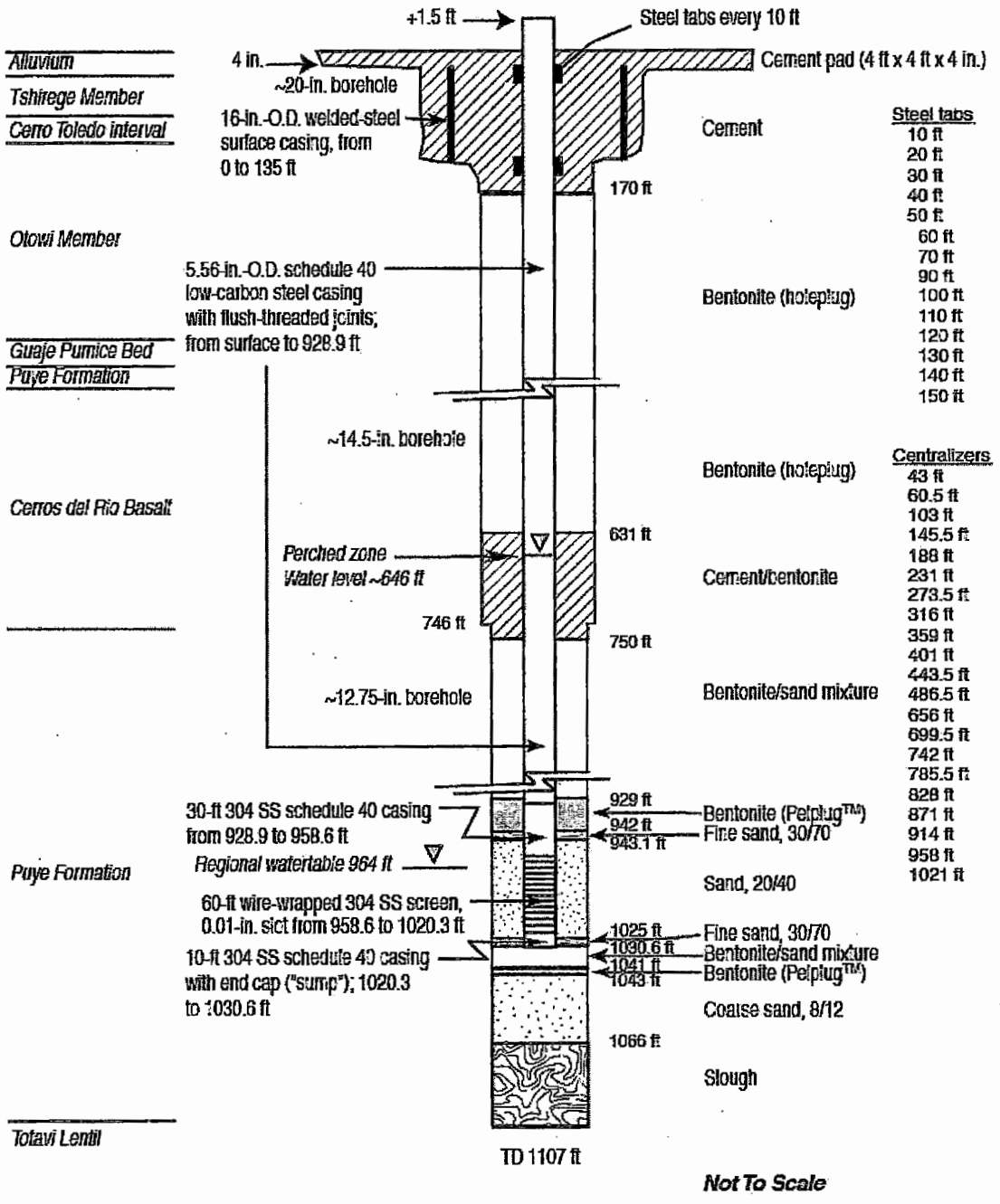
R-1 Well Construction Diagram

05518

R-15 WELL


Geologic unit
Casing diameter
Casing strings and seals
Casing depth
Principal saturated zones encountered
Depth (ft)
0
Alluvium
16.5'
Tshirege Member, Bandelier Tuff
66'
Cerro Toledo interval
120'
100
200
Otowi Member, Bandelier Tuff
300
400
420'
Guaje Pumice Bed
472'
Puye Formation
494'
500
Cerros del Rio basalt
600
700
748.7'
800
900
Puye Formation
1000
1100
1100'
Totavi Lentil
1200
16" casing
13" casing
11" casing
0
420
core
722'
cement plug
748'
740
751.5
core
1107' T.D.
perched saturation
646' (?)
740' (?)
regional saturation
984'
Total core collected = 431.5 ft (39% of borehole).
F2.3-1 / R-15 WELL COMPLETION RPT / 060100 / PTM

05520



F6.2-1 / R-15 WELL COMPLETION RPT / 083000 / PTM

05521

MCO-3 WELL

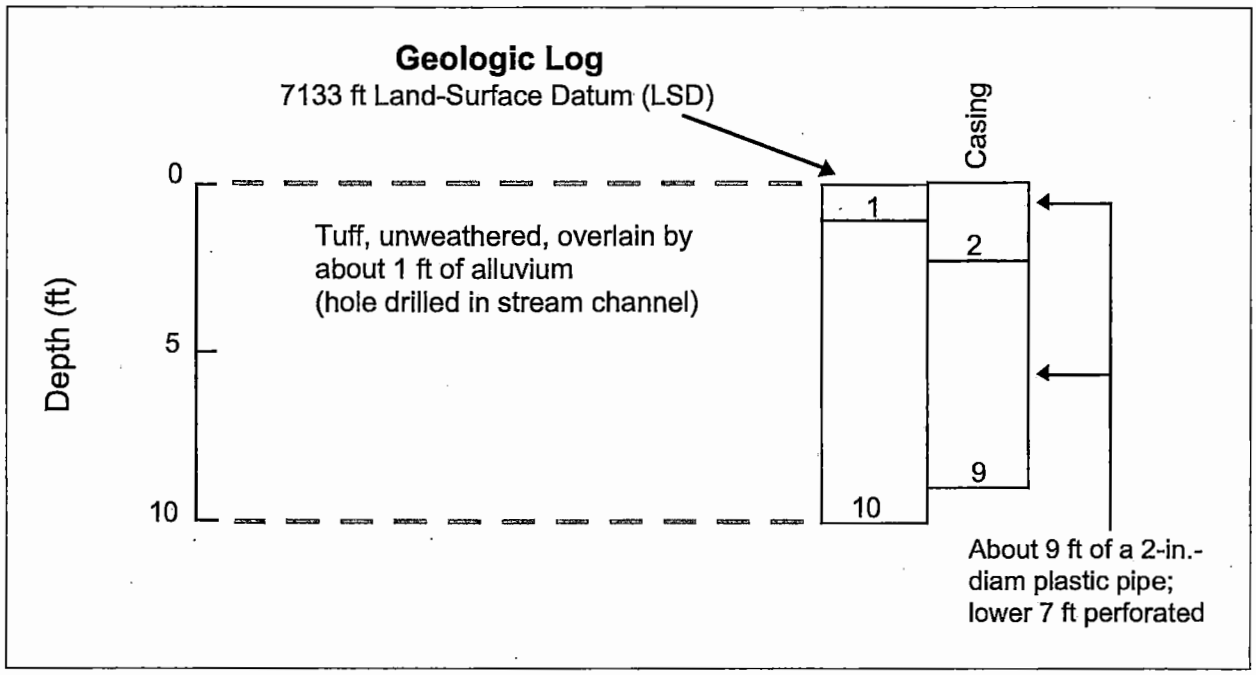


Fig. VI-C. Mortandad Canyon observation well MCO-2, completed November 1960, water level 0.3 ft (Baltz et al. 1963).

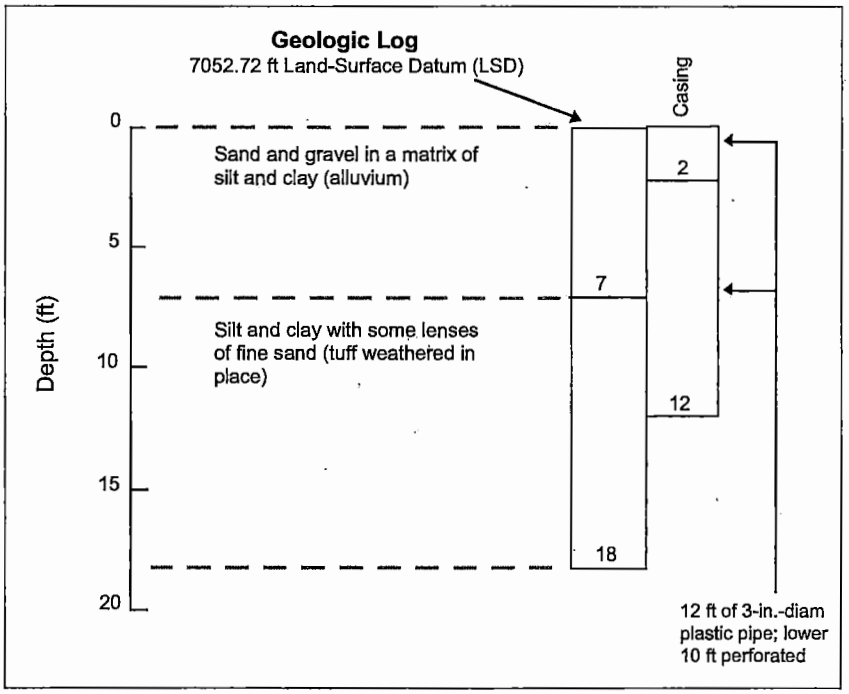


Fig. VI-D. Mortandad Canyon observation well MCO-3, redrilled March 1967 and completed with 3-in.-diam casing, water level 4.4 ft (Baltz et al. 1963; Purtymun 1964).

05523

TABLE VI-B. Geologic Logs and Construction Data for Observation Wells in Mortandad Canyon (20 Obs. Wells)

1. Observation Well MCO-1

Geologic Log	Thickness (ft)	Depth (ft)
Tuff, unweathered, overlain by about 1 ft of silt and sand	8	8

Note: Well abandoned, in stream channel.

2. Observation Well MCO-2

Geologic Log	Thickness (ft)	Depth (ft)
Tuff, unweathered, overlain by about 1 ft of silt and sand	10	10

Note: Well abandoned: in stream channel.

3. Observation Well MCO-3

Geologic Log	Thickness (ft)	Depth (ft)
Alluvium		
Sand and gravel in a matrix of silt and clay	7	7
Tuff (weathered in place)		
Silt and clay with some lenses of sand and gravel	11	18

Construction
12 ft of 3-in.-diam plastic pipe, lower 10 ft perforated.

4. Observation Well MCO-4

Geologic Log	Thickness (ft)	Depth (ft)
Alluvium		
Sand and gravel in a matrix of silt and clay	18	18
Tuff (weathered in place)		
Silt and clay with lenses of sand	6	24

Construction
19 ft of 3-in.-diam plastic pipe, lower 15 ft perforated.

5. Observation Well MCO-4.9

Geologic Log	Thickness (ft)	Depth (ft)
Alluvium		
Sand and gravel in a matrix of silt and clay	27	27
Tuff (weathered in place) silt and clay with gravel	16	43

Construction
30 ft of 3-in.-diam plastic pipe, lower 20 ft perforated.

: 05524

MCO-4B WELL

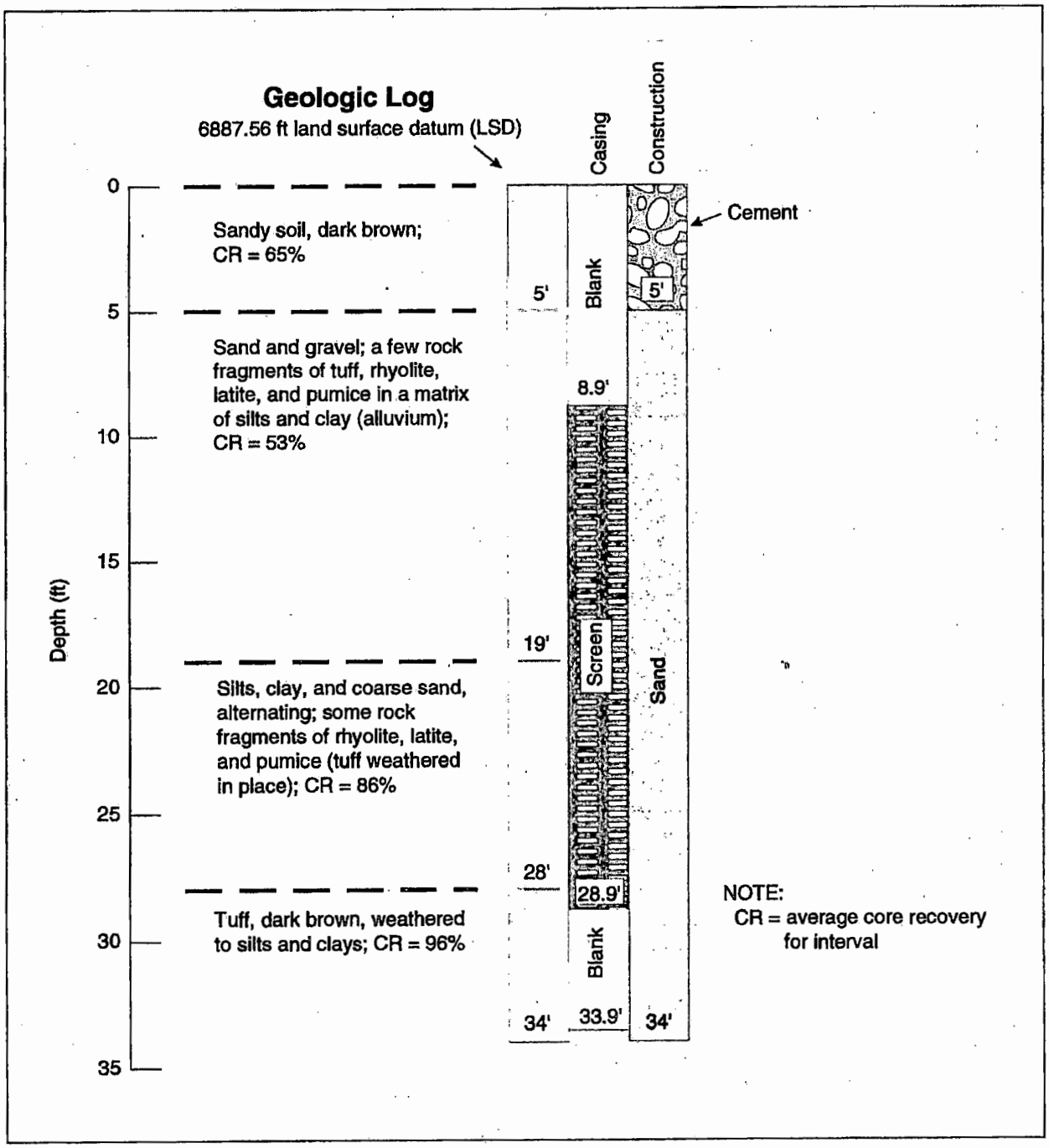


Fig. VIII-L. Mortandad Canyon observation well MCO-4B, completed August 1990, water level 21.7 ft (Purtymun and Stoker 1990).

05526

MCO-6 WELL

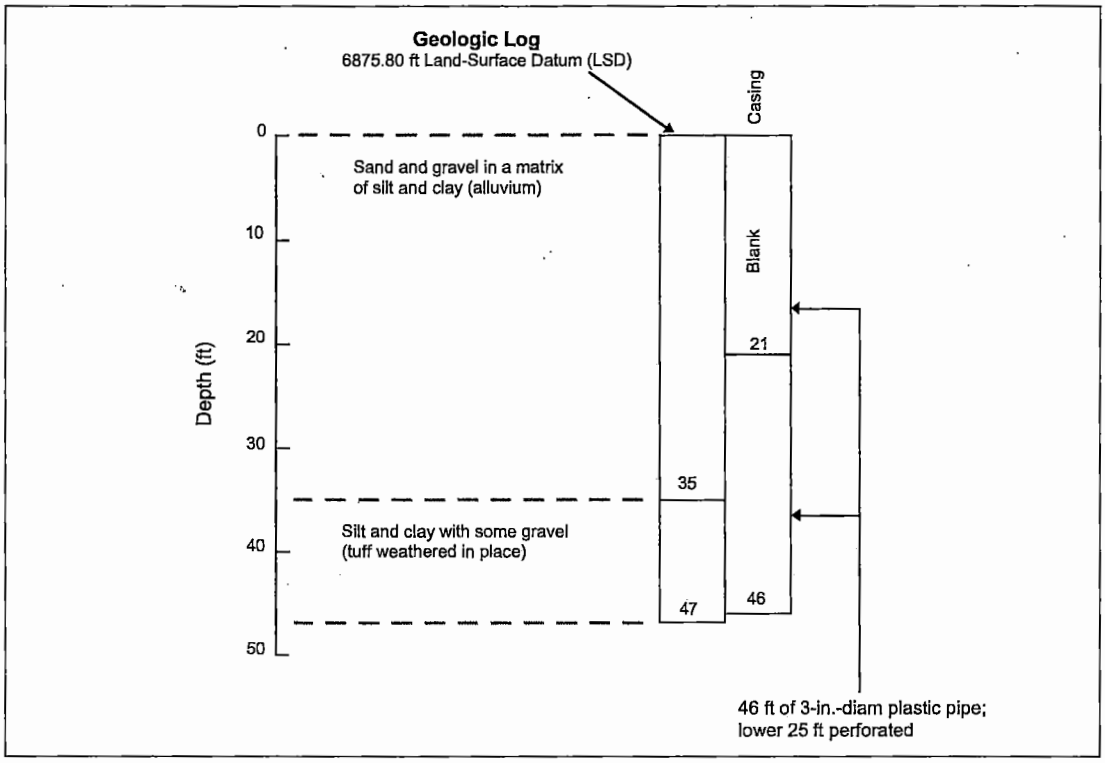


Fig. VI-G. Mortandad Canyon observation well MCO-5, completed October 1960, water level 24.6 ft (Baltz et al. 1963).

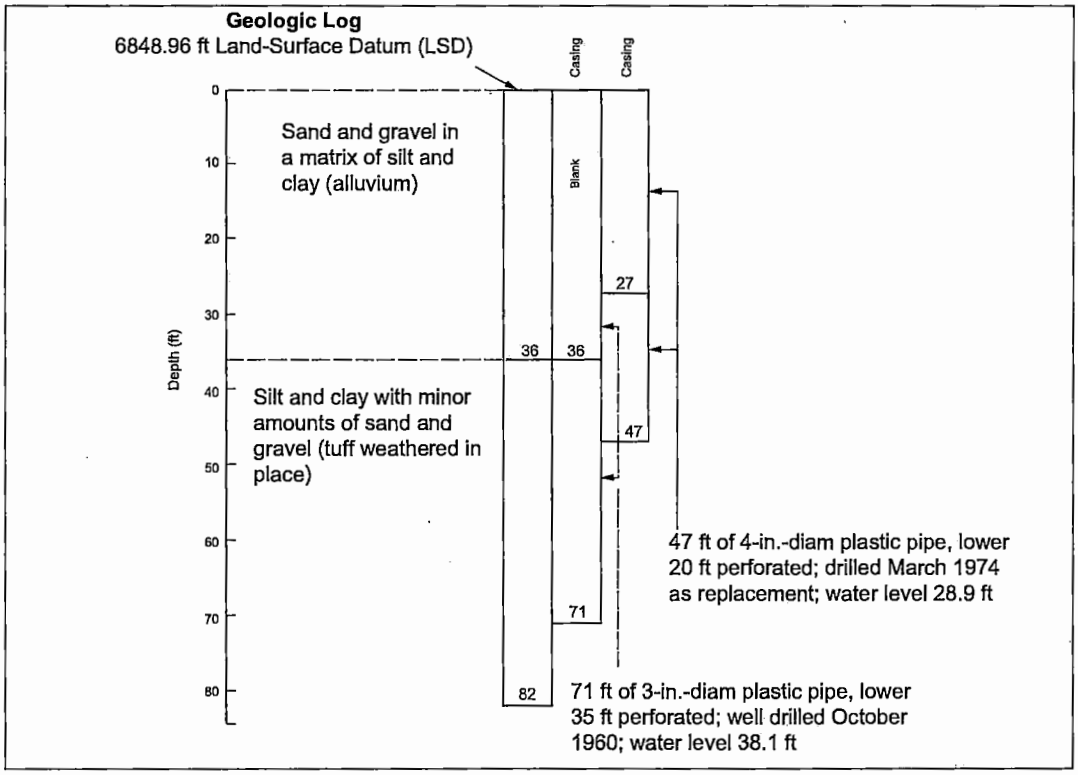


Fig. VI-H. Mortandad Canyon observation well MCO-6, completed October 1960, replaced March 1974 (Baltz et al. 1963, Purtymun 1974).

05529

TABLE VI-B. Geologic Logs and Construction Data for Observation Wells in Mortandad Canyon (20 Obs. Wells)(Continued)

6. Observation Well MCO-5

Geologic Log	Thickness (ft)	Depth (ft)
Alluvium		
Sand and gravel with lenses of silt and clay	35	35
Tuff (weathered in place)		
Silt and clay with some lenses of sand and gravel	12	47

Construction

46 ft of 3-in.-diam plastic pipe, lower 25 ft perforated.

7. Observation Well MCO-6

Geologic Log	Thickness (ft)	Depth (ft)
Alluvium		
Sand, gravel, and occasional cobbles in a matrix of silt and clay	36	36
Tuff (weathered in place)		
Silt and clay with minor amounts of sand and gravel	46	82

Construction

71 ft of 3-in.-diam plastic pipe, lower 35 ft perforated, well drilled October 1960. Well destroyed by flood, summer 1973; redrilled and constructed as a new well about 10 ft to the northeast (March 1974): 47 ft of 4-in.-diam plastic pipe, lower 20 ft perforated.

8. Observation Well MCO-6.5A

Geologic Log	Thickness (ft)	Depth (ft)
Alluvium		
Sand and gravel in a matrix of silt and clay	47	47

Construction

45 ft of 2-in.-diam plastic pipe, lower 20 ft perforated.

9. Observation Well MCO-6.5B

Geologic Log	Thickness (ft)	Depth (ft)
Alluvium		
Sand and gravel in a matrix of silt and clay	42	42

Construction

42 ft of casing, upper 22 ft of 4-in.-diam steel pipe; lower 20 ft of 4-in.-diam plastic pipe, perforated.

05529

MCO-7 WELL

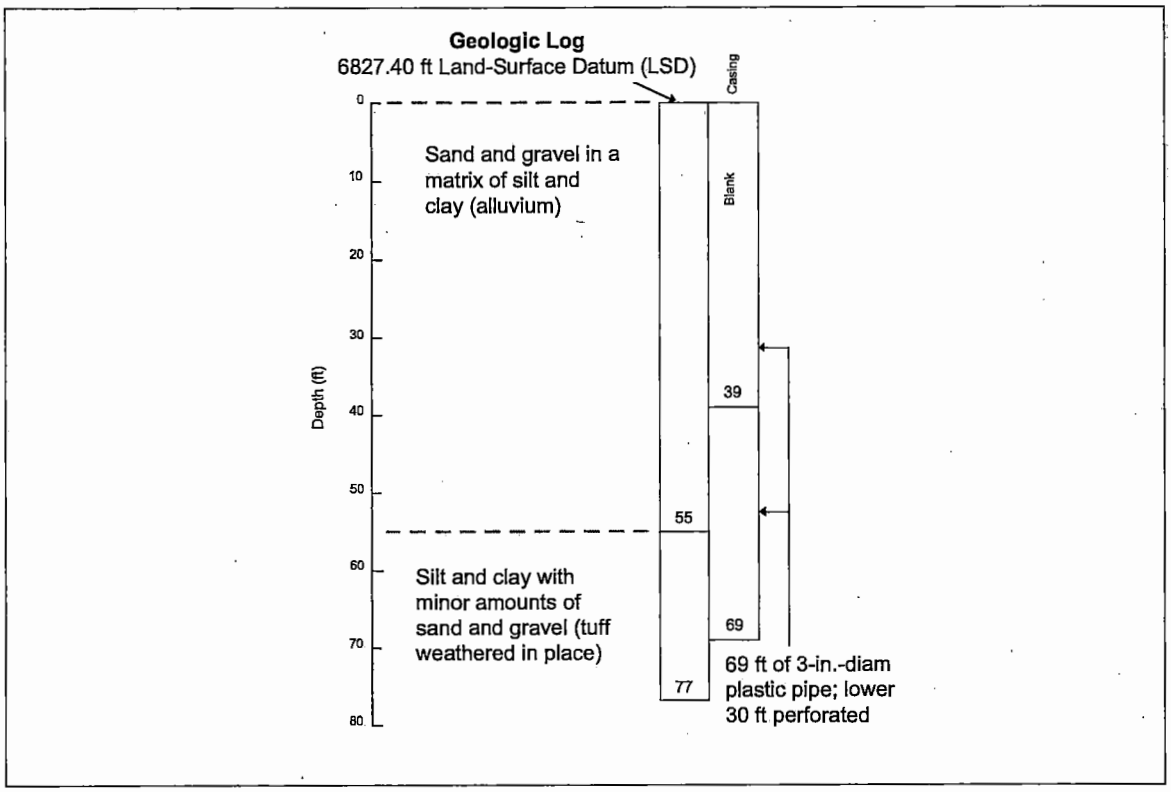


Fig. VI-K. Mortandad Canyon observation well MCO-7, completed October 1960, water level 39.7 ft (Baltz et al. 1963).

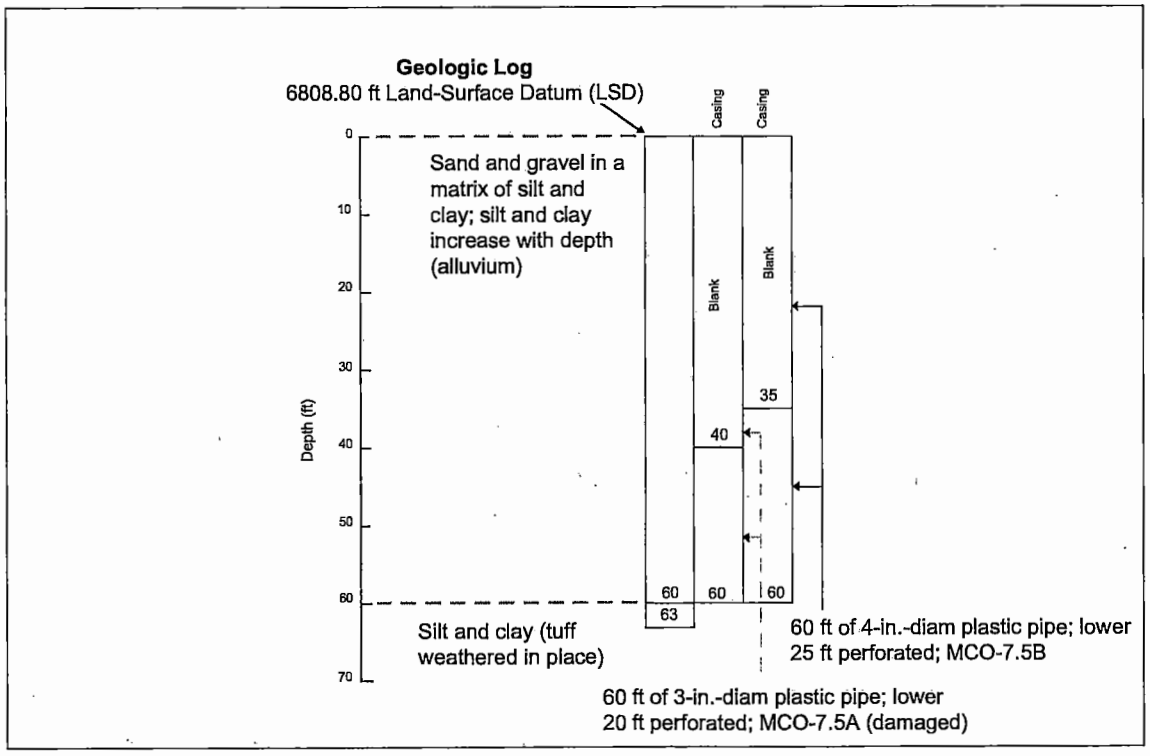


Fig. VI-L. Mortandad Canyon observation well MCO-7.5A (damaged), completed November 1961, water level 41.2 ft; and adjacent well MCO-7.5B, completed April 1974, water level 42.1 ft (Purtymun 1964, 1974).

: 05531

TABLE VI-B. Geologic Logs and Construction Data for Observation Wells in Mortandad Canyon (20 Obs. Wells)(Continued)

10. Observation Well MCO-7

Geologic Log	Thickness (ft)	Depth (ft)
Alluvium		
Sand and gravel in a silt and clay matrix	55	55
Tuff (weathered in place)		
Silt and clay with lenses of sand and gravel	22	77

Construction
69 ft of 3-in.-diam plastic pipe, lower 30 ft perforated.

11. Observation Well MCO-7.5A/7.5B

Geologic Log	Thickness (ft)	Depth (ft)
Alluvium		
Sand and gravel in a matrix of silt and clay; silt and clay increase with depth	60	60
Tuff (weathered in place) silt and clay	3	63

Construction
November 1961, 60 ft of 3-in.-diam plastic pipe, lower 20 ft perforated; well destroyed by falling tree, replaced April 1974 about 6 ft to the west: 60 ft of 4-in.-diam plastic pipe, lower 25 ft perforated.

12. Observation Well MCO-8

Geologic Log	Thickness (ft)	Depth (ft)
Alluvium		
Sand and gravel in a matrix of silt and clay; silt and clay increase with depth	61	61
Tuff (weathered in place)		
Silt and clay with lenses of fine to coarse sand	31	92

Construction
84 ft of 3-in.-diam plastic pipe, lower 20 ft perforated; well damaged, bailer stuck at about 23 ft.

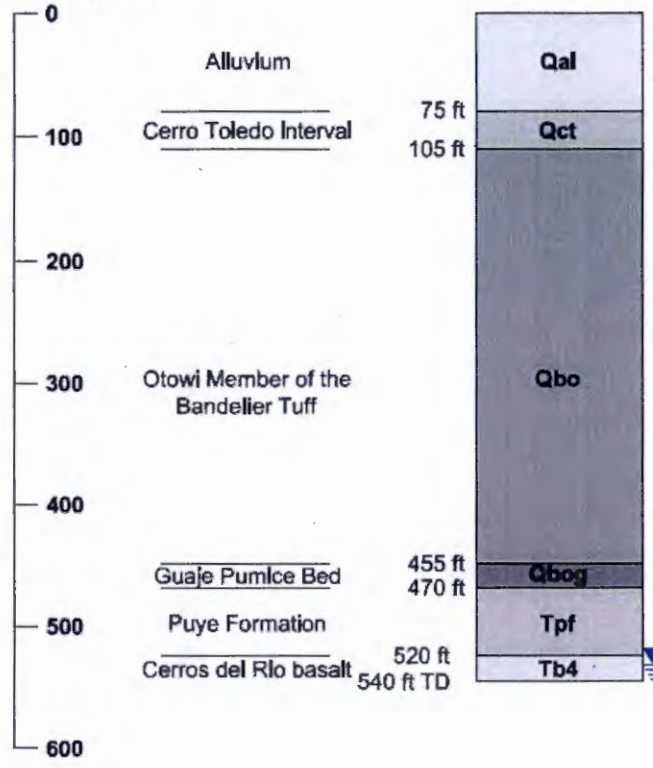
13. Observation Well MCO-8A

Geologic Log	Thickness (ft)	Depth (ft)
Alluvium		
Sand and gravel in a matrix of silt and clay; silt and clay increase with depth	52	52

Construction
50 ft of 2-in.-diam plastic pipe, lower 10 ft perforated.

: 05532

MCOI-4 WELL



DRILLING INFORMATION

DRILLING COMPANY/PERSONNEL
WDC Exploration
M. Daniels, C. Matthews, C. Bufkin, R. Price
Drill Rig: Speedstar 90k

DRILLING METHOD
Air Rotary Tri-cone bit with casing hammer (0 - 80 ft bgs)
Air Rotary Tri-cone bit (80 - 519 ft bgs)
Air Rotary Downhole hammer (519 - 540 ft bgs)

Borehole
Drilling Start Date: 10/24/04 Time: 16:50
Drilling End Date: 11/02/04 Time: 17:30

DRILLING FLUID TYPE
Air (0 - 80 ft bgs)
Air+water+QUIK-FOAM® (80 - 540 ft bgs)

Notes:
1. Geologic contacts are preliminary and subject to change.
2. Perched water at 59 ft bgs. Zone sealed off by surface casing.
3. Video survey indicated borehole wall moist below 504 ft bgs.
4. Groundwater level at 528.70 ft bgs in open hole after reaching TD of 540 ft bgs

KLEINFELDER		BOREHOLE SUMMARY DATA SHEET I-4 Mortandad Canyon Los Alamos National Laboratory Los Alamos, New Mexico	FIGURE 5.1-1
Drawn By: C. Bhongir	Date: April 2006		
Project No.: 49436	Filename: 49436_01_0.dwg		
Scale: not – to – scale	Revision: –		

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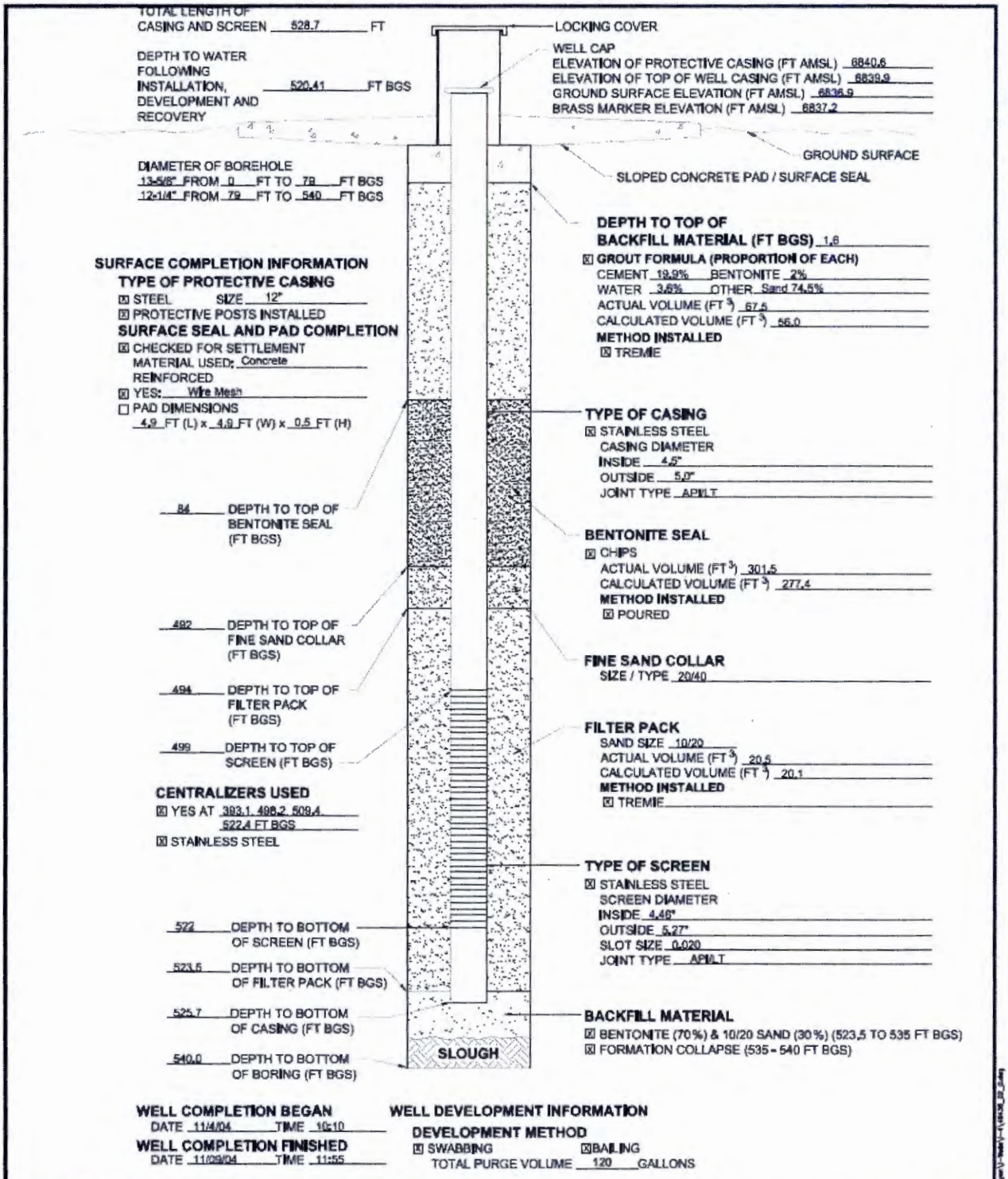

KLEINFELDER		WELL SCHEMATIC Characterization Well I-4 Mortandad Canyon Los Alamos National Laboratory Los Alamos, New Mexico	FIGURE 6.2-1
Drawn By: C. Bhongir	Date: April 2006		
Project No.: 49436	Filename: 49436_02_0.dwg		
Scale: Not-to-scale	Revision: -		

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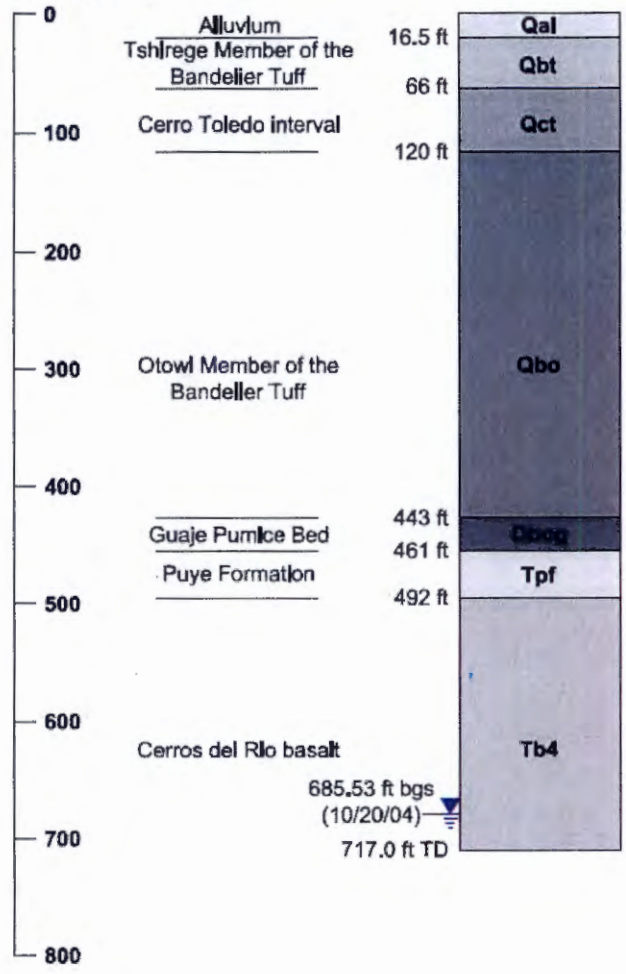
MCOI-5 WELL



DRILLING INFORMATION

DRILLING COMPANY/PERSONNEL
WDC Exploration
M. Daniels, C. Matthews, C. Bufkin, R. Price
Drill Rig: Speedstar 90k

DRILLING METHOD
Air Rotary Tri-cone bit with casing hammer (0 - 59 ft bgs)
Air Rotary Tri-cone bit (59 - 482 ft bgs)
Air Rotary Downhole hammer (482 - 717 ft bgs)

Borehole
Drilling Start Date: 10/15/04 Time: 14:40
Drilling End Date: 10/18/04 Time: 18:32

DRILLING FLUID TYPE
Air (0 - 62.8 ft bgs)
Air+water (62.8 - 108 ft bgs)
Air+water+QUIK-FOAM® (108 - 717 ft bgs)

Notes:
1. Geologic contacts are preliminary and subject to change.
2. No wet/saturated zones noted above approximately 685 ft bgs.
3. Groundwater level in open borehole after reaching TD was 685.53 ft bgs.

KLEINFELDER		BOREHOLE SUMMARY DATA SHEET I-5 Mortandad Canyon Los Alamos National Laboratory Los Alamos, New Mexico	FIGURE 5.1-1
Drawn By: C. Landon	Date: April 2006		
Project No.: 49436	Filename: 49436_01_0.dwg		
Scale: not -- to -- scale	Revision: --		

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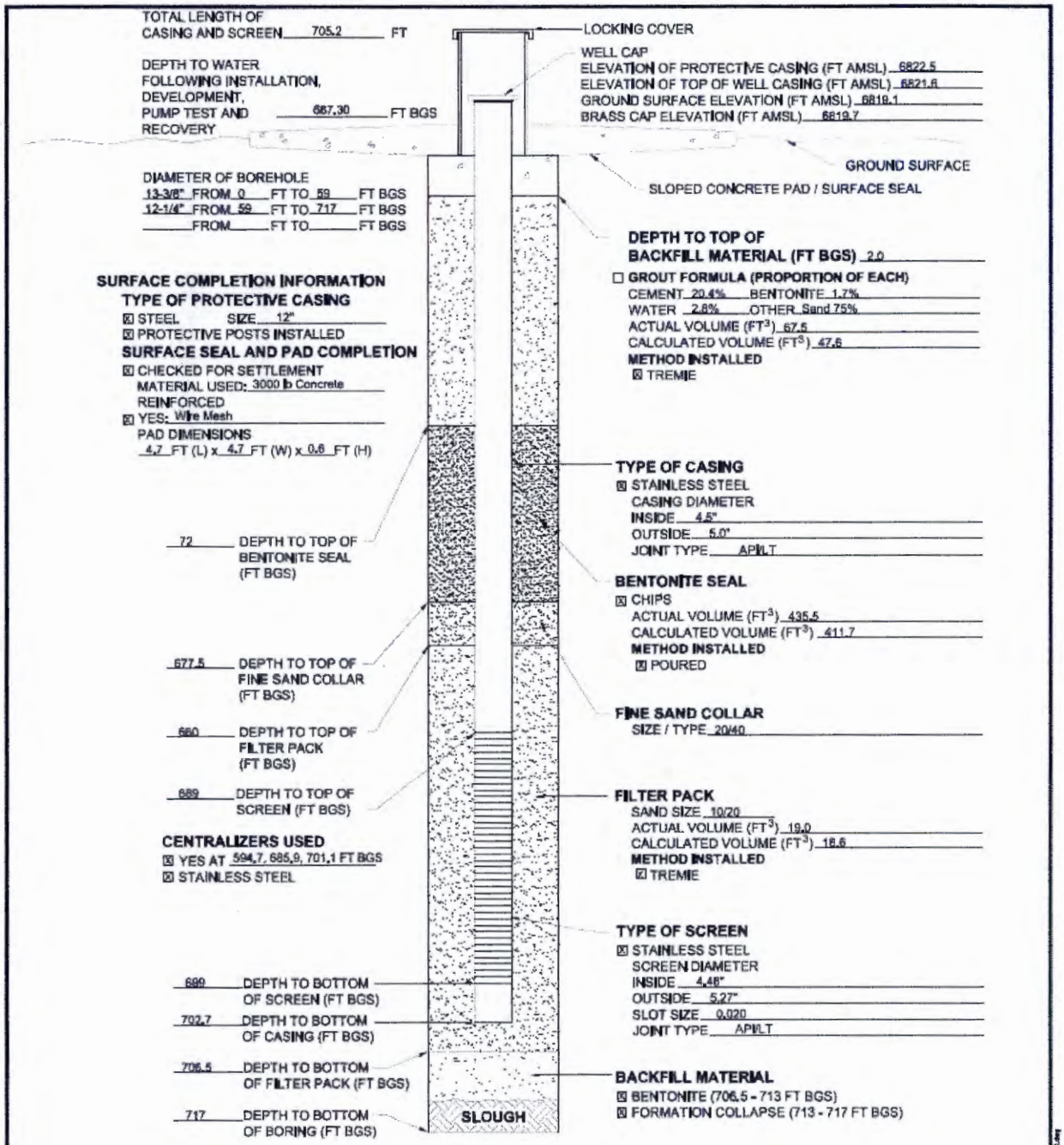

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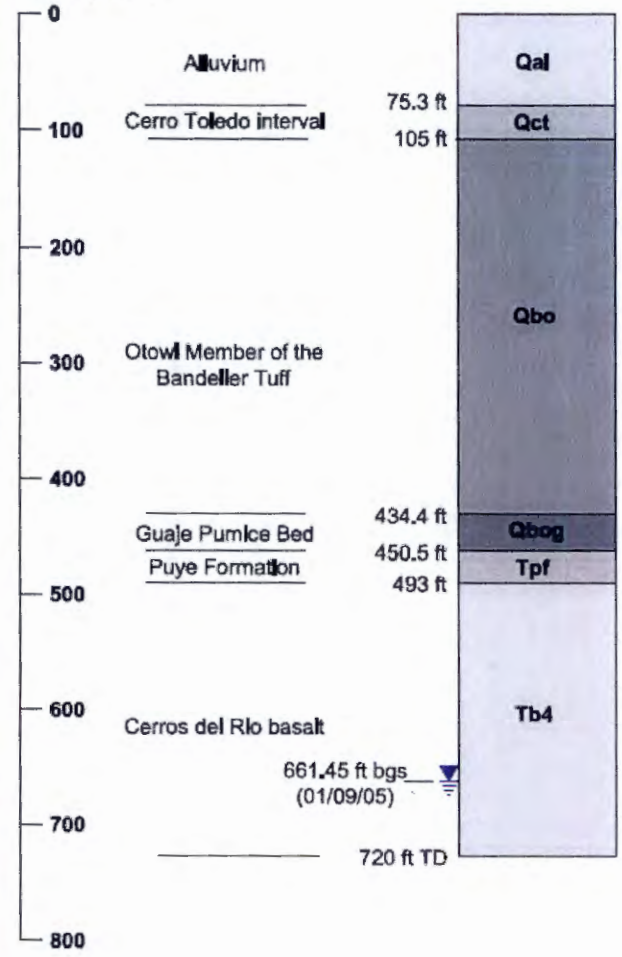
MCOI-6 WELL



DRILLING INFORMATION

DRILLING COMPANY/PERSONNEL
WDC Exploration
M. Daniels, C. Matthews, R. Price
Drill Rig: Gefco 50k
Spectrum Exploration
S. Jager
Drill Rig: DB-540

DRILLING METHOD
Corehole
0 - 498.2 ft bgs
Borehole
Air Rotary Tri-cone bit with casing hammer (0 - 60.5 ft bgs)
Air Rotary Tri-cone bit (60.5 - 495 ft bgs)
Air Rotary Downhole hammer (495 - 720 ft bgs)

Corehole
Drilling Start Date: 10/21/04 Time: 15:40
Drilling End Date: 10/28/04 Time: 18:09
Borehole
Drilling Start Date: 01/03/05 Time: 18:05
Drilling End Date: 01/06/05 Time: 17:28

DRILLING FLUID TYPE
Corehole: Air (0 - 498.2 ft bgs)
Borehole: Air, water, QUIK-FOAM®
Air (0-60.5 ft bgs)
Air+water+QUIK-FOAM® (60.5 - 720 ft bgs)

Notes:
1. Geologic contacts are preliminary and subject to change.
2. Wet/saturated zone in Alluvium at approximately 57.5 ft bgs in corehole.
3. Groundwater level in open borehole after reaching TD was 661.45 ft bgs.

KLEINFELDER		BOREHOLE SUMMARY DATA SHEET I-6 Mortandad Canyon Los Alamos National Laboratory Los Alamos, New Mexico	FIGURE 5.1-1
Drawn By: C. Landon	Date: April 2006		
Project No.: 49436	Filename: 49436_01_0.dwg		
Scale: not – to – scale	Revision: –		

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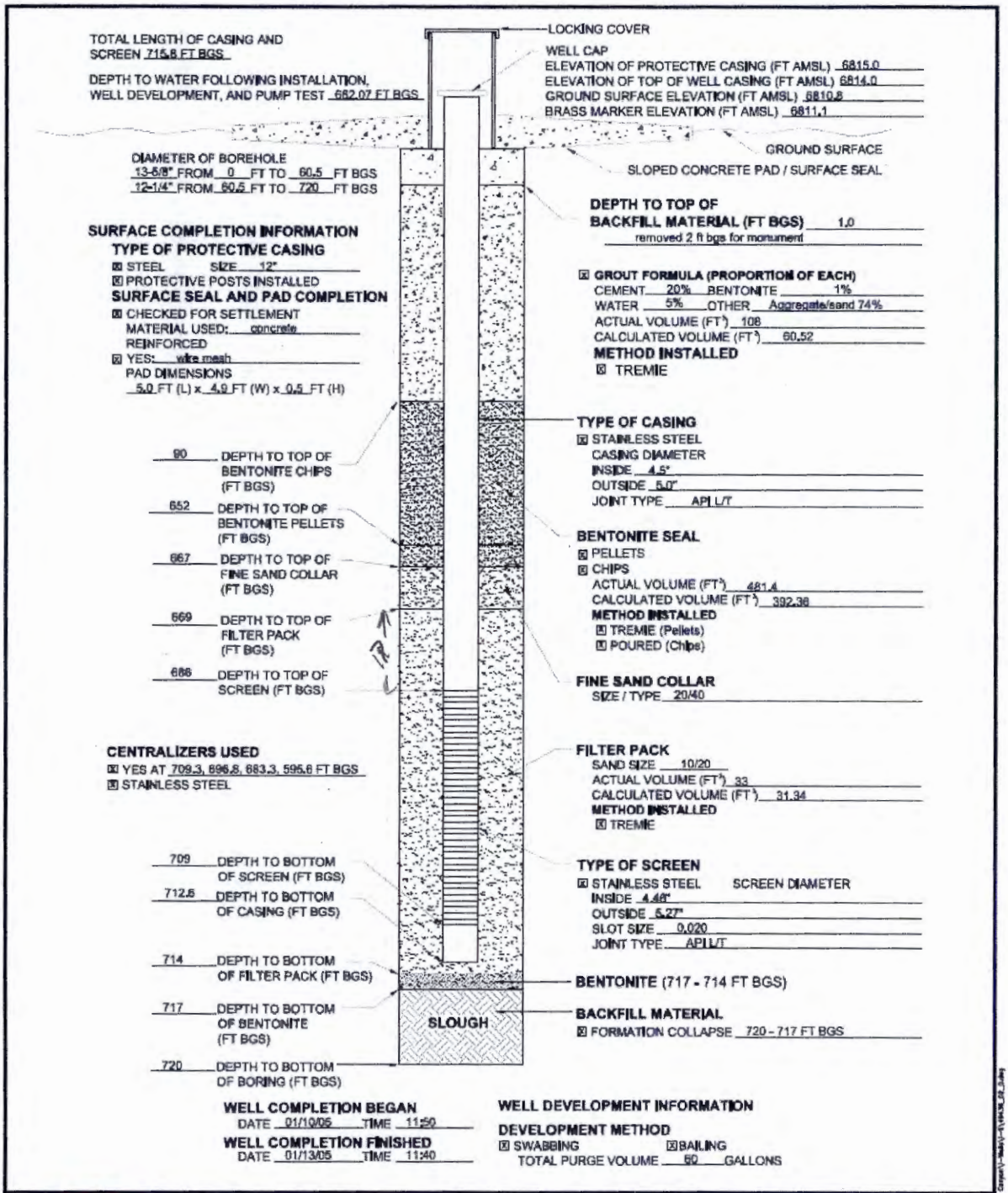

KLEINFELDER		WELL SCHEMATIC I-6 Mortandad Canyon Los Alamos National Laboratory Los Alamos, New Mexico	FIGURE 6.2-1
Drawn By: C. Bhongir	Date: April 2006		
Project No.: 49436	Filename: 49436_02_0.dwg		
Scale: Not-to-scale	Revision: -		

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APPENDIX F

GEOLOGY

TABLE OF CONTENTS

1. SOIL INFORMATION
   - TYPIC EUTROBORALFS, SL - ALANOS
   - LITHIC HAPLUSTALFS, SL - HACKROY

2. GEOTECHNICAL INVESTIGATIONS:
   - TA-50 RADIOACTIVE LIQUID WASTE TREATMENT FACILITY
   - TA-50-0250 WASTE MITIGATION RISK MANAGEMENT (WMRM)
   - TA-52 ZERO LIQUID DISCHARGE SOLAR EVAPORATION TANKS

3. PLAN AND MAP VIEWS OF STRATIGRAPHIC UNITS BENEATH MDA C.

SOIL INFORMATION

TYPIC EUTROBORALFS

AND

LITHIC HAPLUSTALFS

Taxonomic Classification of the Soils

Sandoval County Area, New Mexico, Parts of Los Alamos, Sandoval, and Rio Arriba Counties

[An asterisk by the soil name indicates a taxadjunct to the series]

Soil name	Family or higher taxonomic classification
Alanos	Clayey-skeletal, mixed Typic Eutroboralfs
Hackroy	Clayey, mixed, mesic Lithic Haplustalfs
Mirand	Fine, mixed Mollic Eutroboralfs
Nyjack	Fine-loamy, mixed, mesic Aridic Haplustalfs

Map Unit Description (Brief, Generated)

Sandoval County Area, New Mexico, Parts of Los Alamos, Sandoval, and Rio Arriba Counties

[Minor map unit components are excluded from this report]

Map unit: 162 - Hackroy-Nyjack association, 1 to 5 percent slopes

Component: Hackroy (45%)

The Hackroy component makes up 45 percent of the map unit. Slopes are 1 to 5 percent. This component is on plateaus on uplands. The parent material consists of residuum weathered from tuff. Depth to a root restrictive layer, bedrock, lithic, is 8 to 20 inches. The natural drainage class is well drained. Water movement in the most restrictive layer is moderately low. Available water to a depth of 60 inches is very low. Shrink-swell potential is high. This soil is not flooded. It is not ponded. There is no zone of water saturation within a depth of 72 inches. Organic matter content in the surface horizon is about 2 percent. This component is in the F036XB133NM Pinus Edulis/rhus Trilobata/bouteloua Gracilis ecological site. Nonirrigated land capability classification is 7s. This soil does not meet hydric criteria.

Component: Nyjack (40%)

The Nyjack component makes up 40 percent of the map unit. Slopes are 1 to 5 percent. This component is on mesas on uplands. The parent material consists of eolian deposits over slope alluvium derived from tuff. Depth to a root restrictive layer, bedrock, paralithic, is 20 to 40 inches. The natural drainage class is well drained. Water movement in the most restrictive layer is moderately high. Available water to a depth of 60 inches is moderate. Shrink-swell potential is low. This soil is not flooded. It is not ponded. There is no zone of water saturation within a depth of 72 inches. Organic matter content in the surface horizon is about 1 percent. This component is in the F048AY011NM Pinus Ponderosa-Juniperus Scopulorum/quercus Gambelii ecological site. Nonirrigated land capability classification is 6c. This soil does not meet hydric criteria.

Map unit: 283 - Mirand-Alanos complex, 5 to 40 percent slopes

Component: Mirand (45%)

The Mirand component makes up 45 percent of the map unit. Slopes are 5 to 30 percent. This component is on mountain slopes on mountains. The parent material consists of colluvium derived from volcanic rock. Depth to a root restrictive layer is greater than 60 inches. The natural drainage class is well drained. Water movement in the most restrictive layer is low. Available water to a depth of 60 inches is high. Shrink-swell potential is moderate. This soil is not flooded. It is not ponded. There is no zone of water saturation within a depth of 72 inches. Organic matter content in the surface horizon is about 65 percent. This component is in the F048AY010NM Pinus Ponderosa/festuca Arizonica-Danthonia Parryi ecological site. Nonirrigated land capability classification is 7c. This soil does not meet hydric criteria.

Component: Alanos (30%)

The Alanos component makes up 30 percent of the map unit. Slopes are 5 to 40 percent. This component is on mountain slopes on mountains. The parent material consists of slope alluvium over colluvium derived from volcanic rock. Depth to a root restrictive layer is greater than 60 inches. The natural drainage class is well drained. Water movement in the most restrictive layer is moderately low. Available water to a depth of 60 inches is low. Shrink-swell potential is high. This soil is not flooded. It is not ponded. There is no zone of water saturation within a depth of 72 inches. Organic matter content in the surface horizon is about 1 percent. This component is in the F048AY009NM Pseudotsuga Menziesii-Pinus Ponderosa/festuca Arizonica ecological site. Nonirrigated land capability classification is 7c. This soil does not meet hydric criteria.

2C horizon
Hue: 10YR or 7.5YR
Value: 5 to 7 when dry, and 4 to 6 when moist
Chroma: 3 or 4
Texture: sand, loamy sand, gravelly sand, or loamy fine sand
Salinity: from less than 2 to 16 mmhos/cm.

Note: The water table ranges from 4 to 6 feet.

Alanos Series

Map units: 283, 290
Depth class: very deep
Drainage class: well drained
Landform: mountain slopes and hillsides
Parent material: slope alluvium and colluvium derived from tuff and rhyolite
Elevation: 7,800 to 9,500 feet (2,377 to 2,896 meters)
Slope: 5 to 40 percent
Climatic data:
Mean annual precipitation: 20 to 25 inches (508 to 635 millimeters)
Mean annual air temperature: 42 to 45 degrees F. (5.6 to 7.2 degrees C.)
Frost-free period: 60 to 90 days

Taxonomic class: Clayey-skeletal, mixed Typic Eutroboralfs

Typical Pedon

Alanos loam, in an area of mapping unit 290, Alanos-Rock outcrop complex, 20 to 40 percent slopes; Los Alamos County; Frijoles Quadrangle. NAD 83, UTM 13—03 78 360 E—39 67 869 N.

A—0 to 4 inches; grayish brown (10YR 5/2) loam, dark grayish brown (10YR 4/2) moist; weak fine granular structure; soft, very friable, slightly sticky and nonplastic; many fine and medium roots; 10 percent gravel; neutral; abrupt smooth boundary.

E—4 to 9 inches; light gray (10YR 7/2) loam, grayish brown (10YR 5/2) moist; weak fine granular structure; slightly hard, very friable, nonsticky and nonplastic; common fine roots; few fine vesicular pores; 10 percent gravel; neutral; abrupt smooth boundary.

BE—9 to 18 inches; pinkish gray (7.5YR 7/2) and reddish brown (5YR 5/4) very gravelly loam, brown (7.5YR 5/2) and reddish brown (5YR 4/4) moist; weak fine subangular blocky structure; hard, very friable, slightly sticky and slightly plastic; common very fine roots; common fine black (5YR 2/1) iron and manganese concretions; 55 percent gravel; medium acid; clear smooth boundary.

Bt1—18 to 26 inches; reddish brown (5YR 5/4) extremely gravelly clay, reddish brown (5YR 4/4) moist; weak fine subangular blocky structure; hard, firm, sticky and plastic; few fine roots; few fine tubular pores; common fine black (5YR 2/1) iron and manganese concretions; common thin clay films in pores and on gravel; 20 percent cobbles and 55 percent gravel; medium acid; clear smooth boundary.

Bt2—26 to 60 inches; brown (7.5YR 5/4) extremely gravelly clay, brown (7.5YR 4/4) moist; moderate medium subangular blocky structure; hard, firm, sticky and plastic; few fine roots; few fine tubular pores; few thin clay films in pores and on gravel; 20 percent cobbles and 55 percent gravel; medium acid.

: 05546

Range in Characteristics

Particle-size control section: 35 to 55 percent clay
Other features: Some pedons are slightly alkaline in the lower subhorizons.

A horizon
Hue: 7.5YR or 10YR
Value: 5 or 6 dry, 3 to 5 moist
Chroma: 2 or 3
Texture: loam or cobbly loam

E horizon
Hue: 7.5YR or 10YR
Value: 6 or 7 dry, 4 or 5 moist
Chroma: 2 to 4
Texture: loam, gravelly loam, or cobbly loam

Bt horizon
Hue: 7.5YR or 10YR
Value: 5 to 7 dry, 3 to 6 moist
Chroma: 2 to 6
Texture: extremely gravelly clay loam, extremely gravelly clay, or very gravelly clay
Concretions: fine or medium iron and manganese concretions are in the upper part of the Bt horizon.

Note: C horizons are below 38 inches in some pedons.

Atarque Series

Map units: 324, 396
Depth class: very shallow to shallow
Drainage class: well drained
Landform: breaks; dipslopes of cuestas, hills, mesas, and ridges
Parent material: slope alluvium derived from sandstone and shale
Elevation: 5,700 to 6,600 feet (1,737 to 2,012 meters)
Slope: 5 to 45 percent
Climatic data:
Mean annual precipitation: 13 to 16 inches (330 to 406 millimeters)
Mean annual air temperature: 48 to 52 degrees F. (10 to 11.1 degrees C.)
Frost-free period: 110 to 130 days

Taxonomic class: Loamy, mixed, mesic Lithic Haplustalfs

Typical Pedon

Atarque sandy loam, in an area of mapping unit 324, Rock outcrop-Atarque-Menefee complex, 5 to 25 percent slopes; Sandoval County; Ponderosa Quadrangle; about 2 miles northeast of the Jemez Pueblo; 200 feet south and 1,400 feet east of the northwest corner of sec. 11, T 16 N, R 2 E. NAD 27; UTM 13—03 45 805 E—39 44 974 N.

A—0 to 3 inches; light brown (7.5YR 6/4) sandy loam, dark brown (7.5YR 4/4) moist; moderate very thin platy structure; soft, very friable, nonsticky and nonplastic; many very fine roots; neutral; clear smooth boundary.
Bt—3 to 9 inches; reddish brown (5YR 5/4) sandy clay loam, reddish brown (5YR 4/4) moist; moderate fine and medium subangular blocky structure; hard, firm, sticky and plastic; common very fine roots; many very fine tubular pores; many thin clay films on faces of peds and lining pores; neutral; clear smooth boundary.

: 05547

Bk2—17 to 45 inches; white (N 8/0) and very pale brown (10YR 8/3) extremely gravelly sandy loam, light gray (10YR 7/2) and very pale brown (10YR 7/3) moist; massive; hard, firm, nonsticky and nonplastic; weakly cemented; few fine roots; few fine tubular pores; strongly effervescent; calcium carbonate and siliceous material dominant throughout entire horizon causing 90 percent weak cementation, interrupted only by fractures less than 3 mm wide and less than 4 inches apart; 5 percent cobbles and 60 percent gravel; moderately alkaline; diffuse irregularly boundary.

Bk3—45 to 60 inches; very pale brown (10YR 7/3) very gravelly sandy loam, pale brown (10YR 6/3) moist; massive; soft, very friable, nonsticky and nonplastic; few fine roots; 5 percent cobbles and 50 percent gravel; strongly effervescent; calcium carbonate disseminated throughout and engulfing coarse fragments; moderately alkaline.

Range in Characteristics

Particle-size control section: 5 to 15 percent clay
Depth to the weakly cemented horizon: 12 to 26 inches

A horizon
Hue: 7.5YR or 10YR
Value: 5 to 7 dry, 3 to 5 moist
Chroma: 2 to 4

B horizons
Hue: 7.5YR or 10YR
Value: 5 to 8 dry, 4 to 7 moist
Chroma: 0 to 4
Texture: gravelly, very gravelly, and extremely gravelly sandy loams

Hackroy Series

Map units: 21, 162
Depth class: very shallow to shallow
Drainage class: well drained
Landform: summits of mesas and plateaus
Parent material: residuum from tuff
Elevation: 6,000 to 7,200 feet (1,829 to 2,195 meters)
Slope: 1 to 8 percent
Climatic data:
Mean annual precipitation: 13 to 16 inches (330 to 406 millimeters)
Mean annual air temperature: 48 to 52 degrees F. (10 to 11.1 degrees C.)
Frost-free period: 110 to 130 days

Taxonomic class: Clayey, mixed, mesic Lithic Haplustalfs

Typical Pedon

Hackroy sandy loam, in an area of mapping unit 162, Hackroy-Nyjack association, 1 to 5 percent slopes; Los Alamos County; White Rock Quadrangle; on the east end of Ancho Canyon Trail; unsectionized; NAD 83, UTM 13—03 87 647 E—39 61 208 N.

A—0 to 3 inches; brown (10YR 5/3) sandy loam, brown (10YR 4/3) moist; weak fine subangular blocky structure; hard, friable, nonsticky and nonplastic; many fine roots; common fine tubular pores; slightly alkaline; abrupt smooth boundary.

: 05548

Bt—3 to 13 inches; reddish brown (5YR 4/4) clay, dark reddish brown (5YR 3/4) moist; moderate fine prismatic structure; hard, firm, sticky and plastic; many fine roots; few very fine tubular pores; 3 percent gravel; continuous clay films on faces of peds; slightly alkaline; abrupt smooth boundary.
2R—13 inches; tuff.

Range in Characteristics

Particle-size control section: 35 to 50 percent clay
Depth to lithic contact: 8 to 20 inches

A horizon
Hue: 7.5YR or 10YR
Value: 4 or 6 dry, 2 to 4 moist
Chroma: 2 to 4

Bt1 horizon
Hue: 7.5YR or 5YR
Value: 3 to 6 dry, 3 or 4 moist
Chroma: 4 or 6, dry or moist

Hagerman Series

Map units: 227, 240
Depth class: moderately deep
Drainage class: well drained
Landform: hills, mesas and ridges
Parent material: eolian material and alluvium derived from sandstone
Elevation: 5,700 to 6,400 feet (1,737 to 1,951 meters)
Slope: 1 to 5 percent
Climatic data:
Mean annual precipitation: 10 to 13 inches (254 to 330 millimeters)
Mean annual air temperature: 52 to 54 degrees F. (11.1 to 12.2 degrees C.)
Frost-free period: 120 to 140 days

Taxonomic class: Fine-loamy, mixed, mesic Ustollic Haplargids

Typical Pedon

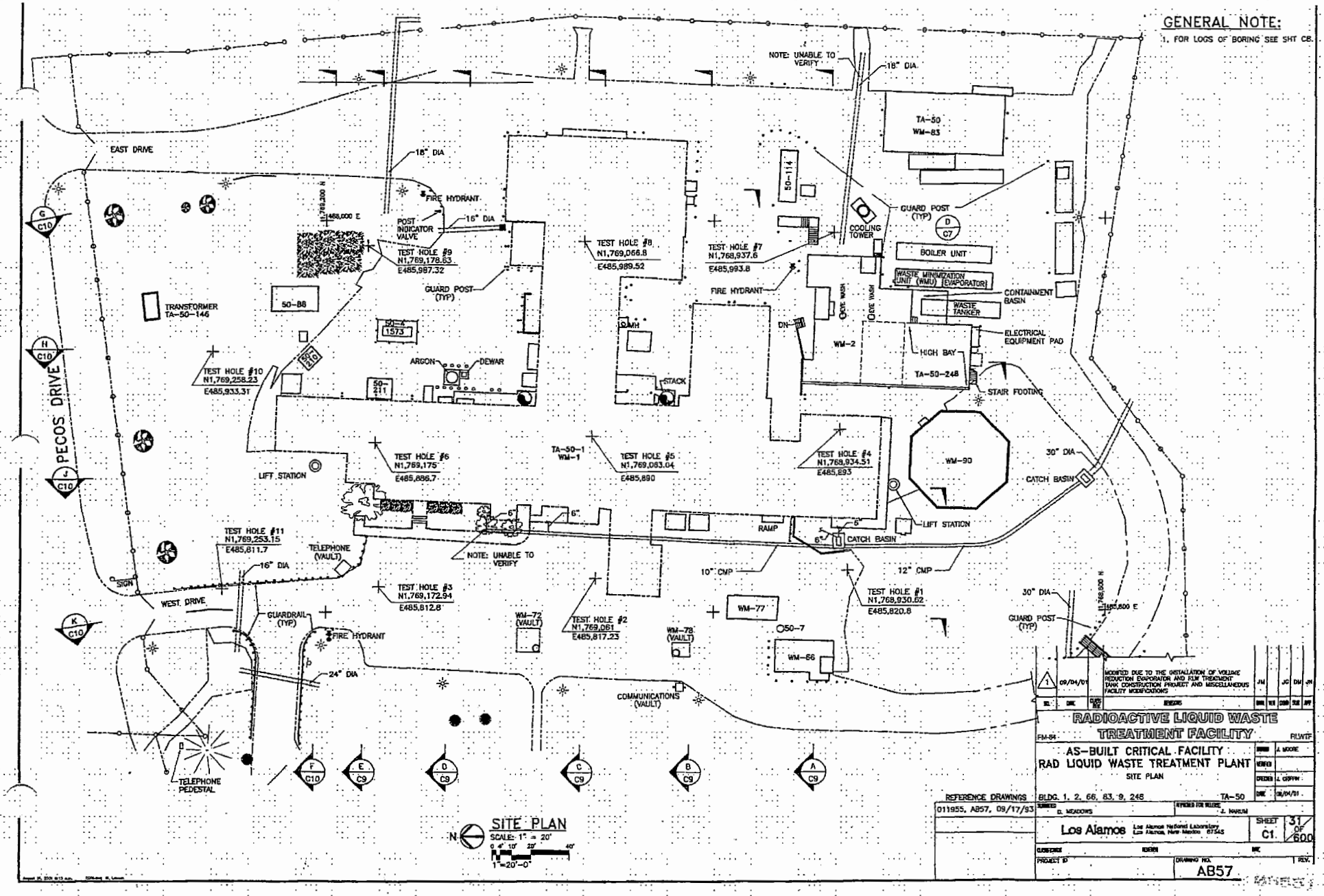
Hagerman fine sandy loam, in an area of mapping unit 240, Penistaja-Hagerman association, 1 to 5 percent slopes; Sandoval County; Cabezon Peak Quadrangle; about 1.5 miles southeast of the Rio Puerco along the Gas Company of New Mexico pipeline; unsectionized; NAD 83, UTM 13—03 13 428 E—39 43 499 N.

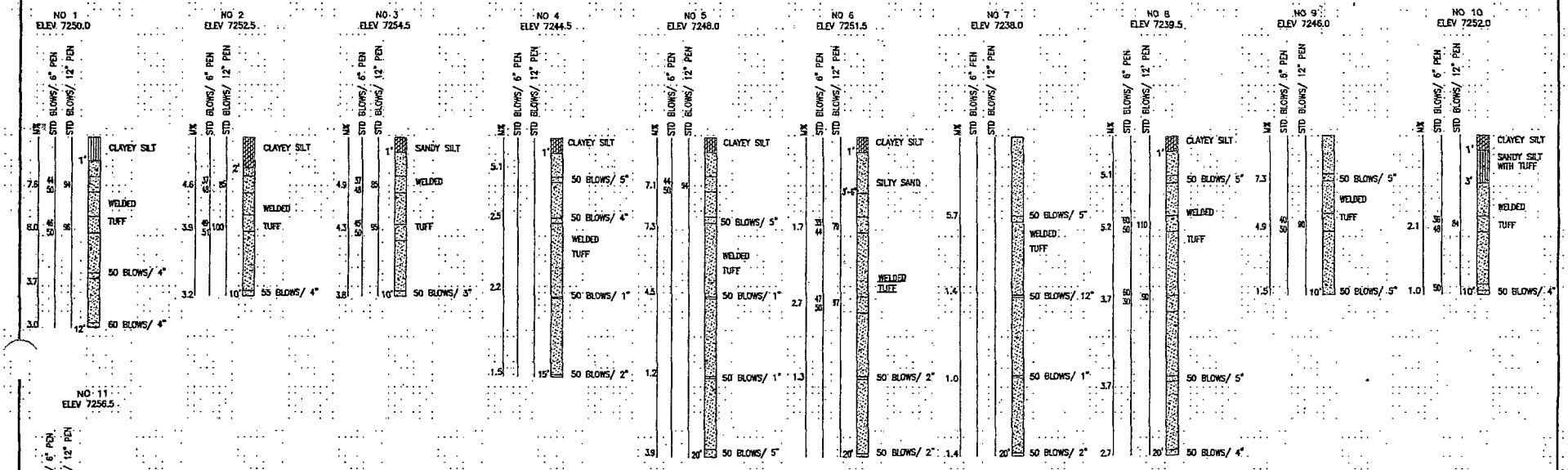
A—0 to 2 inches; brown (7.5YR 5/4) fine sandy loam, dark brown (7.5YR 4/4) moist; weak fine granular structure; soft, very friable, nonsticky and nonplastic; common medium and many fine roots; moderately alkaline; clear smooth boundary.
Bt—2 to 9 inches; brown (7.5YR 4/4) clay loam, dark brown (7.5YR 4/4) moist; moderate medium subangular blocky structure; slightly hard, firm, sticky and plastic; common medium and many fine roots; thin continuous clay films on faces of peds; moderately alkaline; clear smooth boundary.
Btk—9 to 24 inches; light brown (7.5YR 6/4) clay loam, brown (7.5YR 5/4) moist; moderate medium subangular blocky structure; hard, firm, sticky and plastic; few medium and many fine roots; few thin clay films on faces of peds; strongly effervescent; few fine accumulations of calcium carbonate; moderately alkaline; clear smooth boundary.
2R—24 inches; sandstone.

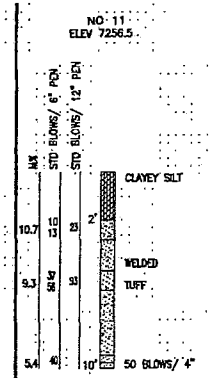
TA-50 RLWTF

GEOTECHNICAL INVESTIGATION

SITE MAP AND BORE LOGS


GENERAL NOTE:
1. FOR LOGS OF BORING SEE SHT C8.
NOTE: UNABLE TO VERIFY
18" DIA.
TA-50
WM-83
EAST DRIVE
18" DIA
FIRE HYDRANT
POST INDICATOR VALVE
16" DIA
N1,769,200 N
468,000 E
TEST HOLE #9
N1,769,178.63
E485,987.32
TEST HOLE #8
N1,769,066.8
E485,989.52
TEST HOLE #7
N1,768,937.6
E485,993.8
50-114
GUARD POST (TYP)
D
C7
COOLING TOWER
BOILER UNIT
WASTE MINIMIZATION UNIT (WMU) EVAPORATOR
CONTAINMENT BASIN
WASTE TANKER
FIRE HYDRANT
TRANSFORMER TA-50-146
50-88
50-1573
SWG 210
ARGON
DEWAR
50-211
SUMP
STACK
DN
OPEN WASH
OPEN WASH
WM-2
HIGH BAY
TA-50-248
ELECTRICAL EQUIPMENT PAD
STAIR FOOTING
TEST HOLE #10
N1,769,258.23
E485,933.31
PECOS DRIVE
G C10
H C10
I C10
TEST HOLE #6
N1,769,175
E485,886.7
TA-50-1
WM-1
TEST HOLE #5
N1,769,083.04
E485,890
TEST HOLE #4
N1,769,934.51
E485,893
WM-90
30" DIA
CATCH BASIN
LIFT STATION
6"
RAMP
LIFT STATION
CATCH BASIN
TEST HOLE #11
N1,769,253.15
E485,811.7
TELEPHONE (VAULT)
16" DIA
NOTE: UNABLE TO VERIFY
10" CMP
12" CMP
SIGN
WEST DRIVE
TEST HOLE #3
N1,769,172.94
E485,812.8
TEST HOLE #2
N1,769,061
E485,817.23
TEST HOLE #1
N1,768,930.62
E485,820.8
WM-77
50-7
WM-72 (VAULT)
WM-78 (VAULT)
WM-66
30" DIA
N1,768,800 N
485,800 E
GUARD POST (TYP)
K C10
GUARDRAIL (TYP)
FIRE HYDRANT
24" DIA
COMMUNICATIONS (VAULT)
TELEPHONE PEDESTAL
F C10
E C9
D C9
C C9
B C9
A C9
SITE PLAN
N
SCALE: 1" = 20'
0 4' 10' 20' 40'
1"=20'-0"
REFERENCE DRAWINGS
011955, A857, 09/17/93
1 09/04/01 MODIFIED DUE TO THE INSTALLATION OF VOLUME REDUCTION EVAPORATOR AND RLW TREATMENT TANK CONSTRUCTION PROJECT AND MISCELLANEOUS FACILITY MODIFICATIONS
RADIOACTIVE LIQUID WASTE TREATMENT FACILITY
FM-84
RLWTF
AS-BUILT CRITICAL FACILITY
RAD LIQUID WASTE TREATMENT PLANT
SITE PLAN
BLDG. 1, 2, 66, 83, 9, 248
TA-50
D. MEADOWS
J. MARUM
Los Alamos
Los Alamos National Laboratory
Los Alamos, New Mexico 87545
SHEET C1.
31 OF 600
PROJECT ID
DRAWING NO. AB57
REV.





LOGS OF BORING

STD BLOWS/ 12" PEN	THE NUMBER OF BLOWS REQUIRED TO DRIVE A 2 INCH OUTSIDE DIAMETER, 1.3750 INCH INSIDE DIAMETER STANDARD SPLIT SPOON SAMPLER THRU A VERTICAL DISTANCE OF 1-FOOT, USING A 140# HAMMER WITH A FREE FALL OF 30 INCHES, UNLESS OTHERWISE NOTED.
STD BLOWS/ 6" PEN	PENETRATION COUNT AT 6 INCH VERTICAL INTERVALS
M%	MOISTURE CONTENT IN PER CENT

GENERAL NOTES:

1. WATER TABLE NOT ENCOUNTERED IN ANY TEST HOLE.
2. TEST HOLE BORINGS WERE MADE DURING APRIL, 1961 WITH 4 INCH POWER AUGER.
3. FOR LOCATION OF TEST HOLES, SEE SHEET C1
4. NOT AS-BUILT VERIFIED

NO.	DATE	CLASS REV	REVISION	DRN	VER	CHKD	SUB	APP
1	09/04/01		GENERAL REVISIONS	JM		JG	DM	JH

RADIOACTIVE LIQUID WASTE TREATMENT FACILITY

FM-84 FILWTF

AS-BUILT CRITICAL FACILITY
RAD LIQUID WASTE TREATMENT PLANT
LOGS OF BORING

DRAWN C. BINKLEY
CHECKED J. GRIFFIN
DATE 09/04/01

REFERENCE DRAWINGS
011955, AB57, 09/17/93

BLDG. 1 TA-50

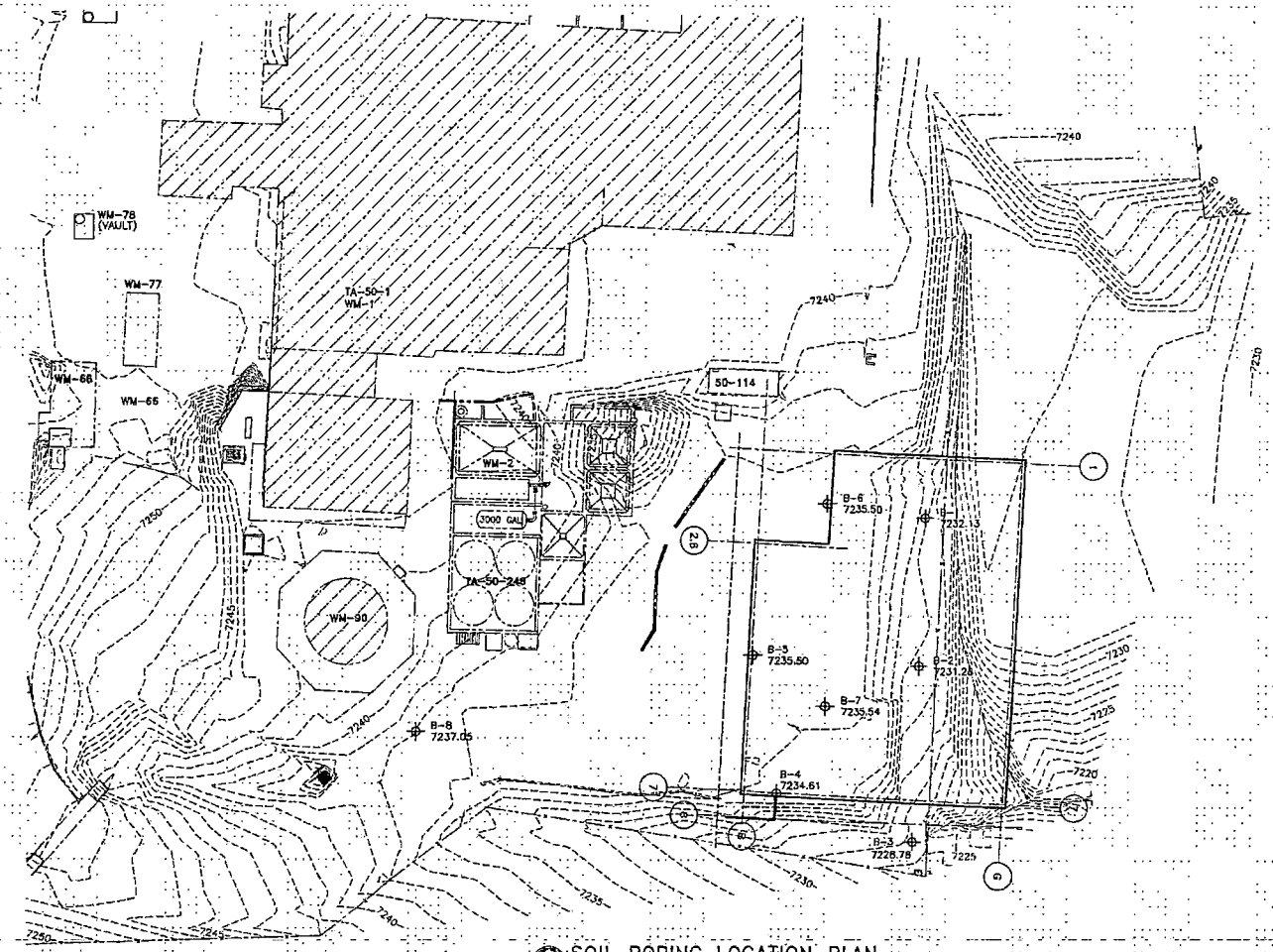
SUBMITTED D. MEADOWS
APPROVED FOR RELEASE J. NARUM

Los Alamos Los Alamos National Laboratory Los Alamos, New Mexico 87545

SHEET C8 38 OF 600

PROJECT ID
DRAWING NO. AB57
REV. 1

TA-50-250 WMRM
GEOTECHNICAL INVESTIGATION
SITE MAP AND BORE LOGS



SOIL BORING LOCATION PLAN
SCALE: 1"=20'-0"
20' 10' 0 10' 20'
1"=20'-0"

GENERAL NO. 3

1. SOIL BORINGS WERE DRILLED BY KLEINFELDER, INC. INFORMATION SHOWN HERE IS REPORTED IN GREATER DETAIL IN THE SOILS REPORT PREPARED BY KLEINFELDER, INC. JOB No. 59-0010145.001 AND DATED JANUARY 15, 2001, WHICH IS REPRODUCED IN THE SPECIFICATIONS OF THIS CONTRACT.
2. SUCH INFORMATION IS NOT A WARRANTY OF SUBSURFACE CONDITIONS AND MAY NOT REFLECT SUBSURFACE CONDITIONS OVER THE ENTIRE PROPOSED CONSTRUCTION AREA. THE CONTRACTOR SHALL BE RESPONSIBLE FOR HIS/HER INTERPRETATIONS AND USE OF THE INFORMATION. ALSO NOTE GENERAL PROVISIONS "SITE INVESTIGATION AND CONDITIONS AFFECTING THE WORK".
3. THE AVAILABILITY OR USE OF THE SOILS INVESTIGATION REPORT AND LOGS OF TEST BORINGS SHALL NOT BE CONSTRUED AS A WAVER OF THE CONTRACTORS DUTY TO EXAMINE THE SITE AND THE CONDITIONS AFFECTING THE WORK, AND DOES NOT RELIEVE THE CONTRACTOR FROM THE RISK OF SOIL OR SUBSURFACE CONDITIONS WHICH COULD REASONABLY BE ANTICIPATED OR FROM PROPERLY FULFILLING THE TERMS OF THE CONTRACT.
4. IF THIS SHEET IS NOT 24 X 36, THEN IT IS A REDUCED SIZE PLOT. USE GRAPHIC SCALE ACCORDINGLY.

NO	DATE	CLASS REV	DESCRIPTION	DRN	DES	CHKD	SUB	APP
0	10/07/04	U	ISSUED FOR CONSTRUCTION	SS	HC	DJM	DJM	JJ

THE AUSTIN COMPANY
CONSULTANTS ■ DESIGNERS ■ ENGINEERS ■ CONSTRUCTORS

TA-50 PUMP HOUSE AND INFLUENT STORAGE FACILITY

SOIL BORING LOCATION PLAN

BLDG 250 TA-50

DRAWN	S SHARP
DESIGN	D McGREGOR
CHECKED	H GOLBURN
DATE	10/07/04

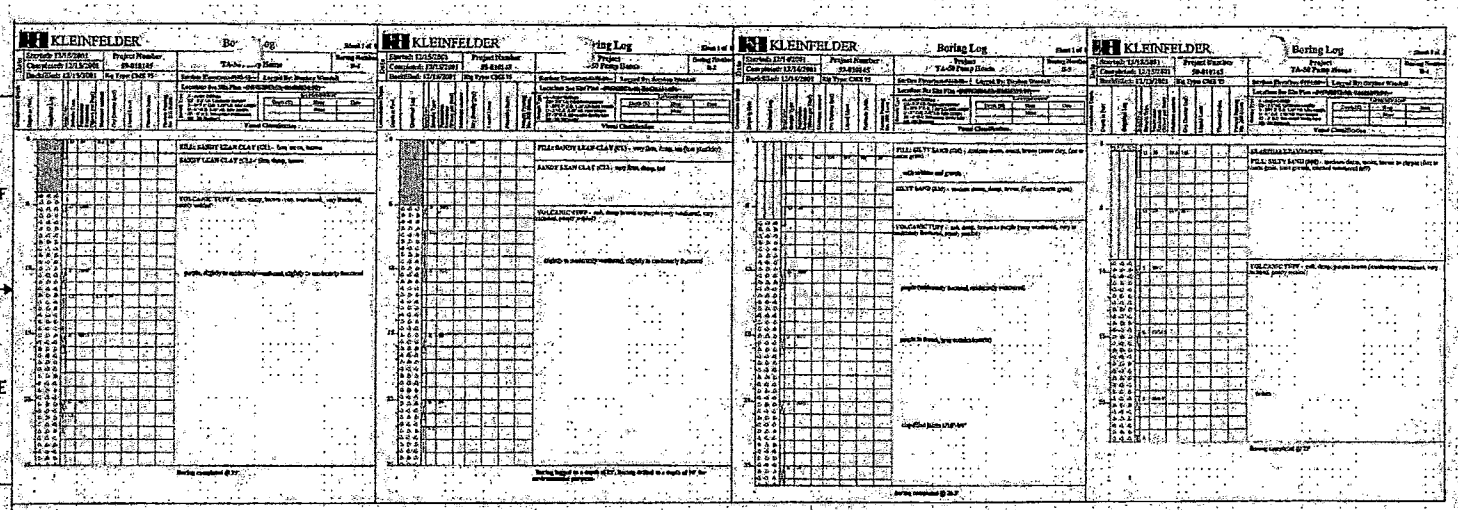
SUBMITTED
AUTHORITY TO RELEASE DAN MCGREGOR
APPROVED FOR RELEASE
PROJECT TEAM LEADER JIM JONES

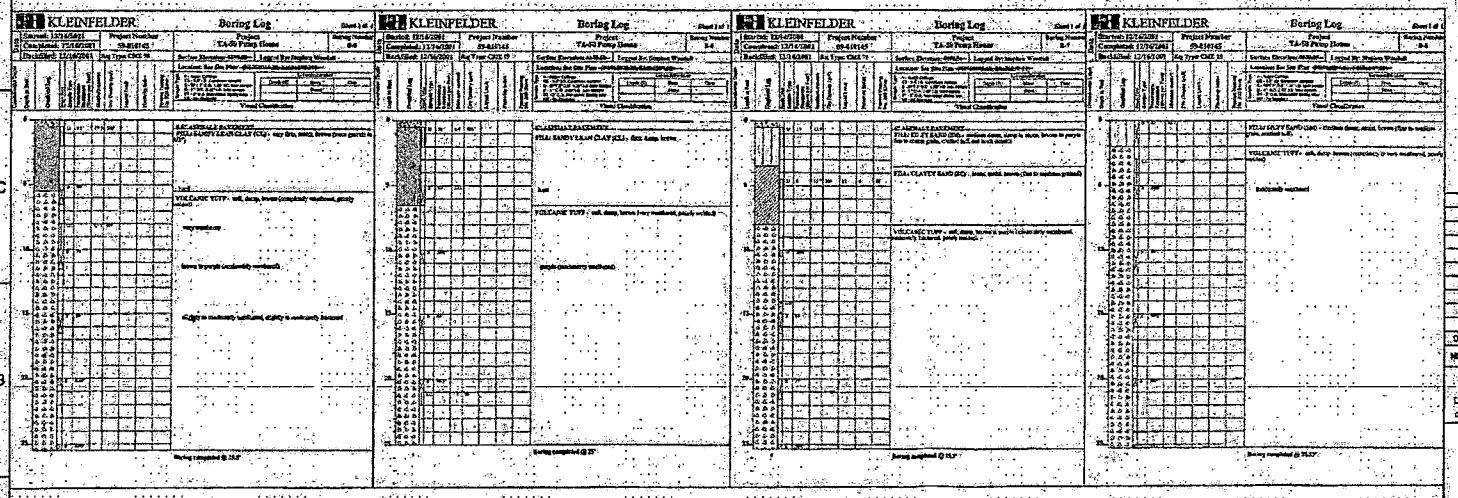
Los Alamos NATIONAL LABORATORY
PO Box 1663 Los Alamos, New Mexico 87545

SHEET C-1000
7 OF 194

CLASSIFICATION U
REVIEWED David Gardner DATE 10/13/04
PROJECT ID 100145
DRAWING NO. C53029
REV 0

10-8-04





GENERAL NOTES

1. SOIL BORINGS WERE DRILLED BY KLEINFELDER, INC. INFORMATION SHOWN HERE IS REPORTED IN GREATER DETAIL IN THE SOILS REPORT PREPARED BY KLEINFELDER, INC. JOB No. 59-0010145.001 AND DATED JANUARY 15, 2001, WHICH IS REPRODUCED IN THE SPECIFICATIONS OF THIS CONTRACT.
2. SUCH INFORMATION IS NOT A WARRANTY OF SUBSURFACE CONDITIONS AND MAY NOT REFLECT SUBSURFACE CONDITIONS OVER THE ENTIRE PROPOSED CONSTRUCTION AREA. THE CONTRACTOR SHALL BE RESPONSIBLE FOR HIS/HER INTERPRETATIONS AND USE OF THE INFORMATION. ALSO NOTE GENERAL PROVISIONS "SITE INVESTIGATION AND CONDITIONS AFFECTING THE WORK".
3. THE AVAILABILITY OR USE OF THE SOILS INVESTIGATION REPORT AND LOGS OF TEST BORINGS SHALL NOT BE CONSTRUED AS A WAIVER OF THE CONTRACTORS DUTY TO EXAMINE THE SITE AND THE CONDITIONS AFFECTING THE WORK, AND DOES NOT RELIEVE THE CONTRACTOR FROM THE RISK OF SOIL OR SUBSURFACE CONDITIONS WHICH COULD REASONABLY BE ANTICIPATED OR FROM PROPERLY FULFILLING THE TERMS OF THE CONTRACT.
4. BORING LOGS SHOWN HERE ARE ALSO INCLUDED IN VOL. 1 of 3 OF DESIGN SUBSTANTIATION DOCUMENTS UNDER SECTION #1.

REVISED BORING LOG COORDINATES AND ELEVATIONS

Exploratory Boring	Northing (ft)	Easting (ft)	Elevation (ft)
B-1	1769765.74710558	1627082.35742702	7232.13
B-2	1769712.58331194	1627060.12642983	7231.28
B-3	1769648.29452928	1627057.62530623	7228.76
B-4	1769655.15252320	1627007.67294858	7234.81
B-5	1769718.47504956	1626998.60893148	7235.50
B-6	1769771.00946131	1627025.72102702	7235.50
B-7	1769927.89671973	1627023.44090222	7235.84
B-8	1769688.84269021	1626975.27368144	7237.05

NO	DATE	CLASS REV	DESCRIPTION	DWN	DES	CHKD	SUB	APP
0	10/07/04	D	ISSUED FOR CONSTRUCTION	SS	RE	DM	DJB	JJ

THE AUSTIN COMPANY
CONSULTANTS in RESEARCH + ENGINEERS in CONSTRUCTION

TA-50 PUMP HOUSE AND INFLUENT STORAGE FACILITY

SOIL BORING LOGS

DRAWN	S SHARP
DESIGN	D McGREGOR
CHECKED	M COLBURN
DATE	10/07/04

BLDG. 250 TA-50

SUBMITTED: AUTHORITY TO RELEASE, DAN WICHART

APPROVED FOR RELEASE: PROJECT TEAM LEADER, JJ JONES

Los Alamos NATIONAL LABORATORY — PO Box 1663, Los Alamos, New Mexico 87545

SHEET C-1001

8 OF 194

CLASSIFICATION: U | REVIEWED: [signature] | DATE: 10/7/04

PROJECT ID: 100145 | DRAWING NO.: C53029 | REV: 0

05555

TA-52 ZERO LIQUID DISCHARGE (ZLD) SOLAR EVAPORATION TANKS

GEOTECHNICAL INVESTIGATION

BORE LOGS

DATE DRILLED: 6-13-11
LOCATION: See Location Diagram
ELEVATION: Not Determined

BORING NO. 1

EQUIPMENT TYPE: CME-75
DRILLING TYPE: 7"HSA
FIELD ENGINEER: S. DeWeese

MOISTURE CONTENT (% OF DRY WT.)	DRY DENSITY (LBS/CU FT)	SAMPLE TYPE	SAMPLE	BLOW COUNTS	DEPTH (FEET)	USCS	GRAPHIC	SOIL DESCRIPTION
4.2		N		23		SM		SILTY SAND; slightly clayey, very fine, light brown, medium dense, dry
3.0		N		65				TUFF; slightly weathered, light gray with some light brown, intensely fractured, thinly bedded, moderately hard, dry
3.9		N		88	5			
0.6		N		61				fresh, light gray, thickly bedded, hard
0.7		N		64	10			slightly weathered, some brown, thinly bedded, moderately hard
0.5		N		71	15			fresh, light gray, thickly bedded
1.2		N		50/4"	20			slightly weathered, some brown, very fractured, thinly bedded, hard
1.0		N		48	25			intensely fractured, moderately hard
								BORING TERMINATED AT 26.5 FEET

THIS SUMMARY APPLIES ONLY AT THIS LOCATION AND AT THE TIME OF LOGGING. CONDITIONS MAY DIFFER AT OTHER LOCATIONS AND MAY CHANGE AT THIS LOCATION WITH TIME. DATA PRESENTED IS A SIMPLIFICATION.

N- STANDARD PENETRATION TEST
R- RING SAMPLE
NR- NO SAMPLE RECOVERY
G- GRAB SAMPLE
B- BUCKET SAMPLE

NOTES: Groundwater Not Encountered

WESTERN TECHNOLOGIES INC.

PROJECT: ZERO LIQUID DISCHARGE PROJECT - LANL
REF. NO.: 3221JJ103

PLATE
A - 4

BORING LOG

05557

DATE DRILLED: 6-13-11
LOCATION: See Location Diagram
ELEVATION: Not Determined

BORING NO. 2

EQUIPMENT TYPE: CME-75
DRILLING TYPE: 7"HSA
FIELD ENGINEER: S. DeWeese

MOISTURE CONTENT (% OF DRY WT.)	DRY DENSITY (LBS/CU FT)	SAMPLE TYPE	SAMPLE	BLOW COUNTS	DEPTH (FEET)	USCS	GRAPHIC	SOIL DESCRIPTION
4.9		N		29		SM		SILTY SAND; slightly clayey, very fine, brown, medium dense, dry to slightly damp
3.7		G						
2.3		N		62				TUFF; fresh, light gray, intensely fractured, thickly bedded, moderately hard, dry
2.4		N		66	5			slightly weathered, hard
1.4		N		74				fresh
1.3		N		75	10			moderately hard
0.7		N		71	15			
0.3		N		47	20			
0.3		N		35	25			
								BORING TERMINATED AT 26.5 FEET

THIS SUMMARY APPLIES ONLY AT THIS LOCATION AND AT THE TIME OF LOGGING. CONDITIONS MAY DIFFER AT OTHER LOCATIONS AND MAY CHANGE AT THIS LOCATION WITH TIME. DATA PRESENTED IS A SIMPLIFICATION.

N- STANDARD PENETRATION TEST
R- RING SAMPLE
NR- NO SAMPLE RECOVERY
G- GRAB SAMPLE
B- BUCKET SAMPLE

NOTES: **Groundwater Not Encountered**

WESTERN TECHNOLOGIES INC.

PROJECT: ZERO LIQUID DISCHARGE PROJECT - LANL
REF. NO.: 3221JJ103

PLATE
A - 5

BORING LOG

05558

DATE DRILLED: 6-13-11
LOCATION: See Location Diagram
ELEVATION: Not Determined

BORING NO. 3

EQUIPMENT TYPE: CME-75
DRILLING TYPE: 7"HSA
FIELD ENGINEER: S. DeWeese

MOISTURE CONTENT (% OF DRY WT.)	DRY DENSITY (LBS/CU FT)	SAMPLE TYPE	SAMPLE	BLOW COUNTS	DEPTH (FEET)	USCS	GRAPHIC	SOIL DESCRIPTION
12.7		N		13		SM		SILTY SAND; with some clay, brown, loose, slightly damp
5.4		G						
13.6	89	R		50/5.5"				some tuff, brown with light gray, very dense
0.4		N		60	5			TUFF; fresh, light gray, intensely fractured, thinly bedded, moderately hard, dry
0.8		N		56				
1.5		N		43	10			
0.9		N		34	15			
13.6		N		20	20			slightly weathered, with clay interbedded, light gray with brown
27.2		N		14	25	CL		CLAY; with caliche, brown and tan, medium dense, damp
								BORING TERMINATED AT 26.5 FEET

N- STANDARD PENETRATION TEST
R- RING SAMPLE
NR- NO SAMPLE RECOVERY
G- GRAB SAMPLE
B- BUCKET SAMPLE

NOTES: **Groundwater Not Encountered**

THIS SUMMARY APPLIES ONLY AT THIS LOCATION AND AT THE TIME OF LOGGING. CONDITIONS MAY DIFFER AT OTHER LOCATIONS AND MAY CHANGE AT THIS LOCATION WITH TIME. DATA PRESENTED IS A SIMPLIFICATION.

WESTERN TECHNOLOGIES INC.

PROJECT: ZERO LIQUID DISCHARGE PROJECT - LANL
REF. NO.: 3221JJ103

PLATE
A - 6

BORING LOG : 05569

DATE DRILLED: 6-13-11
LOCATION: See Location Diagram
ELEVATION: Not Determined

BORING NO. 4

EQUIPMENT TYPE: CME-75
DRILLING TYPE: 7"HSA
FIELD ENGINEER: S. DeWeese

MOISTURE CONTENT (% OF DRY WT.)	DRY DENSITY (LBS/CU FT)	SAMPLE TYPE	SAMPLE	BLOW COUNTS	DEPTH (FEET)	USCS	GRAPHIC	SOIL DESCRIPTION
7.0		N		32		SM		SILTY SAND; with some clay and caliche, brown and tan, dense, dry to slightly damp
3.9		G						
4.3		N		49				TUFF; fresh, light gray, intensely fractured, thinly bedded, moderately hard, dry
1.4		N		55	5			
1.5		N		80				
2.8		N		67	10			
0.1		N		50/6"	15			
0.3		N		76	20			
0.1		N		44	25			
								BORING TERMINATED AT 26.5 FEET

THIS SUMMARY APPLIES ONLY AT THIS LOCATION AND AT THE TIME OF LOGGING. CONDITIONS MAY DIFFER AT OTHER LOCATIONS AND MAY CHANGE AT THIS LOCATION WITH TIME. DATA PRESENTED IS A SIMPLIFICATION.

N- STANDARD PENETRATION TEST
R- RING SAMPLE
NR- NO SAMPLE RECOVERY
G- GRAB SAMPLE
B- BUCKET SAMPLE

NOTES: Groundwater Not Encountered

WESTERN TECHNOLOGIES INC.

PROJECT: ZERO LIQUID DISCHARGE PROJECT - LANL
REF. NO.: 3221JJ103

PLATE
A - 7

BORING LOG : 05560

DATE DRILLED: 6-13-11
LOCATION: See Location Diagram
ELEVATION: Not Determined

BORING NO. 5

EQUIPMENT TYPE: CME-75
DRILLING TYPE: 7"HSA
FIELD ENGINEER: S. DeWeese

MOISTURE CONTENT (% OF DRY WT.)	DRY DENSITY (LBS/CU FT)	SAMPLE TYPE	SAMPLE	BLOW COUNTS	DEPTH (FEET)	USCS	GRAPHIC	SOIL DESCRIPTION
4.9		N		32		SM		SILTY SAND; with some clay, brown, dense, slightly damp
5.0		G						
2.8		N		45				TUFF; fresh, light gray, intensely fractured, thinly bedded, moderately hard, dry
0.9		N		51	5			
1.0		N		49				
0.9		N		57	10			
1.4		N		72	15			
1.7		N		50/6"	20			
1.6		N		71	25			
								BORING TERMINATED AT 26.5 FEET

THIS SUMMARY APPLIES ONLY AT THIS LOCATION AND AT THE TIME OF LOGGING. CONDITIONS MAY DIFFER AT OTHER LOCATIONS AND MAY CHANGE AT THIS LOCATION WITH TIME. DATA PRESENTED IS A SIMPLIFICATION.

N- STANDARD PENETRATION TEST
R- RING SAMPLE
NR- NO SAMPLE RECOVERY
G- GRAB SAMPLE
B- BUCKET SAMPLE

NOTES: Groundwater Not Encountered

WESTERN TECHNOLOGIES INC.

PROJECT: ZERO LIQUID DISCHARGE PROJECT - LANL
REF. NO.: 3221JJ103 .

PLATE
A - 8

BORING LOG : 05561

PLAN AND MAP VIEWS

STRATIGRAPHIC UNITS BENEATH MDA C

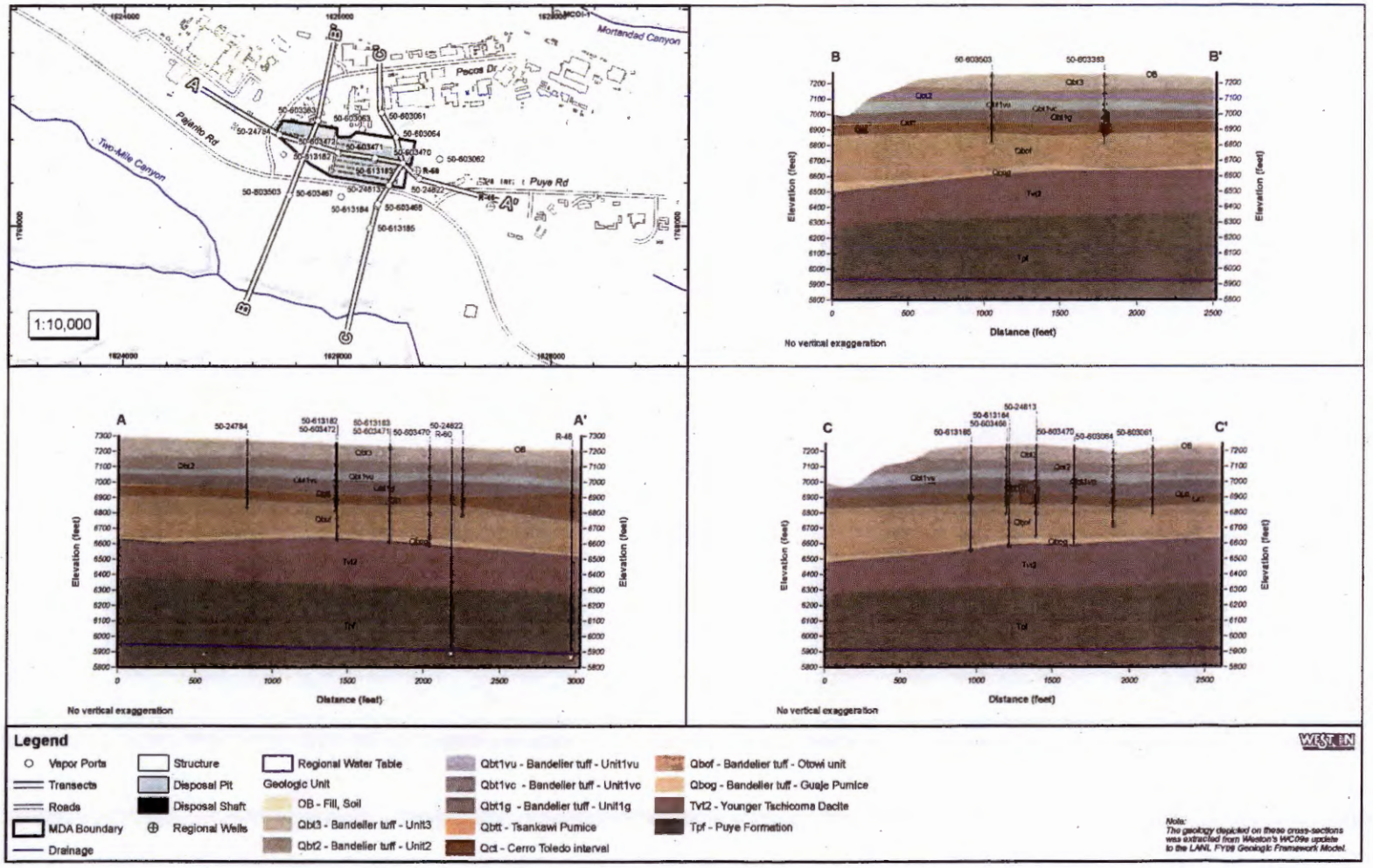


Figure 4.3-2 Plan and map views of stratigraphic units beneath MDA C. Also included are the locations of vapor-monitoring wells and ports as well as regional wells R-60 and R-46 and their well screen locations

05563

APPENDIX G

CONTIGENCY PLAN

TA-50 RLWTF CONTINGENCY PLAN – DP-1132

PER THE JANUARY 27, 2012 NMED LETTER

(SEE APPENDIX A) GRANTING A 45-DAY EXTENSION,

THIS ITEM WILL BE ADDRESSED AND INFORMATION WILL BE SUBMITTED TO NMED UNDER SEPARATE COVER BY APRIL 2, 2012.

APPENDIX H

CLOSURE PLAN

TA-50 Radioactive Liquid Waste Treatment Facility (RLWTF)

Groundwater Discharge Permit Application (DP-1132)

Closure Plan and Post-Closure Monitoring

I. Closure

In the event that operations at the RLWTF should cease, and the facility is proposed to be permanently closed, the Permittees shall perform the following closure measures for systems of treatment and control associated with the facility:

- The collection system shall be decontaminated, and removed or plugged so that a discharge to the RLWTF can no longer occur.
- Wastewater shall be drained from the system components and disposed of in accordance with all local, state, and federal regulations.
- Disconnect and/or plug piping, tanks, and treatment units that could allow a discharge or leak of liquid wastewater.
- Solids shall be disposed of from treatment units and tanks, including, influent tanks, feed tanks, clarifiers, effluent tanks, wastewater storage tanks and other units. Removed solids shall be contained, transported, and disposed of in accordance with all local, state, and federal regulations. The Permittees shall maintain a record of all solids transported for off-site disposal.
- Tanks and components shall be removed and disposed of according to applicable local, state, and federal laws. Provided such tanks and components are not required to meet other local, state, or federal requirements. Re-grade the area with suitable fill to blend with surface topography and promote positive drainage to prevent ponding.
- In the event that evidence of leakage from piping, tanks, or treatment units is discovered during closure activities, the Permittees shall implement the contingency plan required by this Discharge Permit.

05567

II. Post-Closure

1. Permittees shall continue to monitor groundwater wells as identified in the Discharge Permit, and at the same frequency required by the Discharge Permit for at least five years after closure.
2. If monitoring results show that a groundwater quality standard in Section 20.6.2.3103 NMAC are being exceeded; the Permittee shall implement the contingency plan required by this Discharge Permit.
3. Following notification from NMED that post-closure monitoring may cease, the Permittees may plug and abandon the monitoring well(s) provided that such monitoring wells are not required to meet another regulatory program, including the 2005 Order on Consent.
4. When all closure and post-closure requirements have been met, the Permittees may submit a written request for termination of the Discharge Permit to NMED.

[NMSA 1978, § 74-6-5.D, Subsection B of 20.6.2.3109 NMAC, Subsection A of 20.6.2.3107.

III. Reporting and Record-Keeping

1. After closure activities, the Permittees shall submit a Closure Report containing the following:
   a) Verification (photographic or narrative) that lines leading to the tanks and other units have been plugged or removed so that a discharge can no longer occur.
   b) A description of the volume and mass (dry weight) of residual solids removed from the tanks and other units and the ultimate disposal of the solids.
2. Permittees shall submit records of activities required for closure and post-closure as set forth in this Permit.

[NMSA 1978, § 74-6-5.D, Subsection B of 20.6.2.3109 NMAC, Subsection A of 20.6.2.3107 NMAC]

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APPENDIX I

REFERENCED DOCUMENTS

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1. COMPACT DISC (CD) CONTAINING THE FOLLOWING DOCUMENTS:

   - LOS ALAMOS NATIONAL LABORATORY'S HYDROGEOLOGIC STUDIES OF THE PAJARITO PLATEAU: A SYNTHESIS OF HYDROGEOLOGIC WORKPLAN ACTIVITIES (1994-2004). LA-14263-MS.
   - 2009 HYDROGEOLOGIC SITE ATLAS. LAUR-09-3763.
   - GROUNDWATER LEVEL STATUS REPORT FOR 2010 LOS ALAMOS NATIONAL LABORATORY. LA-14437-PR.
   - CONCEPTUAL MODELS OF VADOSE ZONE FLOW AND TRANSPORT BENEATH THE PAJARITO PLATEAU, LOS ALAMOS, NEW MEXICO. VADOSE ZONE JOURNAL, VOL. 4, AUGUST 2005.
   - NRCS SOIL SURVEY OF SANDOVAL COUNTY AREA, NEW MEXICO, PARTS OF LOS ALAMOS, SANDOVAL, AND RIO ARRIBA COUNTIES.
   - 2006 MORTANDAD CANYON INVESTIGATION REPORT. LA-UR-06-6752
   - 2011 INTERIM FACILITY-WIDE GROUNDWATER MONITORING PLAN, REVISION 1. LA-UR-11-6958.

2. COMPACT DISC (CD) CONTAINING THE FOLLOWING DOCUMENT:
   - ENVIRONMENTAL SURVEILLANCE AT LOS ALAMOS DURING 2010. LA-14445-ENV.

APPENDIX J

MAPS

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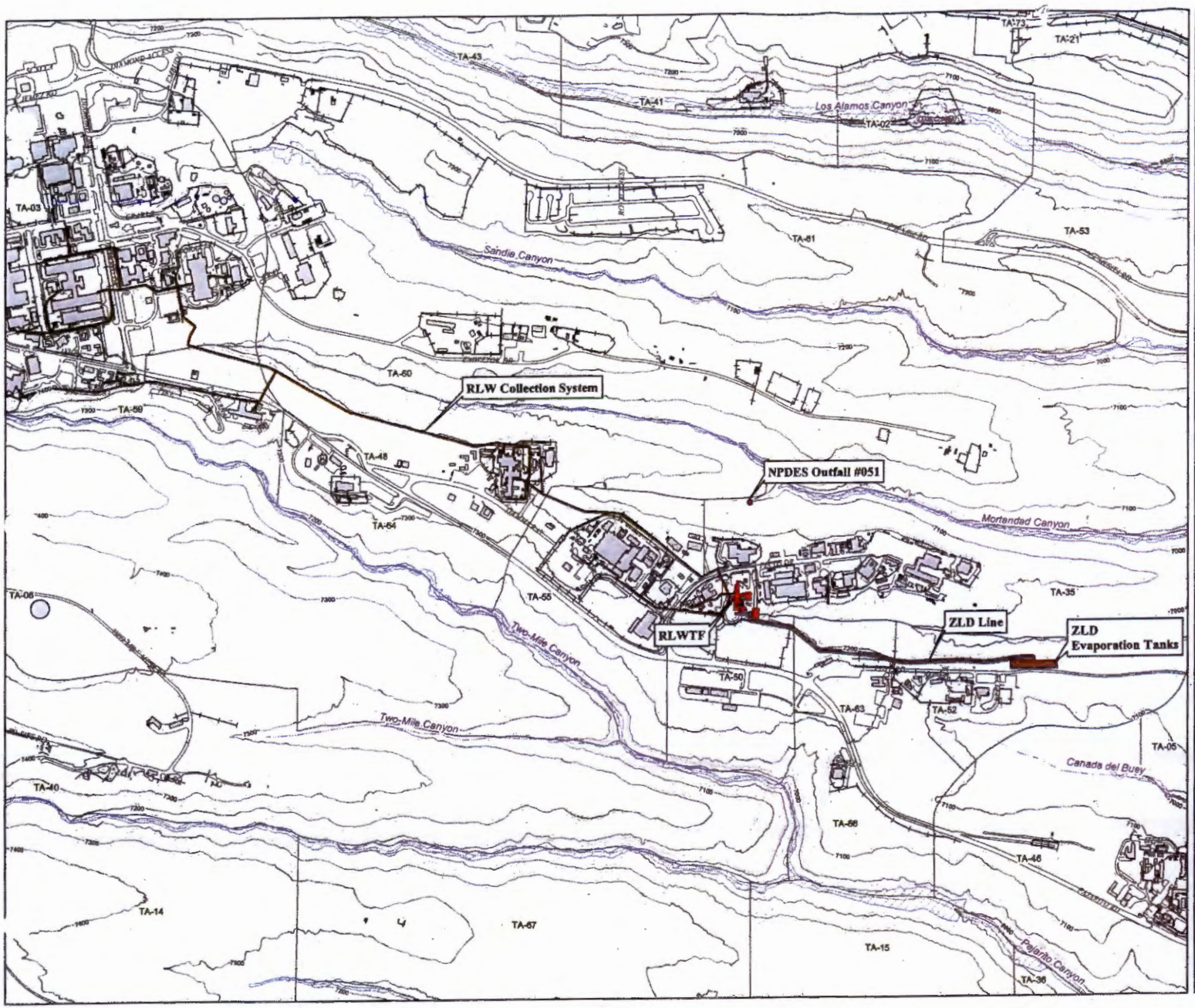
2. MAP #2 - TA-50 RLWTF, RLW COLLECTION SYSTEM, NPDES OUTFALL #051, TA-52 ZLD SOLAR EVAPORATION TANKS, AND 100-YEAR FLOOD PLAIN

3. MAP #3 - LANL SOILS MAP

4. MAP #4 - TA-50 RADIOACTIVE LIQUID WASTE TREATMENT FACILITY (RLWTF), STORM DRAIN SYSTEM MAP

MAP #1

: 05571



TA-50 RL TF, RLW Collection System, NPDES Outfall 051, ZLD Evaporation Tanks, and the 100-Yr Floodplain

- NPDES Outfall 051051
- Fences
- Drainages
- Paved roads
- RLW Collection system
- ZLD line
- ZLD Evaporation tanks
- RLWTF buildings
- Structures
- Technical areas
- 100-year floodplain

N

Feet
0 312.5 625 1,250 1,875 2,500

0 125 250 500 750 1,000
Meters

1:12,000

State Plane Coordinate System
New Mexico, Central Zone, US Feet
NAD 1983 Datum, NGVD 1929

Map Created By: Winters Red Star
Map #12-0009-03 17 JANUARY 2012

MAP #2
LA-UR-12-00672
ENV-DO-12-0005

DATA SOURCE:

ER Project Locations; Los Alamos National Laboratory, ESH&Q Waste and Environmental Services Division, erPL4-20110821; 1:2,500 Scale Data; 04 August 2011.

Hypsography, 100, 20,10 Feet Contour Interval; Los Alamos National Laboratory, ENV Environmental Remediation and Surveillance Program; 1991.

Paved Road Area; Los Alamos National Laboratory, KSL Site Support Services, Planning, Locating and Mapping Section; 05 January 2004; as published 29 November 2010.

Security and Industrial Fences and Gates; Los Alamos National Laboratory, KSL Site Support Services, Planning, Locating and Mapping Section; 05 January 2004; as published 29 November 2010.

Structures; Los Alamos National Laboratory, KSL Site Support Services, Planning, Locating and Mapping Section; 05 January 2004; as published 29 November 2010.

Technical Area Boundaries; Los Alamos National Laboratory, Site Planning & Project Initiation Group, Infrastructure Planning Office; September 2007; as published 13 August 2010.

WQH Drainage_arc; Los Alamos National Laboratory, ENV Water Quality and Hydrology Group; 1:24,000 Scale Data; 03 June 2003.

ZLD line and tank; Los Alamos National Laboratory,ENV DATA AND ANALYSIS Group, X:\Projects\11-Projects\11-008\DATA\Digitized VLD_LINES_01112012\VLD_TANK.shp; 11 January 2012

Disclaimer: This map was created for work processes associated with the Water Quality & RCRA. All other uses for this map should be confirmed with LANL ENV-RCRA

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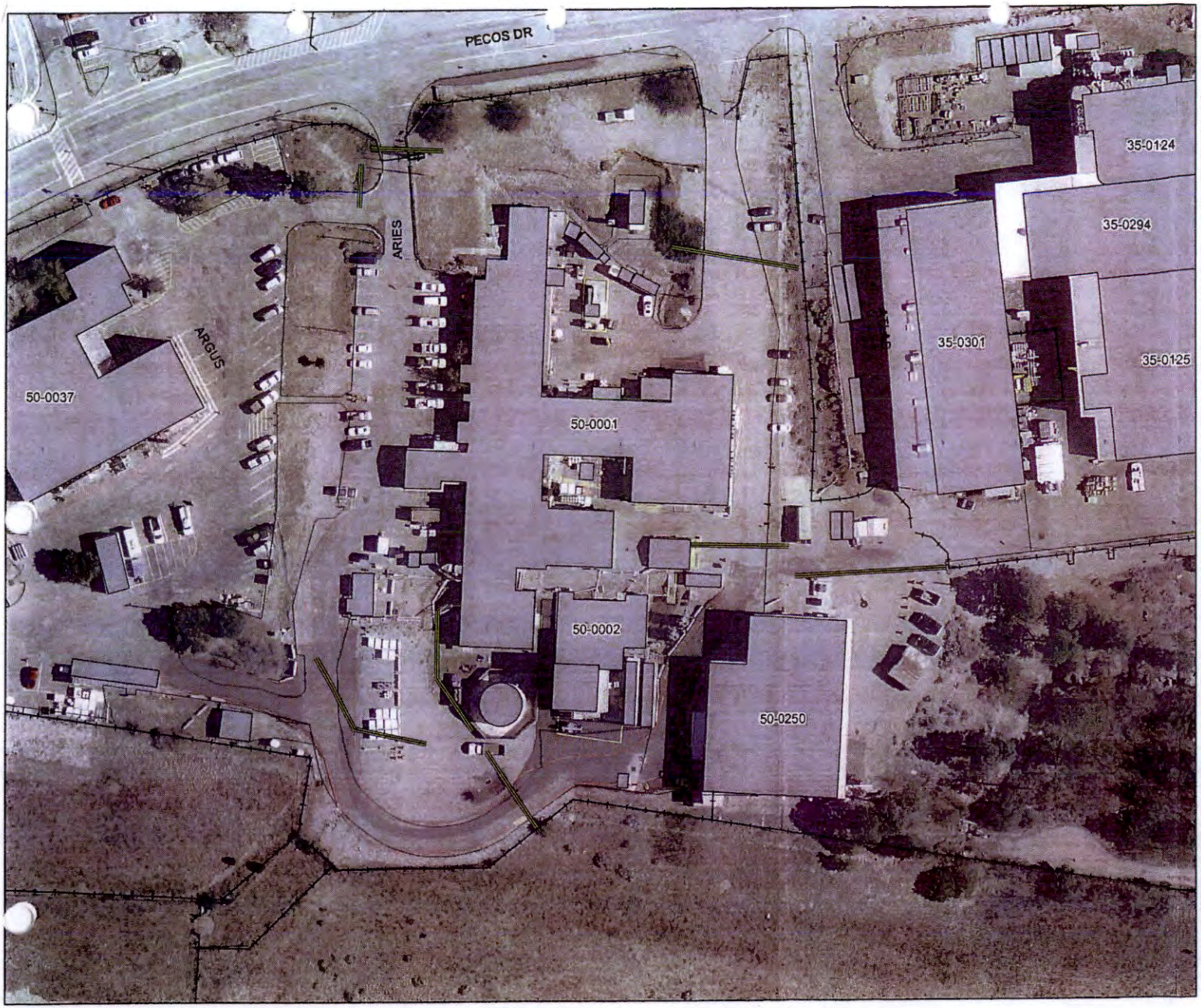
MAP #3



TA-50
Radioactive Liquid Waste Treatment Facility (RLWTF), Storm Drain System

Storm drain
Fences
Paved Roads
Structures

N

Feet
0 25 50 100 150 200

0 5 10 20 30 40
Meters

1:800

Map Created By: Winters Red Star
Map #12-0009-01 11 JANUARY 2012

State Plane Coordinate System
New Mexico, Central Zone, US Feet
NAD 1983 Datum

MAP #4
LA-UR-12-00672
ENV-DO-12-0005

DATA SOURCE:

Paved Road Arcs: Los Alamos National Laboratory, KSL Site Support Services, Planning, Locating and Mapping Section; 06 January 2004; as published 29 November 2010.

Orthophotography, 2011 Los Alamos National Laboratory Aerial Photography, Site Planning and Project Initiation Group, APRIL 2011.

Security and Industrial Fences and Gates; Los Alamos National Laboratory, KSL Site Support Services, Planning, Locating and Mapping Section; 06 January 2004; as published 29 November 2010.

Storm Drain Line Distribution System; Los Alamos National Laboratory, KSL Site Support Services, Planning, Locating and Mapping Section; 06 January 2004; as published 29 November 2010.

Structures; Los Alamos National Laboratory, KSL Site Support Services, Planning, Locating and Mapping Section; 06 January 2004; as published 29 November 2010.

Disclaimer: This map was created for work processes associated with the Water Quality & RCRA
All other uses for this map should be confirmed with LANL ENV-RCI

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1 of 7

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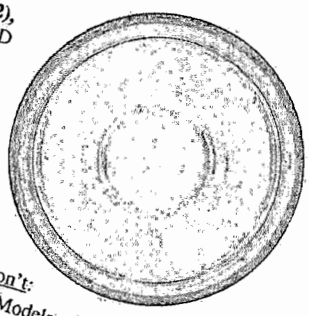
Hydrogeologic Studies LA-14263-MS.
Hydrogeologic Site Atlas. LAUR-09-3763.
Groundwater Level Status Rpt. LA-14437-PR.

Discharge Permit Application (DP-1132),
RLWTF and TA-52 ZLD
ENV-DO-12-0005;
LAUR-12-00672
UNCLASSIFIED



Los Alamos
NATIONAL LABORATORY
Los Alamos NM 87545

Contents Con't:
Conceptual Models of Vadose Zone Vadose Zone Journal, Vol. 4, August 2005.
NRCS Soil Survey.
Mortandad Canyon Investigation Report. LA-UR-06-6752
Groundwater Monitoring Plan. LA-UR-11-6958.

LA-14263-MS
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Los Alamos National Laboratory's Hydrogeologic Studies of the Pajarito Plateau:

A Synthesis of Hydrogeologic Workplan Activities (1998–2004)

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Issued: December 2005

Los Alamos National Laboratory's Hydrogeologic Studies of the Pajarito Plateau:

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Edited by:
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Bruce A. Robinson
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05578

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This report culminates the implementation of the Hydrogeologic Workplan, approved by the New Mexico Environment Department in March 1998. The Workplan was sponsored by the U.S. Department of Energy and the University of California. It was written by an interdisciplinary group of contributing authors representing various Los Alamos National Laboratory divisions, programs, and projects. Many of these individuals were also contributing authors of this Hydrogeologic Synthesis Report. These authors were members of the Groundwater Integration Team (GIT) that was created to implement the Hydrogeologic Workplan.

Over the past eight years, many individuals, too numerous to mention, contributed to studies performed under the Workplan. In particular, contributions made by the GIT members were significant and are much appreciated. The leadership of Charles Nylander as Program Manager throughout the history of the Workplan is appreciated, as is the technical oversight provided by Bruce Robinson. The Hydrogeologic Synthesis Report was much improved by reviews by Alice Barr, Al Eddebbarh, June Fabryka-Martin, Don Hickmott, Ellen Louderbough, Everett Springer, and Ardyth Simmons. In addition, significant peer review of the Hydrogeologic Synthesis Report was provided by External Advisory Group (EAG) members, who were professionally involved in implementation of the Hydrogeologic Workplan, and their contributions are appreciated. The EAG members are Robert Charles, Elizabeth Anderson, Charles McLane, David Schafer, Robert Powell, and Jack Powers. We thank the staff of the Daniel B. Stephens and Associates Visual Resources Group for improving the quality of figures. Finally, the professional contributions made by Ardyth Simmons and Kelly Collins in completing the compilation and editing of this document are appreciated.

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Los Alamos National Laboratory's Hydrogeologic Studies of the Pajarito Plateau: A Synthesis of Hydrogeologic Workplan Activities (1998–2004)

edited by

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ABSTRACT

This report provides a comprehensive description of the hydrogeologic setting beneath the Pajarito Plateau and Los Alamos National Laboratory (LANL). It is based on interpretative synthesis of hydrogeologic and geochemical data collected through December 2004. Since 1998, twenty-five regional aquifer wells and six intermediate-zone wells have been completed for hydrogeologic characterization. Characterization of the hydrogeologic setting was undertaken in order to fulfill regulatory requirements for characterization and monitoring. This report provides the data and information necessary to evaluate the existing monitoring network and, if necessary, to design an enhanced monitoring network.

Los Alamos National Laboratory (LANL) is situated on the Pajarito Plateau, located within the Española Basin section of the Rio Grande Rift. The Española Basin, as well as the Pajarito Plateau on its western edge, is filled with Miocene and Pliocene-age sediments and volcanic rocks. The topographic plateau is formed by Pleistocene Bandelier Formation ash-flow tuffs from the Jemez volcanic field, which cover the basin-fill sediments.

Groundwater occurs in three settings beneath the Pajarito Plateau: alluvial groundwater, intermediate-perched saturated zones, and the regional aquifer. Alluvial groundwater occurs to a limited and variable extent in the alluvium lining canyon bottoms. Alluvial groundwater provides pathways for LANL-derived contamination introduced into canyons to migrate to significant lateral distances and infiltrate to greater depths.

Flow and transport of water in the vadose zone varies by rock type. Most of the plateau is covered with nonwelded to moderately welded Tshirege and Otowi Member ash-flow tuffs of the Bandelier Tuff. Unsaturated flow and transport through these nonwelded to moderately welded tuffs occurs predominantly through the porous matrix. On the western edge of the plateau, both fracture and matrix-dominated flow can occur, depending on the degree of welding (or matrix conductivity) of the tuff. In contrast to the flow behavior in the Bandelier Tuff units, much of the vadose zone flow through the basalt units is almost certainly fracture dominated. Beneath the Pajarito Plateau, perched water bodies in the vadose zone may be important components of subsurface pathways that facilitate movement of contaminated fluids from the ground surface to the water table of the

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regional aquifer. Perched water is most often found in Puye fanglomerates, the Cerros del Rio basalt, and in units of the Bandelier Tuff.

The regional aquifer beneath the Pajarito Plateau is part of an aquifer which extends throughout the Española Basin (an area roughly 6000 km2). This aquifer is the primary source of water for the Laboratory, the communities of Santa Fe, Española, Los Alamos, and numerous pueblos. The sources of recharge to the regional aquifer are diffuse recharge in the Sierra de los Valles and focused recharge from wet canyons on the Pajarito Plateau. Natural discharge from the regional aquifer is primarily into the Rio Grande directly or to springs that flow into the Rio Grande. The aquifer is under water-table conditions across much of the Plateau, but exhibits more confined aquifer behavior near the Rio. Hydraulic properties are highly anisotropic, with vertical hydraulic conductivities much smaller than horizontal hydraulic conductivites, resulting in a muted response at the water table to supply-well pumping at greater depths. Flow modeling simulations suggest that flow beneath the Rio Grande (west to east) has been induced by production at the Buckman wellfield just east of the Rio Grande, which supplies the city of Santa Fe. Because of the heterogeneous nature of the aquifer, groundwater velocity varies considerably over short distances. The fastest velocities are in the basalts where fracture flow is assumed.

Imprinted on the natural variations in chemistry along flowpaths is the presence of contaminants historically released since the early 1940s when Laboratory operations commenced. The impacts to groundwater at the Laboratory have occurred mainly where effluent discharges have caused increased infiltration of water. The movement of groundwater contaminants is best seen through the distribution of conservative (that is, non-reactive) chemical species. Under many conditions, compounds like RDX, tritium, perchlorate, and nitrate move readily with the groundwater. In many settings, chemical reactions do not retard the movement of these compounds or decrease their concentrations, although the activity of tritium does decrease due to radioactive decay. For some compounds or constituents (uranium, strontium-90, barium, some HE compounds, and solvents), movement is slowed or their concentrations are decreased by adsorption or cation exchange, precipitation or dissolution, chemical reactions like oxidation/reduction, or radioactive decay. Other constituents (americium-241, plutonium, and cesium-137) are nearly immobile because they are strongly adsorbed onto sediment particles.

The distribution of tritium in the regional aquifer supports the conceptual model that surface effluent discharges have caused the cases where Laboratory contaminants are found at depth. In most cases, the highest regional aquifer tritium values are found near where effluent discharges have occurred, but are much lower than values observed in overlying alluvial or intermediate perched groundwater. The lower regional aquifer values may be due to dilution of recharge by other groundwater sources as well as radioactive decay due to recharge times of decades.

The conceptual models of the hydrologic system beneath the Pajarito Plateau have been translated into numerical models. A site-wide model for performing first-order analysis of travel time through the vadose zone across the entire Pajarito Plateau was used to identify areas where contaminant pathways are likely to exist. Results indicated that the predicted travel times on mesas are variable, but for the

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most part are greater than 1000 years, ranging from 1000–5000 years in the eastern portions of the Laboratory to 20,000 to 30,000 years in the western region. Two factors control these results: infiltration rate and hydrostratigraphy. Generally, travel times less than 100 years are predicted in the portions of canyons with net infiltration of 300 mm/yr to 1000 mm/yr, especially in locations where the Bandelier Tuff is thin.

The regional aquifer model has been applied to predict fate and transport of contaminants in the regional aquifer, in order to optimally place monitoring wells and inform risk assessment studies; and to provide guidance in prioritization of data collection activities.

Armed with the understanding gained from the Hydrogeologic Workplan activities, it is now possible to develop improved groundwater monitoring strategies or conduct more cost-effective detailed studies of individual canyons where initial studies have suggested that groundwater risk may exist.

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1.0 INTRODUCTION

This report provides a comprehensive description of the hydrogeologic setting beneath the Pajarito Plateau and Los Alamos National Laboratory (LANL). It is based on interpretative synthesis of hydrogeologic data collected through December, 2004. Characterization of the hydrogeologic setting was undertaken in order to fulfill regulatory requirements for characterization and monitoring. This report provides the data and information necessary to evaluate the existing monitoring network and, if necessary, to design an enhanced monitoring network. Monitoring network evaluation and design are not addressed in this report. Recommendations included in this report are for scientific interest only, and are not necessary to comply with the regulatory requirements.

LANL is located in Los Alamos, Santa Fe, and Sandoval counties of north-central New Mexico, roughly 25 mi northwest of Santa Fe (Figure 1-1). It is owned by the Department of Energy (DOE) and co-operated by DOE and the University of California (UC). Work at LANL began in 1943 with the mission to design, develop, and test nuclear weapons.

Beginning in 1945, the US Geological Survey (USGS) became involved in various studies to develop the water supply at LANL (LANL 1995). Special studies to protect and monitor groundwater quality were initiated by LANL in 1949. Thus, groundwater monitoring has been conducted at LANL for over 50 years. The first monitoring network was limited to the water supply wells, a handful of test wells, and springs. The monitoring network evolved as environmental programs, such as those managed by LANL's Environmental Restoration (ER) organization (now Environmental Stewardship—Environmental Remediation & Surveillance Program [ENV-ERS]), added more wells, primarily in the shallow alluvial systems, as potential monitoring points.

In 1997, LANL personnel began a site-wide hydrogeologic characterization program, which is described in the Hydrogeologic Workplan (LANL 1998). The primary objective of the characterization program was to sufficiently refine the understanding of the hydrogeologic systems so that, if appropriate, an enhanced monitoring network could be designed. The Hydrogeologic Workplan was implemented, resulting in installation of 25 regional aquifer wells. Data from sampling and measurements taken at these wells have provided information about the subsurface geologic environment, including the vadose zone and intermediate perched and regional aquifer groundwater. This report is a synthesis of data from Hydrogeologic Workplan activities and all other groundwater-related investigations conducted at LANL since 1997. Collection and analysis of groundwater data is ongoing at LANL, associated with site-specific (not site-wide) investigations. It is considered unlikely that information from wells drilled after December 2004 will significantly change the understanding of the site-wide hydrogeologic setting described in this report. In some cases, analysis and interpretation of data lags behind data collection, and what is presented here does not include analysis of all data collected up to December 2004. Analysis of the data collected as part of the site-wide characterization has sufficiently improved the understanding of the hydrogeologic system and the ability to design and implement an integrated site-wide groundwater monitoring program.

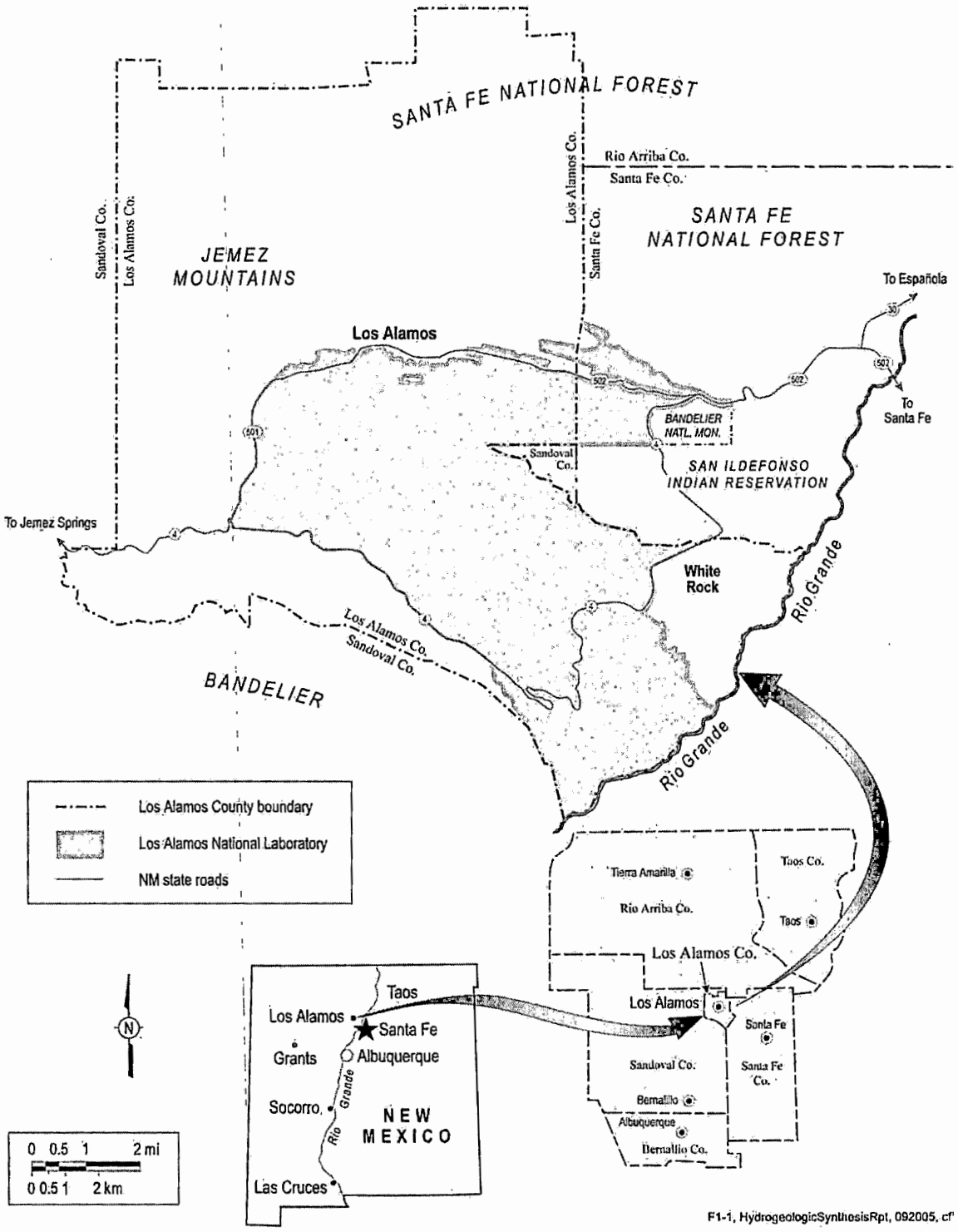

Figure 1-1. Location of Los Alamos National Laboratory.

1.1 Technical Objectives of the Hydrogeologic Workplan

The primary technical objective of the Hydrogeologic Workplan was to collect data necessary to evaluate and, if necessary, enhance the groundwater monitoring network at LANL. The technical objectives of the Hydrogeologic Workplan were intended to be comprehensive with respect to groundwater regulatory requirements for characterization and monitoring, described in Appendix 1-A. The regulatory requirements included

- Resource Conservation and Recovery Act (RCRA) operating permit which requires monitoring for RCRA units, unless a groundwater monitoring waiver is demonstrated.
- New Mexico Environment Department (NMED) letters requiring a better understanding of the hydrogeologic regime in order evaluate groundwater monitoring waivers submitted by LANL.
- RCRA permits Hazardous and Solid Waste Amendments (HSWA) module requirements to characterize the hydrogeologic setting.

Specifically, NMED identified four issues that needed to be resolved in order to evaluate the groundwater monitoring waivers submitted by LANL (Appendix 1-A):

- Individual zones of saturation beneath LANL had not been adequately delineated and the "hydraulic interconnection" between these was not understood.
- The recharge area(s) for the regional and intermediate aquifers and any associated effects of fracture-fault zones with regard to contaminant transport and hydrology had not been identified.
- The groundwater flow direction(s) of the regional aquifer and intermediate aquifers, as influenced by pumping of production wells, were unknown.
- Aquifer characteristics could not be determined without additional monitoring wells installed within specific intervals of the various aquifers beneath the facility.

Table 1-1 is a crosswalk of HSWA module requirements for groundwater characterization, how they have been addressed, and which sections of this report contain that information.

1.2 Hydrogeologic Characterization Overview

In order to establish the data quality objectives that guided the development of the Hydrogeologic Workplan (LANL 1998), the information needed to evaluate and design a monitoring network was articulated. Groundwater at LANL occurs in three modes: alluvial, perched intermediate groundwater in the vadose zone, and the regional aquifer. Figure 1-2 shows the relationship between the Pajarito Plateau topography and modes of groundwater. In general, to monitor the quality of water that has the potential to be impacted by releases of hazardous or radioactive wastes, there must be an understanding of the following:

Table 1-1.
Crosswalk Between HSWA Permit Requirements* and Synthesis Report Section

HSWA Permit Reference	Permit Requirement	Synthesis Report Sections
Task III.A.1.a	A description of the regional and facility specific geologic and hydrogeologic characteristics affecting groundwater flow beneath the facility	Section 2.2, Section 2.4
Task III.A.1.b	An analysis of any topographic features that might influence the groundwater flow system	Section 2.1.3
Task III.A.1.c	An analysis of fractures within the tuff, addressing tectonic trend fractures versus cooling fractures	Section 2.5.4
Task III.A.1.d	Based on field data, tests, (gamma and neutron logging of existing and new wells, piezometers, and borings) and cores, a representative and accurate classification and description of the hydrogeologic units which may be part of the migration pathways at the facility (e.g., the aquifers and any intervening saturated and unsaturated units)	Section 2.3; Section 4.2.12
Task III.A.1.e	Based on field studies and cores, structural geology and hydrogeologic cross sections showing the extent (depth, thickness, lateral extent) of hydrogeologic units which may be part of the migration pathway identifying Unconsolidated sand and gravel deposits Zones of fracturing or channeling in consolidated and unconsolidated deposits Zones of high or low permeability that might direct and restrict the flow of contaminants	Section 2.3; Section 4.1.2; Section 4.2.12
Task III.A.1.f	Based on data obtained from groundwater monitoring wells and piezometers installed upgradient and downgradient of the potential contaminant source, a representative description of water level or fluid pressure monitoring	Section 2.4.2
Task III.A.1.g	A description of manmade influences that may affect the hydrogeology of the site	Section 2.7.6
Task III.A.1.h	Analysis of available geophysical information and remote sensing information such as infrared photography and Landsat imagery	Appendix 2-A
Task III.A.2.d	Characterize rock and soil units above the water table including saturated hydraulic conductivity	Section 2.2, Section 2.3, Section 2.4.1
Task III.A.2.e	Characterize rock and soil units above the water table including porosity	Section 2.2, Section 2.3, Section 2.4.1
Task III.A.2.j	Characterize rock and soil units above the water table including depth of water table	Section 2.2, Section 2.3, Section 2.4.1
Task III.A.2.k	Characterize rock and soil units above the water table including moisture content	Section 2.2, Section 2.3, Section 2.4.1
Task III.A.2.l	Characterize rock and soil units above the water table including effect of stratification on unsaturated flow	Section 2.4.1

Table 1-1.
Crosswalk Between HSWA Permit Requirements* and Synthesis Report Section (continued)

HSWA Permit Reference	Permit Requirement	Synthesis Report Sections
Task III.A.2.m	Characterize rock and soil units above the water table including infiltration	Section 2.4.1
Task III.A.2.n	Characterize rock and soil units above the water table including evapotranspiration	Section 2.4.1; Section 2.4.2
Task III.A.2.o	Characterize rock and soil units above the water table including residual contaminants in soil	Section 2.4.1, Appendix 3-A
Task III.A.2.r	Characterize rock and soil units above the water table including water balance scenarios	Section 2.4.1
Task III.C.1.a	A description of horizontal and vertical extent of any immiscible or dissolved groundwater plume(s) originating from the facility	Appendix 3-A
Task III.C.1.b	The horizontal and vertical direction of contaminant movement in groundwater	Section 3.2; Section 4.1; Section 4.2.11; Section 4.2.12
Task III.C.1.c	The velocity of contaminant movement in groundwater	Section 4.1; Section 4.2.11; Section 4.2.12
Task III.C.1.d	The horizontal and vertical concentration profiles of any 40 CFR Part 264 Appendix IX constituents and radiochemical constituents in the groundwater plume(s)	Section 3.2; Appendix 3-A
Task III.C.1.e	An evaluation of factors influencing the plume movement	Section 3.1, Section 3.2, Section 4.1, Section 4.2.12
Task III.C.1.f	An extrapolation of future plume movement	Section 4.1, Section 4.2.12

* LANL, 1995.

- Potential sources of contaminants: contaminant character, inventory, and locations
- Release mechanisms that introduce contaminants to the environment
- Contaminant transport mechanisms from the location of the release to groundwater
- Transport of contaminants through the groundwater system: direction and velocity of groundwater and of contaminants

Monitoring data needs were identified for each component of the groundwater system: alluvial, intermediate perched groundwater in the vadose zone, and regional aquifer and the connections between the components. Figure 1-2 shows the overall hydrogeologic conceptual model. In wet canyons, where surface water is present, the water infiltrates the alluvium in the canyon bottoms and forms alluvial groundwater. Dry canyons and mesas do not have alluvial groundwater. Alluvial groundwater flows down the canyon until it reaches an area where infiltration is enhanced by thin or absent Bandelier Tuff, highly fractured rock below the alluvium, or anthropogenic alterations (e.g. sediment traps). In areas with enhanced infiltration, alluvial groundwater percolates through the vadose zone and collects in relatively more permeable units, if there are any present beneath the canyon, e.g. fractured basalt. Alluvial groundwater and perched intermediate groundwater continue to percolate through the deeper vadose zone until they reach the regional

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aquifer. The interconnected nature of the hydrogeologic system may allow anthropogenic constituents that are present in surface water to be transported into alluvial groundwater, the vadose zone and to the regional aquifer.

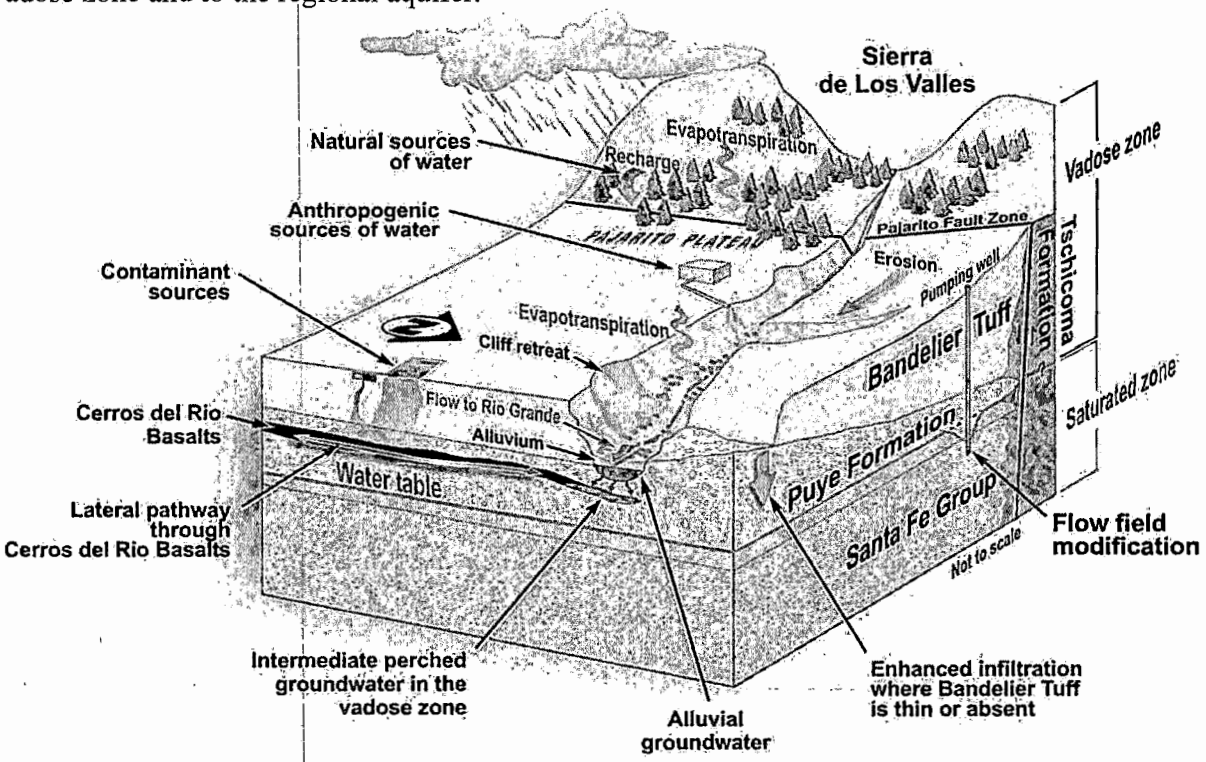

Figure 1-2. Groundwater components at LANL.

The data collection articulated in the Hydrogeologic Workplan considered elements of risk assessment, e.g. sources, release mechanisms, and transport, because these same elements are important in establishing a monitoring network capable of detecting releases. Thus, the data collected under the auspices of the Hydrogeologic Workplan are considered adequate to support risk assessment, but are not intended to serve as a risk assessment. Characterizing the source terms and release mechanisms or other chemical phenomena is the subject of ongoing investigations and information from those investigations was used in developing the Hydrogeologic Workplan (LANL 1998). Characterizing the alluvial component of the hydrologic system was undertaken in conjunction with investigating source terms and the results of the alluvial investigations are reported here (Section 2.4) because of the importance of alluvial groundwater in the hydrogeologic system. The primary focus of the Hydrogeologic Workplan (LANL 1998) activities was on the deeper groundwater components and to understand the movement of contaminants through the vadose zone and in the regional aquifer.

Since 1998, twenty-five regional aquifer wells and six intermediate-zone wells have been completed for hydrogeologic characterization (Table 1-2). The locations of the hydrogeologic characterization wells are shown on Figure 1-3. Well completion fact sheets (Appendix 1-B) and well completion reports document the drilling, well construction, well completion, testing, and

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sampling for each characterization well. A description and analysis of the characterization sampling for many wells are documented in geochemistry reports.

1.3. Topical Organization

The most basic control on the movement of water and contaminants through the system is the rocks through which the water moves. The conceptual model of the site is built from surface and subsurface geologic data (Appendix 2-A). Section 2.1 describes the regional geologic setting as a context for understanding the stratigraphic framework of the Pajarito Plateau presented in Section 2.2. Cross sections that illustrate the relationship between the stratigraphic units are critical for understanding how groundwater flows (Section 2.3).

The hydrologic properties of stratigraphic units in the vadose zone and regional aquifer are described in Section 2.4. This section quantifies the properties of the hydrologic units and explains the sources of data, including the uncertainties in the properties. The hydrologic properties and processes are combined to create conceptual models of the alluvial, vadose zone, and regional aquifer components in Sections 2.5, 2.6 and 2.7, respectively.

The natural groundwater geochemistry of the Pajarito Plateau is important to understand in order to identify and quantify contaminants added to the system. The background groundwater chemistry is integrated with geochemical processes to provide the comprehensive geochemical model described in Section 3.1. Overprinted on the natural water chemistry are the contaminants potentially released by LANL activities. Section 3.2 synthesizes the contaminant distribution data with respect to hydrologic processes and explores the contaminant transport implications.

Numerical modeling is an analytical tool that can be used to integrate and synthesize the sometimes widely-spaced point hydrogeologic field data and that predicts how the hydrologic system will behave at different times and under different conditions in the future. However, before models can be used for prediction, they must adequately reproduce the current conditions. The vadose zone and regional aquifer models that have been developed adequately reproduce current conditions beneath the Pajarito Plateau are described in Sections 4.1 and 4.2. These sections include the underlying assumptions, hydrologic processes, calibration, and predictions for flow and transport.

Section 5 summarizes the information presented in Sections 2, 3 and 4 and highlights how the refined understanding of the hydrogeologic systems can be applied to evaluating the adequacy of the existing the monitoring system and, if necessary, the design of an enhanced monitoring network.

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Table 1-2.
Los Alamos National Laboratory Hydrogeologic Characterization Wells

Well	Location	Date Completed	Primary Drilling Methods	Type of Drilling Fluid Used	Total Depth (ft bgs*)	Number of Screens[1]	Reference
R-1	Mortandad Canyon	November 2003	Conventional-circulation fluid-assisted air-rotary methods with casing advance to 90 ft followed by conventional-circulation fluid-assisted air-rotary drilling in an open hole to[2] TD at 1165 ft.	Air and municipal water mixed with Quik-FOAM, EZ-MUD	1165	1–R	Kleinfelder, 2004e
R-2	Pueblo Canyon	October 2003	Conventional-circulation fluid-assisted air-rotary drilling in an open hole to 403 ft followed by conventional-circulation mud rotary drilling to TD at 943 ft.	Air and municipal water mixed with Quik-FOAM, EZ-MUD in the upper part and municipal water mixed with bentonite, soda ash, PAC-L in the lower part	943	1–R	Kleinfelder, 2004b
R-4	Pueblo Canyon	October 2003	Conventional-circulation fluid-assisted air-rotary drilling in an open hole to 266 ft followed by conventional-circulation mud rotary drilling to TD at 844 ft.	Air and municipal water mixed with Quik-FOAM, EZ-MUD in the upper part and municipal water mixed with bentonite, soda ash, PAC-L in the lower part	844	1–R	Kleinfelder, 2004a
R-5	Pueblo Canyon	June 2001	A combination of reverse- circulation fluid-assisted air-rotary methods in open hole and with casing advance to 870 ft followed by reverse-circulation fluid-assisted air-rotary drilling in an open hole to TD at 902 ft.	Air and municipal water mixed with Quik-FOAM, EZ-MUD	902	2–I 2–R	LANL, 2003a
R-6	Los Alamos Canyon	December 2004	Conventional-circulation air-rotary and fluid-assisted air-rotary drilling methods in an open hole to 945 ft followed by conventional-circulation mud rotary drilling in a cased hole (casing set to 815 ft depth) to TD at 1303 ft.	Air and municipal water mixed with Quik-FOAM, EZ-MUD in the upper part and municipal water mixed with bentonite (Max-Gel and Quik-Gel), N-seal, Drispac, and soda ash in the lower part	1303	1–R	Well completion report unavailable
R-7	Los Alamos Canyon	February 2001	Reverse-circulation fluid-assisted air-rotary methods with casing advance to 290 ft followed by reverse-circulation fluid-assisted air-rotary drilling in an open hole to TD at 1097 ft.	Air and municipal water mixed with Quik-FOAM, EZ-MUD	1097	2–I 1–R	Stone et al. 2002
R-8	Los Alamos Canyon	February 2002	A combination of reverse- circulation fluid-assisted air-rotary methods in open hole and with casing advance to 809 ft followed by reverse-circulation fluid-assisted air-rotary drilling in an open hole to TD at 880 ft.	Air and municipal water mixed with Quik-FOAM, EZ-MUD	880	2–R	LANL, 2003b

Table 1-2.
Los Alamos National Laboratory Hydrogeologic Characterization Wells (continued)

Well	Location	Date Completed	Primary Drilling Methods	Type of Drilling Fluid Used	Total Depth (ft bgs*)	Number of Screens[1]	Reference
R-9	Los Alamos Canyon	October 1999	A combination of reverse-circulation air-rotary methods in open hole to 175 ft, coring to 419 ft, and with casing advance and reverse-circulation air-rotary methods TD at 771 ft.	Air in upper part of the borehole and air with municipal water mixed with Quik-FOAM, EZ-MUD in the lower part	771	1–R	Broxton et al. 2001a
R-11	Sandia Canyon	August 2004	Conventional-circulation fluid-assisted air-rotary drilling in an open hole to TD at 927 ft.	Air and municipal water mixed with Quik-FOAM, EZ-MUD	927	1–R	Kleinfelder, 2004c
R-12	Sandia Canyon	January 2000	A combination of reverse- circulation air-rotary methods in open hole and with casing advance to 710 ft followed by reverse-circulation fluid-assisted air-rotary drilling in an open hole to TD at 886 ft.	Air and municipal water in the upper part and air with municipal water mixed with TORKEASE, Quik-FOAM, EZ-MUD in the lower part	886	2–I 1–R	Broxton et al. 2001
R-13	Mortandad Canyon	September 2001	A combination of reverse- circulation fluid-assisted air-rotary methods in open hole and with casing advance to TD at 1133 ft.	Air and municipal water mixed with Quik-FOAM, EZ-MUD	1133	1–R	LANL 2003c
R-14	Mortandad Canyon	July 2002	Reverse-circulation fluid-assisted air-rotary methods in open hole to 1225 ft with hole cased to 1050 ft; conventional-circulation mud rotary drilling in open hole from 1225-1285 ft; reverse-circulation fluid-assisted air-rotary methods with casing advance from 1285 ft to TD at 1327 ft.	Air and municipal water mixed with EZ-MUD in the upper part and municipal water mixed with soda ash, bentonite, LIQUI-TROL, in the lower part	1327	2–R	LANL, 2003d
R-15	Mortandad Canyon	February 2000	Reverse-circulation fluid-assisted air-rotary methods with casing advance to TD at 1107 ft.	Air and municipal water mixed with TORKEASE, Quik-FOAM, EZ-MUD	1107	1–R	Longmire et al. 2000
R-16	White Rock Overlook	August 2002	A combination of reverse- circulation fluid-assisted air-rotary methods in open hole and with casing advance to 729 ft followed by reverse-circulation fluid-assisted air-rotary drilling in an open hole to 867 ft. Hole completed using conventional-circulation mud rotary methods from 867 ft to TD at 1287 ft.	Air and municipal water mixed Quick-gel, liqui-trol, Quick-FOAM, and soda ash in the upper part and municipal water mixed Quick-gel, EZ-MUD, liqui-trol, magma-fiber, n-seal in the lower part	1287	4–R	LANL, 2003e
R-18	Mesa above Pajarito Canyon	December 2004	Conventional-circulation fluid-assisted air-rotary drilling methods in an open hole to TD at 1440 ft.	Air and municipal water mixed with Quik-FOAM and EZ-MUD	1440	1–R	Well completion report unavailable

Table 1-2.
Los Alamos National Laboratory Hydrogeologic Characterization Wells (continued)

Well	Location	Date Completed	Primary Drilling Methods	Type of Drilling Fluid Used	Total Depth (ft bgs*)	Number of Screens[1]	Reference
R-19	Mesa above Potrillo Canyon	April 2000	Reverse-circulation fluid-assisted air-rotary methods with casing advance to 227 ft followed by reverse-circulation fluid-assisted air-rotary drilling in an open hole to TD at 1902 ft.	Air and municipal water mixed with TORKEASE, Quik-FOAM, EZ-MUD	1902	2–I 5–R	Broxton et al. 2001d
CdV-R-15-3	Cañon de Valle	September 2000	Reverse-circulation fluid-assisted air-rotary methods with casing advance to 722 ft; install casing; complete hole by reverse-circulation fluid-assisted air-rotary drilling in an open hole to TD at 1722 ft.	Air and municipal water mixed with Quik-FOAM, EZ-MUD plus polymers	1722	3–I 3–R	Kopp et al. 2002
CdV-R-37-2	Cañon de Valle	October 2001	A combination of reverse- circulation fluid-assisted air-rotary methods in open hole and with casing advance to 825 ft followed by reverse-circulation fluid-assisted air-rotary drilling in an open hole to TD at 1664 ft.	Air and municipal water mixed with Quik-FOAM, EZ-MUD	1664	1–I 3–R	Kopp et al. 2003
R-20	Pajarito Canyon	January 2003	Conventional-circulation mud rotary drilling to TD at 1365 ft.	Municipal water mixed Quick-gel, liqui-trol, Quik-FOAM, soda ash, PAC-L, n-seal (mineral fiber)	1365	3–R	LANL, 2003f
R-21	Cañada del Buey	January 2003	Conventional-circulation air-rotary drilling in an open hole to 237 ft followed by conventional-circulation fluid-assisted air-rotary drilling in an open hole to TD at 995 ft.	Air and municipal water mixed with Quik-FOAM, EZ-MUD	995	1–R	Kleinfelder, 2003f
R-22	Mesa above Pajarito Canyon	December 2000	A combination of reverse- circulation fluid-assisted air-rotary methods in open hole and with casing advance to 1345 ft followed by reverse-circulation fluid-assisted air-rotary drilling in an open hole to TD at 1489 ft.	Air and municipal water mixed with Quik-FOAM, EZ-MUD	1489	5–R	Ball et al. 2002
R-23	Pajarito Canyon	January 2003	A combination of conventional mud-rotary drilling, reverse-circulation fluid-assisted air-rotary drilling in open hole, and reverse-circulation fluid-assisted air-rotary drilling with casing advance to TD of 935 ft.	Municipal water mixed with bentonite, Quick-gel, liqui-trol, Quik-FOAM, soda ash, magna-fiber, PAC-L, n-seal and air with municipal water mixed with Quick-gel, liqui-trol, Quik-FOAM, and soda ash	935	1–R	LANL, 2003g
R-25	Mesa above Cañon de Valle	February 1999	Reverse-circulation fluid-assisted air-rotary drilling with casing advance to TD of 1942 ft.	Air and municipal water mixed with TORKEASE, Quik-FOAM, EZ-MUD	1942	4–I 5–R	Broxton et al. 2001e

Table 1-2.
Los Alamos National Laboratory Hydrogeologic Characterization Wells (continued)

Well	Location	Date Completed	Primary Drilling Methods	Type of Drilling Fluid Used	Total Depth (ft bgs*)	Number of Screens[1]	Reference
R-26	Cañon de Valle	October 2003	Conventional-circulation fluid-assisted air-rotary drilling in an open hole to 1000 ft; casing installed to 1000 ft; borehole completed by conventional-circulation mud-rotary drilling in an open hole to TD at 1490.5 ft.	Air and municipal water mixed with Quik-FOAM, EZ-MUD	1490.5	1–I 1–R	Kleinfelder, 2004f
R-28	Mortandad Canyon	December 2003	Conventional-circulation fluid-assisted air-rotary methods with casing advance to 80 ft followed by conventional-circulation fluid-assisted air-rotary drilling in an open hole to TD at 1005 ft.	Air and municipal water mixed with Quik-FOAM, EZ-MUD	1005	1–R	Kleinfelder, 2004d
R-31	Ancho Canyon	March 2000	A combination of reverse- circulation fluid-assisted air-rotary methods in open hole and with casing advance to 787 ft followed by reverse- circulation fluid-assisted air-rotary methods with casing advance to TD at 1103 ft.	Air and municipal water mixed with Quik-FOAM, EZ-MUD	1103	1–I 4–R	Vaniman et al. 2002
R-32	Pajarito Canyon	January 2003	Reverse-circulation fluid-assisted air-rotary drilling in open hole to 908; install casing; complete hole by conventional-circulation mud rotary drilling in an open hole to TD at 1008 ft.	Air and municipal water mixed with Quick-gel, liqui-trol, Quik-FOAM, and soda ash in the upper part and municipal water mixed with Quick-gel, liqui-trol, EZ-MUD, magma-fiber, PAC-L, n-seal in the lower part	1008	3–R	LANL, 2003h
R-33	Ten Site Canyon	October 2004	Conventional-circulation air-rotary and fluid-assisted air-rotary drilling methods in an open hole to 1030 ft followed by reverse-circulation fluid-assisted air-rotary drilling methods in an open hole to TD at 1140 ft.	Air and municipal water mixed with Quik-FOAM, EZ-MUD	1140	1–R	Completion report not available
R-34	Cedro Canyon	August 2004	Conventional-circulation air-rotary and fluid-assisted air-rotary drilling methods in an open hole to TD at 1065 ft.	Air and municipal water mixed with Quik-FOAM and EZ-MUD	1065	1–R	Completion report not available
MCOB T-4.4	Mortandad Canyon	June 2001	Reverse-circulation fluid-assisted air-rotary drilling using casing advance to 130 ft followed by reverse-circulation fluid-assisted air-rotary drilling in an open hole to TD at 767 ft.	Air and municipal water mixed with Quik-FOAM, EZ-MUD	767	1–I	Broxton et al. 2002

Table 1-2.
Los Alamos National Laboratory Hydrogeologic Characterization Wells (continued)

Well	Location	Date Completed	Primary Drilling Methods	Type of Drilling Fluid Used	Total Depth (ft bgs*)	Number of Screens[1]	Reference
MCOB T-8.5	Mortandad Canyon	June 2001	Reverse-circulation fluid-assisted air-rotary drilling using casing advance to 130 ft followed by reverse-circulation fluid-assisted air-rotary drilling in an open hole to TD at 740 ft.	Air and municipal water mixed with Quik-FOAM, EZ-MUD	740	—	Broxton et al. 2002
R-6i	Los Alamos Canyon	December 2004	Conventional-circulation air-rotary and fluid-assisted air-rotary drilling in an open hole to TD at 660 ft.	Air and municipal water mixed with Quik-FOAM	660	1–I	Completion report not available
R-9i	Los Alamos Canyon	March 2000	Reverse-circulation fluid-assisted air-rotary drilling in an open hole to TD at 322 ft.	Air and municipal water mixed with EZ-MUD	322	2–I	Broxton et al. 2001c
CdV-16-1(i)	Cañon de Valle	November 2003	Conventional-circulation fluid-assisted air-rotary drilling in an open hole to TD at 683 ft.	Air and municipal water mixed with Quik-FOAM, EZ-MUD	683	1–I	Completion report not available
CdV-16-2(i)	Cañon de Valle	December 2003	Conventional-circulation fluid-assisted air-rotary drilling in an open hole to TD at 1063 ft.	Air and municipal water mixed with Quik-FOAM, EZ-MUD	1063	2–I	Completion report not available
CdV-16-3(i)	Cañon de Valle	January 2004	Conventional-circulation fluid-assisted air-rotary drilling in an open hole to TD at 1405 ft.	Air and municipal water mixed with Quik-FOAM, EZ-MUD	1405	—	Completion report not available

* bgs = below ground surface
[1] R = screen(s) in regional groundwater; I = screen(s) in intermediate-depth (perched) groundwater
[2] TD = total depth

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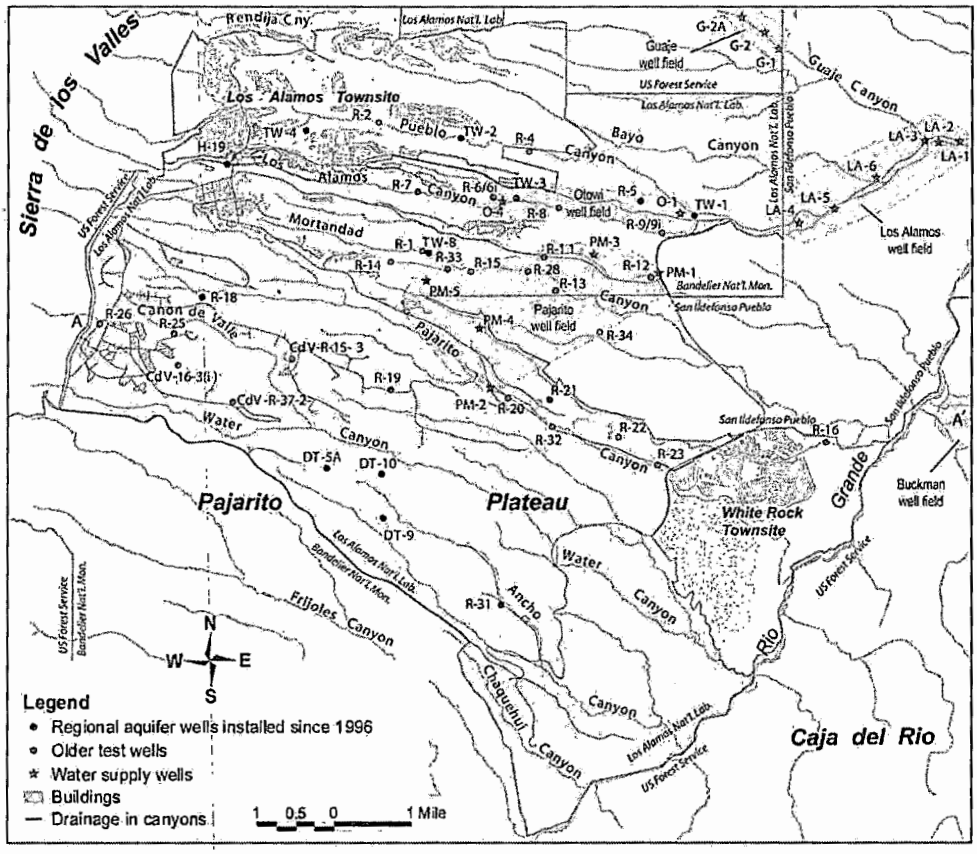

Figure 1-3. Locations of the Hydrogeologic Workplan characterization wells.

2.0 HYDROGEOLOGY

Groundwater occurs in three settings beneath the Pajarito Plateau: alluvium, intermediate perched saturated zones, and the regional aquifer. The major source of recharge to the regional aquifer is precipitation within the Sierra de los Valles. However, alluvial groundwater on the Pajarito Plateau is a source of recharge to underlying intermediate perched saturated zones and to the regional aquifer.

This section describes the conceptual understanding of the hydrogeology beneath the Pajarito Plateau. The conceptual models of the hydrogeologic system described here are based on empirical observations combined with knowledge of geologic and hydrologic processes. These conceptual models are the foundation of the numerical models described in Section 4. First, the geologic conceptual model is described to provide an understanding of the geologic units that are present. Second, the connection between geology and hydrology is discussed because the geology is the first-order control on the Pajarito Plateau hydrology. Finally, the conceptual models for the alluvial groundwater, perched intermediate groundwater, and the regional aquifer are described.

2.1 Geologic Conceptual Model

The geologic conceptual model for the LANL site is developed from (1) past studies of site and regional geology that predate implementation of the Hydrogeologic Workplan, including over 50 years of mapping, drilling, and regional geophysical studies; (2) borehole data collected specifically for the Hydrogeologic Workplan; and (3) integration of results from current Hydrogeologic Workplan studies with other studies in the region, particularly those that are brought together by the Española Basin Technical Advisory Group. Table 2-1 provides a summary of the types of information used to develop the geologic conceptual model and Appendix 2-A contains a detailed description of the geologic types of data used to develop the conceptual model.

There are localized subsurface geologic data associated with drilling boreholes and regional geologic data, surface and subsurface, which are obtained by aerial surveys and work done by others on a regional scale. The localized subsurface geologic data are obtained from:

- Cuttings and core
- Borehole geophysical data
- Borehole video logs
- Drilling rates and character

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Table 2-1.
Summary of Geologic Data

Data Type	Purpose	Data Collection	Data Records	Archives
Lithologic Information from Cuttings	Direct measurements of the top and bottom and character of the hydrogeologic units at each borehole. Correlations of rock units among boreholes are key components of the site-wide 3-D geologic model for the plateau.	Approximately 500 to 700 ml of bulk drill cuttings were collected every 5 ft, as conditions permitted, to the total depth (TD) of each boring. Cuttings were visually examined and a small subset of core and cuttings was selected for additional characterization: X-ray diffraction for mineralogy, X-ray fluorescence for rock chemistry, thin-section petrography, and $^{40}Ar/^{39}Ar$ age dating.	Lithologic logs summarize rock lithologies, alteration features, and stratigraphic contacts from visual examination and interpretations of borehole geophysical logs.	Core and cuttings are currently archived at the ENV Division Sample Management Facility located at Technical Area 3, building 03-0271-101. All borehole materials are stored in core boxes labeled with the well name, box number, and footage range for the box.
Lithologic Information from Core	Core was collected to fulfill a number of characterization objectives, including: • geology of perched saturated zones and aquitards • hydrologic and chemical analyses of vadose-zone samples (e.g. moisture, anions) • hydraulic properties of selected hydrogeologic units.	Core was collected from dedicated core holes and from selected intervals in some regional aquifer boreholes.	Same as for cuttings above.	Same as for cuttings above

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Table 2-1.
Summary of Geologic Data (continued)

Data Type	Purpose	Data Collection	Data Records	Archives
Drilling Information	Observations about drilling characteristics by the drillers and on-site geologists contributed to understanding the hydrogeology of the boreholes.	Major lithologic and stratigraphic contacts were commonly marked by significant changes in drill penetration rates. Drilling rates are primarily affected the competency of the rocks being penetrated. Hard rock units have slow drilling rates, whereas less-competent rocks were drilled more rapidly. Important information about water-bearing strata was obtained when drillers noted changes in the drilling fluids circulating through the borehole.	These observational data were recorded in field logs, and they provided supplemental information that aided the interpretation of hydrogeologic data from other sources such as cuttings and geophysical logs.	N/A
Borehole Geophysical Data	Determine the geologic and hydrologic characteristics of the vadose zone, perched saturated zones, and regional aquifer. Preliminary logs were used by contractor, DOE, and LANL personnel to help select well screen locations and to evaluate borehole conditions prior to well construction.	*LANL*: caliper, spontaneous potential, single-point resistance and induction, and natural gamma radiation logs. *Contractor:* wire-line logging service was contracted to obtain a more extensive suite of borehole geophysical logs once the borehole reached total depth	Preliminary results of geophysical logs were generated in the logging truck at the time the geophysical services were performed. Contractor reprocessed the field measurements to correct them and to combine the logs into a single presentation enabling integrated interpretation.	Results of contractor geophysical logging and analysis are summarized in an interpretive report that is included in each well completion report.

Table 2-1.
Summary of Geologic Data (continued)

Data Type	Purpose	Data Collection	Data Records	Archives
Borehole Video Logs	To obtain lithologic information and to help determine stratigraphic contacts; visual examination of borehole walls for evidence of perched saturation; document water levels in the boreholes; document the as-built condition of installed well components; assess the effectiveness of well development techniques; to assess problematic borehole conditions and to guide fishing operations for tools and equipment lost downhole.	Borehole video was used in each borehole or completed well. The videos were viewed by geologists to assess geologic conditions. Often used in conjunction with geophysical logs to determine the locations of perched zones in some boreholes and the presence and nature of fractures.	Video logs were collected during installation of workplan wells.	N/A
Regional Airborne Surveys	Focus groundwater investigations by defining the conductivity structure beneath the plateau. Gravity data were used to help define regional structure beneath the Pajarito Plateau.	A total of 762 line kilometers of MegaTEM® time domain EM data and magnetic data were collected (80% of LANL area). Flight lines spaced at 105 m within the laboratory boundaries, and at 210 m in buffer zones. Lines oriented N20E, with tie lines about 2000-meter spacing.	Maps of Residual Magnetic Intensity (RMI), apparent conductance and conductivity depth slices at various depths, multiparameter profiles with conductivity-depth-transform (CDT) sections for flight lines and digital archives of line and grid data.	All of the processing assumed a "layered-earth" model, and inversions were: single points/multiple depths (1-D), multiple depths along individual flight lines (2-D), or a constant depth on multiple flight lines (2-D). The results of all three models, for each flight line are available as Adobe PDF files.

Note: N/A = not applicable

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Geologic data derived from regional-scale studies were obtained from multiple sources, including:

- Surface geophysical data were used to help constrain the site-wide geologic model (Appendix 2-A). These data include regional gravity data, airborne electromagnetic data, high resolution resistivity, and magnetotellurics. Gravity data were used to help define regional structure beneath the Pajarito Plateau. Airborne electromagnetic data, high resolution resistivity, and magnetotelluric data were used to focus groundwater investigations by defining the conductivity structure beneath the plateau
- Numerous local and regional mapping projects and geological studies have provided important information supporting development of geologic conceptual models and digital realizations of these models.
- Española Basin workshops were hosted annually by the Española Basin Technical Advisory Group and sponsored by the U.S. Geological Survey, the New Mexico Bureau of Geology and Mineral Resources, Los Alamos National Laboratory, and the city of Santa Fe.
- The Seismic Hazards program at LANL was an important source of information about faults and fractures in the vicinity of the Laboratory.
- Students and their advisors from the graduate programs from the University of New Mexico and New Mexico State University, New Mexico Institute of Mining and Technology, and the University of Texas have provided additional hydrogeologic information for the Jemez volcanic field, the Espanola Basin, and the Puye Formation.

2.1.1 Goals of the Geologic Model

- Define the geologic setting of the groundwater system beneath the Pajarito Plateau
- Relate lithologic properties of rocks to groundwater flow characteristics and rock/water interactions
- Provide a benchmark for comparing new data to predicted geology
- Improve selection of new well sites based on iterative evaluation of hydrogeologic information
- Provide a framework for numerical flow and transport models of the vadose and saturated zones

2.1.2 Site-Wide Geology

The discussion of site-wide geology presented here is condensed from a summary by Broxton and Vaniman (2005). More detailed, fully referenced information is available in that publication. The deep characterization wells drilled in the time period from 1997 to 2004 have provided the foundation for constructing the geologic framework surfaces presented in this section.

2.1.2.1 Regional Setting

The Pajarito Plateau lies at the volcanically and seismically active boundary between the Colorado Plateau and the Rio Grande Rift in north-central New Mexico (Figure 2-1). The Rio Grande rift is a major geologic feature that consists of north-trending, fault-bounded basins

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extending from central Colorado to northern Mexico. The local area of subsidence, termed the Española Basin, lies between two larger basins—the Albuquerque Basin to the south and San Luis Basin to the north (Kelley, 1978). The Española Basin is about 70 km (44 mi) long and 60 km (37 mi) wide. The plateau overlies the deepest part of the west-tilted Española Basin adjacent to the highlands of the Jemez volcanic field. Geologic units consist of Miocene and Pliocene basin-fill deposits and interfingering volcanic rocks from the Jemez and Cerros del Rio volcanic fields. Miocene and Pliocene sedimentary and volcanic rocks are covered by Pleistocene ash-flow tuffs making up the Pajarito Plateau.

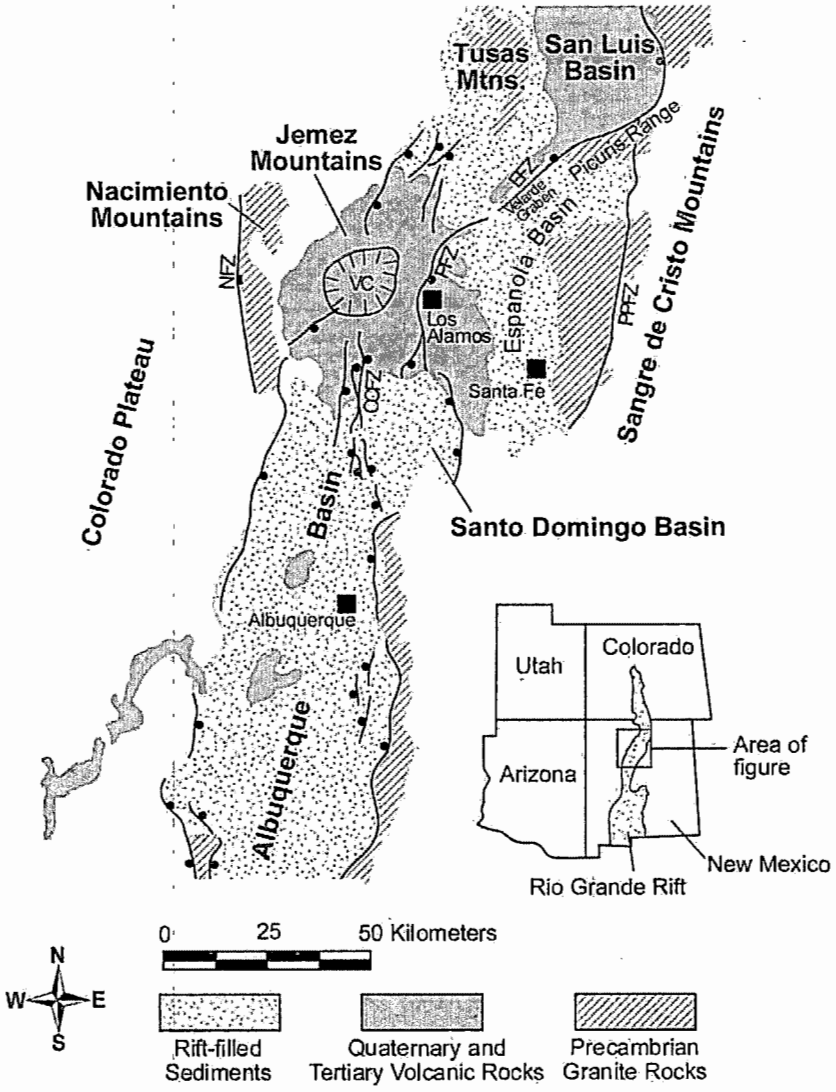

Figure 2-1. Locations of major structural and geologic elements near LANL. Major fault systems are shown with ball on downthrown side. VC is the Valles Caldera complex; NFZ is the Nacimiento fault zone; CCFZ is the Cañada del Cochiti fault zone; PFZ is the Pajarito fault zone; and PPFZ is the Picuris-Pecos fault zone.

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The western structural margin of the Española Basin is partly covered by rocks of the Jemez volcanic field, but probably includes a broad zone of north-trending faults such as the Cañada de Cochiti fault zone (Figure 2-1) that cut older volcanic units in the south-central part of the volcanic field (Gardner and Goff, 1984). The present active western boundary of the Española Basin is the Pajarito fault zone, a narrow band of north- and northeast-trending normal faults that delineate the western margin of the Pajarito Plateau. Neogene displacement along the Pajarito fault zone is dominantly down to the east with episodic faulting indicated by progressively larger offsets in older rock units.

Gravity data (Biehler et al., 1991; Ferguson et al., 1995) indicates the deepest part of the Española Basin coincides with three deep, intrabasinal grabens arrayed along the Pajarito and Embudo fault systems. From north to south, these subbasins include the Velarde graben (Manley, 1979, 1984), a north-northeast trending basin beneath Santa Clara pueblo, and a north-trending basin near Los Alamos. The Pajarito fault zone forms the western boundary of the Los Alamos subbasin (Biehler et al., 1991; Ferguson et al., 1995; Smith, 2004). Gravity data suggest that the eastern boundary is bounded by buried faults that lie east of the southern projections of the Rendija Canyon and Guaje Mountain (Ferguson et al., 1995), but the location and size of faults in this area are not well known.

The basement of the Española Basin is an eroded terrane of Eocene-Precambrian aged rocks uplifted during the Laramide mountain-building episode (orogeny, approximately 65 million years ago (m.y.a.). One of these uplifted areas, the Pajarito uplift, is bounded on the east by the Picuris-Pecos fault in the Sangre de Cristo Range and on the west by the Pajarito fault (Cather, 2004; Smith, 2004). At the time of Laramide uplift, the Pajarito fault was a westward-verging reverse fault, but it was reactivated as a down-to-the-east normal fault during Neogene (within the last 24 m.y.) subsidence of the Española Basin.

2.1.2.2. Structural Geology of the Pajarito Plateau

The Pajarito fault zone and its associated structures are the most prominent tectonic features of the LANL site (Figure 2-2). The fault, which forms a 120-m (400-ft) high escarpment on the western margin of the plateau, has the surface expression of a large, north-trending, faulted monocline. Along strike the fault varies from a simple normal fault to broad zones of small faults, faulted monoclines, and unfaulted monoclines. These varied styles of deformation are all considered expressions of deep-seated normal faulting. The amount of fault displacement for older rock units is not known because thick deposits of Bandelier Tuff cover critical relations. Stratigraphic separation on the Tshirege Member of the Bandelier Tuff (1.22 Ma) ranges between 80 and 120 m (260 to 400 ft) along the segment of the fault west of LANL (Gardner et al., 1999). Holocene movements (within the last 10,000 years) and historic seismicity indicate this fault system is still active.

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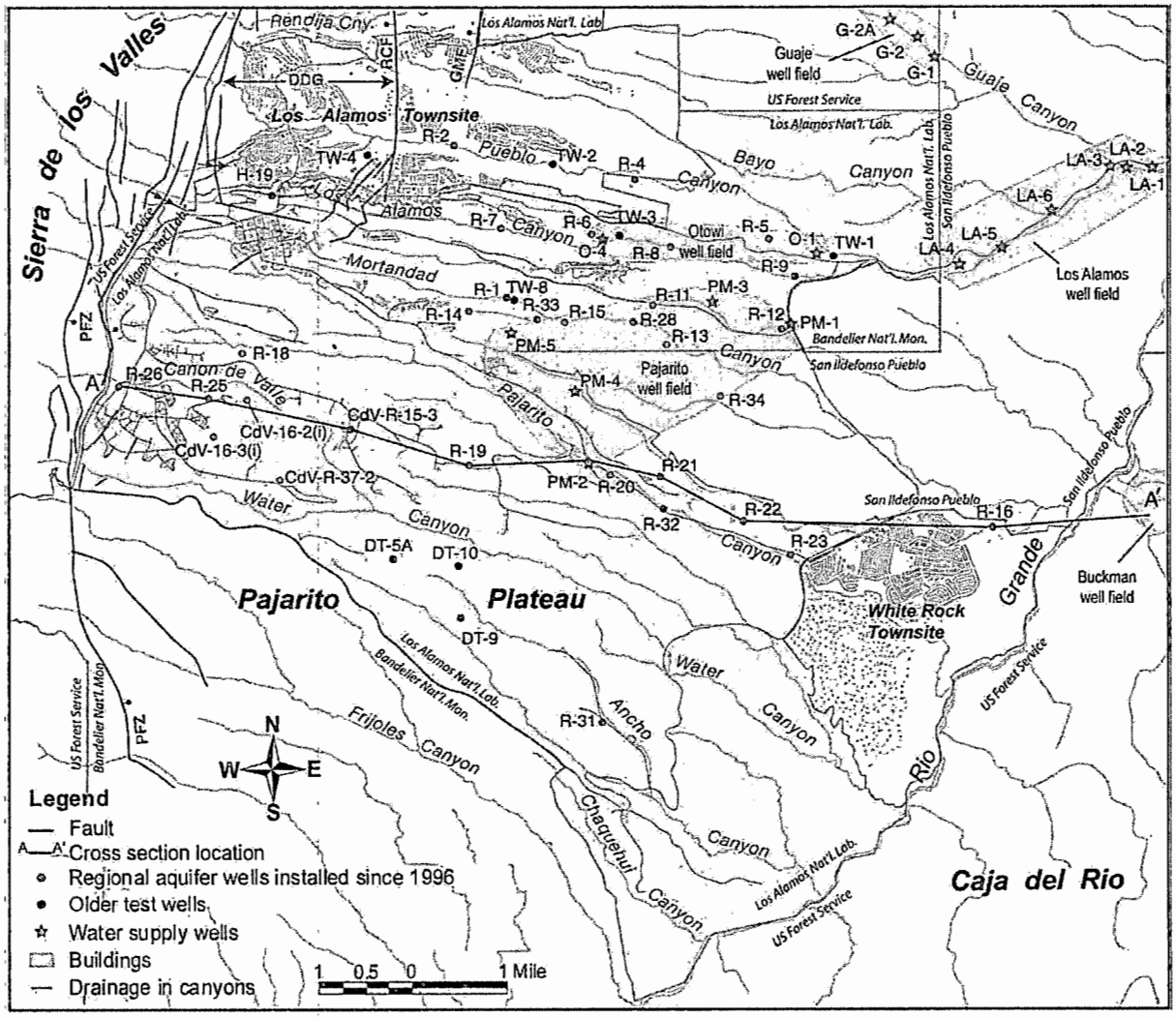

Figure 2-2. Location map of the central Pajarito Plateau.

Yellow-shaded area is the Los Alamos National Laboratory. Also shown are the municipalities of Los Alamos and White Rock. East- and southeast-trending canyons are incised into the plateau. Water supply wells are shown as blue stars and the water-supply well fields are indicated in blue shading; additional wells of Guaje well field extend north of this map. The Buckman well field provides water to Santa Fe. Water supply wells LA-1 through LA-6 are no longer used for municipal water production. New regional aquifer wells installed since 1998 are shown as red dots. Older test wells are shown as black dots. Line A-A' shows the location of the cross-section in Figure 2-5. Main elements of the Pajarito fault zone are shown in blue. PFZ is the main trace of the Pajarito fault zone; RCF is the Rendija Canyon fault; GMF is the Guaje Mountain fault; and DDG is the Diamond Drive graben. Faults modified from Gardner et al. (2001) and Lewis et al. (2002).

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Other major faults on the Pajarito Plateau include the Rendija Canyon and Guaje Mountain faults. The Rendija Canyon fault, located in the northern part of the plateau, is a north-trending normal fault with down-to-the-west displacement. The Rendija Canyon fault dies out as a simple normal fault on the north side of LANL. Southward across LANL it is replaced by a broad arc of small-displacement faults that trend in a southwesterly direction towards the main trace of the Pajarito fault. The Guaje Mountain fault lies east of and is generally parallel to the Rendija Canyon fault. It is also a north-trending normal fault with down-to-the-west displacement. Surface traces of the Guaje Mountain fault die out north of LANL.

Additional faults are probably buried beneath the cover of Bandelier Tuff on the Pajarito Plateau. Where exposed along the east side of the basin, Santa Fe Group rocks are cut by numerous north-trending normal faults. Similar fault densities and orientations are probably present in the basin-fill sediments beneath the Pajarito Plateau. Unfortunately, existing well data are of limited use in defining these structures because of the complex depositional patterns and interfingering relations of Pre-Bandelier rock units beneath the plateau.

2.1.2.3 Volcanic Setting of the Pajarito Plateau

The Pajarito Plateau overlaps two volcanic fields whose activities were coeval with rifting. The plateau is bounded on the west by the Jemez volcanic field, a nearly circular volcanic field 72 km (45 mi) in diameter that includes the Valles caldera (Figure 2-1). The plateau is bounded on the southeast by the smaller Cerros del Rio volcanic field. The Jemez volcanic field was an important source of sediments during basin subsidence and the basin-fill sediments interfinger laterally with rocks of both volcanic fields.

Cerros del Rio Volcanic Field

The Cerros del Rio volcanic field is mainly exposed as the Caja del Rio basalt plateau on the east side of the Rio Grande. The surface of the basalt plateau ranges in elevation from 6000 to 7396 ft. The exposed part of the volcanic field extends about 26 mi in a north-south direction and is up to 12 mi wide. The volcanic field extends an additional 7 mi to the west beneath the Pajarito Plateau, where Bandelier Tuff covers it. The exposed portion of the volcanic field is made up of about a dozen volcanoes and >70 vents of cinder cones, plugs, and tuff rings. Basalts and related intermediate-composition lavas are the predominant rock types, and most were erupted between 2.3 and 2.8 Ma. The Rio Grande cuts a south-southwesterly course through the northwestern part of the basalt plateau, forming White Rock Canyon (Broxton and Vaniman 2005).

Jemez Volcanic Field

The Jemez volcanic field lies at the intersection of the northeast-trending Jemez lineament, a major crustal structure of Precambrian ancestry, and north-trending faults of the Rio Grande Rift. Volcanism over the last 14 million years (m.y.) built up the Jemez Mountains, while contemporaneous tectonic rifting resulted in subsidence of the Española Basin, the area extending from the Valles caldera to the western margin of the Sangre de Cristo Mountains. The Jemez volcanic highlands were a major source of Miocene and Pliocene volcaniclastic sediments that were deposited as alluvial fans in the western part of the Española Basin. Eastward, these volcaniclastic deposits interfinger with arkosic basin-fill sands and gravels derived predominantly from Precambrian–cored uplifts on the east side of the Española Basin.

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The Jemez volcanic field began to develop between ~14 and 10 Ma with the eruption of predominantly basaltic and rhyolitic rocks of the Keres Group. Major rock units of the Keres Group include:

- **~14.5 to 7.6 Ma:** Basalts that were erupted predominantly in the southern and northeastern parts of the volcanic field.
- **~12.4 to 8.8 Ma:** The Canovas Canyon Rhyolite of the Keres Group, made up of rhyolite domes and associated pyroclastic deposits that were erupted from vents aligned along faults of the Cañada de Cochiti fault zone.
- **~10.6 to 7.1 Ma:** 1000 km^3 of andesite and subordinate basalt and rhyodacite that were erupted as part of the Paliza Canyon Formation.
- **7.1 to 6.0 Ma:** High-silica rhyolite plugs, domes, and tuffs of the Bearhead Rhyolite, including thick tuffaceous deposits of the Peralta Canyon Member, that were erupted from along faults of the Cañada de Cochiti fault zone.

The period from 6 to 7 Ma also coincided with a transition to predominantly dacitic volcanism throughout the volcanic field (Gardner et al., 1986). Porphyritc dacitic lavas of the Tschicoma Formation of the Polvadera Group were erupted primarily between 5 and 3 Ma (Goff and Gardner, 2004; G. WoldeGabriel, personal communication) from large, overlapping dome complexes typified by the extensive exposures of this formation in the highlands of the Sierra de los Valles west of the Pajarito fault zone.

Volcanism in the Jemez volcanic field reached a climax with eruption of the Bandelier Tuff from the Toledo and Valles calderas. The Bandelier Tuff has two members, each consisting of a basal pumice fall overlain by a petrologically related succession of ash-flow tuffs. Eruption of the two members was accompanied in each case by caldera collapse. The Otowi Member (1.61 Ma) was erupted from an earlier caldera that was nearly coincident with, and was largely destroyed by, the younger Valles caldera. The Valles caldera formed during the eruption of the Tshirege Member (1.22 Ma). About 300 km^3 of high-silica rhyolite magma was erupted for each of the two Bandelier Tuff members. Deposits of Bandelier Tuff form radially distributed flat-topped tuff plateaus that dip away from the central volcanic highlands. The Pajarito Plateau at LANL is made up of Bandelier Tuff that flowed more than 21 km across the western Española Basin.

An interval of about 400,000 years separated the eruptions of the two Bandelier Tuff members. During this interval, domes of Cerro Toledo Rhyolite were emplaced northeast and southeast of the earlier Toledo caldera. Tephras from these domes were deposited as ash and pumice falls over the Sierra de los Valles and Pajarito Plateau. The Cerro Toledo interval is a mixture of reworked Cerro Toledo Rhyolite tephras and Tschicoma dacite sediments eroded from the Sierra de los Valles.

2.2 Stratigraphic Framework of the Pajarito Plateau

A generalized diagram showing the stratigraphic sequence of rock units of the Pajarito Plateau is shown in Figure 2-3. Rock units are described below from oldest to youngest. The stratigraphy, lithology, and geochronology of the Santa Fe Group beneath the Pajarito Plateau are known primarily through drillhole data because Bandelier Tuff covers these older rock units. Based on

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exposures near the Rio Grande and new drillhole data, the Santa Fe Group beneath the Pajarito Plateau is believed to include, in ascending order, the Tesuque Formation, older fanglomerate deposits of the Jemez volcanic field, the Totavi Lentil and older river gravels, pumice-rich volcaniclastic rocks, and the Puye Formation. Recent mapping of basin sediments north and east of Los Alamos suggests that the Tesuque Formation, as used in this report, may include rocks of the Chamita Formation (Koning et al., 2005). The older fanglomerate and pumice-rich volcaniclastic rocks are new units that are given provisional informal names. These units are generally similar to the Puye and Cochiti Formations, but are older than rocks normally assigned to them. Redefining the Puye and Cochiti Formations is beyond the scope of this report, and the older fanglomerates and pumice-rich volcaniclastic rocks are treated as informal units until they can be incorporated into the new stratigraphic framework being developed for the Española Basin (see discussion in Smith, 2004). In the vicinity of the Pajarito Plateau, Santa Fe Group deposits interfinger with or are overlain by volcanic rocks of the Jemez and Cerros del Rio volcanic fields. Rock units older than the Santa Fe Group (e.g., early Tertiary and older rocks) are not described here because they underlie the Laboratory at considerable depth and have not been penetrated by deep drillholes. These prebasin rock units are described in papers by Biehler et al. (1991), Cather (1992 and 2004), Ferguson et al. (1995), and Smith (2004).

The total thickness of the Santa Fe Group in the eastern and northern part of the Española Basin is as much as 1450 m (4800 ft) (Galusha and Blick, 1971). The Yates La Mesa no. 2 exploration well penetrated 1200 m (3966 ft) of Tesuque Formation in the south-central part of the basin (Meyer and Smith, 2004). However, the thickest Santa Fe Group deposits are believed to occur in the western Española Basin beneath the Pajarito Plateau (Kelly, 1978; Biehler et al., 1991; Ferguson et al., 1995; Smith, 2004). The thickness of these deposits is not well known because the deepest wells on the plateau (e.g., PM-5 with a depth 950 m; 3110 ft) do not fully penetrate the basin-fill sediments. Biehler et al. (1991) estimate that the Santa Fe Group in the central basin might be as much as 2000 m (6650 ft) thick based on gravity data. Cross sections by Kelly (1978) and Koning and Maldonado (2001) show up to 2750 to 3300 m (9000 to 10000 ft) of Santa Fe Group deposits in the central and western parts of the basin. Drillhole data and outcrops indicate that Santa Fe Group deposits are considerably thinner (<500 m; <1640 ft) west of the Pajarito fault (Goff and Gardner, 2004).

This section includes structure contour maps (contoured elevations at the top or bottom of a hydrogeologic unit) and isopach maps (contoured maps showing the unit thickness). These maps, which are prepared by interpolation between points of one-dimensional drillhole data, provide information on the extent of a unit beneath the site and the relative contribution of each unit to the hydrostratigraphy at any given point. Isopach and structure-contour figures representing key hydrostratigraphic units include:

- Cerro Toledo interval (Figure 2-4),
- Otowi Member ash flows (Figure 2-5),
- Guaje Pumice Bed at the base of the Otowi Member (Figure 2-6),
- Cerros del Rio lavas (Figures 2-7 and 2-8),
- Pumiceous volcaniclastic rocks (Figure 2-9).

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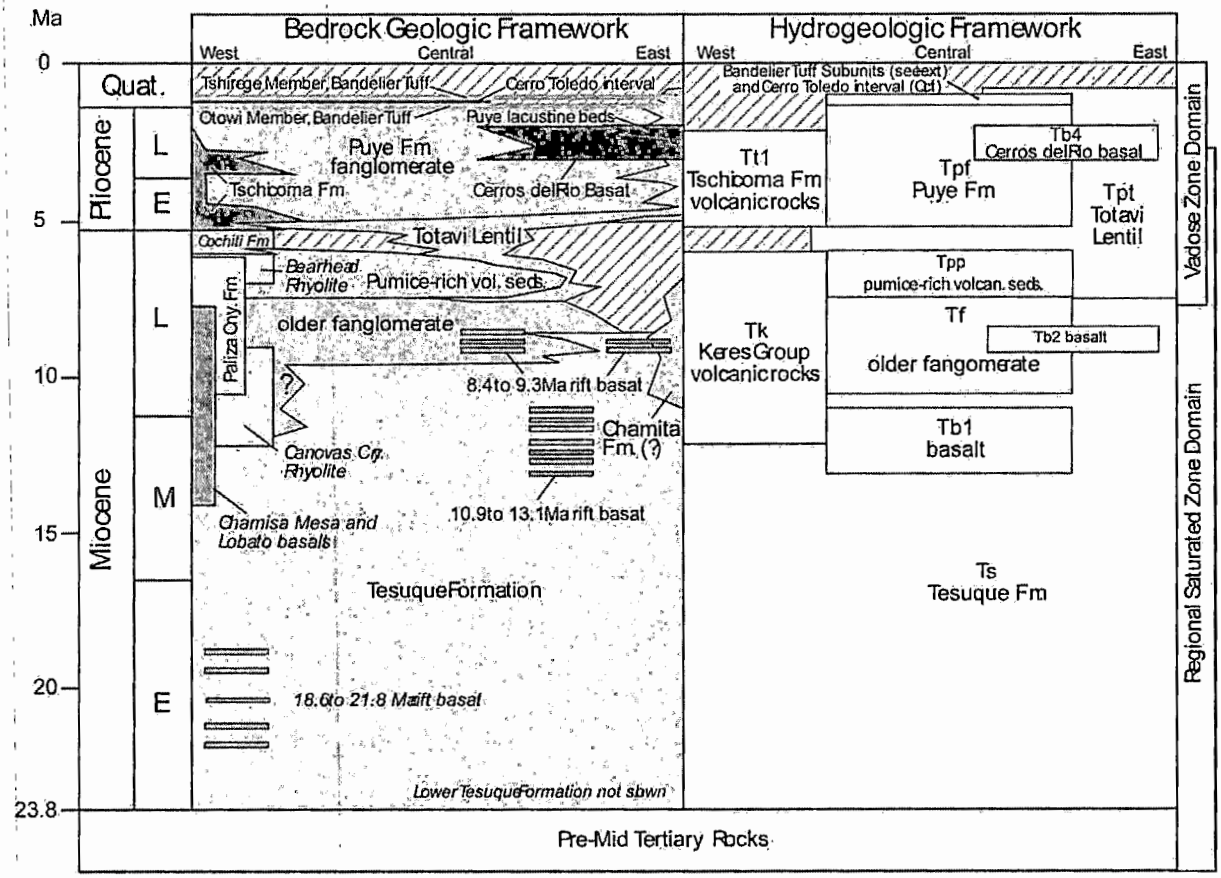

Figure 2-3. Pajarito Plateau stratigraphy and hydrogeologic units as used in this report. The bedrock geologic framework shows the stratigraphy of the plateau and the adjacent Sierra de los Valles. Units with italicized names are not exposed or penetrated by boreholes in the immediate vicinity of the plateau, but they are coeval units of the Jemez volcanic field that may be important source rocks for plateau deposits. The hydrogeologic framework shows units that are defined for site-wide numerical modeling (Broxton and Vaniman, 2005).

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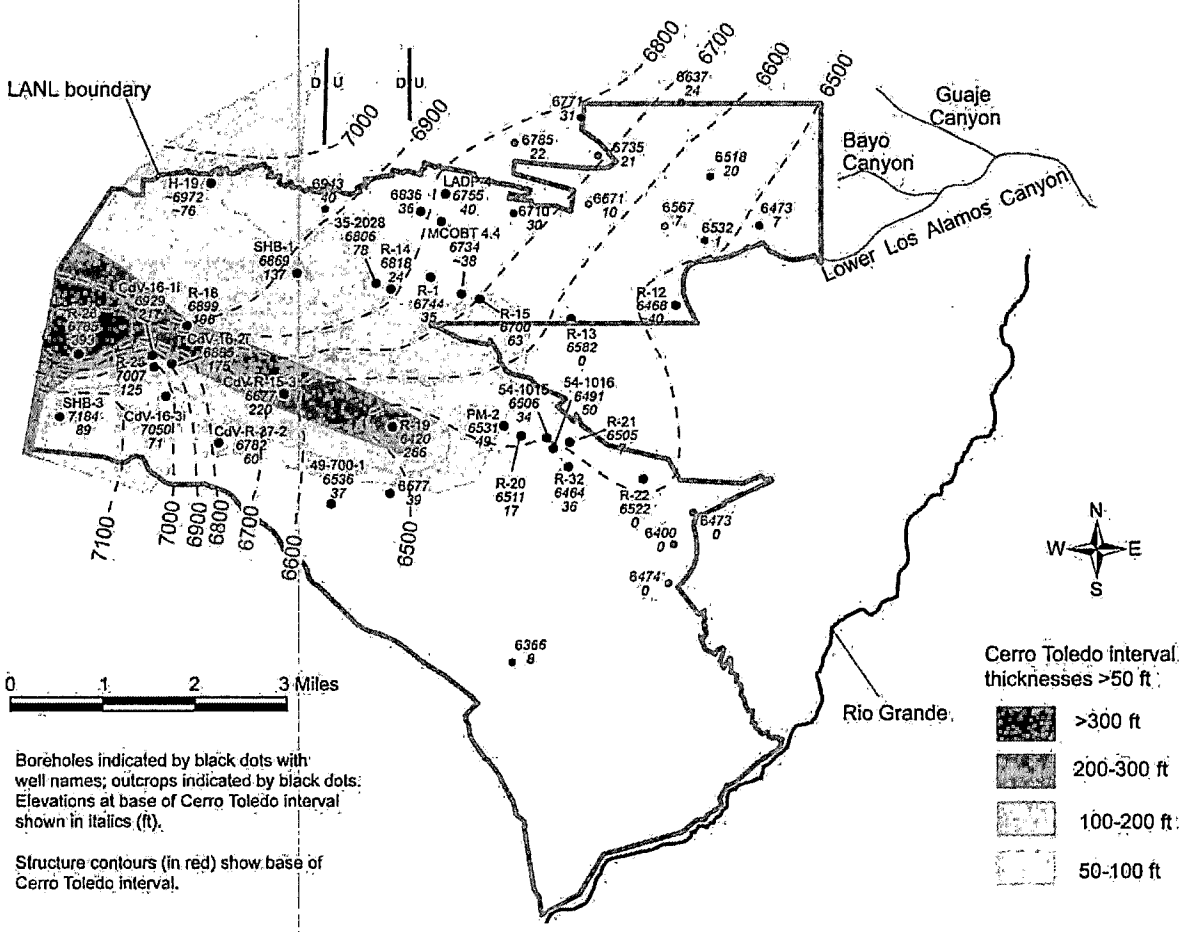

Figure 2-4. Structure contour and isopach map for the Cerro Toledo interval. Structure contours for base of unit indicate that Cerro Toledo filled a broad southeast-trending paleovalley incised into the Otowi Member (see isopach map for Otowi Member in Figure 2-5). The thickest Cerro Toledo deposits coincide with the axis of the paleovalley.

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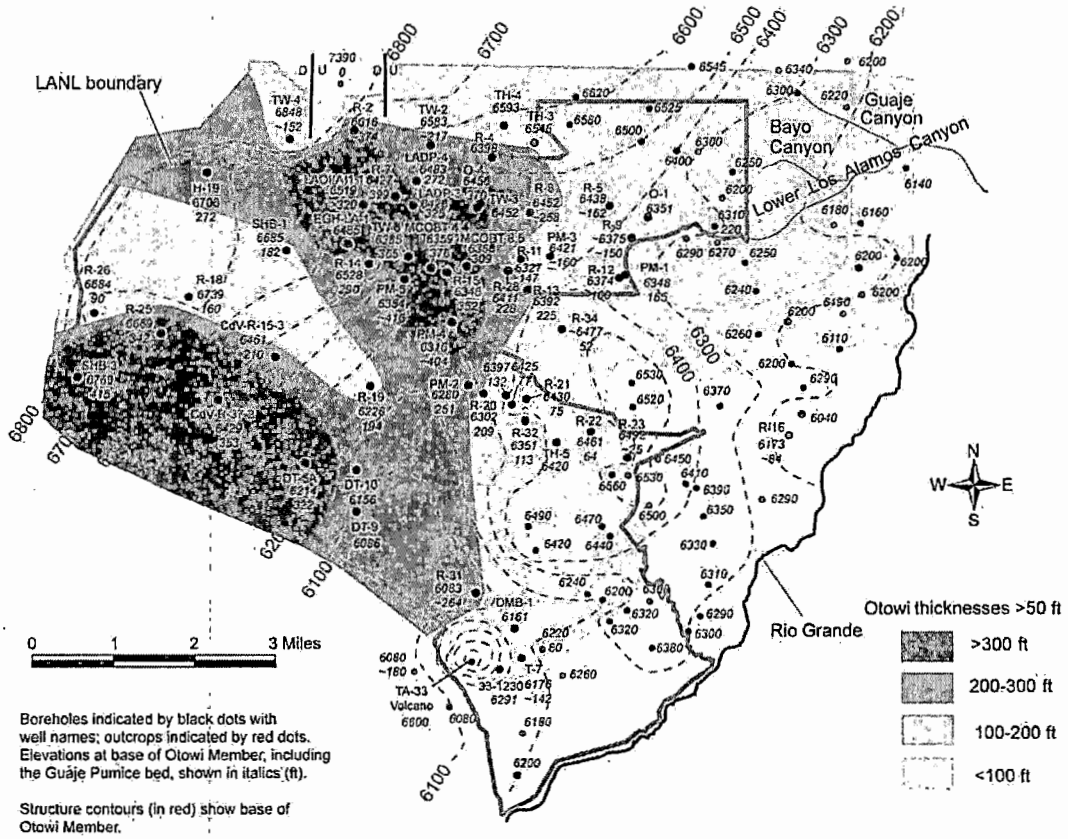

Figure 2-5. Structure contour and isopach map for the Otowi Member of the Bandelier Tuff. Structure contours are for base of Guaje Pumice Bed and show the paleotopography prior to eruption of the Otowi Member. Otowi ash-flow tuffs filled a broad north-trending paleovalley bounded by the Sierra de los Valles highlands on the west and the Cerros del Rio basaltic highland on the east. The variable thickness of the Otowi Member on the western side of the plateau represents deep erosion of these poorly consolidated nonwelded tuffs prior to eruption of the Tshirege Member.

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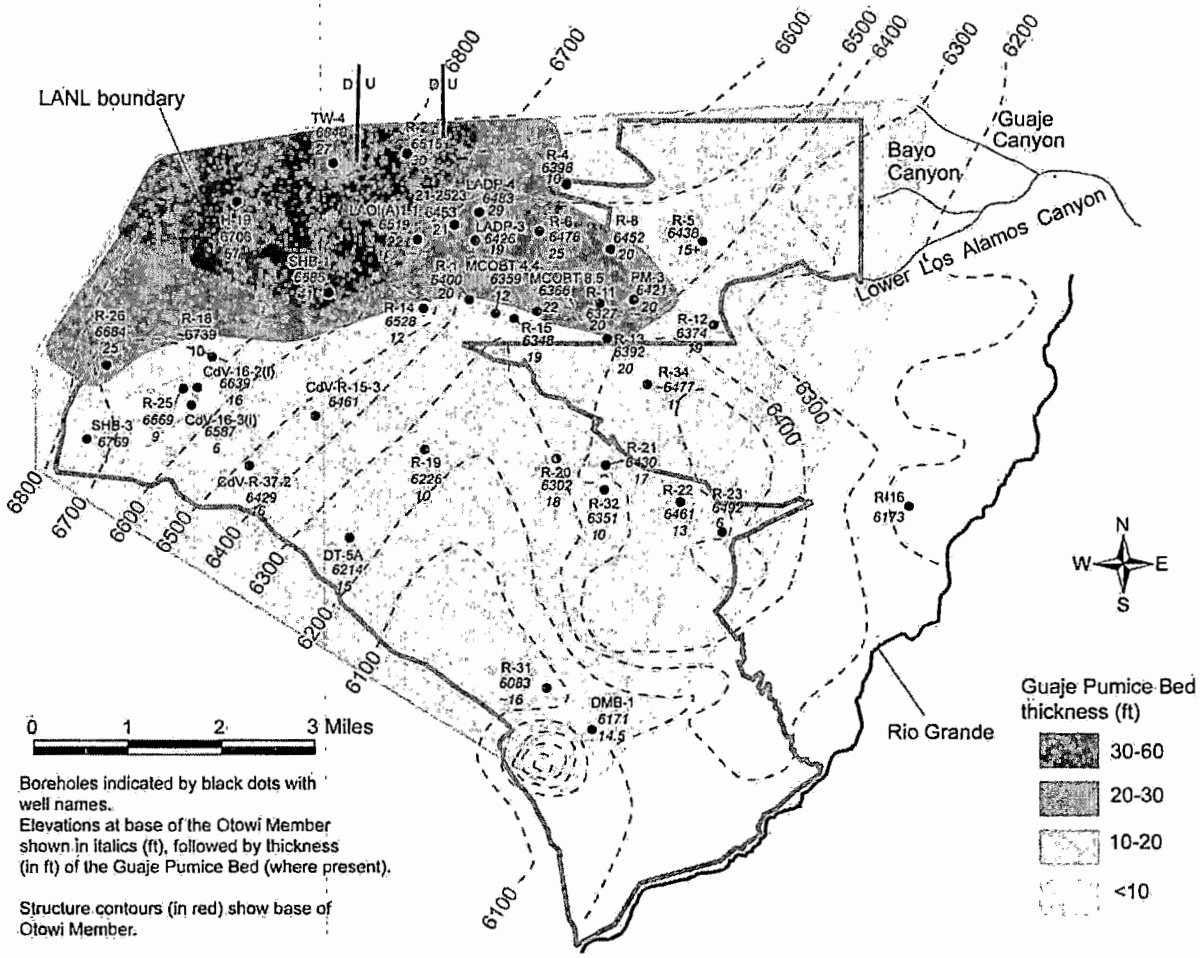

Figure 2-6. Isopach and structure contour map of the Guaje Pumice Bed.

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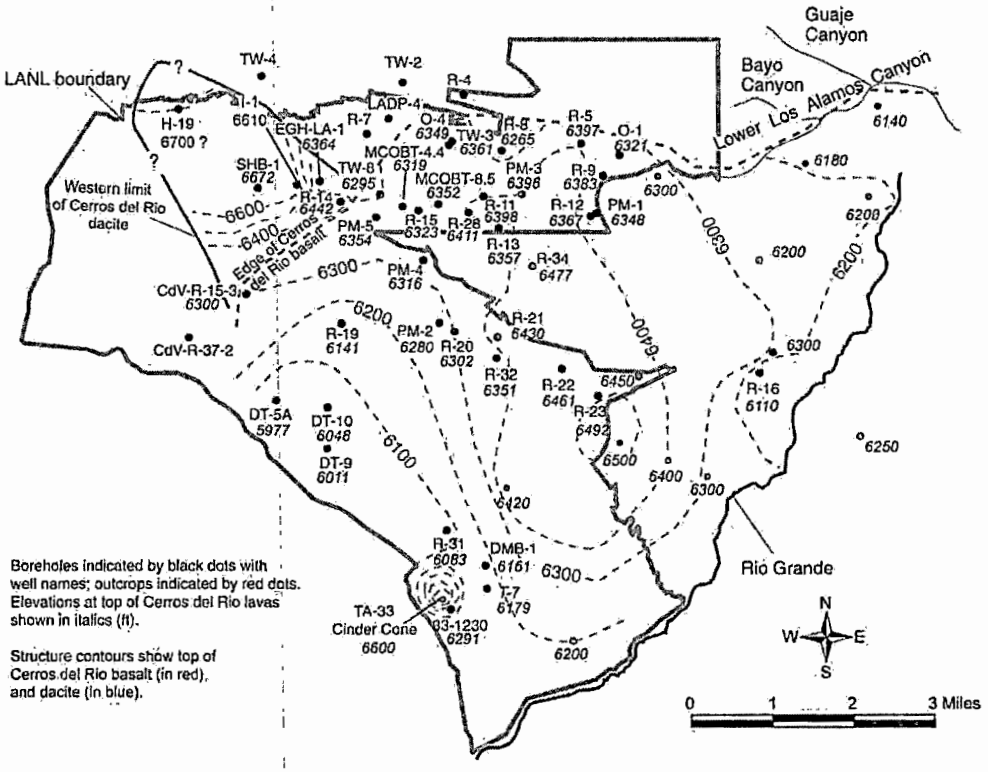

Figure 2-7. Structure contour for the top of Cerros del Rio basalt and western dacite on the Pajarito Plateau. Green dashed line indicates the northern and western extent of the Cerros del Rio volcanic field. Blue line indicates western extent of dacitic lavas that were contemporaneous with the basalts. Top of Cerros del Rio basalts formed broad north-trending highland on east side of plateau. This highland is now covered by Bandelier Tuff.

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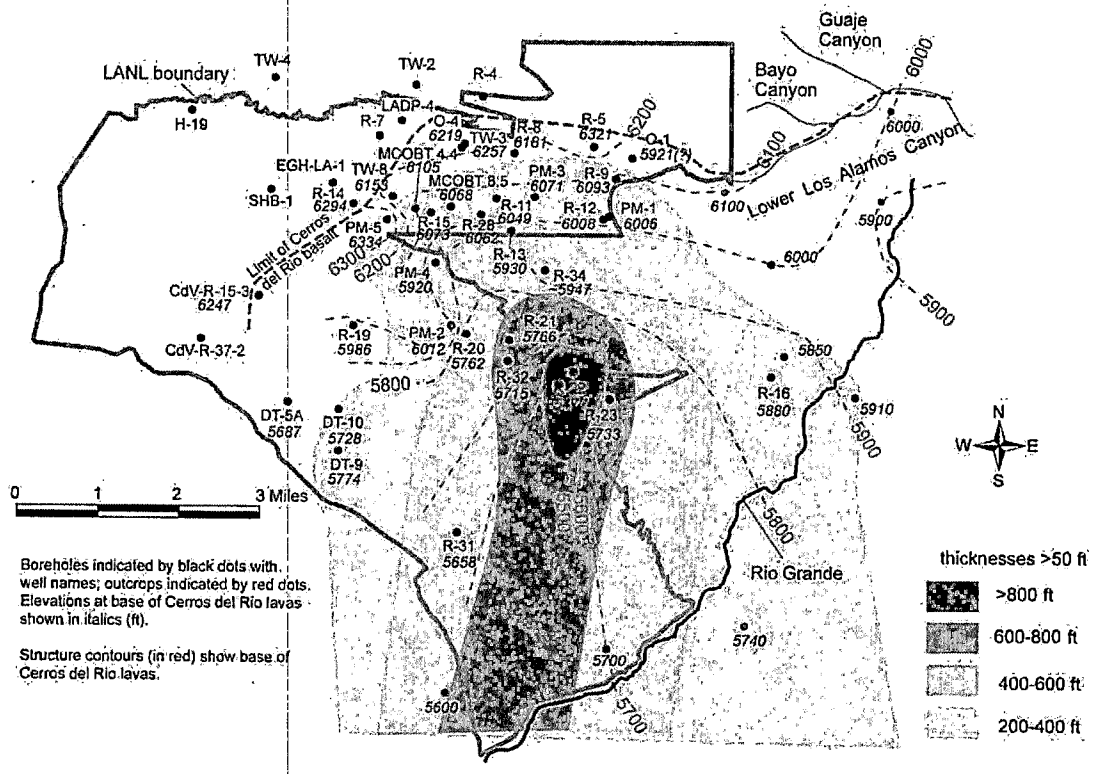

Figure 2-8. Structure contour for the base of Cerros del Rio basalt with isopachs showing the cumulative thickness of flows. Green dashed line indicates the northern and western boundary of the Cerros del Rio volcanic field. The maximum thickness of basalt corresponds with structural-contour lows, suggesting that the basalts accumulated in topographic basins.

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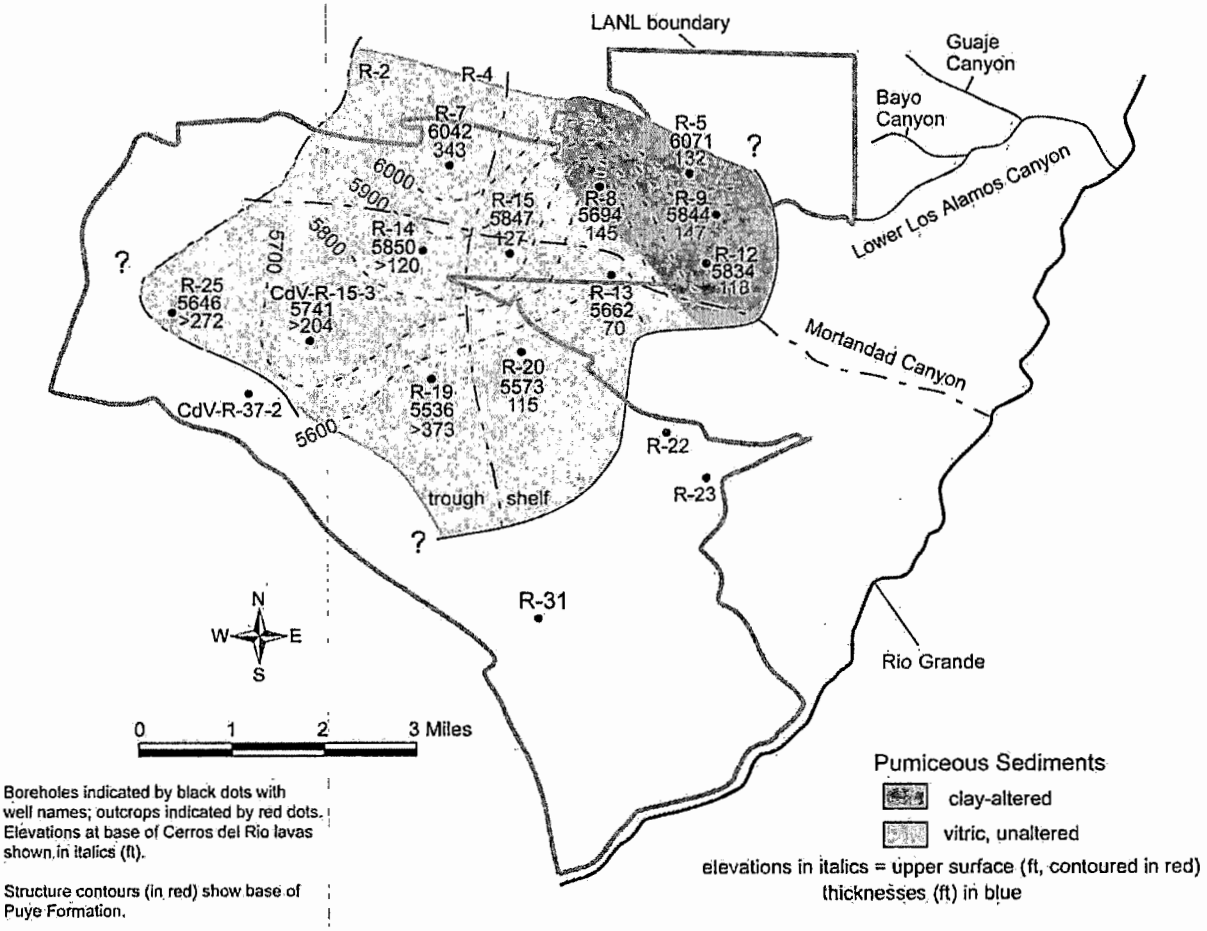

Figure 2-9. Topography at the upper surface of the pumiceous deposits underlying Puye Formation fanglomerates, with pumiceous deposit thicknesses (ft) indicated in blue. Color shading is used to distinguish vitric unaltered pumiceous deposits from those that are clay-altered.

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Each of these figures is based on the interpretations of cuttings, geophysical logs, and in some cases borehole video data to determine the elevations of the upper and lower stratigraphic contacts for individual stratigraphic units. Isopach maps for shallow units that crop out in canyon walls, such as the Cerro Toledo interval and the Otowi Member, are corrected for the effects of the modern canyon incision. Each point on the figure represents either a borehole (with borehole name listed) or an outcrop location (without a borehole label). The data points list the elevation of the basal contact in ft above sea level (asl) and the unit thickness in ft. Dashed red contours are hand-generated and indicate an interpretation of the topology of the geologic contact; increasingly darker shades of blue indicate increasing unit thickness above this topologic surface.

2.2.1 Tesuque Formation

The Miocene Tesuque Formation is partially penetrated by wells in the eastern part of the Pajarito Plateau where it makes up a significant portion of the aquifer for local communities and LANL (Purtymun, 1995). It is primarily made up of thick fluvial deposits consisting of partly lithified, arkosic sediments derived from Precambrian granite, pegmatite, and sparse sedimentary rocks of the Sangre de Cristo Range and from Tertiary intermediate to felsic volcanic rocks from northern New Mexico and possibly southern Colorado (Cavazza, 1989). Individual beds are generally less than 3 m (10 ft) thick and consist of massive to planar- and cross-bedded light pink-to-buff siltstone and sandstone, with minor lenses of pebbly conglomerate. Exposures near the Rio Grande (Koning and Maldonado, 2001) indicate that the Tesuque Formation beneath the plateau probably consists primarily of the Pojoaque Member. In well PM-5, a 110-m (360-ft) thick series of basalt flows within the Tesuque Formation yielded a $^{40}Ar/^{39}Ar$ date of 11.39 ± 0.40 Ma (WoldeGabriel et al., 2001).

Based on Formation Microimager (FMI) logs for well R-16, bedding in the Tesuque Formation on the east side of the plateau dips predominantly towards the west-northwest (LANL, 2003). The mean dip is 11° but dips tend to be greater in the lower part of the well (median dip 14° below 1170 ft) than in the upper part (median dip 9°). Tesuque beds just east of the Rio Grande dip westward mainly at angles of 3° to 10° (Koning and Maldonado, 2001).

2.2.2 Miocene Basalts

Miocene basalts are intercalated with Santa Fe Group deposits in the east-central part of the Pajarito Plateau. WoldeGabriel et al. (1996) divided these basalts into two age groups based on $^{40}Ar/^{39}Ar$ dates. The older group ranges in age from 10.9 to 13.1 Ma and is largely found in the vicinity of Guaje Canyon. The younger group ranges in age from 8.4 to 9.3 Ma and is found over a wide area that extends from Bayo Canyon on the north to Ancho Canyon on the south and from PM-1 on the east to PM-5 to the west.

2.2.3 Older Fanglomerate

The informal term "older fanglomerates" refers to a thick sequence of late Miocene fan deposits that were shed from the Jemez volcanic field into the western Española Basin. These deposits, which are found only in deep boreholes, are important for the development of high-yield,

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low-draw-down municipal and industrial water supply wells on the Pajarito Plateau (Purtymun, 1995). Purtymun (1995) called these deposits the "Chaquehui Formation" and assigned them a post-Chamita and pre-Puye age. From borehole observations, the Chaquehui Formation consisted of up to 1500 ft of gravels, cobbles, and boulders derived from the Jemez volcanic field and volcanic, metamorphic, and sedimentary rocks derived from highlands to the north and east. However, the Miocene deposits identified as Chaquehui Formation in deep wells are more appropriately called "older fanglomerates" because recent stratigraphic studies indicate the Chaquehui Formation type section consists of younger (late Pliocene) phreatomagmatic deposits (Heiken et al., 1996).

The older fanglomerates are widespread beneath the Pajarito Plateau, based on borehole observations. These deposits are mostly made up of volcanic detritus derived from Keres Group rocks and possibly from early Tschicoma Formation centers. They are characterized by dark, lithic sandstones and gravel and cobble deposits dominated by fresh to silicified, subangular to rounded andesite, latite, and porphyritic dacite. Subordinate clasts (<10%) include subangular to rounded rhyolite and basalt, and rounded quartzite. Rounded granite and angular chert clasts are generally rare (<1%) (Broxton and Vaniman 2005).

Precambrian quartzite, granite, and chert clasts are persistent, but in low abundance in the older fanglomerates. The source of Precambrian clasts may be Santa Fe Group rocks that were exposed within the Jemez volcanic field at the time of Keres volcanism. Stratigraphic relationships described by Gardner and Goff (1996) indicate that Santa Fe Group deposition interfingered with Keres volcanism in the caldera area. Additionally, rounded quartzite and granitic gneiss pebbles are found in lag gravels on the resurgent dome of the Valles caldera where they presumably weathered out of Santa Fe Group rocks in megabreccia blocks that slumped into caldera during caldera collapse (Goff et al., 2003).

The maximum thickness of older fanglomerate penetrated by wells is 1650 ft in well Otowi-4. However, thicknesses could be greater to the west where drillholes did not fully penetrate the unit. The westward thickening wedge of volcaniclastic sedimentary deposits corresponds to the zone of thick, highly productive aquifer rocks that extend northeastward across the central plateau as described by Purtymun (1995). The western boundary of this thick sequence of sediments is poorly defined, but recent drilling results suggest that these rocks probably extend to the Pajarito fault zone. The older volcaniclastic deposits abruptly thin eastward between east-west pairs of wells such as R-23/R-22 and Otowi-1/Otowi-4. The transition zone generally corresponds to the eastern boundary of the gravity low beneath the Pajarito Plateau described by Ferguson et al. (1995).

2.2.4 Totavi Lentil

The Totavi Lentil is made up of river-channel sands and gravels that crop out along the Puye escarpment, in lower Los Alamos and Guaje Canyons, and along White Rock Canyon. These rocks are also penetrated by a number of wells on the Pajarito Plateau. These axial-channel deposits were named the Totavi Lentil of the Puye Formation for a type section in Los Alamos Canyon (Griggs, 1964). Griggs recognized their importance as ancestral Rio Grande deposits,

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and he used them to delineate the base of the Puye Formation with which they are conformable in outcrops.

The Totavi Lentil is a poorly consolidated conglomerate containing well-rounded cobbles and gravels of Precambrian quartzite, granite, and pegmatite with subrounded to subangular cobbles and boulders of silicic to intermediate and rarer basaltic volcanic rocks. Precambrian clasts typically make up >80% of the clasts in the deposits. Though commonly subordinate in abundance, clasts of volcanic rocks from the Jemez volcanic field make up to 50% of the deposit in some interbedded horizons. Lenses of loose, well sorted, fine to coarse sands containing abundant quartz and microcline are intercalated with the conglomerate. Totavi deposits are generally ~50 ft thick near the Rio Grande and thicken to the northwest (Griggs, 1964). An unusually thick sequence of quartzite-rich conglomerate (>323 ft) was penetrated in well R-31, located in Ancho Canyon. A number of wells (e.g. R-5, R-9, R-12, R-32) did not encounter the Totavi Lentil, indicating that these channel conglomerates may form lenticular deposits of limited lateral extent.

Based on new well data, it is evident that ancient river deposits in the Pajarito Plateau area are coeval with variety of stratigraphic units that span a longer time interval than previously recognized. River gravels occur beneath the pumice-rich volcaniclastic rocks (described below) in wells R-13, R-15, R-20, R-33, R-34, PM-1, PM-2, and PM-5. These river gravel deposits are generally 10- to 30-m (30- to 100-ft) thick and include abundant well-rounded gravels of quartzite, angular to subangular basalt, andesite, and dacite, and minor metavolcanics. Granitic clasts are rare to absent. Radiometric ages indicate the overlying pumice-rich volcaniclastic rocks are late Miocene in age. In well H-19, river gravels 3-m (10-ft) thick occur as rounded quartzite pebbles between two Tschicoma lava flows (Griggs, 1955, 1964). The quartzite-dominated clast compositions suggest these gravels were derived from the Tusas Mountains and were transported southward by the ancestral Rio Chama, with tributaries draining the Jemez volcanic field. A late Miocene age for the early riverine deposits is consistent with geologic interpretations that through-going rivers were established in the Española Basin prior to about 6.96 Ma (Smith et al., 2001; Smith, 2004).

2.2.5 Pumice-Rich Volcaniclastic Rocks

The pumice-rich volcaniclastic rocks (pumiceous deposits) are characterized by well-bedded horizons of light-colored, reworked, tephra-rich sedimentary deposits and subordinate primary ash- and pumice-fall deposits. These rocks consist mainly of tuffaceous sandstones and contain a few beds of lava-rich gravels. The underlying older fanglomerate and overlying Puye Formation contain higher percentages of gravel and cobble beds. In a number of wells, pumice-rich volcaniclastic rocks are separated from the older fanglomerate by the Totavi Lentil (axial deposits of the ancestral Rio Grande).

The pumice-rich deposits typically contain 10 to 30% subangular to rounded, rhyolitic lapilli mixed with 70 to 90% ash and lithic sands. Gravels contain porphyritic dacite, rhyolite, and lesser andesite and basalt. Some intervals contain as much as 90% subangular to angular pumice lapilli that represent primary fall deposits or reworked deposits that underwent minimal transport. In most areas, pumice lapilli are vitric and show little effect from submergence within

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the regional saturated zone except for oxidation on clast surfaces and minor clay development in vesicles.

However, these deposits are diagenetically altered where most of the volcanic glass is replaced by smectite in the northeastern portion of the Laboratory, an area defined by wells R-5, R-8, R-9, and R-12. Shadings of blue in Figure 2-9 distinguish vitric unaltered pumiceous deposits (pale blue) from those that are heavily clay-altered and retain little or no glass (dark blue). The formation of clay in this area is locally accompanied by abundant calcite and variable amounts of zeolite alteration. Because of the extent of alteration, the lack of preservation of glass, and the loss of many petrographic clues for individual pumice bed correlation, it is difficult to determine whether the heavily altered pumices are related to the unaltered pumice or represent an earlier pumice unit and an earlier alteration event.

Most lapilli in the pumice-rich volcaniclastic rocks are aphyric or contain sparse phenocrysts of quartz, sanidine, and plagioclase, but the presence of some biotite-, hornblende-, and pyroxene-phyric varieties indicates that multiple volcanic sources supplied tephra to these deposits. Seven recent $^{40}Ar/^{39}Ar$ feldspar ages between 6.8 and 7.5 Ma were obtained from crystal-poor pumice falls in six wells that penetrate into this unit. The younger ages overlap the 6.01 to 7.1 Ma range of ages reported for the Bearhead Rhyolite (Justet, 1996; Smith, 2001) and the older ages are slightly older. Additional work is taking place to investigate the relation between the pumice-rich volcaniclastic rocks and Keres Group silicic volcanism with the goal of assigning the pumiceous sediments to either the Puye or Cochiti Formations or delineating them as a separate formation.

The pumice-rich volcaniclastic rocks thin northeastward across the central part of the plateau and are absent north of Pueblo Canyon. Borehole geophysical logs indicate that these deposits dip 5° to 15°, primarily towards the southwest and west. Figure 2-9 illustrates structure contours and thickness of pumiceous deposits that occur over a broad region beneath the central portion of the Laboratory where multiple pumice beds have been encountered. Observations from boreholes suggest that the structure of these pumiceous deposits is complex, including both primary and reworked pumiceous units intermixed with fanglomerates. Nevertheless, the pumiceous unit is predictably encountered in the area shown in Figure 2-9. Drilling experience shows that this unit is highly transmissive, providing a difficult drilling horizon where injected fluids are likely to be lost. Hydrologic testing shows that the pumiceous deposits have relatively high transmissivity (Section 2.3.4.2).

In Figure 2-9 the structure contours represent the top, rather than the bottom of the pumiceous deposits. This is done because the bottom of this unit is poorly constrained in R-series drillholes to the south and west, where this unit was seldom penetrated. The structure contours at the top of the pumiceous unit show that it slopes to the south and shows evidence of incision of a broad south-trending paleocanyon, filled by Puye fanglomerate, in the central portion of the Laboratory. This broad canyon is somewhat similar to that seen at the base of the Bandelier Tuff (Figure 2-6) and at the base of the Cerros del Rio volcanic rocks (Figure 2-8), suggesting that broadly south-trending canyons have been a common feature for over 5 m.y. prior to the eruption of the Bandelier Tuff. The present west-northwest/east-southeast drainages on the plateau may be a relatively recent drainage pattern that developed on the thick east-sloping tuff ash flows emplaced after 1.6 Ma.

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2.2.6 Tschicoma Formation

The Tschicoma Formation of the Polvadera Group consists of thick, predominantly dacite to low-silica rhyolite lava flows erupted from large overlapping dome complexes. Major peaks in the Sierra de los Valles, including Cerro Grande, Pajarito Mountain, Caballo Mountain, and Tschicoma Mountain, are compositionally distinct lava domes that represent separate volcanic source areas for detritus that was shed to form the Puye fanglomerates. Low-silica rhyolite erupted from a deeply eroded dome complex in the upper Rendija Canyon and Guaje Mountain area yielded three ages between 4.95 and 5.32 Ma. Dacites of the Cerro Grande, Pajarito Mountain, and Caballo Mountain centers have closely overlapping ages of 2.91 Ma to 3.34 Ma (Broxton and Vaniman, 2005).

Outcrops of the Tschicoma Formation in the Sierra de los Valles are primarily gray to purplish-gray lavas characterized by pronounced jointing and flow foliation. The interflow zones between flow units are commonly marked by blocky breccias. Flow interiors consist of dense, massive rock that is commonly devitrified to form a microcrystalline groundmass, giving the rocks a stony appearance. Chilled volcanic glass is sometimes preserved in flow tops and bottoms. Fragmental deposits of ash and lava debris occur in the distal parts of the formation.

The Tschicoma Formation is at least 2,500 ft thick in the Sierra de los Valles, but has a variable thickness due to the lenticular shapes of its lava flows. The Tschicoma Formation thins eastward under the western Pajarito Plateau where it interfingers with the Puye Formation. The Tschicoma Formation was encountered in wells TW-4, H-19, CDV-16-3(i) and CDV-R-37-2 in the western part of the Pajarito Plateau, but is absent in boreholes to the east, with the possible exception of thick dacite lava in boreholes EGH-LA-1, SHB-1, and I-1. These lavas may be assigned to the Tschicoma but their source and distribution is presently unknown.

2.2.7 Puye Formation

The Puye Formation is a large apron of overlapping alluvial and pyroclastic fans that were shed eastward from the Jemez volcanic field into the western Española Basin (Griggs, 1964; Turbeville et al., 1989). The Puye Formation unconformably overlies rocks of the Santa Fe Group (Tesuque Formation), and the Otowi Member of the Bandelier Tuff unconformably overlies it. Turbeville et al. (1989) estimated its areal distribution at 200 mi^2 and its volume at ~3.6 mi^3. Because its primary source area was volcanic domes in the Sierra de los Valles, the Puye Formation overlaps and post-dates the Tschicoma Formation in age. The Puye Formation is subdivided into fanglomerate and lacustrine facies.

The fanglomerate facies, the dominant unit of the Puye Formation, is a heterogeneous assemblage of clast- to matrix-supported conglomerates, and of gravels and lithic-rich sandstones. Clasts in the coarsest deposits consist of subangular to subrounded cobbles and boulders of latite, dacite, rhyolite, and tuff in a poorly sorted matrix of ash, silts, and sands. Consolidated mudflow deposits are common throughout the unit, and tend to be cliff-forming. At least 25 ash beds of dacitic to rhyolitic composition are interbedded with the conglomerates and gravels (Turbeville et al., 1989).

The lacustrine facies includes lake and riverine deposits in the upper part of the Puye Formation. These deposits are characterized by lacustrine fine sand, silt, and clay up to 30 ft thick. Basaltic ash beds (maar deposits) up to 10 ft thick are locally present above or below the lacustrine deposits. The lacustrine facies includes some well-rounded riverine gravels of Precambrian quartzite and gneiss that fill channels cut into the underlying fanglomerates. The lacustrine facies crops out in lower Los Alamos Canyon and extends both northward and southward in discontinuous outcrops for several miles. Apparently, their extent is limited to the eastern side of the plateau because they are found only in wells R-9, R-12, and R-16. Because of their spatial and temporal association with palagonitic basalt flows and maar deposits, these lacustrine deposits probably represent periods of damming and diversion of the Rio Grande caused by the eruptions of lavas within the Cerros del Rio volcanic field.

The Puye Formation reaches a maximum thickness of >1000 ft in well R-25 on the western side of the Laboratory but thins to 50 ft in areas north of the Pajarito Plateau. In the central and eastern portions of LANL, it is about 600 ft thick and the upper Puye is interbedded with basaltic lavas of the Cerros del Rio volcanic field.

2.2.8 Basaltic Rocks of the Cerros del Rio Volcanic Field

Cerros del Rio basalts typically form thick sequences of stacked lava flows separated by interflow breccia, scoria, sediment, and ash. These rocks are mostly basalts and basaltic andesites, but subordinate dacite is present within thick basalt stacks in the east and central plateau (e.g. Ball et al., 2002) or is found as isolated flows on the western side of the volcanic field. Cerros del Rio lavas were erupted from vents located both east and west of the Rio Grande (Smith et al., 1970; Aubele, 1978; Kelley, 1978).

In major-element composition the dacitic components are very similar to partially contemporaneous dacitic lavas that occur within the highlands of the Tschicoma Formation to the west. However, dacites are less abundant than basalts within the Cerros del Rio and these thin dacitic lavas have relatively few of the common hydrous minerals (amphibole and biotite) that characterize most of the Tschicoma lavas. These distinctions are important because they strongly affect the hydrogeologic character of the lavas. Lavas of the Cerros del Rio lie within suites of relatively thin (a few tens of feet), largely basaltic lava flows with laterally extensive flow-boundary rubble zones that provide pathways for flow. Lavas of the Tschicoma Formation are far more massive, up to hundreds of feet thick, and are generally poorly transmissive (Griggs, 1964).

Individual flows typically range in thickness from about 3 ft to more than 100 ft. The internal structures of flows show some similarities to those described for the Columbia River Basalt Group in Washington, Oregon, and Idaho and for Snake River basalts in Idaho (Swanson et al., 1979; Whiteman et al., 1994; Faybishenko et al., 2000). In ascending order, the flows are characterized by: (1) a flow base characterized by vesicular basalt with clinker and scoria, (2) a colonnade zone made up of vertical, large-diameter columns bound by cooling joints, (3) a thin zone of complexly-overlapping fractures, and (4) a flow top of vesicular basalt with scoria and clinker. In addition to highly porous clinker zones associated with flow tops and bottoms, interflow zones include cinder deposits and sedimentary deposits. Interflow cinder deposits are

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fairly common, and their thickness is highly variable (0 to 100 ft), depending on proximity to source vents. The thickest cinder deposits are as much as 300 ft thick on or near source vents (e.g. R-34). Interflow sedimentary deposits are generally thin (<20 ft) where present and consist mostly of reworked basaltic rocks. In the eastern part of the plateau, where the basalts interacted with surface water, flow bases commonly include porous, pillow-palagonite complexes.

The basaltic rocks of the Cerros del Rio volcanic field include buried remnants of maar volcanoes in White Rock Canyon. The aprons of fragmental debris surrounding these buried craters consist of thin layers of basaltic ash and sediments. The maar deposits resulted from steam explosions that occurred where basalt erupted through an aquifer or standing body of water. Thin maar deposits were identified at the base of the Cerros del Rio basalt in R-9 and R-12.

The distribution, form, and thickness of the Cerros del Rio volcanic field beneath the plateau are illustrated in Figure 2-7, which shows the topography at the top of the Cerros del Rio and Figure 2-8, which shows structure contours (red dashed lines) at the base of the Cerros del Rio. In Figure 2-8 shadings of purple represent the variation in thickness of the total Cerros del Rio deposits that lie between the two contoured surfaces in these figures.

Figure 2-7 shows that the upper surface of the Cerros del Rio is irregular, with a broad highland that extends from north to south under the east-central portion of the Laboratory. This highland is largely buried beneath the Bandelier Tuff, but remnants of the eastern slope extending from the highland are exposed beneath the town of White Rock. The highland represents distributed volcanic centers that produced most of the basaltic and dacitic lavas that underlie the Laboratory. Direct evidence of these eruptive centers is found in thick cinder deposits that were encountered in drillholes R-22 and especially R-34, and a low cinder-covered volcanic center exposed just south of R-23 in TA-36. These cinder deposits are extremely porous and generally provide highly transmissive media, but they are localized around volcanic centers so that enhanced groundwater flow is likely to extend for less than one mile, based on the extent of the TA-33 cinder cone (Figure 2-7).

Figure 2-8 shows the topography at the base of the Cerros del Rio volcanic series and the exceptional thickening of these deposits beneath R-22 and (probably) extending along a paleocanyon extending to the south. The extent of this deep trough to the north and south is not well defined by current drillhole locations. Based on the absence of Totavi-like deposits within this channel at R-22 and the lack of evidence to the northeast in the canyon walls of lower Los Alamos Canyon, it is likely that the head of the canyon rose steeply to the northwest and drained the Sierra de los Valles. This thick keel of lavas and intercalated rubble zones occurs largely beneath the regional aquifer water table and hosts an important part of the regional aquifer beneath the southeast portion of the Laboratory. It is possible that this feature could affect the flow direction and head distributions at depth.

2.2.9 Bandelier Tuff

The Laboratory facilities are located almost entirely on mesa and canyon outcrops of Bandelier Tuff. The Bandelier Tuff consists of ash flows and minor airfall pyroclastic deposits with ages of

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1.61 Ma for the Otowi Member and 1.22 Ma for the Tshirege Member (Izett and Obradovich, 1994). The two Bandelier Tuff members are separated by the Cerro Toledo interval, which is a stratified sequence of volcaniclastic sediments and tephra of mixed provenance. Although it occurs between the ash-flow members of the Bandelier Tuff, the Cerro Toledo interval is not considered part of the Bandelier Tuff, a usage consistent with the original definition by Bailey et al. (1969).

2.2.9.1 Otowi Member, Bandelier Tuff

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, porous, nonwelded ash-flow tuffs that form colluvium-covered slopes along the base of canyon walls. The Otowi ash-flow tuffs are vitric and contain light gray-to-orange pumice supported in a white to tan ashy matrix of glass shards, broken pumice, crystals, and rock fragments. The Otowi Member is made up of multiple ash flows, but individual ash-flow deposits cannot be traced in the subsurface using core and cuttings from widely spaced boreholes. The base of the member is called the Guaje Pumice Bed (Figure 2-6), and is discussed below. In some drillholes, a shift in borehole gamma measurements in the central part of the unit provides a useful datum for correlations between drillholes. The nonwelded ash-flow tuffs of the Otowi Member collectively form a relatively homogenous rock unit throughout the plateau. Transport through this hydrogeologic unit appears to occur primarily by matrix flow, although open fractures may contribute to transport locally (e.g., R-25). Although made up of multiple flow units, the combined Otowi ash flows are massive, and borehole geophysical logs show only minor variations in density and porosity.

The present maximum thickness of Otowi Member occurs in two areas in the western part of the plateau where the deposits are about 350 to 400 ft thick. Otowi deposits are only <100 to 300 ft thick between these two areas. The thin deposits are overlain by unusually thick Cerro Toledo sediments that apparently accumulated in a broad east-southeast-trending drainage incised into the top of the Otowi Member. On the eastern side of the plateau, the Otowi Member is 0 to 100 ft thick. Thinning of the deposits eastward reflects both the general thinning of the Otowi Member away from its caldera source and thinning of the ash-flow tuffs over the Cerros del Rio highland on the east side of the plateau. Structure contours indicate that Otowi ash-flow tuffs filled a broad south-draining paleovalley west of the Cerros del Rio basaltic highland.

Figure 2-5 shows structure contours (red dashed lines) at the base of the Otowi Member of the Bandelier Tuff and color shading in purple that represents relative overall thickness of the unit. The Otowi Member thickens from the central portion of the Laboratory toward the west, with the exception of a paleocanyon that is aligned with and filled by the thick Cerro Toledo deposits shown in Figure 2-5. To the east, south of PM-1 where Otowi deposits ramp up onto the Cerros del Rio basaltic volcanic centers with little or no Puye sediment cover, the Otowi deposits are thinner than to the northeast where they are underlain mostly by eastward-sloping Puye fans. In the south-central portion of the Laboratory the Otowi deposits fill a broad south-trending valley formed by low terrain between Puye fans sloping down from the west and Cerros del Rio highlands to the east, such as the TA-33 volcano.

The Guaje Pumice Bed occurs at the base of the Otowi Member and is an extensive marker horizon in outcrop and wells. The Guaje Pumice Bed contains layers of sorted pumice fragments

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whose mean size varies between 2 and 4 cm. It has an average thickness of ~15 ft over much of the plateau, but thickens considerably to the northwest (Figure 2-6). Geophysical logs show that the Guaje Pumice Bed has a higher porosity than overlying Otowi ash-flow tuffs and underlying Puye Formation. The Guaje Pumice Bed appears consistently as a zone of higher porosity and elevated moisture content in CMR geophysical logs. Because of this property the Guaje Pumice Bed can provide a relatively thin (a few feet to a few tens of feet) but laterally continuous horizon capable of local saturation.

Figure 2-6 uses color shading to represent the thickness of the Guaje Pumice Bed. Because the Guaje Pumice Bed formed as a pumice fall rather than an ash flow, the tendency to thin away from the source (the Valles caldera) is much less pronounced except for the area underlying the northwestern corner of the Laboratory. The distribution of pumice fall deposits is more strongly influenced by prevailing wind direction at the time of eruption, compared with the largely internal energy sources that distribute ash flows. A general lack of incision and weathering at the top of the Guaje Pumice Bed indicates that little time elapsed before it was buried by magmatically related ash flows of the Otowi Member. Locally, however, the Guaje Pumice is unusually thin compared to surrounding areas and may have been partially eroded before or during the passage of the earliest Otowi ash flows. In the eastern portion of the Laboratory the Guaje Pumice Bed is seldom more than a few feet thick and is locally absent.

2.2.9.2 Tephra and Volcaniclastic Sediments of the Cerro Toledo Interval

The Cerro Toledo interval crops out in Los Alamos Canyon and in canyons to the north, and it occurs in many of the wells on the plateau. It unconformably overlies the deeply eroded Otowi Member and its thickness is highly variable (3 to 390 ft). Figure 2-4 shows structure contours at the base of the Cerro Toledo interval and a colored representation of relative overall thickness of the unit. Structure contours for the base of the Cerro Toledo indicate that this unit fills a broad southeast-draining valley fed by one or more canyons exiting the Sierra de los Valles. The thickest Cerro Toledo deposits coincide with the axis of this paleovalley.

The predominant rock type in the Cerro Toledo interval is rhyolitic tuffaceous sandstone and tephra. These deposits contain abundant crystal-poor ash and pumice, and clasts of vitric to devitrified rhyolite lava and minor obsidian. They represent the reworked equivalents of Cerro Toledo Rhyolite tephra erupted from the Cerro Toledo and Rabbit Mountain dome complexes located northeast and southeast of the Valles caldera, respectively. Primary pumice-and ash-falls are interbedded with these sedimentary deposits in most locations.

Clast-supported gravel, cobble, and boulder deposits of porphyritic Tschicoma dacite derived from the Tschicoma Formation are also interbedded with the tuffaceous rocks. In some deposits, the dacitic detritus is volumetrically more important than the tuffaceous detritus. These coarse dacitic deposits commonly define the axial portions of channels incised into the underlying Otowi Member.

In the western part of the plateau, the Cerro Toledo interval contains a large component of crystal-rich tuffaceous detritus. These tuffaceous sediments represent reworked Otowi tuff that accumulated in drainages incised into the Otowi Member prior to emplacement of the Tshirege

Member. These reworked Otowi deposits are interbedded with other volcaniclastic deposits derived from Cerro Toledo and Tschicoma sources.

Data from boreholes R-19, CdV-R-15-3, CdV-16-1(i), R-18, and R-26 revised the conceptual model for the Cerro Toledo interval, which was a general thinning from Cerro Toledo age volcanic sources in the caldera to the northwest of the Laboratory to distal deposits toward the east-southeast (Broxton and Vaniman, 2005). These boreholes, however, showed that the thickening is not uniform and the Cerro Toledo sediments fill a deep and broad east-southeast draining paleocanyon in the middle western portion of the Laboratory. This paleocanyon is incised into the top of the Otowi ash flows; the overlying base of the Tshirege Member of the Bandelier Tuff and the underlying base of the Otowi Member (Figure 2-5) show no such canyon development. The structure contours that show the base of the Cerro Toledo interval in Figure 2-4 show the topology of the canyon eroded into the top of the Otowi ash flows. The exact width and the orientation of this canyon, whether it is one canyon or several, and where this canyon connected to paleodrainages toward the Rio Grande to the east are relatively unconstrained points that allow a certain amount of latitude in the way that Figure 2-4 is constructed.

2.2.9.3 Tshirege Member, Bandelier Tuff

The Tshirege Member is the upper member of the Bandelier Tuff and is the most widely exposed bedrock unit of the Pajarito Plateau. It is a multiple-flow, ash-and-pumice sheet that forms the prominent cliffs throughout the plateau. 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 over 200 ft thick in the north-central part of LANL and over 600 ft thick near the southern edge of LANL.

The Tshirege Member differs from the Otowi Member most notably in its generally greater degree of welding compaction. Time breaks between the successive emplacements of ash-flow units caused the tuff to cool as several distinct cooling units. For this reason the Tshirege Member is a compound cooling unit, consisting of at least four cooling subunits that display variable physical properties vertically and horizontally. These variations in physical properties reflect zonal patterns of varying degrees of compaction, welding, and glass crystallization. The welding and crystallization zones in the Tshirege Member produce vertical variations in properties such as density, porosity, hardness, composition, color, and surface weathering patterns. The degree of welding in each of the cooling units generally decreases from west to east, reflecting higher emplacement temperatures and thicker deposits closer to the Valles caldera.

The Tsankawi Pumice Bed forms the base of the Tshirege Member. Where exposed, it is commonly 2 to 3 feet in thickness. This pumice-fall deposit contains sorted pumice lapilli (diameters reaching about 2.5 in) in a crystal-rich matrix. Several thin ash beds are interbedded with the pumice-fall deposits.

Because the thick Tshirege ash flow tuffs make up a significant portion of the upper vadose zone, brief descriptions are provided below for the major subunits of the member, from bottom to top:

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- **Qbt 1g** is the lowermost subunit above the Tsankawi Pumice Bed. It consists of porous, nonwelded, and poorly sorted ash-flow tuffs. 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 alteration. The tuffs of Qbt 1g are nonwelded and have an open, porous structure.
- **Qbt 1v** forms alternating cliff-like and sloping outcrops composed of porous, nonwelded, but crystalline tuffs. The "v" stands for vapor-phase crystallization that together with crystallization of glass in shards and pumices (devitrification) transformed the rock matrix into microcrystalline aggregates of silica polymorphs and sanidine. The tuffs of Qbt 1v are generally nonwelded to slightly welded, and have an open, porous structure.
- **Qbt 2** forms a distinctive, medium brown, vertical cliff that stands out in marked contrast to the slope-forming, lighter colored tuffs above and below. A series of laminated and cross-bedded deposits commonly mark its base in the eastern part of the Laboratory. In the central and western part of the Laboratory, the boundary between Qbt 2 and Qbt 1v is gradational and the distinction between the two units is somewhat arbitrary. Qbt 2 is typically the most strongly welded tuff in the Tshirege Member. Vapor-phase crystallization of flattened shards and pumices is extensive in this subunit.
- **Qbt 3** is a nonwelded to partly welded, vapor-phase altered tuff that forms the cap rock of mesas in the central part of the Pajarito Plateau. Qbt 3 becomes moderately to densely welded in the western part of the plateau.
- **Qbt 4** is a complex unit consisting of nonwelded to densely welded ash-flow tuffs and thin intercalated surge deposits. Devitrification and vapor-phase alteration are typical in this unit, but thin zones of vitric ash-flow tuff occur locally. The occurrence of Qbt 4 is limited to the western part of the Pajarito Plateau.

2.2.10 Alluvium and Colluvium

Holocene and late Pleistocene canyon-floor alluvium consists of stratified, lenticular deposits of unconsolidated fluvial sands, gravels, and cobbles (Reneau et al., 1996). Smaller canyons whose headwaters are located on the plateau contain detritus exclusively of Bandelier Tuff. Larger canyon systems that head in the Sierra de los Valles contain Bandelier detritus mixed with dacite detritus derived from the Tschicoma Formation. Active and inactive channels and floodplains form complex, cross-cutting deposits. These fluvial sediments interfinger laterally with colluvium derived from canyon walls. In Pueblo Canyon alluvium is about 11 ft thick on the west side of the plateau and about 18 ft thick near the confluence with Los Alamos Canyon. Mortandad Canyon has 1 to 2 ft of alluvium near its headwaters and more than 100 ft of alluvium (plus colluvium) near the eastern LANL boundary.

Alluvium of probable early Pleistocene age overlies Bandelier Tuff on mesas throughout the plateau (Reneau and McDonald, 1996). The alluvial deposits form fairly continuous deposits on the western side of the plateau, but only remnants of these deposits are preserved further east. These alluvial deposits are primarily made up of coarse dacitic detritus from the Sierra de los Valles, but some locations also contain Valles Rhyolite (Cerro del Medio and El Cajete) fall deposits or their reworked equivalents. These deposits record the locations post-Tshirege alluvial fans and streams that predate incision of canyons on the plateau (Reneau and McDonald, 1996).

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Colluvium consists of slope or cliff detritus shed gravitationally into canyons. In most instances only large blocks of colluvium can be distinguished from locally derived alluvium, where the colluvial blocks are identified with material in adjacent cliffs. Colluvial blocks are commonly overlain by alluvium, as in the wider reaches along Mortandad Canyon where blocks of upper devitrifed units of the Tshirege Member, often several feet in diameter, are found beneath alluvial sands and gravels in drillhole MCOBT-8.5.

2.3 Geologic Conceptual Model Cross-Sections

The geologic conceptual model is based on the accumulated geologic, geophysical, and hydrogeologic data described in Section 2.1. Regional and local data sources are used to constrain possible visualizations of the thickness and extent of major hydrogeologic units beneath the Laboratory. Of all data sources, the principal sources for building the subsurface components of the geologic conceptual model are obtained through the R-hole drilling program conducted under the Hydrogeologic Workplan. These data are supplemented by drilling data collected from boreholes that were drilled for other purposes. Because samples and geophysical logs from earlier boreholes are largely unavailable, and earlier wells were not drilled with the goal of obtaining a sitewide hydrogeologic model, the R-series wells provide the best available dataset for subsurface geology at the Laboratory. The various types of stratigraphic data from R-series wells and from other boreholes used to support the geologic conceptual model are summarized in Appendix 2-A.

2.3.1 Geology at the Water Table

The distribution of bedrock units at the top of regional saturation is shown in Figure 2-10. Regional groundwater enters the Pajarito Plateau by underflow through the rocks that underlie the Sierra de los Valles (Griggs, 1964; Purtymun, 1984). This underflow is supplemented by recharge from drainages that cross the plateau (Kwicklis et al., 2005). Hydrogeologic conditions beneath the Sierra de los Valles west of the Pajarito fault zone are largely unknown because there are no deep wells in this area. Groundwater probably flows through Tschicoma lavas and underlying geologic units at depth, based on stratigraphic cross-sections (see Section 2.3.2). The geologic units beneath the Tschicoma Formation are poorly constrained but probably consist of Keres Group volcanic rocks, Santa Fe Group sediments, Eocene sedimentary rocks, Paleozoic and Mesozoic sedimentary rocks, and Precambrian crystalline rocks (Smith et al., 1970; Goff and Gardner, 2004; Smith, 2004). In the western part of the plateau, in the vicinity of Pueblo and Water Canyons, the water table is straddled by two lobes of down-faulted Tschicoma lavas that extend up to 3 km (2 mi) east of the Pajarito fault zone. Based on the physical characteristics of the rocks, groundwater flow through dacite most likely occurs as fracture flow in the lava interiors and as porous flow in interflow zones and interbedded clastic deposits.

In the central part of the plateau, the regional water table occurs within basin-fill deposits that become progressively older to the east. These basin-fill deposits consist of the Puye Formation, pumice-rich volcaniclastic rocks, older fanglomerates, and the Tesuque Formation (Figure 2-10). The most productive municipal supply wells on the plateau occur in this area where long well

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screens (500 m [1600 ft]) span the Puye Formation, pumiceous deposits, Totavi deposits, older fanglomerates, and Tesuque sedimentary rocks and basalts.

Basalt straddles the water table in two areas. The most extensive is located in the south-central part of the plateau where as much as 195 ft of saturated Pliocene Cerros del Rio basalt occurs at the top of the regional zone of saturation in well DT-10 and 290 ft occurs in well R-22 (Figure 2-10). A smaller region of older Miocene basalts straddles the water table in a north-trending zone extending between wells R-12 to R-5. The southern extent of this zone is poorly constrained.

The Tesuque Formation is the primary rock unit making up the regional aquifer in the eastern part of the plateau and in the Buckman well field east of the Rio Grande (Figure 2-10). Miocene basalts are interbedded with the Tesuque Formation beneath parts of the plateau, but are absent in wells drilled to depths of 300 to 575 m (1000 to 1900 ft) in the Buckman well field (Shomaker, 1974). Most of the production from municipal supply wells in Guaje Canyon and in lower Los Alamos Canyon comes from the Tesuque Formation.

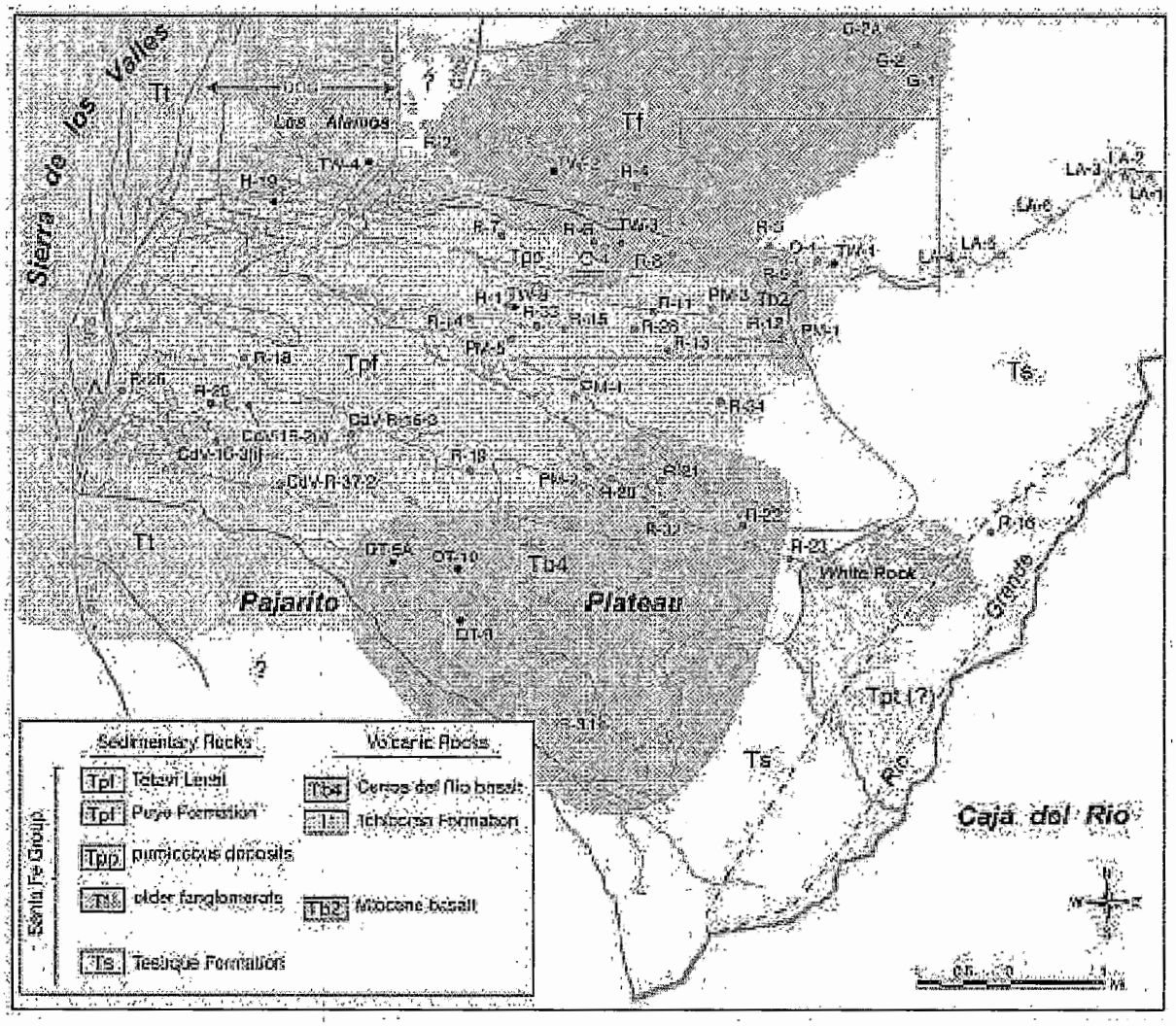

Figure 2-10. Map showing distribution of geologic units at the top of the regional saturated zone beneath the Pajarito Plateau. The wells that provided geologic control for this map are indicated by dots using the same color schemes as Figure 2-2. The LANL boundary is shown by the green outline, and the Pajarito fault zone is shown in blue. The map portrays the dominant rock unit in the upper 50 ft of the regional saturated zone.

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2.3.2 Representative Cross-Sections

The full three-dimensional implementation of the geologic model is discussed in Section 4.1. The 3D model is tested against conceptual cross-sections that incorporate time-stratigraphic constraints, structural considerations, and correlations and limitations that take into account source regions and settings beyond the boundaries of the 3D model. The development of a manageable 3D model is time-intensive and requires treatment of geologic units on a large scale, where some details must necessarily be incorporated into larger units or ignored. Conceptual cross-sections help to test ideas concerning site geology, present details that may not be manageable in the 3D model, and provide a means of rapid testing of new borehole data against existing concepts.

Figure 2-11 shows alignments for eight conceptual geologic cross-sections that cover the Laboratory area. Included are four conceptual cross-sections for principal drainages:

- Los Alamos Canyon (Figure 2-12),
- Mortandad Canyon (Figure 2-13),
- Pajarito Canyon (Figure 2-14), and
- Water Canyon (Figure 2-15).

In addition, four cross-sections of approximately southwest-northeast alignment cross the grain of drainage at the Laboratory from western to eastern portions of the site (Figures 2-16, 2-17, 2-18, 2-19). Each geologic section is presented here at a vertical exaggeration of 10:1 in order to permit appropriate labeling and allow a level of detail that would not be possible at true vertical scale. Each geologic section is described separately below.

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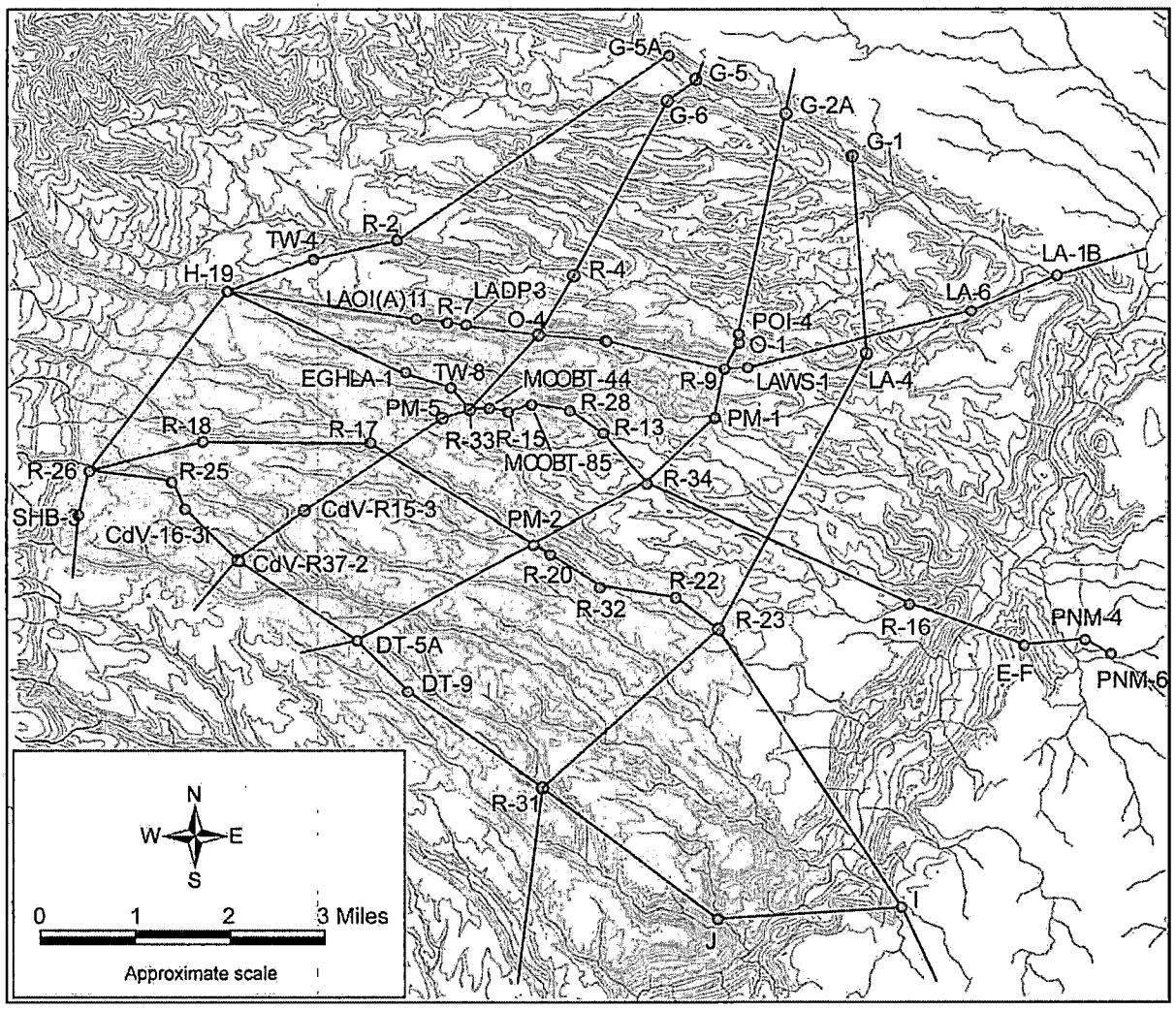

Figure 2-11. Lines of cross-section for Figures 2-12 through 2-19.

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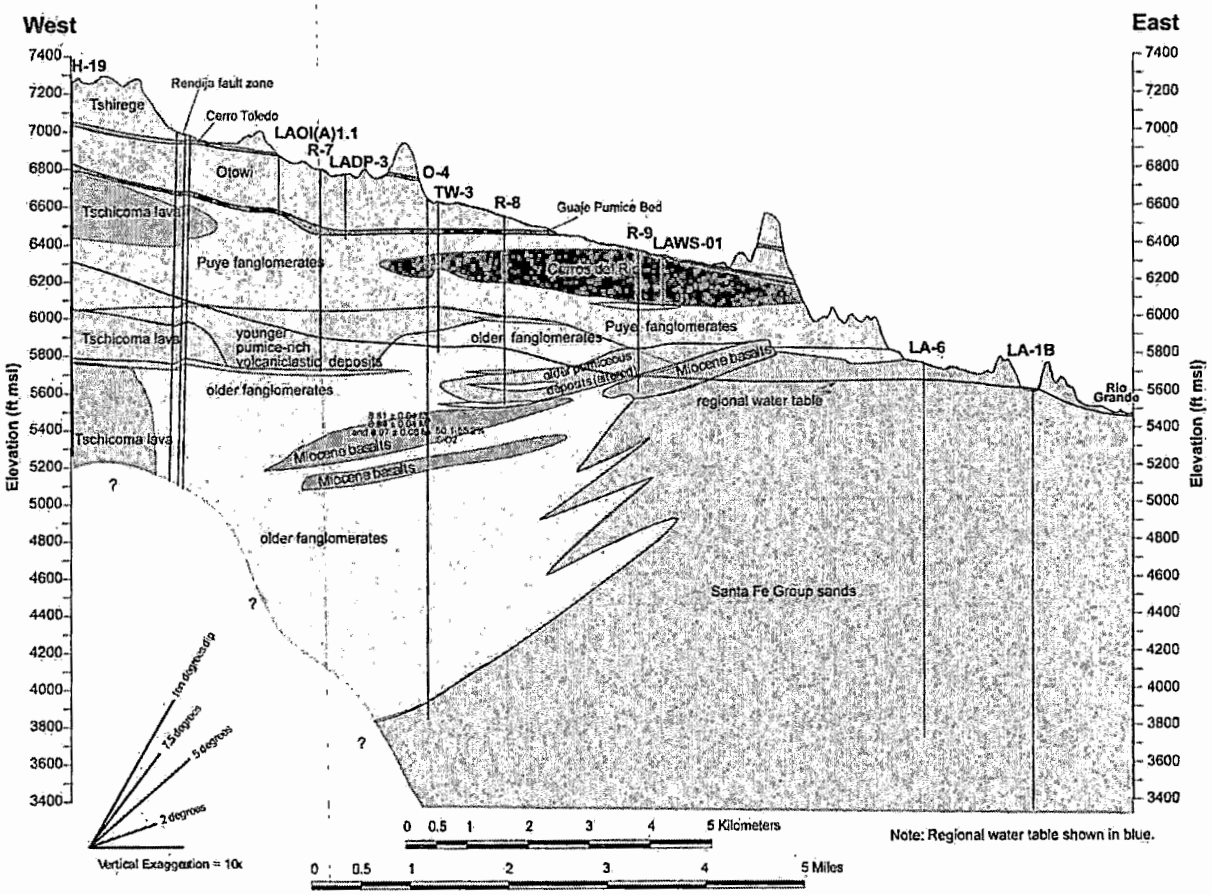

Figure 2-12. Conceptual cross-section for Los Alamos Canyon. Blue line is regional water table.

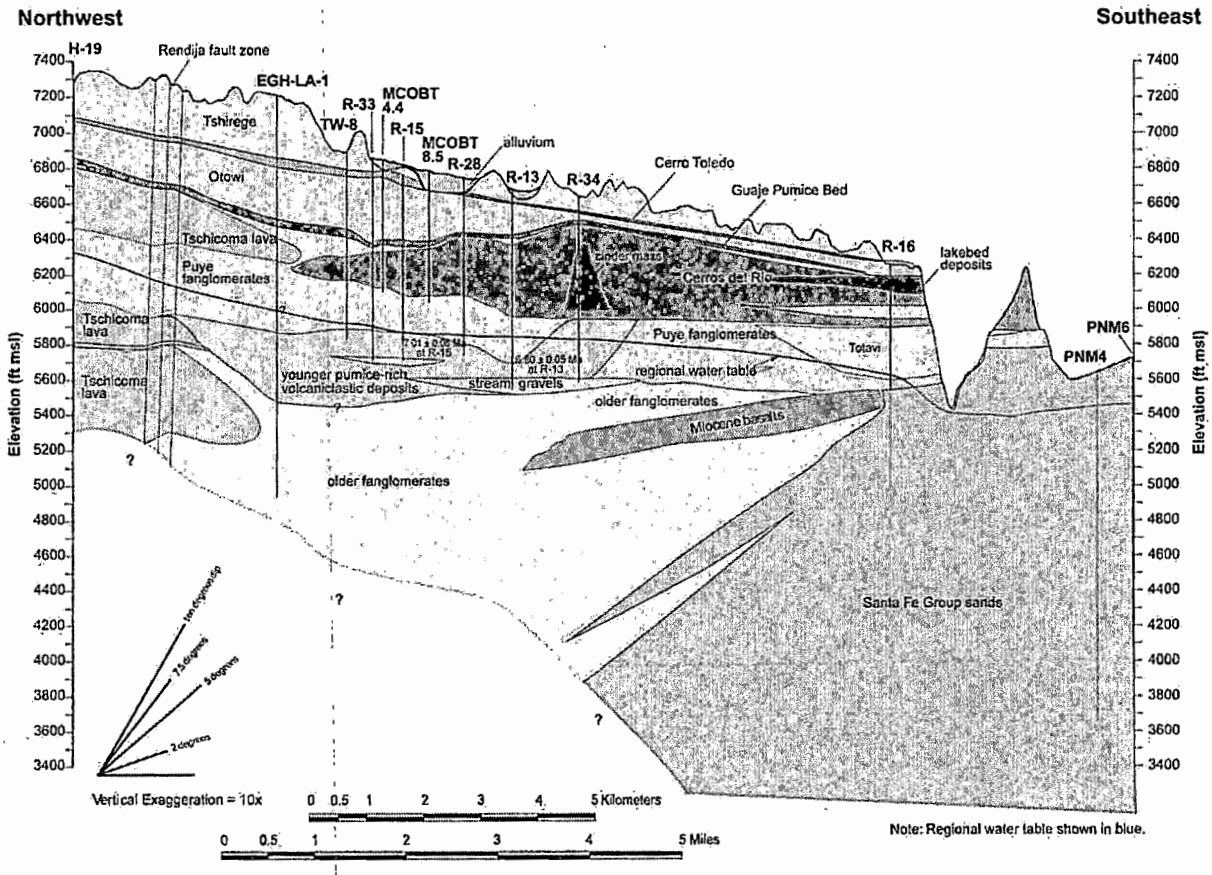

Figure 2-13. Conceptual cross-section for Mortandad Canyon. Regional water table is shown in blue.

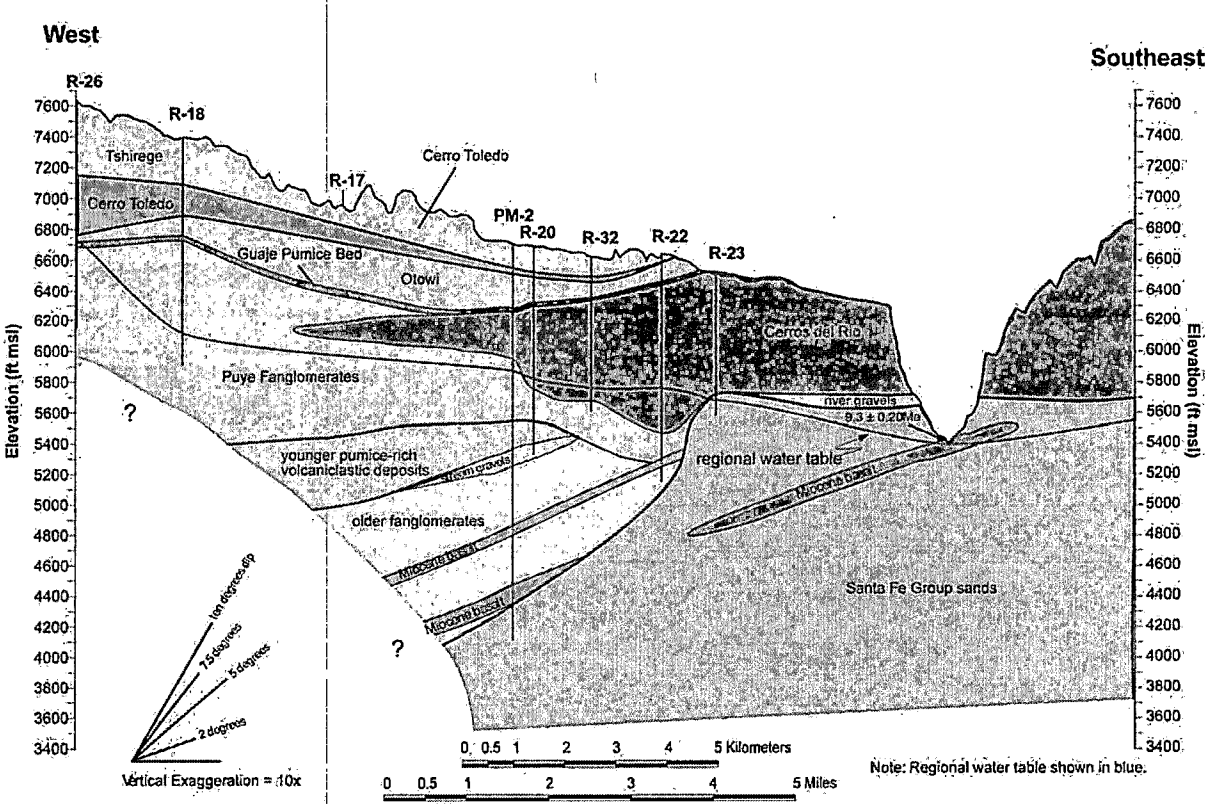

Figure 2-14. Conceptual cross-section for Pajarito Canyon. Water table is shown in blue.

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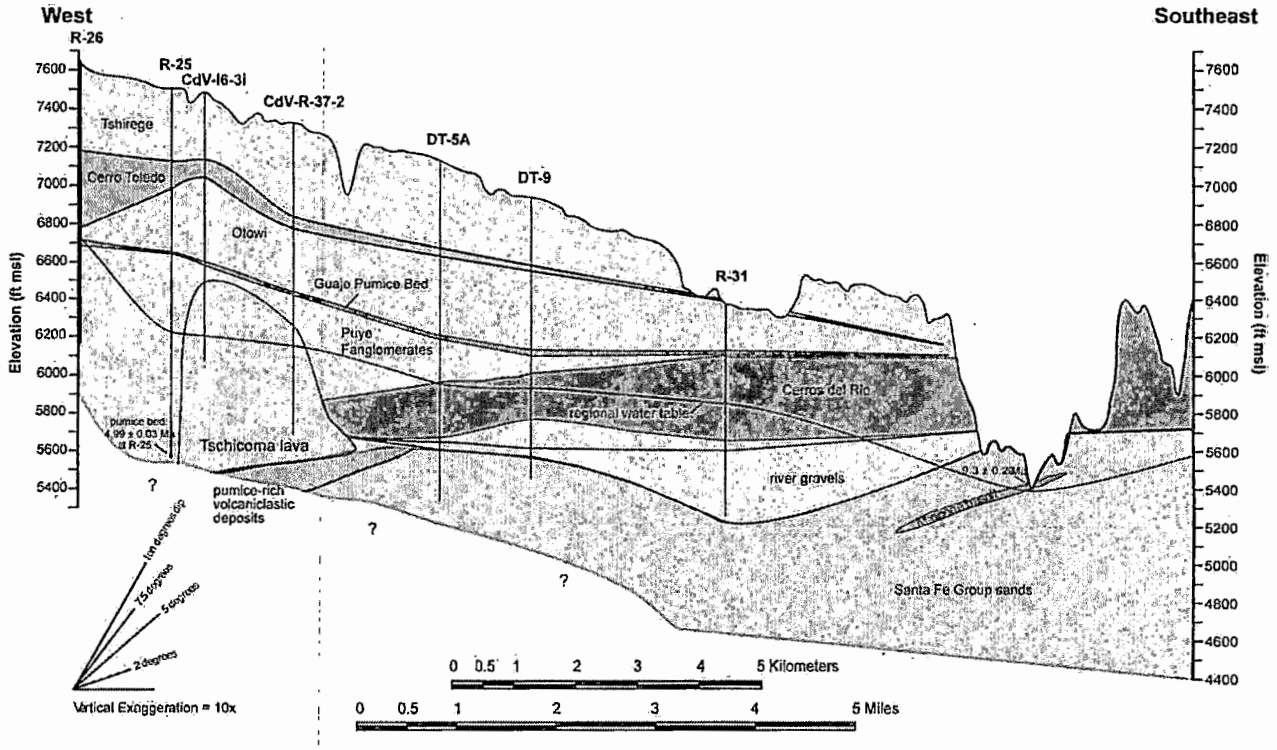

Figure 2-15. Conceptual cross-section for Water Canyon. Water table is shown in blue.

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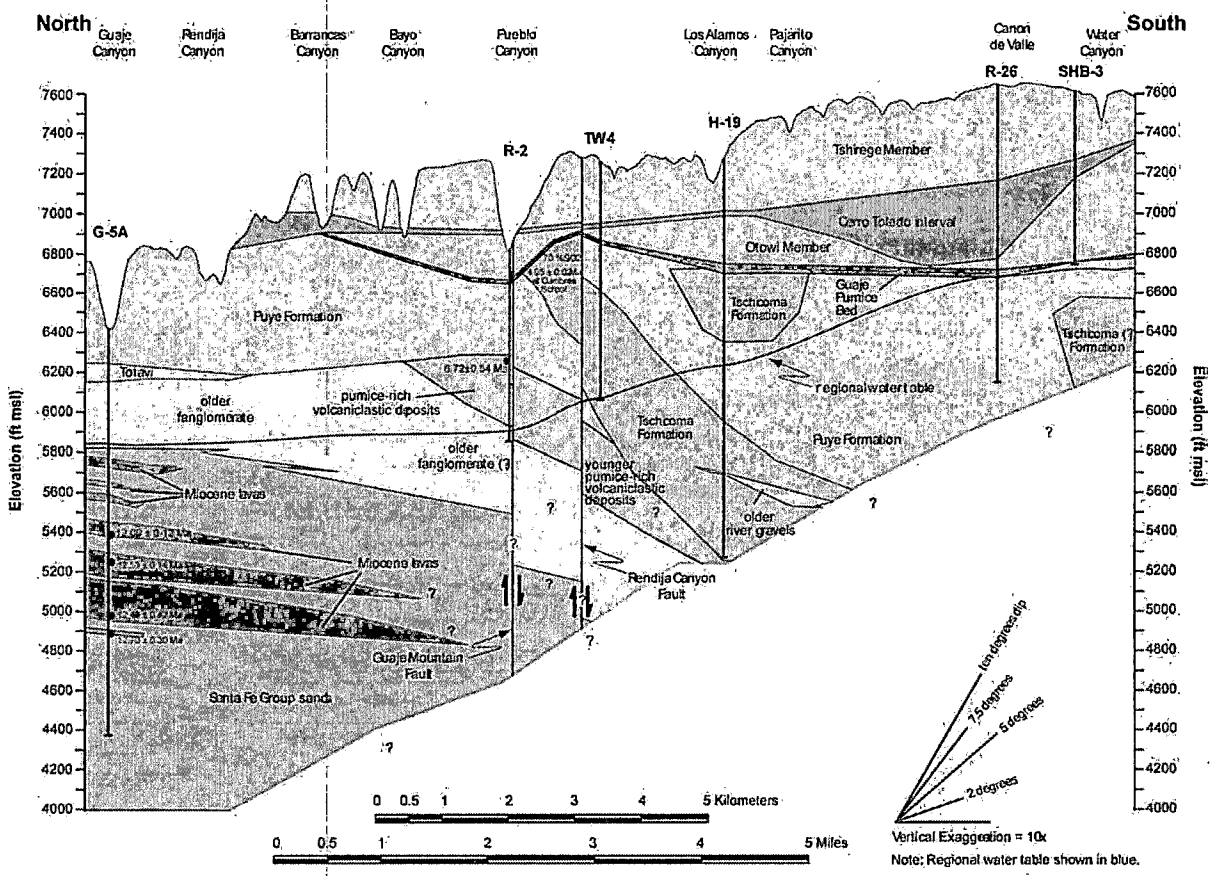

Figure 2-16. Conceptual north-south cross-section for the western portion of the Laboratory.

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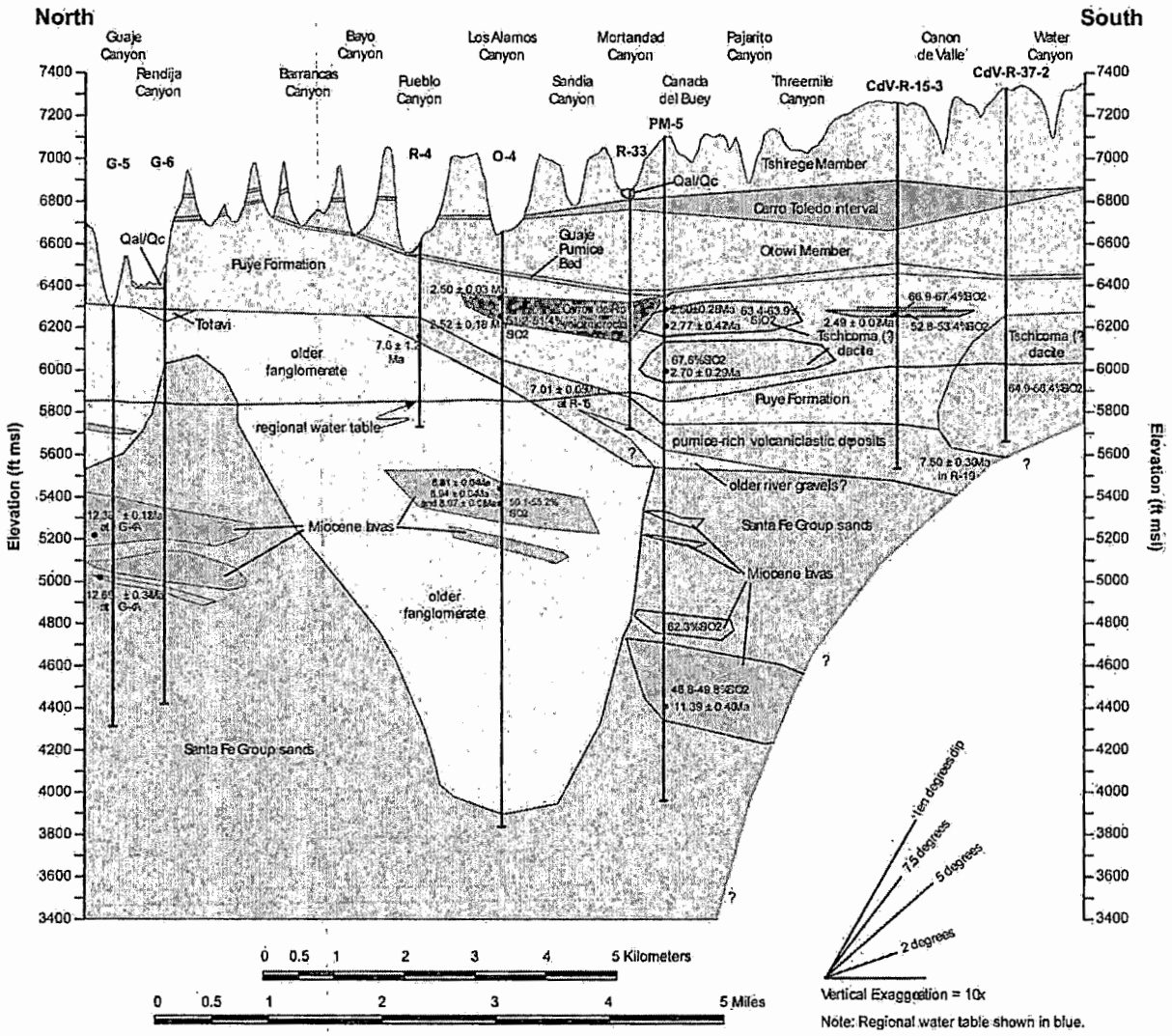

Figure 2-17. Conceptual southwest-northeast cross-section from TA-16 through the west-central portion of the Laboratory.

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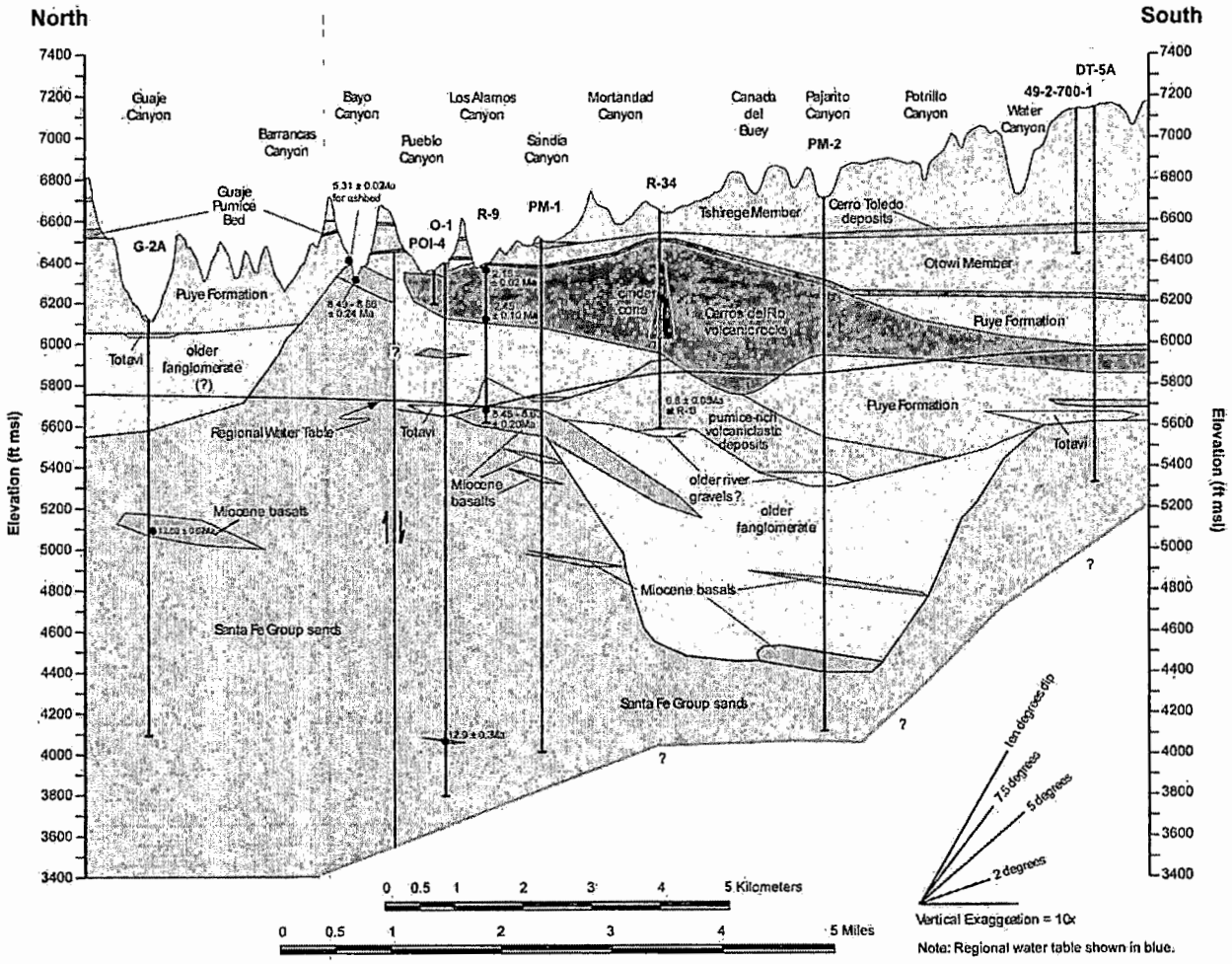

Figure 2-18. Conceptual southwest-northeast cross-section from TA-49 through the central portion of the Laboratory.

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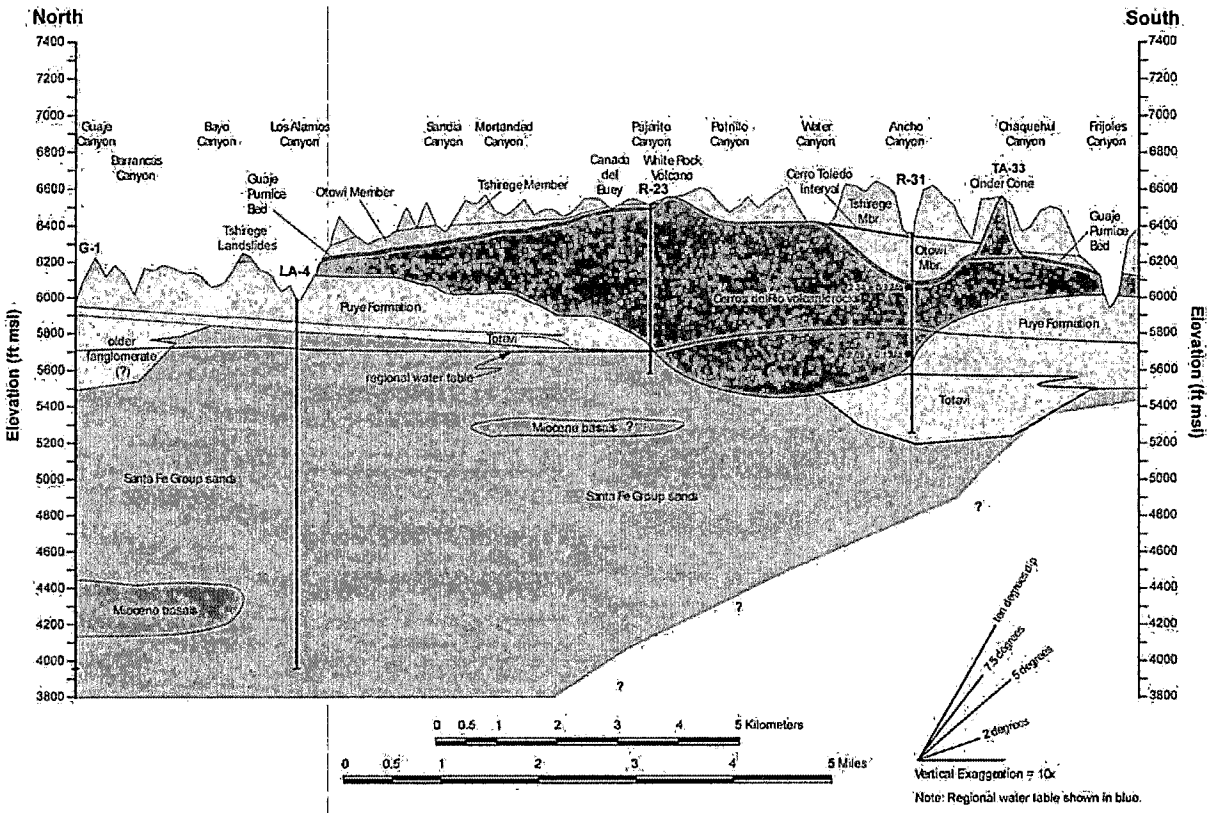

Figure 2-19. Conceptual north-south cross-section through the eastern portion of the Laboratory.

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2.3.2.1 Los Alamos Canyon Cross-Section

Figure 2-12 shows a cross-section based on boreholes along the length of Los Alamos Canyon, from H-19 to the Rio Grande. At the western margin of this section, thick Tschicoma lava flows are shown extending almost to the Rendija fault zone or slightly beyond. The lack of dacitic lavas in R-7 suggests that the lavas do not extend this far to the east; however, lithologic homogeneity of dacitic lithologies in thick Puye fanglomerate sequences at R-7 may indicate that the dominant lava sources are not far away. From the opposite direction, Cerros del Rio lavas extend from exposures in lower Los Alamos Canyon to O-4 but not to R-7. The "lava gap" at R-7 provides a section of more homogeneous lithology (Bandelier, Puye, and pumice-rich volcaniclastic rocks) from canyon bottom to regional water table without interference from low-porosity dacitic or basaltic lava flow.

Pumice-rich volcaniclastic rocks at R-7 occur in a series of primary or reworked pumice beds intercalated with fanglomerates. In this cross-section these are referred to as "younger pumiceous deposits" to distinguish them from heavily clay-altered and possibly older pumice deposits observed at greater depth in O-4, R-8, and in R-9. In reality these may be unaltered and altered variants of a single unit and the distinction shown here may be abandoned if future studies provide a link between these deposits. The lenses and thin layers labeled as "river gravels" refer to well-rounded gravels that contain at least 10% Precambrian lithologies (quartzite, with and without granite and schists, etc.). As noted in Section 2.2.4, relationships between these gravels and the Totavi are uncertain.

Dips on hydrostratigraphic units in this cross section vary with age; the youngest units dip to the east and older units dip to the west. This variation in dip reflects in part the progressive drop in structural elevation along the Pajarito fault zone, just west of H-19. Younger contributions of Tschicoma lavas, steep fanglomerate slopes shed from these fans, and proximally thick Bandelier ash flows provide the east-dipping masses at higher stratigraphic levels.

2.3.2.2 Mortandad Canyon Cross-Section

Figure 2-13 shows a cross-section beginning at borehole H-19, dropping into Mortandad Canyon at TW-8 and extending along Mortandad Canyon, then to R-16 and across the Rio Grande to well PNM6 in the Buckman well field. This cross section begins in the west where Tschicoma dacitic lavas were found in drillhole H-19, but here the uppermost lavas are extended to borehole EGH-LA-1. The implied relationship between dacitic lavas in these two drillholes is speculative because there are no samples from H-19 to test similarity. If there is continuity of dacitic lavas between H-19 and EGH-LA-1 to the west as shown, then there is likely little or no "lava gap" between Tschicoma dacites and Cerros del Rio basalts as seen in the vicinity of R-7 in Figure 2-12.

The top of the pumiceous deposits, beneath Puye fanglomerates, is well defined in boreholes from TW-8 to R-13. The data from EGH-LA-1 and R-34 are largely inferred due to poor sample returns in these drillholes. There is also a lack of information to indicate whether or not there is a series of clay-altered and possibly older pumiceous deposits, as shown in Figure 2-12, on top of the Miocene basalts shown here. As in the previous cross-section for Los Alamos Canyon, dips on most units vary from easterly in upper horizons to westerly in lower horizons. The evidence for westerly dips in Santa Fe Group sands for this section is based largely on extrapolation from

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the FMI dips recorded in drillhole R-16 (see Table 1-A-1). The pumice-rich volcaniclastic deposits dip 5-7° to the southwest at R-1 and R-33 and 6° to the southeast at R-28.

The south-trending paleocanyon at the base of the Bandelier Tuff is more evident in this section than in the more northerly section along Los Alamos Canyon (Figure 2-12). In Figure 2-13 the axis of the paleocanyon is clearly transected in the vicinity of drillholes R-33 to MCOBT-8.5. Evidence for a comparable canyon, offset to the east, may be seen in the depth to pumiceous deposits at R-13, but the paucity of deep cuttings from R-34 make this interpretation somewhat speculative. Evidence for the cinder mass within the Cerros del Rio at R-34 however is very good, and it is likely that a buried basaltic vent source is close to the R-34 drill site, although the distance and direction to the vent are not constrained.

2.3.2.3 Pajarito Canyon Cross-Section

Figure 2-14 shows a cross-section beginning at borehole R-26, extending to the location of well R-18 and planned well R-17, then along Pajarito Canyon to well R-23 and across the Rio Grande to a measured section on the eastern canyon wall (Dethier, 1997). In this cross section the deep erosion into the Otowi ash flows and filling of this eroded canyon by Cerro Toledo deposits is evident (compare with Figures 2-4 and 2-5). As in the Mortandad Canyon cross section, the broad south-trending valley filled by Bandelier Tuff is visible west of PM-2, although placement of the valley axis will depend on observations yet to be obtained from future drillhole R-17.

The deepest point filled by Cerros del Rio lavas in this section is at R-22. This point is the principal evidence for the south-trending paleocanyon seen in Figure 2-8, although the exact trend and the head of the canyon are poorly constrained by current borehole data. The west-dipping Miocene basalts are suggested by dips seen in other drillholes to the north, in outcrop along White Rock Canyon (Dethier, 1997), and by suggested correlations between Miocene basaltic lavas in PM-2 and R-22 and between PM-2 and basalt outcrops in White Rock Canyon. At R-20, FMI logs show that the pumice-rich volcaniclastic deposits dip about 5° to the southwest.

2.3.2.4 Water Canyon Cross-Section

The cross-section shown in Figure 2-15 runs approximately parallel to the southern boundary of the Laboratory, from borehole R-26 to two measured sections on the western and eastern walls of White Rock Canyon (Dethier, 1997). Here the axis of the paleocanyon at the base of the Bandelier Tuff is less evident because the eastern wall of that paleocanyon is essentially flat, from borehole DT-9 to White Rock Canyon. An older and more prominent paleocanyon is shown in the vicinity of borehole R-31, filled by accumulation of largely Precambrian sands and gravels marking a previous channel of the ancestral Rio Grande. The depth of this paleochannel is poorly known because borehole R-31 was unable to penetrate completely through the gravel deposit.

Boreholes CdV-16-3(i) and CdV-R-37-2 were both completed within thick sequences of Tschicoma Formation dacitic lavas. These lavas do not occur in borehole R-25; moreover, lavas encountered in boreholes DT-5A and DT-9 are poorly characterized but are believed to be flows within the Cerros del Rio volcanic field that are likely younger than these thick dacitic lavas, although no samples of these lavas are available for dating. Completion of planned drillhole

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R-27 within Water Canyon north of DT-5A will address this question by providing samples of these lavas. Specifically, the well will provide additional information about the composition of lavas in the vicinity of TA-49 and their possible relationship with the lavas encountered in CdV-16-3(i) and CdV-R-37-2. In this cross-section the dacitic lavas in CdV-16-3i and CdV-R-37-2 are shown as being limited in lateral extent. The flow base for these lavas is speculated to be at the top of the older fanglomerates, but actual stratigraphic relations are unknown at this time.

2.3.2.5 Western Boundary Cross-Section

Figure 2-16 shows a cross-section from south of borehole SHB-3 extending up along the western boundary of the Laboratory, northeast to borehole G-5A in Guaje Canyon. This section shows in cross-section the depth and width of the paleocanyon cut into the Otowi Member and filled by deposits of the Cerro Toledo interval in the vicinity of borehole R-26. To the north the Otowi Member has been eroded away and the sediments of the Cerro Toledo interval are deposited on fanglomerates of the Puye Formation. Fanglomerates of the Puye Formation are considerably thicker beneath the Laboratory than to the north. The pumice-rich volcaniclastic and older fanglomerate are believed to occur beneath the western part of LANL but their presence is speculative because boreholes do not fully penetrate the thick Puye Formation in that area. The correlation of dacitic lavas in TW-4 and H-19 is based on lithologic descriptions of phenocryst minerals, but the lack of available cuttings from these boreholes means that this correlation cannot be tested.

2.3.2.6 West-Central Cross-Section

Figure 2-17 shows a cross-section from south of borehole CdV-R-37-2 and extending northeast across the Laboratory to borehole G-5 in Guaje Canyon. In this section the chemical composition of the lavas (wt% SiO_2) and available radiometric ages are shown to indicate how the lavas can be used as a guide in stratigraphic interpretation. In general, the ages of lavas assigned to the Cerros del Rio volcanic field or to the older Miocene sequences correlate with stratigraphic depth. The Tschicoma intermediate-composition lavas at the margins of the Laboratory, as in borehole CdV-R-37-2, have not been fully penetrated by any boreholes and the nature of their basal contacts is not known.

As in Figure 2-15, the pumiceous deposits and the underlying river gravels (Totavi) are shown with a southern component of dip, consistent with FMI dip information described earlier. The river gravels can be extended as a continuous unit between boreholes R-33 and PM-5. However, another interpretation would be as unconnected river channels at different elevations, as seen in the east-central cross-section to the east (Figure 2-18).

The cross-section suggests that there is considerable incision into the top pf the Santa Fe Group sands prior to deposition of the older fanglomerate in the vicinity of O-4. This interpretation is supported by the presence of younger Miocene basalts at O-4 that occur at the same structural levels as older Miocene basalts beneath Guaje Canyon. The orientation of possible paleovalleys incised into Santa Fe Group sands cannot be determined because most boreholes in the central and western part of the plateau are not deep enough to penetrate the base of the older fanglomerates. Relations described by Griggs (1964) for wells in the Guaje Canyon areas suggest that some uppermost Santa Fe Group sands interfinger with the older fanglomerate.

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2.3.2.7 East-Central Cross-Section

Figure 2-18 shows a cross-section from southwest of borehole DT-5A extending northeast across the Laboratory to drillhole G-2A in Guaje Canyon. This section crosses a high point in the Cerros del Rio volcanic field at borehole R-34. As in the western-boundary and west-central cross-sections (Figures 2-16 and 2-17) the stratigraphy beneath the Bandelier Tuff at the southern Laboratory boundary is speculative. If the lavas penetrated by borehole DT-5A are attributed to the Cerros del Rio (see Figure 2-8) rather than the Tschicoma Formation, the distinction from Cerros del Rio volcanic rocks shown as a contact here may unnecessary. The lack of samples for analysis from borehole DT-5A allows either interpretation, but this problem should be resolved when borehole R-27 is completed in Water Canyon north of DT-5A.

Petrographic and radiometric data from lavas outcropping in Bayo Canyon and comparable data from lavas in borehole R-9 suggest an offset of several hundred feet down to the south, interpreted in this cross section as a normal fault between Bayo and Pueblo canyons, covered by and not offsetting the Bandelier Tuff. Other explanations are possible but fault offset is supported by observed offset of exposures in Bayo Canyon. The number and distribution of faults beneath the Laboratory remains largely unknown, but continuity in many younger units, particularly the Bandelier Tuff and Cerros del Rio volcanic rocks, limits the amount of significant fault offset in the central and eastern Laboratory area to units older than about 3 Ma. As in Figure 2-17, the cross section shows a paleovally incised into the top of Santa Fe Group sands filled by older fanglomerate. These relationships are based on descriptions of the pre-Puye rock units described in the lithologic logs for PM-1, PM-2, and DT-5A, and they cannot be verified because drill cuttings for these wells are not available.

2.3.2.8 Eastern Cross-Section

Figure 2-19 shows a cross-section from south of borehole R-31 extending northeast and then north across the eastern portion of the Laboratory to drillhole G-1 in Guaje Canyon. This figure illustrates the thinning and local absence of the Otowi Member of the Bandelier Tuff over highlands of Cerros del Rio volcanic rocks. The very thick sequence of Cerros del Rio volcanic rocks between boreholes R-23 and R-31 has a total depth that is poorly constrained but likely to have filled a paleocanyon (see Figure 2-8). Continuity of Totavi river gravels from north to south is shown as disrupted in the vicinity of this paleocanyon, for such gravels are missing in several boreholes near this feature. At greater depth the stratigraphic sequence is dominated by Santa Fe Group sands, based on evidence from boreholes in lower Los Alamos Canyon (e.g., LA-4), boreholes to the east (R-16), and exposures mapped in White Rock Canyon (Dethier, 1997).

2.4 Hydrologic Properties

The geologic units of the Pajarito Plateau are organized into more generalized hydrogeologic units that form the framework for flow and transport numerical models (Section 4). Hydrogeologic units are subdivided based on lithologic characteristics believed to result in different hydrologic properties. A comparison of geologic and hydrologic frameworks for the plateau region is provided in Figure 2-3.

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2.4.1 Vadose Zone Hydrologic Properties

The vadose zone, the region between the ground surface and the regional aquifer, consists of variably saturated rocks, and locally saturated zones. The hydrologic properties controlling the flow of water from the surface to the regional aquifer are the saturated hydraulic conductivity (ksat) and the unsaturated hydraulic properties. As explained in basic hydrology texts and in references related to the vadose zone beneath the Pajarito Plateau such as Rogers and Gallaher (1995), when rocks are not completely saturated, the moisture retention curve defines the relationship between the volumetric water content of a soil or rock and its capillary pressure (sometimes referred to as the matric suction or matric potential). As the pores fill with water, capillary forces result in the small-diameter pores filling first, and at progressively larger water contents, the larger pores fill. The resistance to flow is much lower for the large-diameter pores, so that the unsaturated hydraulic conductivity increases as a strong function of the water content, reaching a maximum when the medium is saturated. Under unsaturated conditions, the local water content and matric potential are controlled by the percolation flux; the local values of these variables modulate themselves in response to changes in the local percolation rate, in order that fluid may pass through the rock under gravity-driven or capillary-flow conditions. For unsaturated conditions flux and water content are related and flow is in response to a gradient that is composed of capillary and gravitational terms.

Although most contaminants of concern associated with past LANL operations travel in the liquid phase, gas-phase transport is an important mechanism for radon and also for various volatile organic chemicals present in the subsurface. Furthermore, vadose zone observations used to estimate permeability at larger scales tend to be pneumatic, that is, based on the response of gas-phase pressures to changes in the air pressure exerted at the surface. When treating vapor transport, the permeability to the gas phase is the relevant property. Although in principle the permeability of the medium should be independent of the fluid (air or water), the role of fractures and issues of scale dependence come into play. Given that open fractures are most likely to be air-filled under ambient conditions, fractures dominate the behavior for gas-phase contaminant transport and the interpretation of pneumatic data.

To quantify the scale dependence of permeability of the Bandelier Tuff and to demonstrate the role of fractures, permeability estimates across all scales from laboratory samples to the scale of a mesa have been compiled. For the Laboratory scale, the geometric mean values of saturated hydraulic conductivity reported by Rogers and Gallaher (1995) are used, and water properties at standard conditions are used to convert conductivities to permeabilities. Parameter estimates for larger scales include gas-phase permeability estimates from Neeper (2002) for the tuff, and hydraulic conductivity measurements for the basalts from Stauffer and Stone (2005). In that study, Neeper (2002) presents field-scale results of pneumatic testing using straddle packers, and larger scale estimates based on the interpretation of the pressure responses to barometric cycles. The packer tests are termed "intermediate scale," and the estimates based on response to barometric cycles are called the "large scale."

Figure 2-20 compares the permeability estimates for the three scales. The laboratory scale values represent matrix permeability and discount the role of fractures, as unfractured samples were typically tested. Permeability values are at least one order of magnitude smaller than the

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Intermediate-scale estimates. The large-scale values are similar to the intermediate scale, except in certain highly fractured regions, where even higher estimates of permeability are made. The most striking difference with scale is for the Cerros del Rio basalt, where core samples represent competent, low-permeability rock, whereas the field scale is dominated by large, open fractures or cavities that transmit air with virtually no resistance. Field observations in the basalts indicate that pressure changes at the surface are transmitted rapidly to depth (Neeper, 2002).

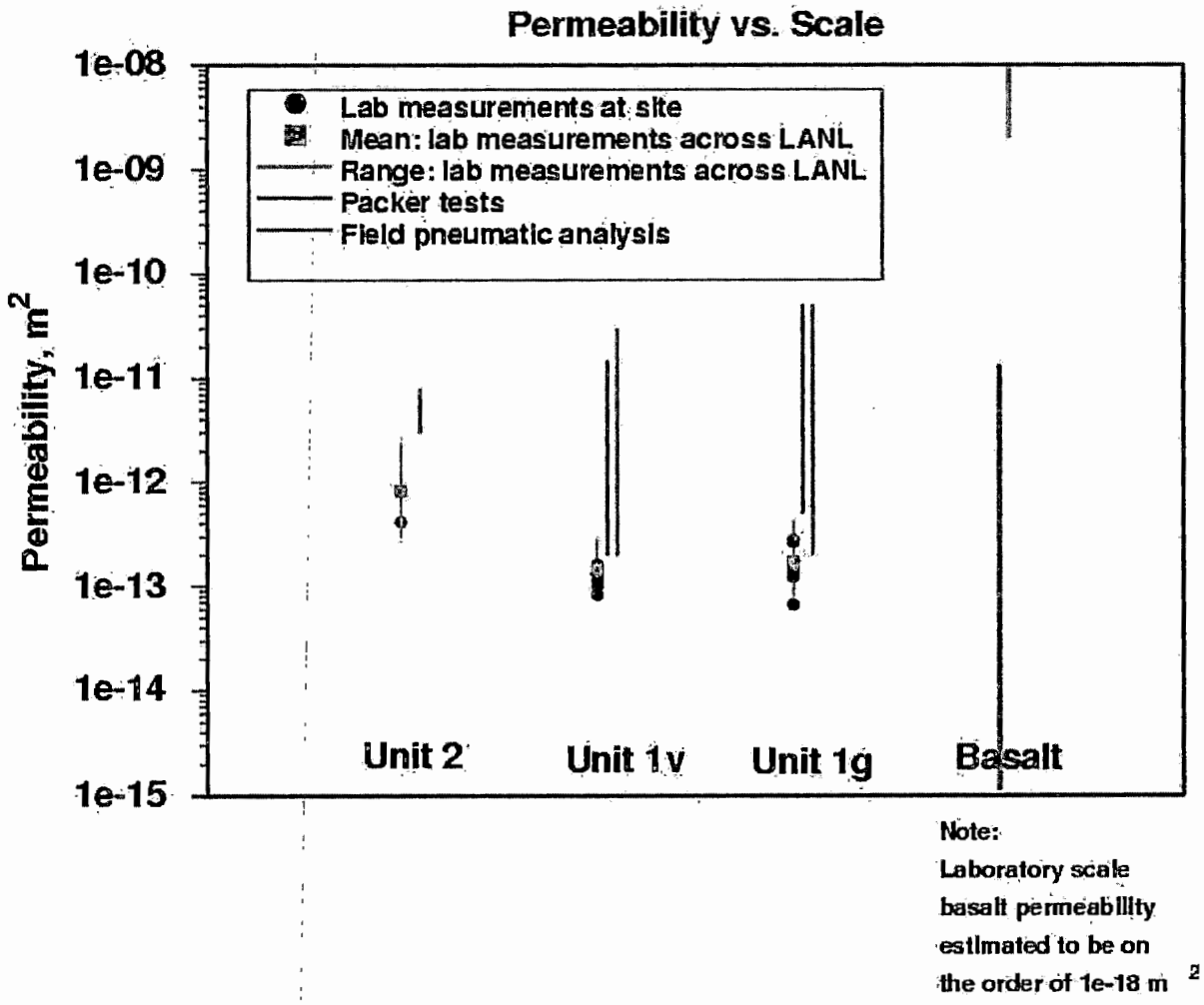

Figure 2-20. Permeability as a function of measurement scale for Bandelier Tuff (units 1g, 1v, and 2) and basalts.

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These results illustrate the role of measurement scale and rock type on estimating the effective permeability of the rocks in the vadose zone. Clearly, fractures, faults, or other large-scale features exert control on the properties of the rock as scale increases. In this comparison, we have mixed the results of water and air flow observations to examine the role of scale. While it is apparent that the role of fractures in transmitting air through the vadose zone must be considered, the question of water flow and the role of fractures must also be considered. Robinson et al. (2005) provide field evidence and numerical model results that suggest that the Bandelier Tuff transmits water through the porous and permeable matrix even for cases in which water is injected at very high percolation rates. Furthermore, the hydrologic properties measured in samples collected from boreholes suffice to describe the percolation of water through the Bandelier Tuff under unsaturated conditions. That study concluded that as long as the percolation rate is lower than the local saturated hydraulic conductivity, water initially present in fractures is imbibed into the rock matrix. Therefore, rock properties of the matrix are most important, except perhaps near the surface where high-fracture-density zones may coincide with regions of high local infiltration rate. Matrix flow is an important simplification that makes vadose-zone characterization in individual canyons a more tractable problem.

In contrast to the Bandelier Tuff, the basaltic rocks clearly exhibit rapid flow through fractures and other fast pathways, and the permeability of the rock matrix is essentially irrelevant to the rates of water percolation (Stauffer and Stone, 2005). The difference is the orders of magnitude lower matrix permeabilities of these rocks, compared to the Bandelier Tuff.

2.4.2 Regional Aquifer Hydrologic Properties

Aquifer properties that are relevant to issues of groundwater quality and quantity are hydraulic conductivity, specific yield (unconfined aquifer) or storativity (confined aquifer), and effective porosity. This subsection summarizes all available information, both recent data collected in R-wells and older estimates from water supply wells. No new information on storage properties of the rocks has been collected in R-wells; this discussion, therefore, will rely entirely on older data.

There are inherent uncertainties associated with any particular estimate of aquifer properties, and there are two particularly important issues to consider when assessing these estimates. First, at the field-scale, these are quantities that are virtually impossible to measure directly. They can only be measured indirectly, via measuring the response of the aquifer to stress, then applying a theoretical model to that response. In a particularly complex aquifer such as the one beneath the Pajarito Plateau, the models used to interpret aquifer tests are necessarily much simpler than the actual aquifer and this will affect the accuracy of the test interpretation. Second, in a complex aquifer, hydraulic conductivity will vary substantially depending on the scale over which it is measured. Tests conducted in wells with long screens (such as water supply wells) and/or tests conducted over long time periods will sample large portions of the aquifer and the results will be average properties of the aquifer, including possible structural features such as faults. Short-term tests and/or tests in wells with short screens will sample small-scale features. The results from such tests will tend to show much greater variability than those in the first category. Only field-scale test results are considered here, since these are most pertinent to field-scale flow and transport in the regional aquifer. Borehole geophysics and bench-scale test approaches to

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estimating hydraulic conductivity are not summarized here, although borehole geophysics-based estimates of effective porosity are discussed.

2.4.2.1 Expected Lithologic Controls on Regional Aquifer Hydrologic Properties

The two major types of aquifer rocks beneath the Pajario Plateau are sedimentary and volcanic rocks. The hydrologic properties of sedimentary and volcanic rocks can be very different and they are discussed separately.

Sedimentary units include the Puye Formation, pumice-rich volcaniclastic rocks, Totavi Lentil, older fanglomerate, Santa Fe Group sands, and sedimentary deposits between basalt flows. Based on outcrop and borehole observations, all these units are expected to be highly heterogeneous and strongly anisotropic, with a much higher conductivity parallel to sedimentary beds than perpendicular to these beds. Figure 2-21 shows photographs of the Puye Formation and the Santa Fe Group showing the typical nature of bedding. Figure 2-22 shows an outcrop of the Totavi Lentil, a unit found at the base of the Puye in some locations, containing cobble beds with abundant quartzite.

The Puye Formation is heterogeneous, containing a variety of sedimentary lithologies. Based on previous studies by Waresback et al. (1984) and Turbeville (1991) significant heterogeneity is expected to occur at scales from kilometers to meters (laterally) and meters to centimeters (vertically).

Due to lack of drill core, it is generally not possible to identify the depositional environments penetrated by R-wells within the Puye. Cuttings and borehole geophysics were used to distinguish between Puye fanglomerate (dacite detritius and sparse to absent pumice fragments), pumice-rich volcaniclastic rocks (abundant pumiceous fragments), Totavi Lentil (rounded clasts of abundant quartzite and other Precambrian lithologies), and older fanglomerate (volcanic detritus and sparse quartzite). The pumic-rich volcaniclastic rocks are expected to have a relatively high porosity, given the abundance of fairly coarse vitric pumice fragments. This high porosity *may* translate to high permeability. In some areas the pumiceous rocks are extensively clay-altered and permeability may be greatly reduced. The Totavi Lentil, an ancestral Rio-Grande alluvial deposit, is possibly the most transmissive of the sedimentary units due to the abundance of unconsolidated sands and gravels (see Figure 2-22). Fine-grained sediments, which may have low permeability, are also present in this unit.

Purtymun (1995) identified a thick zone of highly productive aquifer rocks that extends northeastward across the central plateau. Recent revisions to the plateau stratigraphy (Section 2.1) suggest that this zone includes older fanglomerate deposits, pumiceous volcaniclastic rocks, and lower portions of the Puye Formation. As will be shown below, both high and low permeability rocks are present within this zone.

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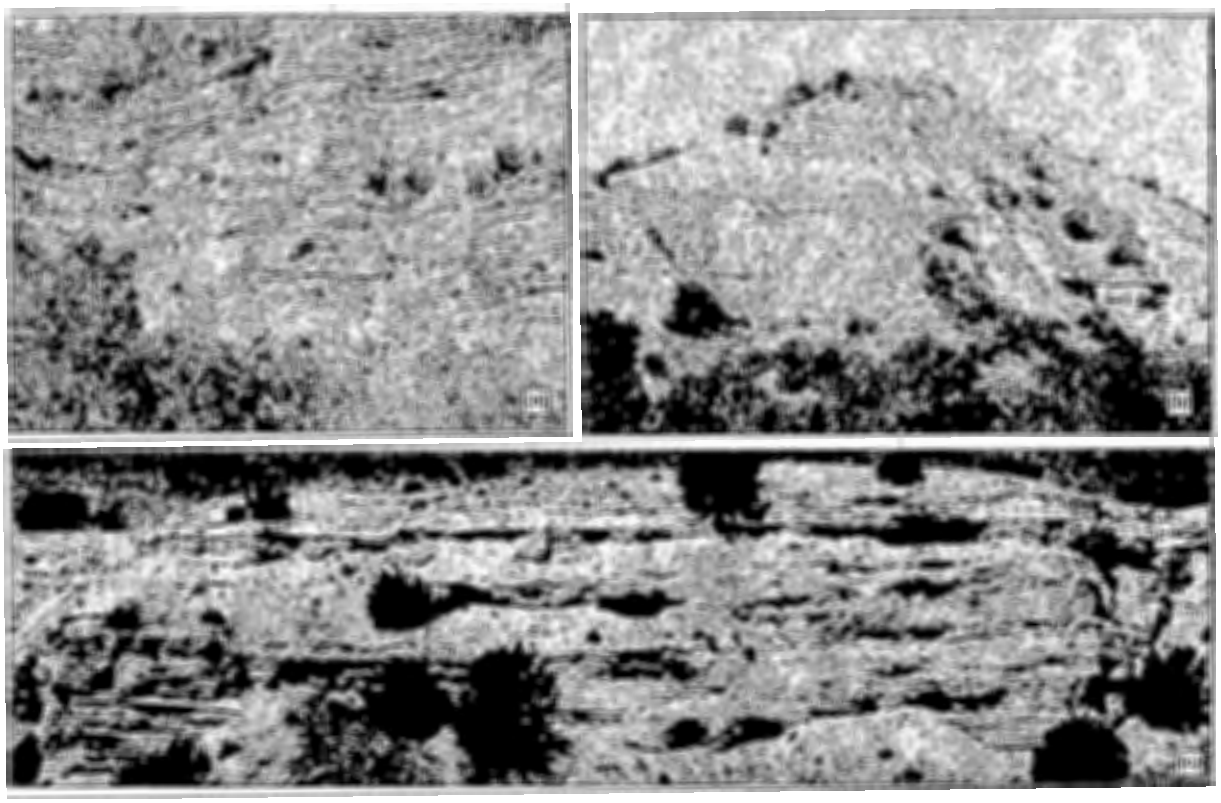

Figure 2-21. (a) Outcrop of the Puye Formation, Rendija Canyon (north of LANL); (b) Outcrop of the Santa Fe Group, lower Los Alamos Canyon (east of LANL); (c) Outcrop of the Santa Fe Group, near Española (provided by Gary Smith, UNM Dept. of Earth and Planetary Sciences).

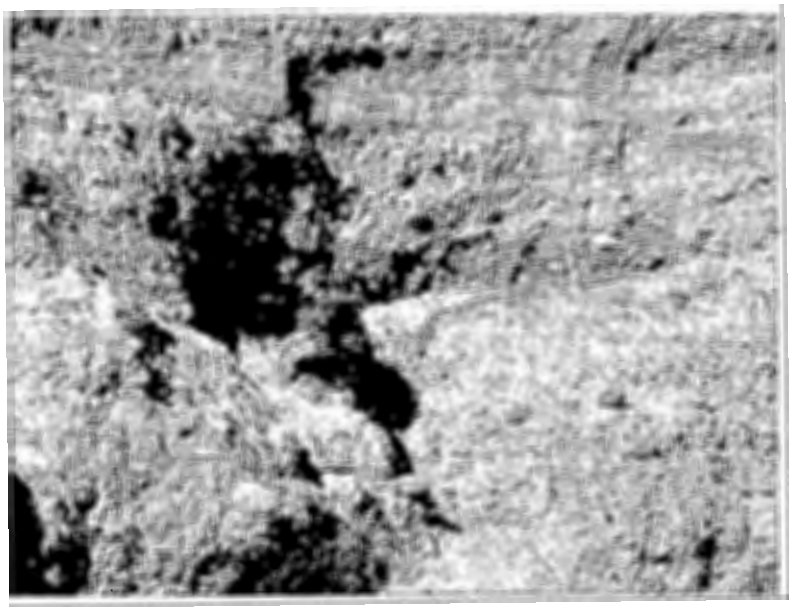

Figure 2-22. Outcrop of Totavi Lentil along SR 304 (D. Vaniman in foreground).

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In heterogeneous units like these sedimentary deposits, it is particularly important to determine the lateral continuity of the high-permeability facies such as coarse stream channel deposits. However, it has not been possible to correlate individual beds in the Puye Formation because channel and overbank deposits in alluvial fan settings form complex, cross-cutting deposits, many of which are channelized or of limited lateral extent. Because of similar source rocks, clast compositions fail to provide distinct criteria for discriminating individual beds, particularly for boreholes spaced as far apart as the R-wells.

The storage properties of these rocks are expected to be within the normal range for sedimentary aquifers: specific yield (Sy) between 0.01 and 0.3 and storativity (S) between 5.E-3 and 5E-5. Likewise, effective porosity values are expected to be in the normal range for sedimentary rocks from 0.1 to 0.3 (Freeze and Cherry, 1979).

Volcanic rocks on the Pajarito Plateau include intermediate-composition lavas of the Tschicoma Formation and basalts (Cerros del Rio, Bayo Canyon, and Miocene basalts within the Santa Fe Group). These volcanic rocks consist of stacked lava flows separated by interflow zones. Figure 2-23 shows an example of Cerros del Rio basalt. Flow interiors are made up of dense impermeable rock that is variably fractured. The interflow zones contain highly porous breccias, clinker, cinder deposits, and sedimentary deposits. Groundwater flow in lava interiors is controlled by fractures, with hydraulic conductivity determined by aperture dimensions, fracture density, interconnectivity, and the presence or absence of fracture-filling minerals. Porous flow is expected to dominate groundwater flow in the interflow zones. Both nonfractured flow interiors and clay-filled fractured zones are expected to have very low permeability; zones with significant, connected open fractures, lava tubes, and interflow zones are expected to have higher permeability and low porosity, a combination of properties which can lead to very fast travel times (Stauffer and Stone, 2005).

The lava interiors presumably have very low effective porosity (<<0.1) and negligible storativity. Highly fractured zones and interflow zones may have larger porosity and storativity values, comparable to values expected for sedimentary rocks. Moderately fractured zones may have low effective porosity (10^{-3}–10^{-4}). Table 2-2 summarizes qualitative expectations of aquifer properties based on lithology and on the available data, augmented by field-scale testing, model calibration, and head gradients.

Fault zones. There are several faults on the plateau, including the Pajarito fault zone and the Rendija Canyon and Guaje Canyon faults (Figure 2-2). These are primarily oriented north-south, with local deviations. There are numerous north-south trending faults in the Santa Fe Group within the larger Española Basin; these types of faults are presumably present beneath the plateau, but they are covered by younger rocks. In general, faults can be conduits to flow (if open) or barriers to flow (if cemented or clay-filled). Field hydrologic evidence has been interpreted based on both of these occurrences. For example, Griggs and Hem (1964) postulated the presence of a fault acting as a flow barrier based on pumping tests in the Guaje Canyon wells. By contrast, Purtymun (1977) and Blake et al. (1995) observed evidence of faults acting as conduits for upward flow of deep thermal waters in the Santa Fe Group, based on geochemical and thermal evidence in lower Los Alamos Canyon wells and San Ildefonso wells. More recently, Keating et al. (2003), suggested that the large-scale effective permeability of the

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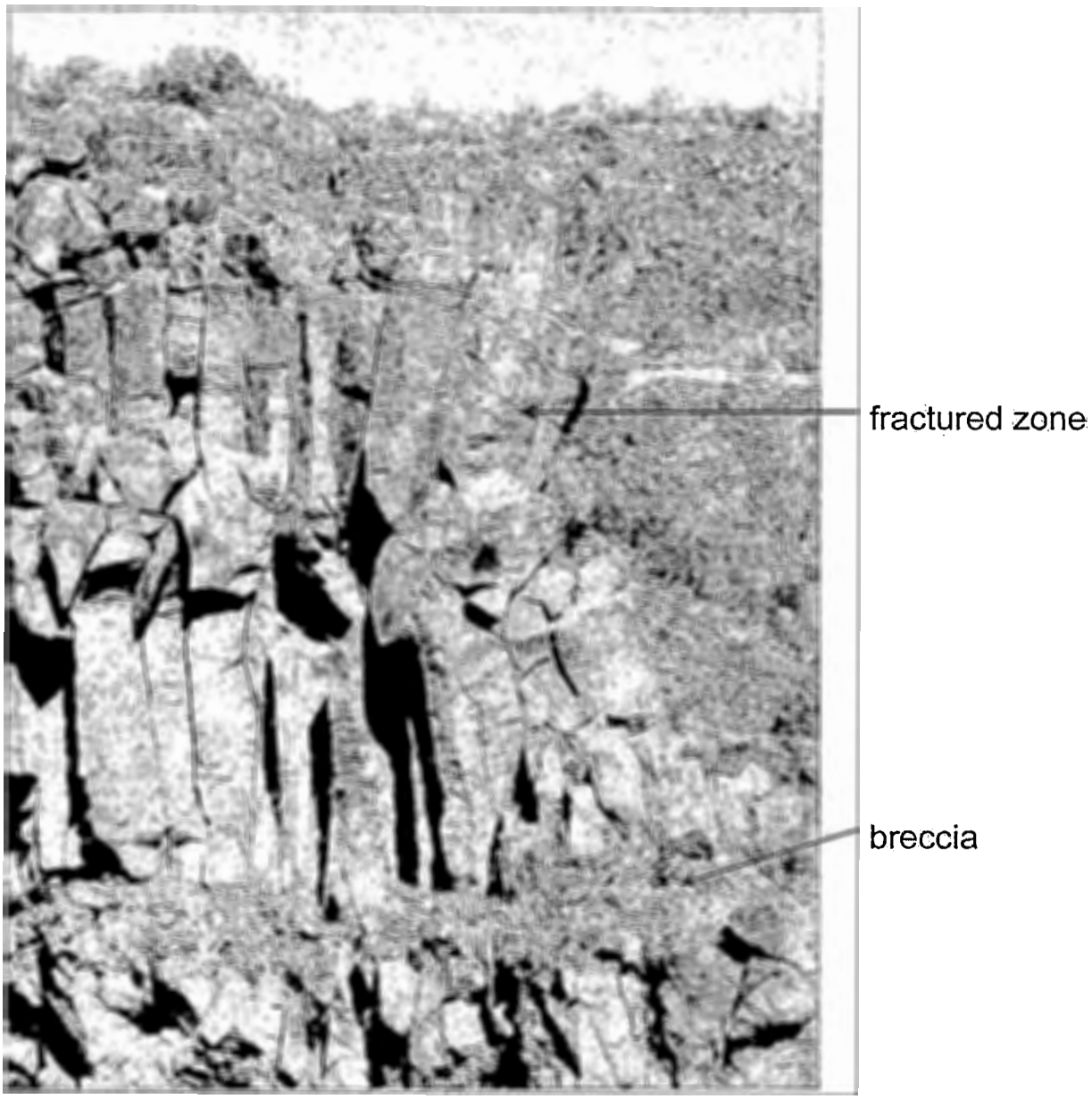

Figure 2-23. Outcrop of Cerros del Rio basalt at White Rock Overlook (east of LANL).

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Table 2-2.
Inferred Properties of Hydrostratigraphic Units, Based on Field-Scale Testing, Model Calibration, and Head Gradients

Stratigraphic Unit	Sub-Unit	Description	Hydraulic Conductivity	Effective Porosity	Storage
Puye	Fanglomerate	Stream channel, overbank, colluvium, and lahar deposits	Extremely variable(0.007–45 m/day), both the highest and lowest K estimates on the plateau occur within this unit	0.07–0.2	No data
	Pumiceous	Ash and pumice-rich layers, both air fall and reworked	Extremely variable (0.3–6 m/day)	0.15–0 .2	No data
Lava flows (Tb1, Tb2, Tb4, Tt)	Massive	Pore space (vesicles) is not connected	<0.15 m/day	No data	No data
	Fractured	In flow interiors, fractures tend to be vertical; near flow tops and bottoms, many fracture orientations are observed, including sub-horizontal	1–9 m/day	No data	No data
	Breccia zones	Highly fractured rock, either open or clay-filled	No data	No data	No data
Santa Fe Group	Sandy	Alluvial fan deposits (stream channel, colluvium, overbank)	Relatively uniform (0.3 m/day); faults may decrease large scale effective K	No data	Log10 [m_{-1}] ~ –3.8 to–4.8
	Fanglomerate	Stream channel, overbank, and colluvium,	Variable (0.1–5.3 m/day), no evidence of very high permeability	No data	Log10 [m_{-1}] ~ –5.5

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Pajarito fault zone is lower than surrounding rocks, based on observations of large horizontal gradients and model interpretations of these gradients. They also concluded that the large-scale effective permeability of the Santa Fe Group is lower than that indicated by individual pump test results (summarized below). These results indicate that faults in the Santa Fe Group, which tend to be north-south trending (transverse to the hydraulic gradient), may act as flow barriers in the direction perpendicular to their orientation, lowering the large-scale effective permeability of the aquifer.

2.4.2.2 Contact between Units

Depths to contacts between the major geologic units are generally well established, but their physical characteristics must be inferred from cuttings and geophysical logs. Outcrop data provide additional information about these contacts. Intra-formational and between-unit sedimentary contacts are generally conformable but are frequently disrupted by facies transitions and channel incisions. Individual beds can be traced laterally over the scale of meters to hundreds of meters. Major erosional unconformities between principal units, such as the Puye and Tesuque Formations, probably occur beneath the Pajarito Plateau, but the nature and orientations of features such as paleocanyons are unknown. Features such as clay-rich soils occur internally within some units like the Puye Formation, but do not appear to be important along intraformational contacts.

The contacts between coarse-grained units, such as the Puye Formation or the older fanglomerate, and fine-grained sediments of the Tesuque Formation may have hydrologic significance because of the juxtaposition of fundamentally different lithologies. Where exposed in the eastern part of the plateau, the contact between Puye rocks and Tesuque strata is a slight angular unconformity. Hydraulic gradients are generally easterly/southeasterly on the plateau (Figure 2-24). Within the Puye Formation, this driving force is parallel to the east-dipping beds. In contrast, within the Tesuque Formation, beds tilt to the west. This anisotropic condition will result in larger flow resistance and possible local deviations in flow direction within the Tesuque rocks.

The contact between the older fanglomerate and the Tesuque Formation may also be hydrologically important. In Guaje Canyon, thick sequences of older fanglomerate interfinger laterally for several kilometers with the Tesuque Formation (see Griggs, 1964 for discussion of these relations). The effect of these interfingering relations on groundwater flow is not known but could include changes in potentiometric surface gradients and partial confinement of groundwater in older fanglomerate enclosed by less permeable Tesuque strata. In Los Alamos and Pueblo Canyons, lateral infingering between the older fanglomerate and the Tesuque Formation appears to be more abrupt. The lithologic difference between the older fanglomerate in Otowi-4 and the Tesuque Formation in Otowi-1 is striking, and the lateral hydraulic conductivity should decrease eastward. The presence of altered Miocene basalts in the Tesuque Formation in wells R-9 and R-12 should also contribute to a decrease in hydraulic conductivity eastward.

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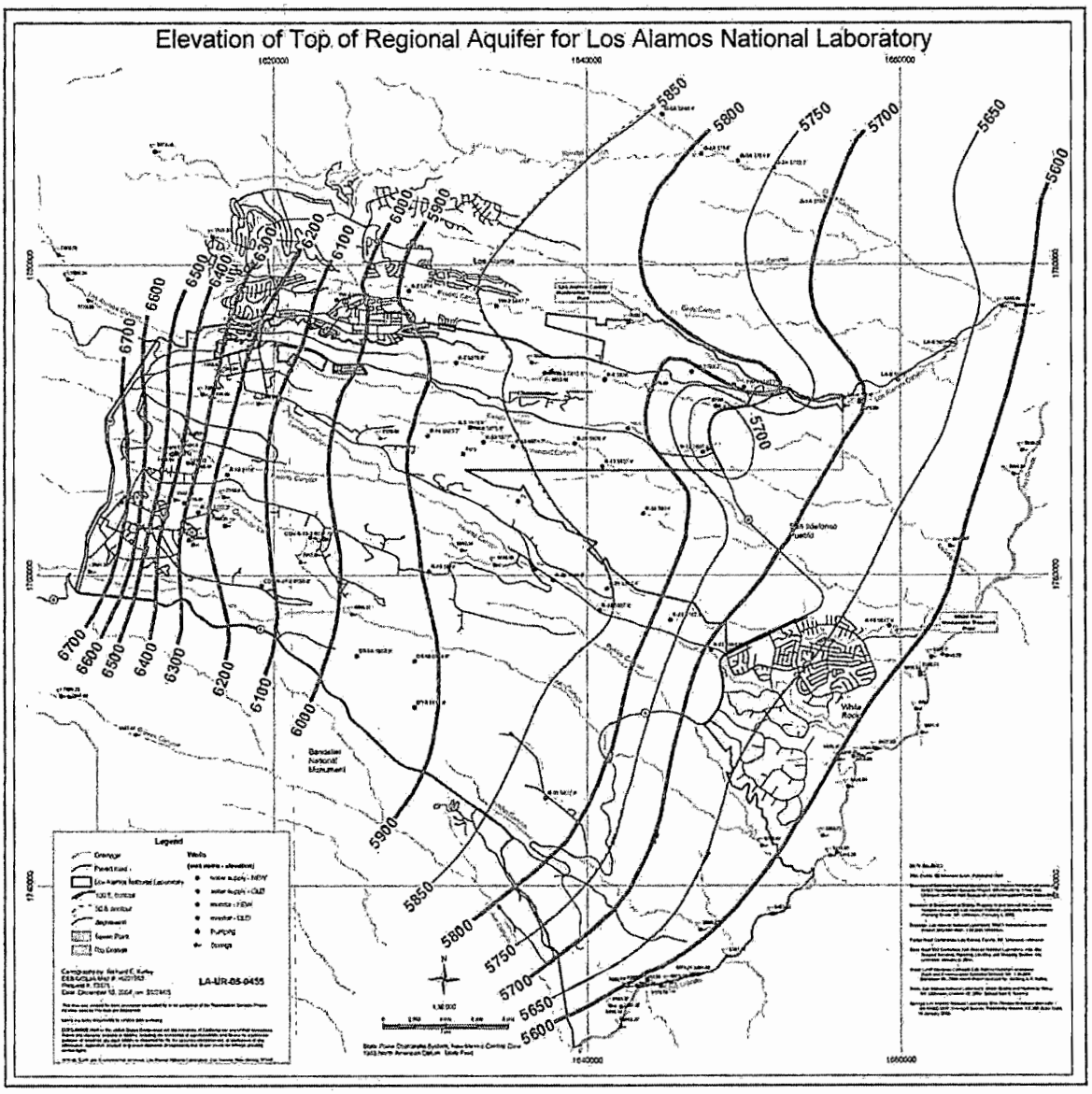

Figure 2-24. Regional aquifer water table map.

We note again that the sedimentary rocks themselves are highly stratified, and so contrasts between layers within these rocks may be as hydrologically significant (or more so) than the contacts between major geologic units described above. Contacts within volcanic units can have significant hydrologic impact. The contacts between lava flows are generally represented by interflow zones that can be very transmissive or, if clay-filled, barriers to flow. One example of a low-permeability, clay-filled interflow zone was that encountered in screen 2 of R-9i. This zone appears to act as a confining bed; water levels rose significantly in the borehole after the well penetrated this zone. Contacts between sedimentary and volcanic rocks can be structurally complex, as in the inferred paleovalley in the eastern part of the plateau that is filled by Cerros

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del Rio basalt (Section 2.2.8; Figure 2-8). Groundwater flow from west to east may be more tortuous and possibly diverted when encountering such large-scale structures.

2.4.2.3 Regional Aquifer Hydraulic Conductivity

Inferences based on field-scale testing. Over the last 40 years, hydraulic conductivity has been measured using pump tests and straddle-packer injection tests in 61 locations within the Pajarito Plateau; some locations have been measured multiple times. Table 2-3 presents a compilation of these test results (86 in all). For those wells tested multiple times, or for which multiple interpretations of a single test are available, we selected one representative value for the discussion and analyses below (these are indicated with an asterisk in Table 2-3). All these tests are within the regional aquifer, with the exception of a perched zone in R-9i that is included because it represents a test of saturated basalt. If the screened interval for a test contained at least 50% of a single stratigraphic unit, the test was categorized as representing that unit. Some wells (all the PM wells, for example) are screened across too many rock units and are labeled as "mixed" in Table 2-3.

Figure 2-25 shows a histogram of the 61 hydraulic conductivity values, which range from 0.007 m/day (R-26, screen 2) to 45 m/day (R-28). The geometric mean of these estimates is 0.6 m/day, and the distribution appears to be lognormal, although we ascribe no special significance to this fact, other than to point out that it is a convenient distribution for modeling purposes. Based on the distribution, the standard deviation of the lognormal distribution is 0.76 in units of ln(m/d).

Figure 2-26 illustrates the spatial variation in hydraulic conductivity on the plateau. There are two areas with relatively high hydraulic conductivity ($K > 3$ m/day): the north-central aquifer beneath LANL (TW-2, R-4, TW-3, R-11, R-28, and R-13) and the south-central aquifer beneath LANL (R-19, screen 6, DT-10, DT-9). The location of these zones overlaps the zone of high-yield wells identified by Purtymun (1984). However, based on new geologic data and interpretations, the rocks making up this zone consist of a variety of sedimentary and volcanic units in addition to those attributed to the "Chaquehui Formation" by Purtymun. Also, it is clear that lower conductivity zones also exist within Purtymun's proposed northeast-trending high-production trough, indicating that it is a heterogeneous portion of the aquifer, with locally high and low permeability zones.

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Table 2-3.
Estimates of Hydraulic Conductivity from Well Tests on the Pajarito Plateau

Well	Source	Method	m/day	ft/day	Unit	Screen		Comments
						Top	Bottom	
DT-10	Purtymun (1995)	Pump test	4.53	14.87	Tb4	472	475	Tf, Tpt, and Tpf also
R-22-2	McLin and Stone (2004)	Injection	0.01	0.04	Tb4	289	301	Could be a breccia zone
R-31-3	McLin and Stone(2004)	Injection	0.15	0.48	Tb4	203	206	0
R-9i-1	McLin and Stone (2004)	Injection	2.16	7.10	Tb4	331	429	Fractured
R-9i-2	McLin and Stone (2004)	Injection	0.03	0.11	Tb4	82	85	Massive
G-3A	Shomaker (1999)	Pump test	0.45	1.48	Tb1	180	604	
G-5A	Shomaker (1999)	Pump test	0.23	0.75	Tb1	228	604	
R-22-4	McLin and Stone (2004)	Injection	0.16	0.54	Tb1	420	422	Fractured basalt with alteration
CDV-R-15-3-5	Well completion report	Injection	0.08	0.25	Tpf	411	413	0
R-13	McLin and Stone (2004)	Pump test	5.36	17.60	Tpf	292	311	Straddles Tpf/Tpp contact
R-22-3	McLin and Stone (2004)	Injection	0.10	0.32	Tpf	388	390	High glass to clay ratio
R-26-2	Shafer (personal communication)	Pump test	0.00	.002	Tpf	433	440	
R-28	Kleinfelder (2004)	Pump test	45.42	149.00	Tpf	285	292	Tpf according to cuttings, Tpp/Tpf mixture according to geophysics
R-32-3	McLin and Stone (2004)		0.37	1.20	Tpf			
R-11	Kleinfelder (2004)	Pump test	35.51	116.50	Tpp	261	268	Assigned by Broxton and Vaniman
R-19-7	McLin and Stone (2004)	Injection	6.71	22.00	Tpp	558	561	0
R-19-6	McLin and Stone (2004)	Injection	5.67	18.60	Tpp	526	529	0
R-1	Kleinfelder (2004)	Pump test	1.19	3.90	Tpp	314	322	Assigned by Broxton and Vaniman

Table 2-3.
Estimates of Hydraulic Conductivity from Well Tests on the Pajarito Plateau (continued)

Well	Source	Method	m/day	ft/day	Unit	Screen		Comments
						Top	Bottom	
R-34	Shafer (personal communication)	Pump test	1.07	3.5	Tpp	269	276	
TW-8	Purtymun (1995)	Pump test	1.02	3.35	Tpp	290	325	0
R-15	McLin (2004)	Pump test	0.67	2.20	Tpp	292	311	Small portion is Tpf
R-14-2	McLin and Stone(2004)	Injection	0.30	1.00	Tpp	390	404	0
CDV-R-15-3-6	Well completion report	Injection	0.03	0.10	Tpp	499	501	0
R-4	Kleinfelder (2004)	Pump test	5.30	17.40	Tf	242	249	0
O-4*	Purtymun (1995)	Pump test	1.23	4.02	Tf	340	791	Basalt and Tsf, as well
O-4	Stoker et al. (1992)	Pump test	2.18	7.15	Tf	340	791	
O-4	Purtymun et al. (1995)	Pump test	2.88	9.46	Tf	340	791	
G-6	Purtymun (1995)	Pump test	0.27	0.90	Tf	213	460	And basalt and a little Tsf
R-2	Kleinfelder (2004)	Pump test	0.09	0.31	Tf	277	284	Very fine grained with fine-scale bedding
R-22-5	McLin and Stone (2004)	Injection	0.08	0.27	Tf	441	443	High glass to clay ratio
G-1*	Purtymun (1995)	Pump test	0.29	0.94	Tsf	86	604	Also Tf and basalt
G-1	Griggs (1964)	Pump test	0.40	1.31	Tsf	86	604	
G-1	Griggs (1964)	Pump test	0.55	1.79	Tsf	86	604	
G-1A	Purtymun (1995)	Pump test	0.37	1.22	Tsf	83	461	Significant Tf?
G-2*	Purtymun (1995)	Pump test	0.37	1.22	Tsf	86	597	Significant Tf?
G-2	Griggs (1964)	Pump test	0.05	0.16	Tsf	86	597	
G-2	Griggs (1964)	Pump test	0.54	1.78	Tsf	86	597	
G-2A	Shomaker (1999)	Pump test	0.21	0.70	Tsf	172	431	0
G-3*	Griggs (1964)	Pump test	0.27	0.90	Tsf	134	544	Also Tf and basalt
G-3	Purtymun (1995)	Pump test	0.22	0.71	Tsf	134	544	
G-4*	Purtymun (1995)	Pump test	0.46	1.51	Tsf	130	587	Also Tf and basalt

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Table 2-3.
Estimates of Hydraulic Conductivity from Well Tests on the Pajarito Plateau (continued)

Well	Source	Method	m/day	ft/day	Unit	Screen		Comments
						Top	Bottom	
G-4	Griggs (1964)	Pump test	0.63	2.05	Tsf	130	587	
G-4	Griggs (1964)	Pump test	0.91	3.00	Tsf	130	587	
G-4A	Shomaker (1999)	Pump test	0.36	1.17	Tsf	200	604	0
G-5*	Purtymun (1995)	Pump test	0.36	1.17	Tsf	141	558	0
G-5	Griggs (1964)	Pump test	0.50	1.65	Tsf	141	558	
G-5	Griggs (1964)	Pump test	0.72	2.35	Tsf	141	558	
LA-1B	Purtymun (1995)	Pump test	0.38	1.25	Tsf	99	516	0
LA-3*	Theis and Conover (1962)	Pump test	0.16	0.51	Tsf	32	264	0
LA-3	Theis and Conover (1962)	Pump test	0.08	0.25	Tsf	32	264	
LA-3	Purtymun (1995)	Pump test	0.13	0.44	Tsf	32	264	
LA-3	Theis and Conover (1962)	Pump test	0.14	0.46	Tsf	32	264	
LA-3	Theis and Conover (1962)	Pump test	0.22	0.72	Tsf	32	264	
LA-2	Purtymun (1995)	Pump test	0.14	0.47	Tsf	32	264	
LA-2*	Purtymun et al. (1995)	Pump test	0.20	0.66	Tsf	32	264	
LA-2	Purtymun et al. (1995)	Pump test	0.36	1.17	Tsf	32	264	
LA-4	Purtymun (1995)	Pump test	0.23	0.76	Tsf	230	599	0
LA-5*	Theis and Conover (1962)	Pump test	0.20	0.67	Tsf	134	530	0
LA-5	Purtymun (1995)	Pump test	0.12	0.40	Tsf	134	530	
LA-6*	Purtymun, (1977)	Pump test	0.29	0.96	Tsf	128	542	0
LA-6	Purtymun (1977)	Pump test	0.22	0.73	Tsf	128	542	
LA-6	Purtymun (1995)	Pump test	0.37	1.22	Tsf	128	542	

Table 2-3.
Estimates of Hydraulic Conductivity from Well Tests on the Pajarito Plateau (continued)

Well	Source	Method	m/day	ft/day	Unit	Screen		Comments
						Top	Bottom	
O-1*	Purtymun (1995)	Pump test	0.19	0.63	Tsf	310	755	Thin basalt
O-1	Purtymun et al. (1993)	Pump test	0.25	0.81	Tsf	310	755	
R-16-2	McLin (2005; personal communication)	Pump test	0.49	1.6	Tsf	187	187	
R-16-3	McLin (2005; personal communication)	Pump test	0.61	2.0	Tsf	306	314	
R-16-4	McLin (2005; personal communication)	Pump test	0.49	1.6	Tsf	367	392	
TW-2	Purtymun (1995)	Pump test	9.84	32.29	Tpt	234	251	0
TW-3	Purtymun (1995)	Pump test	4.90	16.08	Tpt	245	248	0
R-31-4	McLin and Stone (2004)	Injection	3.38	11.10	Tpt	252	255	0
R-31-5	McLin and Stone (2004)	Injection	2.53	8.30	Tpt	307	310	0
TW-1	Purtymun (1995)	Pump test	0.16	0.54	Tpt	193	196	0
R-32-1	McLin and Stone (2004)	Injection	1.28	4.20	Tpt			
CDV-R-37-4	Well completion report	Injection	3.46	11.36	Tt	472	475	0
CDV-R-37-3	Well completion report	Injection	2.14	7.01	Tt	472	475	0
TW-4	Purtymun (1995)	Pump test	0.78	2.55	Tt	364	367	0
PM-1	Purtymun (1995)	Pump test	1.26	4.15	Mixed	288	756	
PM-2	Purtymun (1995)	Pump test	1.14	3.75	Mixed	306	695	
PM-3	Purtymun (1995)	Pump test	7.31	23.99	Mixed	291	772	
PM-4	Purtymun (1995)	Pump test	0.98	3.22	Mixed	384	870	
PM-5	Purtymun (1995)	Pump test	0.22	0.71	Mixed	439	936	
DT-5A	Purtymun (1995)	Pump test	0.69	2.28	Mixed	357	555	
DT-9	Purtymun (1995)	Pump test	4.98	16.35	Mixed	317	457	

An asterisk (*) after a well number indicates inclusion in statistical summaries.

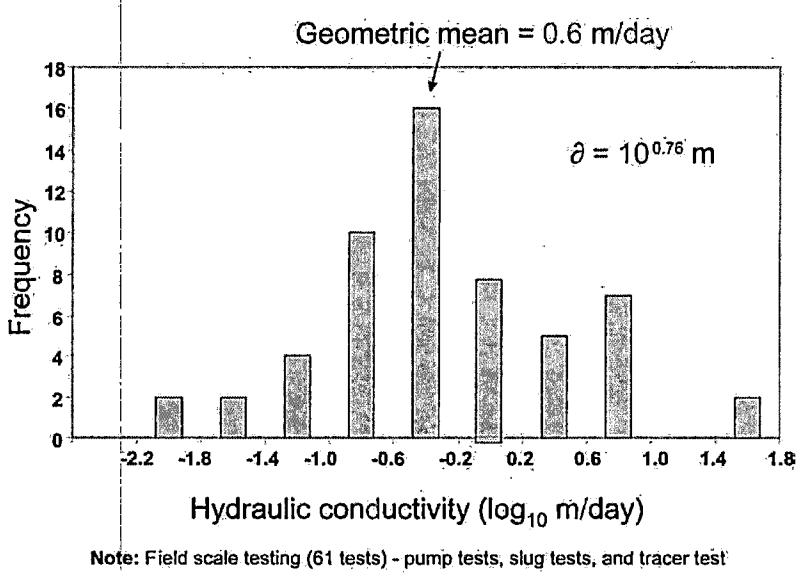

Figure 2-25. Distribution of hydraulic conductivity estimates, derived from tests of 59 wells on the plateau; N = 59; geometric mean = 0.6 m/day.

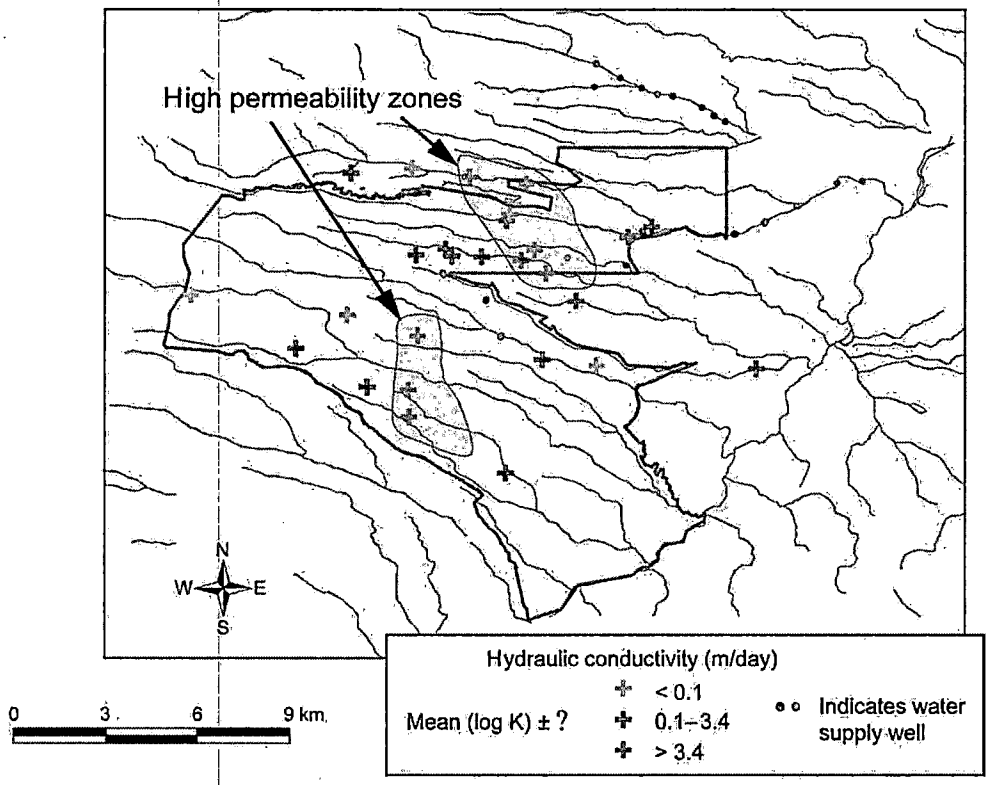

Figure 2-26. Hydraulic conductivity estimates in the regional aquifer. If multiple screens have been tested at a single location, the uppermost result is shown. Red line is the outline of the Laboratory.

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In several wells there are multiple estimates of hydraulic conductivity at different depths (R-22, CDV-R-15-3, CDV-R-37-2, R-16, R-31, R-19, R-9i); in these cases we show the uppermost screen result in Figure 2-26. Only two of these wells, R-9i and R-31, show significant difference in hydraulic conductivity with depth. R-31, screen 3 (uppermost regional aquifer screen), completed in basalt, is very poorly conductive. The two lower screens, 4 and 5, completed in the Totavi Lentil, are very conductive. For this reason, they are shown in Figure 2-26 as connected to the southern high permeability zone. Both screens in R-9i are completed in basalt. The upper conductive screen is located in an interval that includes highly fractured basalt and an interflow zone, and the lower nonconductive screen is located within clay-filled interflow breccia at the base of the basalt sequence. The other wells (R-22, CDV-R-15-3, CDV-R-37-2, and R-19) show consistent results in all screens. This is particularly interesting in the case of R-22 and CDV-R-15-3, where the screens are located in a variety of rock units.

The hydraulic conductivity values for major rock units of the regional aquifer are shown in Figure 2-27 and summarized in Table 2-4. Cerros del Rio basalt, Puye Formation, pumiceous volcaniclastic rocks, Totavi Lentil, older fanglomerate, and Santa Fe Group sands are clearly heterogeneous. The Santa Fe Group sandy unit (Tesuque Formation) appears to be more uniform, although many of the wells representing this unit have very long screens (>300 m), which would tend to smooth the effect of small-scale heterogeneity. Nonetheless, the short screens within Tesuque sands tested at R-16 gave results similar to those obtained from wells with long screens.

The variation within the Cerros del Rio basalt may be related to whether the tested interval contains abundant open fractures (as reported at R-9i, screen 1) or is a clay-filled interflow zone (reported at R-9i, screen 2). All three tests within the Tschicoma Formation represent interflow zones and/or breccia and show relatively high permeability. Both outcrop and borehole observations suggest that much of the Tschicoma Formation is, in fact, massive and so these tests of breccia zones may not be representative of the larger aquifer unit. Some of the low permeability measurements in the Cerros del Rio basalt may represent clay-filled fractures in flow interiors or clay-filled interflow breccia zones.

A number of factors could explain the variability of hydraulic conductivities within the Puye, the Totavi, and the Santa Fe Group fanglomerate, including different degrees of alteration (clay content) and intraformational depositional facies (e.g., stream channel versus overbank deposits). Depositional facies are characterized by different grain sizes and degrees of sorting, but bedding characteristics and rock fabric are needed to evaluate the depositional setting. Bedding and rock fabric cannot be identified from drill cuttings, however borehole geophysical tools such as FMI logs can provide information that may be relevant (Table 2-5). In some cases, depositional environments inferred from FMI logs (Table 2-5) appear to be related to measured hydraulic conductivities. For example, the coarse-grained, poorly sorted gravels and cobbles in CdV-R-15-3, screens 5 and 6, are consistent with deposits expected in proximal alluvial fan deposits. The K values measured here (0.08 and 0.03 m/day, respectively) are lower than most on the plateau. The four highest conductivity zones in Tpf or Tpp, measured in R-28, R-11, R-4, and R-13, are associated with well-bedded sands and gravels with sparse cobbles located in the medial portion of the Puye alluvial fans. Fractures are visible in the screened intervals of the R-11 and R-13 wells.

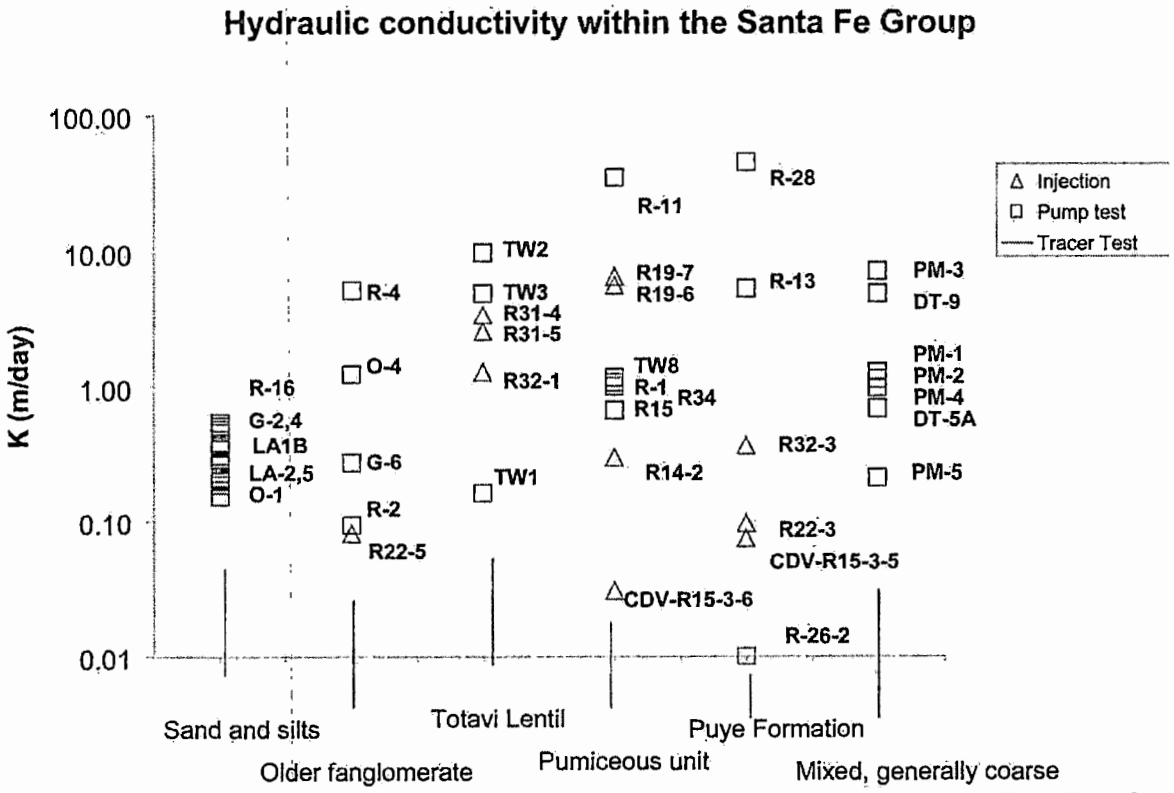

Figure 2-27-a. Hydraulic conductivity within the Santa Fe Group. (See Table 2-3 for a list of wells.)

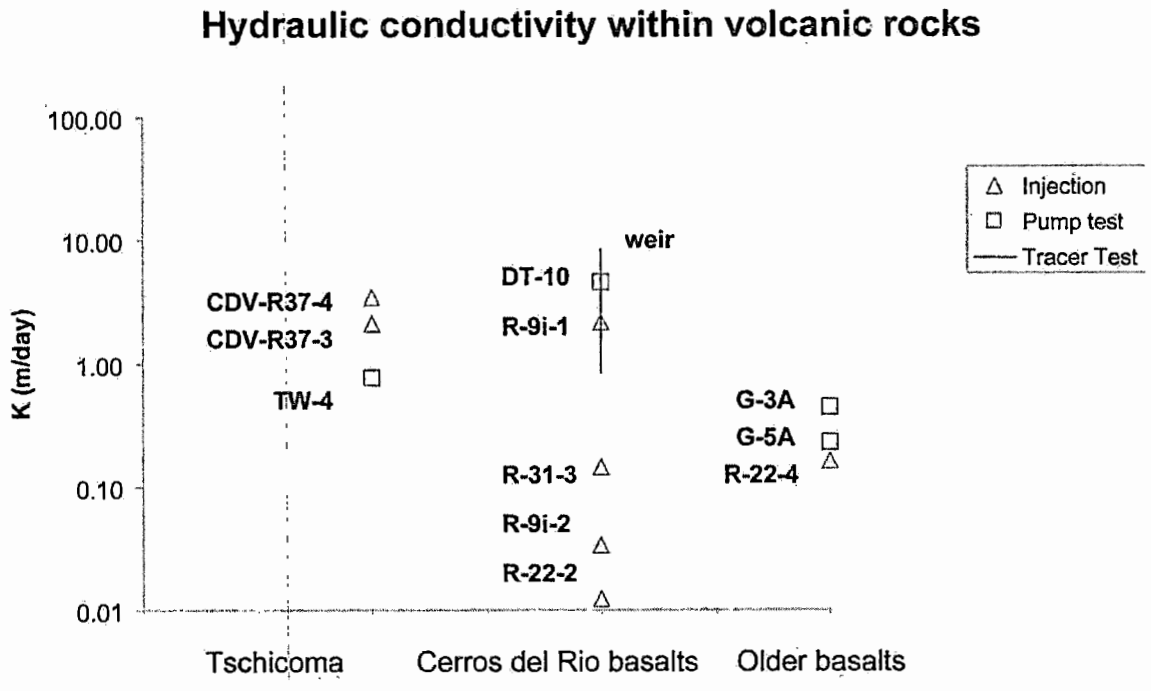

Figure 2-27-b. Variation of hydraulic conductivity in volcanic rocks of the Pajarito Plateau.

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Table 2-4.
Summary Table of Hydraulic Conductivity for Each Hydrostratigraphic Unit

Unit		Number of Wells	m/day	Max m/day	Geometric Mean
Cerros del Rio		5	<0.1	4.5	0.2
	Older	3	0.2	0.6	0.3
Puye	fanglomerate	6	.007	45	0.4
	pumiceous	9	0.3	36	1.3
Totavi		5	0.2	9.8	2.1
Santa Fe Group	Fanglomerate	5	0.1	5.3	0.4
	Sandy	18	0.2	0.5	0.3
	(off plateau data)*	15	<0.1	4.4	0.1
Tschicoma		3	0.2	9.8	0.9

Source: Daniel B. Stephens (1994)
Note: An asterisk (*) means reported in the literature by numerous workers.

There are exceptions to these trends, however. For example, screen 3 of R-32 is also completed in the medial portion of Puye Formation alluvial fans, but has lower conductivities than the wells listed above. The screened interval in R-28 does not show evidence of fractures, yet it has a higher conductivity than does R-11, which is screened across an interval containing several fractures.

The possible influence of alteration can be examined by comparing the percentage of clay present in a hydrostratigraphic unit to the spatial variation in permeability. As shown in Figure 2-28a, there is a tendency for the Puye Formation and pumice-rich volcaniclastic rocks to be more altered in the southeastern portion of the plateau, which may explain the low K values estimated for R-22, screen 3 and R-32, screen 3. However, low clay content is not necessarily associated with higher conductivity. R-26, screen 2 in the western part of the plateau has low clay content and a low K value. Presumably a combination of facies distributions and post-depositional alteration are contributing to the complex patterns evident in Figure 2-26. Data on which to base these results are somewhat limited, and additional data collection could shed light on this issue.

There is no readily apparent correlation between alteration trends in the pumiceous unit (Figure 2-28b) and hydraulic conductivity. In fact, the lowest K values reported for this unit (CDV-R-15-3, screen 6, and R-14, screen 2) are both in regions of lowest clay content. With the limited data available, it appears that alteration within the pumiceous unit is not the only factor controlling hydraulic conductivity.

Table 2-5.
Summary of Formation Micro-Image (FMI) Data Derived from Borehole Geophysics

Drillhole	K m/day	Unit	Texture	Bed thickness	Orientation	Fractures	Effective porosity	Comments
R-26	0.002	Tpf	Very coarse, crude bedding, boulders 2 ft tall	Most are 5–10 ft (some are 0.5 ft)	10–40°	nd	2–0%	Similar to outcrops in upper Guaje, vertical k should be large, probably is colluvium (like at the bottom of a fault scarp)
CDV-R15-3-5	nd	nd	Discrete packages of coarse and fine layers, 1520% is boulder beds, rest is sand and gravels, perhaps thin clay beds, overlapping channel deposits and some overbank	1–5 ft (sand beds are 1 ft)	nd	nd	nd	Coarse layers are comparable to R-26
CDV-R15-3-6	nd	nd	Coarser than screen 5, mostly discrete sand bodies (above screen in sandpack are gravel and coarse sands)	0.5–5 ft	nd	nd	nd	Similar to outcrops in upper Rendija Canyon
R-13	17.6	Tpf (upper half of screen)	Sand and gravel beds, a few cobbley lenses	1 ft–3 ft	nd	One 8' vertical, another dipping, intersecting 2 ft of screen	>60%	Medial fan
	nd	Tpp (upper half of screen)	Fine bedding, intercolated in coarser beds of gravels and cobbles	2-6 in.	nd	nd	nd	
R-11	116.5	Tpp	No fine-grained beds, very stratified	0.5 ft (up to 3 ft)	<10°	Fractures visible (one 2 ft long)	5–10%	
R-28	149	Tpf	Very similar to R-11, very stratified, perhaps can correlate beds	nd	5–10° (S and E)	None visible	15–60%	

Table 2-5.
Summary of Formation Micro-Image (FMI) Data Derived from Borehole Geophysics (continued)

Drillhole	K m/day	Unit	Texture	Bed thickness	Orientation	Fractures	Effective porosity	Comments
R-4	17.4	Tf	Mostly sands and gravels, very sparse cobbles, very stratified	Few tenths up to 1 ft	5–0° (30° max)	nd		
R-2	0.31	Tf	Coarser, 15% cobbles, the rest is sand and gravels	Most are 1–2 ft (range 0.5–3 ft)	Many dips are to the west	nd	5–10%	
R-16-2	1.6	Tsf	Sands and silts, a little gravel (10% or less)	0.1–1.5 ft	2–10° variable direction	nd	nd	
R-16-3	1.8	Tsf	Sands and silts, sand beds are massive (2' thick)	nd	10–5° dip, strongly westerly	nd	nd	
R-16-4	1.7	Tsf	Fine laminar bedding, silts sands, perhaps some cross-bedding	0.1 ft or less (max of 0.5 ft)	10–0° (to the west)	nd	nd	
R-34	3.5	Tpp	Fairly coarse, gravels with some cobble beds, lesser amount of sand	Mostly 3 ft (0.5 to 4 ft)	Not many data, 5–10°	Most commonly 35% (10–60)	nd	Pumice looks mostly reworked, possibly one fall bed

Note: nd = no data

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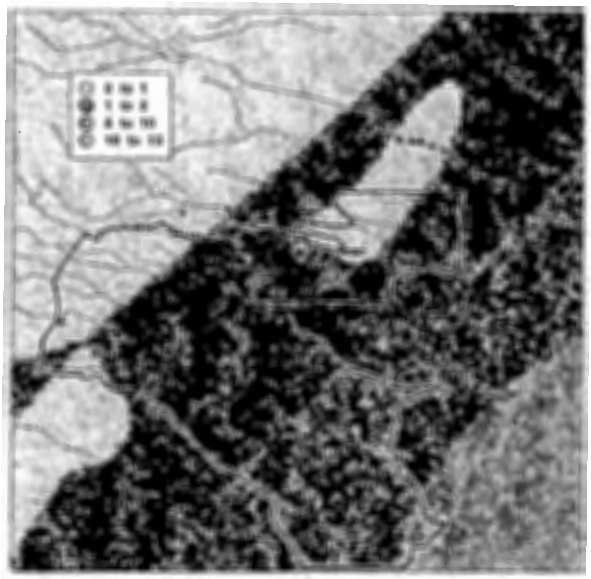
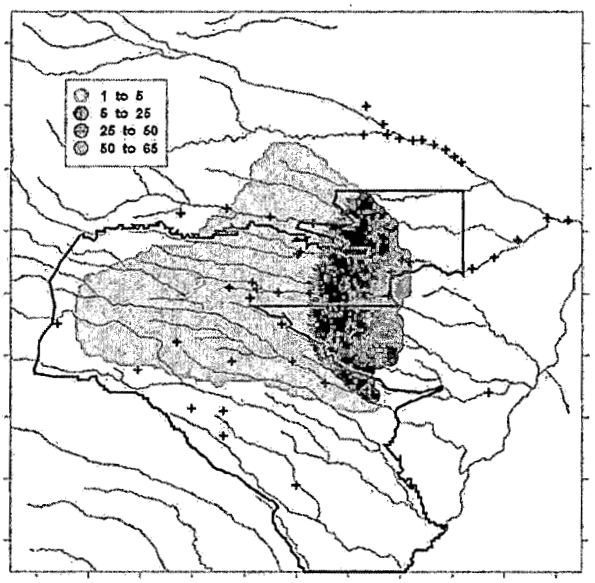
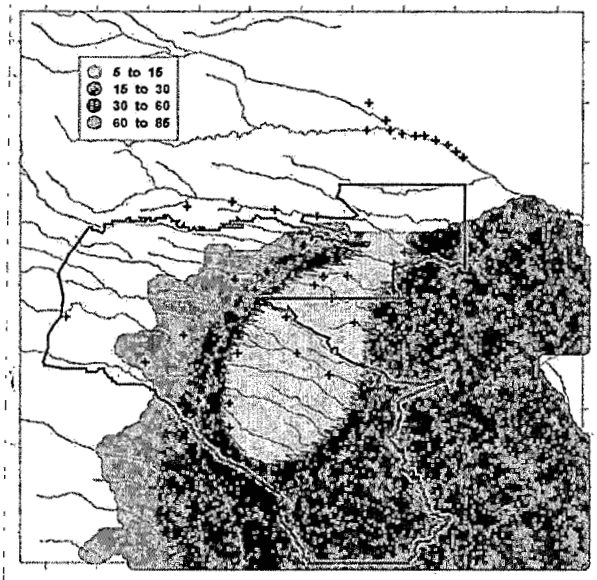


(a) Percentage of clay within Puye Pumiceous Unit



(b) Percentage of clay within Puye Fanglomerate Unit



(c) Percentage of clay-filled breccia within the Cerros del Rio Basalt

Figure 2-28. Comparison of the percentage of clay present in a hydrostratigraphic unit to the spatial variation in permeability: (a) percentage of clay within the Puye pumiceous unit; (b) percentage of clay within Puye fanglomerate unit; (c) percentage of clay-filled breccia within the Cerros del Rio basalt.
Note: + = well locations

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The percent of clay-filled breccia within the Cerros del Rio basalts (Figure 2-28c) is relatively high to the southeast and this factor may explain the low K value estimated for R-22, screen 2 and R-31, screen 3. These areas coincide with the topographically-highest part of the Cerros del Rio basalts on the Pajarito Plateau, and they probably are proximal volcanic vent areas. The low values for K and high degrees of alteration here, both within the basalts and within the Puye, suggest that hydrothermal alteration may have affected the rocks in this area.

Despite the evident variability in most of the rock types, the average properties of the rocks derived from our limited data sets show a few distinctions. The geometric mean hydraulic conductivity of the pumice-rich unit and Totavi Lentil appear to be significantly greater than the other rock types (Table 2-4). At large scales, this trend may be important for flow and transport calculations. At small scales, however, the variability evident in both these rock types will be very important to consider. Local flow directions in the vicinity of release locations and water supply wells are likely to depend strongly on these small-scale differences in hydrologic properties.

Inferences based on hydraulic gradients. Head gradients will tend to be larger in low permeability rocks, and so head data can be used, at least in a qualitative way, to infer information about permeability. Other controls on head gradients, such a recharge and pumping, complicate this approach. It is evident from the water table map (Figure 2-24) that there is large spatial variation in head gradients at the top of the aquifer. If these variations were entirely or mostly due to variations in permeability, we might conclude that rocks and structures on the western portion of the plateau (Tschicoma Formation, Pajarito Fault zone) have relatively low permeability. However, mountain-front recharge creates hydrologic conditions that lead to larger gradients, even if the rocks were homogeneous. In addition, there is an increase in permeability towards the center of the plateau (older fanglomerate, pumiceous rocks, Puye Formation and Cerros del Rio basalts). The gradient is relatively steep in the vicinity of R-22, where hydraulic testing indicates very low permeability (locally) in the Cerros del Rio basalts.

2.4.2.4 Anisotropy

As mentioned above, bedding within the Santa Fe Group and the Puye Formation is likely to cause higher permeability parallel to beds than perpendicular to beds. Large vertical head gradients measured in R wells are evidence of anisotropy; persistent vertical gradients are presumably caused by intermittent low-permeability strata that provide resistance to vertical flow. The beds within the Puye Formation range from centimeters to meters in thickness. Most are very low angle, dipping to the east. In contrast, beds within the pumiceous volcaniclastic rocks tend to dip to the southwest (R-20, R-2, R-7, R-19, and R-33). Beds within the Santa Fe Group exposed on the eastern margin of the plateau dip approximately 2–5° to the west (Golombek et al. 1983). Data from R-16 suggest that shallow layers are very low-angle, but deeper layers dip as much as 14° to the west. Hydrologic modeling and pump test analysis suggests that vertical permeability is 100 to 1000 times lower than horizontal permeability in the Santa Fe Group silts and sands (Hearne, 1985; McAda and Wasiolek, 1988; Keating et al., 2003).

If the north-south trending fault zones on the plateau tend to be barriers to flow, this would cause horizontal anisotropy, with north-south permeability higher than east-west permeability. Multiple-well pump tests on the plateau could be used to test this hypothesis.

2.4.2.5 Porosity

Tracer tests, which provide the most valuable information about effective porosity, have not been conducted in the saturated zone at this site. The only available data come from interpretations of borehole geophysical logs, using the combined magnetic resonance (CMR) tool. Using only data from the Puye Formation and the pumice-rich volcaniclastic rocks within the saturated zone, estimates of total porosity based on geophysical logs from R-7, R-19, and CDV-R-15-3 have been compiled. Figure 2-29 shows the distribution of these estimates, with data collected at 0.5 ft intervals. Table 2-6 summarizes the data. The mean effective porosity for these units as estimated from these logs (0.01–0.2) are somewhat low for sedimentary rocks (0.1–0.3, from Freeze and Cherry 1979). There is some indication that these values relate to hydraulic conductivity. For example, CDV-R-15, which has a high proportion of very low effective porosity measurements, also has a relatively low hydraulic conductivity (0.03–0.08 m/day; Table 2-6). R-19 has higher mean effective porosities and higher K values (5.7–6.7 m/day). However, there are significant differences in effective porosities between screens 5 and 6 in CDV-R-15 that do not correlate with differences in hydraulic conductivity.

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Table 2-6.
Summary of Effective Porosity Estimates based on Borehole Geophysics

Well	Mean Effective Porosity	N	Formation	Hydraulic Conductivity (m/day)
CDV-R-15[a]	0.07	744	Tpf, Tpp	-
CDV-R-15-4	0.06	87	Tpf	-
CDV-R-15-5	0.01	13	Tpf	0.08
CDV-R-15-6	0.16	15	Tpp	0.03
R19[a]	0.1	1466	Tpf, Tpp	-
R19-6	0.2	14	Tpp	5.7
R19-7	0.2	15	Tpp	6.7
R7[a]	0.09	293	Tpf, Tpp	-

[a] all depths within Puye Formation
Note: - = no data
Note: For comparison, hydraulic conductivity values derived from in situ testing (Table 2-3) are also shown.

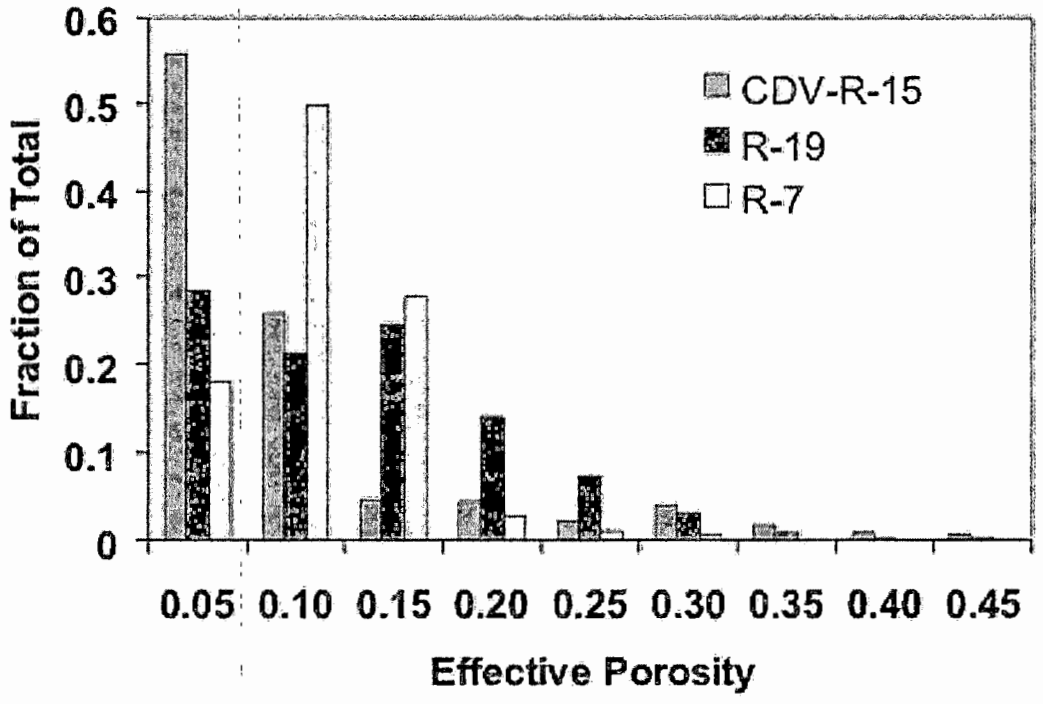

Figure 2-29. Distribution of effective porosity measured within the Puye Formation beneath the regional aquifer water table.

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2.4.2.6 Storage Properties

Storage properties of rocks will depend on whether the aquifer is unconfined or confined; delineating these two conditions beneath the plateau has been difficult. There are a number of interpretations in the literature about the degree and extent of confined conditions on the Parjarito Plateau. Based on limited data, Cushman (1965) concluded that the aquifer is under water table conditions beneath the plateau, with the exception of the vicinity of the Rio Grande where water table conditions exist in shallow layers and confined conditions exist at depth. Purtymun (1974) suggested that water table conditions exist on the western margin of the plateau and artesian conditions exist along the eastern edge and along the Rio Grande. Recent drilling has confirmed the existence of water table conditions at many locations beneath the plateau. Pump test results for water supply wells, drilled to depths up to 2000 ft below the water table on the plateau, suggest that the deeper portions of the aquifer behave as either:

- "Leaky confined" in the Los Alamos well field, specific storage $S_s \sim 10^{-4.8}$/m (Theis and Conover, 1962); and in O-4, $S_s \sim 10^{-5.5}$/m (Purtymun et al., 1995a and 1995b) or
- Unconfined in O-1, $S_s \sim 10^{-3.8}$/m (Purtymun et al., 1990, Purtymun and McLin, 1990).

In the LA wellfield, Theis and Conover (1962) expanded on the "leaky confined" interpretation by stating that there are, in fact, several aquifers and several semiconfining beds in this well field. Just to the southeast, along the Rio Grande, the aquifer has been called "partially confined" (Balleau Groundwater, 1995).

Drilling activities conducted during the Hydrogeologic Workplan have shown that in most R-wells, at all screens, the aquifer is unconfined. Heads tend to decrease with depth (see Figure 2-45, Section 2.7.7). In the shallowest portion of the aquifer (the upper 150 m), specific yield is presumably dominated by effective porosity (see Table 2-6 for estimates in the Puye Formation). Specific yield is likely to be very low for basalts. No new information is available for the deeper, leaky-confined portions of the aquifer.

2.4.3 Summary of Hydrologic Properties

Pump test data (Table 2-3, Figures 2-26 and 2-27) illustrate the heterogeneity of the aquifer, with K values ranging from 0.007 to 45 m/day The geometric mean hydraulic conductivity is 0.6 m/day; the larger-scale effective permeability may be lower due to large-scale structures and/or untested, low-permeability portions of the aquifer, based on the lower permeability values obtained in regional aquifer model calibrations (Section 4.2). Table 2-2 presents a summary of inferred properties of each of the lithologies present in the regional aquifer.

Heterogeneity tends to be particularly significant in the Puye Formation, pumiceous volcaniclastic rocks, Totavi Lentil, and older fanglomerate. The wide variety of depositional environments within the Puye Formation are consistent with this observation. However, it is difficult to go beyond this general statement to develop a predictive relationship between facies and hydrologic properties. On average, the permeabilities of the Puye Formation, pumiceous volcaniclastic rocks, Totavi Lentil, and older fanglomerate are similar and ranges of permeability overlap one another.

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As shown in Figure 2-26, there appear to be two zones near the top of the aquifer that are particularly conductive (>3 m/day). These zones are not correlated with hydrostratigraphy, suggesting that structure or alteration may be the controlling factor. No high permeability zones occur east of R-13. Large-scale trends in alteration (Figure 2-28) do not explain the location of these zones; although alteration may be an important factor in the location of a low-conductivity zone in the southeast (R-31 and R-22).

The older fanglomerate unit is also heterogeneous, consistent with its probable depositional history. The Tesuque sandy unit appears to be less heterogeneous, due to the dominance of relatively well-sorted sand and silt layers (Section 2.2.1). Discrepancies between pump test data and model-calibrated values suggest the possibility that large-scale structures such as north-south trending faults may lower the large-scale effective permeability of this unit.

Permeabilities of volcanic rocks appear to be bimodal, presumably a function of whether the groundwater is associated with fractures in flow interiors or is found in interflow zones between lavas. The amount of clay filling pore space in these settings can also affect permeability. Permeabilities of the fractured Tschicoma and Cerros del Rio lava flows are of the order of 1 to 9 m/day; permeability of poorly fractured flow interiors or clay-filled fractured units is much lower (<0.15 m/day). Limited data on Bayo Canyon basalts suggest an intermediate permeability.

Based on the depositional environment (Figure 2-21) of the Puye Formation and the Santa Fe Group, strong anisotropy (horizontal K >> vertical K) is predicted. This is confirmed by modeling studies, pump test analyses, and by the presence of large vertical gradients in many R-wells. The ratio of horizontal to vertical K may be as large as 1000 (see Section 2.4.2.3). If north-south trending low-permeability faults exist within these units (as modeling results suggest; Keating et al., 2003), this would tend to cause horizontal anisotropy.

Although porosity data are limited, geophysical logs indicate that the effective porosity of the sedimentary rocks is relatively low (0.07–0.2). Small-scale data from these geophysical logs need to be augmented by interwell tracer tests to obtain larger scale, transport-related porosity values that can be used in numerical models and transport-velocity estimates.

2.4.4 Uncertainties in the Relationship between Geologic and Hydrogeologic Units

This section describes uncertainties and sources of error in defining the relationships between hydrogeologic properties and lithology. Three of the uncertainties described here are large scale, in that they reflect the reliability of stratigraphic assignments. The large-scale uncertainties are:

- Extent and hydrogeologic nature of the Cerros del Rio unit
- Unassigned pumiceous sediments of uncertain age
- Totavi variants (see Section 2.4.4.3 below)

The remaining two uncertainties are small scale, in that they address uncertainties in the composition within a single stratigraphic unit or of a single property. The small-scale uncertainties are:

- Disposition of Santa Fe Group sediments
- Spatial variation in permeability within sedimentary rocks

2.4.4.1 Extent and Nature of the Cerros del Rio Hydrogeologic Unit

The Cerros del Rio hydrogeologic unit straddles the top of regional saturation across much of the southeastern portion of the LANL site (Figure 2-10). The thickness of the unit has proved difficult to predict in critical areas (e.g., drillhole R-22 within TA-54) because multiple flows from different source areas accumulated as stacked sequences in topographically low areas. The nature of the volcanic deposits is highly variable and has led to difficult drilling, as at R-34 where the drill site appears to have been located above a buried cinder cone with no surface expression and unknown shape and lateral extent (Figure 2-14). Data from the basalt field in the Snake River Plain indicate that permeability in basaltic volcanic sequences can vary by 10 orders of magnitude from the laboratory to the field scale, and the flow field can be strongly anisotropic (Whelan and Reed, 1997). Drilling experience in this unit at LANL shows that air permeability can be very high; open boreholes generally "breathe" with diurnal barometric variation as soon as they penetrate into the Cerros del Rio deposits. All of these features indicate significant importance of the Cerros del Rio in flow and transport. At present the 3-D geologic model allows for estimation of relative percent of flow interior, open breccia, and clay-filled breccia for each borehole, but such distributed percentages may not be sufficient for adequate hydrogeologic characterization where stochastic flow simulation may require knowledge of volcanic stratigraphy (Whelan and Reed, 1997). In addition, a conceptual model describing the characteristic length scales of the basalt subunits would also be required.

2.4.4.2 Unassigned Pumice-Rich Volcaniclastic Rocks

The extent of clay alteration in pumiceous sediments can be a critical hydrogeologic parameter, for the unaltered deposits are highly transmissive whereas local zones of extensive clay alteration transform the pumice-rich intervals into aquitards. Extensive pumiceous sediments (Figure 2-9) are widely distributed beneath Puye fanglomerates in the central portion of the LANL site. This unit is not known in outcrop and was not anticipated when drilling for the Hydrogeologic Workplan began. Radiometric dates of 6.8 and 7.5 Ma from pumice in this unit suggest a possible relationship with Peralta Tuff to the south, but petrographic variation and stratigraphic occurrence indicate that multiple volcanic sources supplied tephra to these deposits. The pumiceous sediments in R-9 and R-12 are completely altered to smectite, whereas other occurrences have little clay and are essentially unaltered. It is uncertain whether the altered and unaltered pumice units are related. This uncertainty can have considerable impact on how the pumiceous deposits are represented in cross-section for the conceptual geologic model (see Figure 2-12) and in 3-D for the numerical geologic model, as well as having an impact on flow and transport properties.

2.4.4.3 Totavi Variants

The Totavi may be an important transmissive unit at the site, providing a significant flowpath where laterally contiguous, making the treatment of this unit in the 3-D numerical geologic model particularly important. The axial deposits left by paleochannels of the Rio Grande are well defined in outcrop by their high abundance of Precambrian lithologies derived from northern sources. Dethier (1997) provides extensive data for these deposits exposed along the eastern margin of the LANL site; his definition of the Totavi notes that it contains "generally >80%

quartzite and other resistant lithologies from northern New Mexico, but clasts from the southern Sangre de Cristo range are common locally." The high quartzite abundance is distinctive. Previous conceptual models of the LANL site geology have extended these axial gravels in a continuous unit beneath the site as a horizon underlying Puye fanglomerates. More recent drilling has provided evidence of many stream gravels at varied stratigraphic levels, most with a smaller abundance of Precambrian stream gravels (generally <25% Precambrian gravel) and with more gravels from volcaniclastic sources. Furthermore, new radiometric dates on pumice-rich volcaniclastic rocks indicate that underlying river gravels are considerably older than the Totavi deposits exposed on the east side of the plateau. The construction of a Totavi unit is thus problematic, with some areas where the stream gravels are moderately extensive and other areas with isolated channels (e.g., cross-sections in Figures 2-12 and 2-13). Therefore, the representation of the Totavi unit within the geologic framework model is illustrative.

2.4.4.4 Disposition of Santa Fe Group Sediments

The impact of distinguishing different lithologies of Santa Fe Group sediments can be of hydrogeologic significance in defining the extent of more productive gravels and in construction of hydrogeologic unit boundaries. The Santa Fe Group sediments exposed in outcrop along the eastern margin of the LANL site consist of sands and lesser stream gravels, commonly with some amount of carbonate cement, that are derived predominantly from plutonic and metamorphic Precambrian sources. The 1997 conceptual geologic model for the site projected extensive amounts of Santa Fe Group sediments beneath the site that were predicted to be encountered by most drillholes deeper than ~1000–1500 ft. Furthermore, the central and most hydrologically productive zone was interpreted as consisting of deposits of equivalent age that contained more abundant volcaniclastic material. More recent drillholes have found that this deeper volcaniclastic material is predominantly of Jemez-derived lithologies and is distinct from the generally arkosic deposits of the Tesuque Formation. Recent work in the Española Basin suggests that "lithosomes" of the Santa Fe Group grade laterally and interfinger, as fault displacements episodically dropped the western margin of the basin. However, the downdropping western margin of the basin, which is beneath the LANL site, may also have been the locus of past flow for major drainages. At this time it is uncertain whether the lithologic variations in these older sediments beneath the site reflect interfingered facies of similar age or unconformable, younger channel deposits in paleocanyons cut into the older Santa Fe Group sands. Resolution of this uncertainty could confirm or rule out the existence of long-distance, high-permeability pathways in the regional aquifer.

2.4.4.5 Spatial Variation in Permeability within Sedimentary Rocks

With the exception of the relatively uniform sandy sub-unit of the Santa Fe Group, variability within hydrostratigraphic units tends to be much larger than variability between hydrostratigraphic units. To understand intra-unit variability, using limited data the possible role of texture (Table 2-5) and alteration (Figure 2-28) have been examined and no consistent relationships were found. There does not appear to be a method to deterministically interpolate the spatial variation in permeability within these sedimentary rocks, given the available data. It is possible that a larger dataset and better information about sedimentary facies (if cores were available, for example) would allow a better understanding of the mechanisms controlling hydraulic conductivity. Even so, local variation may be sufficiently great that accurately

interpolating point data (tests at wells) within a deterministic 3-D framework model from known point estimates may not be feasible.

For the purposes of modeling flow and transport through sedimentary rocks in the saturated zone, it may be more appropriate to use a probabilistic approach based on the statistical properties of the hydraulic conductivity dataset rather than a deterministic approach based on defined geometries of hydrostratigraphic units (Section 4.2.10). Another promising method may be to use head data directly to infer heterogeneities in the aquifer (Doherty et al., 1994).

Although the data suggest there are no large differences in permeability between the volcanic and sedimentary rocks, differences in porosity and storage characteristics are likely to be large. For this reason, it is important to delineate the extent of the volcanic rocks in a 3-D framework model of the site for the purposes of flow and transport modeling.

Available porosity data are very limited; more data could be derived from existing borehole geophysical logs and perhaps a geostatistical model of porosity could be built from those logs.

2.4.4.6 Influence of Structure on Groundwater Flow

The influence of structures on groundwater flow is uncertain, but the evidence suggests that structure plays a role in groundwater flow beneath the Pajarito Plateau. First, the large head gradients across the Pajarito fault zone indicate that the faults exert control on flow. Associated modeling results described in Section 4.2.10 suggest that the Pajarito fault zone and north-south trending faults in the Santa Fe Group may act as flow barriers at large scales. Zones of high permeability in the center portion of the plateau (Figure 2-26), which cross hydrostratigraphic boundaries, suggest that perhaps large-scale features such as faults play an important role here.

Further interdisciplinary work combining geophysics, geochemistry, hydrology, and geology investigations would be required to better understand the processes controlling variability in aquifer properties at this site. Given the large heterogeneities in flow and transport properties and the complexities of the hydrogeologic formations, it is unlikely that transport models can ever be based purely on a deterministic hydrogeologic framework. Rather, models should be based on a blend of deterministic (e.g., 3-D hydrogeologic framework models) and geostatistical approaches.

2.5 Alluvial Groundwater Conceptual Model

The alluvial groundwater conceptual model is based on data collected during investigations of alluvial groundwater systems at LANL that have been conducted to meet various objectives not specific to the Hydrogeologic Workplan (Appendix 1-A). Most of the early investigations were driven by alluvial groundwater contamination concerns in canyons with persistent alluvial saturation along significant segments of the canyon, and most of the early investigations were conducted in Mortandad Canyon. Examples of these studies include those conducted by Purtymun (1974), Purtymun et al. (1983), and Stoker et al. (1992). Many of these investigations were conducted in collaboration with the United States Geological Survey. Additional investigations conducted in the mid-1990s measured alluvial aquifer properties (Koening and Guevara, 1992) and calculated bulk groundwater flow velocity (Gallaher, 1995). Purtymun

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(1995) contains a significant body of additional information and references pertaining to alluvial groundwater investigations conducted at the Laboratory up to the mid-1990s.

2.5.1 Physical Setting

Average annual precipitation across the Pajarito Plateau ranges from over 0.5 m along the western boundary near the Jemez Mountains to less than 0.36 m to the east at the Rio Grande (Bowen, 1990). Most precipitation occurs either as winter/spring snow or as summer "monsoonal" rains. As a result, most infiltration occurs episodically during spring snowmelts or during the intense summer thunderstorm season.

Surface-water flow in the canyons is generally ephemeral or intermittent, although a few canyons have short stretches with perennial surface flow. Anthropogenic discharges from water treatment outfalls can be a significant source of water in some canyons. Infiltration of these surface sources forms near-surface perched alluvial groundwater systems in many of the canyons (Stone et al., 2001). These alluvial groundwaters are not sufficiently extensive for domestic use. Nevertheless, these waters are an important component of the subsurface hydrologic system. In addition, laboratory contaminants introduced into the canyons can affect shallow groundwaters. Therefore, alluvial groundwaters provide pathways for contamination to migrate to significant lateral distances and potentially to greater depths.

The deposits that comprise alluvial groundwater aquifers are confined to the bottoms of canyons and are composed of axial fluvial deposits interbedded with deposits of alluvial fans, colluvium, and rock fall from adjacent mesa slopes. For watersheds that head on the Pajarito Plateau (e.g., Mortandad and Sandia Canyons), the source of sediment is primarily Bandelier Tuff and, to a much lesser extent, other formations such as the Cerro Toledo interval. Tschicoma dacite and Bandelier Tuff are primary sources of sediment for watersheds that head in the Sierra de los Valles. Canyons that have Bandelier Tuff as the primary source of sediment tend to have predominantly sand-sized alluvial fill with some interbedded coarser-grained side-slope deposits, including colluvium, whereas canyons that head in the Sierra de los Valles have alluvial fill that contains a wide range of grain sizes including dacitic boulders and gravels. Available data indicate that the thickness of alluvium and colluvium in the canyons ranges from a few feet up to approximately 100 feet.

2.5.2 Hydrology

The presence and extent of saturation within the canyons is dependent on a number of variables including source(s) of water, volume and persistence of water sources, the magnitude and location of infiltration of groundwater from the alluvial system to underlying bedrock units (i.e., loss to underlying vadose zone), and evapotranspiration.

These controls on variability of saturation are difficult to quantify, but are based largely on observations made during drilling for installation of alluvial monitoring wells and piezometers in several canyons, including, Los Alamos and Mortandad Canyons, and Cañon de Valle. Adjacent boreholes commonly show different saturated conditions and sometimes a borehole with substantial saturation will be adjacent to one or more boreholes with no or minimal saturation.

This phenomenon is likely related to juxtaposition of facies with highly variable hydrologic properties, such as porosity, permeability, or hydrologic conductivity (Figure 2-30; Reneau and McDonald, 1996).

2.5.2.1 Alluvial Recharge

Recharge to alluvial groundwater systems on the Pajarito Plateau occurs via infiltration from three primary sources: storm-water runoff, anthropogenic effluents, and snowmelt. Each of these recharge sources produces a characteristic groundwater response. The conceptual model for alluvial system recharge on the Pajarito Plateau is based on continuous stream flow, precipitation, and water-level data collected within the Los Alamos and Pueblo Canyon watersheds (including DP Canyon). Three example plots (Figures 2-31, 2-32, and 2-33) show the relations of precipitation, stream flow, and groundwater hydrographs for several representative alluvial monitoring wells in Los Alamos and Pueblo Canyons. The precipitation data shown in the plots are values of average daily precipitation estimated using Theissen weighted averages of precipitation measured within and near the watershed (Dunne and Leopold, 1978). This approach is described in greater detail in LANL (2004) and in Reneau and Kuyumjian (2005). These examples are believed to be representative of canyons across the plateau.

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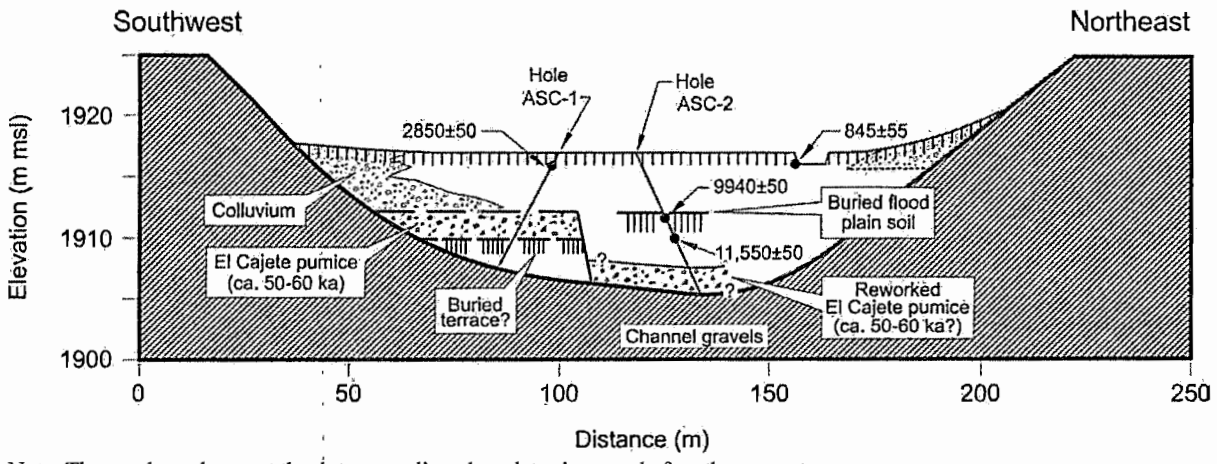

Note: The numbers shown at the dots are radiocarbon dates in years before the present.
Source: Reneau and McDonald (1996).

Figure 2-30. Schematic cross section of complex stratigraphy within the alluvial package in Ancho Canyon.

Examples of recharge via infiltration of storm water are shown in Figure 2-31. The water-level record for monitoring well LAO-0.3 in Los Alamos Canyon is plotted against precipitation data and the stream flow record at gaging stations E025, E030, and E042. The water-level data show generally rapid rises in response to summer and fall precipitation events and associated storm water runoff. Good examples are the large precipitation events in mid-August 2001 and late June 2002. These water-level rises occur instantaneously and generally correlate well with the stream flow record, indicating infiltration into the streambed during floods. The duration of the recessional limb varies between events. Several small but distinct increases in the water-level recorded during late spring and summer months are not related to precipitation events, but rather are related to draining of the Los Alamos Reservoir for dredging and maintenance following the Cerro Grande fire. Storm-water runoff can be generated from precipitation in upland portions of watersheds, directly onto the plateau, or on impervious surfaces in developed areas within the Laboratory or in the Los Alamos townsite.

Effluent-supported recharge results in more sustained and consistent water levels, as shown in Figure 2-32. Groundwater levels observed in monitoring well PAO-4 are dominated by infiltration of effluent discharged from the Bayo wastewater treatment plant (WWTP) to the stream channel in Pueblo Canyon (Figure 2-2). The variation in water-level elevations down canyon of the WWTP is controlled primarily by seasonal rerouting of effluent for "downstream" uses such as watering at the Los Alamos County golf course. Other examples of canyon reaches with similar effluent-supported recharge include effluent/upper Mortandad Canyon (TA-50 outfall) and upper Sandia Canyon (power-plant outfall). These sources represent relatively consistent sources of recharge to alluvial groundwater creating stable alluvial groundwater levels. During dry periods in drier canyons that have little natural runoff, anthropogenic sources provide the majority of groundwater recharge.

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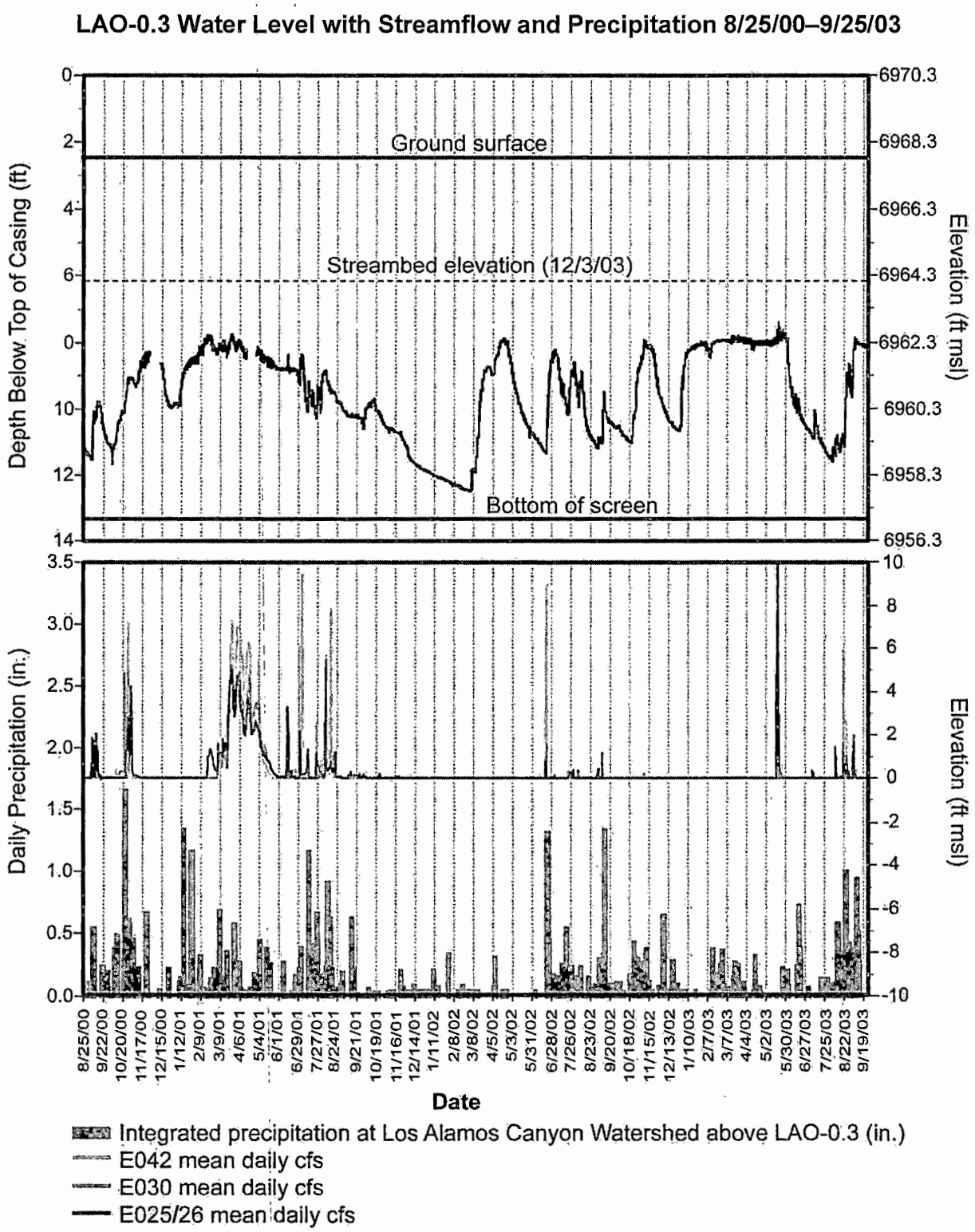

Figure 2-31. LAO-0.3 water level with streamflow and precipitation.

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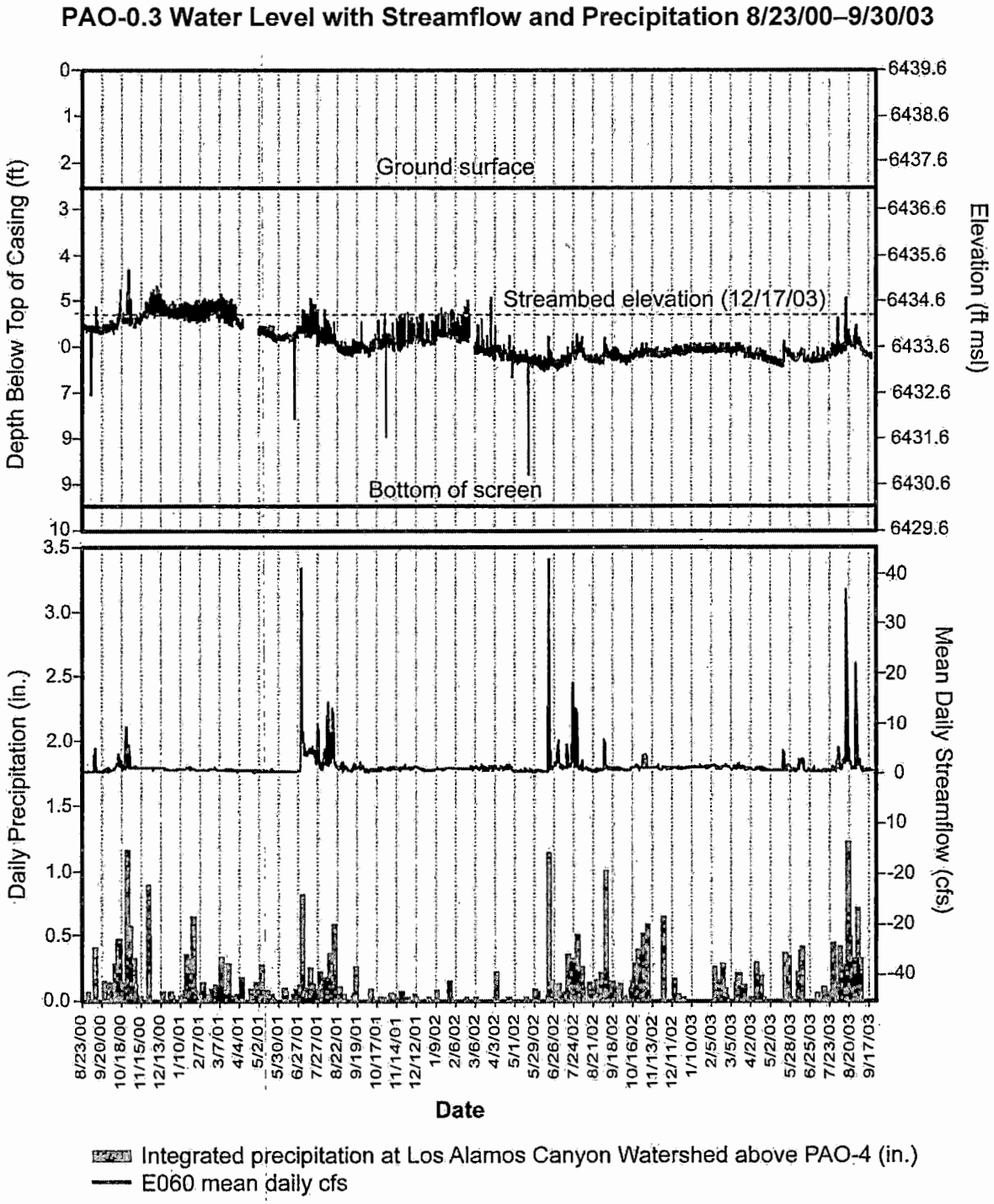

Figure 2-32. PAO-4 water level with streamflow and precipitation.

Recharge also occurs in response to winter/spring snowmelt. Figure 2-31 shows rising alluvial groundwater levels during the late winter to early spring of each of the years represented on the plot. All three winter/spring periods show alluvial-groundwater-level responses prior to initiation of sustained streamflow at even the most up-canyon gaging station, E025. The winter and spring

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of 2000–2001 alluvial-groundwater-level shows a substantial response to snowmelt runoff from an appreciable winter snowpack. The alluvial-groundwater-level response occurs over one month prior to initiation of stream flow at E025. The conceptual model for this type of response is that recharge within the alluvium is associated with early-season snowmelt that infiltrates into alluvium in the upper canyon and creates an underflow recharge front that advances down canyon. Once the aquifer saturation has reached capacity (i.e., the elevation of the adjacent stream channel), stream flow is initiated, suggesting that stream flow during these periods represents discharge from the aquifer to the channel.

Figure 2-33 shows groundwater-level data from four alluvial groundwater monitoring wells in Los Alamos Canyon. Initiation of the alluvial-groundwater-level rise in the winter/spring of 2001 at each well occurs prior to the onset of sustained surface water flow. This suggests that the persistent baseflow conditions associated with snowmelt infiltration may actually be sustained largely from discharge of groundwater to the channel. Long-duration snowmelt runoff is most significant in watersheds with upland drainage basin areas, although watersheds that drain developed areas with pavement and storm-drain systems can provide short-duration, pulsed snowmelt runoff associated with melt from individual events.

The down-canyon extent of alluvial groundwater saturation varies significantly from year to year and seasonally. During dry years, and especially during years with limited spring snowmelt runoff, saturation may not extend far from the upland sources of snowmelt recharge.

Gray (1997; 2000) and LANL (2004) investigated alluvial groundwater in Los Alamos Canyon, creating a numerical model that calculated infiltration of alluvial groundwater to the underlying vadose zone. Results indicate that the alluvial groundwater infiltrates into the underlying vadose zone at variable rates along the length of the canyon with a higher rate of loss estimated for a portion of the canyon coincident with the projected trace of the Guaje Mountain fault (mapped to the north but not evident in the walls of Los Alamos Canyon). Nested piezometer data from Los Alamos Canyon (LANL 2004) corroborate modeling results indicating greater infiltration rates in the vicinity of the projected Guaje Mountain fault. The variability in infiltration rates is interpreted to be caused by either loss into permeable units underlying the alluvium or loss within zones of relatively greater fracture size or density.

In addition to the watershed-scale investigation of alluvial groundwater responses to various recharge sources, site-specific alluvial groundwater investigations have been conducted in DP Canyon and in Cañon de Valle. A potassium bromide tracer study was conducted in DP Canyon in 2003 to investigate alluvial groundwater travel times, surface water/groundwater exchange, hydrologic linkage from reach DP-2 to DP Spring, and to measure vertical hydraulic gradients and seepage velocity into the underlying Bandelier Tuff. The primary conclusions regarding alluvial recharge from this study were that surface water/groundwater exchange is an important recharge mechanism and that groundwater flow is transient, primarily controlled by episodic recharge from townsite runoff. For a detailed description of these findings, see LANL (2004) and LANL (2003a).

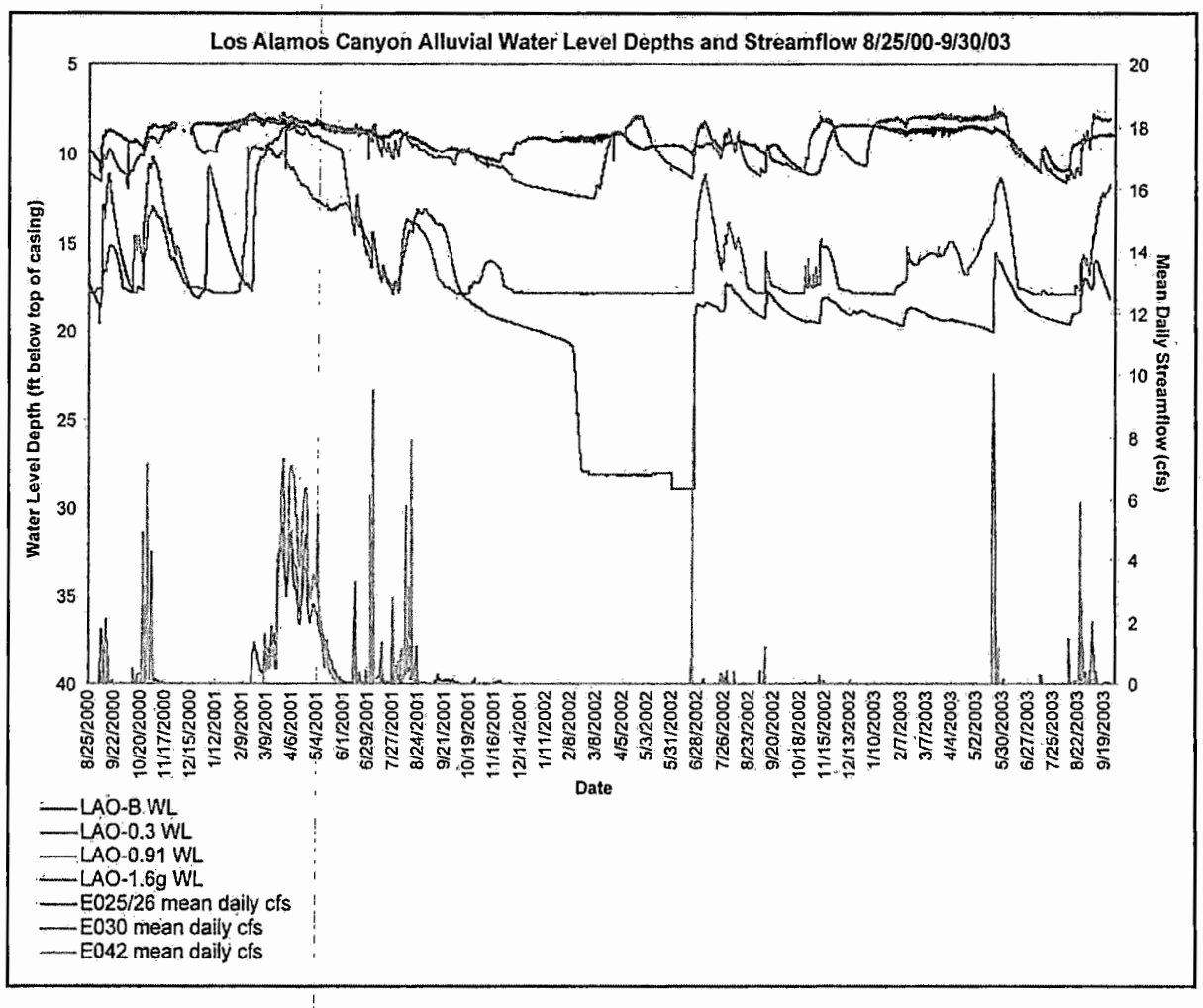

Figure 2-33. Los Alamos Canyon alluvial water level depths and stream flows.

To quantify infiltration, Kwicklis et al. (2005) developed a map of average annual "net infiltration" in the Los Alamos area, based on physical features such as elevation, vegetation, surface geology and stream flow (Figure 2-34). They define net infiltration as that water remaining after accounting for evapotranspiration in the shallow subsurface (i.e., the root zone). They estimate the highest net infiltration rates in canyons, especially those that head in the mountains, with magnitudes of up to a few hundred millimeters per year caused by channelized runoff. In contrast, much lower net infiltration rates occur across mesas and in the smaller canyons that head on the plateau (see Section 4.1 for a site-wide numerical model employing these concepts).

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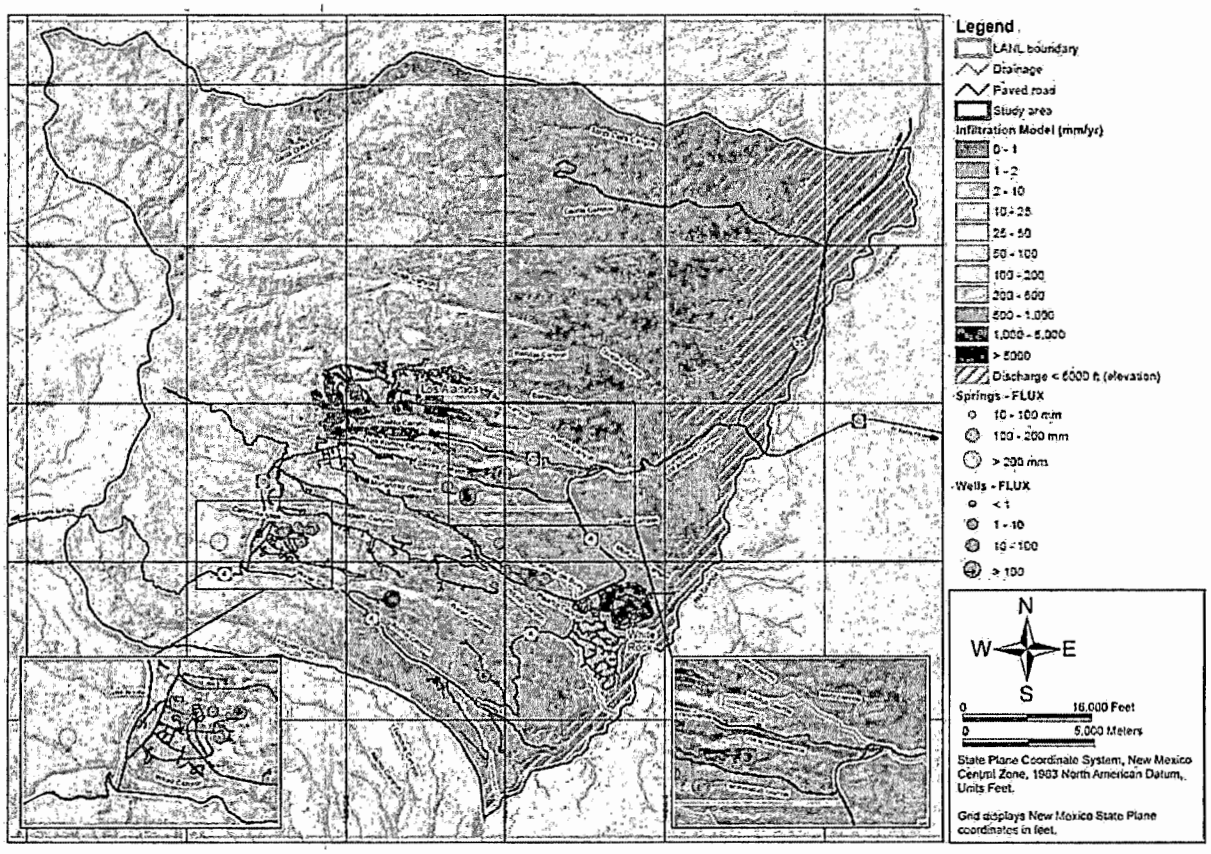

Figure 2-34. Estimated infiltration on the Pajarito Plateau (reproduced from Kwicklis et al., 2005).

2.5.2.2 Alluvial Aquifer Properties

Observations of alluvial groundwater were initially focused on understanding the distribution of contaminants. Purtymun (1974) performed one of the first quantitative investigations where groundwater velocities were calculated from a tritium release in Mortandad Canyon. The release from the TA-50 outfall was a planned event staged to discharge wastewater containing elevated tritium. Groundwater velocities calculated from travel time of the tritium centroid showed values ranging from 20 meters/day in the upper canyon, where alluvium is thin and the alluvial aquifer volume is small, to approximately 2 meters/day in the lower canyon where the canyon widens and alluvium thickens to approximately 30 meters (Table 2-7). These observations indicate that alluvial groundwater flow can be highly variable along the length of a canyon. Other factors influencing system-scale groundwater velocity include aquifer sediment textures, stratigraphic complexity, and hydraulic gradient.

Gallaher (1995) calculated Darcy velocity (Table 2-7) from mean saturated hydraulic conductivities (Table 2-8) and water table gradients in Los Alamos Canyon. Using the results from slug tests conducted by Koening and Guevara (1992), Gallaher estimated the rate of groundwater movement in alluvium at 0.75 meters/day. Additional saturated conductivity values for Los Alamos and Mortandad Canyons are presented in Table 2-8. Slightly lower hydraulic

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conductivities in middle Mortandad Canyon may be due to an overall fining of the alluvial material in that portion of the canyon.

Gray (1997, 2000) measured aquifer parameters, calculated a hydrologic budget and performed numerical modeling of groundwater flow in Los Alamos Canyon. Hydraulic conductivity measurements from these studies are included in Table 2-9.

2.5.2.3 Cerro Grande Fire Effects

The May 2000 Cerro Grande fire produced significant hydrologic changes in the watersheds west of the Laboratory (BAER 2000). Loss of vegetation and forest litter, development of ash covers, and extreme hydrophobic soil conditions, primarily in the upland portions of watersheds, greatly reduced the capacity for infiltration and storage of precipitation. Rapid surface-water runoff in the first two summer monsoon seasons following the fire contained high ash content with a complex mixture of inorganic and organic compounds. Calcium, magnesium, silica, potassium, sodium, and carbonate were among the constituents concentrated in the ash (Longmire et al., 2002).

A detailed water-level and water-quality record was obtained from Los Alamos and Pueblo Canyons using dedicated multiparameter pressure transducers installed in a series of alluvial monitoring wells. Hydrologic system effects were manifested as rapid water-level response to numerous post-fire floods and possibly also earlier-than-typical onset of a snowmelt runoff response. Reduced or eliminated forest canopy is thought to have allowed winter snow to melt shortly after individual precipitation events and early in the spring. There were stormwater related excursions in water-quality parameters, including increases in pH in the alluvial groundwater and elevated concentrations of several constituents in alluvial groundwater due to infiltration of ash-rich storm water. A detailed discussion is presented in Chapter 7 and Appendix B of the Los Alamos and Pueblo Canyons Investigation Report (LANL, 2004). It is not known how long such perturbations will persist, although the effects of the fire are expected to progressively decrease over time as the upper watershed recovers.

2.6 Vadose Zone Conceptual Model

The vadose zone is the section of soil and rock material between the alluvial groundwater or the ground surface (where alluvial groundwater is not present) and the regional aquifer water table. Beneath the Pajarito Plateau, the thickness of the vadose zone ranges from about 600 feet to over 1,200 feet. Intermediate-depth perched groundwaters are present within the vadose zone. Specific intermediate perched zones that occur beneath major canyons and in the western portion of the Laboratory are described in Section 2.7.

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Table 2-7.
Groundwater Velocities in Alluvial Aquifers on the Pajarito Plateau

Measure Locations	Source	Distance between Measurement Points (m)	GW Velocity (m/d)	Test Type
Upper Los Alamos Canyon	A	Approximately 7000	0.75	Calculated from (mean K_s[A]), average gradient of stream channel (0.027), and an estimated porosity of 0.3.
Mortandad Canyon				
MCO-5 to MCO-6	B	393	^{3}H 16 Cl 25	Tritium (^{3}H) and chloride (Cl) TA-50 discharge tracer test
MCO-6 to MCO-7	B	320	^{3}H 4.2 Cl 5.1	Tritium (^{3}H) and chloride (Cl) TA-50 discharge tracer test
MCO-7 to MCO-7.5	B	290	^{3}H 4.4 Cl 5.6	Tritium (^{3}H) and chloride (Cl) TA-50 discharge tracer test
MCO-7.5 to MCO-8	B	185	^{3}H 1.7 Cl 2.3	Tritium (^{3}H) and chloride (Cl) TA-50 discharge tracer test

Note: Calculated groundwater velocity using mean saturated hydraulic conductivity from LAO-C, LAO-1, LAO-2, LAO-3, LAO-3A, LAO-4, LAO-4.5A, LAO-4.5C, LAO-5.

A Gallaher (1995)

B Purtymun (1974)

Table 2-8.
Saturated Hydraulic Conductivity Values for Alluvial Groundwater on the Pajarito Plateau

Well/Piezometer	Location	Mean Ksat (cm/sec)	Test Type
Los Alamos Canyon			
Piezometer	LAP-1-#1a	4.67E-04	Rising head slug test; Bouwer-Rice solution
Piezometer	LAP-1-#2a	1.32E-03	Rising/falling head slug test; Bouwer-Rice (1976)
Piezometer	LAP-1-#3a	2.71E-03	Rising/falling head slug test; Bouwer-Rice (1976)
Piezometer	LAP-1.5-#1a	2.62E-03	Rising/falling head slug test; Bouwer-Rice (1976)
Piezometer	LAP-1.5-#2a	4.43E-03	Rising/falling head slug test; Bouwer-Rice (1976)
Piezometer	LAP-1.5-#3a	9.42E-03	Rising/falling head slug test; Bouwer-Rice (1976)
Piezometer	LAP-3a	3.10E-03	Rising/falling head slug test; Bouwer-Rice (1976)
Piezometer	LAP-3.5-#1a	2.660E-03	Rising/falling head slug test; Bouwer-Rice (1976)
Piezometer	LAP-3.5-#2a	1.27E-03	Rising/falling head slug test; Bouwer-Rice (1976)
Piezometer	LAP-3.5-#3a	2.82E-05	Rising/falling head slug test; Bouwer-Rice (1976)
Piezometer	LAP-4-#1a	2.58E-05	Rising/falling head slug test; Bouwer-Rice (1976)
Piezometer	LAP-4-#2a	2.20E-05	Rising/falling head slug test; Bouwer-Rice (1976)
observation well	LAO-Bb	7.01E-03	slug tests; Bouwer-Rice (1976)
observation well	LAO-Cc	1.16E-03	slug tests; Bouwer-Rice (1976)
observation well	LAO-0.3b	1.25E-02	slug tests; Bouwer-Rice (1976)
observation well	LAO-0.6b	7.58E-03	slug tests; Bouwer-Rice (1976)
observation well	LAO-0.91b	3.56E-02	slug tests; Bouwer-Rice (1976)
observation well	LAO-1c	1.58E-02	slug tests; Bouwer-Rice (1976)
observation well	LAO-1.6(g)b	4.82E-03	slug tests; Bouwer-Rice (1976)
observation well	LAO-2c	1.01E-02	slug tests; Bouwer-Rice (1976)
observation well	LAO-3c	1.34E-02	slug tests; Bouwer-Rice (1976)
observation well	LAO-3ac	1.22E-02	slug tests; Bouwer-Rice (1976)

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Table 2-8.
Saturated Hydraulic Conductivity Values for Alluvial Groundwater on the Pajarito Plateau (continued)

Well/Piezometer	Location	Mean Ksat (cm/sec)	Test Type
observation well	LAO-4c	2.41E-02	slug tests; (1976)
observation well	LAO-4.5b	2.55E-03	slug tests; (1976)
observation well	LAO-4.5ac	2.33E-03	slug tests; (1976)
observation well	LAO-4.5cc	2.77E-03	slug tests; (1976)
observation well	LAO-5c	3.35E-03	slug tests; (1976)
Mortandad Canyon			
observation well	MCO-3c	3.72E-02	slug tests; (1976)
observation well	MCO-4c	7.13E-04	slug tests; (1976)
observation well	MCO-4Cc	3.47E-04	slug tests; (1976)
observation well	MCO-4.9c	2.88E-05	slug tests; (1976)
observation well	MCO-5c	5.41E-05	slug tests; (1976)
observation well	MCO-6c	7.08E-04	slug tests; (1976)
observation well	MCO-7.5c	9.63E-04	slug tests; (1976)
observation well	MCO-7Ac	1.06E-04	slug tests; (1976)
observation well	MCO-7c	5.11E-04	slug tests; (1976)
observation well	MT-3c	2.93E-05	slug tests; (1976)

a Results have been published in the Los Alamos and Pueblo Canyons Investigation Report (LANL, 2004b).
b Results from 1998 slug tests (Los Alamos and Pueblo Canyons Investigation Report (LANL, 2004b).
c Results from 1995 slug tests.

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2.6.1 Climate and Infiltration

Arid and semi-arid regions often exhibit thick vadose zones. Infiltration is often focused in topographic lows or beneath surface water bodies, rather than being diffuse, as is common in wetter climes (e.g. Sanford, 2002). The average annual potential evapotranspiration (PET) rates far exceed precipitation rates. Under these conditions, infiltration events that propagate beneath the root zone are sporadic and occur only when the short-term infiltration rate exceeds the ET rate, such as during snowmelt or after large rainstorms. Consequently, the rates for deeper infiltration are difficult to quantify through traditional water balance studies because this component of the water-balance can be orders of magnitude smaller than the other components (Devries and Simmers, 2002; Scanlon et al., 2002; Sophocleous, 2002; Sanford, 2002; Flint et al., 2002). These generalities apply to the near-surface hydrology of the Pajarito Plateau, which has a semiarid climate.

The infiltration rate estimates from canyon bottom alluvium and mesa top sites developed by Kwicklis et al. (2005) (Figure 2-34) can be tested for consistency against the estimated infiltration rates inferred from moisture content profiles. In Section 4.1.3.2, a set of numerical models for wells LADP-3 and LADP-4 in Los Alamos Canyon are presented showing that moisture profiles reflect the conceptual model of high infiltration in canyons and low infiltration in mesas. That analysis also shows that the uncertainties associated with such estimates are quite high (in the range of a factor of 3). However, by combining moisture content, tracer or contaminant profiles, and water budget information, a more constrained estimate can be achieved. One of the purposes of the vadose zone numerical models being developed is to provide the additional constraints afforded by the use of multiple, independent data sets (Robinson et al. 2005a).

2.6.2 General Description of Conceptual Models

Conceptual models for vadose zone flow and transport on the Pajarito Plateau are based on observations from a variety of data sources, including both mesa-top and canyon sites under both natural conditions and disturbed conditions resulting from Laboratory operations. The key conceptual-model elements describe percolation of water through both fractured and relatively unfractured volcanic tuffs, buried sedimentary formations, and basalts. The types of data incorporated into the development of the conceptual models include water content and pore-water chemical compositions from borehole samples for naturally occurring tracers, introduced tracers, and Laboratory contaminants.

The conceptual models differentiate the rate of percolation by their location and surface hydrologic setting, including wet and dry canyons, and wet, dry, and disturbed mesas. Perched water is often found beneath wetter canyons, either associated with near-surface alluvial systems or at intermediate depths, along low-permeability interfaces such as buried soils and unfractured or clay-filled horizons of basalt flows. Alluvial groundwater is discussed in Section 2.4, while perched water is addressed in Section 2.6. The generalized view of the role of wet and dry canyons on vadose zone flow and transport is quantified in the numerical model section of this report (Section 4).

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2.6.2.1 Mesas

Dry finger mesas constitute most of the mesa area on the plateau. The hydrologic conditions on the surface and within these dry mesas lead to slow unsaturated flow and transport. The mesas shed precipitation as surface runoff to the surrounding canyons such that most deep infiltration occurs episodically following snowmelt (Section 2.4.2.1). Much of the water that does enter the soil zone is lost through evapotranspiration (ET). As a result, annual net infiltration rates for dry mesas are less than ten mm/yr and are more often estimated to be on the order of one mm/yr or less (Kwicklis et al., 2005). Since the dry mesas are generally comprised of nonwelded to moderately welded tuffs with low water content, flow is likely to be matrix dominated. Wetter mesas, supporting ponderosa forest above densely welded and fractured tuff in the western portion of the plateau, may provide fracture flow to a few meters to tens of meters depth but evidence of fracture infiltration usually diminishes at the depth of the first nonwelded horizon. For most of the LANL site, travel times for contaminants migrating through mesas to the regional aquifer are expected to be several hundred to thousands of years (Newman, 1996; Newman et al., 1997b; Birdsell et al., 2000; and Section 4.1.1 of this report).

The topographic relief of these steep-sided mesas influences their internal hydrologic conditions as well. High solar radiation, strong winds, and fluctuations in barometric pressure cause temperature and pressure gradients between the surface of the mesa and its interior. These gradients enhance air circulation through the mesas, which is thought to enhance deep evaporation (Neeper 2002; Neeper and Gilkeson, 1996; Newman, 1996; and Newman et al., 1997b). This additional drying in the mesa-top units further slows downward water flow and transport of dissolved species. However, these same conditions enhance vapor transport of volatile species (Stauffer et al., 2005).

Anthropogenic discharges and surface disturbances due to laboratory operations can drive infiltration rates higher in usually dry mesas. In some cases, multiple disturbances of mesa sites through liquid waste disposal, asphalt covers, and/or devegetation have caused mesa infiltration rates to temporarily increase to near wet canyon levels (representative values are given in Section 4.1). Even with elevated infiltration, at most sites flow remains matrix dominated. Fracture flow has occurred in a few instances beneath long-term liquid disposal sites with ponded conditions. However, fracture flow ceases once liquid disposals stop. Infiltration rates are expected to return to low, near-background levels when the surface and vegetation return to natural conditions.

An exception to the general concepts just discussed occurs for mesas along the mountain front of the plateau. Due to their higher elevation, these mesas receive higher precipitation and higher infiltration than the drier mesas in the central and eastern portions of the plateau (Birdsell et al., 2005). Mountain-front areas also have units of the Tshirege Member that are more strongly welded, yielding rocks with more fracturing and lower matrix permeabilities. Under these conditions, infiltrating water travels laterally through fractures and other fast pathways, often issuing at springs that feed the canyons in this area. These near-surface processes can be thought of as sources for deeper vadose zone transport from canyon bottoms, although the possibility of deeper vertical migration from the mesa source without first entering the canyon is also possible.

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2.6.2.2 Canyons

This section summarizes the hydrologic conditions present in canyons characterized as either wet or dry. Several features characterize naturally wet canyons on the Pajarito Plateau. Their headwaters are in the mountains, they have large catchment areas (13 to 26 km^2), surface flow occurs frequently, and alluvial groundwater systems exist in the canyon floors. In some cases, anthropogenic sources can elevate flows sufficiently in smaller dry canyons that head on the plateau so that they act as wet canyons. In addition, springs issuing from the sides of mesas are a water source in the mountain front canyons; these springs are a characteristic of wet canyons in the western portion of the plateau. Often, deeper, intermediate perched zones are associated with wet canyons. The geometry of wet canyons promotes hydrologic conditions that yield relatively fast, unsaturated flow and transport.

Wet canyons such as Los Alamos Canyon receive large runoff volumes, either through channeling of precipitation or through wastewater discharges. This runoff, in turn, creates surface-water flow along canyon bottoms, which subsequently infiltrates to form near-surface, alluvial water bodies (Section 2.4.2.1). Lateral flow and transport through surface water and in the alluvial systems are rapid with respect to other subsurface hydrologic processes on the plateau. Rates of lateral transport are even higher during surface flow events, which occur more frequently in the larger wet watersheds than in other areas of the plateau. Sorbing species transport slowly in alluvial waters and more commonly migrate down the canyon floor by sediment transport (LANL, 2004; Lopes and Dionne, 1998; Solomons and Forstner, 1984; and Watters et al., 1983).

It has been suggested that trace quantities of strongly sorbing contaminants can travel via colloid-facilitated transport in the alluvial groundwater (Penrose et al. 1990), although this interpretation of the data from Mortandad Canyon has been called into question (Marty et al., 1997). Since some of the wet canyons that cross Laboratory land have received liquid-waste discharges from outfalls, the alluvial systems act as line sources for both water and contaminants to the deeper vadose zone beneath such canyons (Birdsell et al., 2005). The term "line source" denotes that infiltration is likely at any location along the region defined by the alluvial groundwater; there are probably preferential zones of enhanced infiltration at certain locations that will yield larger than average travel velocities through the deeper vadose zone. The net percolation rates beneath the alluvial systems of wet canyons to the underlying unsaturated zone are expected to be among the highest across the plateau, approaching meters per year (100 - 1000 mm/yr) (Kwicklis et al., 2005).

In addition, the vadose-zone thickness decreases with increasing distance down canyon, due to thinning of the Bandelier Tuff (Section 2.2.9). This is especially true for the deep wet canyons because their canyon bottom elevations are 45 to 60 m lower than smaller canyon systems on the plateau. Contaminants transported down canyon via surface flow or through the alluvial groundwater system often percolate through a geologic column consisting primarily of basalt and fanglomerate with little or no overlying tuff. Downward percolation is believed to be more rapid in the basalt than through moderately welded tuff (Section 2.2.8). Thus, these wet canyons have thinner vadose zones and a smaller portion of the flow path with matrix-dominated flow.

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These stratigraphic factors, compounded by the relatively high deep-percolation rate in wet canyons, likely yield the fastest vadose-zone travel times for contaminants from the land surface of the plateau to the regional aquifer. Transport to the regional aquifer beneath wet canyons is predicted to be on the order of decades to hundreds of years (see Section 4.1 for details).

In contrast to wet canyons, dry canyons such as Potrillo Canyon and Cañada del Buey head on the plateau, have smaller catchment areas (less than 13 square km), experience infrequent surface flows, and have limited or no saturated alluvial systems in their floors. If anthropogenic sources are present, they are small volume sources. These hydrologic factors yield little lateral near-surface contaminant migration and slower unsaturated flow and transport from the surface to the regional aquifer. For example, because surface and alluvial waters are less common, contaminants remain close to their original source locations. Pathways through the vadose zone tend to be longer in the shallow dry canyons that have thicker sections of nonwelded to moderately welded tuff than the deeper-cut wet canyons. Net infiltration beneath dry canyons is much slower, with rates generally believed to be less than tens of millimeters per year and commonly on the order of 1 mm/yr. Finally, transport times to the aquifer beneath dry canyons are expected to be much longer than travel times from the bottom of wet canyons.

2.6.3 Vadose Zone Flow and Transport Mechanisms

Given the description in the previous section of surface and near-surface hydrologic conditions, the next step is to consider the flow and transport mechanisms for water that infiltrates into the subsurface. Most of the plateau is covered with nonwelded to moderately welded Tshirege and Otowi Member ash-flow tuffs (Section 2.2.9). Unsaturated flow and transport through these nonwelded to moderately welded tuffs is thought to occur predominantly through the porous matrix. These units are quite porous, with typical porosities of 40 to 50%, moderate saturated hydraulic conductivities (e.g., 10^{-4} cm/sec), and water contents that are generally far below saturated conditions (2 to 25%) (Abrahams et al., 1961; Rogers et al., 1996a; Birdsell et al., 2000; Springer, 2005).

Although the tuff units are often fractured, flow is expected to be matrix dominated unless conditions approach full saturation due to the presence of a high-flow-rate, constant water source (Soll and Birdsell, 1998), such as beneath liquid-waste disposal pits or outfalls. This result is a consequence of the difference in capillary pressure behavior in a porous matrix versus within a fracture. Even if water is injected into a fracture, capillary forces tend to pull water into the rock matrix over a relatively short flow distance. This concept has been established for a wide variety of fracture and matrix hydrologic properties (e.g., Nitao and Buscheck, 1991; Robinson and Bussod, 2000; Soll and Birdsell, 1998; Robinson et al., 2005a, 2005b).

Field observations and analyses support the matrix-flow hypothesis. Robinson et al. (2005b) modeled a vadose-zone, wellbore injection test that was performed in the Tshirege Member of the Bandelier Tuff (Section 2.2.9.3) and reported by Purtymun et al. (1989). Their analysis examined different numerical representations for the fractured porous medium, including a discrete fracture model, a matrix-dominated continuum model, and a dual-permeability representation. Figure 2-35 shows the field-measured moisture profiles at different times during the injection. Water diffused laterally downward, and upward in a relatively uniform fashion,

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rather than percolating rapidly through a fracture network. The agreement between the matrix-dominated model and the observations was acceptable, both qualitatively and quantitatively (Robinson et al. 2005b). They estimated an equivalent infiltration rate during the injection phase of about 2.7×10^4 mm/yr, which is greater than any estimates of infiltration across the plateau. They concluded that if matrix-dominated flow is observed at the high effective infiltration rate of this injection test, then it is even more likely to be the case under natural conditions on the plateau.

As discussed in Section 2.6.2.1, this general picture that applies in the eastern portion of the Pajarito Plateau must be modified for areas near the mountain front on the western edge, where some of the Tshirege units of the Bandelier Tuff have densely welded intervals as a result of being closer to the volcanic source (Section 2.2.9.3). These more welded units are less porous, with porosities ranging from 17 to 40%, and have low saturated hydraulic conductivities (e.g., 10^{-6} to 10^{-9} cm/sec) (LANL, 2003b). They are also more fractured and can support fracture flow and transport when sufficient water is present. A bromide tracer test and high explosives contaminant distributions suggest that both fracture and matrix-dominated flow can occur near the mountain front depending on the degree of welding (or matrix conductivity) of the tuff (LANL, 1998b; LANL, 2003b). Therefore, the location and degree of welding of the tuff units affects the degree to which fracture flow will be sustained.

In contrast to the behavior of the Bandelier Tuff units, much of the vadose zone flow through the basalt units is almost certainly fracture dominated (flow-base rubble and scoria may also be highly permeable, but these are stratified components of generally limited vertical extent). Under ponded conditions, rapid flow through fractured basalt has been observed (Stauffer and Stone, 2005). The Laboratory fielded an experiment on the upstream side of a low-head weir located in Los Alamos Canyon (Stone and Newell, 2002). Figure 2-36 is a schematic of the field experimental setup. The objective of the experiment was to monitor flow and bromide tracer transport through fractured basalt under typical unsaturated and periodically ponded conditions using three observation boreholes. Following three ponding events, the bromide tracer advanced quickly downward to a depth of several tens of meters in 10 to 14 days after the first ponding event (Stauffer and Stone, 2005). These observations confirm that fracture flow and transport occurs through basalts under ponded conditions. Model calibration of the bromide transport yields an effective fracture porosity in the range of 10^{-2} to 10^{-3} and saturated hydraulic conductivity in the range of 10^{-2} to 10^{-3} cm/sec (Stauffer and Stone, 2005). In fact, the data and simulations both indicate that the bromide continued to advance through the fractured system even after the all the ponded water had infiltrated.

However, under drier conditions no direct observations have been made of vadose-zone flow and transport in these deeper locations. For this reason, the conceptual model for unsaturated flow and transport through basalts is still evolving.

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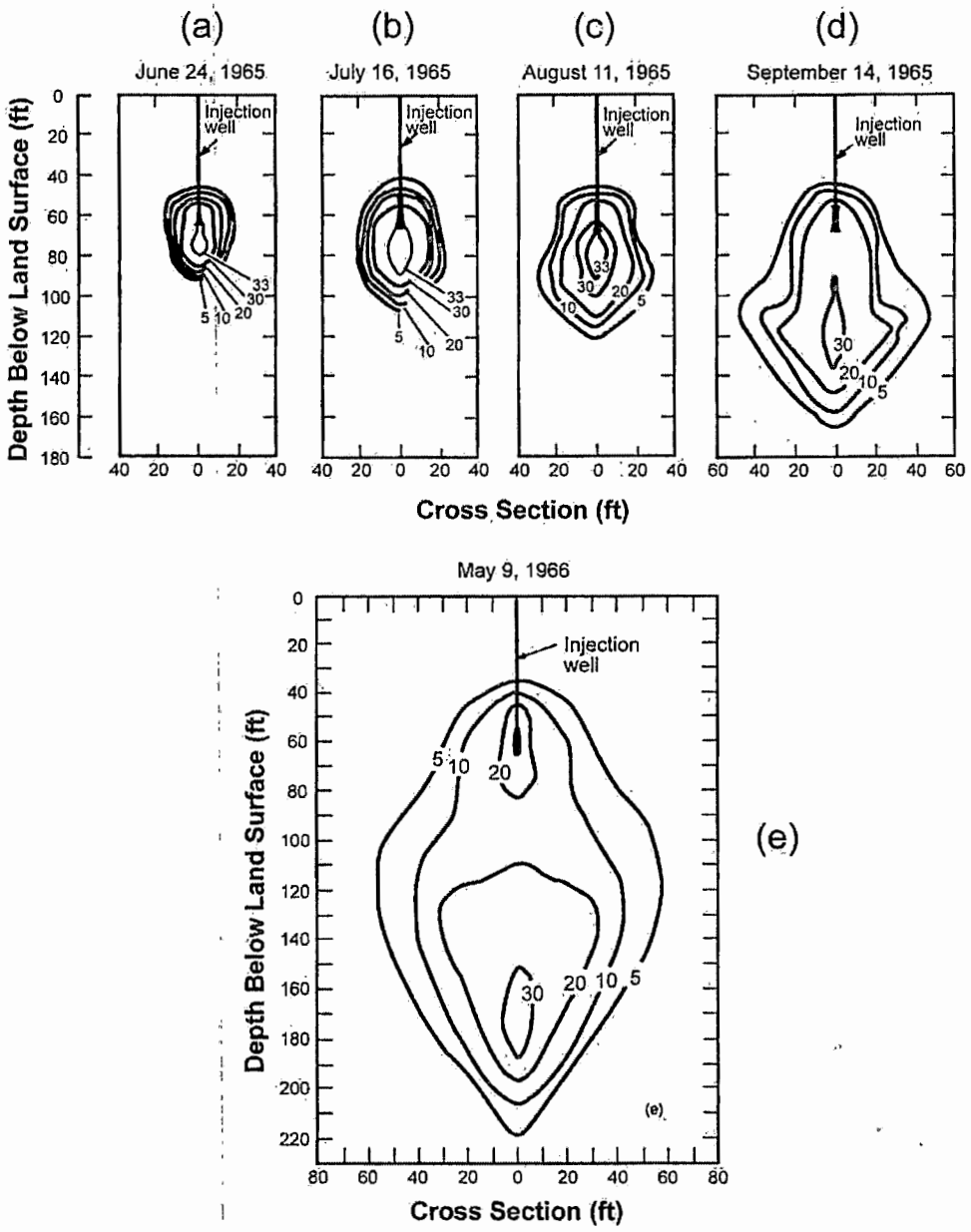

Figure 2-35. Contours of water content constructed from the neutron log data during and after the wellbore injection test: (a) Day 7 after injection; (b) Day 29; (c) Day 55; (d) Day 89 (end of injection phase); (e) Day 327 (post-injection phase). From Purtymun et al. (1989).

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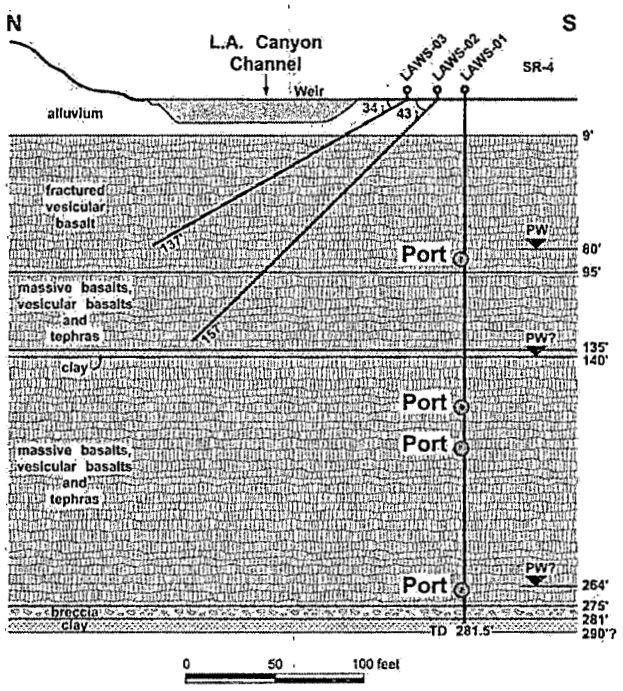
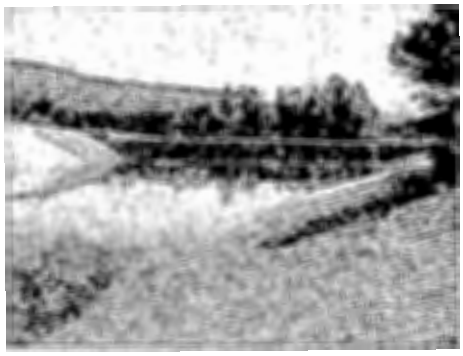


(a)



(b)

Figure 2-36. Low head weir monitoring well setup; (a) schematic; (b) north-south photograph.

2.6.4 Alternative Hypotheses

Although the basic processes outlined in the preceding sections are supported by the available data and observations and form the best current conceptual model, alternative hypotheses are possible and cannot be completely ruled out by the available information. This section briefly discusses the potential alternative conceptual model of fracture flow. In addition, alternative conceptual models for the mechanisms of flow within perched water zones are described in Section 2.7.

Fracture flow through the Bandelier Tuff is a conceptual model that is often proposed, in contrast to the conceptual model of matrix-dominated flow and transport discussed earlier. Although the available information is consistent with matrix flow, it is possible that in certain situations, fracture flow is important, including the examples related to mountain front processes described earlier. Despite the fact that water input into fractures tends to imbibe into the rock matrix, the observations presented earlier may capture the flow behavior of most, but not all of the water flow. It is possible that preferential flow paths through Bandelier Tuff fractures allow a small portion of the infiltrating fluid to travel to significant depths, even though most water imbibes into the matrix. Alternatively, unstable fingering flow through heterogeneous matrix rock could also lead to preferential downward flow. Regarding the TA-50 water injection test, it is possible that a small amount of fast-moving water could have escaped detection and traveled to greater depths via these mechanisms. The implication of this uncertainty is that small quantities of contamination could potentially be observed at some point in the future at greater depths than

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"expected." If this occurs, then we will need to assess whether a relatively small, fast-moving fraction of a released contaminant, combined with a center of mass that travels much more slowly, poses a significant threat to groundwater.

2.7 Perched Water

A common feature of vadose zone flow systems is the presence of perched water. Perching can occur for a number of reasons, including capillary barriers and low-permeability barriers coupled with complex stratigraphic structures in the subsurface (e.g., Bagtzoglou, 2003a, 2003b). Beneath the Pajarito Plateau, perched waters may be important components of subsurface pathways that facilitate movement of contaminated fluids from the ground surface to the water table of the regional aquifer. These perched groundwater bodies are generally too small for use as municipal water supplies. Nonetheless, they are of interest because (1) they represent natural groundwater resources that are protected under State law, (2) their chemical and isotopic characteristics help constrain groundwater transport rates through the vadose zone, (3) their presence may divert, slow, or stop the vertical migration of groundwater through the vadose zone, or they may indicate the presence of a fast subsurface pathway, depending on the characteristics of the perched zone, and (4) they can be used as vadose zone monitoring points that provide early warning of contaminants approaching the regional aquifer.

Characterization of these groundwater bodies is challenging because of the thickness of the vadose zone, the heterogenous nature of bedrock geologic units that serve as host rocks and perching horizons, and the depths of groundwater occurrences. Despite these limitations, substantial new information has been gathered about intermediate perched zones on the plateau. This section summarizes information about the location, depth to water, saturated thickness, and geologic setting of perched water occurrences beneath the Pajarito Plateau. This summary includes data from historical investigations and much new information collected as part of the Hydrogeologic Workplan characterization program.

2.7.1 Perched Water Occurrence

The different modes of groundwater occurrence beneath the Pajarito Plateau are shown conceptually in Figure 2-37. Contaminant distributions in groundwater strongly suggest that groundwater of the plateau alluvial systems is in communication with intermediate perched and regional aquifer groundwater to varying degrees. The focus of this section is the intermediate perched groundwater; a description of the alluvial groundwater is presented in Section 2.5, and the regional aquifer is described in Section 2.8.

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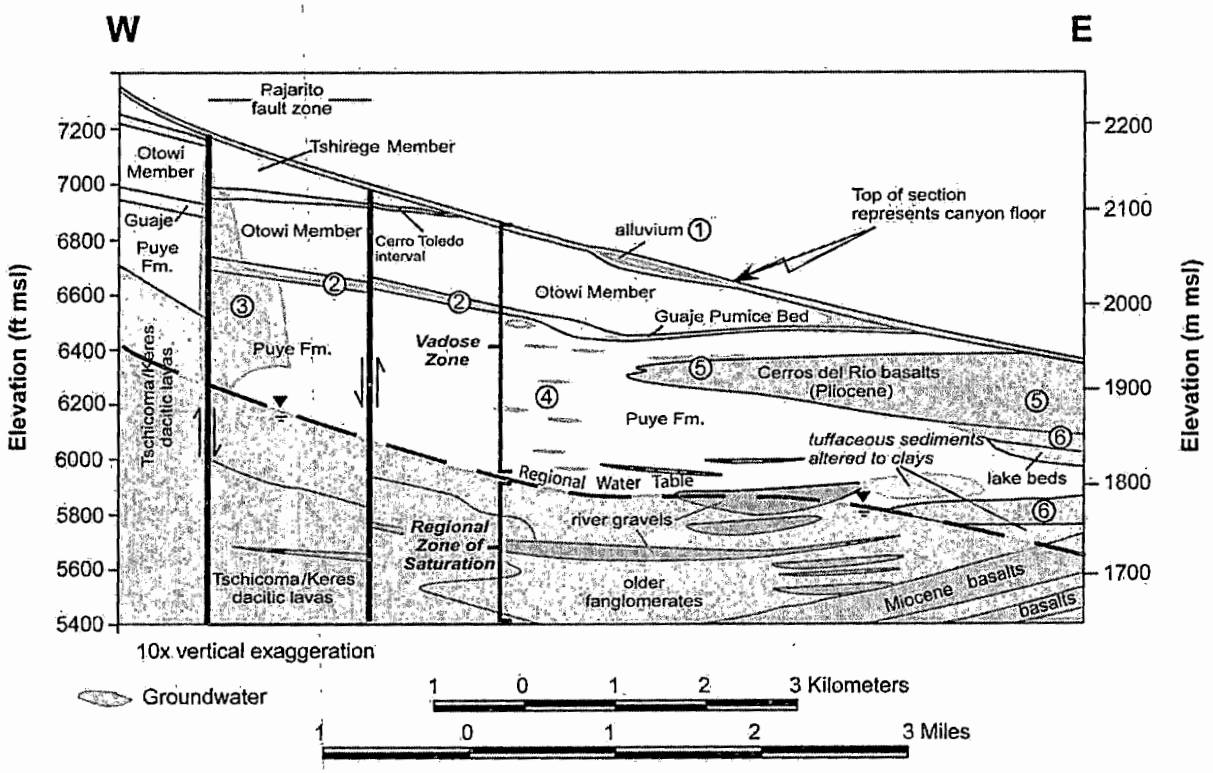

1. Canyon-floor alluvial groundwater—most commonly found in large, wet watersheds with significant snow and storm run off or in smaller watersheds that receive liquid effluent from wastewater treatment plants. Saturated thickness and down-canyon extent varies seasonally.
2. Perched ground water is associated with the Guaje Pumice Bed in Los Alamos Canyon. This perched water body has a lateral extent of up to 3.7 mi Guaje Pumice Bed has a high moisture content but is not fully saturated in most other locations.
3. Cañon de Valle area in the southwest part of LANL. This is the largest perched zone identified on the plateau. A deep-sounding surface-based magnetotelluric survey suggest that this perched zone is discontinuous laterally, occurring as vertical pipe-like groundwater bodies. One interpretation of this zone is that it represents groundwater record(s) formed in response to local recharge beneath a wet cany9on floor. Recharge may be enhanced across the Pajarito fault zone where shallow, densely-welded tuffs rocks are highly fractured.
4. Small zones of perched water formed above stratigraphic traps in Puye fanglomerate. these perched zones tend to be more numerous beneath large wet canyons and less frequent beneath dry mesa tops.
5. Perched groundwater associated with Cerros del Rio basalt. Saturation occurs in fractured basalt flows and in interflow breccias and sediments.
6. Perched zones form in response to local geologic conditions on the eastern side of the plateau. These include perched zones within clay-altered tuffaceous sediments and above lake deposits.

Figure 2-37. Conceptual model of groundwater occurrences beneath the Pajarito Plateau.

Identification of perched groundwater systems beneath the Pajarito Plateau comes mostly from direct observation of saturation in boreholes, wells, or piezometers or from borehole geophysics. Additional information is provided by surface-based electrical geophysics, although these types of investigations are generally limited by their relatively shallow depths of investigation and poor vertical resolution. Identification of larger perched groundwater bodies in boreholes is generally reliable, but use of drilling fluids, which is necessary in most boreholes, may mask smaller or relatively unproductive zones. Defining the lateral extent of saturation is more problematical because of the costs associated with installing deep wells. One geophysical method, a deep-sounding surface-based magnetotelluric survey, has been conducted in the Cañon de Valle/Water Canyon area. The survey results suggest that perched groundwater is

discontinuous laterally, occurring instead as vertical, finger-like groundwater bodies. These geophysical interpretations are currently being tested by additional drilling. Despite these limitations, substantial new information has been gathered about deep perched zones on the plateau during the Hydrogeologic Workplan investigations.

This section briefly summarizes the observed occurrences of perched water. Appendix 2-B contains a comprehensive description of the 33 occurrences of perched groundwater detected in boreholes across the Pajarito Plateau. Perched groundwater is widely distributed across the northern and central part of the plateau (Figure 2-38) with depth to water ranging from 36 to 272 m (118 to 894 ft). The principal occurrences of perched groundwater occur in (1) the large, relatively wet Los Alamos and Pueblo Canyon watersheds, (2) the smaller watersheds of Sandia and Mortandad Canyons that receive significant volumes of treated effluent from LANL operations, and (3) in the Cañon de Valle area in the southwestern part of LANL. Perched water is most often found in Puye fanglomerates (Section 2.2.7), the Cerros del Rio basalt (Section 2.2.8), and in units of the Bandelier Tuff (Section 2.2.9) (Figure 2-38). There are few reported occurrences of perched water in the southern part of LANL, but few deep boreholes are located there and additional perched zones are likely beneath the large wet watersheds of Pajarito and Water Canyons.

2.7.2 Interpretation of Perched Water Observations

General conclusions about the nature of perched groundwater beneath the Pajarito Plateau are based on the observations summarized above. The conclusions pertain to surface hydrologic conditions necessary to support perched groundwater, geologic and hydrostratigraphic controls on perched water occurrence, the lateral and vertical extent of perched zones, and alternative hypotheses about the role of perched zones in contaminant transport.

2.7.2.1 Surface Water Conditions for Perched Water

A requirement for deep perched water to exist is a surface water source (natural or anthropogenic) that supplies water to alluvial systems. The alluvial groundwater systems act as storage for groundwater entering underlying bedrock units at high infiltration rates (Section 2.5). This interpretation is supported by the observation of perched groundwater in wet canyons. In addition, ponding associated with anthropogenic sources is another possible water source that could lead to subsurface perched water.

A special situation also exists in the western portion of the Laboratory, in the mountain-front mesa area at TA-16. In contrast to the dry mesas prevalent further east, these mesas receive greater precipitation (e.g., 500 mm/yr) and increased runoff and infiltration. The wet, mountain-front mesas contain numerous perennial and ephemeral springs. Such springs are rare in the dry mesas of the eastern part of the plateau, except where the regional groundwater aquifer discharges along the Rio Grande.

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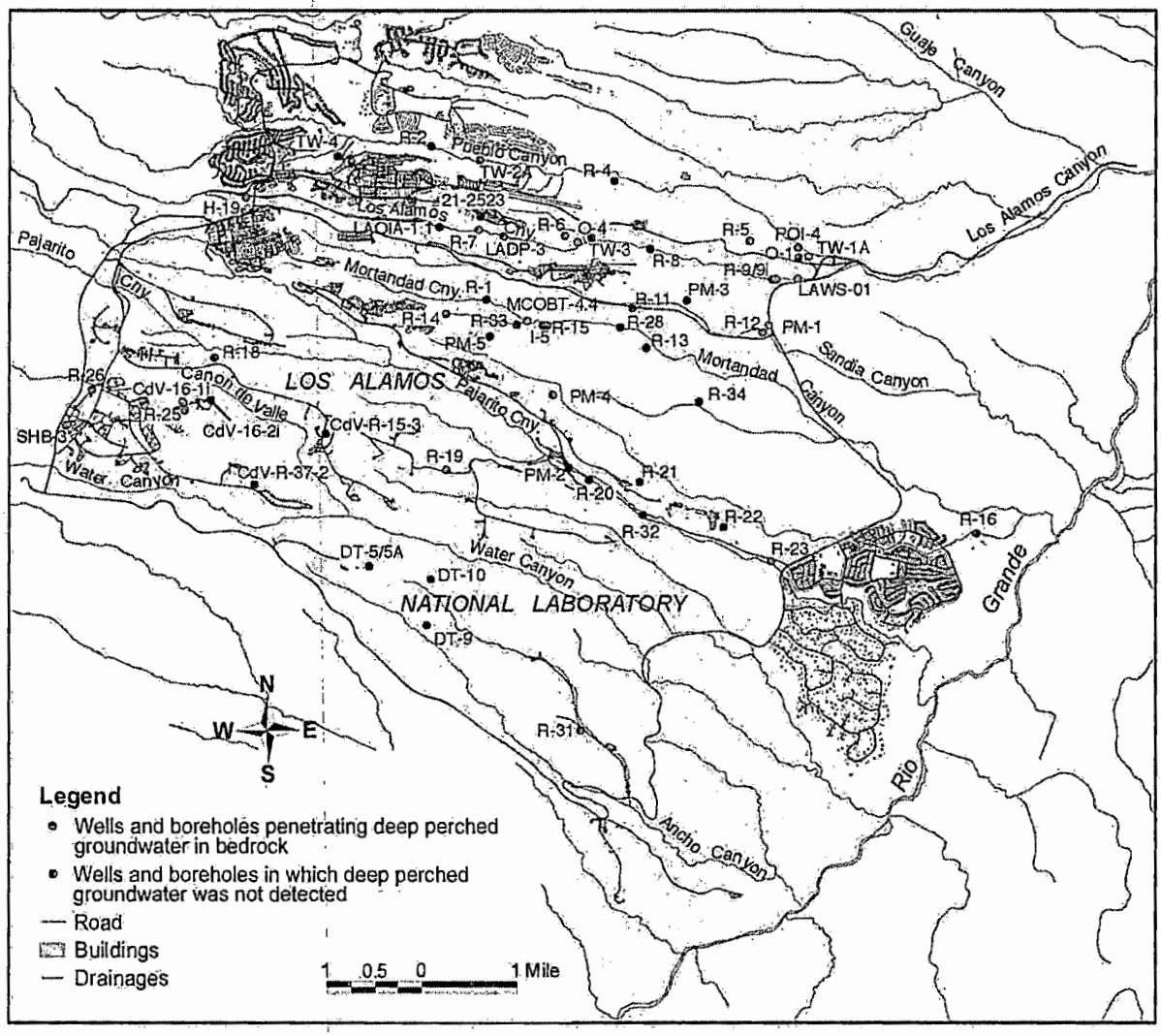

Figure 2-38. Locations of wells and boreholes that have penetrated perched groundwater systems in bedrock.
Note: The area shown in yellow is LANL.

2.7.2.2 Geologic and Hydrostratigraphic Controls on Perched Water Occurrence

Deep perched groundwater occurs most frequently in the Puye Formation (Section 2.2.7) and Cerros del Rio basalt (Section 2.2.8), but some of the thickest and/or most laterally extensive zones involve units of the Bandelier Tuff (Section 2.2.9). Perching horizons include a wide variety of layered geologic lithologies including

- Unfractured basalt flows
- Clay-rich interflow zones in basalt
- Buried soils and other fine-grained deposits in fanglomerate,

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- Clay-altered tuffaceous sediments
- Lake deposits.

Therefore, in addition to high local infiltration rates, low-permeability barriers to downward vertical flow appear to be required to induce perched groundwater (Robinson et al., 2005b). In contrast, there have been no observations of perched groundwater caused by a capillary barrier effect, despite the presence of layered stratigraphy with units of contrasting unsaturated flow properties.

An alternative hypothesis is that the deepest perched water occurrences are a manifestation of complex groundwater flow within the phreatic zone at the top of the regional aquifer. Localized heterogeneities, such as the clay-rich alteration zones in the Puye Formation at well R-9, combined with high recharge, may give rise to a complex flow structure that includes mounding, interconnected saturated zones, and locally confined conditions (Robinson et al., 2005b). However, the complexity of the alteration and the depth of these groundwater zones make detailed characterization prohibitively expensive. Hydrologic testing of the regional aquifer could be conducted to discriminate between alternatives.

With respect to the western portion of the Laboratory, Duffy (2004) discusses the importance of mountain-front processes and hydrologic conditions in semiarid landscapes and suggests that the mountain block and mountain-front areas are the dominant recharge zones in semiarid landscapes. An important hydrostratigraphic feature in this area is that the upper tuff units along the mountain front are often moderately to strongly welded because of close proximity to the caldera source. Welding results in increased fracturing during cooling, and because the mountain-front mesas lie within the Pajarito fault zone, additional fracturing and minor faulting of the tuff units has resulted. The welded tuffs create a hydraulic condition where matrix hydraulic conductivities are low (e.g., 10^{-7} to 10^{-9} cm/sec), but fracture densities are relatively high. Thus, there is a possibility for significant fracture flow. Fracturing appears to control locations of springs along the mountain-front mesas and fracture flow is suggested by water content and contaminant distributions in the tuff proximal to outfalls and wastewater lagoons (LANL, 2003b).

2.7.2.3 Subsurface Extent of Zones of Saturation

Observed saturated thicknesses of perched zones vary from 1 to 128 m (3 to 421 ft). The lateral extent of saturation in these zones is less well understood because costs associated with installing deep wells are high. However, perched groundwater generally is more likely to be present beneath wet canyons, based on observations of both occurrences and nearby absences of perched groundwater in adjacent wells. The extent that perched groundwater flows along dipping geologic strata into areas beneath adjacent mesas is not fully known. However, the few paired canyon/mesa wells such as R-7 and 21-2523 in Los Alamos Canyon and R-22 and R-23 in Pajarito Canyon suggest that perched zones are much less common beneath dry mesas.

2.7.2.4 Flow Conditions Upstream and Within Intermediate Perched Groundwater Zones

The presence of mobile (nonsorbing) anthropogenic chemicals in some perched groundwater zones indicates a connection with surface and alluvial groundwater (e.g., Robinson et al., 2005

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and references therein). The travel time of groundwater moving from the surface to perched groundwater systems is on the order of several decades, based on the age of facilities that are potential sources of contaminants. Within the perched zones themselves, the topography of the perching horizon, the bedding features, and the orientation of interconnected fracture systems probably control local groundwater flow velocity. However, direct evidence such as single-well or multiple-well hydrologic and tracer testing, is not available. Therefore, the following discussion is based on reasonable hydrologic principles rather than direct measurements.

Flow conditions can, in principle, be categorized with the following two end-member conceptual models for flow within a perched water zone:

- *Low-velocity, virtually stagnant water resting in a perching horizon within a local structural or stratigraphic depression.* Water percolates very slowly out the bottom of this zone, or spills over the sides of the depression. This configuration views perching horizons as barriers that slow the downward percolation of water. In several wells, intermediate saturated zones thought to represent perched groundwater were screened but failed to produce significant water (Robinson et al., 2005). These occurrences may represent cases where zones of limited extent were substantially drained when the perching horizon was penetrated during drilling. Once the stagnant water is depleted in an initial round of sampling, there is insufficient recharge to keep the zone saturated.
- *High-velocity, laterally migrating fluid that travels on top of the perching horizon.* This conceptualization suggests that once groundwater reaches a perched zone, it rapidly percolates laterally along high-permeability pathways until the perching horizon pinches out or is breached by high-permeability features such as fractures or lateral changes in lithology. In this scenario, water could move in stairstep fashion from one perching horizon to another. There are no confirmed instances of large-scale, lateral vadose zone pathways beneath the Pajarito Plateau at depths greater than the alluvial groundwater. The case of lateral flow through the wet, mountain-front mesas at TA-16 suggests that this possibility exists at greater depths. Although we categorize the TA-16 observations as shallow for the purposes of this discussion because they discharge via springs in the local canyons, it could be argued that deep pathways with flow geometries similar to those of the mountain-front mesa or today's alluvial groundwater zones are evidence for the possibility of deeper fast pathways elsewhere.

Tracer experiments in alluvial and mountain-front mesa perched zones have been used to measure transport velocities. However, fluid velocity in the deeper perched groundwater zones is unknown due to the lack of direct measurements. The two end-member conceptual models, relatively stagnant fluid in a local subsurface depression, or lateral diversion in the hydrologic unit overlying the perching horizon, cannot be ruled out with existing data. Hydrologic, tracer, or remote geophysical techniques would be required to shed light on this question. Given the complexity and cost of such field campaigns, they should be performed only if model sensitivity analyses indicate that sorting out this issue is important to study impacts, or if remediation of a perched zone is to be conducted.

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2.8 Regional Aquifer Conceptual Model

This section summarizes the current understanding of flow and transport in the regional aquifer beneath the plateau. This work builds on results obtained from earlier hydrologic studies in the region (Griggs and Hem, 1964; Purtymun, 1984; Purtymun and Johansen, 1974; Rogers et al., 1996b). The previous literature is supplemented with interpretations of new data collected by the LANL Groundwater Protection Program. These new data, combined with previous studies, provide the foundation for the flow and transport model development presented in Section 4.2

2.8.1 Regional Hydrologic Setting

This section briefly summarizes the regional hydrologic setting before focusing on the regional aquifer beneath the Pajarito Plateau (Section 2.7.2), which is the subject of this report. The Española Basin (see Figure 2-39) is one of a series of basins located within the Rio Grade Rift zone, a tectonic feature that extends from northern Colorado to the south into Mexico. Elevations within the basin range from more than 3,800 m along peaks in the surrounding mountain ranges to about 1,700 m at the basin surface water outlet. Vegetation is predominantly ponderosa pine forest at higher elevations and piñon pine/ juniper at lower elevations (Spiegel and Baldwin 1963).

The Española Basin and surrounding areas receive annual total precipitation ranging from 18 to 86 cm/yr. Precipitation is strongly elevation dependent (Spiegel and Baldwin 1963). The largest streams in the basin are the Rio Grande and Rio Chama. Median monthly flow, calculated using USGS average monthly flow data for the past 80 years, is 26.0 m^3/s along the Rio Grande (at Otowi Bridge) and 10.0 m^3/s along the Rio Chama (at Chamita) (U.S. Geological Survey, 2001). Numerous tributaries enter these rivers; many of these are ephemeral and many are ungaged. The Rio Grande and the lower reaches of many tributaries comprise the regional groundwater discharge zone.

In most parts of the basin, the water table is 0–60 m below ground surface; but on the Pajarito Plateau the water table is much deeper (up to 350 m below the surface). Throughout much of the basin, the water table appears to intersect the surface at the Rio Grande (Purtymun, 1984). Perched waters exist on the Pajarito Plateau (Robinson et al., 2005) where the unsaturated zone is much thicker than in other parts of the basin (Section 2.7). Contours of predevelopment water level data (Purtymun et al., 1995a, 1995b; U.S. Geological Survey, 1997) indicate that hydraulic gradients are generally towards the Rio Grande (Figure 2-40).

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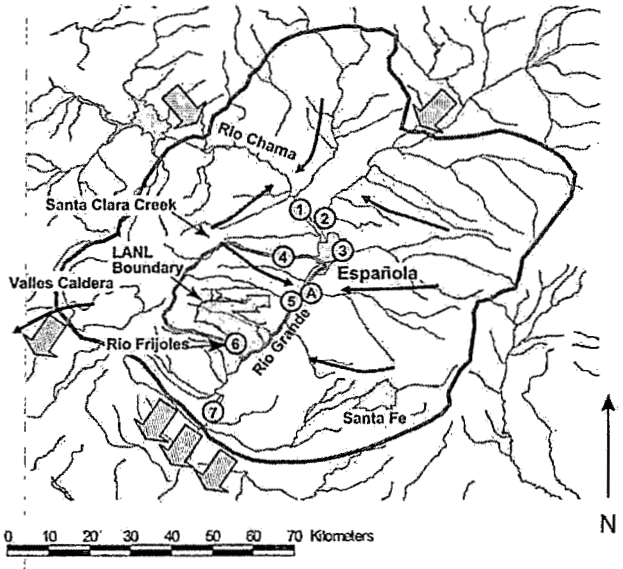

Figure 2-39. The Española Basin and vicinity, with basin-scale numerical model outline shown in red, site-scale model outline shown in green. Black arrows are generalized groundwater flow directions, based on regional water level data (Keating et al., 2003). The striped arrows indicate groundwater flow between the Española Basin and adjacent basins. Circled numbers refer to USGS stream gages: (1) Rio Chama at Chamita; (2) Rio Grande at San Juan; (3) Santa Cruz River; (4) Santa Clara Creek; (5) Rio Grande at Otowi; (6) Rio Frijoles; (7) Rio Grande at Cochiti. Circled "A" indicates the mouth of the Pojoaque Creek.

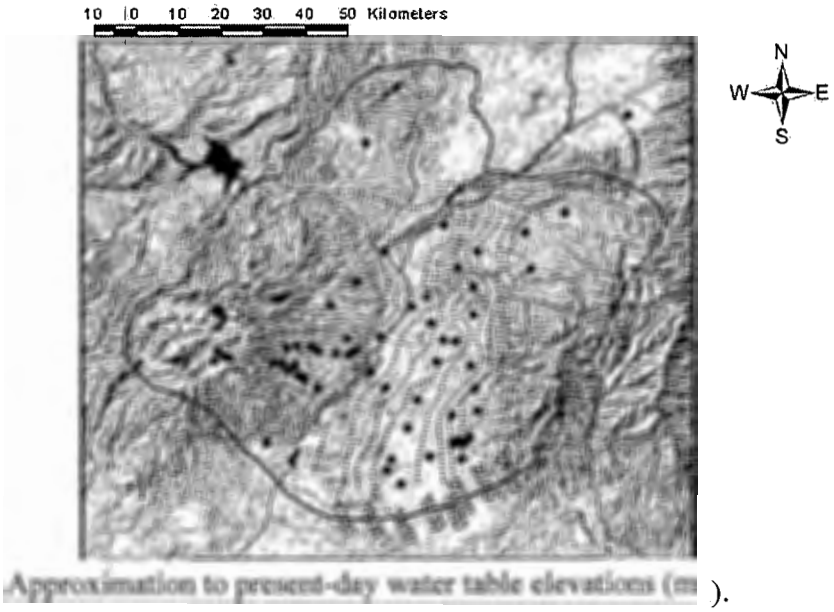

Figure 2-40. Approximation to present-day water table elevations (m).
Note: Some older head data are used to improve the spatial distribution.

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The regional aquifer is a major source of drinking water and agricultural water supply for northern New Mexico. The largest cities in the basin are Santa Fe, Española, and Los Alamos; these all rely primarily on groundwater for municipal supply. In addition to discharges to water supply wells, the aquifer discharges to the Rio Grande, the lower reaches of its tributaries, and to numerous springs. There are additional withdrawals for municipal and agricultural supply. Recharge is thought to occur primarily in the higher elevations—estimates based on water budget and chloride mass balance methods range from 7–26% of total precipitation (Anderholm, 1994; Wasiolek, 1995). Little or no recharge occurs at lower elevations other than along stream channels due to low precipitation rates and high evapotranspiration demand (Anderholm, 1994).

The aquifer is predominantly composed of Santa Fe Group rocks, which are weakly consolidated basin-fill sediments reaching over 3,000 m in thickness near the basin axis (Cordell 1979). Groundwater also occurs in older crystalline rocks along the eastern and northern basin margin and in younger volcanic lavas and volcaniclastic sedimentary rocks in the vicinity of the Pajarito Plateau to the west (Purtymun and Johansen, 1974; Coon and Kelly, 1984; Daniel B. Stephens & Associates, 1994).

2.8.2 Hydrology Beneath the Pajarito Plateau

Groundwater beneath the Pajarito Plateau is part of a regional aquifer which extends throughout the Española Basin (an area roughly 6000 km^2; Figure 2-39). This aquifer is the primary source of water for the Laboratory, the communities of Santa Fe, Española, Los Alamos, and numerous pueblos. Four water supply wellfields exist on the plateau (Figure 2-41); one additional wellfield that supplies the city of Santa Fe (Buckman) sits just to the east of the Rio Grande, close to the plateau. As is the case for many aquifers in the semiarid southwest, there is concern that current withdrawal rates may not be sustainable over long periods of time and current drought conditions might have significant impacts on both surface water and groundwater quantity and quality.

Of more direct relevance to the Hydrogeologic Workplan studies are concerns about water quality, due to a variety of anthropogenic contaminants. Beneath the Pajarito Plateau, there is contamination from various LANL sources in shallow groundwaters in some locations (primarily alluvial aquifers). Some of the LANL-derived contamination has been observed in the regional aquifer at trace concentrations much below the EPA drinking water standards (see Section 3 for a complete discussion of this point). The regional aquifer is the groundwater zone most directly accessible to humans through municipal water-supply wells or springs issuing to the Rio Grande. Therefore, a solid foundation of understanding of the hydrogeologic conditions and controls on flow and transport in the regional aquifer must be obtained in order to make risk-based decisions, to design the required groundwater monitoring network, or to design treatment and remediation systems.

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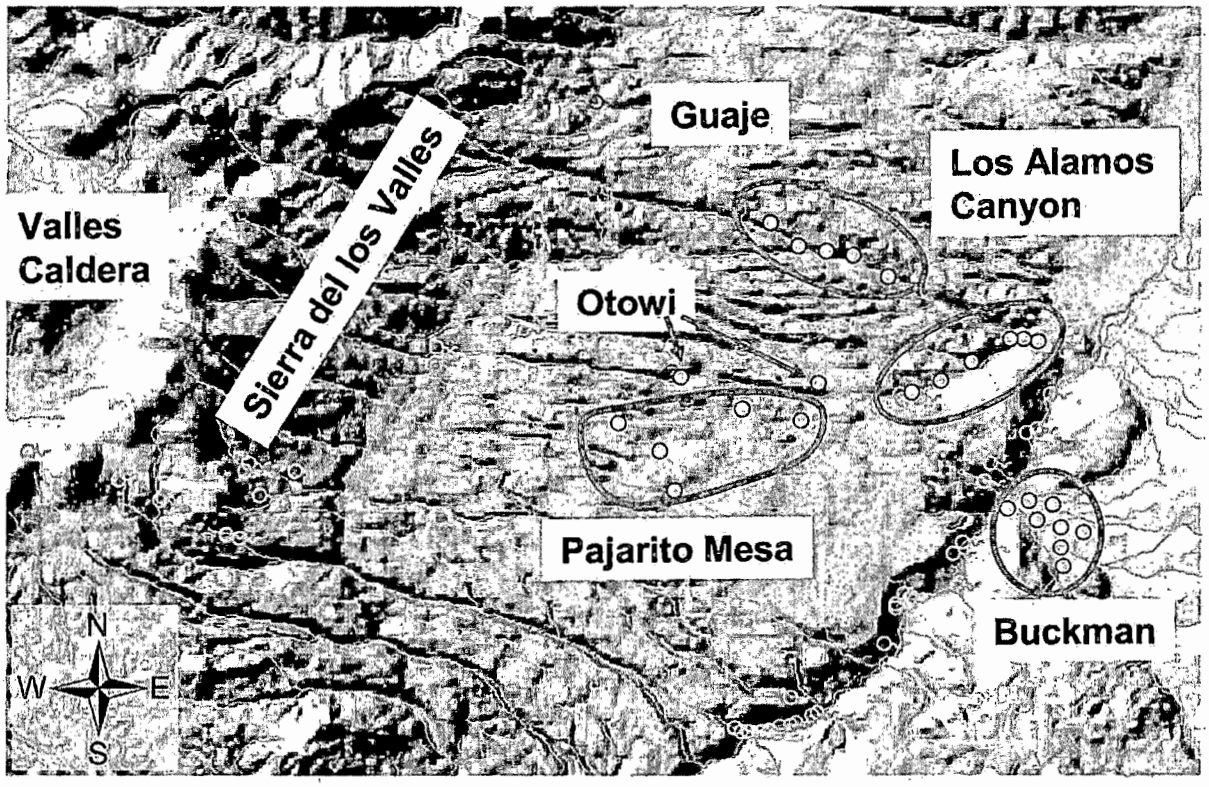

Figure 2-41. The Pajarito Plateau, with major wellfields indicated by enclosures in red.

2.8.3 Water Budget

The water budget for the regional aquifer defines the sources and sinks of water to and from the Española Basin and, on a smaller scale, under the Pajarito Plateau. This section summarizes the state of knowledge and addresses uncertainties in the quantities and spatial distribution of recharge, discharge, and interbasin flow.

2.8.3.1 Recharge

As the water source term, recharge to the regional aquifer provides the driving force for fluid movement through the system. Furthermore, water recharging on the Pajarito Plateau on LANL property can carry with it liquid-borne contamination. This subsection addresses both basin-scale and local recharge, addressing the spatial distribution and quantity of recharge.

2.8.3.1.1 Recharge Distribution

Various theories have been proposed regarding the locations of recharge zones for this aquifer. Griggs (1964) suggested that most of the recharge occurred in the Sierra del los Valles and along stream channels in the western edge of the Pajarito Plateau (Figure 2-41). Purtymun and Johansen (1974) proposed that the major portion of the recharge occurs in the Valles Caldera, with smaller amounts recharging through stream channels in the Sierra del los Valles. However, Blake et al., (1995) argued that recharge could not originate in the Valles Caldera, since the

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chemistry of geothermal waters in the western Valles Caldera is clearly distinct from the groundwaters on the Pajarito Plateau (Blake et al., 1995; Goff and Sayer, 1980). These authors also proposed, on the basis of stable isotope values in groundwaters beneath the plateau, that recharge areas for the aquifer beneath the plateau were either to the north and/or to the east (Sangre de Cristo Mountains) and not to the west. They hypothesized that the two flow systems are separated by the Pajarito fault acting as a flow barrier (Blake et al., 1995).

In contrast, other lines of evidence indicate that the majority of recharge to the basin aquifer occurs in the mountains along the basin margin where precipitation rates are relatively high. This has been shown using water-budget and chloride-mass balance analyses in the eastern portion of the basin (Anderholm, 1994; Wasiolek, 1995). In the course of the Hydrogeologic Workplan studies, inverse modeling using head and streamflow data (Keating et al., 2003) demonstrated that the elevation above which significant recharge occurs at the basin-scale is very well constrained (2195m ± 177m). Modeling results such as this are to some extent a function of the model conceptualization and structure, and therefore do not provide a precise indication of the recharge elevation. Nevertheless, the modeling result agrees with the conclusion on the elevation above which recharge occurs, as determined from those other lines of evidence.

Isotope geochemical information can also be brought to bear on the question of recharge distribution. Distributions of δD and $\delta^{18}O$ ratios are consistent with the conclusion that the mountain front recharge supplies most of the groundwater beneath the Pajarito Plateau (Longmire, 2002a; Longmire, 2002b; Longmire, 2002c; Longmire, 2002d; Longmire, 2002; Longmire and Goff, 2002). Lighter or more negative δD and $\delta^{18}O$ ratios indicate both a cooler climate for precipitation and/or a higher elevation of recharge (Clark and Fritz, 1997). Heavier or less negative δD and $\delta^{18}O$ ratios are representative of a warmer climate for precipitation and/or recharge that occurs at lower elevations. Groundwater samples collected within the Sierra de los Valles have lighter δD and $\delta^{18}O$ ratios relative to those collected beneath the Pajarito Plateau and along the Rio Grande. Precipitation of meteoric water at higher elevations, for example near the Sierra de los Valles, is characterized by cooler temperatures relative to other waters found at lower elevations on the Pajarito Plateau. Long-term temperatures (paleotemperatures) and seasonal variations in temperature also influence $\delta^{18}O$ and δD values because of enrichment or depletion of oxygen-18 and deuterium (Clark and Fritz, 1997).

A plot of δD versus $\delta^{18}O$ (average values) for numerous groundwater samples collected from wells R-9, R-12, R-15, R-19, R-25, R-26, CdV-R-37-2, and CdV-R15-3 and springs within the Valles caldera and Sierra de los Valles is shown in Section 3.1.1.1. In this figure, the Jemez Mountains meteoric line (upper) ($\delta D = 8\delta^{18}O + 12$) (Vuataz et al., 1986) and the mean worldwide meteoric water line (lower) ($(D = 8\delta^{18}O + 10)$ (Clark and Fritz, 1997) are denoted by JMML and MWL, respectively. Analytical uncertainties of $\delta^{18}O$ and δD are ± 0.1 and ± 1‰ (per mil), respectively. Results of stable isotope analyses for the R wells and springs indicate a meteoric source in which the samples plot close to both the JMML and MWL (Section 3.1.1.1). The distribution of isotopic ratios suggests that evaporation of groundwater has not taken place to a significant extent prior to recharge.

The Sierra de los Valles is the likely recharge source for wells R-25, R-26, CdV-R-15-3, CdV-R-37-2 because the Sierra de los Valles springs have similar $\delta^{18}O$ and δD ratios (Blake et al. 1995).

The less negative stable $\delta^{18}O$ and δD values (relative to well R-25) in wells R-9, R-12, R-15, and R-19 are consistent with additional recharge at lower elevations (Section 3.1.1.1). This interpretation is consistent with the concept of local recharge on the plateau as the source for water at shallow depths in the regional aquifer beneath the Laboratory.

Although analyses such as these can be useful in identifying the elevation of recharge, Keating et al. (2005) point out that uncertainties due to variability in isotopic composition of precipitation and potential differences in precipitation and infiltration elevations complicate the use of these isotopic tracers. For example, stable isotope ratios may actually be tracing the *timing* of recharge for very old waters (Phillips et al., 1986), as opposed to the location. Very low $\delta^{18}O$ values (< -14), significantly lower than average modern precipitation signatures at all elevations in the basin, have been measured in groundwaters near the Rio Grande (Anderholm, 1994; Blake et al., 1995). These ratios are indicative of paleorecharge during a cooler climate (Phillips et al., 1986) and were interpreted by Anderholm (1994) and Newman (1996) to indicate recharge during the Pleistocene (with age in order of 8,000 – 17,000 years). These age estimates are consistent with ^{14}C observations suggesting a component of old fluid (Rogers et al., 1996b). Note however that some of these same waters also clearly contain a component of young water, as indicated in Section 3.1.1.3.

A quantitative assessment of the spatial distribution of recharge on the Plateau was recently published by Kwicklis et al. (2005). The goal of the study was to provide a summary of the current state of knowledge on amount and spatial distribution of infiltration. The study was intended to provide quantitative estimates for use in other studies, as well as to provide a baseline that can be tested and improved upon as more data are collected. The study uses streamflow gain and loss data along canyon bottoms from the Pajarito Plateau, along with point infiltration estimates based on moisture content profiles interpreted using the Richards equation, the chloride mass-balance method, transport rates of tritium in canyons on the Plateau, and numerical modeling. The infiltration rates estimated with these techniques were extrapolated to uncharacterized parts of the study area using maps of environmental variables that are correlated with infiltration (such as topography, vegetation cover, and surficial geology and structure) and spatial algorithms implemented with GIS software that use the mapped variables.

The map of estimated infiltration is presented in Figure 2-34. The large-scale characteristics of these estimates are in line with the discussion presented above. Infiltration rates throughout most of the plateau are generally less than 2 mm/yr, whereas infiltration rates in the mixed conifer-dominated areas of the Sierra de los Valles are typically greater than 25 mm/yr and, in the aspen-dominated areas, greater than 200 mm/yr. Thus, at lower elevations, recharge occurs primarily along arroyos and canyons, and infiltration rates are estimated to be low on mesas except near the mountain front (Anderholm, 1994; Birdsell et al., 2005). Despite the low flux, the total quantity of infiltration associated with the mesas is small but not negligible, due to the large area associated with these parts of the plateau.

The Kwicklis et al. (2005) study estimates that of the total infiltration of about 8600 acre-ft/yr (336 kg/sec), about 23% of the infiltration occurs from canyon bottoms on the plateau at lower elevations. This canyon-bottom infiltration includes about 14% of the total from streams that flow at least partly within LANL boundaries. The inserts in Figure 2-34 indicate regions for

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which localized, high-infiltration zones are expected to exist on the plateau. Focused infiltration is expected in the faulted regions associated with the Pajarito fault zone within Cañon de Valle and Water Canyon (see lower left insert in Figure 2-34). Local infiltration at rates up to 1000 mm/yr is estimated. For the insert showing the confluence of Los Alamos and Pueblo Canyons (lower right), rates of 1500–2000 mm/yr are estimated in this region. These high values are a consequence of infiltration directly onto Puye fanglomerates or fractured basalts. In other canyons with similar characteristics, such as Pajarito Canyon, similarly high local infiltration values are expected.

Although relatively small volumetrically compared to mountain recharge to the west, aquifer recharge occurring locally on the plateau is important to the assessment of flow paths of potentially contaminated water. Tritium data confirm that relatively young water is present in the aquifer (Rogers et al., 1996b), indicating fast pathways through the vadose zone beneath LANL. Quantitative estimation of recharge using ^{3}H data is complicated by the sometimes confounding influences of bomb-pulse atmospheric ^{3}H and locally derived ^{3}H related to on-site LANL activities. Elevated ^{3}H in regional aquifer samples has been observed at O-1, TW-1, TW-3, TW-8, LA-1A and LA-2 (Rogers et al., 1996b), as well as in several wells drilled during the more recent characterization drilling program (see Section 3.3).

Kwicklis et al. (2005) used vadose zone occurrences of ^{3}H to estimate the time-dependent transport velocities, from which they derived infiltration rates to the regional aquifer. They found that in Mortandad Canyon, infiltration rates are as high as 2000 mm/yr occur during periods of large volumes of effluent discharge. This infiltration rate has apparently decreased to 100-200 mm/yr once effluent discharge flow rates were reduced. These observations and analysis confirm that local recharge in canyons is an important component of the recharge distribution for the plateau.

2.8.3.1.2 Total Recharge

Estimates of total recharge provide important constraints on flow and transport models of the regional aquifer by tying model calibrations to measured or estimated water balance components. Therefore, various techniques and data sets have been examined to estimate total recharge. Griggs (1964) estimated the total recharge to the aquifer beneath the Plateau to be between 168 and 216 kg/s. McLin et al. (1996) estimated an upper bound of 192 kg/s, based on recovery of water levels in supply wells rested for a period of several months to several years. Using a variety of methods and considering a larger area, the Kwicklis et al. (2005) study discussed above estimates total average annual recharge to the Pajarito Plateau of 336 kg/sec.

A number of researchers have used baseflow gain to the Rio Grande to estimate total aquifer discharge, from beneath both the plateau and the eastern basin. These estimates presumably approximate the total aquifer recharge before significant pumping began. However, total gain must be combined with an estimate of the proportion of the gain that originates beneath the plateau. Long-term average aquifer discharge between the Otowi Bridge gage and the now-submerged Cochiti gage, a reach which bounds the southern portion of the plateau, was estimated by Spiegel and Baldwin (1963) to be 710 kg/sec and more recently by the U.S. Department of Justice to be 400 kg/sec (U.S. Department of Justice and New Mexico State Engineer Office, 1996). The former estimate is significantly higher because the authors did not

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include years of record that indicated the reach to be losing, which was attributed to measurement error. Keating et al. (2005) present an analysis of data from this reach as well as the reach immediately to the north (Española to Otowi), which bounds the northern portion of the plateau. This analysis estimates the total gain to the Rio Grande adjacent to the Pajarito Plateau (Santa Clara Creek to Rio Frijoles) to be approximately 911 kg/sec (+/– 30%). The modeling study of Hearne (1985) assumes 316 kg/sec recharge to the Pajarito Plateau; McAda and Wasiolek (1988) assume 291 kg/sec lateral inflow from the Jemez Mountains.

Aquifer modeling studies can also shed light on the recharge quantities and distribution. Keating et al. (2003) performed basin-scale inverse modeling as part of the Hydrogeologic Workplan, using both streamflow data and transient head data. That study indicated that approximately 253 kg/sec of the gain to the river along this reach originated on the Pajarito Plateau and the Sierra de los Valles. This analysis probably underestimated total recharge on the plateau, in part because the basin model was calibrated to a lower estimate of aquifer discharge north of Otowi Bridge than is indicated by the streamflow analysis subsequently performed by Keating et al. (2005). Part of the reason for the differences between these various estimates of total recharge is that several of the smaller estimates (McLin et al., 1996; Speigel and Baldwin, 1963; and Griggs 1964) emphasized the southern portion of the plateau (including LANL) which, according to the streamflow analysis in Keating et al. (2005), is discharging less water than the northern portion of the plateau.

In summary, although these various estimates span a range and reflect some uncertainty, they are extremely valuable as bounding values for flow and transport modeling in that they constrain the total quantity of water flowing through the aquifer beneath the Pajarito Plateau.

2.8.3.2 Discharge

Data constraining quantity of discharge for the regional aquifer were discussed in Section 2.8.3.1 in the context of estimating recharge. Regarding discharge locations, many authors have identified the Rio Grande as the principal discharge point for the regional aquifer (Cushman, 1965; Griggs and Hem, 1964; Hearne, 1985; McAda and Wasiolek, 1988; Purtymun and Johansen, 1974; Theis and Conover, 1962). Previous reports have cited a variety of evidence to support this, including:

- Streamflow gain along the Rio Grande (Balleau Groundwater, 1995; Purtymun and Johansen, 1974; Spiegel and Baldwin, 1963)
- Measured vertical upward gradients in the vicinity of the Rio Grande (Cushman, 1965; Griggs and Hem, 1964)
- The presence of flowing wells (McAda and Wasiolek, 1988; McLin et al., 1996; Spiegel and Baldwin, 1963)
- Springs along the river (McLin et al., 1996).

Discharge to the river may occur as lateral flow, upward flow, or as flow from springs in White Rock Canyon. Purtymun (1966) suggested that all the springs, which collectively flow approximately 85 kg/sec, discharge water from the upper surface of the main aquifer. Stone (1996) suggested that many of these springs may be discharging perched aquifers rather than the regional aquifer; unfortunately it is difficult to test these alternative hypotheses, although stable

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isotopes may provide some discrimination. It has been emphasized that although discontinuous, low-permeability beds produce confining conditions in the aquifer locally near the Rio Grande and elsewhere in the basin, flow is able to cross the low permeability beds in some locations as water discharges to the river (Hearne, 1985; Spiegel and Baldwin, 1963).

The degree of connection between the aquifer and the Rio Grande has been investigated by Balleau Groundwater (1995), who drilled 16 wells in the alluvial aquifer of the Rio Grande near the Buckman wellfield and conducted pumping tests. They found that head in the alluvium is generally 0.1 to 0.2 feet higher than the Rio Grande, indicating discharge from the alluvium to the Rio Grande. Head in the regional aquifer below the alluvium, at a depth of 59 feet, is about 2.8 feet higher than the Rio Grande. From pumping tests, they concluded that the hydrogeologic system at the site behaves as a layered water-table system in hydraulic contact with the river with delayed yield from pore-water storage and an adjacent river boundary source.

2.8.3.3 Interbasin Flow

Overall groundwater fluxes between the regional aquifer beneath the plateau and the basin and flow between the Española Basin and adjoining basins are not well constrained. It is possible that virtually all the groundwater flowing beneath the Pajarito Plateau flows easterly/southeasterly and discharges to the Rio Grande, and that interbasin flow to the south is small. An alternative possibility, that deep flow discharges instead to the basins to the south, is difficult to confirm or refute because of the lack of hydraulic data collected at discrete intervals at great depths within the aquifer. This could have a large impact on flow conditions at and near the site and thus will be the subject of future study.

The Española Basin is separated from the Albuquerque and Santo Domingo basins to the south by a structural high, a prong of older sedimentary rocks, and several major fault zones (Golombek et al., 1983). The Santa Fe Group aquifer thins significantly at this boundary (Shomaker, 1974). If these structures impede flow to the south, this might enhance both regional aquifer and interflow discharge to the surface. We have not evaluated the possible interflow component to streamflow gain in the southern portion of the basin; if it were significant our estimate of groundwater discharge would be erroneously high.

Numerical models of groundwater flow in the basin have generally predicted the interflow component of flow to the south to be small. The model of Hearne (1985) has no groundwater flow to the south by assumption; the McAda and Wasiolek (1988) and Keating et al. (2003) models allow interflow, but the models predict much larger discharge within the basin (to the Rio Grande) than to basins to the south. For example, Keating et al. (2003) estimated southerly flow from the Pajarito Plateau aquifer to the south to be approximately 9 kg/sec. Uncertainty analysis showed a possible range of values + 34 kg/sec or – 62 kg/sec. All of these values are relatively small compared to the total flow to the Rio Grande.

Regarding basin boundaries to the north and west, fluxes entering the region beneath the plateau were estimated by Keating et al. (2003), using basin-scale head and streamflow data and inverse modeling analysis. They estimated that flow into the plateau from the north was very small or zero, with a relatively large degree of certainty. Inflow from the west (Valles caldera) and outflow to the south is more uncertain, and could be as low as zero or as high as 94 or 34 kg/s,

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respectively. These fluxes are relatively small compared to estimates of total recharge for the plateau.

These modeling results, when combined with recharge and streamflow estimates, result in a self-consistent mass balance on water moving through the aquifer. Given the uncertainties in the individual flow estimates and the inherent difficulty of defining the appropriate structural features for a large-scale model, it is possible that other conceptualizations would provide equally valid representations of the available information. For example, it is possible that a conceptualization in which more water flows from the Española Basin to the adjoining Albuquerque Basin, rather than discharging at the Rio Grande, would prove valid. Elements of such a model conceptualization are (1) less flow restriction to the south; (2) more restricted flow from the deeper, confined aquifer to the Rio; and (3) southerly flow of a fraction of the deeper aquifer from the Sierra de los Valles and the Sangre de Cristo Mountains to the south. Of course, such a conceptualization would also need to be consistent with the available water budget information. The point here is that alternate conceptualizations such as this cannot be unequivocally ruled out and thus should be considered in future numerical models developed for the plateau and the basin.

2.8.4 Aquifer Hydrologic Properties

This subsection briefly summarizes the hydrologic properties of the regional aquifer rocks. A more detailed treatment of this critical topic, including statistical and spatial distributions of hydraulic conductivities measured in aquifer tests, is presented in Section 2.4. The aquifer beneath the plateau consists of the fractured crystalline rocks of the Tschicoma Formation, Cerros del Rio basalts, and older basalt flows, as well as the sedimentary rocks of the Puye Formation and the Santa Fe Group. These units are described in detail in Section 2.1, as well as by Broxton and Vaniman (2005). Both the Santa Fe Group and the Puye Formation are alluvial fan deposits with alternating beds of high and low permeability, with north-south trending faults associated with basin-scale rifting (Kelley, 1978).

Permeability estimates for the Santa Fe Group are primarily derived from pumping tests in water supply wells screened over large intervals; estimates range from 10^{-11} to $10^{-12.8}$ m^2 (Griggs and Hem, 1964; Purtymun, 1995; Purtymun et al., 1995a; Theis and Conover, 1962). Testing of monitoring wells, with relatively short screens completed within the Puye Formation, has shown very large variability (10^{-11} to $10^{-13.5}$ m^2). The basalt flows beneath the plateau include massive, fractured lava units, breccia zones, and inter-flow zones with significant clay content. Permeability within the Cerros del Rio basalts ranges from $10^{-11.2}$ to $10^{-13.8}$ m^2 (Nylander et al., 2002). Testing at R-28 shows the upper bound of permeability to be between $10^{-10.5}$ and $10^{-10.2}$ m^2 (Kleinfelder, 2004b).

Several estimates of specific storage (Ss) have been derived from various pumping tests: $10^{-4.8}$ /m in the Los Alamos Canyon wellfield (Theis and Conover, 1962); $10^{-5.5}$/m and $10^{-3.8}$/m in the Otowi wellfield (Purtymun et al., 1990; Purtymun et al., 1995b). These relatively low values are indicative of confined or leaky-confined conditions at the depth that these observations were made. This point is expanded upon in the next subsection, along with more recent estimates of specific storage based on a pumping test conducted as part of the Hydrogeologic Workplan.

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2.8.5 Anisotropy and Scale Dependence

Both the Santa Fe Group and the Puye Formation are, at least locally, strongly anisotropic. Pumping tests have confirmed that permeability normal to bedding is much lower than permeability parallel to bedding, both on the Pajarito Plateau (McLin et al., 2005; Purtymun et al., 1990; Purtymun et al., 1995b; Stoker et al., 1989) and elsewhere in the basin (Hearne, 1980). Estimates of anisotropy (ratio of vertical to horizontal hydraulic conductivity) vary from 0.00005 (Hearne (1980), pumping test analysis) to 0.04 (Hearne (1980), hydraulic gradient analysis), to 0.01 (McAda and Wasiolek, 1998).

Effective permeability and anisotropy at large spatial scales are difficult to estimate. Many authors have noted the lack of spatial continuity of low or high permeability beds with the Santa Fe Group (Hearne, 1980; Spiegel and Baldwin, 1963; Theis and Conover, 1962) and the difficulty of correlating geophysical or lithologic logs between even closely spaced wells (Cushman, 1965; Shomaker, 1974). Hearne (1980) notes that because of limited spatial continuity in low or high permeability rocks, under a regional pressure gradient vertical flow will occur through circuitous routes and thus effective anisotropy may be less pronounced at large spatial scales than that measured at small scales during pumping tests.

Large-scale, multiple-observation-well aquifer pumping tests are invaluable to examine scale effects and to estimate the impacts of water supply well pumping on pressure gradients in the aquifer. As part of the characterization program, a 25-day aquifer test was conducted at municipal water supply well PM-2 from February 3–28, 2003 (McLin, 2005). The pumping phase was conducted at a constant discharge rate of 1,249 gpm, followed immediately by a 25-day recovery period. Surrounding observation wells were used to record both drawdown and recovery in response to pumping at PM-2. The PM-2 well draws water from a continuous louvered screen between 1,004 and 2,280 ft below ground surface (bgs). Prior to the start of the test, production wells in the vicinity were completely shut down so that hydrostatic conditions in the regional aquifer could recover and a static baseline could be established. Except for the test pumping at PM-2, all of the surrounding water supply wells remained off throughout the test period. Continuous water-level responses to pumping at PM-2 were recorded by transducers that were placed in municipal wells PM-2, PM-4, and PM-5 and in characterization wells R-20 (three separate screens) and R-32 (three separate screens). Periodic responses to pumping were also recorded in characterization wells R-15 (one screen), R-21 (one screen), and R-22 (five separate screens); however, no significant drawdown values were recorded in these latter wells.

Figure 2-42 (from McLin, 2005) shows a layout of PM-2 and nearby monitoring locations during the test. Individual drawdown and recovery water levels in responsive wells demonstrate that the regional aquifer surrounding PM-2 is vertically anisotropic with pronounced resistance to vertical propagation of drawdown at shallower depths. Hydraulically, the aquifer behaves like a semiconfined aquifer at depth with leaky units located above (and perhaps below) a highly conductive layer that averages about 850 ft in thickness. Drawdown in this highly permeable unit was recorded more than 8,800 ft away in well PM-5, while drawdown only 1,225 ft away at the R-20 multiple-screened well was directly related to individual screen depth (Figure 2-43a, from McLin, 2005); the shallowest screen at R-20 showed little drawdown, while the deepest screen

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showed a dramatic response to pumping at PM-2. Similar but more subdued behavior was also recorded 4,457 feet away in the R-32 multiple screened well (Figure 2-43b). In contrast, no recordable drawdown was recorded 8,900 feet away in the R-22 multiple screened well, suggesting that an idealized radius of influence for pressure responses due to pumping at PM-2 was at least 8,800 feet after 25 days of continuous pumping. The idealized radius of influence shown in Figure 2-42 is schematic, based on the available data and is not meant to imply that the pressure response spreads uniformly in all directions.

A schematic diagram proposed by McLin (2005) to interpret the aquifer-pumping test and to estimate hydrologic parameters is reproduced in Figure 2-44. Clearly, this aquifer configuration is highly idealized, in that a single, well-defined semi-confining layer has not been identified, and layered heterogeneities certainly exist within the zone depicted as the deeper aquifer (for example, see the geologic cross section of Figure 3 in McLin, 2005). Nevertheless, using this idealized aquifer configuration, McLin (2005) estimated hydraulic conductivity at the scale of this test to be about 5.0 ft/day (based on an assumed aquifer thickness of 850 ft), with a storage coefficient ranging from about 0.00032 to 0.002. Finally, the observations of muted drawdown at observation points near the water table (significantly above the pumping elevation) suggest that the horizontal-to-vertical anisotropy ratio of hydraulic conductivities is highly variable: McLin (2005) suggests that the ratio of vertical to horizontal hydraulic conductivity may be on the order of 0.01 in some locations within the regional aquifer.

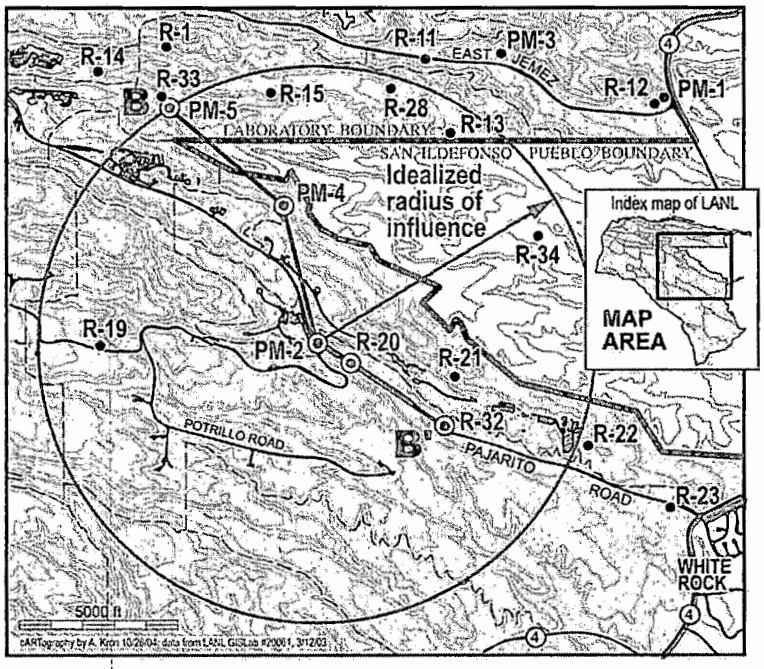

Figure 2-42. Idealized radius of influence of PM-2 on surrounding wells (McLin, 2005).

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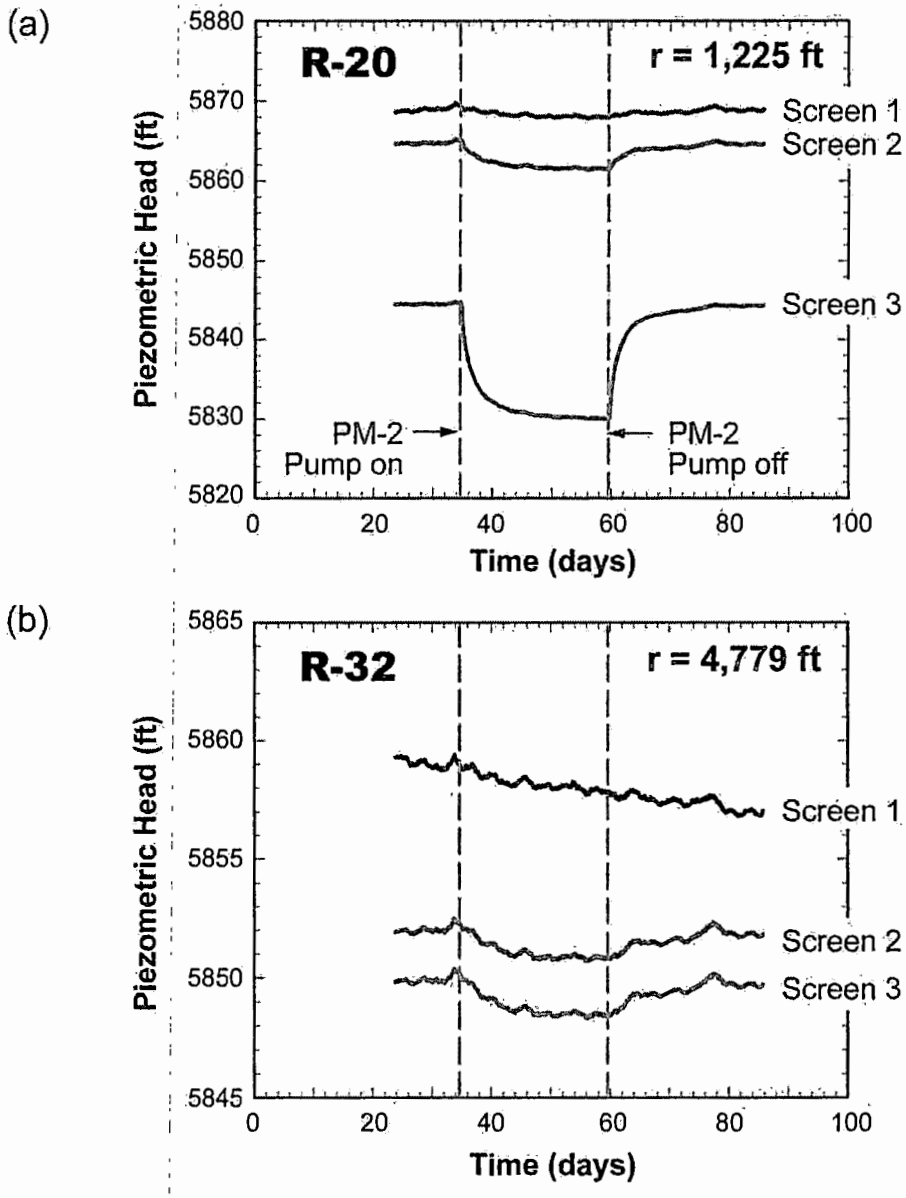

Figure 2-43. Drawdown at wells R-20 (a) and R-32 (b) in response to pumping at PM-2 (McLin, 2005).

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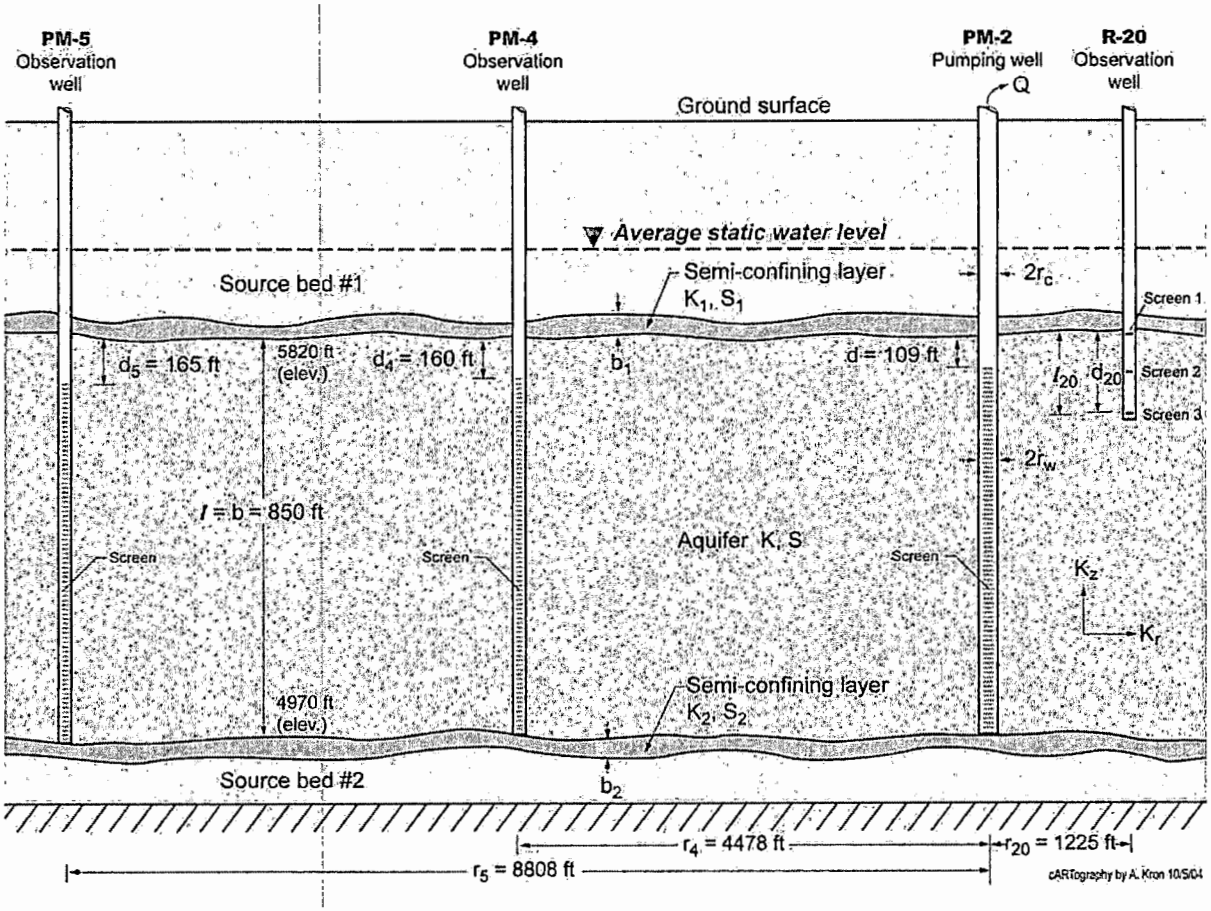

Figure 2-44. Idealized representation of the aquifer near PM-2 during the pumping test. A shallow system that includes the water table is separated from a deeper system by a semiconfining layer of low permeability (McLin, 2005).

The analysis of McLin (2005) suggested an aquifer that behaves as a confined system at early stages in the test, transitioning to a behavior characteristic of leaky-confined aquifer behavior when the long-term drawdown behavior is interpreted. Although the behavior of the pumping test has the signature of a leaky-confined aquifer, with a temporal stabilization of drawdown relative to a confined aquifer, other aquifer flow mechanisms can give rise to similar behavior. For example, either leakage from low-permeability aquitards within a confined aquifer or interception of the cone of depression with a recharge boundary is an alternative explanation. The pumping test illustrated the importance of conducting tests of long enough duration to discern the large-scale behavior of the aquifer at progressively larger scales. Additional tests at other municipal water supply wells are planned to probe the hydrodynamic conditions of the aquifer at different locations. By combining the results of several such tests, we should be able to sort out the various flow mechanisms, thereby uncovering a more detailed picture of flow paths and mechanisms in the aquifer.

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2.8.6 Hydraulic Heads and Flow Directions

The principal reason for studying the regional aquifer in the Hydrogeologic Workplan activities is to determine the direction and rate of movement of water and contaminants. Historically, easterly/southeasterly flow directions in the regional aquifer have been proposed, based on data available to Purtymun and Johansen (1974) and Rogers et al. (1996b). Data collected as part of the Hydrogeologic Workplan confirm this result with a much larger number of wells than were available to earlier studies, particularly wells completed with short screens near the water table.

2.8.6.1 Water Level Map

The potentiometric surface for the regional aquifer is shown in Figure 2-24 (from LANL, 2005). Data used to construct this map are given in Table 2-10 for wells under water table conditions. In addition, data from wells under leaky-confined conditions in lower Los Alamos Canyon were included to augment the spatial coverage of the data because observations at the water table are not available at that location. The analysis of the data used to construct this and other maps of water levels and trends with time is discussed in detail in LANL (2005). The lateral component of gradients along the top of the aquifer beneath the plateau varies over one order of magnitude, from a low of 0.0026 (TW-3 to R-5) to a high of 0.04 (CDV-R-37 to CDV-R-15). Even higher gradients are evident west of R-25 (0.162; R-26 to R-25).

A simple conceptual model for these trends is that gradients are high to the west where significant recharge is occurring and gradients are low in the central plateau where lower recharge rates are occurring and higher permeability rocks are present (Purtymun, 1995). The general easterly-southeasterly flow direction suggested by these gradients is consistent with radiocarbon ages of water from deep wells beneath the Pajarito Plateau, which increase from west to east. Age estimates for groundwaters beneath the plateau range between about one to six thousand years, increasing to several tens of thousands of years near the Rio Grande (Rogers et al., 1996b). However, as will be discussed below, interpretation of these data is complicated by the fact that the flow patterns within the aquifer are complex, and mixing of fluids of different ages is likely. The presence of anthropogenic tritium in the regional aquifer demonstrates that mixed waters of vastly different ages are present in the aquifer.

2.8.6.2 Shallow and Deep Flow Paths

The nature of the measured head gradients suggests that flow in the shallow portion of the aquifer (less than 150 m) below the upper surface of the saturated zone is primarily easterly-southeasterly. The tendency for aquifer rocks to be strongly anisotropic will cause water to move in large part horizontally, despite the strong driving force of vertical head gradients. As described in the previous subsection, the degree to which the uppermost phreatic zone and the deeper, leaky-confined aquifer are hydrologically connected is not known with certainty. Nevertheless, hydrologic testing indicates that there is considerable resistance to vertical flow relative to horizontal flow; this phenomenon is likely to be widespread throughout the aquifer, but the magnitude of the anisotropy ratio at small scales probably varies considerably across the plateau. One interesting observation is that the amount of recharge estimated by Kwicklis et al. (2005) to occur in canyon bottoms on the plateau (77 kg/sec) is close to the total discharge from the springs of 85 kg/sec estimated by Purtymun (1966). This observation is consistent with a

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compartmentalized aquifer with plateau recharge traveling laterally in the phreatic zone, partially isolated from deeper groundwater flow.

In general, the direction of flow in deeper portions of the aquifer (at depths greater than the deepest water supply wells) is unknown because of sparse data, and is likely to be different under pumping conditions than under pre-development conditions. Purtymun (1995) suggested that heads at deeper intervals of the aquifer also have a westerly gradient. It is conceivable that the predominant flow direction under natural gradient conditions could be different from what is found at shallower depths, but data to constrain the direction are insufficient. The conceptual model for the nature of flow discharging to the Rio Grande or flowing to the Albuquerque Basin to the south will likely influence the predicted flow direction deeper in the aquifer. A model with significant flow to the Albuquerque Basin (described in Section 2.8.3.3 as an alternate conceptual model) would lead to more southerly flow paths in the deep aquifer.

2.8.6.3 Influence of Water Supply Well Pumping

Despite evidence for compartmentalized flow with significant flow resistance between the shallower and deeper zones, it is likely that some downward movement of water and contaminants does occur due to pumping of water supply wells at depth. Occurrences of tritium and perchlorate in well O-1 show that flow paths between the shallow and deep aquifer water can exist during production. However, the extent of vertical transport is undoubtedly a function of the local permeability structure between the water table and the pumping interval in the water supply well, which may vary spatially across the plateau. Finally, pumping-induced upward movement of deeper water has been observed in the Los Alamos Canyon wellfield (Gallaher et al., 2004; Purtymun, 1977).

Although our understanding of the impact of water production on aquifer storage and discharge to the Rio Grande is incomplete, there is a clear trend of decreasing water levels over the time period of production from major wellfields on the plateau. Pumping rates increased from near zero in 1945 to 183 kg/sec in 1971 and have been relatively stable since then (171 kg/sec in 2001) (Koch et al., 2004); although year-to-year variability in pumping rates at individual wells has been large. Figure 2-45 (from LANL, 2005) shows the rate of water level decline in ft/yr estimated from long-term monitoring of water levels in wells on the plateau. Details of this map, constructed using a combination of test wells with a long (greater than 10 year) record and more recent characterization wells, are described in LANL (2005). The main features of the map are an area of high water-level decline rate (over 1 ft/yr) along Pueblo Canyon, which lies at the northern edge of data coverage, and an elongated zone of high decline rate (up to 0.8 ft/yr) that runs north to south, just east of and including PM-5, PM-4, and PM-2. This zone then extends east along Pajarito Canyon to R-23.

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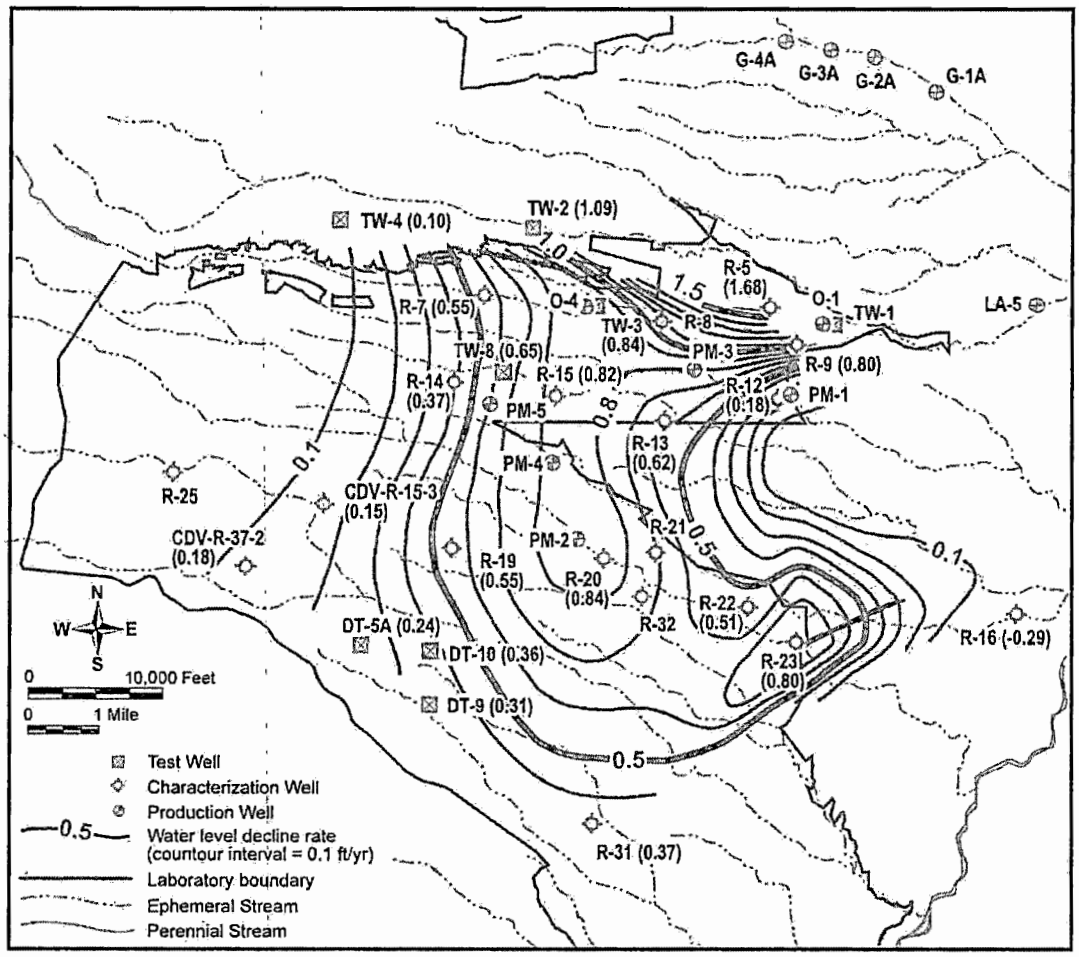

Figure 2-45. Annual water level decline due to municipal water supply well pumping (from LANL, 2005).

In the Los Alamos Canyon wellfield, after substantial water level declines when pumping initiated in the late 1940s, water levels rose and fell in response to inter-annual pumping variability. When the wells were retired in the late 1980s to early 1990s, water levels rapidly increased. Similarly, water levels in the Guaje wellfield decreased initially in response to pumping in the early 1950s and then stabilized until the 1970s; this was interpreted by Koch et al. (2004) to suggest that the aquifer had reached equilibrium. Water levels began to decline gradually again in the 1990s, perhaps due to pumping in nearby wellfields. Pumping in the Pajarito Mesa (PM) wellfield has produced less water level decline than pumping in the Guaje or Los Alamos Canyon wellfields, despite heavy usage. Nevertheless, water levels in PM-1 and PM-3, which have been pumped more consistently than other PM wells, have shown a long, steady decline. Test wells, which are much shallower than water supply wells, have also shown long, steady, declining water levels; before 1970 declines were very small (~1 m); since 1970 declines have increased to a total of ~5 m.

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The impact of production on storage in the aquifer was estimated by Rogers et al. (1996b). They calculated storage depletion by estimating the volume of the combined cones of depression observed in all the wellfields on the plateau, assuming drainage under water table conditions, and by assuming uniform aquifer properties (porosity = 0.1). They concluded that the total storage loss has been approximately equal to total production in the time period 1949 – 1993, and thus perhaps that there has been no significant net recharge to the wellfields during this period. In contrast, McLin et al. (1996) suggested that significant recharge has occurred, since water levels have recovered in wells that were allowed to rest a period of several months or several years. Flow modeling is one approach to estimate the proportion of storage loss that has been replaced by recharge. Simulations suggest that flow beneath the Rio Grande (west to east) has been induced by production at the Buckman wellfield. Calculations show that this flux may have increased from zero (pre-1980) to approximately 45 kg/s at present, or ~20% of the total annual production at Buckman (Keating et al. 2003).

2.8.7 Aquifer Hydrodynamics

The hydrodynamics in various portions of the aquifer beneath the plateau is critical to determining the potential pathways of contaminant transport. There have been numerous theories proposed in the literature on the degree and extent of confined conditions of the plateau. This is not too surprising considering the extremely complex geologic structure of the plateau and the inherent limitations of short-term pumping tests. Based on limited data, Cushman (1965) concluded that the aquifer is under water-table conditions beneath the plateau, with the exception of the vicinity of the Rio Grande, where water-table conditions exist in shallow layers and confined conditions exist at depth. Purtymun (1974) suggested that water-table conditions exist on the western margin of the plateau and artesian conditions exist along the eastern edge and along the Rio Grande.

Drilling associated with the characterization program has confirmed existence of water-table conditions at many locations beneath the plateau. Table 2-10 shows the water levels in wells (or, for wells with multiple screens, in the uppermost screen below the water table) used to construct the water table map discussed in Section 2.8.6. Clearly, the characterization program has revealed the presence of unconfined conditions locally over most regions of the plateau, with the exception of locations near the Rio Grande, where confined conditions are generally observed.

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Table 2-10.
Water-Level Data Used to Create the Revised Piezometric Water-Level Contours for the Top of the Regional Aquifer

Well Name-Screen Zone	Water Elevation (ft)	Data Vintage	Well Name-Screen Zone	Water Elevation (ft)	Data Vintage
CDV-R15-3-4	6020.1	2004	R-14-1	5883.7	2005
CDV-R-37-2-2	6138.8	2004	R-15	5851.7	2005
DT-10	5919.8	2003	R-16-2	5642.9	2004
DT-5A	5958.8	2003	R-18	6118.0	2004
DT-9	5917.9	2002	R-19-3	5888.0	2005
G-1A	5705.0	2001	R-20-1	5865.9	2003
G-2A	5750.7	2001	R-21	5853.4	2004
G-3A	5704.5	2001	R-22-1	5762.9	2004
G-4A	5784.0	2001	R-23	5696.6	2004
G-5A	5848.4	2001	R-25-5	6232.3	2004
H-19	6228.0	1949	R-26-1	7034.8	2003
LA-4	5706.0	1987	R-28	5839.4	2005
LA-5	5673.0	1987	R-31-3	5827.9	2002
LA-6	5678.0	1995	R-32-1	5857.8	2005
R-1	5879.9	2005	R-33	5877.0	2004
R-2	5874.0	2004	R-34	5834.0	2004
R-5-3	5769.2	2004	TW-1	5840.2	2003
R-7-3	5879.6	2004	TW-2	5847.7	2000
R-8	5836.0	2004	TW-3	5812.5	1999
R-9	5691.0	2004	TW-4	6071.5	2003
R-12-3	5695.9	2004	TW-8	5875.5	2003
R-13	5837.4	2005			

Source: LANL (2005) and references therein

Significant new information on the relationship of the shallow and deeper regional aquifer hydrodynamics has also been obtained. Potentiometric measurements at several new multiple-screened wells have revealed that decreasing head with depth is a pervasive feature of the aquifer. Head data (in meters) along a vertical cross-section in the southern portion of the plateau, where there are several wells with multiple completions, are presented in Figure 2-46. Decreasing head with depth has been observed in wells in the western portion of the Laboratory (see Figure 2-47 for well CdV-R-15-3) away from pumping well influence, but in a region where increased recharge is expected; near the Rio Grande (see Figure 2-48 for well R-16); in the central portion of the Laboratory (R-19, Figure 2-49); and in locations expected to be more strongly influenced by water supply well pumping (R-20, Figure 2-50). One counter example, well R-31 (Figure 2-51) located in the southern portion of the Laboratory away from municipal water supply wells and the region of expected high recharge, shows a very small (note the expanded scale of the y-axis compared to the other plots) decrease in head with screen depth between screens 2 and 3, but head increases with depth in the lower two screens 4 and 5.

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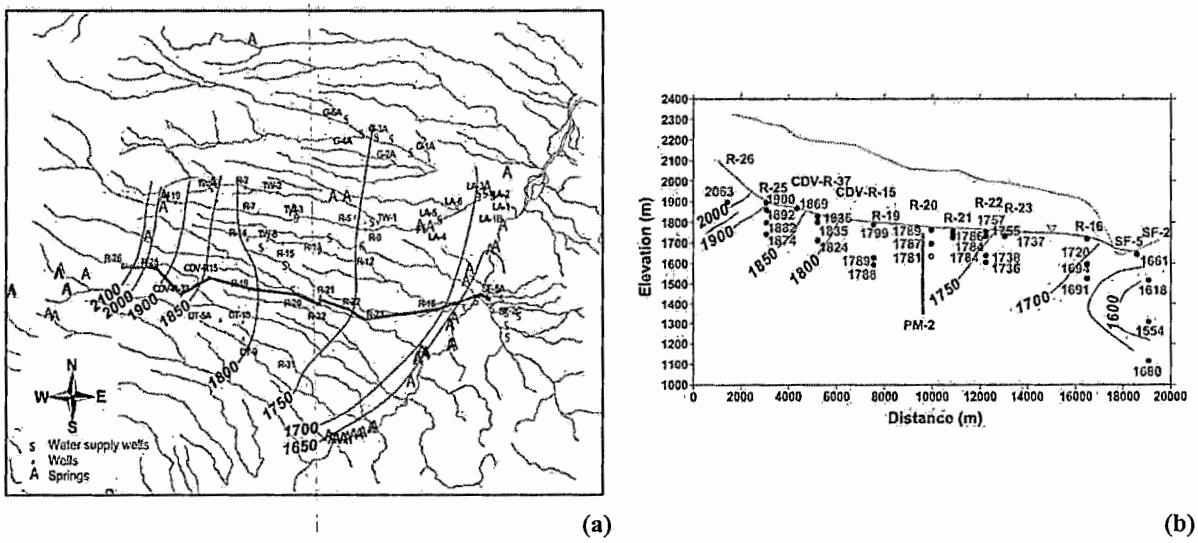

Figure 2-46. (a) Map view showing the location of a cross-section of the plateau. (b) Head data from a vertical cross-section across the southern portion.

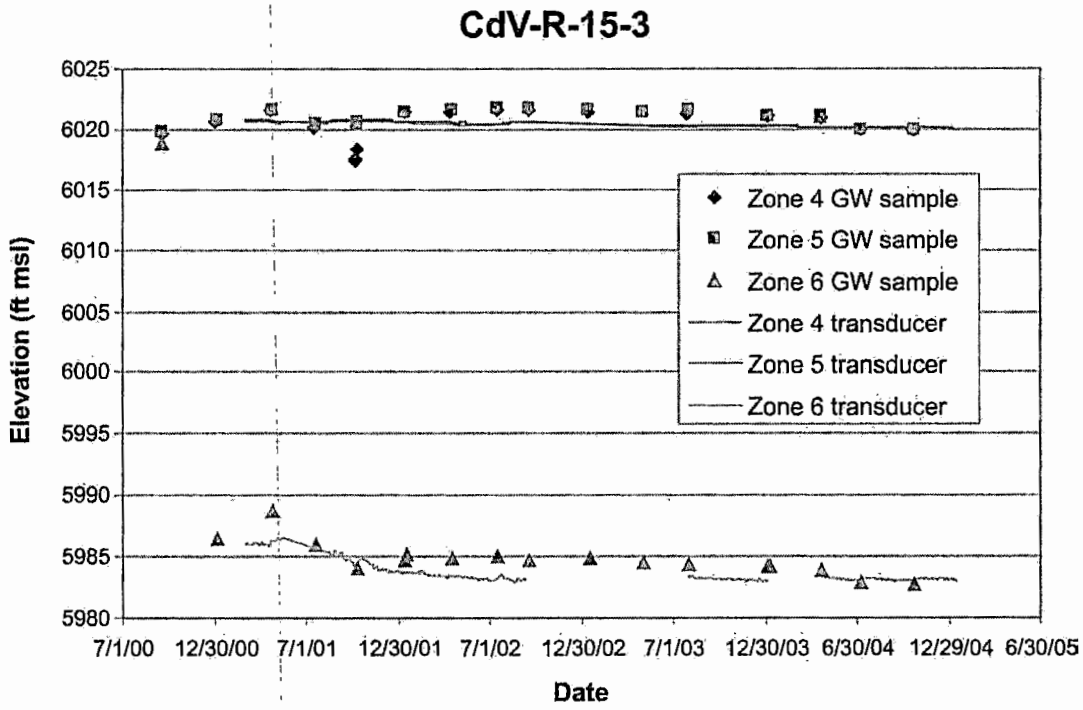

Figure 2-47. Piezometric water levels in different screens in well CdV-R-15-3.

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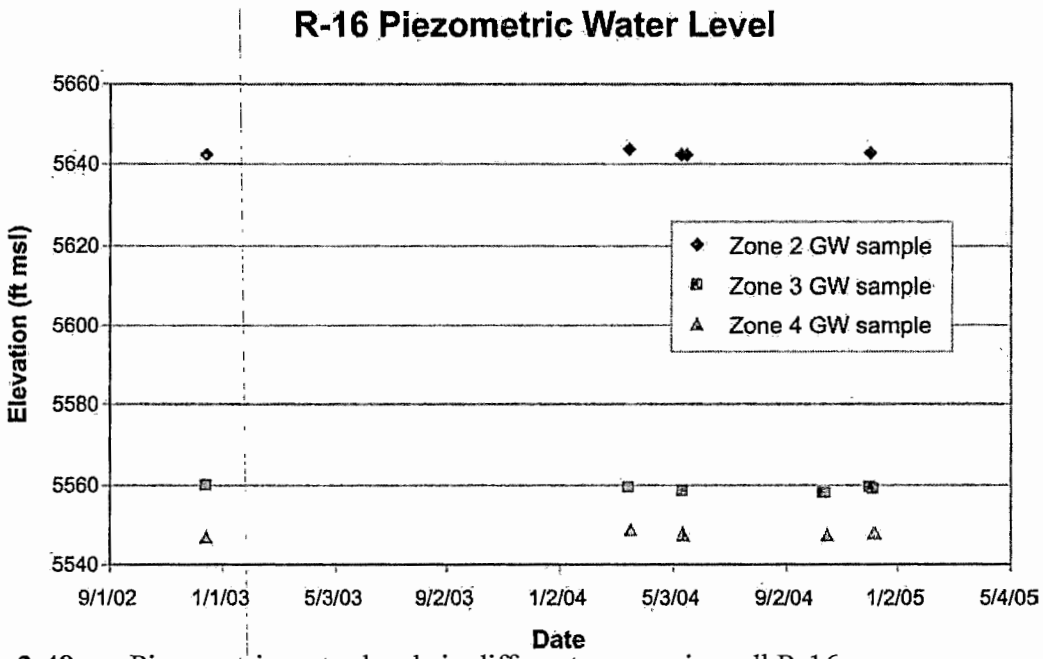

Figure 2-48. Piezometric water levels in different screens in well R-16.

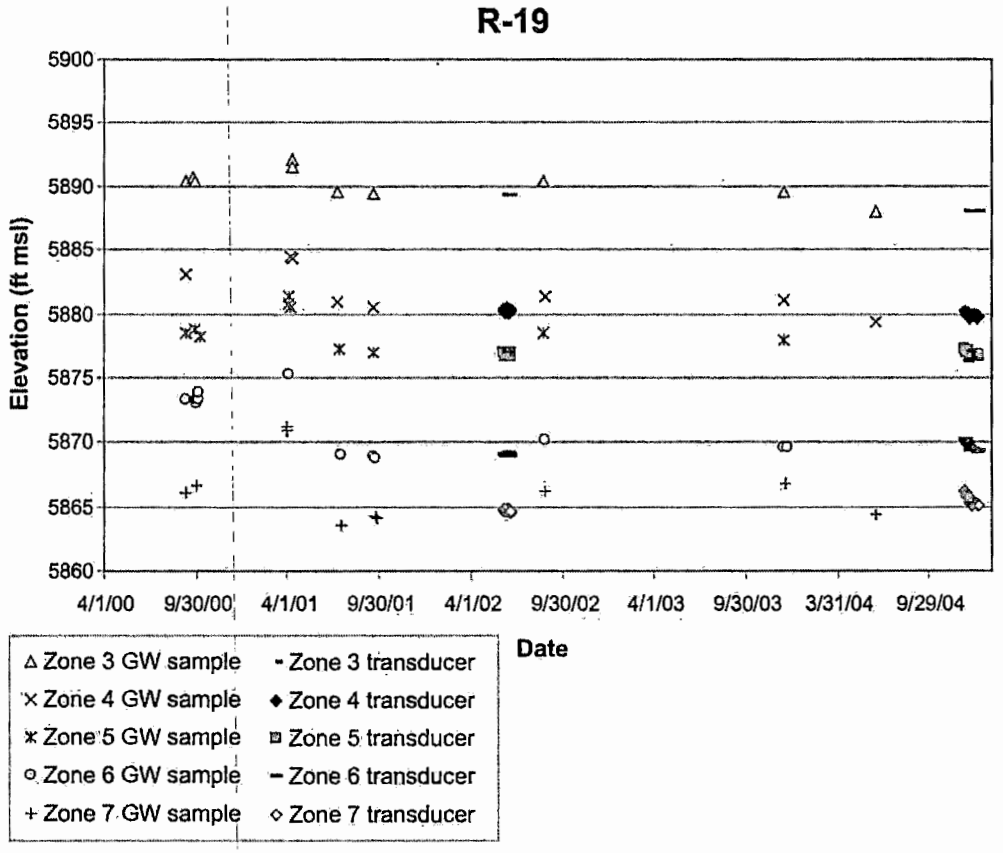

Figure 2-49. Piezometric water levels in different screens in well R-19.

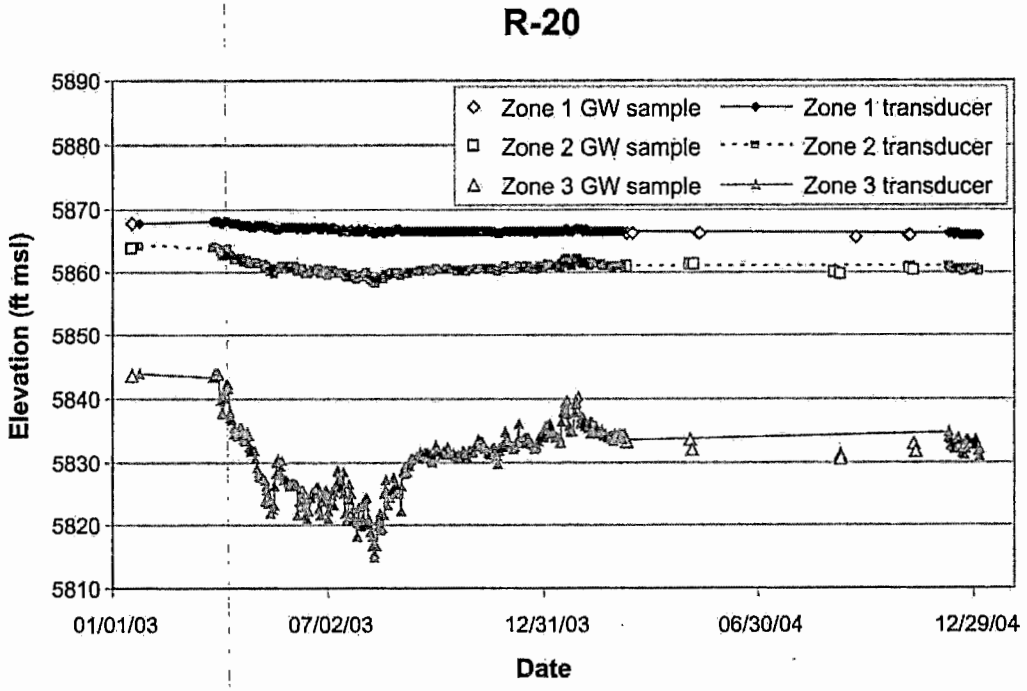

Figure 2-50. Piezometric water levels in different screens in well R-20.

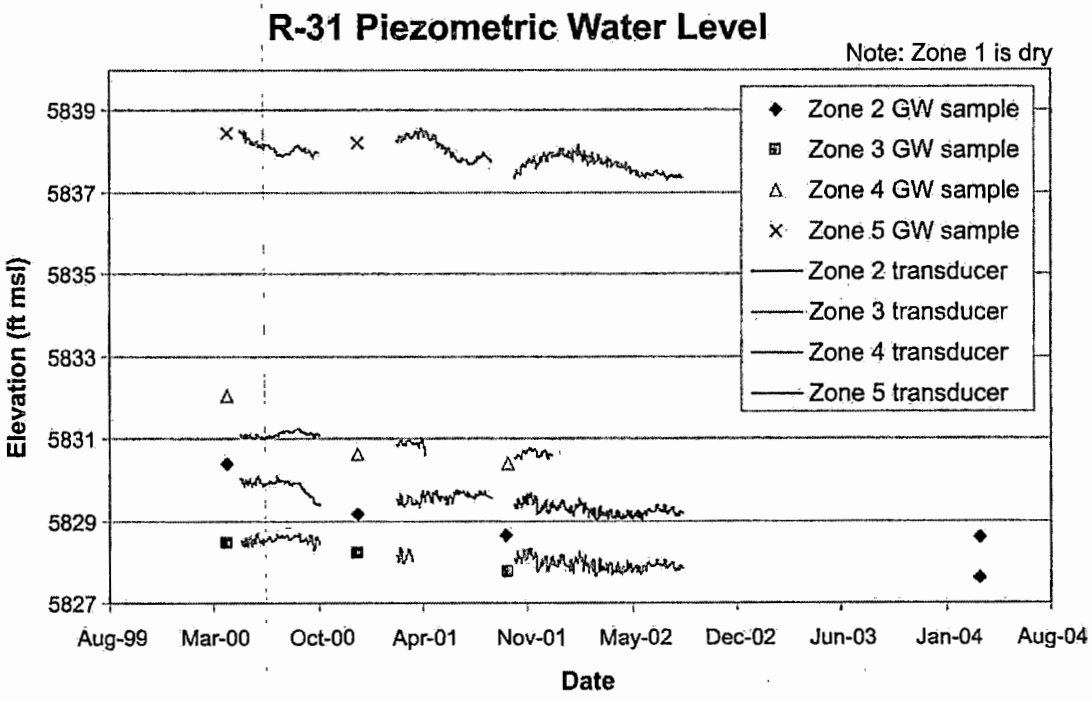

Figure 2-51. Piezometric water levels in different screens in well R-31.

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There are several hydrologic mechanisms that can give rise to the observed data. First, note that in a region with a sloping water table, with recharge at high elevation and discharge at lower elevations, the theoretical result for a uniform medium is lower heads with depth, except close to the discharge zone. This explanation alone is consistent with the uppermost screens of R-31. At greater depths in R-31, the higher heads are perhaps due to a zone that is hydrologically separated from the upper zone, with higher head due to recharge to the west and deep, confined flow beneath the plateau. The reasons for the larger downward head drops in well CdV-R-15-3 (as well as other wells in the vicinity, such as R-25) are uncertain, but are probably due to a combination of high local and mountain front recharge, combined with an extremely complex hydrostratigraphic and structural condition in which poorly connected, compartmentalized flow zones are encountered with depth. The wells in the vicinity of water supply wells on the plateau are clearly influenced by water extraction. It is possible that relatively small head differences with depth before water withdrawal have grown substantially because of pumping. Although data on shallow and deep head declines due to long-term pumping are sparse, it is likely that drawdown at the elevation of pumping is highest, and a more muted drawdown exists at the water table. Finally, for R-16, the lower head with depth is probably caused by pumping at the Buckman wellfield.

The critical element that appears to be necessary to explain the observations from both pumping tests and information from multiple-screened wells is the presence of different hydrodynamic conditions at depth than are present at the top of the regional aquifer. The observations (unconfined conditions and a muted response to pumping at depth) suggest a phreatic zone under water-table conditions that is weakly connected hydrologically to a deeper zone that behaves as a leaky-confined aquifer.

The nature of the aquifer heterogeneities giving rise to this compartmentalized system remains an open question. Two conceptual models appear to be possible. One is that the strongly anisotropic characteristic of the aquifer, which limits vertical movement of groundwater at virtually all depths within the Puye Formation and Santa Fe Group, produces the observed trends with depth. Cushman (1965) noted that this aquifer characteristic can cause an unconfined aquifer to appear confined in a short-term pumping test. This explanation is consistent with the observation of McLin (2005) described in Section 2.8.5 of a hydrograph that transitions from confined to leaky-confined behavior at later times. This conceptual model is implemented in the numerical models of McAda and Wasiolek (1988) and Hearne (1980). The McAda and Wasiolek (1988) model places the majority of water supply wells in the basin within the upper 600-ft-thick unconfined layer of the model.

Another conceptual model is that a laterally extensive low permeability zone exists within the aquifer separating the shallow phreatic zone from a deeper confined aquifer. This is the conceptualization depicted in Figure 2-44. A single, laterally extensive zone of low permeability has not yet been identified in boreholes on the plateau. This fact, combined with observations indicating vertical resistance at all elevations in basalts, the Puye Formation, and the Santa Fe Group, strongly favor the former conceptual model. Either model would be expected to give rise to lateral transport of contaminants reaching the water table, especially at locations relatively unaffected by municipal water well pumping. The anisotropic model would allow for vertical

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contaminant pathways to water supply wells in locations where continuous high-permeability pathways are present.

2.8.8 Velocities and Travel Times

Transport velocities and travel times through the regional aquifer are poorly understood, because of the lack of tracer tests and in-situ measurements of effective porosity. Data concerning the spatial distribution of anthropogenic contaminants in the regional aquifer have been difficult to use to constrain regional aquifer travel times because of the exceptionally thick and complex vadose zone, which makes it impossible to define the location and timing of contaminant entry to the regional aquifer. Transport over significant distances in the alluvial aquifers is known to occur, and complex vadose zone lateral pathways are also possible, though they have not been directly observed, except for the shallow subsurface pathways identified in the mountain front portion of the plateau (See Section 2.6.2.1). Despite these limitations, we note that no evidence of larger-scale migration of contaminant plumes has been observed, although the presence of anthropogenic chemicals at low levels in springs discharging to the Rio Grande at White Rock Canyon has been suggested by some to be due to regional aquifer transport (Section 3.2). Lack of evidence of migrating plumes may indicate that they travel too slowly to be observed over the relatively short period of study, or that sampling locations are not present in the right locations in sufficient density to track a migrating plume.

In principle, isotopic data can constrain possible transport velocities. These data clearly demonstrate that some waters beneath the plateau and discharging to the Rio Grande are thousands of years old, similar to ages of groundwaters measured in the Albuquerque Basin to the south (Plummer et al., 2004). Tritium data, described in Section 2.8.3, clearly demonstrate that young waters are present as well. These young and old waters may co-mingle at numerous locations within the aquifer including the discharge zone at the Rio Grande.

Therefore, there is no single answer to the question: How old is the groundwater? Mixing between older and younger waters is the norm for the waters sampled from the regional aquifer. Figure 2-52 illustrates that in many instances, both younger and older components are present. Tritium measurements at wells tapping the top of the regional aquifer near Los Alamos Canyon and Mortandad Canyon (among others), as well as isolated observations that include some of the springs discharging at White Rock Canyon, indicate a component of the water is young (less than 60 years old). Reconciling these observations with age estimates of several thousand years based on C-14 requires a model in which fluids of vastly different ages mix, yielding disparate age estimates from the different groundwater tracers.

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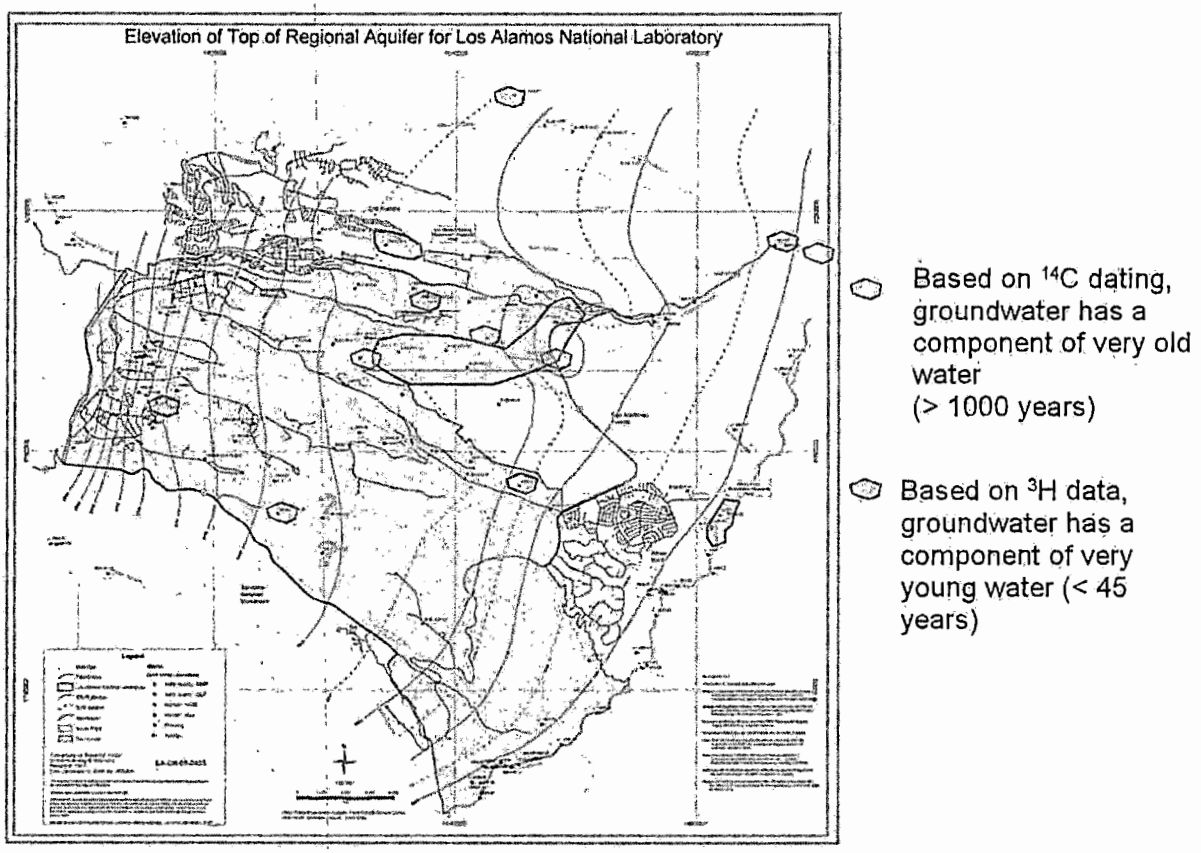

Figure 2-52. Diagram of the locations of "young" and "old" water at different locations. The figure shows that waters with different apparent ages, based on different geochemical indicators, can co-exist at the same location.

The model prediction of transport velocity and ultimate point of discharge of a contaminant in the regional aquifer is intimately tied to, even controlled by, the conceptual model used to develop the numerical model. If the picture emerging from the data described above of a compartmentalized aquifer is valid, then contaminants would travel laterally in the phreatic zone and arrive at springs discharging at the Rio Grande. These flow paths would be predominantly within the Puye Formation and the Cerros del Rio basalts, the geologic units commonly present at the water table of the regional aquifer (Figure 2-10). Travel times through these rocks might be expected to be relatively short. For example, taking the hydraulic conductivity of 1 m/d, a gradient of 0.02, and a porosity of 0.1, the computed velocity of a contaminant moving with the water (with no adsorption to the rock) is about 70 m/yr. Travel times on the order of 100 years would therefore be predicted to the springs from the most easterly zones of contaminated waters in the alluvial aquifers on LANL property.

The role of supply-well pumping in altering these directions and points of discharge is a function of the conceptual model and the water usage scenario chosen for examination. Section 4.2.12. presents a capture zone analysis suggesting that contaminants reaching the regional aquifer beneath canyons on the plateau will be largely captured by the PM wells. Anisotropic conditions in the regional aquifer that tend to keep transport pathways shallow are overcome by induced

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downward gradients, and contaminants are drawn to the depths of the screens of the water supply wells, where they are captured. Implicit in these results is the conceptualization of discrete pathways leading to downward transport, perhaps through tortuous "windows" of high-permeability rock in between discontinuous low-permeability layers. A more continuous low-permeability zone between the contaminant residing at the water table and the water supply well would create two disconnected zones at the scale of a contaminant plume. Under this scenario, contaminants would be isolated to the phreatic zone and travel to a down-gradient supply well or the Rio Grande, despite pumping near the contaminant source.

Another important consideration is that steady-state capture-zone results require the assumption of constant pumping for a long enough time for a water particle to arrive at the well. This water usage scenario maximizes the induced downward gradient, exaggerating the downward gradients and leading to flow paths in which capture by the water supply wells is favored over lateral transport at shallow depths. If transport velocities are low enough, water supply wells are likely to be taken out of service before this theoretical arrival at the well would occur. In this case, the actual transport problem is inherently transient, and predictions are intimately tied to the actual water withdrawal scenario. In summary, these complexities render the predictions model- and scenario-dependent. Interpretations based on such models must keep this fact in mind. In the future, a broader range of water-usage scenarios and transient capture zone analyses should be used to fully explore these alternatives.

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3.0 GROUNDWATER GEOCHEMISTRY, CONTAMINANT DISTRIBUTIONS, AND IMPLICATIONS FOR FLOW AND TRANSPORT

It is important to understand geochemical processes and the natural water quality beneath the Pajarito Plateau, so that anthropogenic perturbations to the natural system can be identified and quantified. The natural geochemistry of groundwater is the result of physiochemical interactions between air, water, soil, biota, and aquifer material. Geochemical processes are influenced by several factors, including the composition of the groundwater, groundwater temperature, microbial populations, the mineralogical composition of the aquifer material(s), and the length of time the water is in contact with aquifer material(s). Section 3.1 describes the conceptual model of geochemical processes and reactions for the Pajarito Plateau and surrounding area. It also describes the "background" water chemistry, that is, the water chemistry not affected by Laboratory activities.

Imprinted on the natural variations in chemistry is the presence of contaminants historically released since the early 1940s when Laboratory operations commenced. While most of the contaminants are at concentrations largely below regulatory standards, they demonstrate the presence of pathways for groundwater flow and contaminant transport from the surface to deeper groundwater. The impacts to groundwater at the Laboratory have occurred mainly where effluent discharges have caused increased infiltration of water. The depth to which chemical constituents move in the subsurface is determined partly by their chemical behavior: non-reactive constituents move readily with groundwater, while reactive or adsorbing constituents move a shorter distance.

In most cases where effluent sources have been eliminated, groundwater concentrations of non-reactive discharged contaminants have decreased far below past levels (e.g., RDX, nitrate, tritium, and perchlorate) in alluvial groundwater. These mobile contaminants readily move through the subsurface and are detected within perched intermediate zones and at the regional water table beneath several canyons, including Pueblo Canyon, Los Alamos Canyon, Sandia Canyon, Mortandad Canyon, and Cañon de Valle (HE in Cañon de Valle is an exception to this). In the case of reactive or adsorbing chemicals, the concentrations remain elevated significantly above background levels after elimination of discharges or other contaminant source terms (e.g., excavation and removal of contaminated sediments). These include constituents such as strontium-90 and the actinides (americium-241, plutonium-238, and plutonium-239,-240). A discussion of observed contaminant distributions within alluvial and perched intermediate zones and the regional aquifer is provided in Section 3.2. Many of the characterization wells and their chemical data are not included because characterization sampling conducted as part of the Hydrogeologic Workplan is not complete.

3.1 Geochemical Conceptual Model

A geochemical conceptual model that describes the geochemical environment beneath the Pajarito Plateau combines knowledge of geochemical processes with observations of water chemistry at sampling locations and mineralogy of aquifer materials. The components that contribute to the geochemical conceptual model include

- natural chemical compositions of groundwater,

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- residence time,
- reactive minerals controlling groundwater composition and solute mobility,
- adsorption and precipitation reactions,
- redox conditions controlling solubility, and
- chemical speciation.

The following subsections discuss these conceptual model components and describe the observations and data that are the basis of each component.

3.1.1 Natural Chemical Composition of Groundwater

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, older basalts, and the Santa Fe Group). As a result of geochemical processes, the natural composition of groundwater in the three hydrostratigraphic settings varies along flow paths from recharge areas in the Sierra de los Valles, west of the Laboratory, to the discharge areas along the Rio Grande to the east. Recharge also occurs along canyon reaches that contain saturated alluvium.

A hydrochemical investigation was conducted from 1997 to 2000 to define the background chemical composition of groundwater beneath the Pajarito Plateau. Based on the data and information compiled, the statistical properties of natural (background) distributions of stable isotopes (δD, $\delta^{15}N$, and $\delta^{18}O$), tritium, and major and trace solutes in groundwater were established. A complete description of the background study is available in LANL (2005a).

Natural groundwater (alluvial, intermediate, and regional aquifer) ranges from calcium-sodium bicarbonate composition within the Sierra de los Valles to a sodium-calcium bicarbonate composition east and northeast of the Laboratory. Sodium bicarbonate groundwater occurs within the regional aquifer in lower Los Alamos Canyon and at several White Rock Canyon springs near Otowi Bridge (Blake et al. 1995; LANL, 2001a; LANL, 2002; LANL, 2004b). Figure 3-1 shows average background concentrations of specific conductance, major cations and anions, silica, tritium, and several trace elements including barium and uranium analyzed during six sampling rounds (LANL 2005a).

Concentrations of trace elements increase from alluvial groundwater to perched intermediate zones to the regional aquifer. They also increase from west to east within the regional aquifer due to increasing solute residence times and water/rock interactions, including recipitation/dissolution and adsorption/desorption reactions. The highest natural solute concentrations are associated with older groundwater within the regional aquifer. Concentrations of dissolved bicarbonate, sodium, calcium, and uranium increase from west to east. The following subsections discuss the evolution of natural groundwater chemistry from the recharge zone, along the flow paths, and out to the discharge zone.

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3.1.1.1 Geochemistry of the Recharge Zone

Groundwater generally has the lowest total dissolved solids (TDS) in the recharge area and increases in TDS along flow paths (Figure 3-1, where TDS is approximated by specific conductance). The Sierra de los Valles provides most of the recharge to groundwater beneath the Pajarito Plateau, based on distributions of stable isotopes, including δD and $\delta^{18}O$ ratios (Figure 3-2). This interpretation was presented in Section 2.8.3.1.1. Recharge water derived from precipitation near the Sierra de los Valles contains natural tritium (19 to 71 pCi/L), which decays to less than 3 pCi/L along groundwater flow paths within non-contaminated perched intermediate zones and the regional aquifer beneath the central and eastern parts of the Laboratory (Figure 3-1).

3.1.1.2 Aqueous Geochemistry along the Flow Path

This subsection evaluates or describes solutes or dissolved species occurring along groundwater flow paths, which show variation among the three types of saturated zones. Variation in solute concentration results from the mixing of groundwaters, mineral precipitation (solute sink), mineral dissolution (solute source), and adsorption/desorption reactions. Natural groundwater quality in the regional aquifer beneath the Pajarito Plateau is excellent and, with the exception of arsenic in Guaje Canyon groundwater, does not exceed federal and state drinking water standards.

The occurrence of reactive minerals within aquifer material controls the composition of groundwater chemistry along flow pathways. Calcium, sodium, and bicarbonate are the dominant major ion solutes in natural groundwater beneath the Pajarito Plateau and surrounding areas. Bicarbonate is the dominant anion in groundwater at Los Alamos (LANL 2005a). This solute increases in background concentrations from shallow alluvial groundwater to the regional aquifer (Figure 3-3). Bicarbonate forms complexes with several trace metals, which has a direct influence on the metal's mobility or transport in the subsurface. Low concentrations of natural bicarbonate and calcium within the alluvium and perched intermediate zones within the Bandelier Tuff and the Puye Formation are insufficient to precipitate calcium carbonate (calcite) (Figure 3-4). Calcite is not typically observed within these saturated zones under natural conditions. In contrast occurrences of calcite within the Santa Fe Group basalt and sediments are reflective of higher concentrations of both calcium and bicarbonate.

Silica is the next most abundant solute found in surface water and groundwater within the Los Alamos area (Figure 3-1) because of hydrolysis reactions taking place between soluble silica volcanic glass and water. All groundwater sampled as part of the background investigation (LANL 2005) are oversaturated with respect to quartz, which is the most stable mineral of the silica phases (Lindsay 1979). Dissolved silica concentrations, however, are not controlled by quartz because this mineral is less reactive than volcanic and sedimentary glass found within the different hydrostratigraphic units. Groundwater within the three groundwater zones is calculated to be in equilibrium with silica glass. In some instances, dissolved silica can be used as a tracer to evaluate groundwater flow from the silica-rich (pumice-rich) Puye Formation to the underlying Santa Fe Group basalt encountered at wells R-9 and R-12. Groundwater flowing through the Bandelier Tuff (well LAOI(A)-1.1) and some sections of the pumiceous-rich Puye

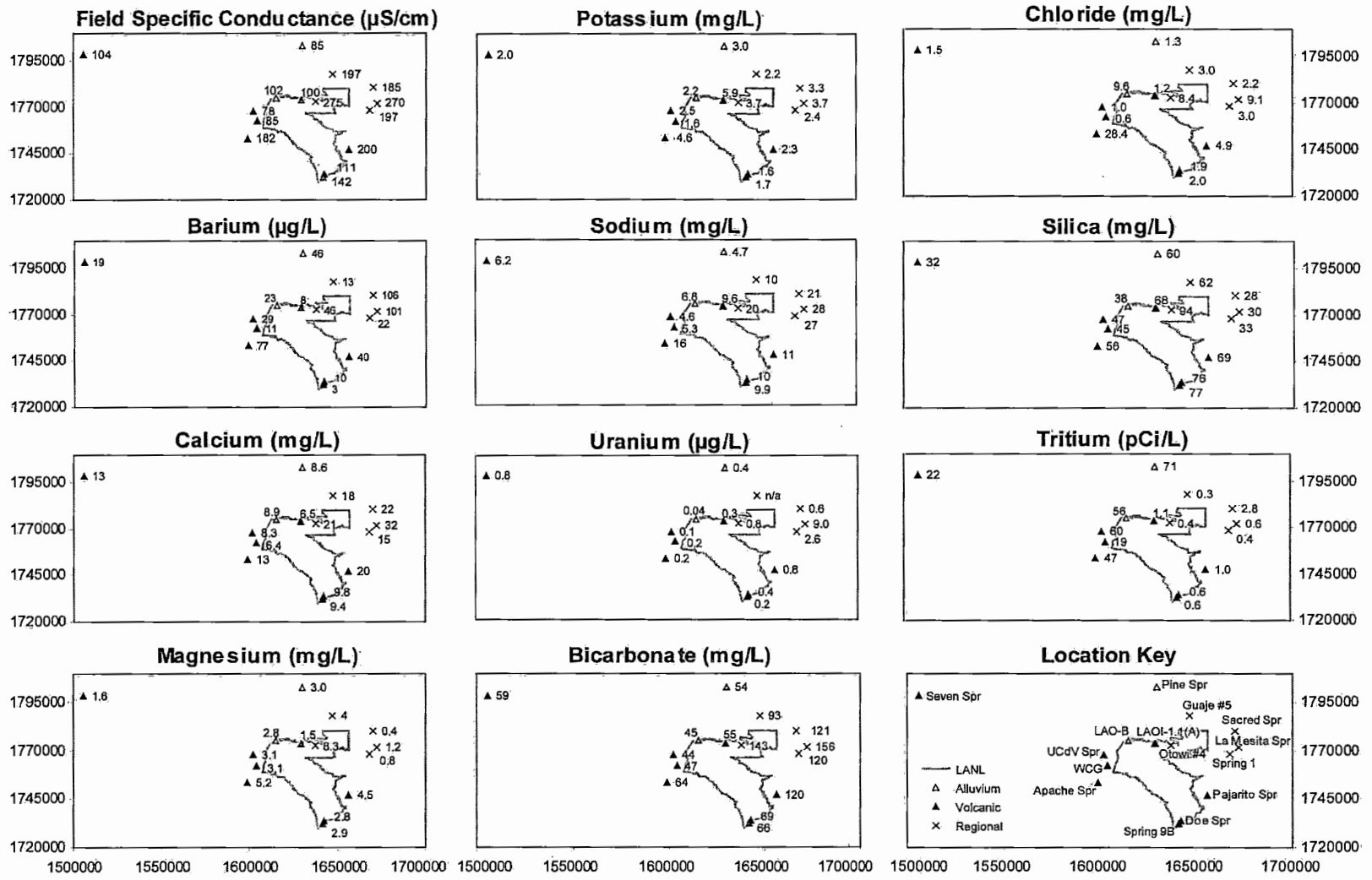

Figure 3-1. Average spatial distributions (n = 6) for key analytes in LANL background wells and springs (LANL, 2005a).

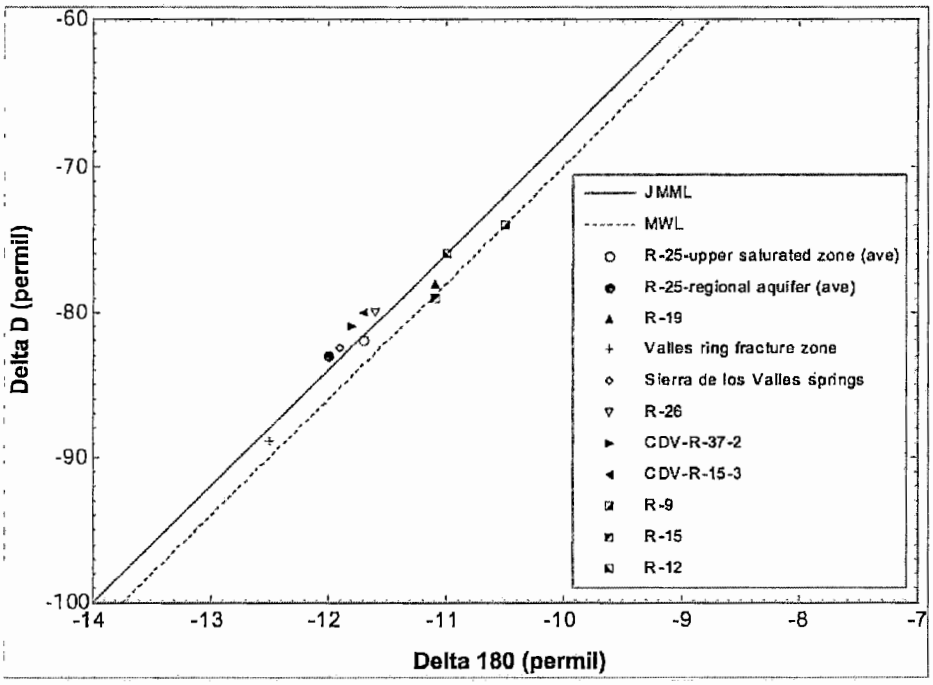

Figure 3-2. Stable isotope results for wells R-9, R-12, R-15, R-19, R-25, R-26, CdV-R-15-3, and CdV-R-37-2, and for other springs in the Jemez Mountains. (The upper line is the Jemez Mountains meteoric line and the lower is the mean worldwide meteoric line.)

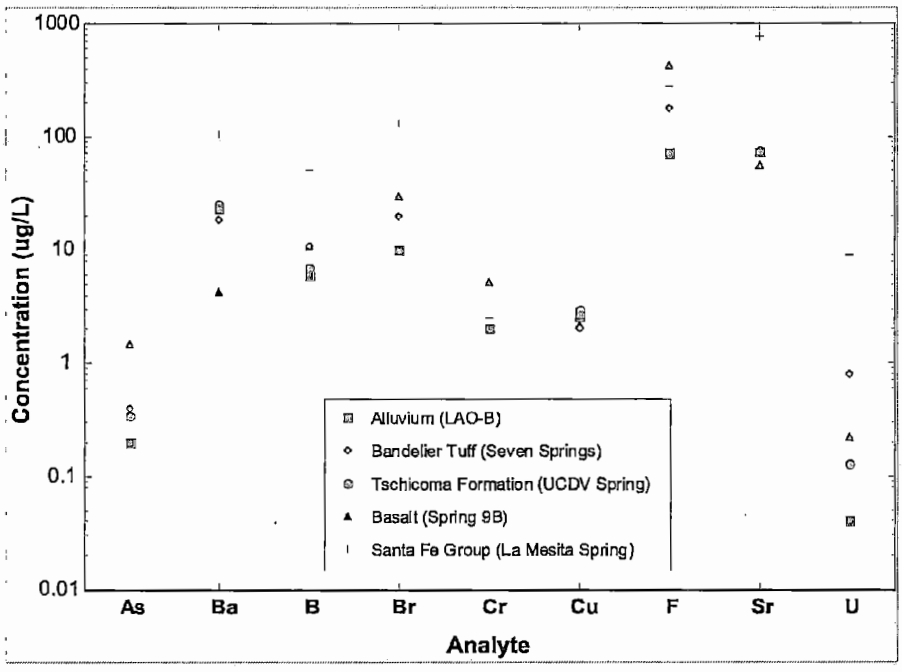

Figure 3-3. Average dissolved concentrations of selected natural trace elements in a represenative well or spring within alluvial and perched intermediate groundwater and the regional aquifer. Note: Average of six rounds.

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Formation (wells R-7 and R-15) is characterized by higher dissolved silica concentrations than groundwater flowing through the Cerros del Rio basalt (well R-9i and Spring 9-B) (Figure 3-4). This contrast is attributable to the fact that the volcanic glass within the basalt is both less abundant and less reactive than the ubiquitous glass within the Otowi Member of the Bandelier Tuff and pumiceous-rich Puye Formation.

Figure 3-3 shows average dissolved concentrations of several natural trace elements within alluvial and perched intermediate groundwater and the regional aquifer. Average concentrations of natural arsenic, chromium, and fluoride were the highest within the Cerros del Rio basalt (Spring 9B). Variations in groundwater trace element concentrations depend on solute residence time, speciation, and extent of water-rock interactions. Many trace elements show considerable variations, even in young recharge water. For example, average concentrations of barium, boron, bromide, strontium, and uranium are the highest within the regional aquifer in the Santa Fe Group at La Mesita Spring. Average concentrations of dissolved natural uranium were 9.1 µg/L at La Mesita Spring, which is 300 times greater than that observed at well LAO-B in alluvium (Figure 3-3).

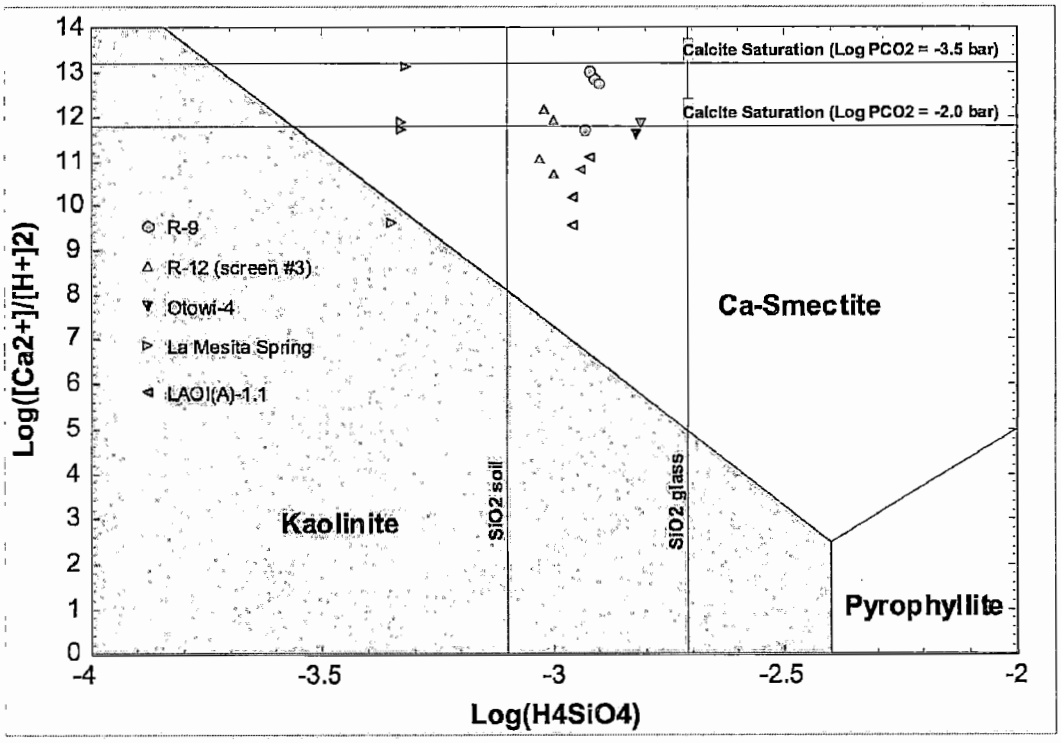

Figure 3-4. Activity diagram of log activity $[H_4SiO_4]$ versus log activity $Ca^{2+}/[H^+]^2$ at 25°C for wells Otowi-4, R-9, R-12 (screen #3), and LAOI(A)-1.1 and La Mesita Spring.
Note: These were selected because of observed smectite in x-ray diffraction of core and cuttings.

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Naturally occurring solid organic matter containing carbon, oxygen, nitrogen, and hydrogen is an important component of alluvial sediments within and surrounding the Laboratory. Dissolved organic carbon (DOC) is derived from leaching of solid organic matter and concentrations of DOC are typically less than 2 mg carbon (C)/L within perched intermediate zones and the regional aquifer. Higher concentrations of DOC (up to 20 mg C/L) are found in soil, surface water, and alluvial groundwater within the upper reaches of Los Alamos Canyon where runoff through grasslands and forests takes place. The DOC contains dissociated carboxylic acids that are stable as anions above pH 4.5 (Thurman, 1985). The anions are mobile in the groundwater. Dissolved organic carbon mainly occurs in the forms of humic and fulvic acids (Vilks and Bachinski, 1996). These acids occur as anions and can complex with calcium and magnesium, which can influence precipitation reactions involving calcite.

Leaching of ash produced from the Cerro Grande fire in May 2000 resulted in the generation of elevated concentrations of total organic carbon (TOC), consisting of both DOC and suspended organic carbon (SOC). Shortly after the Cerro Grande fire, increased concentrations of TOC were observed in surface water and alluvial groundwater within Pueblo Canyon, Los Alamos Canyon, Pajarito Canyon, and other watersheds. Since 2002, concentrations of TOC have decreased in surface water, but remain elevated in alluvial and perched-intermediate groundwater. Total organic carbon provides an excellent tracer for tracking movement of recent water (post Cerro Grande fire) in the subsurface. For example, concentrations of TOC have exceeded 300 mg C/L in perched zones within the Cerros del Rio basalt at the Los Alamos Canyon weir (Stone et al., 2004).

3.1.1.3 Geochemistry of the Discharge Zone

Groundwater chemistry within discharge zones can significantly differ from that characteristic of recharge zones. Total dissolved solids generally increase along groundwater flow paths. Specific conductance provides an indirect measurement of TDS and both parameters increase from west to east along groundwater flow paths. For example, groundwater within the Sierra de los Valles contains specific conductance values typically less than 100 µS/cm (Figure 3-1). Springs discharging within White Rock Canyon, however, have specific conductance greater than 100 µS/cm. Concentrations of sodium also increase relative to calcium and magnesium at selected White Rock Canyon springs. This change in major cation chemistry most likely results from cation exchange processes with reactive minerals along flow paths, including smectite, kaolinite, and volcanic glass (discussed in Section 3.1.3).

Groundwater within a discharge zone, at the end of groundwater flow paths, generally has the highest mineral or solute content and also represents the oldest water, provided that mixing with younger groundwater has not taken place. The main groundwater discharge zone for the Sierra de los Valles and the Sangre de Cristo Mountains occurs as springs and gaining reaches along the Rio Grande. Older groundwater within the regional aquifer tends to have higher concentrations of trace elements due to a combination of mineral dissolution and desorption processes. Many trace elements, including arsenic(III, V) and uranium(VI), form anions and tend to desorb from mineral surfaces under basic pH conditions (Langmuir, 1997). Dissolved concentrations of major cations and anions, arsenic, uranium, and other trace elements are higher in groundwater east of the Rio Grande based on water quality/geochemical data collected by the New Mexico

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Environment Department (NMED) and most recently by LANL. Based on water samples brought in to the Pojoaque water fair in 2004, concentrations of natural uranium in groundwater are generally in the range from up to 0.2 ppm along the Rio Grande and eastward toward the Sangre de Cristo Mountains. In contrast, uranium concentrations in the regional aquifer beneath the Pajarito Plateau rarely exceed 0.1 ppm.

In the discharge zone, as well as along flow paths, tritium is an excellent tracer that can be used to qualitatively date or bound the age of groundwater less than 61 years old, with a few exceptions. Background springs discharging within White Rock Canyon typically have tritium concentrations less than 1 pCi/L, indicating that groundwater is greater than 61 years old. This pre-dates historic discharges associated with the Laboratory and atmospheric fallout that may provide sources of recharge. These springs are characterized by groundwater flow paths that are of variable lengths and differing groundwater residence times.

3.1.2 Residence Times

Residence times of groundwater and chemical solutes increase both with depth and from west to east across the Pajarito Plateau within each groundwater zone. Groundwater flow paths within the regional aquifer generally are from west to east based on water level measurements. Accordingly, the concentrations of natural major ions and trace elements increase with distance along flow paths.

In the Sierra de los Valles, a known recharge area west of the Laboratory, a component of groundwater is less than 61 years old, based on measurable activities of tritium observed in springs. Movement of groundwater through fractured volcanic rock within the Sierra de los Valles is rapid in most cases (Water Canyon Gallery, Apache Spring, upper Cañon de Valle Spring, and Pine Spring). With a few exceptions, most springs in the discharge zone in White Rock Canyon, however, do not contain tritium, and the age of groundwater probably ranges between 3,000 and 10,000 years and possibly even older (Rogers et al. 1996b).

The oldest groundwater residence times within the regional aquifer are on the order of several to tens of thousands of years, based on carbon-14 dating (Rogers et al, 1996b). The carbon-14 dates provide a reasonable estimate of the maximum age of groundwater within the regional aquifer, provided that mixing with more recent water or older water with lower alkalinity has not taken place. Groundwater within the regional aquifer becomes progressively older from west to east (Rogers et al, 1996b). Presence of tritium near the water table and within the regional aquifer beneath the Laboratory, however, confirms that a much younger component of groundwater is present in the regional aquifer. Small concentrations of anthropogenic tritium (less than 100 pCi/L) at some locations are suggestive of mixing of a majority of old water with a component of young water at the regional water table. Mixing ratios using chloride or bromide are needed as additional information to more precisely determine fractions of young and old groundwater.

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3.1.3 Reactive Minerals Controlling Groundwater Composition and Solute Mobility

Because there are variations in pH, temperature, and major ion and trace element chemistry within shallow and deep saturated zones, different reactive minerals and amorphous solids precipitate or dissolve. In some instances, they control the major ion composition of groundwater. Some of these phases, including hydrous ferric oxide, manganese (oxy)hydroxide, smectite, calcite, and zeolites, have a high adsorptive capacity for trace elements including chromium, lead, strontium, and thorium, and radionuclides including americium-241, cesium-137, and plutonium-238, -239, -240. Reactive minerals and amorphous solids approach equilibrium with groundwater when the residence time exceeds the reaction half time (amount of time required for 50% of reactant A to form product B assuming there is no B initially present). This condition is usually met within perched intermediate zones and the regional aquifer based on observed mineralogy, because hydrous ferric oxide is present in all the groundwater zones.

Calcite and smectite are two important minerals that have been observed in core samples collected from several R wells. The stability of reactive phases, including $CaCO_3$ (calcite) and calcium smectite, can be evaluated by considering concentrations of major dissolved ions, chemical composition of minerals, and equilibrium concepts. Figure 3-4 is a log activity diagram showing the stability of several minerals including kaolinite, pyrophyllite, silica soil, silica glass, and calcium smectite. Groundwater samples collected from selected wells R-9, Otowi-4, R-12 (screen #3), and LAOI(A)-1.1 and La Mesita Spring are also plotted on the figure. Important points from this figure are as follows:

- Most groundwater is oversaturated with respect to calcium smectite, as the groundwater samples plot within that stability field.
- One sample collected from La Mesita Spring plots within the stability field for kaolinite due to a lower pH measurement.
- Groundwater is oversaturated with respect to SiO_2 soil (amorphous silica) and undersaturated with SiO_2 glass, which suggests that some of the silica could be formed from pedogenic (soil-forming) processes.
- La Mesita Spring (representative of young recharge water) is undersaturated with respect to silica soil and silica glass and has lower concentrations of silica relative to those measured in groundwater samples collected at wells R-9, Otowi-4, R-12, and LAOI(A)-1.1.

Under equilibrium conditions, calcite controls dissolved concentrations of calcium and bicarbonate within the regional aquifer. Beneath the western and central portions of the Laboratory, however, calcite is relatively rare in most of the lithologies characterized at the regional aquifer water table (Figure 2-10) except for the pre-Puye Formation Santa Fe Group sediments. These sediments have variable amounts of dispersed calcite cement (0-20 wt%). There is also a zone of post-depositional alteration centered in the northeastern portion of the Laboratory where calcite alteration is common in the Puye fanglomerate and the pumiceous sediments. Calcite precipitation is observed in Santa Fe Group sediments near the Rio Grande.

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As groundwater flows through perched intermediate zones and the regional aquifer, chemical and mineralogical compositions of reactive phases, including silica glass, change over time. For example, silica glass is the most soluble component of the aquifer material (Puye Formation and unassigned pumiceous unit) and reacts with groundwater to form clay minerals, such as kaolinite and smectite. These alteration phases have been observed at wells R-5, R-8A, R-9, and R-12. Calcium-sodium smectite has been observed in core and cutting samples collected from R-9 (Broxton et al., 2001a). Smectite has also been observed in rock samples collected from Santa Fe Group sediments in lower Los Alamos Canyon (Vaniman, unpublished data). The presence of smectite enhances natural attenuation of anthropogenic metals stable as cations, including strontium and barium, because this phase increases the adsorption capacity of the aquifer material under circumneutral pH conditions (discussed in more detail in Section 3.1.4).

The saturation index (SI) is an indicator of whether a mineral is likely to precipitate or dissolve under particular groundwater conditions. The SI is defined as the $\log_{10}$(activity product/solubility product). Precipitation of reactive minerals, including calcite, occurs in groundwater under near neutral pH conditions. Figure 3-5 shows saturation indices for calcite versus calcium and bicarbonate concentrations (millimoles/liter) at selected background springs and wells. The computer program MINTEQA2 (Allison et al., 1991) was used to perform SI calculations. For a given solid phase at equilibrium, the SI is equal to 0 ± 0.05. Oversaturation (positive SI) implies precipitation, whereas undersaturation (negative SI) implies dissolution. Native alluvial and perched intermediate groundwaters are calculated to be undersaturated with respect to calcite, and dissolution of this mineral takes place. This is consistent with the absence of calcite within the natural alluvium at the Laboratory. Groundwater samples collected at wells R-9, R-12, and Otowi-4 and La Mesita Spring generally are saturated with respect to calcite, whereas LAOI(A)-1.1 is not. Activities of dissolved calcium and bicarbonate at well LAOI(A)-1.1 are not sufficient to precipitate calcite. Calcite typically is not observed in native groundwater within the alluvium and Bandelier Tuff. The regional aquifer (Santa Fe Group sediments) is slightly undersaturated, but within thermodynamic uncertainty, with respect to calcite.

3.1.4 Adsorption and Precipitation Reactions

Adsorption occurs when dissolved species interact with surfaces of aquifer material coated with hydrous ferric oxide, manganese dioxide, clay minerals, or other adsorbents. Adsorption is usually reversible with the net effect being that the transport of the absorbed species is much slower than that of the water. Hydrous ferric oxide is an important adsorbent present in different aquifer materials beneath the Pajarito Plateau. Other adsorbents of metals include smectite, calcite, manganese oxide, and solid organic carbon, which can provide additional adsorption sites on aquifer material and within the unsaturated zone. Hydrous ferric oxide has a specific surface area of 600 m^2/g, which is much higher than quartz or silica gel that have specific surface areas of 0.14 and 53 to 292 m^2/g, respectively (Langmuir, 1997). Many metals and radionuclides including barium, chromium, nickel, uranium, strontium-90, americium-241, plutonium-238, and plutonium-239, -240 typically adsorb onto hydrous ferric oxide-coated particles between pH values 5 and 8.

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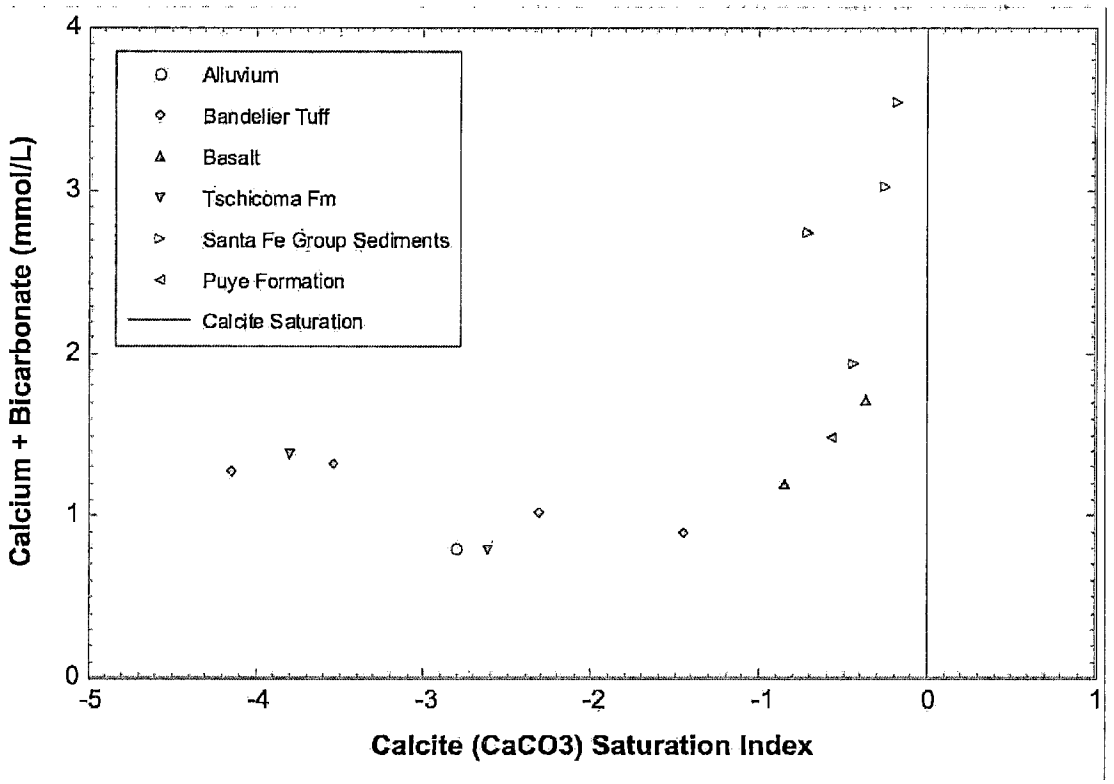

Figure 3-5. Saturation indices for calcite versus calcium and bicarbonate concentrations (millimoles/liter) at springs and wells representing different aquifer types at LANL (perched, intermediate, and regional).

Concentrations of inorganic contaminants (actinides, fission products, and trace elements) remaining within treated effluents are too small to be removed from solution through precipitation, based on results of computer simulations. Downgradient from Laboratory discharge points, adsorption processes are considered to dominate over mineral precipitation for continual removal of metals and radionuclides from alluvial groundwater. As a result, concentrations of adsorbing radionuclides and inorganic species generally decrease downgradient along the groundwater flow path. Alluvial material provides the largest reservoir for constituents from treated Laboratory effluent, including strontium-90, cesium-137, plutonium-238, plutonium-239, -240, and americium-241 because the constituents readily adsorb onto clay- and silt-sized material. For example, it is hypothesized that strontium-90 has been reversibly adsorbed on alluvial sediments by cation exchange, and the sediments provide a continuing source of this constituent to the alluvial groundwater. Eventually, strontium-90 will decay to stable zirconium-90 (via short-lived yttrium-90), reducing its remaining radioactivity by a factor of two approximately every 29 years.

Based on numerous studies reported in the literature, and supported by field observations documented in LANL Surveillance Reports (e.g. LANL, 1996a, 2000a, 2001a, 2002) and

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experimental results, the relative adsorption of HE compounds, radionuclides and inorganic species decreases at circumneutral pH (6 to 8) conditions as follows:

cesium-137 (highest adsorption) = americium-241 > barium > strontium-90 > uranium > nitrate = molybdate = sulfate = chloride = perchlorate = TNT > RDX = tritium (lowest adsorption).

Cations adsorb more strongly than anions under acidic to circumneutral pH conditions because adsorbents, including hydrous ferric oxide, smectite, and silica glass, are characterized by a net-negative surface charge (Langmuir, 1997). (Oxy)anions, including molybdate, nitrate, and perchlorate, are mobile in groundwater under circumneutral to basic pH conditions due to the net-negative surface charge on the adsorbent. Neutral species including TNT, RDX, and tritium do not adsorb to any significant extent onto inorganic mineral surfaces. Characterization and surveillance data collected within Pueblo Canyon, Los Alamos Canyon, Mortandad Canyon, and Cañon de Valle support the observed mobilities of anions (chloride, molybdate, nitrate, perchlorate, sulfate, and uranium) and neutral species (RDX, TNT, and tritium). High explosive compounds undergo hydrophobic sorption with solid organic matter present in alluvial channels, including Cañon de Valle, but such material is not present in significant concentrations in the regional aquifer.

Other variables that influence adsorption processes include precipitation and dissolution of the adsorbent, adsorption capacity, and changes in aqueous chemistry. Adsorption capacities of unsaturated and saturated material may change over time due to changes in solution composition, contaminant speciation and reactive phase mineralogy. In isolated cases where effluent discharges have changed alluvial groundwater alkalinity or pH, trace elements such as strontium and barium may precipitate as $SrCO_3$, $BaCO_3$, and coprecipitate as $(Sr\text{-}Ba)SO_4$. These precipitation processes are considered to be important within the upper reaches of Cañon de Valle and Mortandad Canyon.

Cation exchange reactions typically influence major cation compositions of groundwater. This influence is especially true for older groundwater with a long residence time characteristic of the regional aquifer east of the Rio Grande. Cation exchange between divalent, magnesium and calcium and monovalent sodium results in increasing water hardness (increased calcium and magnesium) in which calcium typically dominates over magnesium as the dominant dissolved cation. Softening of water occurs when calcium and magnesium are removed from groundwater and sodium becomes the dominant cation. This water-softening process is observed northeast of the Laboratory (former lower Los Alamos wellfield) and along sections of the Rio Grande.

3.1.4.1 Adsorption and Precipitation of Uranium(VI) Species

Uranium is a naturally occurring trace element found in groundwater and it is also processed at the Laboratory. This subsection provides a summary of the aqueous chemistry and adsorptive characteristics of this actinide because of its importance to background conditions and Laboratory effluents.

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Uranium is a naturally occurring actinide found essentially in all soils, sediments, rocks, surface waters, and groundwaters worldwide. Whole rock concentrations of uranium within the Bandelier Tuff, Cerros del Rio basalt, and Puye Formation range from less than 1 to over 10 mg/kg or ppm (Longmire et al. 1996a, Broxton et al. 2001a). Silica-rich rocks, including the Bandelier Tuff, contain higher concentrations of uranium than do the less siliceous rocks, including the Cerros del Rio basalt and Puye Formation.

Background concentrations of dissolved uranium within alluvium, perched intermediate zones, and the regional aquifer are generally detectable but at concentrations less than 1 μg/L in groundwater beneath the Pajarito Plateau (Longmire et al., 1996b, LANL 2005a). These naturally low concentrations of dissolved uranium are probably controlled by aqueous solubilities of minerals containing uranium. For example, zircon ($ZrSiO_4$) is a trace mineral found within the Bandelier Tuff. Concentration of uranium in a zircon crystal within a sample of the Bandelier Tuff was 1180 ppm (Stimac et al. 1996). This highly refractory mineral has an aqueous solubility of $10^{-15.4}$ M at pH 7. Uranium does not significantly leach out of this mineral at circumneutral pH values (6 to 9) based on its low aqueous solubility. Some uranium concentrated within the Bandelier Tuff is associated with volcanic glass, which has an aqueous solubility of $10^{-2.71}$ M at pH 7. Consequently, there is higher occurrence of uranium in groundwater within the Bandelier Tuff because it is more susceptible to leaching from glass due to its higher aqueous solubility. The rate of uranium leaching from glass, however, is slow, as indicated by the low dissolved concentrations of uranium (<0.5μg/L) measured in perched groundwater within the Bandelier Tuff (well LAOI(A)-1.1).

The uranyl (UO_2^{2+}) cation is analogous to other divalent metal species that significantly adsorb onto hydrous ferric oxide under acidic pH conditions. Increasing concentrations of hydrous ferric oxide result in increasing the adsorption capacity of uranium(VI) complexes because more binding sites are present. Concentrations of hydrous ferric oxide vary between alluvial groundwater, perched intermediate zones, and the regional aquifer. This variation is dependent on chemical weathering of primary iron-rich minerals and iron-rich volcanic glass. Iron-rich glass and minerals within the Cerros del Rio basalt enhance precipitation of increasing amounts of hydrous ferric oxide compared to the Bandelier Tuff, which contains iron-depleted glass and smaller amounts of iron-bearing minerals.

The computer program MINTEQA2 (Allison et al., 1991) was used to model adsorption (surface complexation) of uranium(VI) onto hydrous ferric oxide for perched intermediate groundwater characterized at well R-9. The double layer model (DLM) was selected for the simulation because it takes into account adsorbent characteristics (specific surface area, charge density, and adsorbent concentration) and aqueous chemistry parameters (pH, ionic strength, and solution composition).

Figure 3-6 shows both calculated distributions of adsorbed uranium(VI) complexes onto hydrous ferric oxide and dissolved complexes as a function of pH. Results of the calculation suggest that maximum adsorption takes place at pH 5.5 and decreasing adsorption occurs with increasing pH, which is due to the formation of uranyl carbonate complexes. Uranyl dicarbonate and uranyl tricarbonate complexes do not significantly adsorb onto negatively charged surface sites present

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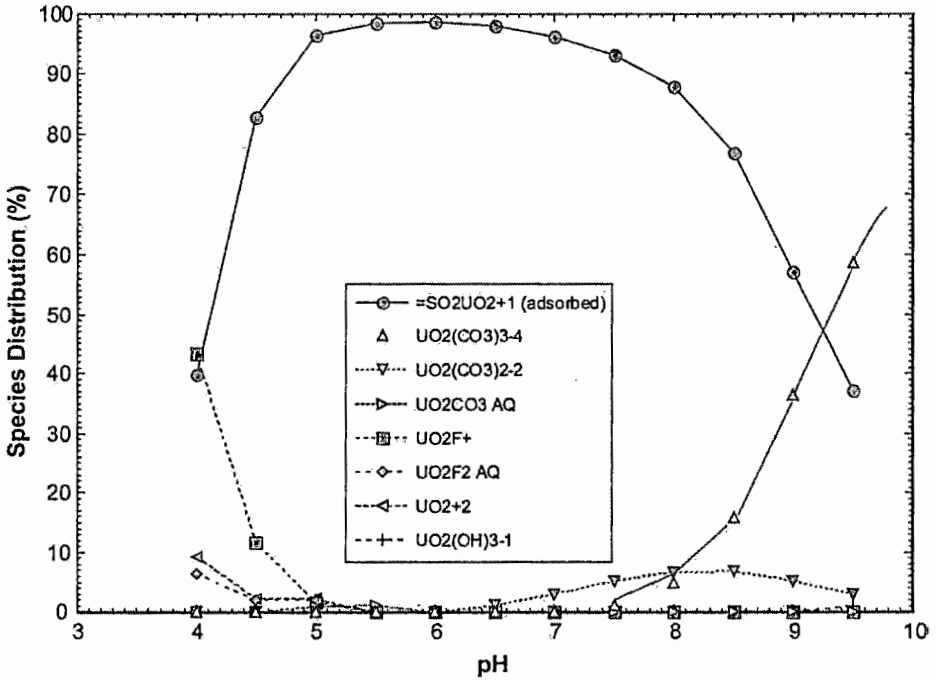

Figure 3-6. Calculated distributions of adsorbed and dissolved uranyl species for well R-9 (275 ft perched zone) (HFO concentration = 1.46 g/L and total dissolved uranyl $[UO_2^{2+}]$ = 0.054 ppm, 25°C). Calculation was made for R-9 because uranium was measured in groundwater whithin the Cerros del Rio basalt.

on hydrous ferric oxide. There is a sharp rise in uranium(VI) adsorption onto hydrous ferric oxide between pH values of 4.0 and 5.0 (Figure 3-6), where uranyl cation species dominate.

Other divalent cations compete with uranyl species in both natural and contaminated groundwater. Calcium (Ca^{2+}) strongly competes with UO_2^{2+} for adsorption sites present on hydrous ferric oxide, based on experimental results, including DLM intrinsic stability constants provided by Langmuir (1997). Concentrations of dissolved calcium are much higher (in the mg/L range) than dissolved uranium (less than 1 µg/L), which allows for more calcium binding onto hydrous ferric oxide.

Similar competition between calcium and the uranyl cation may take place with clay minerals. This has relevance to groundwater chemistry east of the Rio Grande that is characterized by higher concentrations of calcium and uranium compared to groundwater beneath the Pajarito Plateau. This exchange reaction results in concentrations of natural uranium within the regional aquifer ranging from 0.5 µg/L (Los Alamos) to over 1800 µg/L (west of Nambé).

Exchange reactions between calcium and sodium are of importance based on inverse relationships between dissolved calcium, sodium, and uranium. Figure 3-7 shows calcium/sodium ratios (milliequivalents/L) versus uranium concentrations for 127 groundwater samples collected at Pojoaque, New Mexico during June 2004. The highest concentrations of uranium in groundwater occur at lower calcium/sodium ratios. This relationship suggests that

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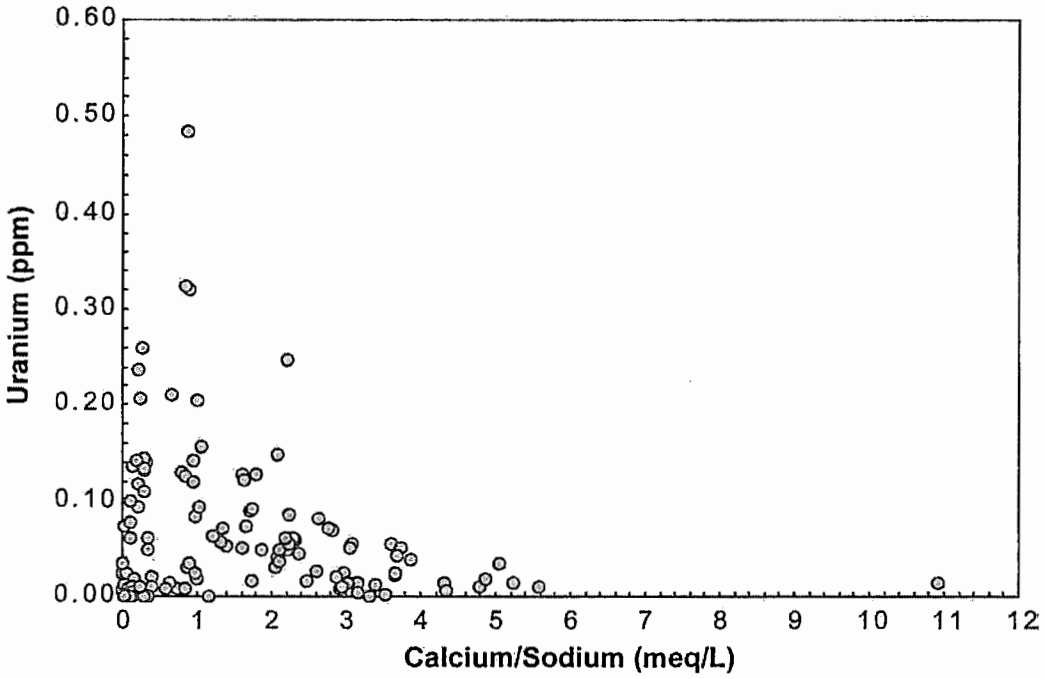

Figure 3-7. Calcium/sodium (meq/L) versus uranium concentrations, Pojoaque water fair, June 2004.

calcium is removed from groundwater, whereas uranium is added to groundwater through cation exchange. Alternatively, the relationship between uranium and sodium/calcium rations could be due to bulk compositional effects rather than cation exchange. In some groundwater samples, calcium is removed to a greater extent than sodium.

Precipitation reactions serve as a sink for removing uranium from solution. There are numerous uranium (VI) minerals that are naturally occurring and are found in aquifers (ore deposits) within sedimentary and igneous rocks. Several uranyl silicate minerals including $(UO_2)_2SiO_4 \cdot 2H_2O$ (soddyite) and $Ca(UO_2)_2(Si_2O_5)_3 \cdot 5H_2O$ (haiweeite) are potentially important within silica-rich groundwater beneath the Pajarito Plateau. Figure 3-8 shows a plot of saturation indices for several reactive minerals including silica solids, carbonate minerals, soddyite, and haiweeite for several groundwater sampling stations including Spring 2B, alluvial well LAO-B, perched intermediate groundwater (well LAOI(A)-1.1), and regional aquifer groundwater (wells Otowi-4, TW-3, R-9, and TW-1). The computer program MINTEQA2 (Allison et al., 1991) was used to perform the saturation calculations.

Temperature, pH, redox potential, and dissolved activities of calcium, uranium(VI), bicarbonate, and silicic acid influence the precipitation/dissolution of soddyite and haiweeite. As bicarbonate concentrations increase, dissolved uranium(VI) reacts to form complexes, which decreases the amount of uranyl cation (UO_2^{2+}) available for precipitation of soddyite and haiweeite. This is counter balanced, however, by increasing concentrations of dissolved calcium that enhances precipitation of haiweeite at Otowi-4, R-9, TW-1, and Spring 2B (Figure 3-8). This assessment is

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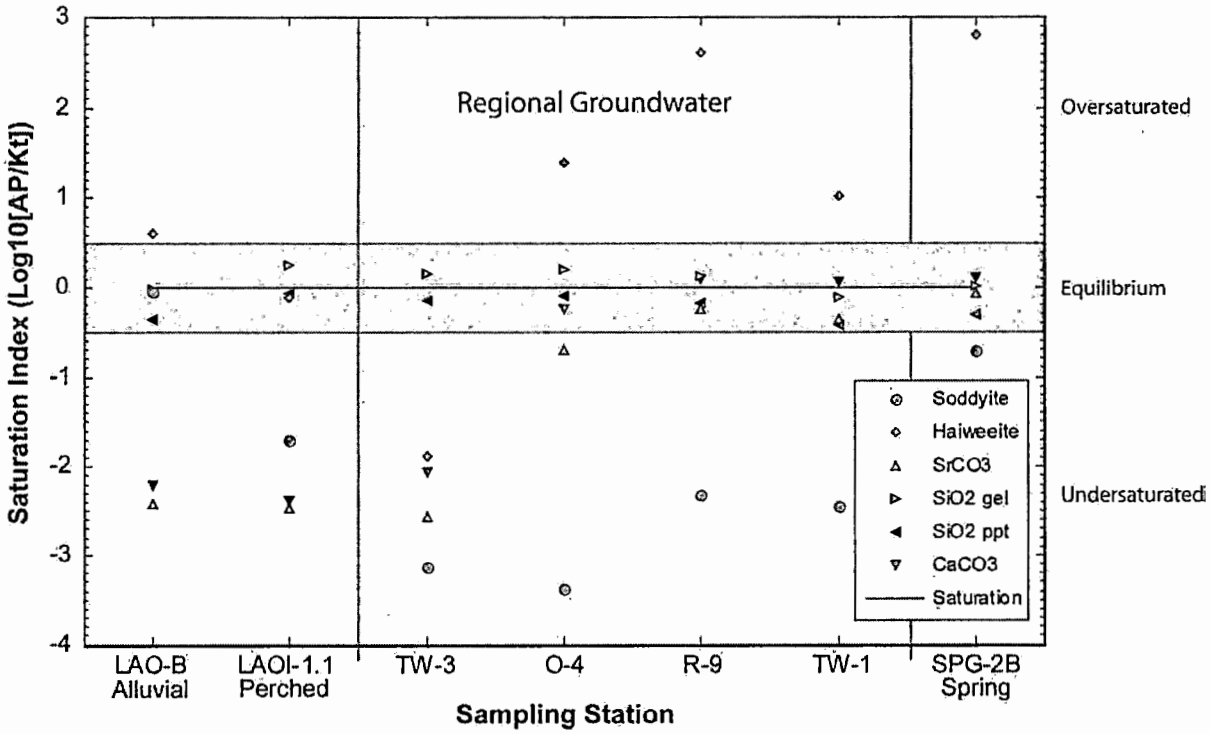

Figure 3-8. Saturation indices for several solid phases in alluvial (LAO-B) and perched intermediate groundwater (LAOI(A)-1.1) and the regional aquifer (Otowi-4, TW-3, R-9 and TW-1) within Los Alamos Canyon, Pueblo Canyon, and Spring 2B. The computer program MINTEQA2 was used to perform the calculations. Note: These wells were selected because they show hyrochemical snapshot of the three aquifer types within the Los Alamos Canyon and a spring.

based on geochemical calculations and the overall oxidizing conditions characteristic of natural groundwater beneath the Pajarito Plateau.

While it is useful to perform saturation index calculations to evaluate mineral equilibrium, most of the deep groundwaters are not in equilibrium with respect to either soddyite or haiweeite. Based on results of the calculations presented, adsorption processes involving uranium(VI) appear to control dissolved concentrations of this actinide in groundwater beneath the Pajarito Plateau.

3.1.5 Redox Conditions

This subsection presents a brief discussion on oxidation-reduction concepts with application to groundwater chemistry characterized during this investigation. Contaminants associated with treated Laboratory effluents that are stable in more than one oxidation state include plutonium(III, IV, V, and VI), uranium(IV and VI), technetium(IV and VII), iron(II and III), and chromium(III and VI). Other contaminants that can undergo reduction include perchlorate,

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molybdate, nitrate, RDX, and TNT. A group of contaminants that is stable in one oxidation state under the geochemical conditions that prevail in groundwater includes americium(III)-241, cesium(I)-137, strontium(II)-90, barium(II), boron(III), and tritium(I). Adsorption and precipitation reactions involving redox-sensitive contaminants are directly influenced by oxidation and reduction reactions. Under oxidizing conditions, species including uranium(VI), sulfate, nitrate, and perchlorate form soluble anions that are mobile in groundwater. Under reducing conditions, however, these species either precipitate from solution (uranium and sulfide minerals), transform (perchlorate) and/or adsorb onto aquifer materials (nitrogen-ammonium).

Oxidation-reduction (redox) reactions are very important in groundwater systems for controlling distributions of trace elements and are quite often mediated by a wide variety of microbes. Redox conditions for groundwater most often cannot be quantified with a single redox couple and oxidation-reduction potential (ORP) (Langmuir, 1997) because numerous couples are present and they differ with respect to kinetic reaction rates (Figure 3-9). Some couples are electrochemically reversible, including the iron(III)/iron(II) and hydrous ferric oxide/iron(II) pairs. However, most pairs are not reversible under normal groundwater conditions in the absence of microbes, including: dissolved oxygen/water, nitrogen (V)/nitrogen(0), nitrogen(V)/nitrogen(III), uranium(VI)/uranium(IV), sulfur(VI)/sulfur(-II), and carbon(IV)/carbon(0, -IV). General trends in redox chemistry, however, can be inferred based on distribution and concentration of redox-sensitive solutes such as iron and manganese, mineralogy of aquifer material, presence or absence of dissolved oxygen, knowledge of microbial populations, and presence of electron donors (reducing agents, reductants), and electron acceptors (oxidizing agents, oxidants).

Under natural or baseline conditions, groundwater under the Pajarito Plateau within perched intermediate zones and the regional aquifer is oxidizing. This is also generally true for alluvial groundwater, although DOC may enhance localized reducing conditions within wetlands occupying some canyon reaches. Naturally occurring and measurable concentrations of dissolved oxygen (DO) (1 to 9 ppm), sulfate (>2 ppm), and nitrate (typically 0.5 ppm) are characteristic of oxidizing conditions. Low concentrations of dissolved iron (<0.5 ppm) and manganese (<0.05 ppm) are also characteristic of oxidizing conditions. Under reducing conditions, concentrations of reduced forms of carbon (methane, hydrocarbons, carbohydrates), nitrogen (ammonium), and sulfur (hydrogen sulfide) would exceed concentrations of the oxidized forms. Iron and manganese reduction would also be observed under reducing conditions. Reducing conditions do not occur in normal groundwater beneath the Pajarito Plateau although they have been encountered in several R wells as a highly localized consequence of residual drilling fluids, as described by Longmire and Goff (2002) and Longmire (2002a, 2002b, 2002d, and 2002e) and Bitner et al. (2004) in detail.

3.1.6 Uranium Speciation

Chemical speciation has a direct control on mineral precipitation and adsorption processes. Special attention is given to uranium in this report because this actinide occurs naturally in groundwater and has also been processed at the Laboratory. Large variations in natural uranium concentrations are observed beneath the Pajarito Plateau and to the east in the Rio Grande Valley.

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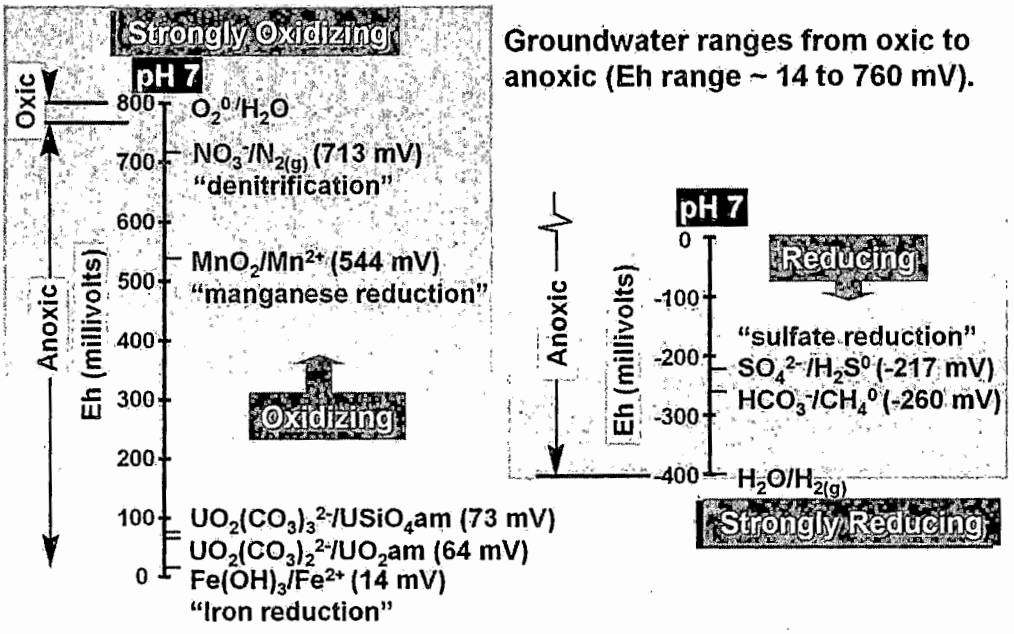

Figure 3-9. Selected oxidation-reduction couples in water at pH 7 and 25°C for the Pajarito Plateau and surrounding areas.

As uranium leaches from minerals and glass, it is stable as uranium(VI) under oxidizing conditions characteristic of aquifer systems beneath the Pajarito Plateau. Uranium(VI) forms strong complexes with bicarbonate and carbonate including $UO_2CO_3^0$, $UO_2(CO_3)_2^{2-}$, and $UO_2(CO_3)_3^{4-}$ (Langmuir 1997) above pH 6.

Figure 3-10 shows calculated distribution of uranium(VI) at Spring 9B discharging from the Cerros del Rio basalt east of the Laboratory. Dissolved concentrations of uranium are typically less than 0.2 µg/L at Spring 9B (LANL 1996a, 2000a, 2001a, 2002).The computer program MINTEQA2 (Allison et al., 1991) was used for the speciation calculations of Spring 9B. The aqueous complex, $UO_2(CO_3)_3^{4-}$ dominates above pH 8.4, whereas $UO_2(CO_3)_2^{2-}$ dominates between pH values of 6.6 and 8.4 at Spring 9B (Figure 3-10). Dissolved uranyl carbonate ($UO_2CO_3^0$) dominates between pH values of 5.0 and 6.6. Spectroscopic evidence has shown that $Ca_2UO_2(CO_3)_3^0$ significantly influences uranium(VI) speciation between pH values of 6 to 10 in calcium-rich uranium-mining waters (Bernhard et al., 2001). This complex may have relevance to groundwater east of the Rio Grande characterized by high calcium and carbonate alkalinity.

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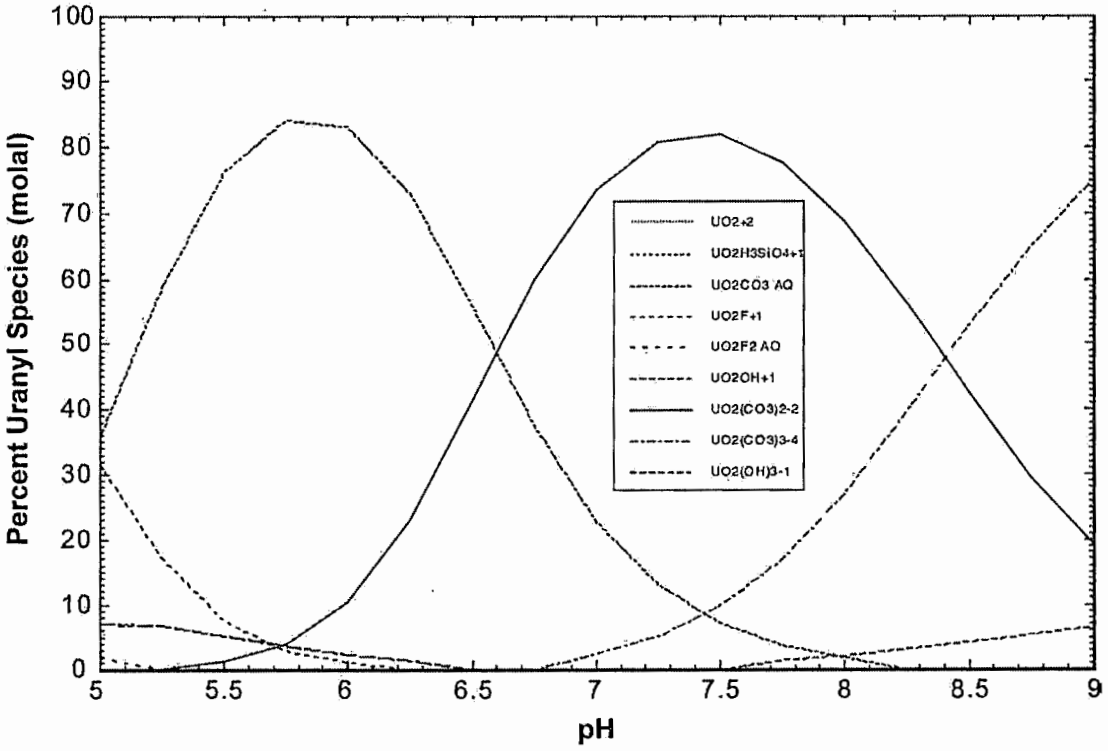

Figure 3-10. Results of speciation calculations for Spring 9B in White Rock Canyon using the computer program MINTEQA2. Log U(VI) = -9.26 molal (m), log F = -4.69 m, log H_4SiO_4 = -2.92 m, and log CO_3^{2-} = -3.07 m at 20.5°C.

Figure 3-11 shows total alkalinity versus uranium concentrations for 127 groundwater samples collected within the Rio Grande Valley near Pojoaque, New Mexico, contrasted with samples from the Pajarito Plateau. Formation of uranyl carbonate complexes has a direct control on the solubility of uranium(VI), leading to dissolved concentrations of uranium much greater than 10 µg/L observed in the Rio Grande Valley.

Uranium(IV) is stable in strongly reducing groundwater containing dissolved sulfide and reduced forms of DOC (Langmuir 1997). Calculations show that uranium(IV) in the form of $U(OH)_4^0$ is stable under reducing conditions below an Eh of –225 millivolts (mV) at pH 7, 25°C, and $10^{-3.0}$ M (61 mg/L) bicarbonate. Formation of uranium(IV) complexes is very unlikely to occur because natural groundwater at Los Alamos, New Mexico is oxidizing and uranium(VI) species are stable. However, in groundwater near Pojoaque uranium(IV) is inferred to be stable in the presence of hydrous ferric oxide reduction.

3.1.7 Summary of Geochemical Conceptual Model

It is important to understand geochemical processes and the natural water quality beneath the Pajarito Plateau, so that anthropogenic perturbations to the natural system can be identified and quantified. While the contaminants are at concentrations largely below regulatory standards or

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risk levels, they demonstrate the presence of pathways for groundwater flow and contaminant transport from the surface to deeper groundwater.

Natural groundwater (alluvial, intermediate, and regional aquifer) ranges from calcium-sodium bicarbonate composition within the Sierra de los Valles to a sodium-calcium bicarbonate composition east and northeast of the Laboratory. The Sierra de los Valles provides most of the recharge to groundwater beneath the Pajarito Plateau and groundwater in the recharge area has the lowest TDS of the overall flow system.

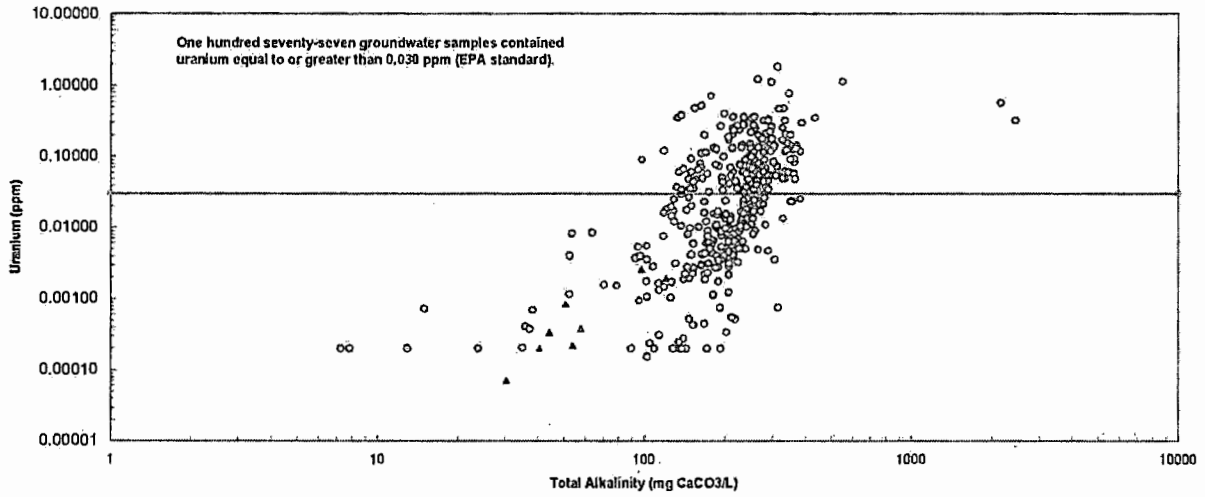

Figure 3-11. Total alkalinity (as carbonate) versus uranium concentrations in groundwater samples collected from the Rio Grande Valley and the Pajarito Plateau. Red triangles are from Pajarito Plateau and blue dots are from the Rio Grande Valley.

Along flow paths variation in solute concentration results from mixing of groundwaters, mineral precipitation (solute sink), mineral dissolution (solute source), and adsorption/desorption reactions. Calcium, sodium, and bicarbonate are the dominant major ion solutes in natural groundwater beneath the Pajarito Plateau and surrounding areas. Silica is the second most abundant solute found in surface water and groundwater within the Los Alamos area because of hydrolysis reactions taking place between soluble silica volcanic glass and water. Variations in groundwater trace element concentrations depend on solute residence time, speciation, and extent of water-rock interactions.

All of the mobile chemicals measured in perched intermediate zones and in the regional aquifer are stable as anions (perchlorate, nitrate, sulfate, chloride, uranium) or as neutral species (RDX, TNT, HMX, boron). Contaminants stable as cations (barium, americium-241, plutonium(V)-238, -239, -240, strontium-90, cesium-137) have migrated within alluvial groundwater and are infrequently detected in deeper groundwater.

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Groundwater within a discharge zone, at the end of groundwater flow paths, generally has the highest mineral or solute content and also represents the oldest water. Residence times of groundwater and chemical solutes increase both with depth and from west to east across the Pajarito Plateau within each groundwater zone. The oldest groundwater residence times within the regional aquifer are on the order of several thousand to tens of thousands of years, based on carbon-14 dating and on flow and transport models.

Geochemical processes that affect the groundwater chemistry include the following:

- ***Precipitation/Dissolution***: Different reactive minerals and amorphous solids precipitate or dissolve and can control the major ion composition of groundwater. As groundwater flows through perched intermediate zones and the regional aquifer, chemical and mineralogical compositions of reactive phases including silica glass change over time. For example, silica glass is the most soluble component of the aquifer material reacting with groundwater to form clay minerals, including kaolinite and smectite. Precipitation reactions serve as a sink for removing uranium from solution.
- ***Adsorption:*** Dissolved species interact with surfaces of aquifer material coated with hydrous ferric oxide, manganese dioxide, clay minerals, or other adsorbents, often resulting in the release of adsorbed species via replacement reactions. Hydrous ferric oxide is an important adsorbent present in different aquifer materials beneath the Pajarito Plateau. Other common adsorbents of metals include smectite, calcite, manganese oxide, and solid organic carbon. Downgradient from Laboratory discharge points, adsorption processes are considered to dominate over mineral precipitation for continual removal of metals and radionuclides from alluvial groundwater. Adsorption processes involving uranium(VI) appear to control dissolved concentrations of this actinide in groundwater beneath the Pajarito Plateau.
- ***Redox Conditions***: Under natural or baseline conditions, groundwater under the Pajarito Plateau within alluvial, perched intermediate zones, and the regional aquifer is oxidizing. Adsorption and precipitation reactions involving redox-sensitive contaminants are directly influenced by oxidation and reduction reactions. Under oxidizing conditions, species including uranium(VI), sulfate, nitrate, and perchlorate form soluble anions that are semimobile in groundwater. Uranium(VI) partly adsorbes onto ferric oxyhydroxide and is semimobile in groundwater between a pH range of 7 to 8.5, typically observed in groundwaters of the Pajarito Plateau. Under reducing conditions, however, these species either precipitate from solution (uranium and sulfide minerals), transform (perchlorate) and/or adsorb onto aquifer materials (nitrogen-ammonium).
- ***Chemical Speciation***: has a direct control on mineral precipitation and adsorption processes. Formation of uranium(IV) complexes is very unlikely to occur because natural groundwater at Los Alamos, New Mexico is oxidizing and uranium(VI) species are stable.

3.2 Contaminant Distributions and Transport

This section describes the sources, presence, and trends through time of chemical constituents in groundwater originating from anthropogenic (principally LANL) sources. The movement rates and distribution of these chemical constituents give an indication of groundwater flow paths and flow mechanisms over time. Appendix 3-A provides a description and map of each canyon, arranged by watershed, because this framework highlights the connection between surface liquid discharge sources and their effects on shallow and deeper groundwater chemistries.

In this section anthropogenic chemical constituents found in groundwater are divided into two classes: contaminants and other anthropogenic chemical constituents. Contaminants in groundwater are chemicals found at concentrations near or exceeding either regulatory standards or, where no standards exist, exceeding EPA screening levels of either hazard index (HI) of 1 or excess cancer risk of 10^{-5}. For chemicals with no standards, the EPA Region VI tap water screening levels were used (http://www.epa.gov/earth1r6/6pd/rcra_c/pdn/screen.htm). For cancer-causing substances, the Region VI tap water screening levels are at a risk level of 10^{-6}, therefore, 10 times these values were used to screen for a risk level of 10^{-5}. A hazard index value of 1 or less indicates that no (noncancer) adverse human health effects are expected to occur.

Anthropogenic chemical constituents other than contaminants are found at lower concentrations, although some of these constituents may have been contaminants (that is, at higher concentrations) in the past.

Table 3-1 summarizes the anthropogenic constituent observations in alluvial, intermediate, and regional aquifer groundwater. Information on Table 3-1 indicates that most canyons with anthropogenic constituents in alluvial groundwater also have anthropogenic constituents in the intermediate (if present) and the regional aquifer. The water quality impacts of effluent releases on alluvial groundwater extend to perched groundwater at depths of a few hundred feet beneath these canyons. The contaminated perched groundwater bodies are separated from the regional aquifer by hundreds of feet of dry rock, and in these wet canyons recharge from the shallow perched groundwater occurs in a time frame of decades. Nevertheless, the magnitude of water quality impacts on the regional aquifer are quite low.

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Table 3-1.
Summary of Factors Influencing Contaminant Distributions in Groundwater at Los Alamos National Laboratory

Canyon	Presence of Contaminant Sources	Water Inputs		Hydrogeologic Controls			Observed Contaminants in Groundwater		
		Natural	Anthropogenic	Enhanced Infiltration	Potential Lateral Pathways	Flow Field Modification	Alluvial	Intermediate	Regional Aquifer
Guaje	Minor dry sources	Low	None	Puye Formation exposed in canyon bottom	None	Near Guaje wellfield	None	No intermediate groundwater	None
Bayo	Previous sources removed; little present source	Low	Low	None, basalts not present in vadose zone	None, basalts not present in vadose zone		No alluvial groundwater present	No intermediate groundwater present	None
Pueblo (including Acid Canyon)	Multiple, liquid sources	Low	High, POTW effluent-supported stream	Yes, associated with faults	No, basalts not present in vadose zone	O-1 located in Pueblo Canyon	Nitrate, boron, tritium (past); Strontium-90	Tritium (TW-2A); nitrate (TW-1A)	Perchlorate (O-1), tritium (O-1, R-4), nitrate (TW-1, O-1, R-4)
Los Alamos (including DP)	Multiple liquid sources	Moderate	High, effluent discharges	Yes, Cerros del Rio basalt exposed in canyon bottom at R-9	Yes, Cerros del Rio basalt present in vadose zone	O-4 located in Los Alamos Canyon	Strontium-90; molybde-num, tritium, plutonium-239, -240, -248	Tritium (LADP-3, R-9i,R-6i); nitrate (R-6i)	Tritium (TW-3, R-9, R-6)
Sandia	Multiple liquid sources	Low	High, effluent discharges	Yes, Cerro Toledo Member exposed in canyon bottom near PM-1	Yes, Cerros del Rios basalts within shallow vadose zone	PM-1 and PM-3 located in Sandia Canyon	Alluvial groundwater not present	Tritium (R-12, R-7), nitrate (R-12)	Tritium (R-12, R-11), nitrate (R-12, R-11)

Table 3-1.
Summary of Factors Influencing Contaminant Distributions in Groundwater at Los Alamos National Laboratory (continued)

Canyon	Presence of Contaminant Sources	Water Inputs		Hydrogeologic Controls			Observed Contaminants in Groundwater		
		Natural	Anthropogenic	Enhanced Infiltration	Potential Lateral Pathways	Flow Field Modification	Alluvial	Intermediate	Regional Aquifer
Mortandad	Multiple liquid sources	Low	High, effluent discharges	Thick pockets of alluvium; sediment ponds	Extensive Cerros del Rio basalt in vadose zone	Within PM wellfield	Americium-241, plutonium-238, plutonium-239, -240, strontium-90, tritium, nitrate, perchlorate, fluoride	Tritium (MCOBT-4.4, R-15), nitrate (MCOBT-4.4), perchlorate (MCOBT-4.4, R-15)	Tritium (R-15, R-28), nitrate (R-15, R-28), perchlorate (R-15)
Canada del Buey	Major dry sources; minor liquid sources	None	None on LANL property; effluent from White Rock POTW	No, canyon bottom underlain by Bandelier Tuff	Extensive Cerros del Rio basalt close to surface	Within PM wellfield	Gross alpha, gross beta	No intermediate perched groundwater is present	None
Pajarito Canyon	Major dry sources	High	Moderate	Yes, Cerros del Rio basalt exposed at the surface from west of R-23 to Rio Grande	Yes, extensive Cerros del Rio basalt	Yes, within PM wellfield	Metals, radio-nuclides, HE, VOCs and anions	HE (springs)	None
Water	Multiple dry and liquid sources in upper part of canyon	High	High	Yes, Cerros del Rio basalt exposed in lower part of canyon	Yes, extensive Cerros del Rio basalts in lower canyon	None	HE, barium		

Table 3-1.
Summary of Factors Influencing Contaminant Distributions in Groundwater at Los Alamos National Laboratory (continued)

Canyon	Presence of Contaminant Sources	Water Inputs		Hydrogeologic Controls			Observed Contaminants in Groundwater		
		Natural	Anthropogenic	Enhanced Infiltration	Potential Lateral Pathways	Flow Field Modification	Alluvial	Intermediate	Regional Aquifer
Cañon de Valle	Multiple dry and liquid sources in upper part of canyon	High	High	No, underlain by thick Bandelier Tuff	Yes, Cerro Toledo interval in vadose zone	None	Barium, HE, perchlorate	HE, barium,	Tritium (R-25), HE(?) (R-25)
Potrillo/ Fence	Minor dry sources	Low	None	No, underlain by Bandelier Tuff	Yes, extensive Cerros del Rio basalt in vadose zone	None	No, alluvial groundwater not present	No, intermediate perched groundwater not present	None
Ancho	Minor dry and liquid sources	Low in upper portion; moderate in lower portion	Minor, septic systems	No, underlain by Bandelier Tuff	No	None	None	No, intermediate perched groundwater is not expected	HE(?) (Ancho Spring)
Chaquehui	Minor dry and liquid sources	Low in upper portion; moderate in lower portion	Low	Yes, basalts exposed at surface in canyon	Yes, extensive Cerros del Rio basalts present in vadose zone	None	No, alluvial groundwater not present	No, perched intermediate groundwater not expected	
Frijoles	No LANL sources	High	None	Yes, basalts exposed in canyon bottom	Yes, basalts in vadose zone	None	No data	No data	
White Rock	No LANL sources	High	Low	Yes, basalts exposed in canyon bottom	Yes, basalts in vadose zone	None	No alluvial groundwater present	No intermediate groundwater is present	Tritium, nitrate (Springs 1, 3, 3A, 4, 5);

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Table 3-1.
Summary of Factors Influencing Contaminant Distributions in Groundwater at Los Alamos National Laboratory (continued)

Canyon	Presence of Contaminant Sources	Water Inputs		Hydrogeologic Controls			Observed Contaminants in Groundwater		
		Natural	Anthropogenic	Enhanced Infiltration	Potential Lateral Pathways	Flow Field Modification	Alluvial	Intermediate	Regional Aquifer
									perchlorate, uranium (Spring 2B)

3.2.1 Contaminant and Constituent Sources

Table 3-1 indicates the factors that have primary influence on distribution of anthropogenic constituents in groundwater. The first factor is the presence of upgradient sources of these constituents. The sources affecting groundwater at the Laboratory are mainly liquid effluents rather than solid waste disposal or other activities. Since the 1940s, liquid effluent disposal by the Laboratory has degraded water quality in the shallow perched groundwater that underlies a few canyons (Figure 3-12). Drainages that received significant radioactive effluent discharges are Mortandad Canyon and Pueblo Canyon from its tributary Acid Canyon, and Los Alamos Canyon from its tributary DP Canyon. Rogers (2001) and Emelity (1996) summarize radioactive effluent discharge history at the Laboratory. Water Canyon, its tributary Cañon de Valle, and Pajarito Canyon have received effluents produced by HE processing and experimentation (Glatzmaier 1993, Martin 1993, LANL, 1998a). Over the years, Los Alamos County has operated three sanitary treatment plants in Pueblo Canyon (LANL, 1981). Only the Bayo plant is currently operating. The Laboratory has also operated numerous sanitary wastewater treatment plants, as shown in Figure 3-12.

Solid waste disposal has less potential to affect groundwater. Most solid waste disposal sites are located on mesa tops where there is little natural or artificial percolation to carry anthropogenic constituents to groundwater. Canyons that have little or no source of anthropogenic constituents (Guaje, Bayo, Potrillo, Fence, Ancho, Chaquehui, and Frijoles) have no anthropogenic constituents in groundwater (Table 3-1). Canyons that had small volume liquid sources or major dry sources are Cañada del Buey and Pajarito Canyon (Table 3-1).

3.2.2 Water Inputs

The second factor influencing anthropogenic constituent distribution in groundwater shown on Table 3-1 is water input, either natural or anthropogenic. The amount of water in a canyon system is a determining factor for transporting anthropogenic constituents. In most cases where Laboratory anthropogenic constituents are found at depth, the setting is one of the following:

- canyons where natural water input is high (Pajarito Canyon, Water Canyon, and Cañon de Valle);
- canyons where anthropogenic water input is high (Pueblo, Los Alamos, Sandia, Mortandad Canyons); or
- mesa-top sites where large amounts of liquid effluent have been discharged (such as retention ponds or outfalls) (mesa tops bounded by Cañon de Valle and Water Canyon).

The presence of water, either natural or from the discharge of effluents to canyons or mesa-top locations in the Laboratory's semiarid setting initiates or increases downward percolation of water. Even under unsaturated flow conditions, this percolation may move significant volumes of water to the regional aquifer within a few decades.

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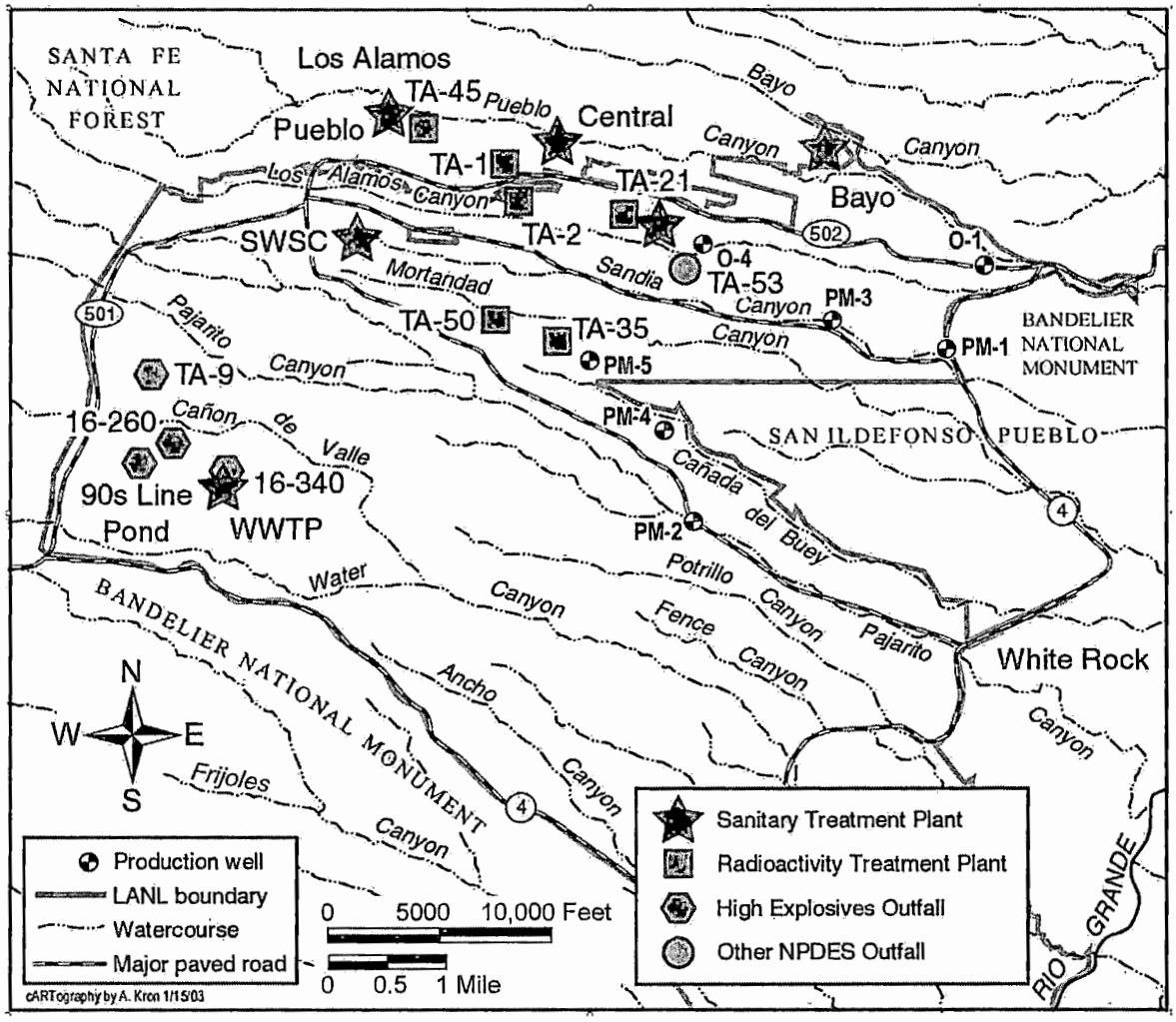

Figure 3-12. Major liquid release sources that have potentially affected groundwater at Los Alamos National Laboratory. Most of these sources are now inactive.

3.2.3 Hydrogeologic Controls

The third factor that contributes to anthropogenic constituent distribution consists of hydrogeologic controls on groundwater pathways and travel rates (Table 3-1). The controls considered most important in influencing contaminant distribution and transport are infiltration at the surface and transport of contaminants in alluvial groundwater, pathways in the vadose zone and transport through intermediate perched groundwater, and flow field modification in the regional aquifer.

The movement of groundwater contaminants is best seen through the distribution of conservative (that is, non-reactive) chemical species. Under most conditions, compounds like RDX, tritium, perchlorate, and nitrate move readily with the groundwater. In many settings, chemical reactions do not retard the movement of these compounds or decrease their concentrations, although the

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activity of tritium does decrease due to radioactive decay. For some compounds or constituents (uranium, strontium-90, barium, some HE compounds, and solvents) movement is slowed or their concentrations are decreased by adsorption or cation exchange, precipitation or dissolution, chemical reactions like oxidation/reduction, or radioactive decay. Other constituents (americium-241, plutonium, and cesium-137) are nearly immobile because they are strongly adsorbed onto sediment particles.

3.2.3.1 Infiltration Rate and Transport in Alluvial Groundwater

The first hydrogeologic control, infiltration rate, affects the movement of anthropogenic constituents from the surface to groundwater. As described in Section 2.5.3, undisturbed Bandelier Tuff has a very low infiltration rate. Areas that have other geologic units (particularly basalt units) exposed in the canyon bottom have higher, or enhanced, infiltration rates. Anthropogenic alterations can also enhance infiltration, for example sediment ponds in Mortandad Canyon and ponds in the Cañon de Valle watershed.

The alluvial groundwater present in several canyons has a small volume relative to the annual volume of runoff or effluents, does not extend beyond the LANL boundary, and is generally completely refreshed by recharge on a time scale of about a year (Section 2.4.1). This rapid turnover of groundwater volume means that, rather than increasing over time, the groundwater concentrations of conservative compounds are controlled by concentrations in recharge sources such as effluent. The principal compounds that accumulate or persist in alluvial groundwater are those, such as strontium-90, that are not highly mobile. Strontium-90 has accumulated mainly in the canyon floor sediments, from which it slowly but continually leaches into the groundwater due to cation exchange, maintaining a nearly steady concentration. In some cases, such as RDV in Cañon de Valle, mobile contaminants also persist, possibly due to their continuing presence in water source regions.

A study by Purtymun et al. (1977) documented this rapid turnover of groundwater and solutes in Mortandad Canyon. Purtymun showed that the mass of various solutes in Mortandad Canyon alluvial groundwater was a fraction of the total solute mass that had been discharged into the canyon over the history of effluent releases. To a first approximation, the entire body of alluvial groundwater in Mortandad Canyon is chemically well mixed, and variations in concentrations of specific sources propagate throughout the groundwater system in times of about a year. Concentrations are at times higher for wells nearest to the outfall, partly because of variable mixing of effluent with ground and surface water. Concentrations appear to decrease downstream from the outfall due to mixing and the occasional higher values in upstream wells. While concentrations vary between wells, overall concentrations of the constituents are generally similar throughout the alluvial groundwater body at a given time.

Rather than a contaminant plume existing within the alluvial groundwater, a relatively small volume of groundwater (with a volume of about 20,000 cubic meters) is completely replenished annually by recharge water (with a volume of about 90,000 to 160,000 cubic meters) which includes the discharges from RLWTF at TA-50. Purtymun et al. (1977) attributed the losses of water to evapotranspiration and infiltration into the underlying tuff. The composition of the alluvial groundwater is a combination of input from the TA-50 facility and other sources such as

runoff and other Laboratory discharges. The groundwater composition nearest the TA-50 discharge point shows short term (weekly or daily) variations related to the TA-50 outfall, but over the longer term (annually), these variations are spread throughout the alluvial groundwater body.

Data for conservative constituents (tritium, nitrate) in alluvial groundwater support the conceptual model that this groundwater has a short residence time and conservative contaminants do not accumulate in alluvial groundwater. The time trend pattern for these contaminants shows a high level when they were being released, followed by a sharp decline in concentration to nearly nondetectable levels when the source is eliminated. Past values of tritium and nitrate in alluvial groundwater in DP, Los Alamos, Pueblo, and Mortandad Canyons exceeded the 20,000 pCi/L MCL (Rogers 1998). Such high values do not occur today in these locations because of improvement in effluent quality, and also possibly because of deeper infiltration of older effluents.

In Pueblo Canyon, tritium activity in alluvial groundwater was 15,000 pCi/L in the early 1970s, nearly a decade after effluent discharges ceased; today it is barely detectable (Figure 3-13). Similarly, alluvial groundwater tritium values in DP and Los Alamos Canyons exceeded 300,000 pCi/L in the late 1960s, but have been barely detectable for the past decade (Figure 3-14). TA-21 effluent caused tritium levels in surface water and alluvial groundwater in and downstream of DP Canyon to reach values up to 5,000,000 pCi/L, or 250 times the MCL (Figure 3-14, Figure 3-15). The tritium levels decreased greatly after discharges ceased. In Los Alamos Canyon above the mouth of DP Canyon, the Omega West Reactor cooling line leaked water containing tritium from 1956 to 1993. As a result of this leak, tritium activity in alluvial groundwater remained at values around 10,000 pCi/L or half of the MCL. Once the leak was discovered and shut off, tritium levels in Los Alamos Canyon water returned to background. In Mortandad Canyon alluvial groundwater tritium activities often exceeded 300,000 pCi/L and even reached 2,000,000 pCi/L, but have fallen below the MCL since the RLWTF adopted effluent limits in 2001 (Figure 3-15, Figure 3-16). At the end of 2000, the RLWTF adopted a voluntary goal of having tritium activity in its effluent below 20,000 pCi/L, and tritium activity in the effluent dropped below that in 2001 and was 10,400 pCi/L in 2003. Tritium activity in alluvial groundwater downgradient of the facility has dropped correspondingly, with a maximum value of 8,770 pCi/L in 2003.

Nitrate levels in Pueblo Canyon surface water and groundwater follow a strong downward trend similar to those for tritium. Nitrate has been discharged from Laboratory radioactive liquid waste effluents and Los Alamos County sanitary wastewater effluent (Figure 3-17, Figure 3-18). The highest values were found in surface water in the 1950s and 1960s, related to both types of sources. With decommissioning of the radioactive outfall in 1964 and moving the sanitary discharge downstream to the Bayo treatment plant, less water and less nitrate have been present in the upper portion of the drainage in recent years. Nitrate in discharges into DP Canyon from TA-21 caused surface water and alluvial groundwater concentrations to exceed 100 mg/L (nitrate as nitrogen), or 10 times the MCL, until discharges ceased in 1986 (Figure 3-18, Figure 3-19). Nitrate concentrations have returned to background since discharges ended. In Mortandad Canyon nitrate (as N) concentrations in alluvial groundwater have generally mirrored the concentration in RLWTF effluent (Figure 3-18, Figure 3-20). The nitrate concentration in the

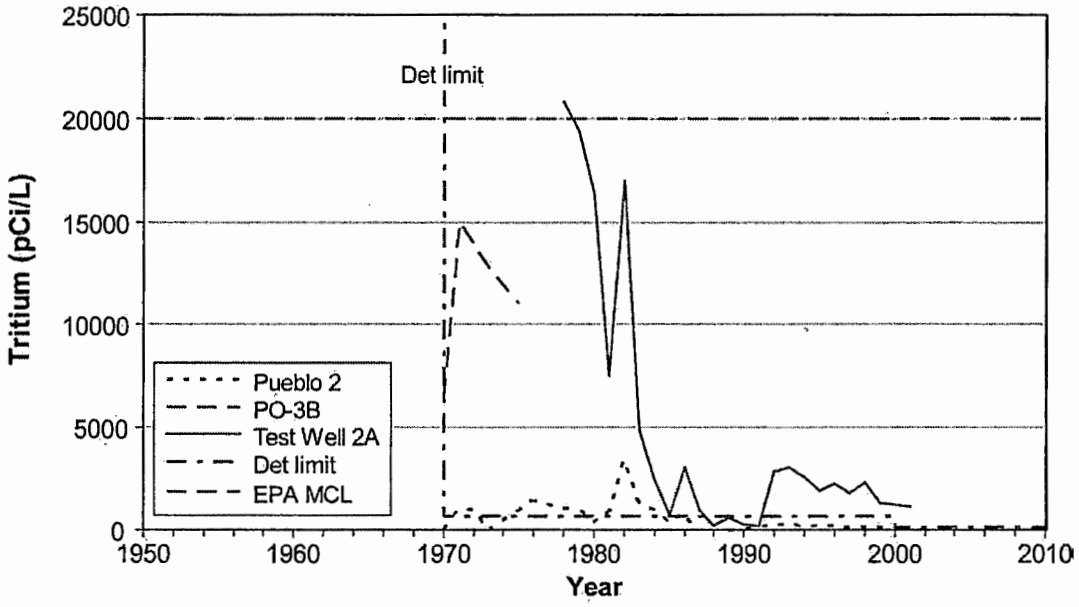

Figure 3-13. Tritium histories in Pueblo Canyon surface water and alluvial and intermediate groundwater zones. Data are annual averages of all results including nondetects; note that detection limits have varied greatly through time.

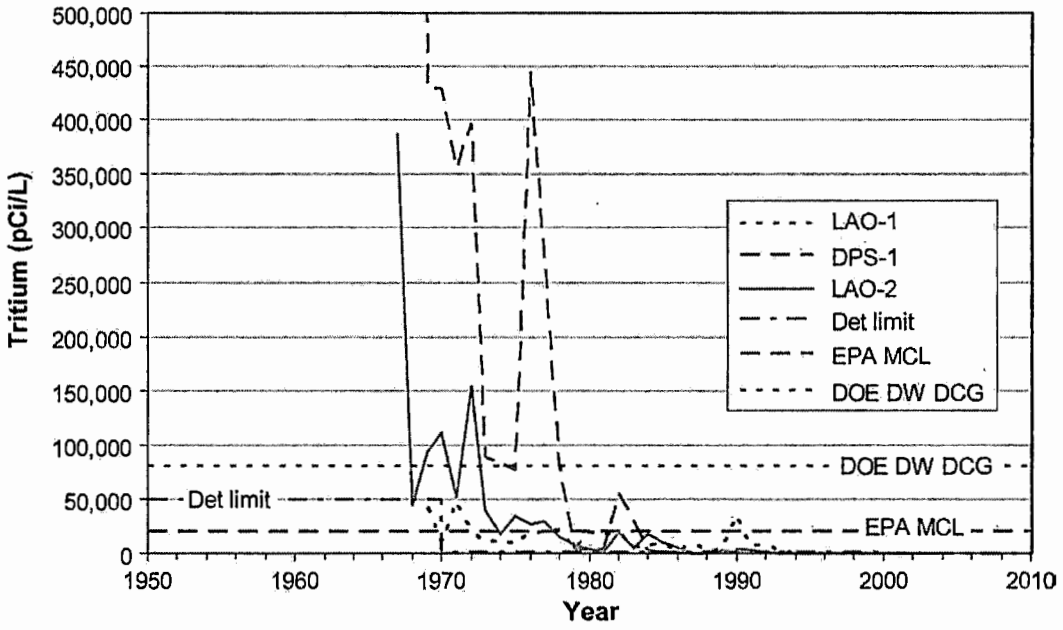

Figure 3-14. Tritium histories in DP and Los Alamos Canyon surface water and alluvial groundwater. Data are annual averages of all results including nondetects; note that detection limits have varied greatly through time.

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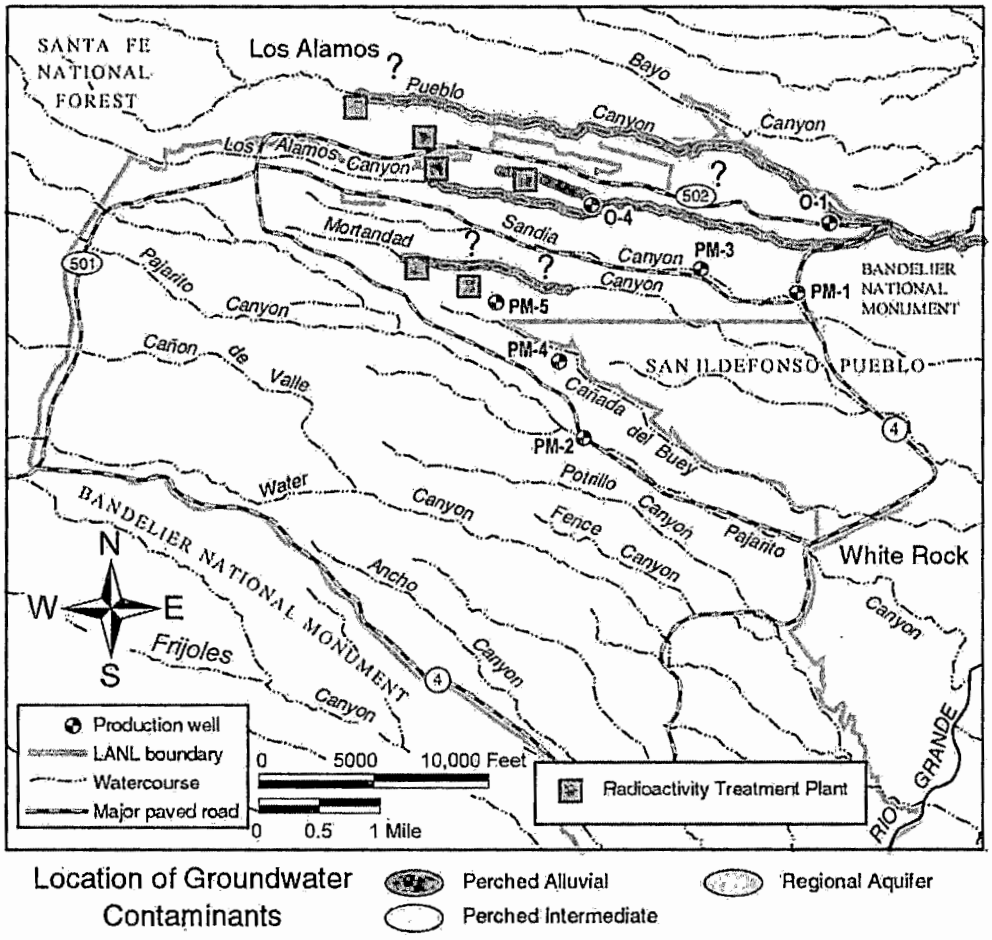

Figure 3-15. Location of inferred past extent of groundwater contamination by tritium above the 20,000 pCi/L EPA MCL. No groundwater tritium exceeded this value in 2003. Different colors indicate the affected groundwater zones. The extent of intermediate groundwater and regional aquifer contamination is based on a limited number of wells; question marks on the maps indicate where contaminant extent is inferred, not necessarily substantiated.

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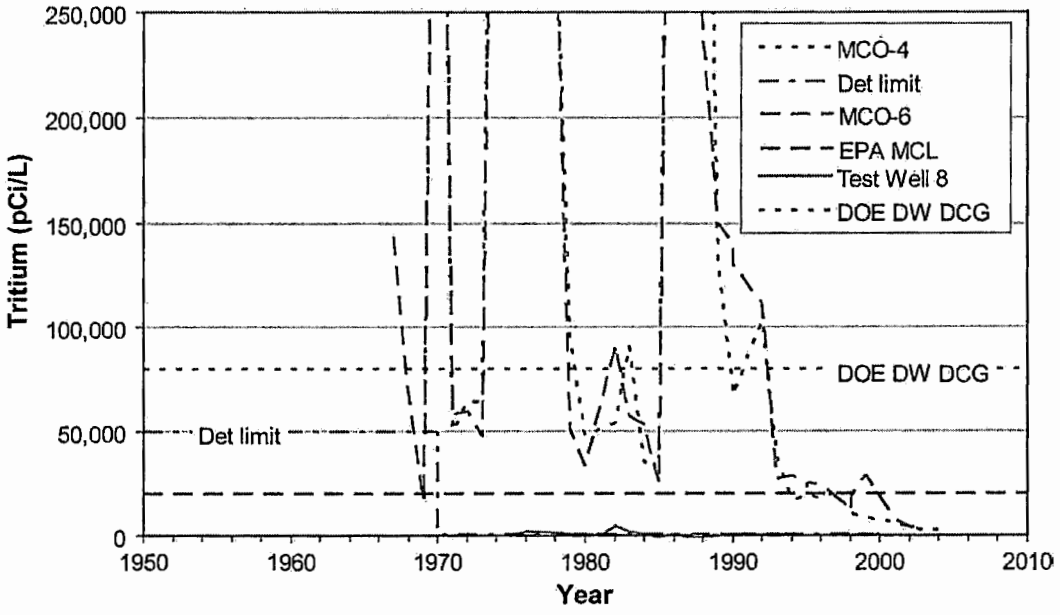

Figure 3-16. Tritium histories in Mortandad Canyon alluvial groundwater and the regional aquifer. Data are annual averages of all results including nondetects; note that detection limits have varied greatly through time.

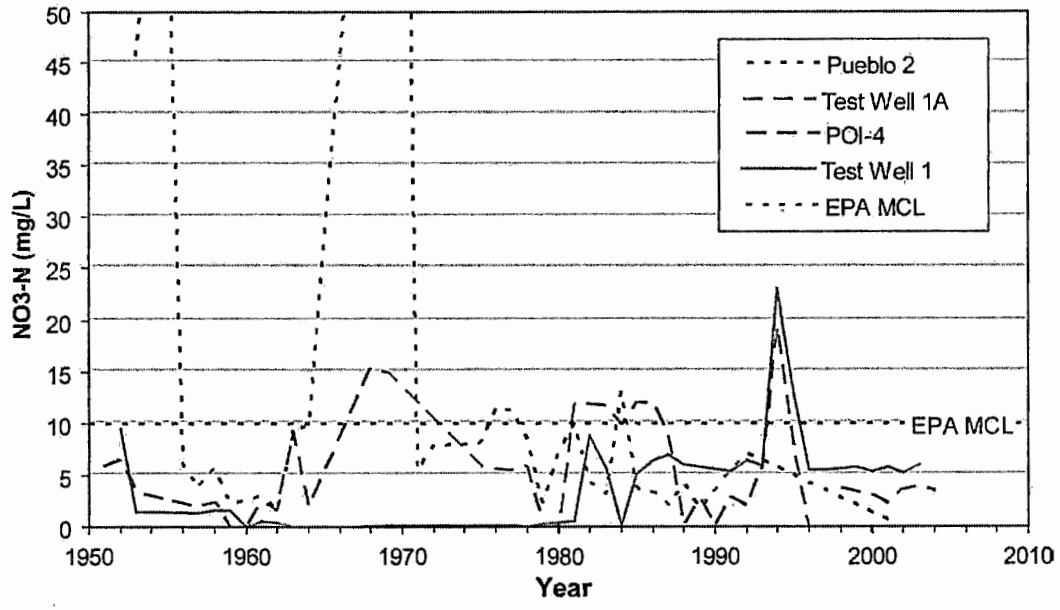

Figure 3-17. Nitrate histories in Pueblo Canyon surface water, alluvial and intermediate groundwater zones, and the regional aquifer. Data are annual averages of all results.

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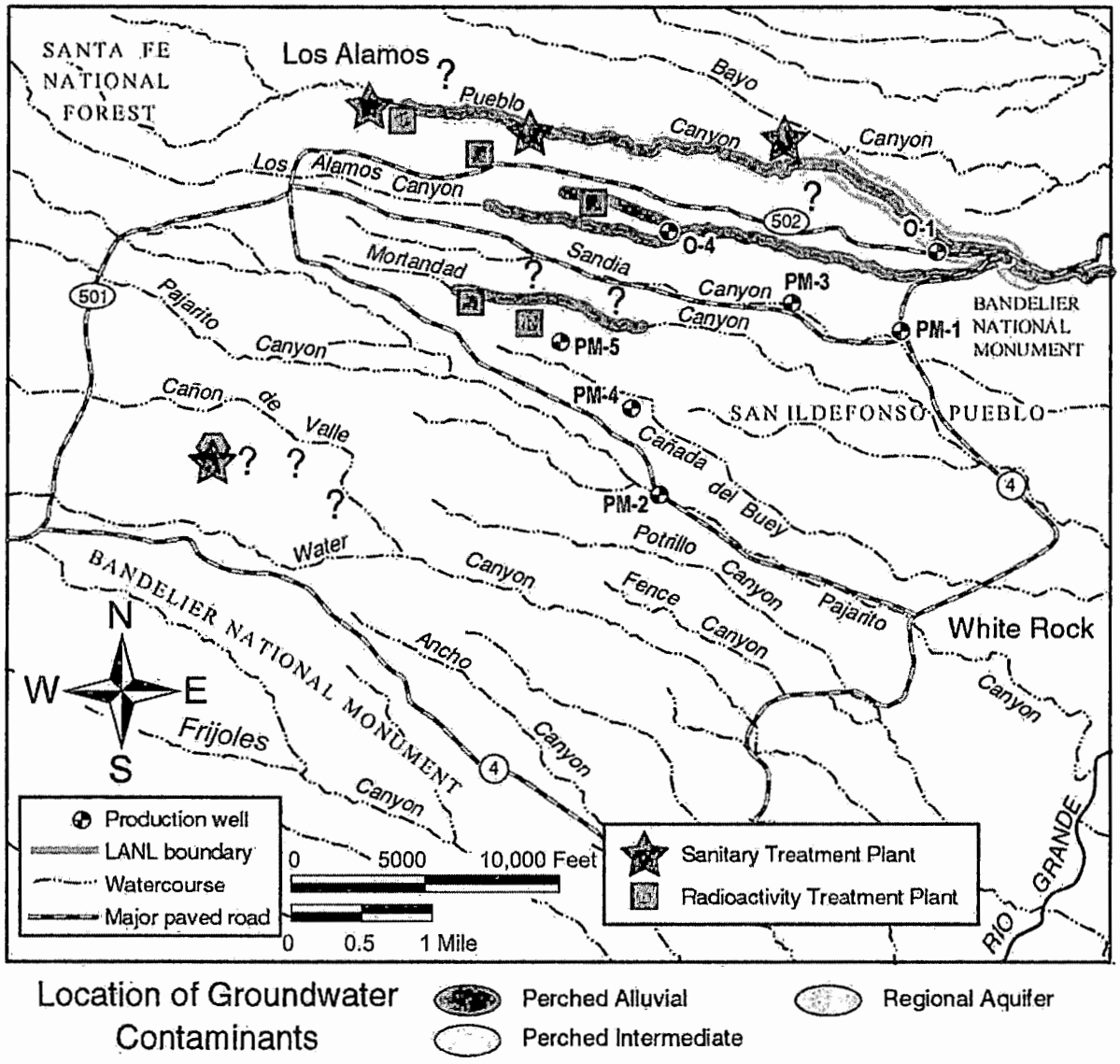

Figure 3-18. Location of inferred past extent of groundwater contamination by nitrate (as nitrogen) above the 10 mg/L EPA MCL. Only intermediate perched groundwater in Mortandad Canyon exceeded this level in recent years. Different colors indicate the affected groundwater zones. Along canyons, the extent of alluvial groundwater contamination lateral to the canyon is not to scale: contamination is confined to the alluvium within the canyon bottom and is narrow at the map scale. The extent of intermediate groundwater and regional aquifer contamination is based on a limited number of wells; question marks on the maps indicate where contaminant extent is inferred, not necessarily substantiated.

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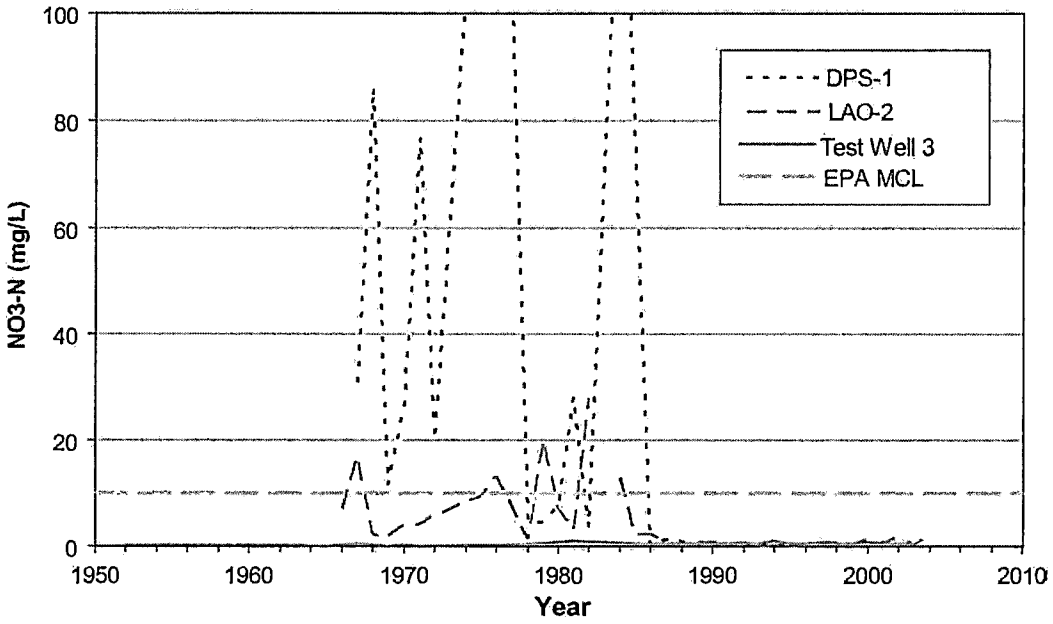

Figure 3-19. Nitrate histories in DP and Los Alamos Canyon surface water, alluvial groundwater, and the regional aquifer. Data are annual averages of all results.

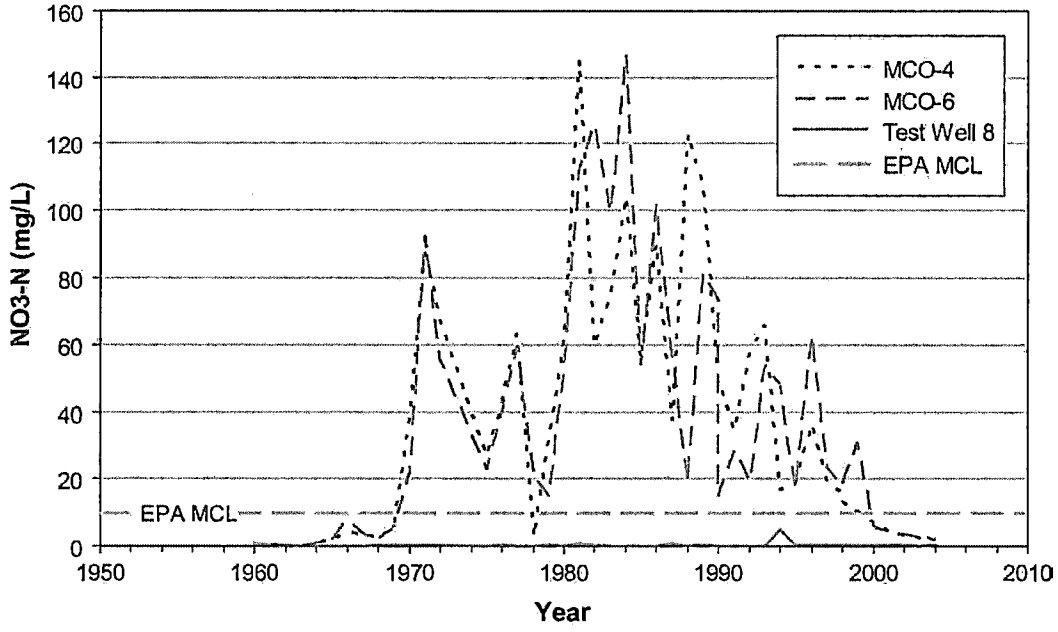

Figure 3-20. Nitrate histories in Mortandad Canyon alluvial groundwater and the regional aquifer. Data are annual averages of all results.

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effluent decreased in 1999 due to improved treatment in the RLWTF, and alluvial groundwater concentrations have fallen below the New Mexico Groundwater Standard of 10 mg/L as a result.

The distribution of perchlorate indicates where effluent releases have occurred in canyons (Figure 3-21). Perchlorate history in Mortandad Canyon shows the rapid decrease in perchlorate after the source was eliminated (Figure 3-22). The perchlorate concentration in the effluent decreased in 2002 due to improved treatment in the RLWTF, and alluvial groundwater concentrations have fallen significantly as a result.

Data for adsorbing constituents (strontium-90, plutonium-239, -240) support the conceptual model of contaminant adsorption onto alluvial sediments. The adsorbing contaminants decline in concentration when the source is cut off, followed by maintenance of a fairly constant low concentration in the groundwater due to cation exchange. The highest measured strontium-90 activity was about 500 pCi/L in Acid Canyon surface water in 1960. With no present source, levels have dropped dramatically and strontium-90 is now seen only at low activities, below 1 pCi/L in alluvial groundwater (Figure 3-23).

In Los Alamos Canyon is strontium-90 contamination in surface water and alluvial groundwater derived from reactor sources at TA-2 and effluent discharges from TA-21 (Figure 3-24). The strontium-90 activity in DP Canyon surface water reached 28,600 pCi/L. There is no present source, and activities dropped greatly after discharges ceased. However, strontium-90 persists in alluvial groundwater at levels above the EPA MCL of 8 pCi/L due to the large inventory in alluvial sediment, which moves to the groundwater by cation exchange (Figure 3-24). Effects of Manhattan Project releases in upper Los Alamos Canyon cause plutonium-239, -240 activity in alluvial groundwater to remain at about 25% of the DOE 4 mrem drinking water derived concentration guide (DCG) of 1.2 pCi/L (Figure 3-25). Discharges from TA-21 resulted in plutonium-239, -240 activity in surface water much above the DOE 4 mrem DCG, even exceeding the 100 mrem DCG of 30 pCi/L in the late 1960s. Plutonium activity decreased substantially with the end of discharges in 1986, but is still occasionally detected in surface water and alluvial groundwater below the former outfall. In Mortandad Canyon the discharge from the RLWTF creates a localized area of alluvial groundwater where strontium-90 persists at levels above the 8-pCi/L EPA drinking-water MCL (Figure 3-26). The radionuclides plutonium-238; plutonium-239, -240; and americium-241 are also present above the 4-mrem DOE DCG for drinking water (Figure 3-27).

3.2.3.2 Vadose Zone Pathways and Transport in Intermediate Groundwater

A hydrogeologic control on movement of anthropogenic constituents through the vadose zone is the presence of geologic units that can act as pathways. In general, these are units that are conducive to perching groundwater and forming intermediate perched groundwater. The water quality impacts from effluent releases extend in a few cases to intermediate perched groundwater at depths of a few hundred feet beneath these canyons. Because the contaminated alluvial groundwater bodies are separated from the intermediate perched groundwater by hundreds of feet of dry rock, pathways within the vadose zone are likely present in those canyons.

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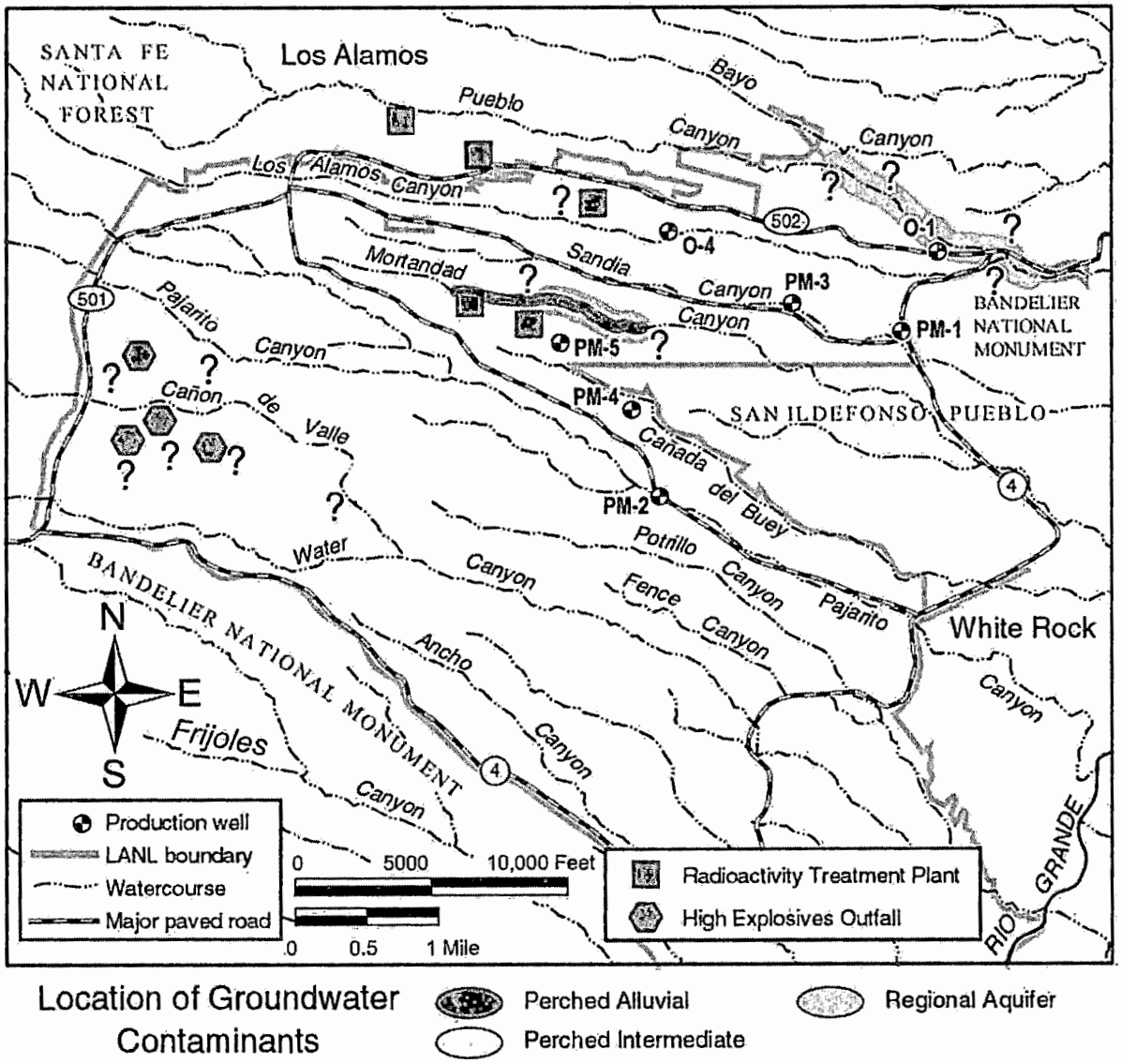

Figure 3-21. Location of groundwater contamination by perchlorate above the 3.7 ppb EPA Region VI risk level. Different colors indicate the affected groundwater zones. The extent of intermediate groundwater and regional aquifer contamination is based on a limited number of wells: question marks on the maps indicate where contaminant extent is inferred, not necessarily substantiated.

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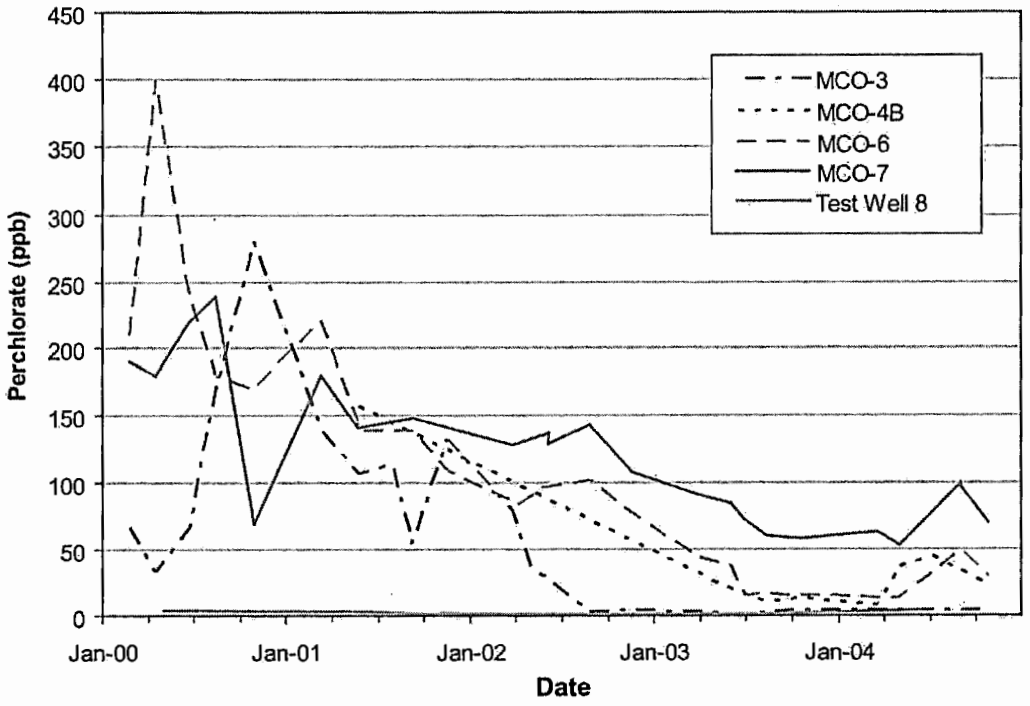

Figure 3-22. Perchlorate histories in Mortandad Canyon alluvial groundwater. All data points are shown.

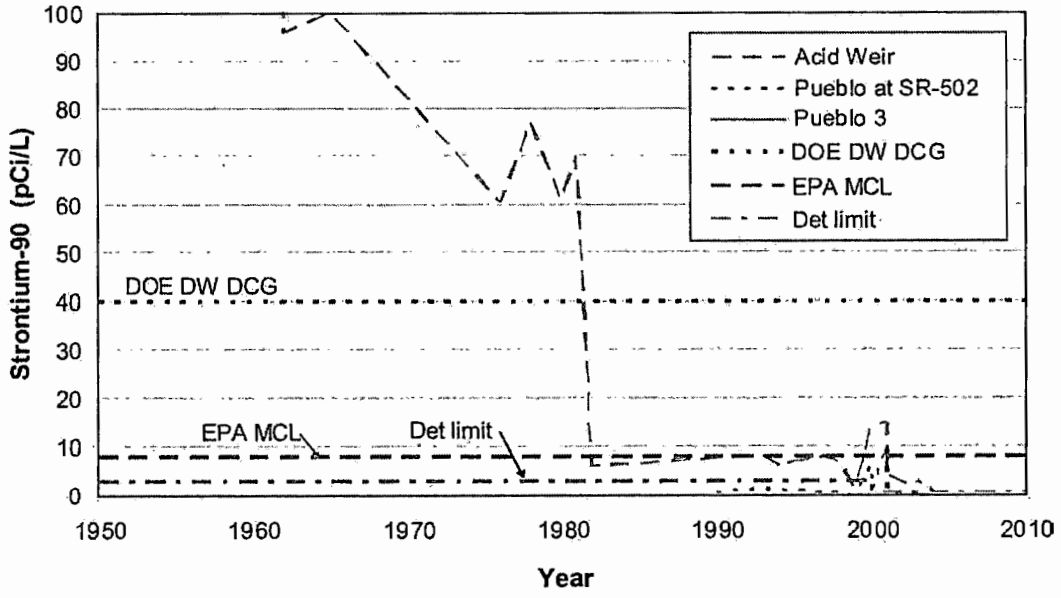

Figure 3-23. Strontium-90 histories in Acid and Pueblo Canyon surface water. The surface water data incorporate the longest record of strontium-90 and the highest values in these canyons; few strontium-90 detections have occurred in groundwater in these canyons. Data are annual averages of all results including nondetects; note that detection limits have varied greatly through time.

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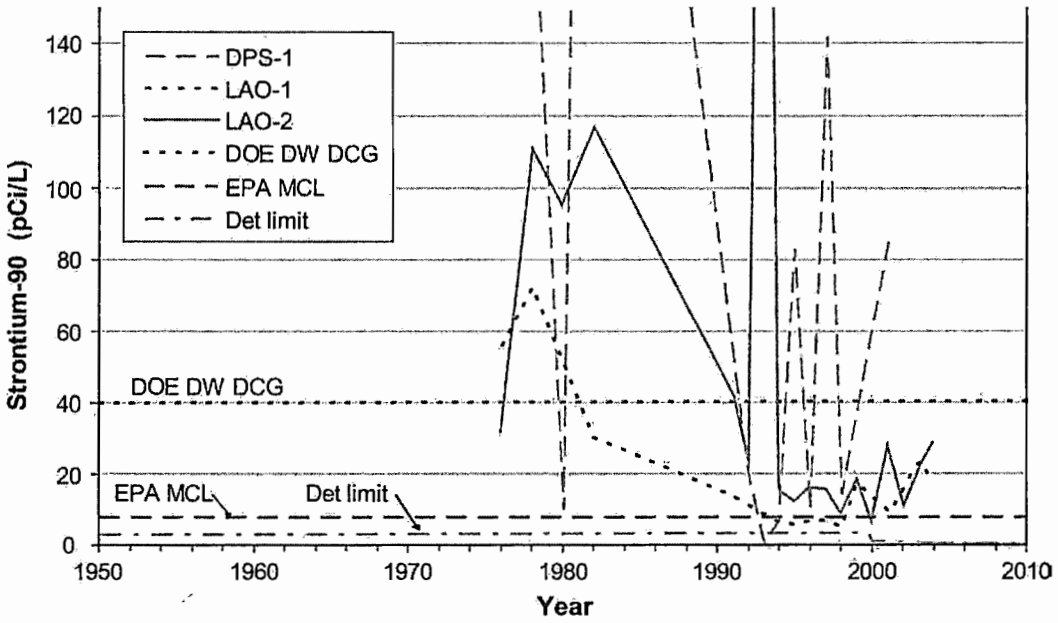

Figure 3-24. Strontium-90 histories in DP and Los Alamos Canyon surface water and alluvial groundwater. Data are annual averages of all results including nondetects; note that detection limits have varied greatly through time.

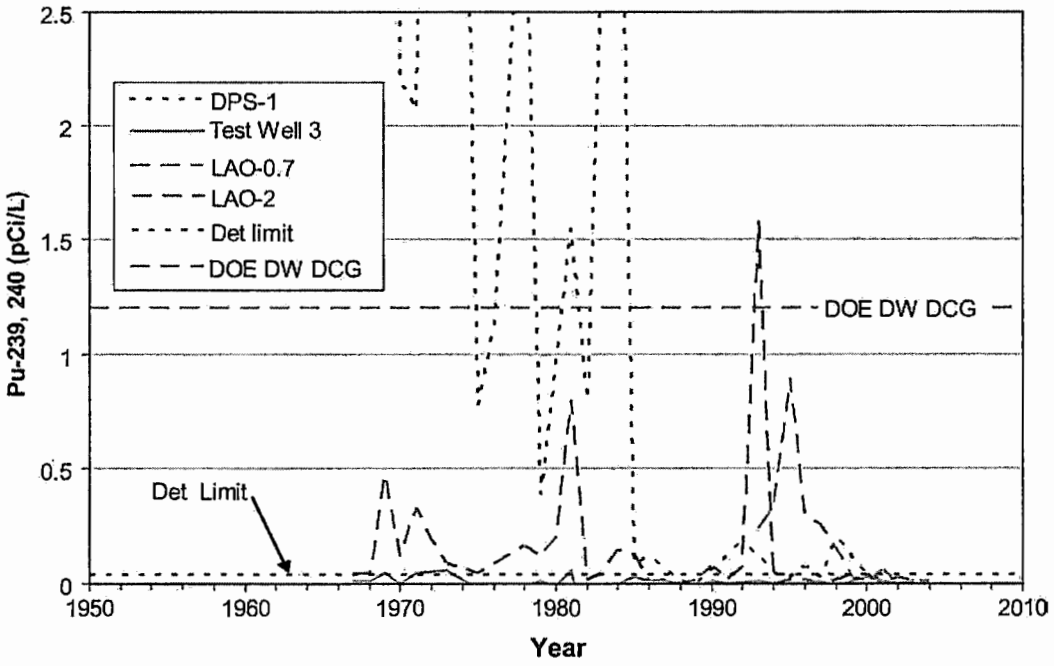

Figure 3-25. Plutonium-239, -240 histories in DP and Los Alamos Canyon surface water, alluvial groundwater, and the regional aquifer. Data are annual averages of all results including nondetects; note that detection limits have varied greatly through time.

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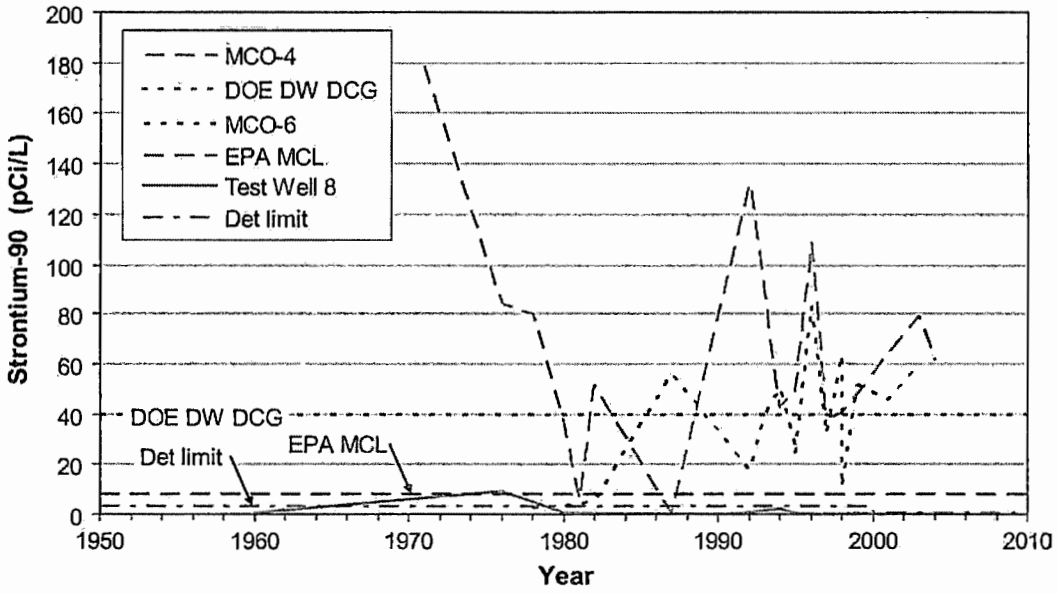

Figure 3-26. Strontium-90 histories in Mortandad Canyon alluvial groundwater and the regional aquifer. Data are annual averages of all results including nondetects; note that detection limits have varied greatly through time.

In Mortandad Canyon, Purtymun et al. (1977) estimated that, on average, about 15% of the surface water and shallow alluvial groundwater was lost to evapotranspiration. Because surface water or alluvial groundwater rarely flows beyond the Laboratory boundary, the remaining 85% of the water that enters the canyon must be lost by infiltration into the underlying tuff. Core profiles (Longmire 2001a) indicate a significant inventory of perchlorate and nitrate within the 400 ft of unsaturated Bandelier Tuff underlying the canyon floor.

Concentrations of contaminants such as nitrate, perchlorate, and tritium in Mortandad Canyon intermediate perched groundwater lie between current and past values in the alluvial groundwater. This banded range of observed concentrations suggests that the alluvial groundwater is a significant source of recharge to the intermediate groundwater; that this recharge requires on the order of decades; and that the solutes in the infiltrating water may be diluted by uncontaminated water already in the vadose zone or in the intermediate perched zone.

Low-level tritium data in intermediate perched groundwater support the conceptual model that alluvial groundwater affected by effluent discharges is a principal source of recharge and contaminants for the intermediate perched groundwater (Figure 3-28). The highest values are found where effluent discharges have occurred, but are much lower than values observed in alluvial groundwater. The lower values may be due to mixing of recharge with other groundwater sources as well as radioactive decay due to recharge time of decades. Higher-than-background tritium values occur in

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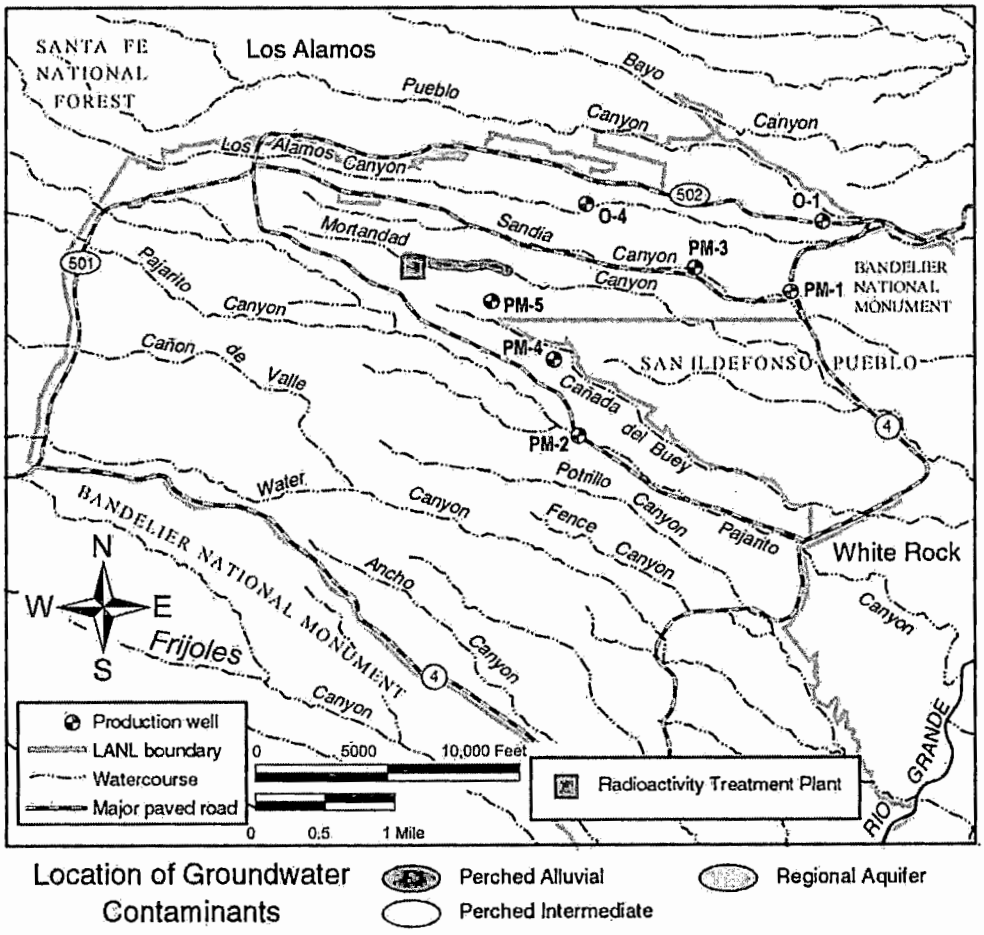

Figure 3-27. Location of groundwater contamination by plutonium-238; plutonium-239, -240; and americium-241 above the 4-mrem DOE DCG for drinking water. The 2003 maximum values in Mortandad Canyon alluvial groundwater for plutonium-238; plutonium-239, -240; and americium-241 were 1.4, 1.3, and 1.4 times the 4-mrem limit, respectively. Different colors indicate the affected groundwater zones.

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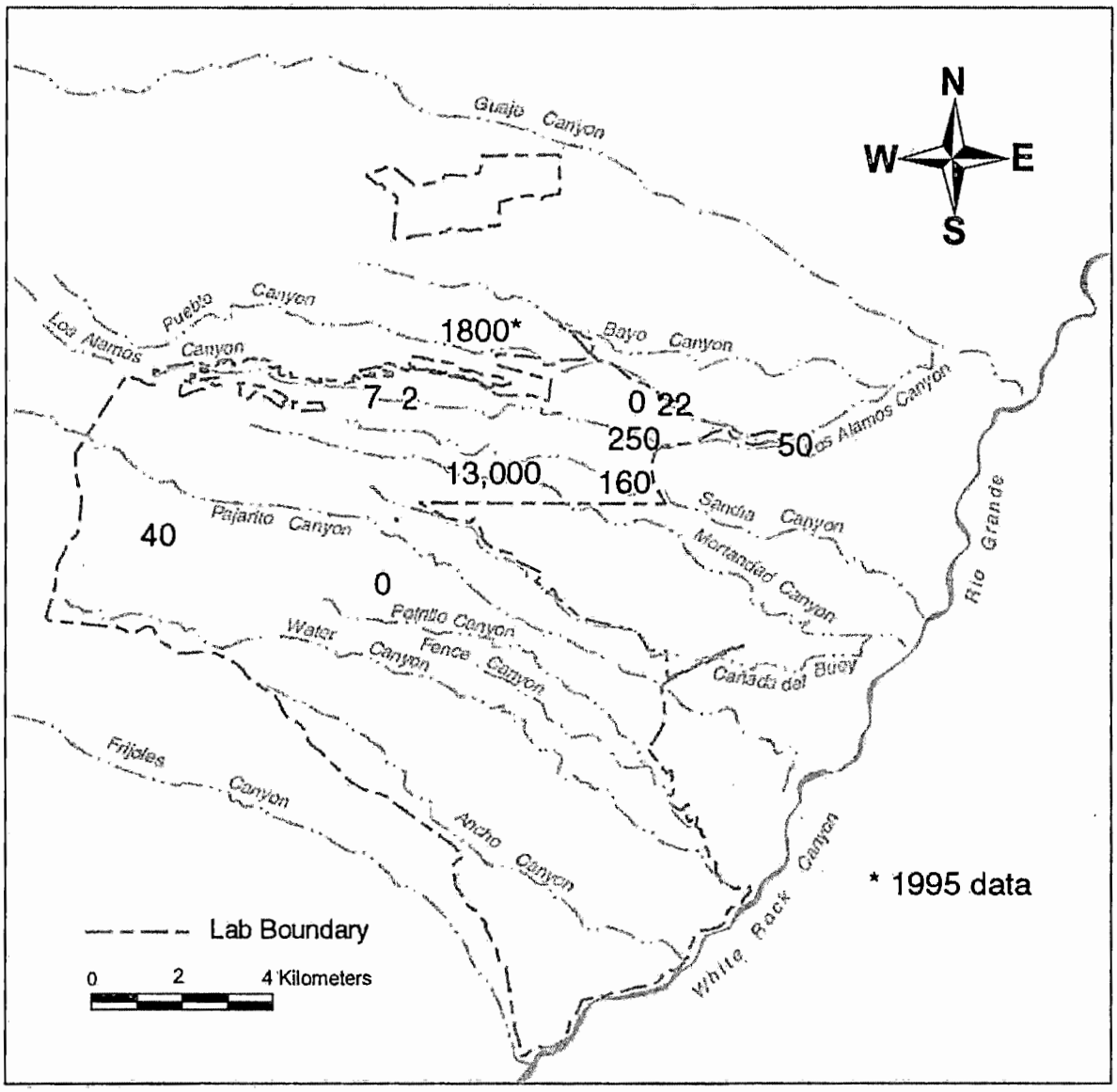

Figure 3-28. Low-detection-limit tritium data from wells and springs sampling intermediate perched groundwater. Data are mainly from 2002 to 2004 and do not include borehole data. The highest values occur where effluent discharges have occurred.

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- R-25 near the 260 outfall and other discharges in TA-16,
- below the former TA-45 discharge in Pueblo Canyon,
- downstream from the Omega West reactor site and TA-21 discharges in Los Alamos Canyon, and
- below the sanitary effluent discharge site in Sandia Canyon, and the RLWTF in Mortandad Canyon.

Tritium time-series data also support a conceptual model that groundwater in the intermediate perched zones may have short residence times. Following cessation on effluent discharge from TA-45 into Acid Canyon in 1964, tritium in the intermediate perched zone sampled by TW-2A fell rapidly during the 1980s (Figure 3-13). Analysis of water samples from TW-2A show that this perched zone continues to contain elevated activities of tritium (2,228 pCi/L). This suggests that tritium associated with the former TA-45 treatment plant has infiltrated the canyon floor and migrated vertically, at least to the depth of the intermediate perched zone at TW-2A. Elsewhere in intermediate perched groundwater tritium has been detected mainly at trace levels (Figure 3-13). Although these incomplete data sets begin 15 years after discharges ceased, they support the conceptual model of short groundwater residence time.

In LADP-3 in Los Alamos Canyon, tritium activities fell rapidly over the decade after the Omega West reactor cooling line leak was stopped. Tritium was initially found in LADP-3 at 5500 pCi/L (Broxton et al. 1995) but activity has declined greatly since then, related to cessation of the Omega West reactor cooling line leak in 1993. Tritium in the two intermediate perched zones at R-9i was about 233 pCi/L at 180 ft and 110 pCi/L at 275 ft.

3.2.3.3 Flow Field Modification and Transport in Regional Aquifer Groundwater

Relatively little contamination reaches the regional aquifer from the alluvial groundwater bodies, and water quality impacts on the regional aquifer, though present, are low. The last hydrogeologic control, flow field modification, is considered important in controlling anthropogenic constituent distribution in the regional aquifer. Anthropogenic constituents that enter the regional aquifer near pumping wells are predicted to have much travel times than those outside the influence of pumping (Section 4).

The distribution of tritium in the regional aquifer supports the conceptual model that surface effluent discharges are the source of Laboratory contaminants at depth (Figure 3-29). The map shows low-level tritium values from 2002-2004 and includes springs and wells.

In most cases, the highest regional aquifer tritium values are found near where effluent discharges have occurred, but are much lower than values observed in overlying alluvial or intermediate perched groundwater. The lower regional aquifer values may be due to dilution of recharge by other groundwater sources as well as radioactive decay due to recharge times of decades. The locations of the highest values in Figure 3-29 are near the recharge sources described in Appendix 3-A, with two additional locations that have high tritium values. One is at R-22 near MDA G, which may be due to past tritium disposal at that site. The second is at

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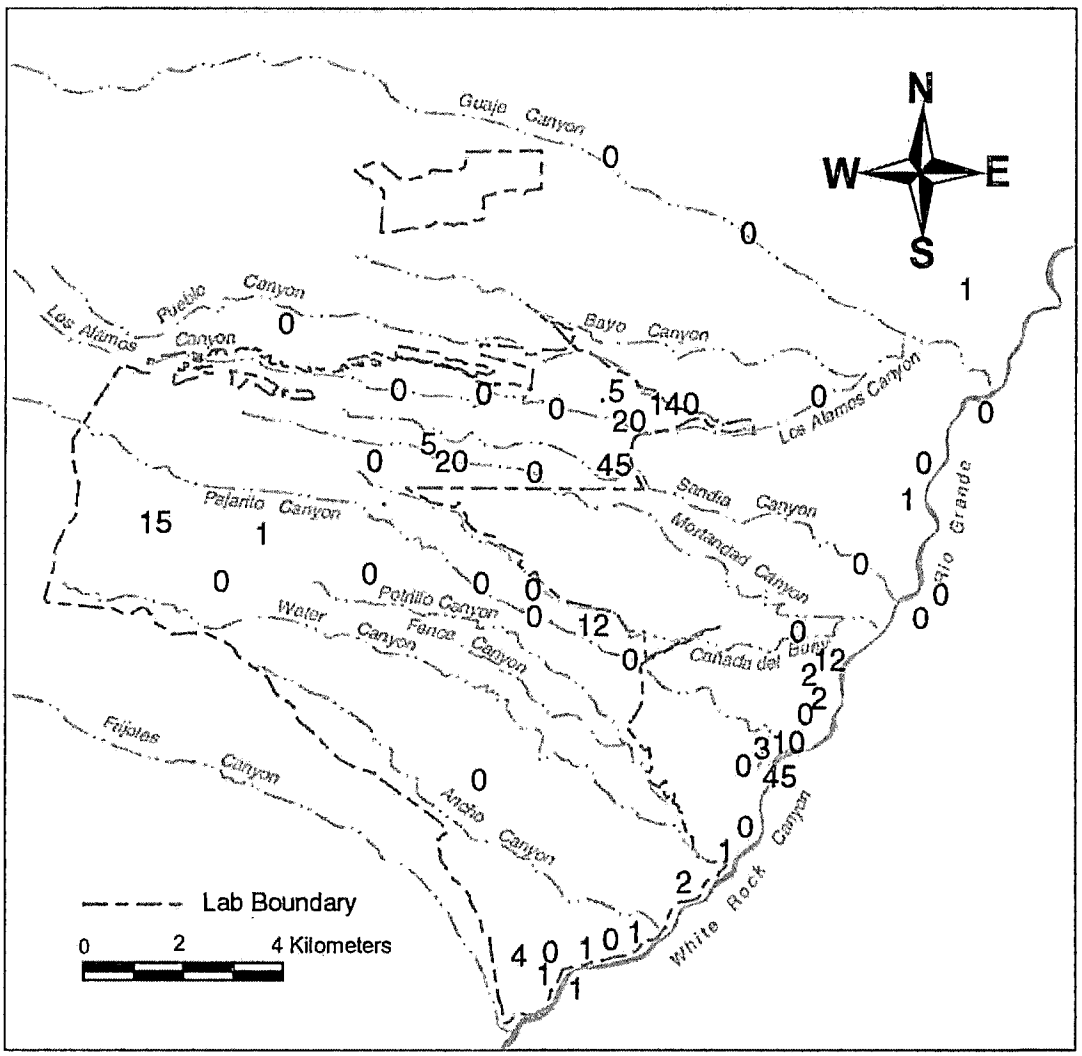

Figure 3-29. Low-detection-limit tritium data from wells and springs sampling the regional aquifer. Data are from 2002 to 2004 and do not include borehole data. The highest values occur where effluent discharges have occurred.

Spring 4B. The values, in the range of 45 pCi/L, are similar to data from rainfall and the Rio Grande and may be due to a component of surface water in the spring sample (LANL 2004b).

3.2.4 Off-Site Transport

Anthropogenic constituents that reach the regional aquifer will be transported along flow paths that will extend either to pumping wells or to the Rio Grande, the discharge area for the regional aquifer in the Española Basin (Section 2). The travel times along the natural flow paths are quite long (tens of thousands of years), but can be shorter for flow paths leading to pumping wells (Section 4).

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As discussed in Section 3.2.1, the most mobile contaminants would be the first to appear in any of the regional aquifer discharge points. Appendix 3-A contains descriptions of canyons and the constituents that have been detected in the regional aquifer. Highly mobile groundwater contaminants including chloride, nitrate, perchlorate, and tritium have migrated into the regional aquifer near LANL. Monitoring data suggest that these constituents may also be discharging in some White Rock Canyon springs. Nitrate, chloride, and sulfate have increased gradually during the past 20 years in Spring 3 and Spring 3A (Figure 3-30). Tritium values in the springs are either in the range of regional aquifer values (less than 3 pCi/L) or up to 45 pCi/L, which could indicate either Laboratory impact or a component of precipitation (tritium in precipitation is 30–450 pCi/L). Perchlorate measured at low levels in some springs appears to be naturally occurring because it is within the range of regional background levels.

Four alternative pathways have been articulated to explain the presence of anthropogenic constituents in White Rock Canyon springs. One potential source is effluent discharged from the county's sewage treatment plants. McQuillan et al. (2004) noted that Los Alamos County water supply well Otowi-1 produces water with above-background nitrate, and detectable perchlorate and tritium, as do some of the springs. The calcium-bicarbonate groundwater at Spring 2B is chemically similar to that in regional aquifer well TW-1 in lower Pueblo Canyon. Although the Spring 2B major ion chemistry is consistent with the upgradient geochemical data from TW-1 in lower Pueblo Canyon, TW-1 is located approximately 4 miles away from Spring 2B. The White Rock Sewage Treatment Plant is very close to the springs. Both TW-1 and Spring 2B are located near (separate) municipal sewage discharges and the common sewage signature could yield similar water chemistries at both sites. Nitrate and chloride are common contaminants associated with sewage effluent.

McQuillan et al. (2004) suggest rapid transport in the regional aquifer from Pueblo Canyon to White Rock Canyon. Contaminants released in Acid Canyon, after having reached the regional aquifer, traveled rapidly through the regional aquifer in an easterly, then southerly path line starting at about Otowi-1 and TW-1, discharging in several springs along White Rock Canyon. However, these flow paths are inconsistent with the gradients in the regional aquifer, based on the latest potentiometric data. This pathway also requires rapid transport through the regional aquifer, contrary to evidence (carbon-14 data) that suggests slow transport through the regional aquifer (Sections 2.7.7 and 4). Water from lower Pueblo Canyon would need to travel many miles through the regional aquifer to Spring 2B with minimal mixing or dispersion in order to account for the observed concentrations.

One further geochemical argument, which suggests that water in Spring 2B does not originate near O-1 and TW-1 in Pueblo Canyon, is the high uranium concentration in Spring 2B water. Uranium concentrations in Spring 2B are sharply anomalous compared to adjacent springs. There have been no high uranium concentrations measured in regional groundwater beneath LANL or Pueblo Canyon (Gallaher et al. 2004) that are comparable to those in Spring 2B. However, high natural uranium concentrations are known to exist throughout the Pojoaque Valley, in the well field in lower LA Canyon, and in the nearby Buckman wellfield. The natural levels have been shown to vary in response to pumping in the old LA wellfield, and delayed impacts may appear in Springs 1 and 2.

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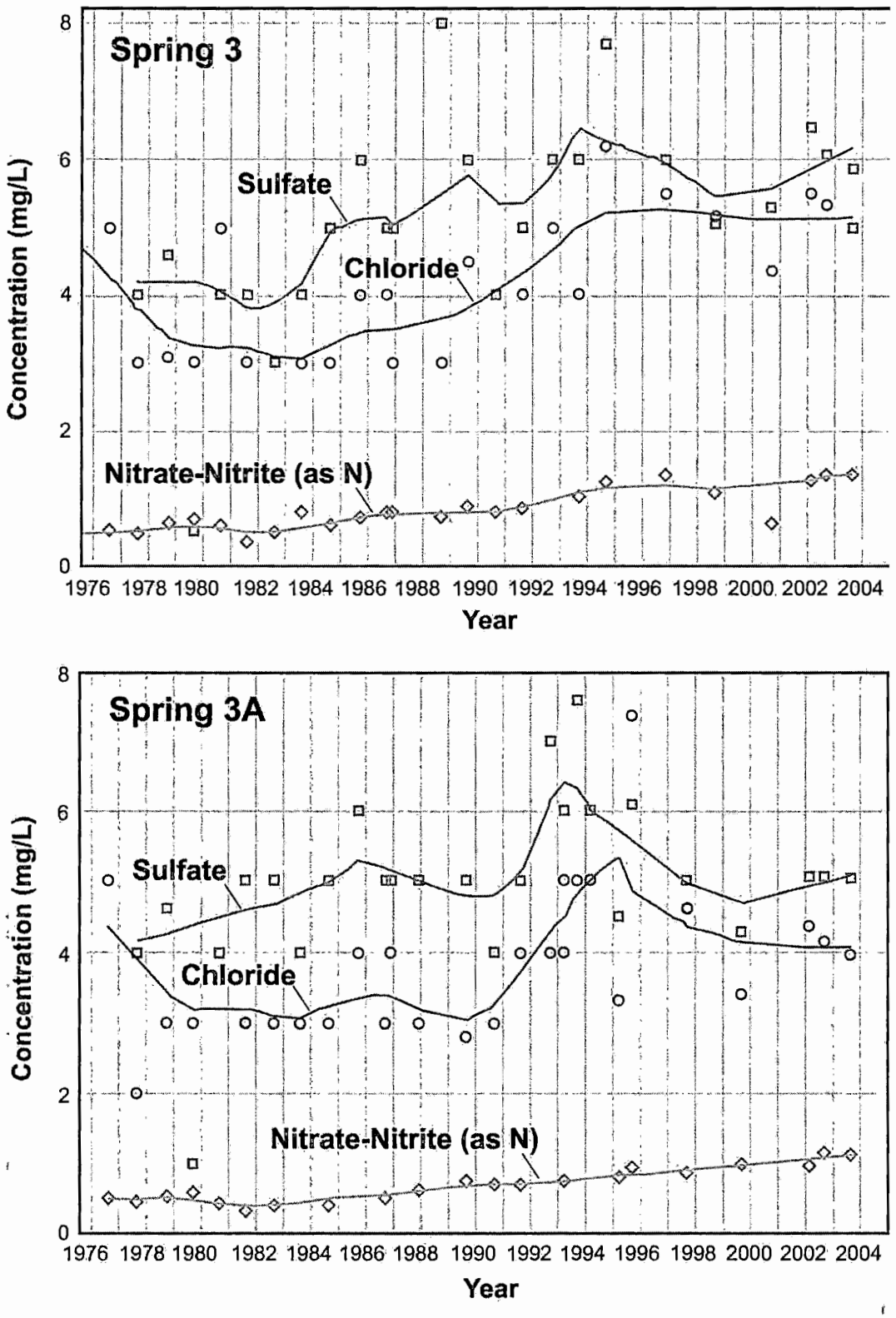

Figure 3-30. Anion concentrations in Springs 3 and 3A. Solid lines are best fit smooths to the data using loess methods (Cleveland 1979).

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A second hypothesized pathway is a local source for contaminants present in the springs. Spring 2B chemistry is consistent with effluent from the White Rock Sewage Treatment Plant (located on the White Rock Canyon rim above Spring 2B). The decades-long increases in nitrate and chloride concentrations in Springs 3 and 3A suggest a sustained source such as an effluent discharge. Surface flows from the plant pass near these springs.

The third potential pathway is near-surface transport of contaminants to the White Rock Canyon springs. LANL contaminants are hypothesized as being transported in surface water and/or shallow groundwater along Pajarito Canyon from TA-9 to White Rock, followed by infiltration near the springs and a relatively short transit through the vadose zone to the regional aquifer. Such fast, shallow paths are more plausible and consistent with available information than fast transport through the regional aquifer. The major ion chemistry in the springs near Pajarito Canyon is generally consistent with that of groundwater along this flow path. Some fast regional aquifer transport would still need to occur for the contaminants to reach the springs.

The fourth possible pathway is transport via alluvial groundwater and fractural basalt. This pathway involves Laboratory contaminants reaching the springs via shallow and deep pathways in which transport is dominated by movement through fractural basalts. Fast transport through the basalts is more plausible than fast transport in the regional aquifer within the Puye Formation or the Santa Fe Group. The basalt-dominated pathway would likely be fast through the vadose zone as well. Drilling to date has not located any major contamination zones in basalt, but such zones could be isolated and difficult to encounter.

If any of the hypothesized alternative fast pathways invoked to explain the possible presence of LANL-derived constituents in springs exist, groundwater beneath LANL may travel more rapidly to downstream wells or springs than previously recognized, but the overall water quality changes would be anticipated to be relatively minor. Faster travel in the regional aquifer likely would result in less natural attenuation (for example, adsorption, radioactive decay, mixing) of any LANL-derived contamination. The monitoring history to date, however, has revealed minor impacts on the regional aquifer beneath the Laboratory. Continued LANL-wide groundwater monitoring is the most effective mechanism for identifying potential off-site transport of contaminants. See Appendix 3-D for discussion of other alternative conceptual transport models.

3.2.5 Summary of Contaminant Distribution and Transport

The impacts to groundwater at the Laboratory have occurred mainly where effluent discharges have increased local infiltration rates and volumes. The depth to which chemical constituents move in the subsurface is determined partly by their chemical behavior: non-reactive constituents move readily with groundwater, while reactive or adsorbing constituents move a shorter distance.

In most cases where effluent sources have been eliminated, groundwater concentrations of non-reactive discharged contaminants have decreased far below past levels (e.g., RDX, nitrate, tritium, and perchlorate) in alluvial groundwater. These mobile contaminants readily move through the subsurface and are detected within perched intermediate zones and at the regional water table beneath several canyons, including Pueblo Canyon, Los Alamos Canyon, Sandia

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Canyon, Mortandad Canyon, and Cañon de Valle. In the case of reactive or adsorbing chemicals, the concentrations may remain elevated above background levels for long periods of time after elimination of discharges or other contaminant source terms (e.g., excavation and removal of contaminated sediments). These include constituents such as strontium-90 and the actinides (americium-241, plutonium-238, and plutonium-239, -240).

4.0 NUMERICAL MODELS

The conceptual models of the hydrogeologic system beneath the Pajarito Plateau, as well as the supporting data and information, were described in Sections 2 and 3. Numerical modeling is an analytical tool that can be used to integrate and synthesize the sometimes widely spaced point hydrogeologic field data and that allows prediction of how the hydrologic system will behave at different times and under different conditions in the future. However, before models can be used for prediction, they must be shown to adequately reproduce current conditions. A caveat is that different model representations (assumptions, boundary conditions, structural features, dimensionality) can in many cases provide equally good fits to available data. This fact, sometimes called equifinality in the hydrologic literature, implies that different model representations may result in significantly different model predictions. In this section we have selected representative model structures that are most consistent with the available information, while acknowledging that conceptual uncertainties also exist. This section describes the site-scale vadose zone and regional aquifer models that have been developed, including the underlying assumptions, hydrologic processes, calibration, and predictions for flow and transport.

4.1 Site-Wide Vadose Zone Flow and Transport Model

Hydrologic modeling of the vadose zone has been conducted to understand the key factors influencing the transport of contaminants from the ground surface to the regional aquifer, and to quantify uncertainties. The main goal of the site-wide vadose zone flow and transport model is to identify regions at the Laboratory where deep migration of contaminants is most likely. These analyses have been useful for guiding and prioritizing site characterization activities and can be used to support risk and performance assessments.

The following summary describes the underlying assumptions and hydrologic processes, and presents numerical modeling predictions of the travel times from the ground surface to the top of the regional aquifer across the Pajarito Plateau. Simulation of travel time of traced water is a necessary first step in predicting the velocities and concentrations of contaminants through the vadose zone. For a modeling analysis that includes predictions of tritium concentrations, see the presentation of a numerical model for Los Alamos Canyon in Section 4.1.3.2.

4.1.1 Model Development

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. The characterization and modeling of vadose zone systems requires knowledge of the water supply, percolation rates and the hydrologic properties of rocks and soils under unsaturated conditions. Such an understanding, at a basic level, has been acquired for the Bandelier Tuff underlying much of the Pajarito Plateau. 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 manmade alterations to the natural system (see Section 4.1.3 for examples).

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Due to the complexity and computational demands of vadose zone models, they typically cover only a small portion of the Laboratory property, and thereby provide only a local picture of the vadose zone system. This section describes a site-wide model for performing first-order analysis of travel time through the vadose zone across the entire Pajarito Plateau. By foregoing some of the complexities in favor of a simpler representation of the flow physics, this model can be extended to include all locations of interest on the LANL property.

The following subsections present the modeling inputs, assumptions, and methodology in more detail.

4.1.1.1 Flow and Transport Processes

Despite the potential complexities associated with vadose zone systems, many basic processes are amenable to characterization and numerical simulation. In the Bandelier Tuff, when the percolation rate is lower than the saturated hydraulic conductivity K_{sat} of the matrix rock, the fluid saturation in the partially water-filled pores modulates itself in order to transmit the fluid under unit-gradient conditions associated with gravity-driven flow. Section 2.6.3 included data suggesting that under most conditions, water percolates through the Bandelier Tuff matrix, and the role of fractures is minor, except for the uppermost units of the Tshirege Member, present only in the westernmost portion of the Laboratory. In these locations, units with very low hydraulic conductivity induce lateral flow, probably through fractures. This phenomenon leads to shallow zones of saturation in which water travels laterally and issues at springs in Cañon de Valle and Water Canyon, from which it flows vertically downward through the rest of the Bandelier Tuff in matrix flow. In contrast, flow through the basaltic and dacitic rocks is assumed to be controlled by fractures. The practical consequence of these conceptual models for travel times will be established in the numerical modeling results. Finally, flow through the Puye Formation is probably also matrix-dominated, although the hydrogeology is complicated and the possibility of channelized, heterogeneous flow must be considered.

In spite of the inherently three-dimensional nature of flow in the vadose zone, an appropriate approximation for estimating travel time is to assume one-dimensional downward percolation of water and migration of contaminants. Intermediate perched groundwater observed in several wells across the Plateau indicates the possibility of lateral diversion (see Section 2.7), but the influence of such groundwater on vadose zone travel time can be assessed in a bounding manner, as is illustrated in Section 4.1.2.3.

4.1.1.2 Infiltration Rate

As the upper fluid flow boundary condition, infiltration is one of the most important inputs for a vadose-zone model. Infiltration is known to depend, often in a complex way, 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. The percolation rate below the zone of evapotranspiration is the direct input to the vadose zone numerical models. Although this rate undoubtedly changes with time due to storm transients, seasonal variations, and climatic variability, it is assumed that such effects are buffered by the hydrologic processes

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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 infiltration rate is also spatially variable at scales ranging from the width of fractured zones to the length of individual canyons.

The methodology for estimating infiltration rates across the Pajarito Plateau is to classify canyons or portions of canyons with a numerical designator, called the Net Infiltration Index (NII). Then, for applying infiltration in the numerical model, each NII would have associated with it an infiltration rate. For the mesas, a uniform infiltration rate of 1 mm/yr was assumed. Appendix 4-A presents the development of the NII values across the Pajarito Plateau; the results are depicted in Figure 4-A-1. Table 4-1 lists, for each NII, the descriptive characteristics of each infiltration class, and the infiltration rates associated with each of the model runs.

4.1.1.3 Numerical Model Implementation

To predict travel time, the FEHM computer code (Zyvoloski et al. 1997) was used to simulate the two-phase, air-water flow problem. For the vertical stratigraphy predicted by the site geologic model, a one-dimensional grid was constructed with 10 evenly spaced numerical grid points within each layer. Hydrologic properties of each unit were assigned based on laboratory measurements and results of previous vadose-zone modeling efforts, and the percolation rate was assigned based on the infiltration map (Figure 2-34). The calculation consists of two steps: first, a steady-state one-dimensional fluid flow calculation is executed to establish the fluid water contents and water velocities through the stratigraphic column from the surface to the water table. Then, this steady-state flow model is used to compute a travel time using particle tracking. After performing the calculation at numerous locations across the Plateau, a site-wide description of vadose zone travel times is assembled in the form of travel-time maps.

To conduct these calculations, several steps of the process were automated within a GIS-based data assembly and querying system. At a given location, the one-dimensional vertical stratigraphy from the site-scale geologic model was used to generate a numerical grid for flow and transport calculations. The point distribution for the one-dimensional models consisted of a high density of points close to drainages across 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. This resulted in a total of 30,577 points across the plateau at which one-dimensional transport times were calculated.

Table 4-1.
Determination of Net Infiltration Index and Net Infiltration Rates Used in the Model

Net Infiltration Index (NII)	Headwaters or Source	Surface Water	Alluvial Water	Net Infiltration Estimate (mm/yr)	
				Base Case	High Infiltration Scenario
1	Plateau	Ephemeral or Intermittent	Not Saturated	1	10
2	Mountain or Small Anthropogenic Source	Ephemeral or Intermittent	Not Saturated	10	30
2	Plateau	Ephemeral or Intermittent	Sometimes Saturated	10	30
2	Plateau	Perennial	Not Saturated	10	30
3	Plateau or Small Anthropogenic Source	Ephemeral or Intermittent	Saturated	100	300
3	Mountain	Ephemeral or Intermittent	Sometimes Saturated	100	300
4	Plateau	Perennial	Saturated	300	1000
4	Mountain or Anthropogenic Source	Ephemeral or Intermittent	Saturated	300	1000
5	Mountain or Large Anthropogenic Source	Perennial	Saturated	1000	3000

4.1.2 Model Results

Numerical modeling results are presented for a "base-case" model for canyons and mesas, after which uncertainty in infiltration rate and the impact of perched water conceptual uncertainty are studied.

4.1.2.1 Base-Case Results

A full-scale map of predicted travel times of a water molecule in the vadose zone (from ground surface to the water table of the regional aquifer) is shown in Figure 4-1. Along each canyon with NII other than 1, travel times are predicted to be less than 1000 years. Although the results in canyons are the main focus of this study, results for the mesas are described first. On mesas, the predicted travel times are variable, but for the most part are greater than 1000 years, ranging from 1000-5000 years on the eastern portions of the Laboratory to 20,000 to 30,000 years in the western region.

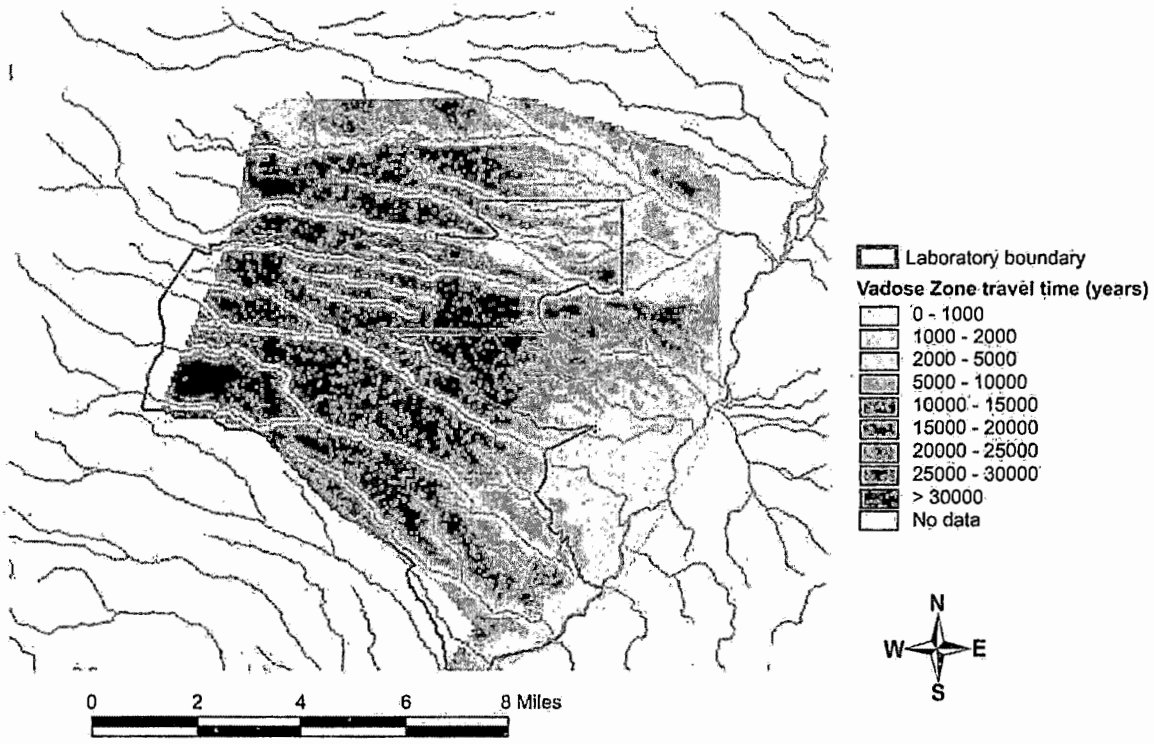

Figure 4-1. Predicted vadose zone travel times (years) to the water table: Base case, full scale of travel times.

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To a first approximation, travel times from mesa tops are controlled by the thickness of the Bandelier Tuff. Because the Bandelier Tuff exhibits matrix percolation, the travel times on the mesas are controlled by slow percolation at a flux of 1 mm/yr through these units. Other units between the ground surface and the water table are the Cerros del Rio basalts, the Puye Formation, and the Tshicoma dacites. The basalts and dacites are modeled with an extremely low porosity (0.01) to capture the conceptual model feature of flow through these units controlled by fast pathways such as fractures or other heterogeneities. Therefore, most of the travel time to the water table is within the Bandelier Tuff, and the travel time map is therefore dominated by the tuff thickness.

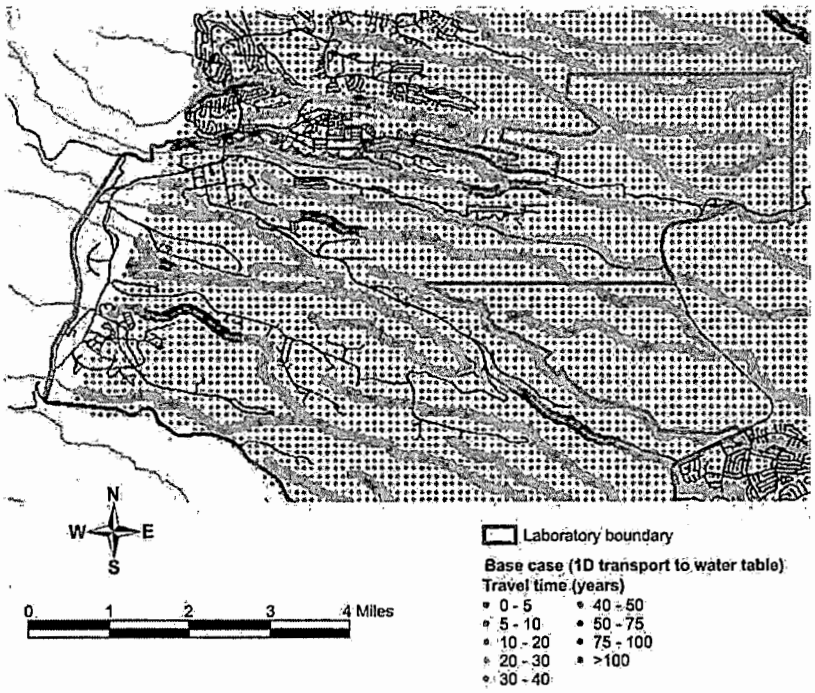
Identification of rapid travel times to the water table from canyon bottoms is important to determine if they are in locations likely to have experienced Laboratory-derived groundwater contamination. Figure 4-2a shows the base-case model result presented in Figure 4-1, except that the travel-time scale ranges from 0 to 100 years (all points with values greater than 100 years are shown in gray). The model predicts that regions of relatively rapid travel times are present 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.

Two factors control these results: infiltration rate and hydrostratigraphy. Generally, travel times less than 100 years 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. Clearly, canyons with high infiltration rates are locations in which travel times through the vadose zone are likely to be relatively short. In addition, Los Alamos and Pueblo Canyons have regions in the vicinity of their confluence in which the Bandelier Tuff is thin or non-existent. Water infiltrates directly onto basaltic rocks or the Puye Formation, thereby yielding rapidly downward flow through fractures or preferential flow channels. The predicted travel times are especially short (5 to 10 years) in these locations.

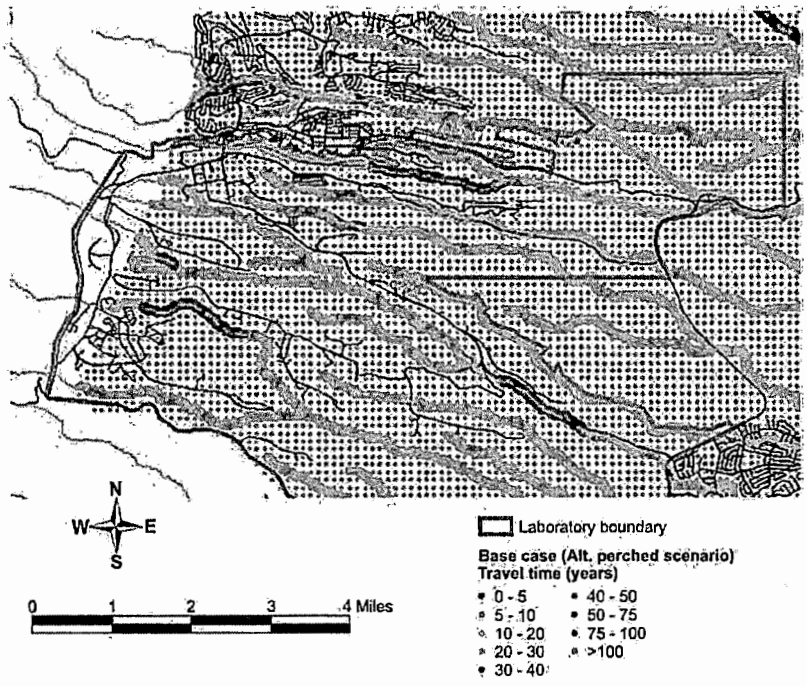
4.1.2.2 Uncertain Infiltration Rate

The infiltration rates associated with the NII are uncertain, and therefore must be varied to investigate the uncertainty in the model predictions. Figure 4-3a shows the same vadose zone travel time map as in Figure 4-2a, but for the high infiltration rate scenario (NII = 4-5). As expected, travel times are shorter at the same location in any particular canyon at the higher infiltration rate. As a result, greater stretches of canyons are predicted to exhibit travel times to the regional aquifer water table of less than 100 years. Specifically, in the high flux scenario, most of Pajarito Canyon, much longer stretches of Mortandad and Los Alamos Canyons, Cañon de Valle/Water Canyons from the west 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 years.

This analysis highlights a key uncertainty in the model: the lack of precision in predicting the percolation rate from canyon bottoms. Because contaminants have been introduced into the groundwater in canyons, it is likely that the percolation rate will be one of the key uncertainties that detailed site characterization may address, possibly in conjunction with sensitivity analyses.



(a)



(b)

Figure 4-2. Predicted vadose zone travel times (years) to the water table, showing only travel times of 100 years or less. Base case percolation scenario: (a) 1-D transport to the water table; (b) alternate perched water model.

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4.1.2.3 Perched Water Conceptual Uncertainty

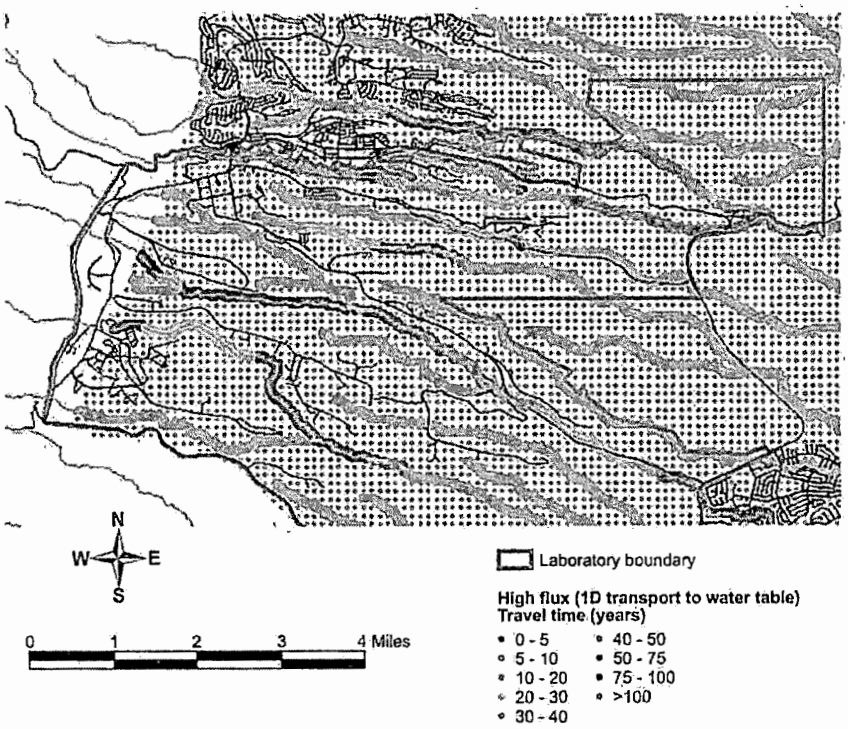
The one-dimensional, vertical transport model assumption is an approximation that may not be valid, given the presence of intermediate groundwater at various locations around the Laboratory. As presented in Section 2.7, zones of saturation have been located directly beneath canyons, where infiltration rates are highest. There is little or no evidence 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 perched water discussed in Section 2.7:

- Low velocity, virtually stagnant fluid
- High velocity, laterally migrating fluid

For the case of stagnant fluid, the one-dimensional pathway approach presented above is an appropriate model. For this case, the calculations already presented are representative. However, the lateral diversion model explicitly violates the one-dimensional assumption, and therefore a bounding approximation is required. In these analyses, it is assumed that the travel time from the surface to the elevation of perching is the same as was modeled previously, but the travel time from the perched water zone to the water table is minimal. This approach yields the shortest overall possible travel time, and therefore is useful for assessing the impact of this conceptual uncertainty. Note that this analysis assumes that lateral displacement of water and contaminants in perched zones is relatively small compared to lateral displacement in alluvial groundwater systems that are the source of deep percolation.

To perform these calculations, regions were identified within the canyons where intermediate groundwater has been observed, and it was assumed that the vadose zone pathway terminates at that location. This allows travel times to be bounded without explicitly modeling transport from the perching horizon to the regional aquifer. Figures 4-2b and 4-3b show the results of the travel time simulations for the alternate perched water conceptual model for each percolation scenario. Comparing these figures to their counterparts for the one-dimensional downward flow cases (Figures 4-2a and 4-3a), the differences in travel time are quite subtle. The regions with vadose zone travel times of less than 100 years remain approximately the same, and the travel times at the same location are only mildly impacted by the perched water conceptual model. For example, for the base-case infiltration scenario, travel times are shorter by about 15-20 years for the alternate perched water model, and for the high flux scenario, these differences are even smaller.

To understand this result, note that transport from the ground surface to the water table in the one-dimensional model 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. Of course, despite this insensitivity of travel time, the arrival location at the water table is potentially quite different for the two cases: this factor should be considered in specific cases of contaminant transport predictions.



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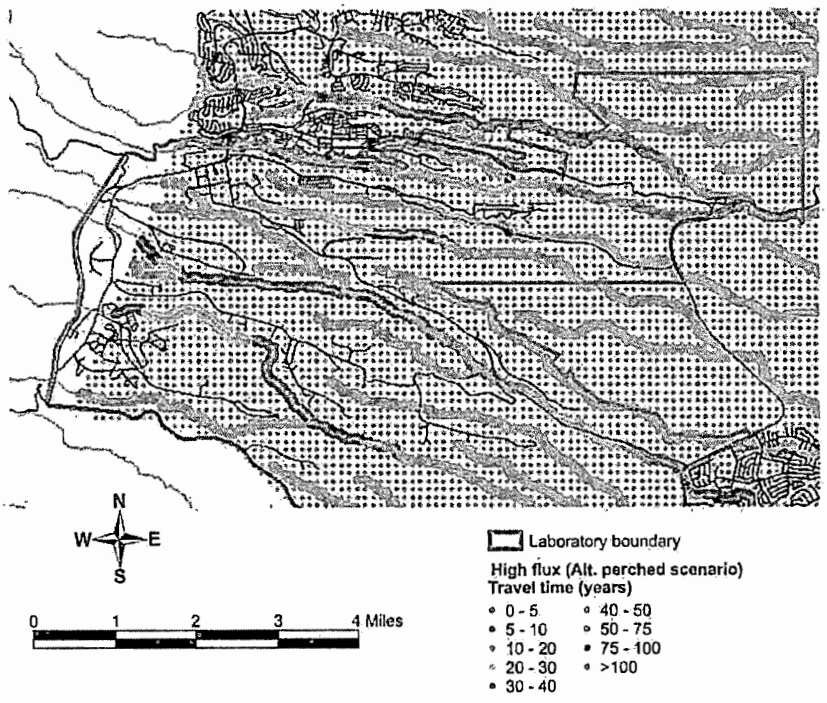

(b)

Figure 4-3. Predicted vadose zone travel times (years) to the water table, showing only travel times of 100 years or less. High percolation flux scenario: (a)1-D to the water table; (b) alternate perched water model.

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4.1.3 Contaminant Transport Model Predictions—Representative Canyon and Mesa Sites

This section presents an overview of modeling studies focusing on two representative LANL sites. The first example models contaminant transport from a relatively dry mesa top, while the other addresses a canyon bottom.

4.1.3.1 MDA G Model

This section highlights the model developed for the Material Disposal Area G (MDA G) performance assessment. A detailed description of the model is provided in Appendix 4-B. A performance assessment (PA) is required to site and authorize permanent disposal facilities for radioactive waste. The purpose of the PA is to demonstrate that performance metrics related to protection of human health and the environment are not likely to be exceeded for a specified period of time. Performance objectives and periods of compliance vary according to the characteristics of the radioactive waste being disposed, but groundwater protection for U.S. sites is always explicitly required for at least 1000 years. This study was designed to predict the groundwater pathway dose in support of the PA of MDA G, an active, low-level, solid radioactive waste site located at LANL, as shown in Figure 4-4 (Fig. 1 of Birdsell et al. 2000).

The three-dimensional unsaturated-zone flow and transport model captures the complex hydrogeology and topography of the site and yields radionuclide flux estimates to the regional aquifer. Within the unsaturated-zone model, the source release of radionuclides is computed for 38 waste disposal pits and four shaft fields, as shown in Figure 4-5 (Figure 3 of Birdsell et al. 2000), each contributing to the total inventory. The continued migration of radionuclides through the aquifer is calculated by using a three-dimensional model designed to maintain the temporally and spatially varying distribution of radionuclide flux from the unsaturated zone.

Due to uncertainty of model parameters, the results of these transport simulations contain intrinsic uncertainty. The greatest uncertainties associated with predicting aquifer-related doses from the site, according to Birdsell et al. (2000), are related to understanding of the mechanisms that control flow and transport within the unsaturated zone and the ability to model these mechanisms. To accommodate both parameter and conceptual model uncertainties, large parameter ranges are used to ensure that the range of calculations captures the behavior of the actual system. However, predicted doses using parameters from the most conservative ends of the uncertain ranges are still well below those that would cause concern.

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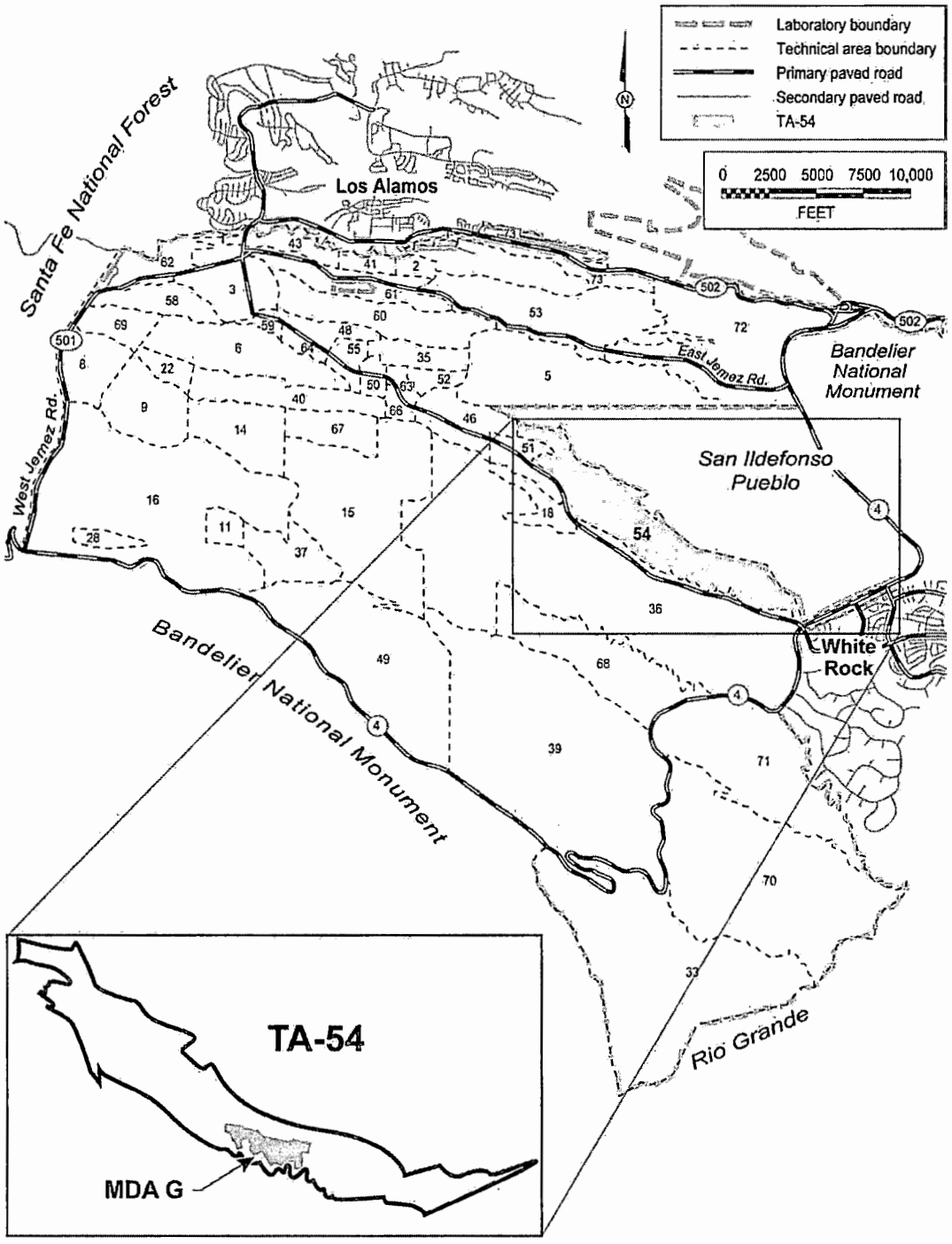

Figure 4-4. Study area for the performance assessment of MDA G, an active low-level, solid radioactive waste site located at LANL (from Birdsell et al. 2000).

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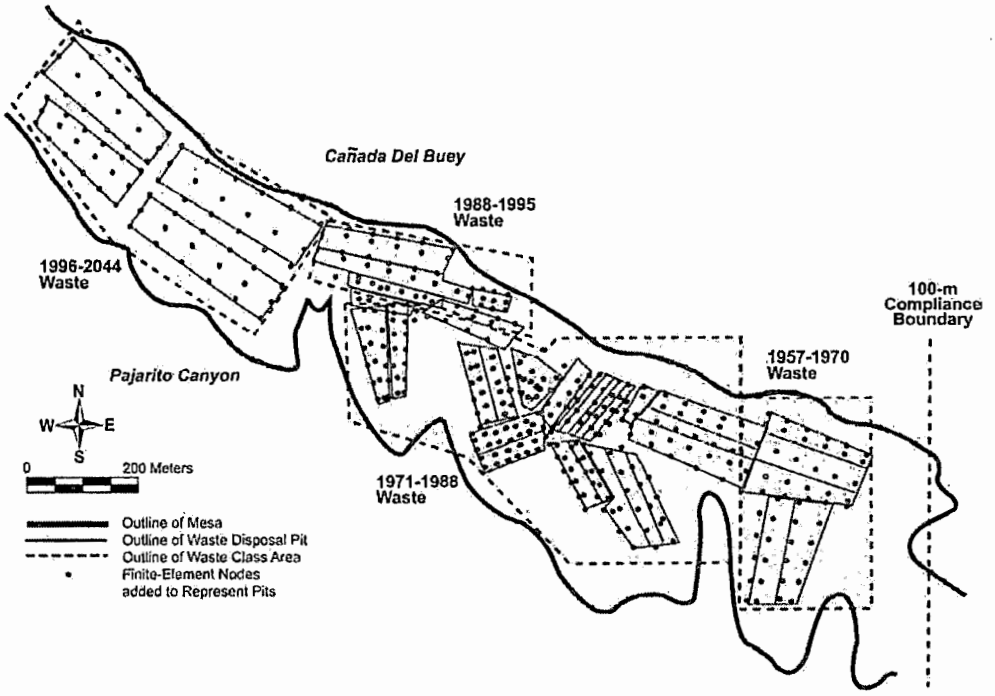

Figure 4-5. Approximate locations of the four waste classes and the 100-m compliance boundary used for the MDA G performance assessment. Also shown are the pit boundaries, internal pit nodes, and the outline of the mesa edge for the three-dimensional unsaturated-zone grid (Figure 3 of Birdsell et al. 2000).

The results recorded by Birdsell et al. (2000) indicate that the mesa-top infiltration rate has the greatest impact on the simulated migration of waste through the unsaturated zone. For the current conceptual and numerical models, it controls both the source release rate and subsequent downward solute migration. This uncertainty was bounded by considering a base-case flow field and high- and low-flow cases. A variation in mesa-top infiltration rate from 1 to 10 mm/yr (Appendix 4-B and Table 4-2) results in a range of six orders of magnitude in the 1000-year groundwater-related doses. Clearly, a good understanding of this key parameter is important to the dose assessment. However, because doses are so much less than the performance objectives, conservative yet realistic infiltration rates seem adequate for the MDA G site.

Table 4-2.
Infiltration Rates (mm/year) Used as Upper Boundary Conditions for MDA G Performance Assessment Simulations (fom Birdsell et al. 2000)

	Mesa Top	Cañada del Buey	Pajarito Canyon
1_1_20 (lowest flow case)	1	1	20
5_1_20	5	1	20
5_1_50 (base case)	5	1	50
10_1_20	5	1	20
10_5_100 (highest flow case)	10	5	100

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Another source of uncertainty is related to flow in the deeper unsaturated-zone units for which few hydrologic data are available. The simulations take virtually no credit for transport times through the Cerros del Rio basalts, which make up more than 50% of the unsaturated zone. The transport results are based on the steady-flow assumption and on the use of matrix hydrologic properties for all tuff units at the site. Understanding of the response of this fractured system to transient flow events remains uncertain. Transient calculations (Birdsell et al. 1999) indicate that the steady-flow assumption is adequate because fluctuations in both saturation and contaminant flux rates dampen with depth, even when including fractures in the upper two units. Fracture infiltration studies (Soll and Birdsell 1998) lead to the conclusion that fracture flow is difficult to initiate and is short-lived in the upper two tuff units at the observed low field saturations. In addition, only Unit 2 and the uppermost portion of Unit 1v-u of the Tshirege Member, Bandelier Tuff, show evidence of significant fracturing (Krier et al. 1997), and these are excavated during disposal operations to depths where the tuff is poorly fractured. Therefore, the waste should not migrate through any highly fractured units until reaching the basalts. These observations help justify the use of the matrix hydrologic properties for the calculations.

In summary, travel times to the regional aquifer from locations on mesas are expected to be large (e.g., > 1000 yr) due to low infiltration rates and matrix-dominated flow. Calculations in this performance assessment model were deliberately conservative and therefore predicted travel times that were an order of magnitude shorter than the base case model presented in Section 4.1.2.1. Exceptions to this general conclusion are in the western portion of the Laboratory (see Section 4.1.1.1) and in locations where the natural mesa-top conditions have been disturbed by Laboratory activities.

4.1.3.2 Los Alamos Canyon Model

This section highlights the model developed for Los Alamos Canyon RCRA Facility Assessment investigations. A detailed description of the model is provided in Appendix 4-C. Los Alamos Canyon, as shown in Figure 4-6, is one of the most complex sites at the Laboratory. A number of technical areas have been or are currently located in or adjacent to the canyon, resulting in multiple release locations along the canyon. This study examined, through a synthesis of available data and the development of numerical models, fluid flow and contaminant transport in the vadose zone beneath Los Alamos Canyon. Modeling of the subsurface hydrology and transport in the vadose zone is also a challenging activity, given the wide range of infiltration rates, the presence of perched water, and the introduction of a host of contaminants of different chemical properties. Because the canyon serves as a collector of a wide range of contaminants, it was necessary to develop a model at the scale of the canyon, rather than at a smaller scale. The specific goals of the model are to

- Synthesize the available data and conceptual understanding of the vadose zone hydrology beneath Los Alamos Canyon;
- Produce a "base-case" numerical model of the subsurface vadose zone hydrology that ultimately can be used to predict contaminant migration rates and concentrations in fluids reaching the regional aquifer beneath the canyon;

- Quantify the uncertainties associated with those predictions by establishing the bounds on system behavior through a suite of possible models, all of which are consistent with the available data, but which bracket the range of possible behavior;
- Provide a simulation tool for predicting the fate and transport of contaminants in Los Alamos Canyon under different assumed hydrologic and ER stewardship scenarios; and
- Demonstrate a model development methodology that can be used in studies of other canyons on the Pajarito Plateau.

This work focuses on the hydrology beneath Los Alamos Canyon, as a first step toward developing a predictive tool that can be used to simulate contaminant migration in the canyon. Since water is the carrier fluid for the contaminants of interest, constructing a realistic flow model that captures the most important hydrologic processes of the vadose zone is an essential first step in the development of a reliable model. Although the study primarily restricts attention to flow issues, tritium transport in the vadose zone is also modeled. Tritium, in the form of tritiated water, is an excellent tracer for groundwater, and hence is included in this modeling study as a constraint on the flow model.

Figures 4-7 and 4-8 show a full three-dimensional view of fluid saturation and a series of two-dimensional vertical slices through the three-dimensional model. As expected, the figure shows wet conditions in the canyon, dry conditions in surrounding mesas. As with the two-dimensional model, this model result shows the overriding importance of the stratigraphy in controlling the water contents in the rock. The local infiltration rate also exerts a strong control on the results. Directly beneath the canyon, fluid saturation is much higher within a given stratigraphic unit than in other parts of the model domain, a reflection of the high infiltration in the canyon.

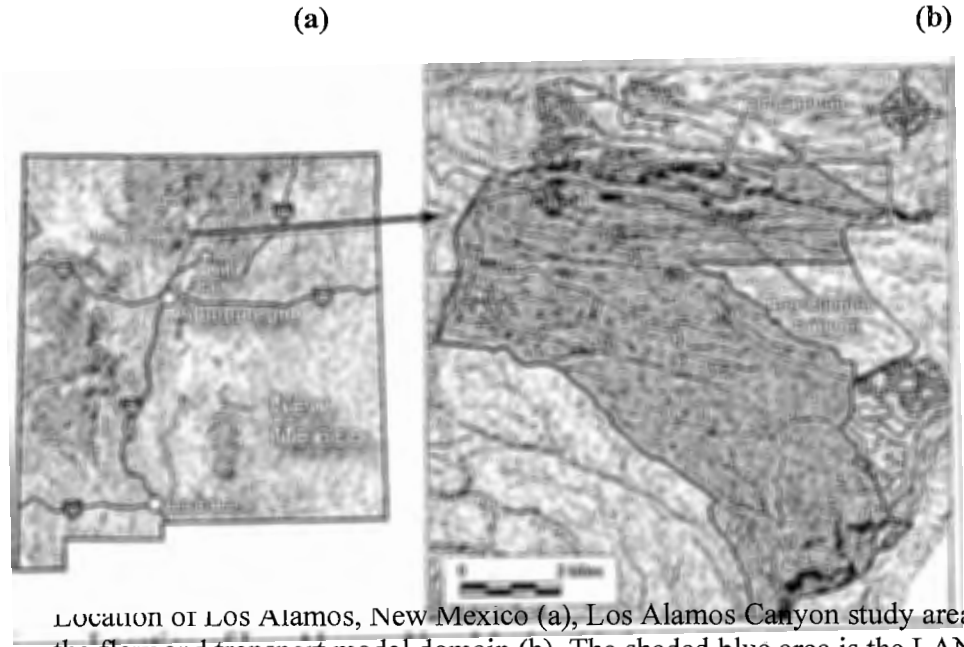

Figure 4-6. Location of Los Alamos, New Mexico (a), Los Alamos Canyon study area, and the flow and transport model domain (b). The shaded blue area is the LANL property; the red box indicates the areal extent of the three-dimensional model domain; and the yellow line is the trace of the two-dimensional model domain.

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Volumetric water content is the primary measurement used to evaluate the model results because adequate data on water content are available from virtually all vadose zone characterization wells. The fits to the data are presented for three different levels of infiltration rates, i.e., the base-case infiltration map, a map with infiltration scaled down by a factor of three from the base map, and a map with infiltration scaled up by a factor of three (Figures 4-C-7 and 4-C-8). It is evident from the following comparisons that the model is able to capture the general features of data:

- The base infiltration map does an adequate job of jointly matching the water content profiles in these wells, despite the different stratigraphy and position relative to the canyon bottom.
- Good fit for LADP-4 illustrates the adequacy of the model in capturing the fluid saturations in the Tshirege Member (not present in the two-dimensional model), as well as in a region where infiltration rates are taken to be significantly lower than in Los Alamos Canyon at LADP-3.
- The need to apply significantly lower infiltration near LADP-4 is best understood by comparing the water content model and data for these two wells. The significantly wetter conditions in LADP-3 are simulated in the three-dimensional model through the setting of high infiltration in the canyon.

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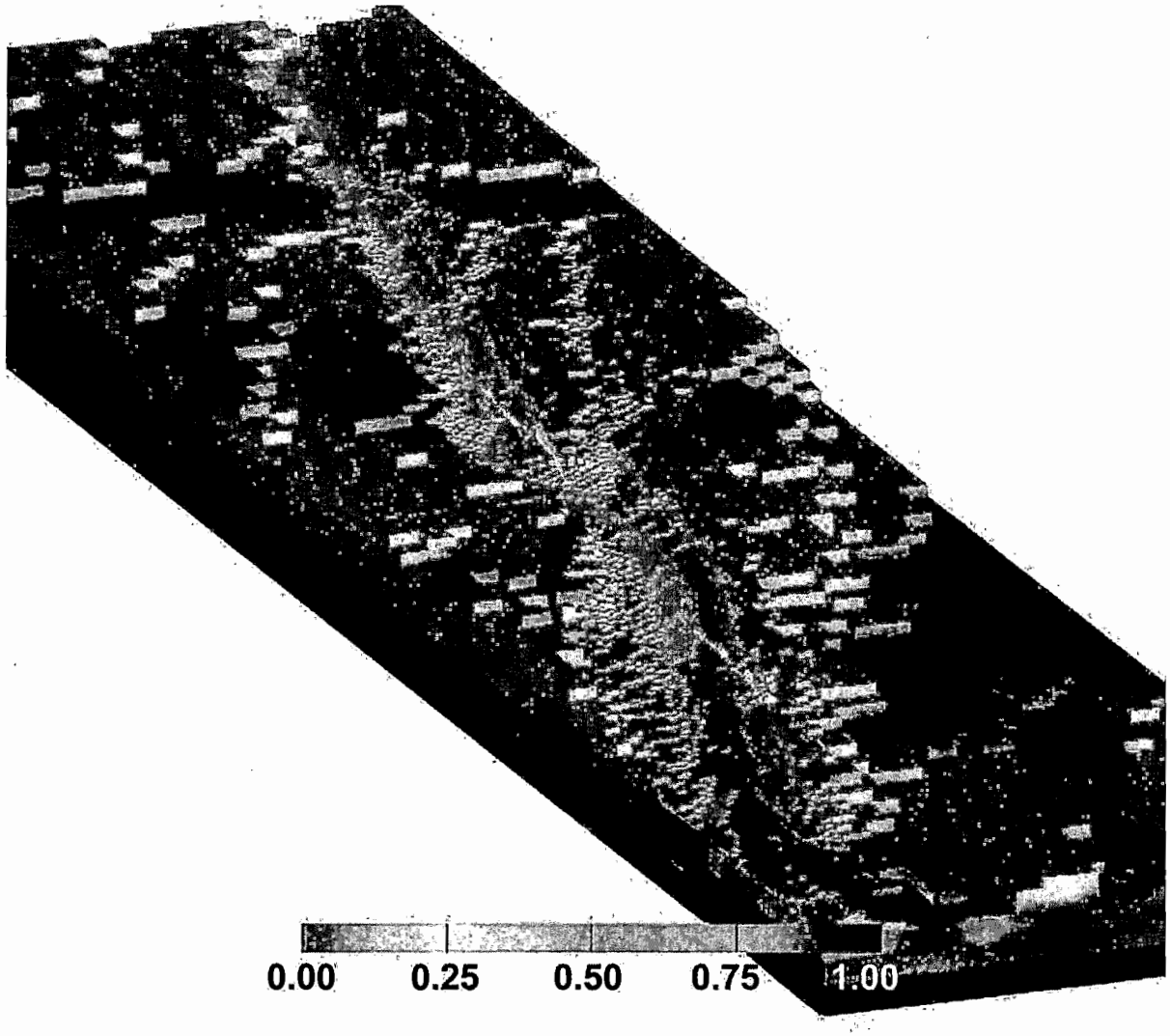

Figure 4-7. Three-dimensional flow model results, showing fluid saturation predictions (%) through the model domain (full model view).

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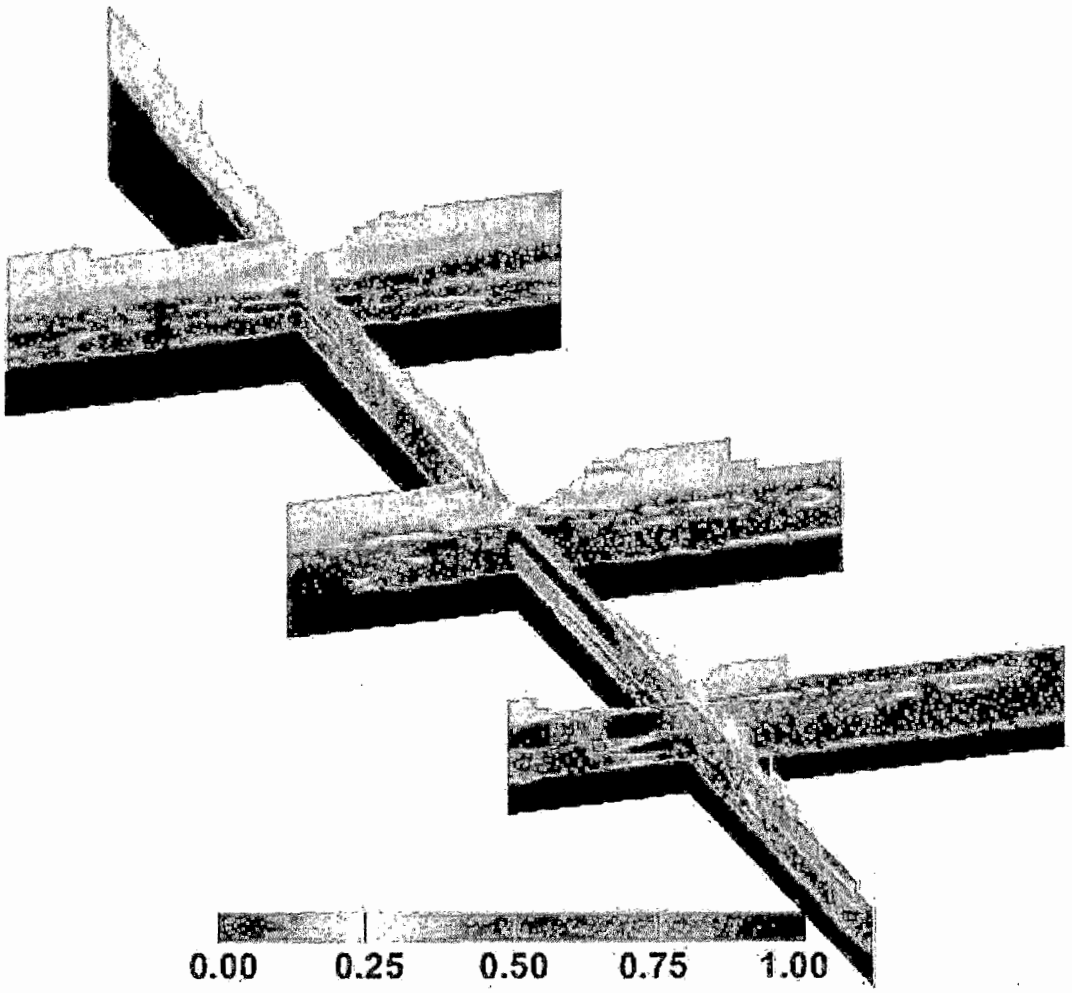

Figure 4-8. Fence diagram showing fluid saturation predictions (%) along one north-south and three east-west cross-sections.

Tritium transport model results are presented to further demonstrate the validity of the model and to explore important processes occurring in the vadose zone. Figure 4-9 is the three-dimensional model prediction of the tritium concentration of fluid reaching the water table in the year 1999. The model results are consistent with the available field data, indicating that regional aquifer fluid collected in well R-7 has undetectable levels of tritium, whereas TW-3 and R-9 show that tritium has reached the regional aquifer. Determining the ability of the model to reproduce the field data more quantitatively is difficult because of mixing of the tritium percolating from the vadose zone with regional aquifer fluid and the subsequent mixing of contaminated and clean fluid in the wellbore itself. The latter difficulty is especially acute for the water supply wells, which may draw water from hundreds of feet of screened length.

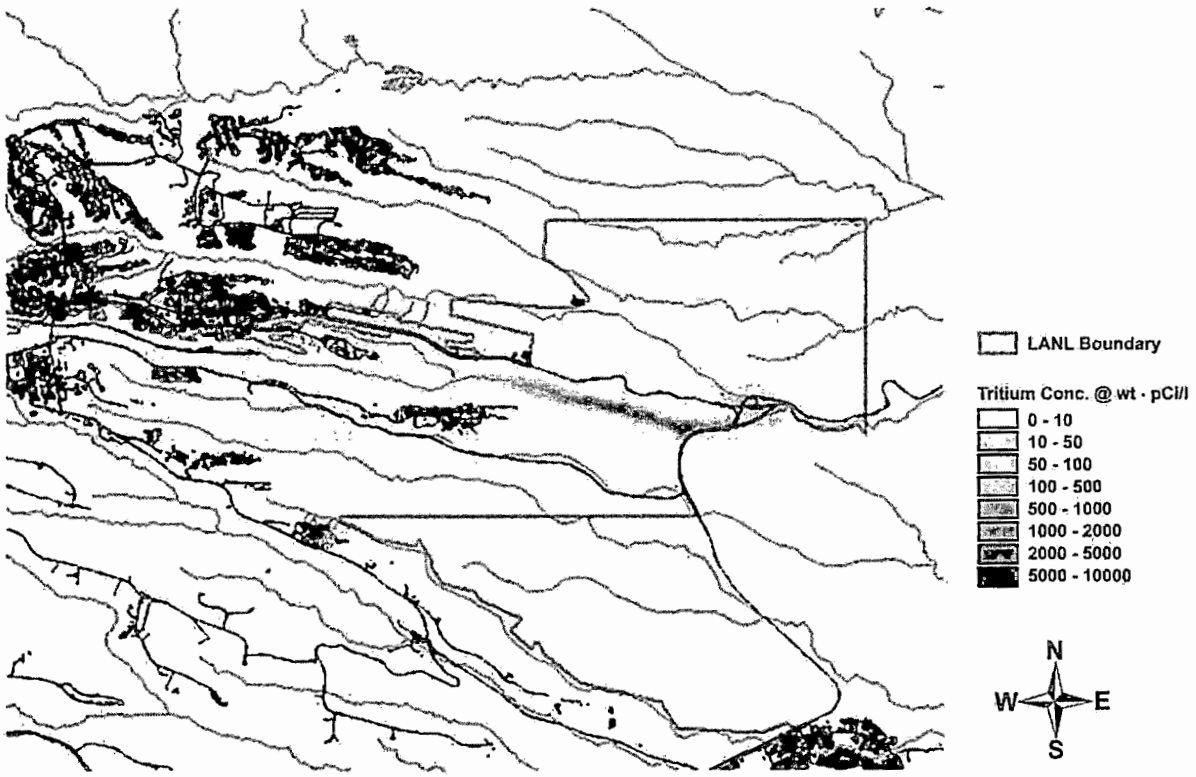

Figure 4-9. Three-dimensional model predictions of the tritium concentration of fluid reaching the water table in the year 1999. Significant, above background concentrations are predicted along the canyon at locations downstream of where the Bandelier Tuff is not present in the canyon bottom.

As a final comparison to the available data, we contrast the model results with regional aquifer water supply well O-1. However, because contaminant transport sources from Pueblo Canyon (north of Los Alamos Canyon) were not included in this model, the conclusions related to O-1 are more qualitative. For this comparison, monitoring information published in LANL (2001) is used. Contaminants tritium, perchlorate, and nitrate are all thought to be nonsorbing in this system, and thus the combined results of all three contaminants are used in this interpretation. Well O-1 has been found to contain measurable levels of perchlorate at about a 5 ppb level, nitrate levels higher than at other regional aquifer wells in the area, and consistent, above-background levels of tritium in the 30-40 pCi/L range. All observations point to both Laboratory-derived contaminants and effluent discharges from Los Alamos County. Past releases in Los Alamos and Pueblo Canyons have traversed the entire vadose zone. The present model explains these observations as a consequence of the hydrostratigraphy along the canyon, with rapid travel times at locations where the Bandelier Tuff is thin or non-existent.

Contrast these results with the transport model for MDA G presented in Section 4.1.3.1. Most important, travel times through the vadose zone are predicted to be orders of magnitude larger

for this mesa site than for transport from the bottom of a wet canyon. These travel-time results are consistent with the site-wide vadose zone results presented in Section 4.1.2. Infiltration rates, which directly impact transport velocities, are much larger in a canyon setting, in which all water in a catchment is channeled to the canyon bottom. A significant percentage of that water will escape evapotranspiration and percolate into the deep subsurface along the canyon. In contrast, a mesa top typically provides opportunity for water to run off as surface water or to be lost as evapotranspiration. Moreover, mesa sites have thick sequences of tuff with exceptionally low matrix flow rates. Therefore, percolation rates are much lower.

4.2 Numerical Models of Flow and Transport in the Regional Aquifer

The first numerical model for the regional aquifer was developed in 1998 in support of the LANL Groundwater Protection Program (LANL 1998). A number of related models have been developed since then, in support of both the Groundwater Protection Program and the Environmental Restoration Program, at a variety of spatial and temporal scales according to the requirements of the particular model application. In general, there have been three goals for these modeling studies:

- Integrate and interpret 3-D site-wide hydrologic and hydrostratigraphic data, to provide a quantitative basis for developing and testing site-wide conceptual models.
- Predict fate and transport of contaminants in the regional aquifer, in order to optimally place monitoring wells and inform risk assessment studies.
- Provide guidance in prioritization of data collection activities, highlighting the importance of those data that could most reduce numerical and conceptual model uncertainty.

As the Hydrogeologic Workplan has progressed, the data sets supporting the modeling studies have been steadily expanding. Updating the model with larger data sets has identified weaknesses in the modeling approaches and prompted changes in the methodology. This iterative process of data collection and model update and evaluation has significantly increased our understanding of the regional aquifer.

4.2.1 Previous Numerical Models

Two models have previously been developed by the USGS for the regional aquifer of the Española Basin, the aquifer system which provides drinking water to Los Alamos, Santa Fe, and Rio Arriba counties, as well as numerous pueblos. In contrast to the LANL modeling effort, these models were developed primarily to address water supply issues—particularly impacts of pumping on streamflow. The first was developed by Hearne (1985), using a computer code he wrote himself. The second was developed by McAda and Wasiolek (1988) (and later refined by Frenzel (1995), using the MODFLOW code (McDonald and Harbaugh 1988). At present, various local and state agencies continue to refine and apply both of these models to water supply issues in this basin.

In many ways, these two models are based on a similar conceptual model of the basin aquifer. Key elements of this conceptual model are as follows: (1) most inflow to the basin occurs as recharge in the mountains flanking the basin and along stream channels within the basin, and

(2) most discharge occurs to the Rio Grande and the lower reaches of its tributaries. A smaller portion of the total inflow and outflow occurs through lateral boundaries (i.e. up to 20% discharges to the Albuquerque Basin), due to structural and topographic features that limit inter-basin flow. The conceptual models of aquifer properties assume that hydraulic conductivity is strongly anisotropic, due to laterally discontinuous bedding features in the Santa Fe Group. The aquifer behaves as confined or leaky-confined, although no large-scale confining beds or low-permeability zones have been identified.

The lateral boundaries of the two models, shown in Figure 4-10, roughly coincide with the extent of basin-fill rocks in the southern portion of the basin (south of Española). Both models use specified flux boundaries to represent losing stream channels. Recharge is applied as specified flux, either at lateral boundaries (representing mountain block recharge) or along the upper model surface (representing recharge along stream channels or areal recharge). Discharge is to the Rio Grande and lower elevations of its major tributaries (specified head and head-dependent boundaries) and to the Albuquerque Basin (specified head in the case of the McAda model).

The conceptual model shared by these models is one of a complex transition from unconfined to leaky-confined conditions at depth, caused by relatively fine-scale bedding features in the rocks that provide resistance to vertical flow. Exact numerical implementation of this complexity is virtually impossible. The Hearne and Frenzel models treat the upper surface of the aquifer as a water table condition. Aquifer properties change from unconfined (top layer) to confined (lower layers); no discrete confining layer is present. Resistance to vertical flow is represented by anisotropy factors ($Kx/Kz \sim 100 - 1000$).

One significant difference between the models is the representation of large-scale heterogeneity. The Hearne model (which only includes the Santa Fe Group aquifer) treats the aquifer as homogeneous and anisotropic, with the numerical grid aligned in parallel with the dip of the beds in the Santa Fe Group. This approach allows the model to reproduce vertical upward head gradients measured in several wells in the eastern basin. The McAda and Frenzel models apply a somewhat ad hoc zonation of aquifer properties, based loosely on pump test results and the need to achieve an adequate model calibration to the data.

Appendix 4-D, Section 3, presents a comparison of inflows and outflows (steady-state, predevelopment) between the two models, as well as more recent estimates of inter-basin flow derived from USGS studies in the Albuquerque Basin.

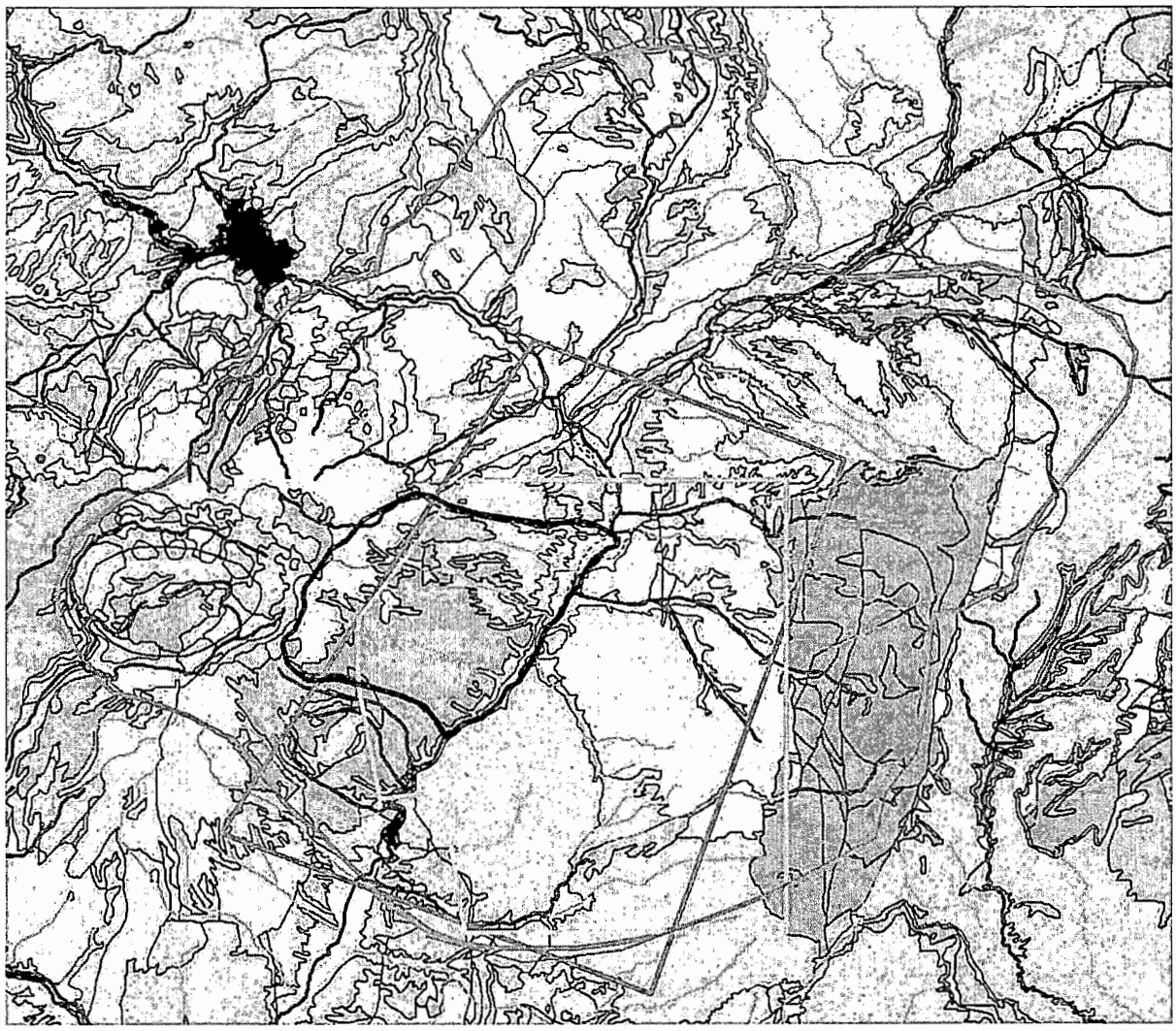

Figure 4-10. Geologic map of the Española Basin. Model outlines: green – McAda-Wasiolek model; red – Hearne model; pink – LANL basin-scale; black – LANL site-scale.

4.2.2 Overview of LANL Model Development

Unfortunately, both the USGS models of this aquifer system place a model boundary along the western edge of LANL; therefore, use of these models for the LANL site would be compromised by boundary effects (Anderson and Woessner 1992). To ensure that all model boundaries were far from the area of interest (LANL) and to incorporate the possible influences of regional flow on local conditions, a new flow model for the basin was developed. This model not only extends the western boundary farther than the existing models, to minimize boundary effects on site-scale simulations, but it also includes the major recharge areas for the basin. The inclusion of the recharge areas for the basin allows for a more comprehensive approach to estimating fluxes of water through the aquifer, as will be discussed below. The basin-scale model has been used to estimate aquifer properties, to estimate fluxes through the aquifer, to examine the possible influences of pumping in the Buckman wellfield on groundwater beneath the plateau

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(and vice versa), to understand regional trends in groundwater quality, and to provide boundary conditions to small, site-scale models.

This initial basin-scale model has undergone several revisions, including increasing grid resolution in the vicinity of LANL and improving the hydrostratigraphic framework model that governs the spatial distribution of aquifer properties. In 2000, a site-scale model for the Pajarito Plateau (see Figure 4-10) was developed with much higher grid resolution than could be achieved with the basin-scale model, and was coupled to the basin-scale model (Keating et al. 2003). The site-scale model has been used to provide contaminant transport calculations, to conduct capture zone analyses, to support monitoring well siting decisions, and to estimate groundwater velocities.

Both the basin and site-scale models have been developed to address site-scale (several to tens of kilometers) issues and this has driven model development. For example, the methods of estimating aquifer properties (Section 2.8) emphasize large-scale effective properties of rocks. These properties may be different than what might be measured at very small scales, such as injection/recovery tests over small intervals in characterization wells or borehole geophysics-based estimates. These models (and model parameters) would not be appropriate for simulating the details of fine-scale (sub-kilometer) flow and transport.

Smaller-scale models have been developed. For example, a 2-D radial model was developed to evaluate the utility of using an R-well as an observation well during a pump test at O-1. In addition, a suite of 2-D and 3-D "box" models were developed to test conceptual models of flow and transport through the highly heterogeneous strata of the Puye Formation.

A principle of model development is to begin simply and gradually add complexity as needed. Even though the models, in their current form, are quite complex, they are much simpler than the aquifer itself. A major focus of the approach has been to implement numerical strategies that are flexible, so that the impacts of conceptual model uncertainty and parameter uncertainty on model predictions can be quickly assessed within a single modeling framework, without building entirely new models.

It should be emphasized that these models are for the regional aquifer only, and therefore do not include alluvial or perched groundwaters. The current versions of the models do not explicitly include springs, so pathways and travel times to springs have not been simulated.

4.2.3 Numerical Framework

All of the LANL models have employed the FEHM code (finite element heat and mass transfer) (Zyvoloski et al. 1997), publicly available software. Underlying this code is a sophisticated grid generating software, LaGrit (Trease et al. 1996) which can capture the details of complex hydrostratigraphy known to exist at this site. For conditions of saturated flow and transport (i.e. the regional aquifer), FEHM solves the same set of equations as do other more widely used codes, such as MODFLOW. The choice of this software for the LANL models was driven by the need to couple saturated zone simulations with vadose zone simulations (which use FEHM), to represent complex hydrostratigraphy, and to eventually investigate complex geochemistry and thermal effects (ongoing work). FEHM is well suited to these types of problems, since

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temperature and density dependent fluid properties can be accurately accounted for. Some of the more simple simulations presented here do not utilize the specialized capabilities of FEHM and LaGrit; these simulations could easily be repeated using a code such as MODFLOW and one would expect the results to be identical (assuming grid resolution and boundary conditions were identical).

Figure 4-10 illustrates the lateral boundaries of the LANL models. In the basin model, boundaries were located such that they were far from the LANL site and coincided with either hydrologic features or structural boundaries. The northern and southern boundaries coincide with major structural transitions between the Española Basin and basins to the south and to the north, where the thickness of the Santa Fe Group aquifer declines from several thousand feet (in the center of the basin) to near zero at the basin margins (Shomaker 1974) (Cordell 1979). The basin is separated from the Albuquerque and Santo Domingo basins to the south by a structural high, a prong of older sedimentary rocks, and several major fault zones. The site-scale model boundaries coincide with a surface water divide (to the west), and surface water courses to the north (Santa Clara Creek), to the east (the Rio Grande), and to the south (Rio Frijoles).

Figure 4-11 illustrates generalized flow directions within the basin and locations of inter-basin flow along model boundaries. Stream gage locations are also indicated; these data are described more in Appendix 4-E.

The LaGrit software (Trease et al. 1996) was used to develop numerical meshes for the basin and site-scale models. A grid refinement algorithm was used that allows extra detail to be placed where needed in the mesh, such as in the vicinity of LANL. The most refined grid, the site-scale model, has a horizontal resolution of 125m × 125m and a vertical resolution of 12.5m in the shallow layers of the aquifer beneath LANL.

4.2.4 Hydrostratigraphy

In contrast to previous models of the basin aquifer, the LANL models define aquifer heterogeneity on the basis of a separate 3-D hydrostratigraphic framework model. This model was developed with surface geologic maps, published cross-sections, geophysical studies, and numerous well logs (see Section 2 and Carey et al. 1999). It is based on structure and lithology, rather than hydrologic data. The degree of detail present in the model is much greater beneath the Pajarito Plateau than for other portions of the basin. This is primarily because there are many more deep characterization wells on the plateau than elsewhere in the basin, but also because of the more complex volcanic and sedimentary stratigraphy of the plateau compared with most other portions of the basin (e.g., Buckman wellfield, entirely within Santa Fe Group sediments).

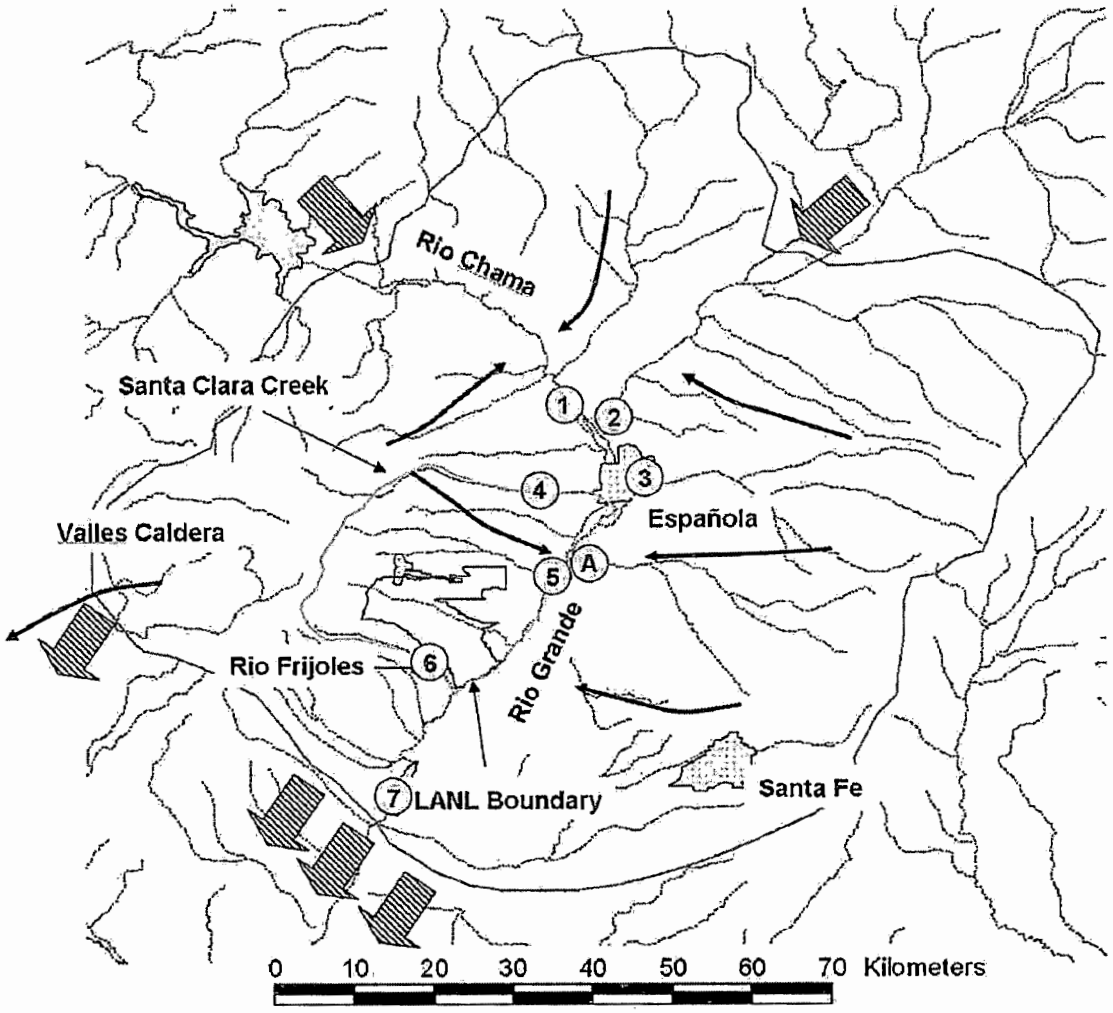

Figure 4-11. The Española Basin, with the basin-scale numerical model outline shown in red, and the site-scale model outline shown in green. Black arrows are generalized groundwater flow directions, based on regional water level data (Keating et al. 2003). Striped arrows indicate groundwater flow between this basin and adjacent basins. Circled numbers refer to USGS stream gages: (1) Rio Chama at Chamita; (2) Rio Grande at San Juan; (3) Santa Cruz River; (4) Santa Clara Creek; (5) Rio Grande at Otowi; (6) Rio Frijoles; (7) Rio Grande at Cochiti. The circled "A" indicates the mouth of Pojoaque Creek (see Appendix 4-E).

The process of overlaying the framework model on the numerical mesh for the flow and transport models has been described in Keating et al. (1999). This process assigns every node in the numerical mesh to one of the defined hydrostratigraphic units (see Appendix 4-D, Section 1). The high vertical resolution in the site-scale model is important to the representation of thin basalt flows and thin gravel beds within sedimentary units known to exist in this aquifer. The current model (September 2004) does not contain the latest update to the 3-D site-wide geologic model, which will include additional mapping from 2003 through 2005, drilling, and characterization data.

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4.2.5 Boundary Conditions

The upper boundary of the model domain represents the top of the saturated zone; these nodes are either no-flow (no recharge), specified flux (recharge), or constant head (river nodes which may either recharge or discharge to the aquifer) (see Figure 4-12). Generally, the lower boundary of the model (no-flow) is the contact between the Precambrian basement and younger rocks. An exception to this is locations where the Precambrian basement crops out (such as in the Sangre de Cristos); in these areas we sub-divide the basement into a shallow, permeable block and a lower, impermeable block.

In the current model formulation, the entire thickness of the aquifer is assigned properties consistent with leaky-confined or confined conditions ($Ss = 10^{-3.3} - 10^{-4.5}\ m^{-1}$). In the current numerical framework, unconfined conditions can be approximated by assigning the shallow layers a relatively high value of specific storage. However, changes in the thickness of the aquifer due to changes in the water table elevation are ignored. This approximation is reasonable for flow simulations in the vicinity of LANL, due to the large thickness of the aquifer (>3000 m) relative to measured changes in heads with time (30–50 m over 50 years). However, transport simulations may be sensitive to this approximation and the model is currently being modified accordingly.

4.2.6 Recharge

Recharge from the unsaturated zone is represented as a specified flux boundary condition along the top of the model. The spatial distribution of recharge across the plateau and in the larger basin is complex and inherently uncertain, since recharge rates cannot be measured directly. The model uses a simple approach to represent the spatial distribution of recharge. The advantage of this approach is that it can be easily manipulated to approximate a wide variety of recharge conditions; this flexibility allows for exploration of uncertainty in model predictions due to the inherent uncertainty of any recharge estimate. The disadvantage of this approach is that it does not capture very fine-scale detail. At present, the models have assumed that recharge is constant in time.

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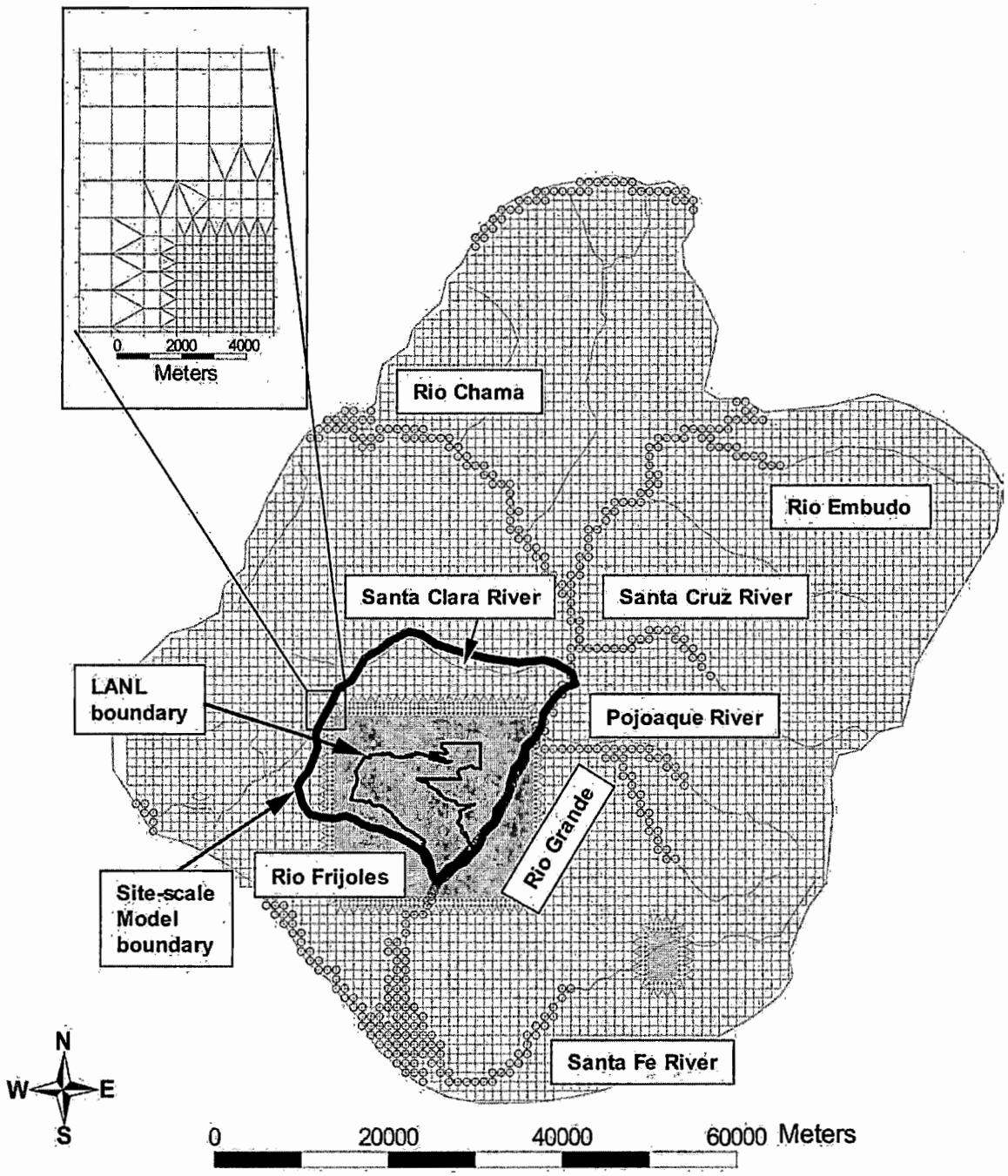

Figure 4-12. Basin model grid (plan view) with site-model boundaries indicated. The inset shows the northwest corner of the octree mesh refinement region. The circles show the locations of specified head nodes along rivers and basin margins.

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There are three types of recharge accounted for in our model: areal recharge (which occurs mostly in the mountains), perennial stream channel recharge (for major streams in the basin), and ephemeral stream channel recharge (for many of the channels on the plateau). Areal recharge is determined as a function of precipitation (which is, in turn, determined by the surface elevation and long-term average precipitation trends in the basin). The details of the recharge model are presented in Appendix 4-D, Section 2. This numerical framework can be used to generate multiple possible models of recharge. Several examples are shown for the site-scale model in Figure 4-13; these different models all impart the same total flux to the aquifer. Table 4-3 shows the parameters used for these examples. For a more extensive discussion of regional and plateau recharge distributions, see Section 2.7.3.1.

4.2.7 Discharge at Rivers and Interbasin Flow

The Rio Grande, its lower tributaries, and locations where inter-basin flow occurs (upper Rio Chama, upper Rio Grande, lower Rio Grande, and Jemez River) are modeled as specified head nodes. Model-predicted fluxes at these boundaries are described in later sections. Heads at the surface are determined using digital elevation model (DEM) data for the basin. Heads at depth along the Española Basin/Albuquerque Basin are specified in accordance with estimates of the water table elevation at this boundary and are constant with depth to the Precambrian boundary. The assumption of "specified head" along the Rio Grande is an approximation suitable for flow and transport calculations far from the river. This simplification is inadequate for addressing the details of stream/aquifer interactions at the Rio Grande and is currently being addressed.

4.2.8 Lateral Boundaries of the Site-Scale Model

The locations of the lateral boundaries of the site-scale model were selected with the expectation that fluxes across the boundaries (which are uncertain) will be small relative to the total flux through this portion of the aquifer. The basin model is used to estimate these fluxes, with estimates of corresponding uncertainty (Keating et al. 2003). Fluxes across these lateral boundaries are explicitly mapped, node by node, onto site-scale model boundaries. That analysis showed that uncertainty in fluxes into the site-scale model (from the north) and out of the site-scale model (to the south) due to basin model parameter uncertainty was relatively small. In contrast, flux uncertainty across the western and eastern boundaries was relatively large. These results are described in more detail below.

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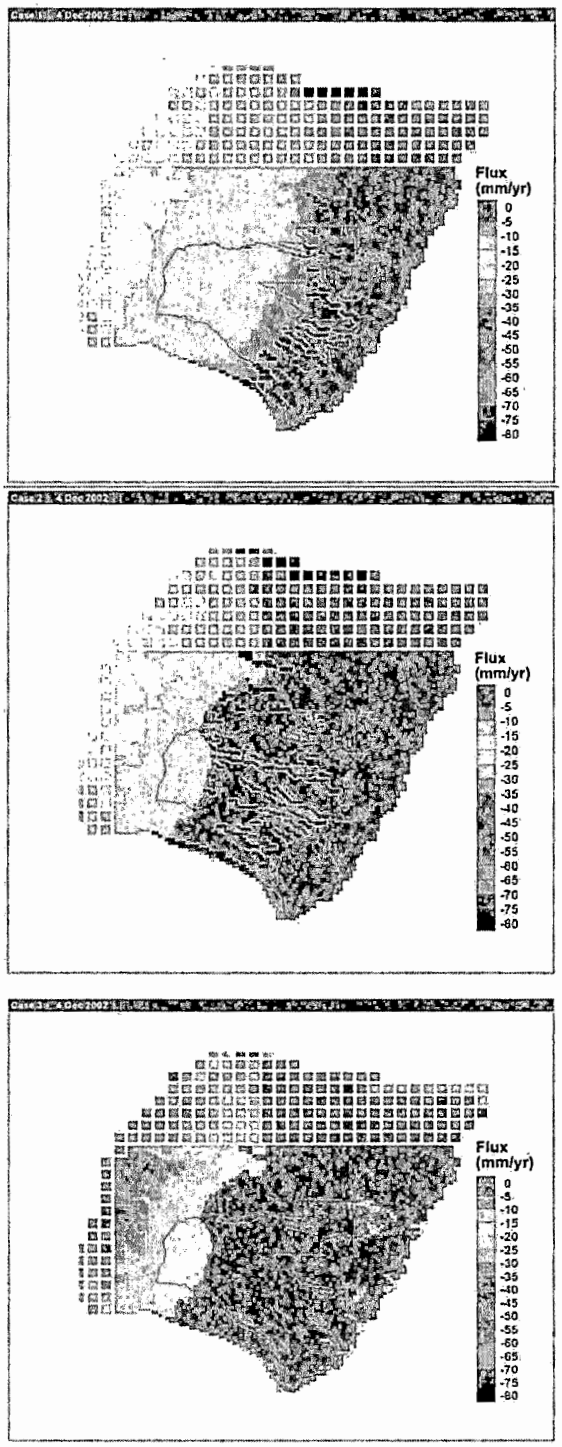

Figure 4-13. Examples of three recharge models, all imparting the same total flux. Model parameters are shown in Table 4-3.

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Table 4-3.
Example Recharge Models, Shown in Figure 4-13.

	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

4.2.9 Data Used in Model Development and Testing

The datasets used in model development and testing are as follows: water level data, well construction and location data, water supply production data, hydrostratigraphy, stream channel location and elevations, hydrologic and structural boundaries for the basin, stream gage data, and selected geochemical data. The water level data, well construction and location data, water supply production data, precipitation data, stream gage data, and geochemical data are tabulated in Keating et al. (2005). Hydrologic divides (used to define model boundaries) and stream channel location and elevations were derived from USGS DEM data. Structural and geologic transitions used to define lateral basin boundaries were derived from Kelly (1978) and Shomaker (1974).

4.2.10 Flow Model Parameters

Model inputs are recharge rates, aquifer properties (permeability, specific storage), and stress (water supply production rates). Model outputs are heads and aquifer discharge (at constant head nodes along the Rio Grande, Rio Chama, and its tributaries, the Jemez River, and lateral boundaries). Other quantities such a travel times, flow directions, and well capture zones can also be derived from the model output.

As is the case in most groundwater systems, model outputs (heads and aquifer discharge) can be measured with much greater accuracy than model inputs (recharge rates and aquifer properties). This study employs the standard techniques of inverse analysis to derive model inputs (recharge rates and aquifer properties) from model outputs (heads and aquifer discharge). This is the same procedure widely used to derive aquifer properties from pump test data. The application of this method is somewhat unusual in that it acknowledges uncertainty in recharge, a complication that is usually neglected. This analysis provides information on aquifer properties and recharge, with quantified uncertainty, which can then be used to drive forward models and produce predictions.

The methodology used for inverse analysis is described in detail in Keating et al. (2000) and Keating et al. (2003). The three sets of calibration data are (1) pre-development heads (little or no impact from pumping), (2) transient heads (1946–2003), and (3) pre-development estimates of aquifer discharge to rivers. The data are listed in Keating et al. (2005). The details of the inverse analysis have changed over time, and the calibration data set has expanded as new wells have been drilled, computational resources have improved, and the hydrostratigraphic framework model has evolved. The aquifer properties derived from this process should represent larger spatial scales than those derived from short-term pump tests (days), since the transient data set

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used represents a long period of time (55 years) and a widely spaced data set (several kilometers).

Table 4-4 illustrates several representative results for inverse analyses conducted using the basin- and site-scale models. See Keating et al. (2003; 2004) for details of these analyses. It is striking that the estimate for the lower Santa Fe Group is so much lower than pump tests conducted in the Los Alamos wellfield (completed entirely within the Santa Fe Group). This may be due to large-scale features, such as north-south trending faults, which would lower the effective permeability of the aquifer. Or this may be due to errors in the analysis or supporting datasets, such as a too low estimate of total recharge to the system. More detailed discussion of the hydrologic properties can be found in Section 2.8.

Figure 4-14 illustrates the degree of match between measured and simulated heads and fluxes at the basin scale, using the parameters shown in Table 4-4 (parameter set 1). Figure 4-15 shows the degree of match between measured and simulated hydrographs in the vicinity of LANL (parameter set 3). The magnitude of measured head response to 60 years of pumping (about 15 m in the central plateau, about 40 m to the east in the Los Alamos wellfield) is adequately reproduced, as is the recovery of heads in the Los Alamos wellfield after the cessation of pumping in 1975). Agreement between simulated and measured heads in water supply wells on a year-to-year basis is less accurate. Possible reasons for this, listed in detail in Keating et al. (2005) include both model errors and measurement errors. Improved fits would require explicit consideration of sub-annual variations in both water production and in measured water level responses.

4.2.11 Transport Model Methods and Parameters

The FEHM transport code employs one of two primary methods to simulate solute transport. The first is a particle-tracking methodology. This method can be used to simulate advection-only transport, which produces path lines and travel times that would be expected to represent the mean behavior of a conservative (non-reactive) solute plume. This method can also be used to simulate advective-dispersive transport, where thousands of particle paths are simulated and the number of particles present in any location represents solute concentrations. The second method is a direct solution of the advection-dispersion equation. This method can be used to simultaneously calculate the migration of multiple solutes, concentrations as a function of time and space, and a full suite of reactions with liquid, solid, and gas phases.

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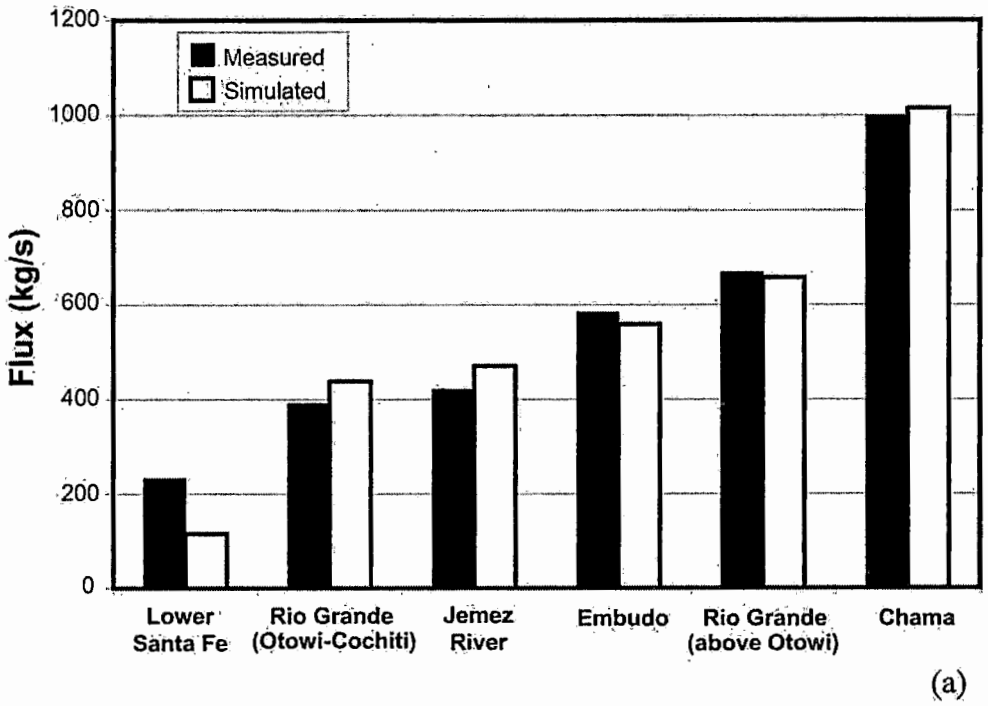
Table 4-4.
Regional Aquifer Model Parameters

		Basin Model		Site Model (2003)		Site Model (2004)A		Site Model (2004)B	
		Value	+/-	Value	+/-	Value	+/-	Value	+/-
Recharge									
	Zmin [m]	2195.0	177.0	2214.0	362.0	2156.1	14.0	2259.8	77.5
	Recharge volume [m^3]	3844.6	511.9	218.5	NA	253.7	NA	263.3	57.9
	α	NA	NA	NA	NA	0.1	NA	0.1	NA
	κ	NA	NA	NA	NA	0.0	NA	0.1	NA
Pemeabilities (log10[m2])									
Crystalline rocks	Deep Basement (pC)	-15.6	8.6	-15.6	305.9	-18.0	NA	-18.0	NA
	Paleozoic/Mesozoic	-15.0	3.2	-15.1	41.0	-13.7	NA	-13.7	NA
	Shallow Sangres	-12.6	0.2	na	NA	NA	NA	NA	NA
	Fractured pC	-13.1	0.6	na	NA	NA	NA	NA	NA
	Tschicoma Formation	-13.0	0.2	-13.0	5.8	-15.3	NA	-14.6	1.0
Keres Group	Tk (shallow)	NA	NA	NA	NA	-12.7	NA	-12.7	NA
	Tk (deep)	NA	NA	NA	NA	-13.7	NA	-13.7	NA
basalts	lumped	-12.2	0.2	-11.9	0.6	NA	NA	NA	NA
	Tb4	NA	NA	NA	NA	-16.1	6.5	-14.9	1.7
	Tb1	NA	NA	NA	NA	-12.1	NA	-13.5	0.4
	Tb2	NA	NA	NA	NA	-12.2	NA	-12.2	0.4
Puye Formation	(lumped)	-14.2	1.4	-14.4	2.7	NA	NA	NA	NA
	Tpt	NA	NA	NA	NA	-12.7	NA	-11.9	0.7
	Tpt-z	NA	NA	NA	NA	-12.7	NA	-17.5	3.2
	Tpp	NA	NA	NA	NA	-16.8	1.1	-11.9	0.3
	Tpf	NA	NA	NA	NA	-13.1	0.2	-12.9	0.7
	Tpf-z	NA	NA	NA	NA	-15.2	NA	-15.9	0.5
	Tpp-z	NA	NA	NA	NA	NA	NA	-11.0	71.9
Santa Fe Group	Tsf-fang[1]	-13.2	0.3	-13.4	0.4	-11.1	0.3	-19.0	75.0
	vertical	-15.5	0.9	-15.6	1.6	-11.4	NA	-18.4	0.6
	Tsf-sandy	-13.2	0.2	-13.1	0.3	-13.3	0.1	-13.4	0.1
	vertical	-15.0	0.4	-15.5	0.9	-14.2	0.1	-13.5	0.2
	East, Pojoaque	-14.1	0.4	NA	NA	NA	NA	NA	NA
	Airport	-12.6	0.8	NA	NA	NA	NA	NA	NA

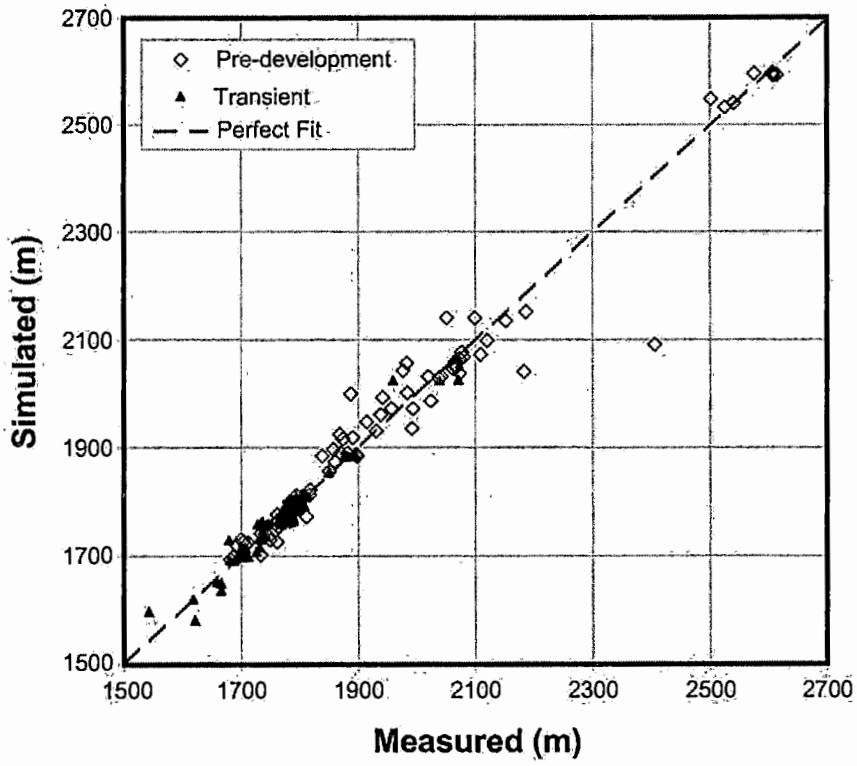
Table 4-4.
Regional Aquifer Model Parameters (continued)

		Basin Model		Site Model (2003)		Site Model (2004)A		Site Model (2004)B	
		Value	+/-	Value	+/-	Value	+/-	Value	+/-
Recharge									
	North	-13.4	0.5	NA	NA	NA	NA	NA	NA
	Ojo Caliente sandstone	-13.3	0.2	NA	NA	NA	NA	NA	NA
	Peñasco embayment	-12.4	0.3	NA	NA	NA	NA	NA	NA
	deep	NA	NA	NA	NA	-16.0	NA	-16.0	NA
	Ancha formation	-12.3	0.5	NA	NA	NA	NA	NA	NA
Pajarito fault zone		-15.3	0.8	-15.3	27.1	-15.0	NA	-13.9	1.3
Specific Storage	(Ss) log10[m-1]	-3.9	0.4	-3.6	0.5	-4.3	0.1	-3.8	0.3

[1]referred to as Tsf-uv in earlier models
NA = not applicable



(a)



(b)

Figure 4-14. For the basin-scale model, comparison between measured and simulated (a) fluxes; (b) heads.

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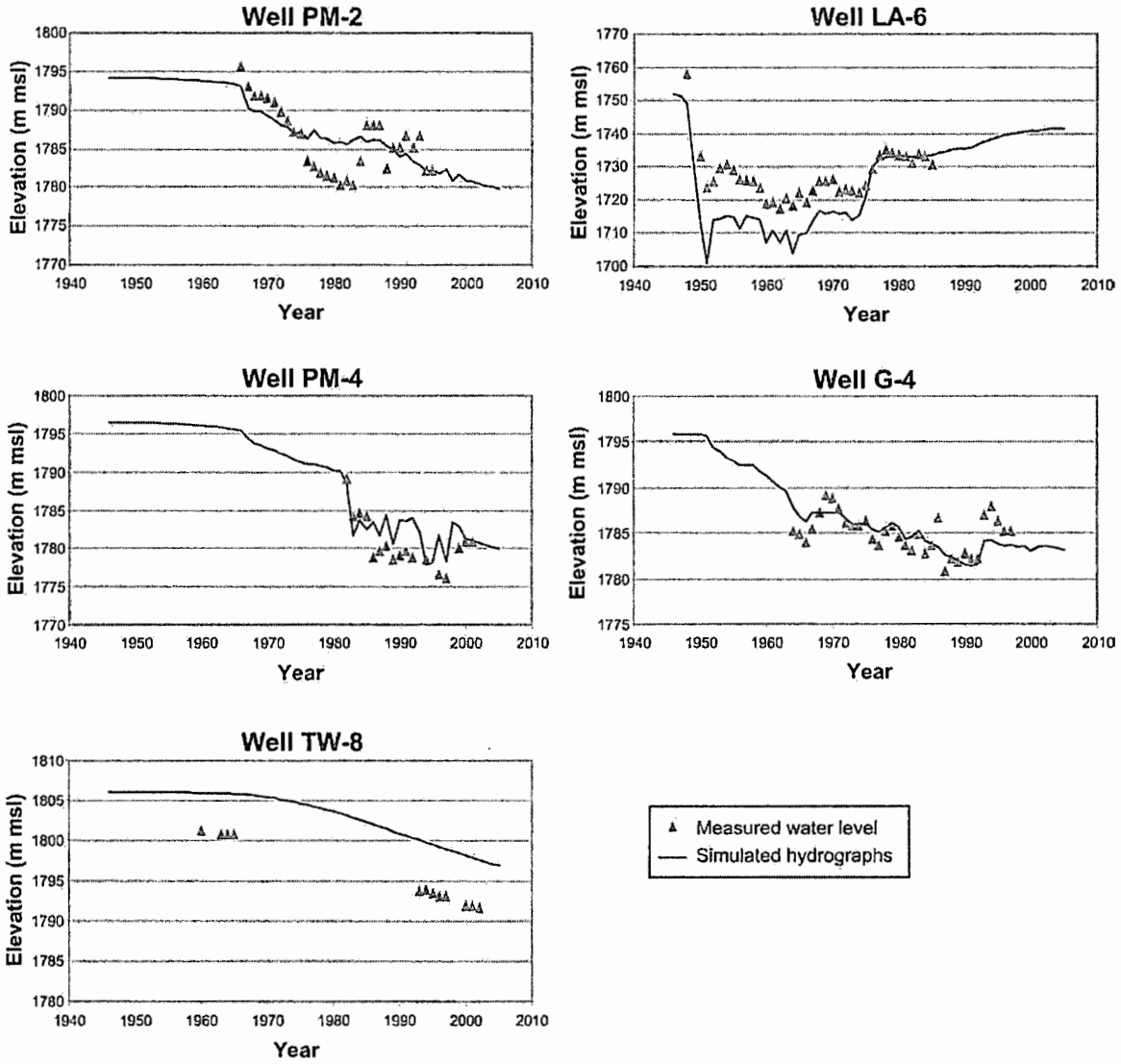

Figure 4-15. Comparison of simulated and measured hydrographs for representative wells on the plateau.

For nonreactive chemistry simulations, the particle-tracking methodology is preferable because it avoids the problem of numerical dispersion. Most of the analyses presented here use this method. One important limitation of this method is that the solution is invalid in portions of the numerical grid where elements are nonorthogonal (see Appendix 4-D, Section 1, Figure 4-D-2). However, in these calculations we restrict our analysis of particle-tracking paths to the fine-grid region at the site scale, thereby avoiding the problem.

Two critical parameters for nonreactive transport simulations are rock porosity (which is linearly proportional to travel time) and dispersivity (which controls the degree of spreading and mixing). Neither of these types of data has been collected in this aquifer at scales meaningful for site-scale transport simulations. Therefore, the model uses literature-derived values appropriate for the types of rocks present in this aquifer.

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4.2.12 Model Applications

There have been three broad categories of model applications. The following subsections present brief examples of modeling studies for each category.

4.2.12.1 Category A: Integrate and interpret 3-D site-wide hydrologic and hydrostratigraphic data, to provide a more quantitative basis for testing site-wide conceptual models than was previously possible.

Many of the fundamental issues pertaining to the regional aquifer are questions that cannot be answered using data collection alone. Where are the predominant recharge areas? How much water is flowing through the aquifer? What are the large-scale hydraulic properties of the aquifer rocks? In what direction is water flowing? What is the pore water velocity of the groundwater? What effect has pumping had in the past and what effect will it have in the future? A great deal of characterization data has been collected over the past few years to address these questions, and the numerical models have been used as a framework for interpreting these data and providing at least partial answers to these questions.

1. Large scale fluxes. Keating et al. (2003) demonstrated the use of inverse and predictive analysis to examine the range of possible fluxes and recharge distributions that could explain the measured head data and stream gage data at the basin-scale. This approach acknowledges the uncertainty in aquifer properties and recharge rates, and attempts to determine to what extent quantitative estimates can be made. The aquifer property estimates that resulted from this approach, with uncertainty, are presented in Table 4-4 (parameter sets 1 and 2); the degree of agreement between measured and simulated heads and base flow gains are presented in Figure 4-14.

As shown in Figure 4-14, this analysis demonstrates that the basin-scale model provides a reasonable fit to measured head gradients and discharge to river reaches. The estimated elevation above which significant areal recharge occurs (2195 m, shown as a red line in Figure 4-16) matches almost exactly the location of the transition proposed by Wasiolek (1995). In addition, the estimated percent of precipitation that becomes recharge in the mountains (8%) falls within, although close to the low end of, the range of watershed study results (Appendix 4-E). The predicted outflow to the Albuquerque Basin of 5,801 acre feet per year (afy) is less than previous USGS studies of the Española Basin (McAda and Wasiolek 1988) and more recent studies of the Albuquerque Basin (14,300 afy) (Plummer et al. 2004). This value could be increased by increasing the percent of precipitation that becomes recharge and still be within the range of reasonable values. These results generally support the conceptual model of total basin-scale recharge and discharge fluxes (tabulated in Appendix 4-D and Appendix 4-E), as well as the generalized spatial distribution of fluxes simulated with the recharge model described in Appendix 4-D, Section 2. It also demonstrates the value, at least at large scales, of the 3-D hydrostratigraphic framework model.

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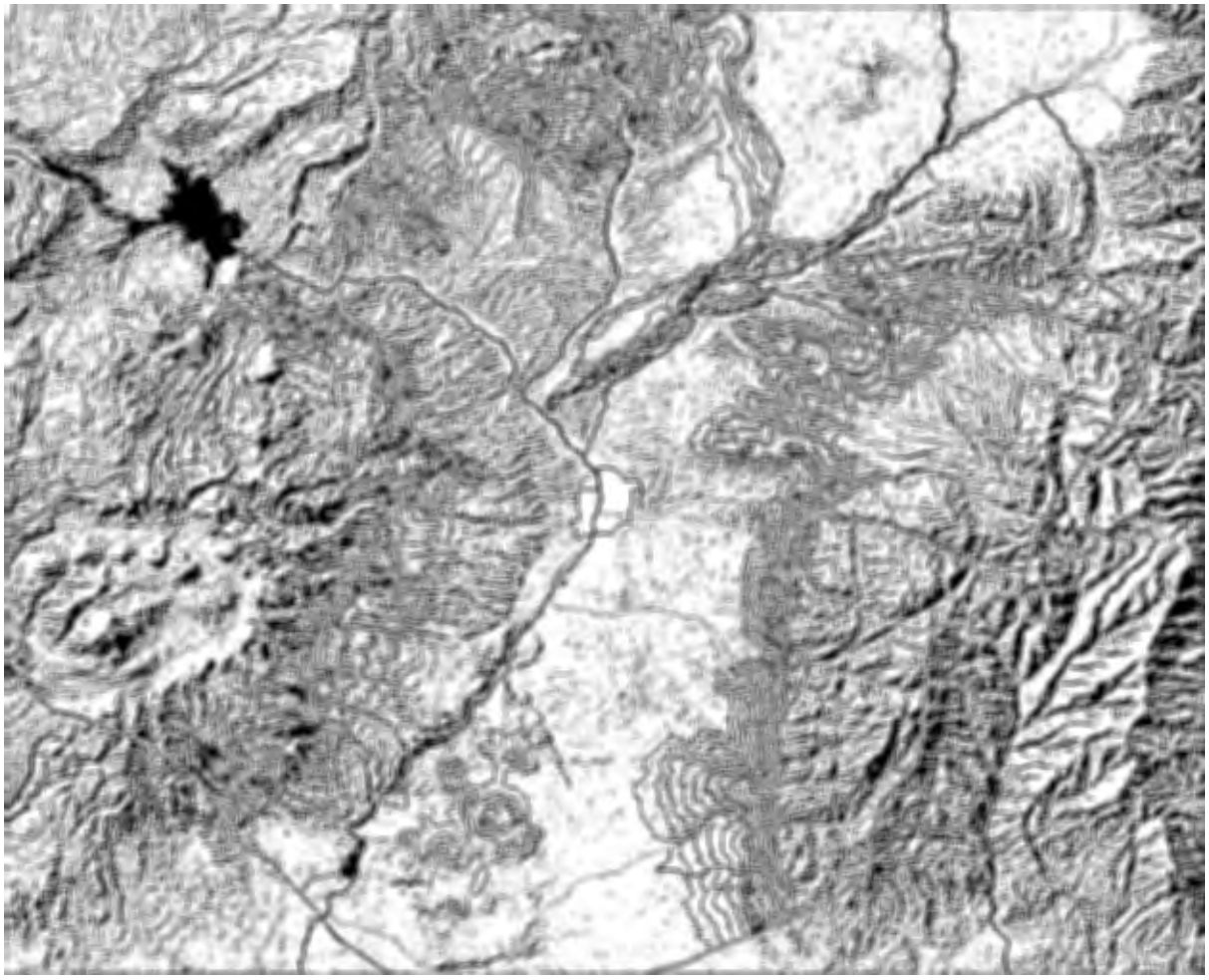

Figure 4-16. Location of predicted transition between significant areal recharge and negligible areal recharge (2195 m), and uncertainty bounds. Pink contours span the elevation uncertainty range.

The results of the basin-scale inverse analysis were used to estimate fluxes across the lateral boundaries of the site-scale model, with uncertainty. Figure 4-17 shows the results of this analysis. Fluxes perpendicular to flow (north and south) were calculated to be relatively small and showed much less uncertainty than fluxes parallel to flow (east and west). Significant flux is predicted to cross both the western and eastern boundaries; the high uncertainty of these estimates, however, means that this uncertainty should be explicitly considered when doing transport calculations that might be affected by these fluxes.

All these results depend on the streamflow analyses being reasonably accurate, the 3-D geologic model capturing the most important large-scale hydrologic features in the aquifer, and the method of inverse analysis fully exploring parameter uncertainty. This technique only explores the impact of numerical model parameter uncertainty; overall uncertainty in recharge and fluxes, which would include conceptual model errors, is undoubtedly larger.

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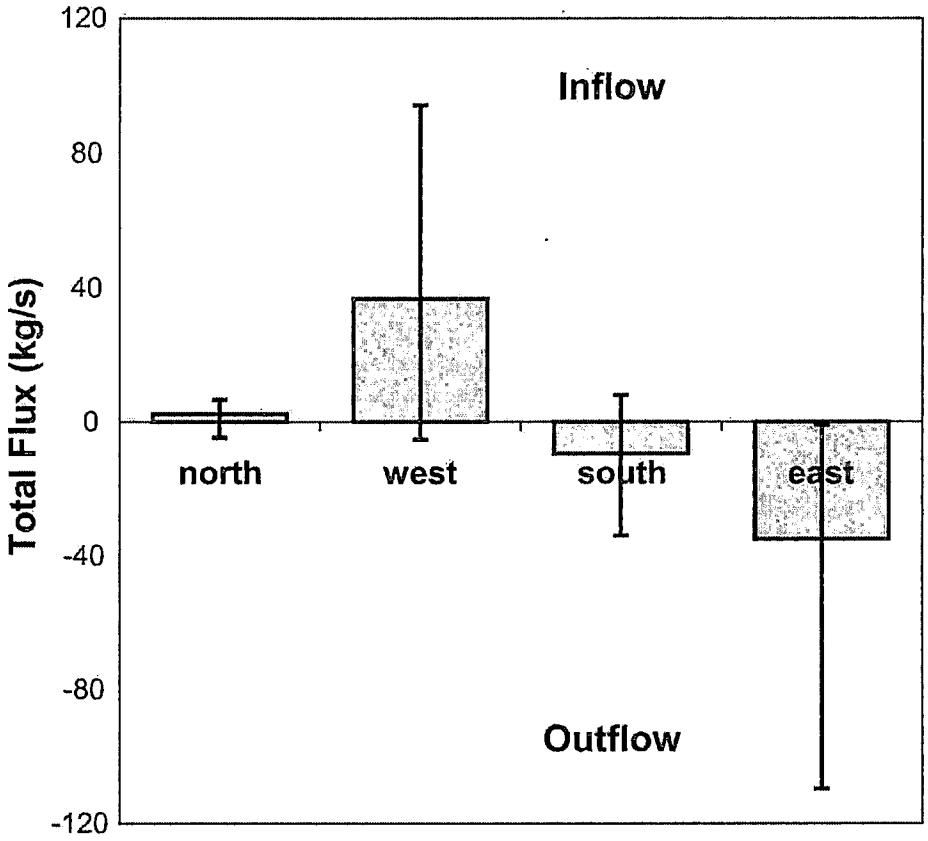

Figure 4-17. Fluxes across lateral site-model boundaries predicted by the calibrated basin model. Error bars represent the 95% nonlinear confidence intervals of estimates.

2. Small-scale fluxes, downgradient of LANL. A more recent study, Keating et al. (2004), used similar techniques to explore not only the question of uncertainty of total flux through the aquifer, but also uncertainty in fluxes through shallow portions of the aquifer immediately downgradient of LANL. This analysis is pertinent to estimates of contaminant transport away from the site. Figure 4-18 shows that parameter uncertainty in the site-scale model (including uncertainty in recharge rates and aquifer properties) contributes significantly to estimates of total recharge for the aquifer, but that the flux through the shallow portion of the aquifer immediately downgradient of the site is more certain. More detailed study of this result did highlight the large uncertainty in fluxes through a single basalt unit, however. Uncertainty in transport parameters, such as porosity, would produce a much larger impact on total velocity uncertainty; therefore, this study suggests that better measurement of fluxes and recharge would be of far less value than collecting site-specific estimates of porosity.

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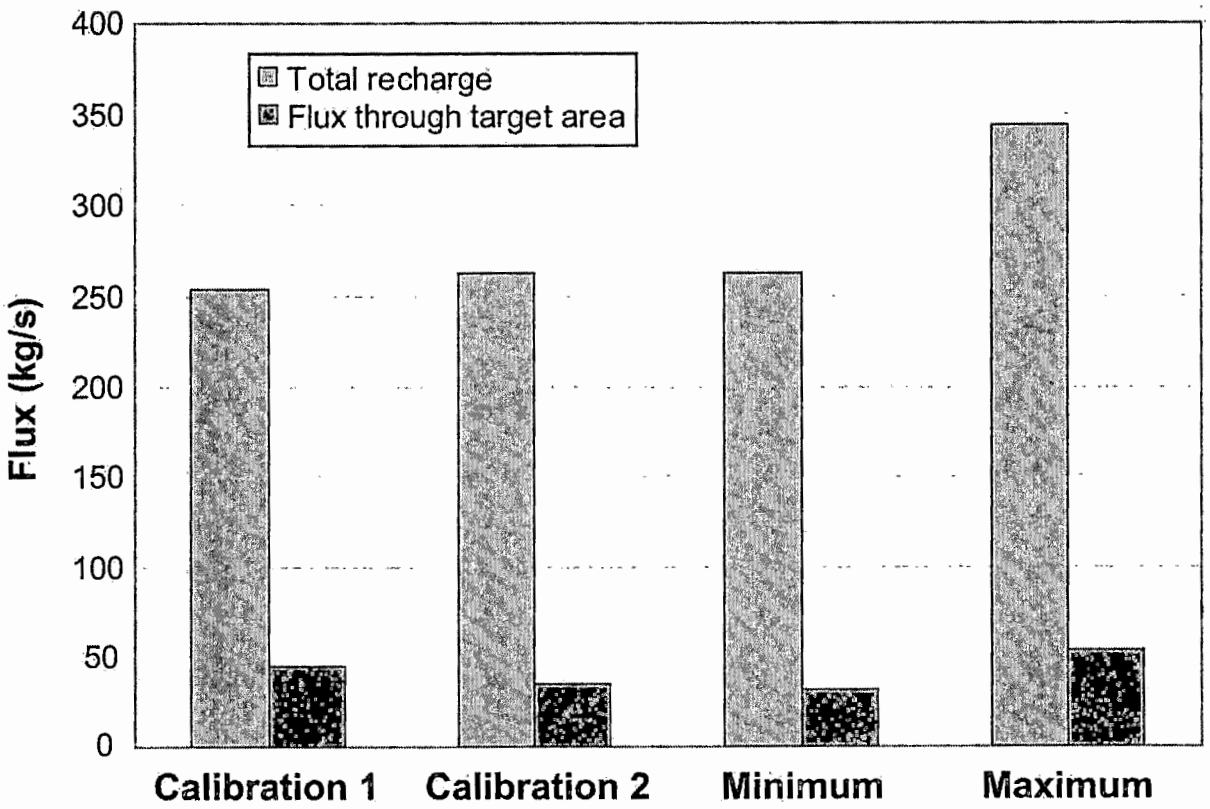

Figure 4-18. Results of predictive analysis, compared to two calibrated models. Blue bars indicate total recharge into the aquifer; red bars indicate flux through the shallow plane east of LANL.

3. Pore-water velocity. Pore-water velocities in the regional aquifer are very poorly constrained. Through modeling techniques described in this report, flow directions and fluxes can be surmised reasonably well, but velocities are very difficult to infer from hydrologic data alone. Contaminant distributions within the regional aquifer have been useful for identifying the location of fast pathways through the vadose zone, but since the exact location and timing of contaminant entry to the water table is highly uncertain, these observations do not constrain velocities in the regional aquifer. The best method for determining velocities is tracer tests.

The LANL model was used to produce a map of velocities at the water table (see Figure 4-19). These velocities are highly uncertain and are used only to illustrate a few key points. First, given the heterogeneous nature of the aquifer, groundwater velocity is likely to vary considerably over short distances. In this map, the fastest velocities are in the basalts where fracture flow (very low matrix porosity) is assumed. Second, flow on the eastern portion of LANL is predicted to be very slow. This is due to the very low permeability of the Santa Fe Group, which is prevalent at the water table east of LANL (see Table 4-4, Figure 2-10, and related discussion in Section 2.8.7).

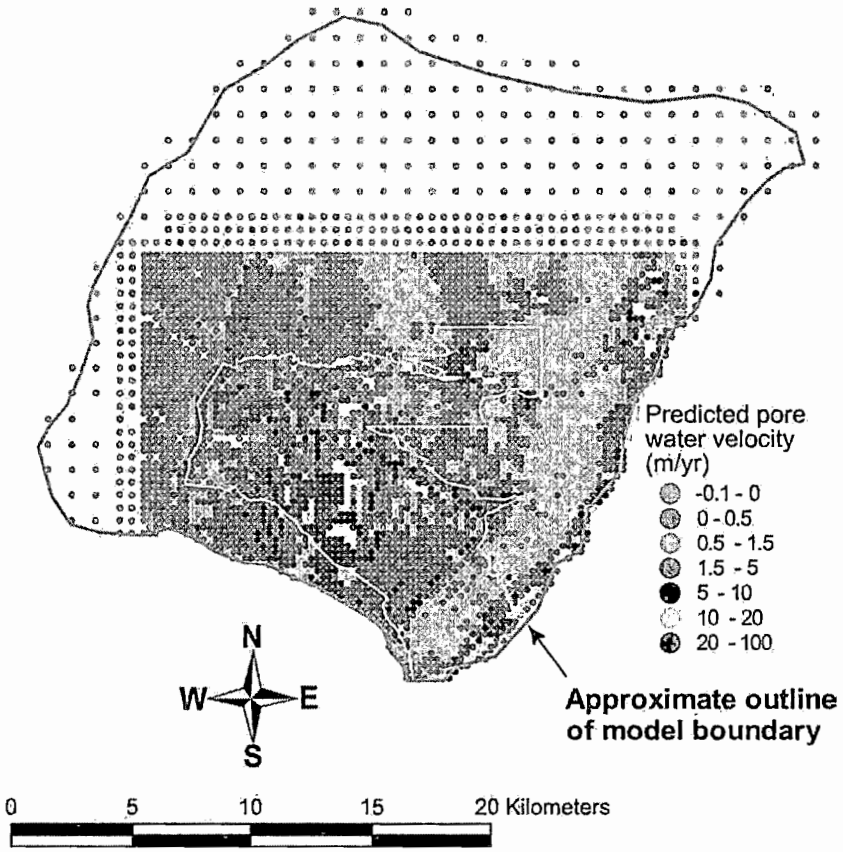

Figure 4-19. Model-predicted horizontal component of pore-water velocity at the water table, in m/yr.

The very slow velocities predicted by the model are consistent with ^{14}C data presented by Rogers et al. (1996a,b). These data are collected in both water supply wells (screened over the upper 2000 ft of the aquifer) and more shallow wells (DT5A, east side and west side artesian). Figure 4-20 shows a comparison of model predicted ^{14}C and measured ^{14}C presented by E. Kwicklis in Keating et al. (2000). One interesting aspect of this comparison is that the model underpredicts the age of the very old waters present near the Rio Grande.

In stark contrast to these predictions, Purtymun et al. (1984) produced a generalized map of pore-water velocity in the regional aquifer. His estimates assumed a uniform hydraulic gradient of 0.01 m/m, a uniform porosity of 0.1, and 1-D lateral flow. Using a 1-D version of Darcy's Law and hydraulic conductivity estimates from local pump tests, his resulting velocities ranged from 20 ft/yr (Los Alamos wellfield) to 345 ft/yr (DT wells). Assuming the high velocity estimate of 345 ft/yr, this would represent a travel time of 134 years across LANL from west to east (~9 miles). McQuillan (2003) used the chemistry data from White Rock Canyon Springs and TW-1 and an assumption of 1-D lateral flow to derive a velocity estimate of 358 ft/year (59 year travel time, ~4 miles). More recently, a report by Rice (2004), concurred with these earlier estimates.

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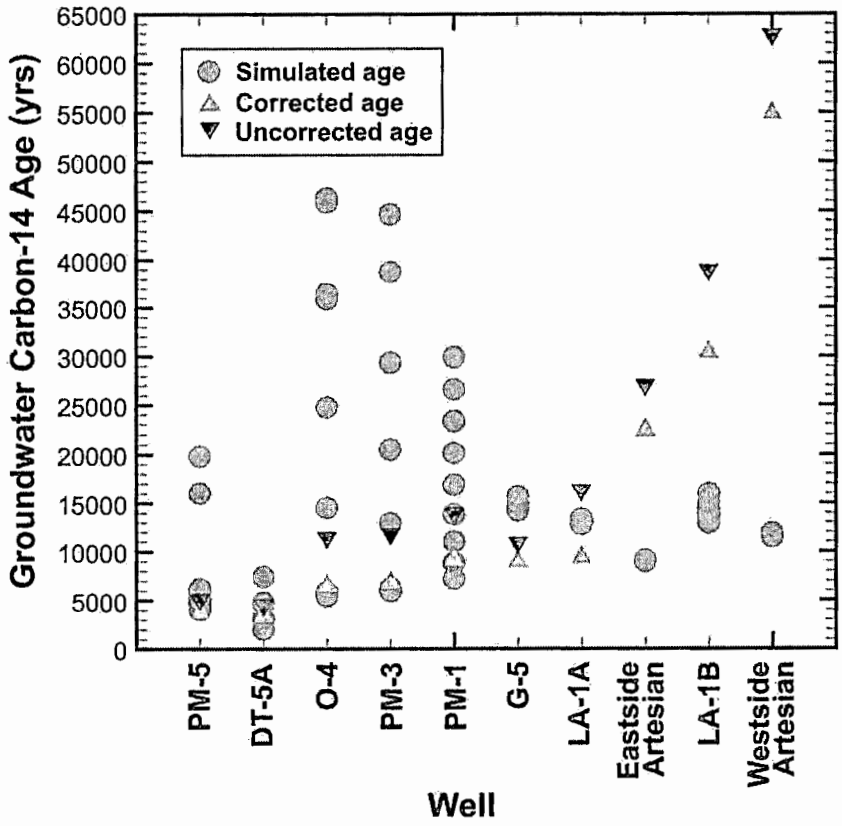

Figure 4-20. Comparison of simulated groundwater carbon-14 ages at nodes within the screened depths of wells with the corrected and uncorrected groundwater ages estimated from measured carbon-14 activities.

At present, it is impossible to compare the McQuillan and Rice calculations to the published LANL regional model predictions, because in the model (as configured for past applications) the springs are above the top of the model and therefore flow to the springs cannot be simulated. This is a subtle but very important distinction because the top of the model at present is entirely within the low-permeability Santa Fe Group in the vicinity of the Rio Grande, whereas slightly higher elevations (which include the springs) are within the more permeable units of the Puye Formation. Some springs also issue from the base of the Cerros del Rio lavas. If transport calculations to the springs are required in the future, minor adjustments to model boundaries will suffice to address this issue.

A more difficult question is that of measured hydraulic head gradients and lateral continuity of highly permeable rocks. The model honors measured gradients (in 3-D), the 3-D hydrostratigraphic framework model, and large-scale effective properties of rock units (see Table 4-4). At present, neither the measured 3-D hydraulic heads nor the permeability/hydrostratigraphy information supports the hypotheses presented by McQuillan and Rice. In such a complex aquifer, however, it is entirely possible that their hypotheses could be correct.

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4. Effect of water supply well production

Capture zones. Understanding the influence of water supply production on the aquifer is important from the perspectives of both water supply and contaminant transport. From a water supply perspective, it is very important to know if the current rates of withdrawal are sustainable. From a contaminant transport perspective, an understanding of capture zones is critical to placement of a "sentry" well to protect a production well and to identification of which receptors are most at risk of contamination.

The LANL models have been used to evaluate the impact of water supply production in a number of studies. The philosophy of this approach has been to start simply and gradually add complexity only when needed. In a sense, all of these studies have illustrated the shortcomings of applying "simple" textbook methods of capture zone analysis to this site. Therefore, this is very much an ongoing study.

Using a relatively simple approach, Vesselinov et al. (2002a) calculated capture zones for the Buckman wellfield and all the Los Alamos wells. The motivation for this study was to determine if the LANL aquifer was within the capture zone for the Buckman wells, either at present or (possibly) in the future. This analysis was based on the standard "steady-state" assumption. The results, shown in Figure 4-21, demonstrated that a significant portion of the aquifer beneath LANL could eventually be captured by the Buckman wells. These results also showed the zones of influence of Los Alamos County water supply wells.

The assumptions inherent in this analysis are that current rates of production in water supply wells continue indefinitely until steady state is reached. Given the characteristics of this aquifer, this is not expected to occur for several hundred years from the present. Some wells in the Guaje field and some wells in the Pajarito field (PM-2, -4, and -5) appear to be stabilizing with respect to pumping; the assumption of steady-state may be applicable to these wells. However, given the dramatic fall of water levels in the Buckman wellfield over the past two decades, steady-state is far in the future. Given the uncertainties of water production over the next few decades (e.g. City of Santa Fe is expected to rest the Buckman field beginning in 2009, the steady-state approximation is questionable for this wellfield. It does, however, show one possibility that should be considered for planning purposes.

Vesselinov and Keating (2003) investigated the impact of dispersion and transients on capture zones analyses. Figure 4-22 shows the predicted capture zones when both dispersion (spreading of the plume) and transients (changes in source term and changes in water supply production) are included in the analysis. These authors concluded that significant errors were incurred when dispersion and/or transients were neglected in the analysis. The importance of transients (changing flow field in response to changing water production rates) highlights the importance of identifying when and where contaminants might reach the water table. For the same point of entry to the water table (for example, beneath Ten Site Canyon), a contaminant reaching the aquifer in 1960 might be captured by PM-1, whereas a contaminant reaching the aquifer in 1990 might be captured by PM-5.

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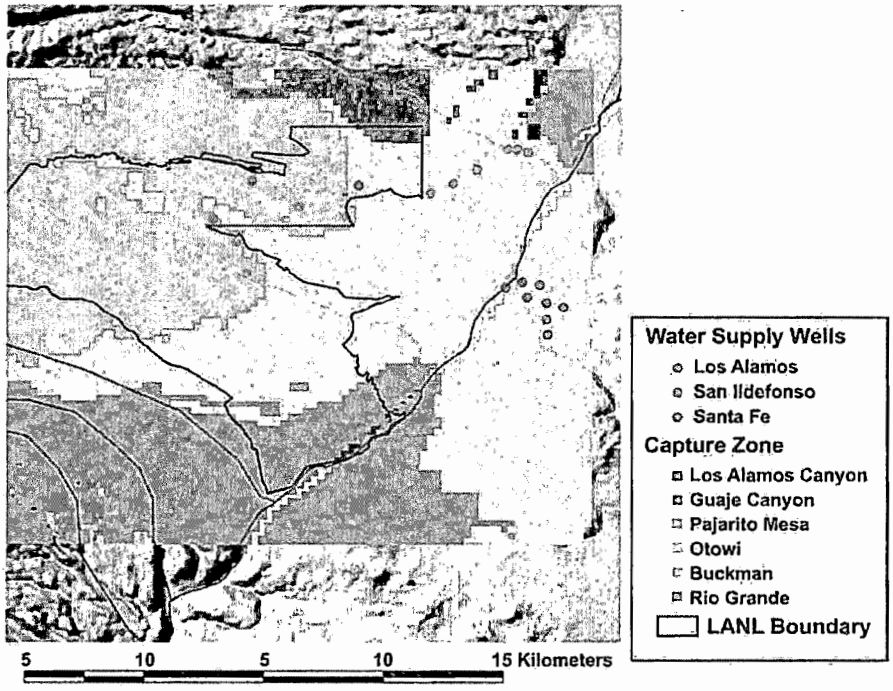

Figure 4-21. Predicted steady-state capture zones for wellfields in the vicinity of Los Alamos (from Vesselinov et al. 2002a).

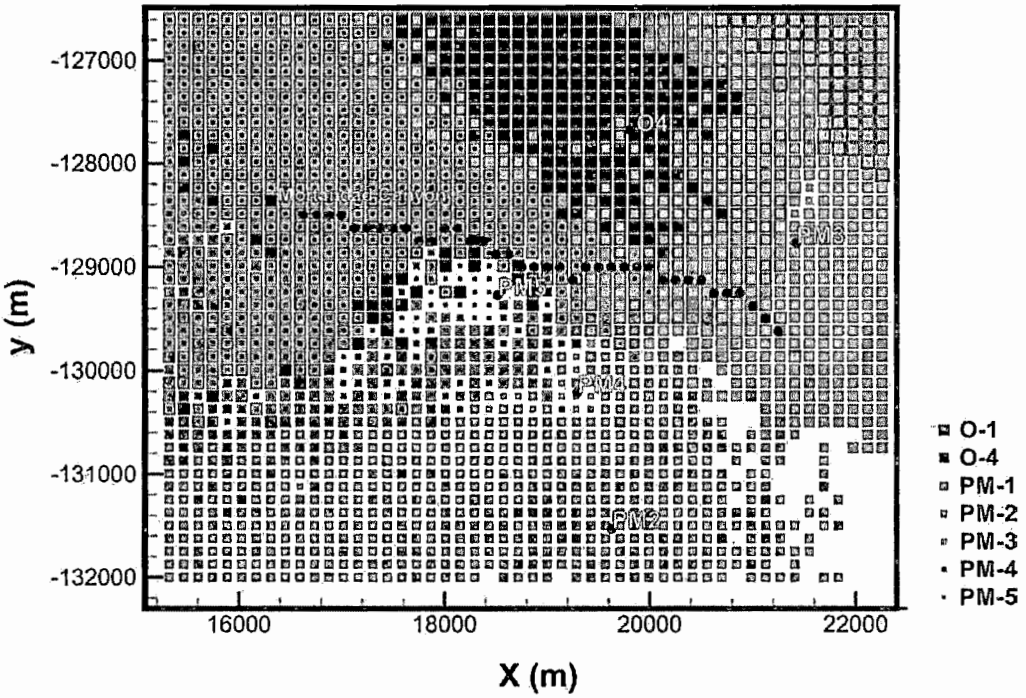

Figure 4-22. Predicted transient capture zones for wellfields in the vicinity of Los Alamos from Vesselinov and Keating (2003).

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Effect on streamflow. In a basin such as the Española Basin, where surface water flow depends to a large degree on groundwater discharge, any water supply production will affect aquifer storage immediately and surface water flow eventually. When the aquifer reaches equilibrium with respect to pumping, the only continued impact will be on surface water flow. Wells drilled near the point of discharge will have a significant effect on surface water flow sooner than wells drilled far from the point of discharge.

Based on parameters shown in Table 4-4 (parameter set 3), the site-scale model was used to predict the percentage of produced water coming from storage and captured streamflow (or recharge) over the past 50 years. Figure 4-23 shows these results, demonstrating that the aquifer is still far from steady-state and that most produced water is still coming from storage.

5. Hydrostratigraphy. All of the studies listed above rely on the 3-D hydrostratigraphic framework model to define heterogeneity within the aquifer, according to the spatial distribution of approximately 15 units. Of course, with relatively sparse boreholes on the plateau there is uncertainty in the exact spatial extent of these units (Section 2.4.4). There also may be important heterogeneities within the hydrostratigraphic units as defined by the 3-D model.

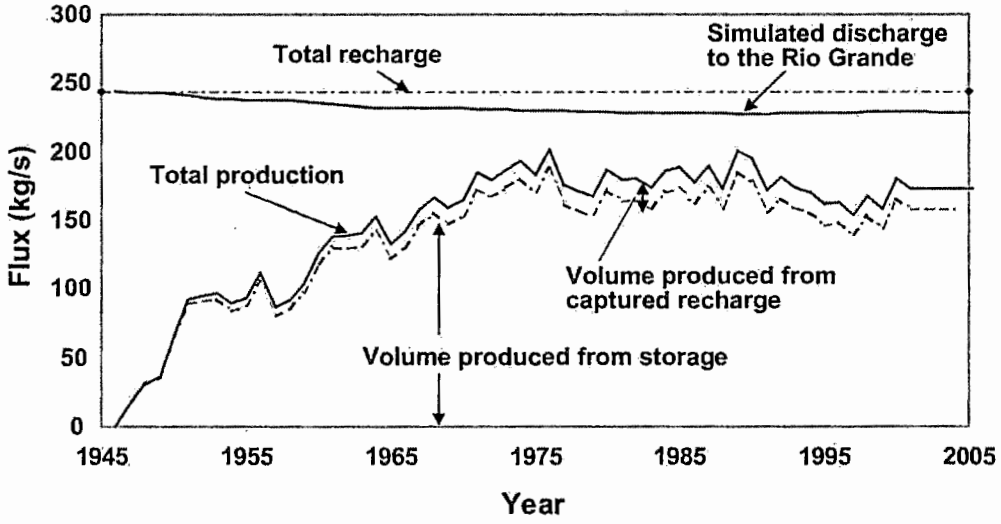

Figure 4-23. Simulated discharge to the Rio Grande, and estimated proportion of production in local wellfields that originates as storage and as captured recharge.

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This study has devoted considerable effort to modeling heterogeneity within the Puye Formation at scales smaller than the 3-D hydrostratigraphic framework model. The Totavi Lentil is of particular interest, since it is characterized by beds of gravel which may be highly permeable. (Note: In situ hydraulic tests have been equivocal on this issue.) The current hydrostratigraphic framework model defines the Totavi Lentil as a continuous sheet of rock at the base of the Puye Fanglomerate; therefore model predictions that assign this unit a high permeability will be conservative (fastest travel times over long distances). Reneau and Dethier (1995) proposed a very different model of the Totavi Lentil, as a series of discontinuous north-south trending ribbons, separated from each other by terraces left behind as the Rio Grande downcut and moved westward over geologic time. Stochastic methods are appropriate for representing this type of heterogeneity, since the exact location of each of these narrow ribbons could never be known. Figure 4-24 illustrates one realization of a stochastic model of the Totavi Lentil, using Markov-chain transition probabilities based on data collected from geologic maps and measured outcrops (Carle 1996; Fogg 1989). This approach, and the data set that underlies it, are described in detail in Keating et al. (2000).

The Santa Fe Group (Tsf) has some intercalated Miocene basalts (Tb2; see cross-sections in Figures 2-12 to 2-19). To examine two extreme end-members, one might consider hypothetical cases where the deeper unit is either 100% Tsf or 100% Tb2. In 2002 a version of the framework model was created that explicitly identified zones that were uncertain, due to sparse borehole control. Figure 4-25 illustrates one such zone, which might be either a basalt or the Santa Fe Group. Figure 4-26 shows the resulting capture zone predictions, first assuming that zone is a basalt and then assuming that zone is the Santa Fe Group. By comparing the two figures, one can determine the impact of uncertainty of the hydrostratigraphy in this zone.

The Puye Fanglomerate also has beds of sand and gravel which, although of limited spatial extent, may be important in contaminant transport. Using textural descriptions from lithologic logs in R-wells, two different stochastic models of this type of heterogeneity were developed, as shown in Figures 4-27 and 4-28. Both of these methods show promise for use in future simulations.

The model calibration process itself can provide useful information about hydrostratigraphy. For example, if the conceptual model is that unit A is high permeability and unit B is low permeability, through the process of model calibration one can determine whether or not that conceptual model is consistent with large-scale head and flux data. This principle was used to test the conceptual model of a north-south trending high-permeability trough within the upper Santa Fe Group, proposed by Purtymun (1995). Carey et al. (1999) formulated this trough within the 3-D framework model as a fairly narrow feature (Figure 4-29a). Through the model calibration process, it was determined that this geometry was consistent with site-wide hydrologic data. Later, in a 2002 update of the 3-D framework model, this feature was significantly enlarged (Figure 4-29b). It was not possible to calibrate a model that assigned a high permeability to this large feature, so this model was discarded. These results suggest that the high permeability trough is likely to either be small, such as shown in Figure 4-29a, or exist as small, discontinuous patches.

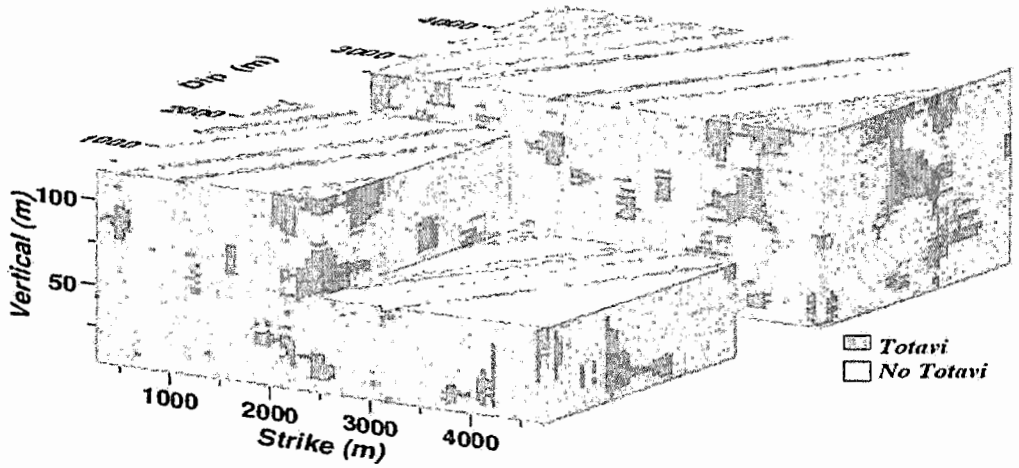

Figure 4-24. Heterogeneity within the Puye Formation; one realization of a stochastic Markov-chain model of the Totavi Lentil (dark pink). Model parameters are based on surface geologic maps and measured outcrops.

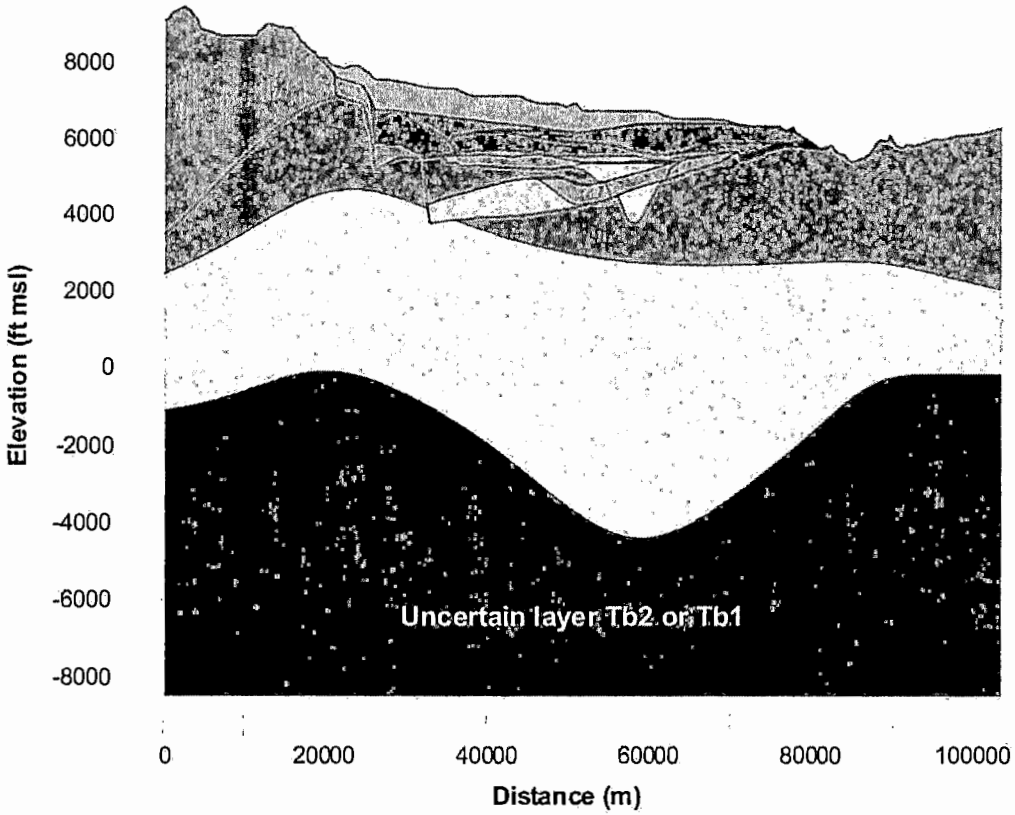

Figure 4-25. Cross section through hydrostratigraphic framework model, showing location of layer selected to perform a sensitivity analysis exploring the uncertainty in the geologic framework. The uncertain zone in pink was assumed to be either Tb2 or Santa Fe Group for the purpose of examining sensitivity.

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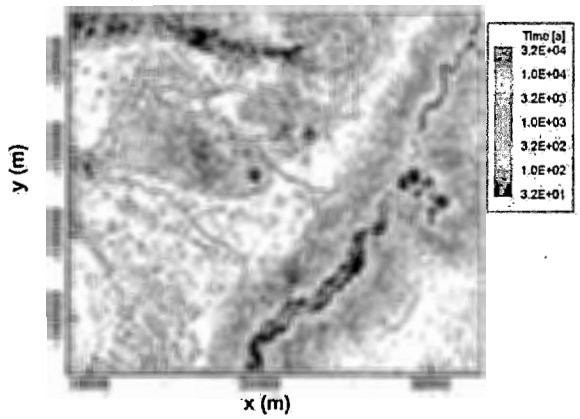
(a) assumes uncertain layer in basalt



(b) assumes uncertain layer in Santa Fe Group

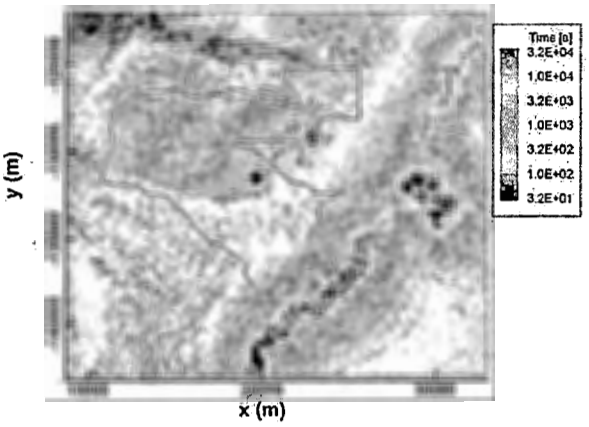


Figure 4-26. Predicted steady-state capture zones for wellfields in the vicinity of Los Alamos, using two different alternative models of hydrostratigraphy.

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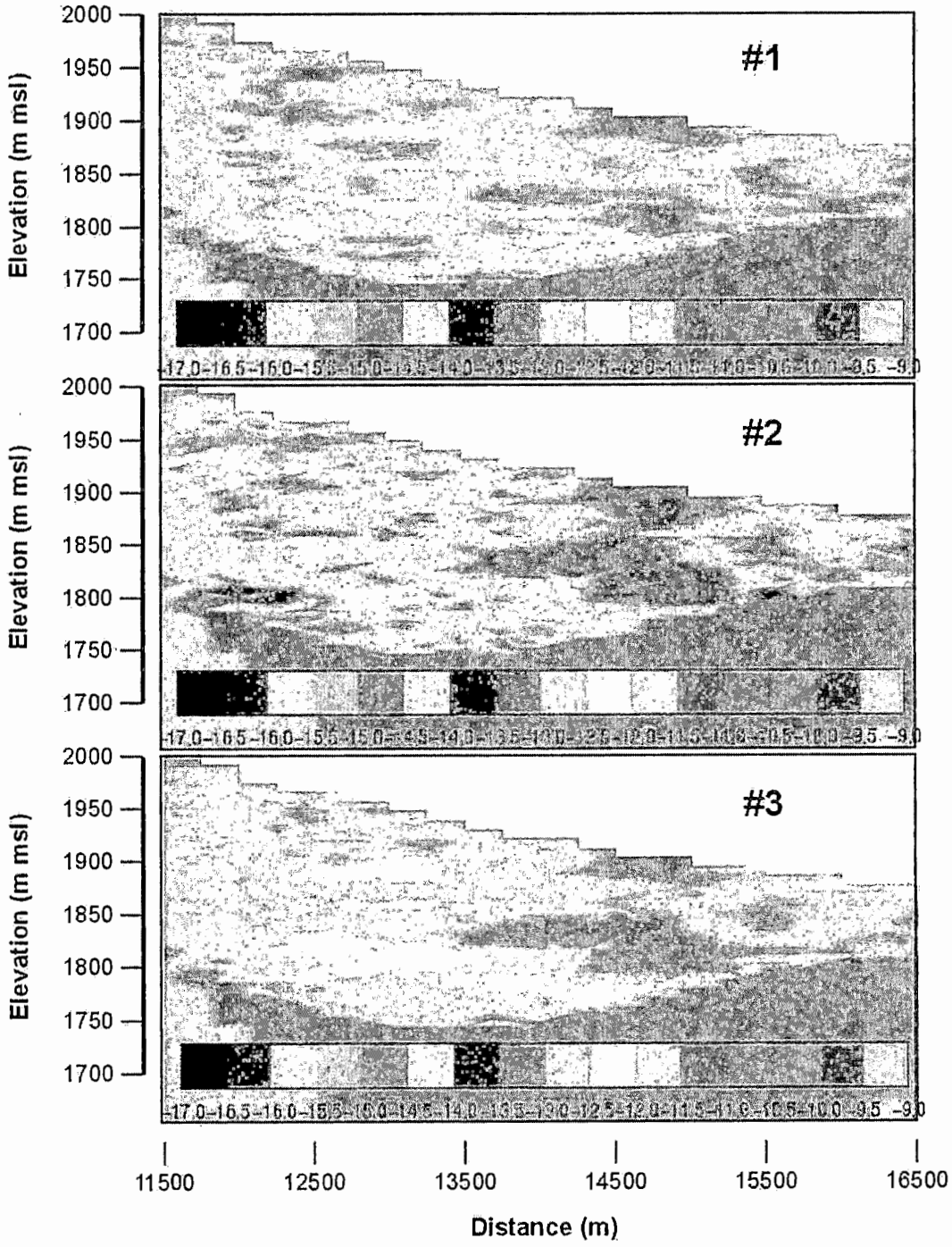

Note: 5X Vertical exaggeration. Color scale represents K in m^2.

Figure 4-27. Heterogeneity within the Puye Formation; three realizations of a stochastic Gaussian model.

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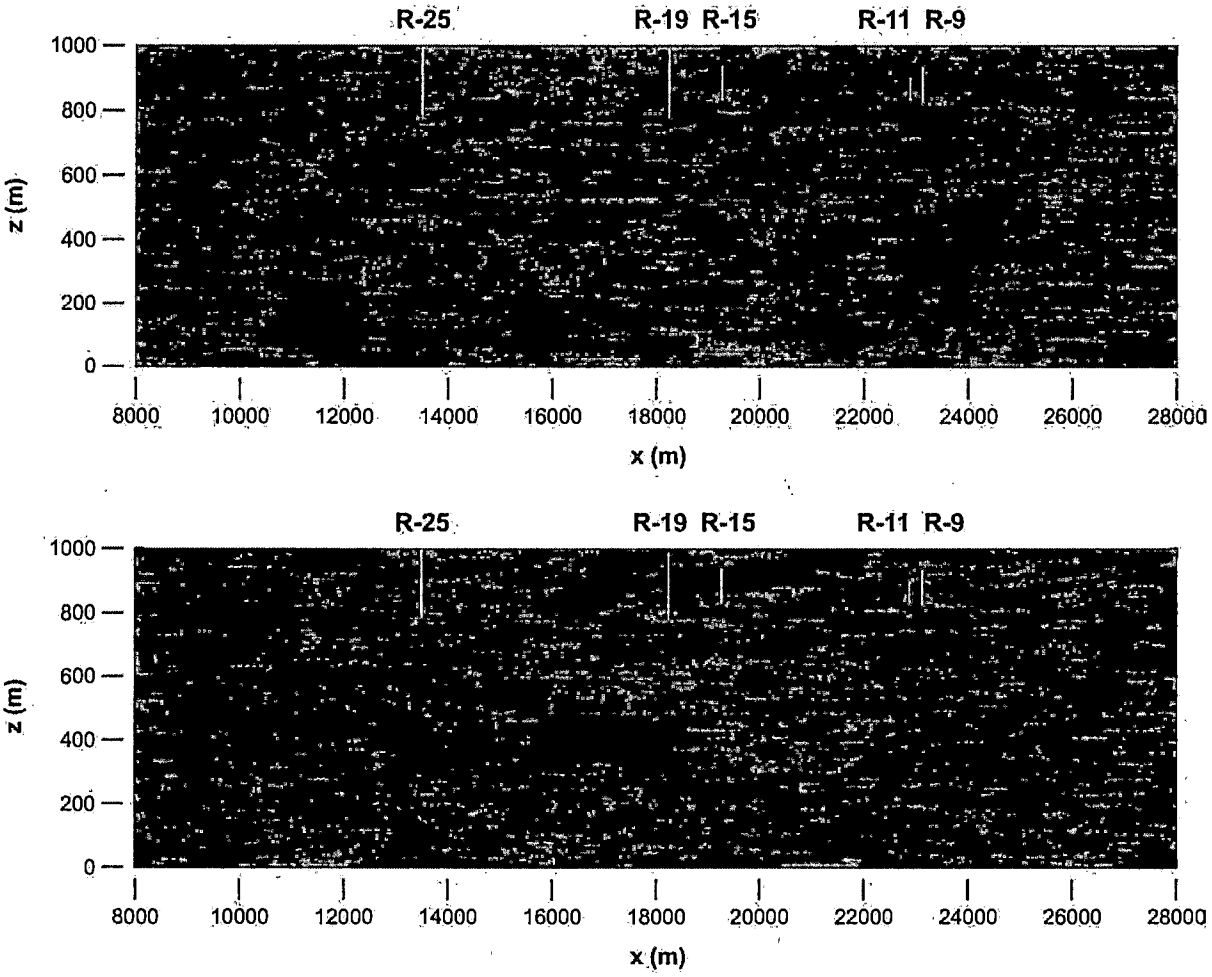

Notes: Examples of Markovian realizations conditioned at well data.
Coarse (blue) 55.2%, fine (red) 44.8%
Mean thickness- coarse: 23m, fine: 18m
Mean length- coarse: 1150 m, fine: 900m

Figure 4-28. Heterogeneity within the Puye Formation, fanglomerate; two realizations of a stochastic Markov-chain model. Model parameters are based on lithologic logs from R-wells.

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Figure 4-29. Two representations of the north-south trending trough in the upper Santa Fe Group.

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4.2.12.2 Category B: Predict fate and transport of contaminants in the regional aquifer, in order to optimally place monitoring wells and inform risk assessment studies.

1. HE transport from TA-16. The first contaminant transport simulations were conducted in response to the discovery of high explosives (HEs) in the upper saturated zone at R-25. The first model predictions were based on a simple premise: that the aquifer is at steady-state (with current rates of production in water supply wells), and that the important heterogeneities were defined by the 3-D hydrogeologic framework model. HE was represented by non-reactive particles in the model, released at the water table both at TA-16 and beneath Cañon de Valle (assuming rapid downstream transport in the alluvium). Figure 4-30 illustrates these results, which show all the contamination eventually being captured by either PM-2 or PM-4. Travel is predominantly within the Puye Formation. Breakthrough curves, shown in Figure 4-31, suggested that travel times would be on the order of hundreds of years. These slow travel times are consistent with the observation that no HE has been found in monitoring wells drilled since this study, at distances relatively close to R-25. A later simulation using a transient flow field demonstrated that the steady-state analysis was sufficient for this problem.

This study was repeated in 2000 with a more realistic approach to modeling heterogeneity within the Puye Formation (see Figure 4-27). By using a stochastic approach, it was hoped to identify possible fast pathways that could significantly change our earlier result. Table 4-5 illustrates the results of this study, for ten different realizations of the Puye Formation. This result showed that given this model of heterogeneity, first arrivals of contaminants could appear at PM-4 in less than 100 years. The shorter travel times in this study are due to preferential transport through a heterogeneous medium.

None of these analyses considered the possible role of model parameter uncertainty on transport predictions. In particular, there was still concern about possible easterly-southeasterly pathways away from TA-16. Predictive analysis (Doherty et al. 1994) was used to explore the range of possible flow directions away from TA-16 that could be achieved by assigning a large number of combinations of permeability and recharge parameters, given the constraint that any model must still match measured heads and fluxes reasonably well. Figure 4-32 shows the results of this analysis, which found that only relatively small variations in flow directions were possible under variable model calibration criteria. The major caveat to this result is that it depends on the hydrostratigraphic framework model being accurate; the "true" uncertainty in flow directions is undoubtedly larger than that shown in Figure 4-32.

2. Siting a characterization well, R-13. One objective for R-13 was that it could eventually be used to monitor possible off-site migration within the regional aquifer of contaminants originating below Mortandad Canyon. Based on the similarity between ^{3}H data in alluvial and perched aquifer wells in Mortandad Canyon and in wells due east in Sandia Canyon (R-9, R-12, and O-1), a due easterly pathway had been proposed earlier. Numerical simulations, shown in Figure 4-33, suggested a slight southerly bend to flow directions due to pumping by PM-3, PM-4, and PM-5. This results in a steady-state flow field, which will tend to exaggerate the effects of pumping over what might be the effects of pumping at present. Based, in part, on these results, R-13 was sited along the LANL boundary, south of the due easterly flow path suggested by geochemical results.

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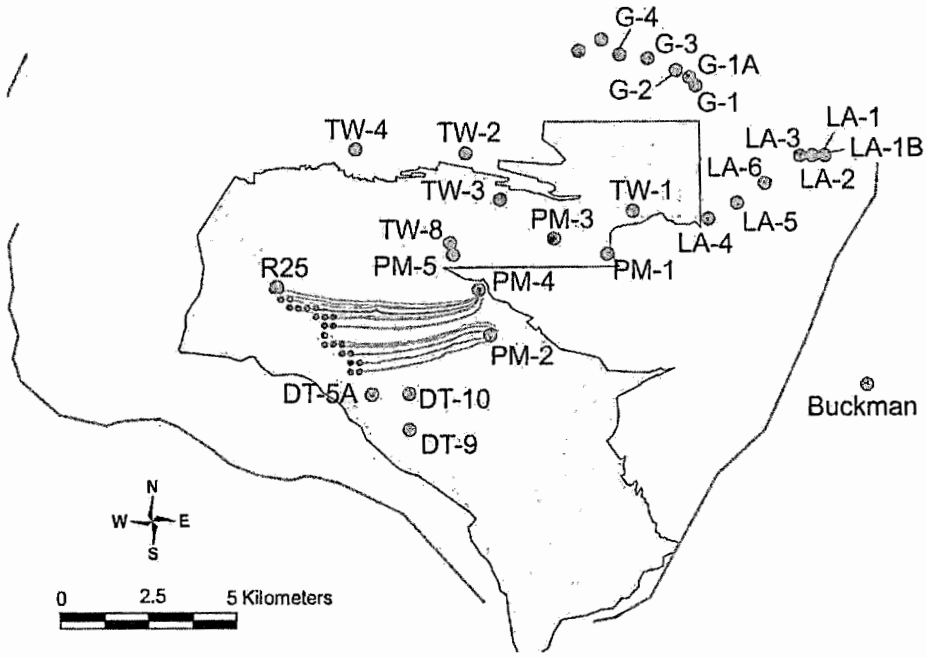
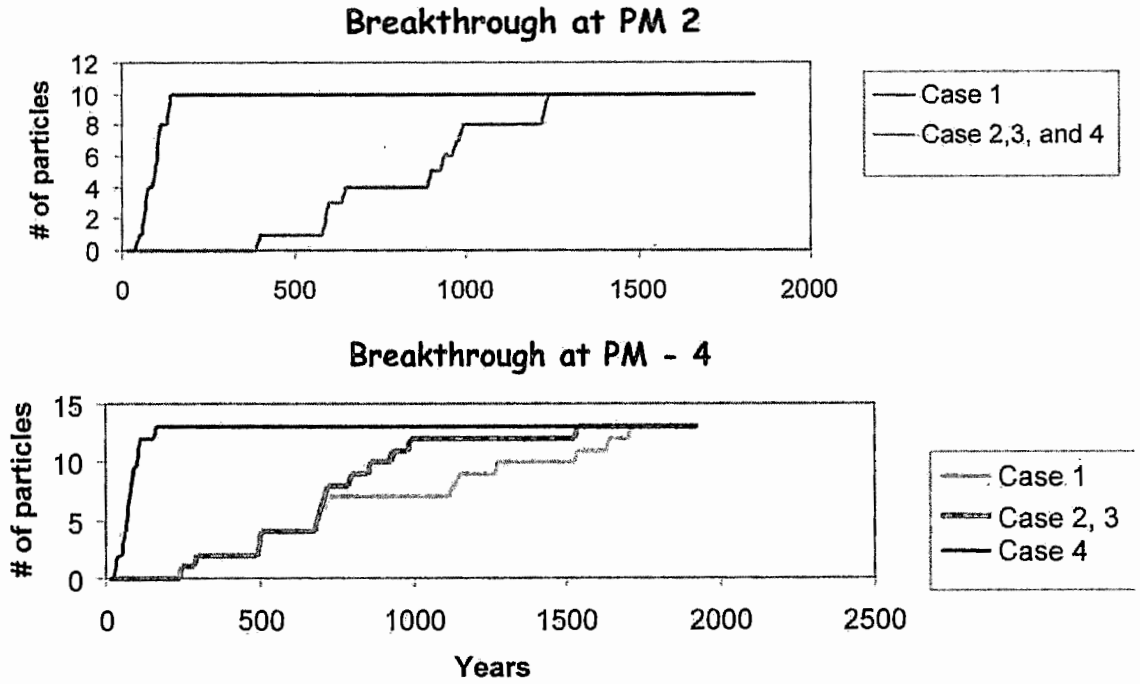


Figure 4-30. Predicted paths for particles released at TA-16 and beneath Cañon de Valle and captured at PM-4 and PM-2.



Note: Cases 1–4 represent different realizations of hydraulic conductivity.

Figure 4-31. Breakthrough curves for particles released at TA-16 and beneath Cañon de Valle at PM-4 and PM-2.

Table 4-5.
Travel Times Calculated Using Ten Different Models of Hydraulic Conductivity within the Puye Formation

		Case 0	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	Case 10
First Arrivals (yrs)	RG	420	320	390	340	340	350	360	370	650	840	920
	PM-2	N/A	250	120	110	200	NA	NA	200	NA	430	NA
	PM-4	120	100	100	90	80	100	90	100	150	180	210
Mean Arrivals (yrs)	RG	730.8	825.2	901.9	935.7	794.4	688.6	675.2	928.6	1229	1626	1569.6
	PM-2	NA	269.9	205.7	259	304.2	NA	NA	249.9	NA	430	NA
	PM-4	139.1	157.4	170.9	226.9	151.6	135.9	127.9	163.8	234	310	318.1
Standard Deviations of Arrivals	RG	201.7	254.8	312.7	379.7	226.1	211.1	213.1	247.7	345.6	478	392.6
	PM-2	NA	20	62.2	81.1	79.6	NA	NA	69.5	NA	0	NA
	PM-4	5.7	21.5	22.7	50.7	32.1	12.8	14.8	25	32.2	42.7	23.9
Percentage of Particles Captured (%)	RG	88.4	6.8	28.3	25.5	4.3	21.4	10.9	9	7	7.7	7.6
	PM-2	0	0.02	6.6	33.8	0.1	0	0	0.1	0	0.02	0
	PM-4	11.6	93.2	65.5	40.9	95.6	79.6	89.3	91	93	92.3	92.4

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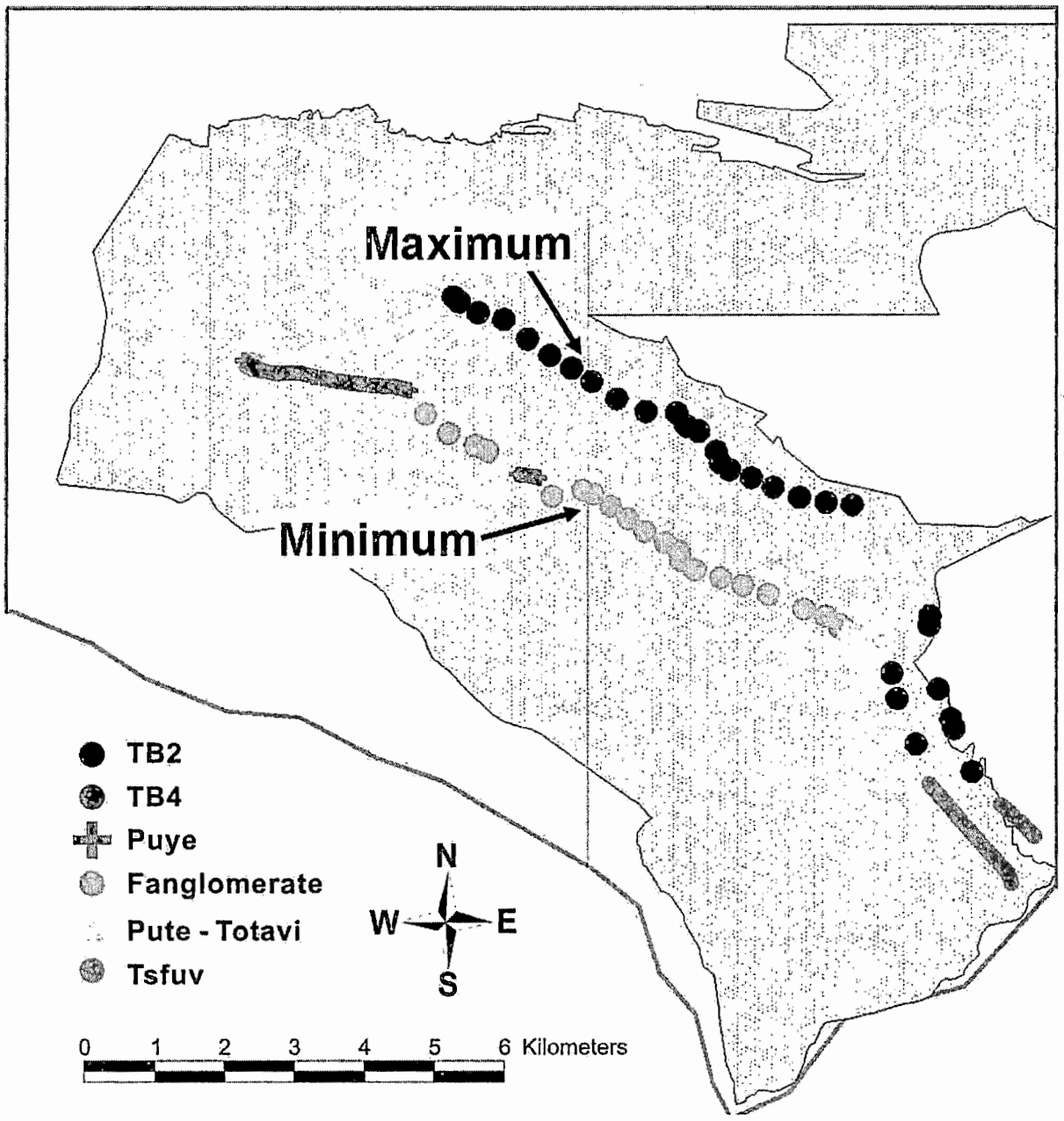

Figure 4-32. Results of predictive analysis, showing the possible range of flow directions (farthest northward and farthest southward) for sources at TA-16. Colors represent hydrostratigraphic units through which the water is flowing.

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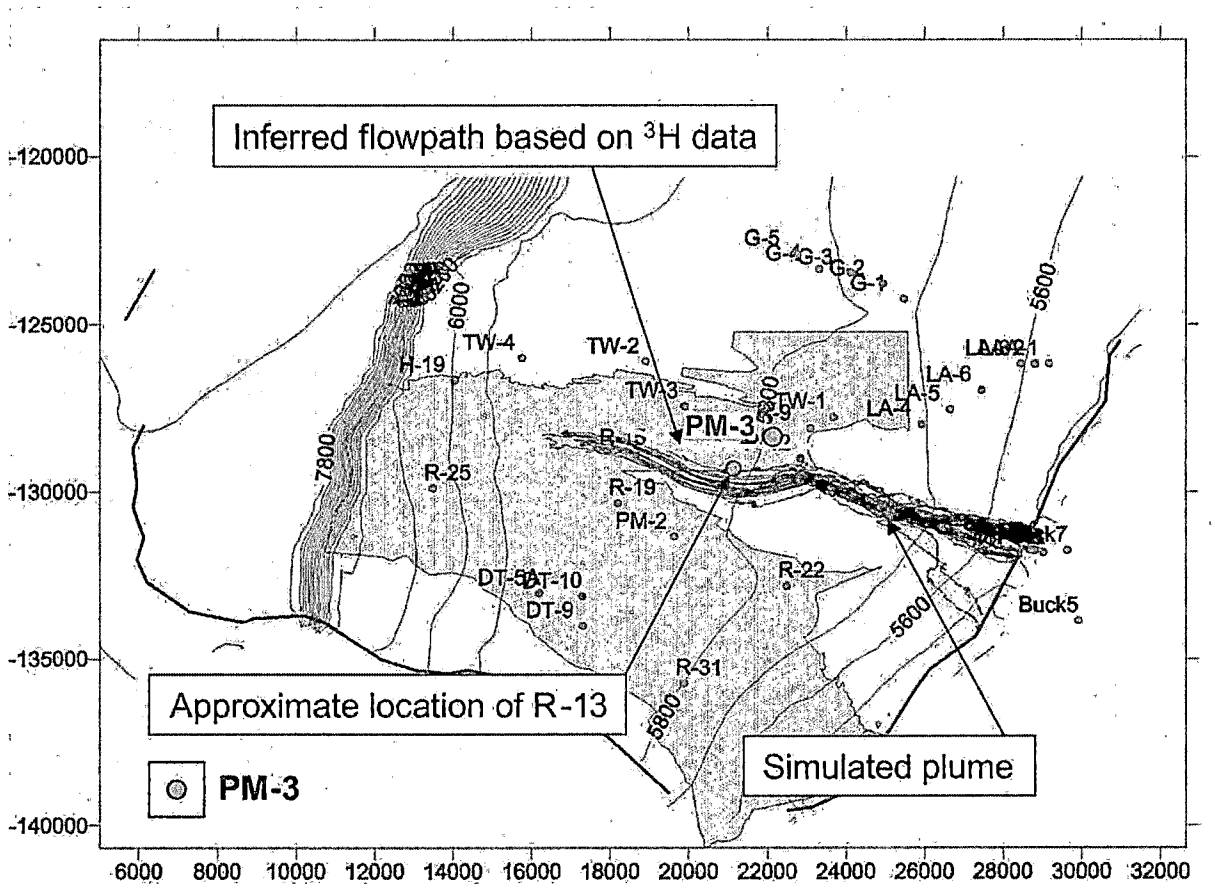

Figure 4-33. Predicted plume migration for sources released at the water table below Mortandad Canyon, based on a steady-state, with pumping, flow field.

Recent analyses of transient capture zones in the vicinity of Mortandad Canyon highlight the fact that flow directions and ultimate point of discharge change both in time and distance along the canyon. Solutes reaching the water table at early times (pre-1970s) and at easterly locations along the canyon probably moved to the east, under natural flow conditions and the pull of PM-1. Solutes reaching the water table at later times and further to the west will likely be drawn to the south. If the location and timing of contaminants reaching the water table is uncertain, the optimal monitoring network therefore will include both easterly and south-easterly monitoring locations.

3. Naturally occurring contamination. Some groundwaters in the Española Basin, including waters in the vicinity of LANL, are contaminated by naturally occurring arsenic, uranium, and flouride (McQuillan and Montes 1998; Purtymun 1977). Data collected in lower Los Alamos Canyon suggest that long-term pumping in water supply wells may increase concentrations of naturally occurring uranium (Gallaher et al. 2004).

Ongoing modeling studies, using the basin-scale model coupled with new water chemistry data collected in cooperation with Santa Fe County and the New Mexico Environment Department,

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are attempting to understand the geochemical mechanisms that enhance dissolution of trace metals in aquifer rocks and the hydrologic mechanisms that may cause groundwater extraction to exacerbate the problem. Figure 4-34 illustrates an example model simulation, which simulates the spatial distribution of total dissolved solids in the basin. The prediction of a large area of high-salt water in the vicinity of Santa Fe has possible implications for water resource planning for that community, i.e., the cost of treating the high-salt water or finding alternate resources.

4.2.12.3 Category C: Provide guidance in prioritization of data collection activities, highlighting the importance of those data that could most reduce numerical and conceptual model uncertainty.

1. Reducing uncertainty in transport predictions away from TA-16. After the analysis shown in Figure 4-32 was completed, the model was used to determine how new monitoring wells might reduce the uncertainty in flow directions and travel times. Hypothetical wells were added with head data at five different locations near the particle path lines (shown in Figure 4-35) to determine the value of the head data in reducing pathway uncertainty. When the analysis was conducted, head data from R-25 were not yet available; therefore, head data at this well were not included in the analysis. Interestingly, of the five potential well locations, it was head data at R-25 that had the most benefit. The reason for this result is that information about the vertical component of the 3-D head field at R-25 helped the model determine the extent to which flowpaths are horizontal (fast) or three-dimensional (much slower).

2. Capture zone of PM-5. A similar methodology was used to determine the type of data that would be of most benefit to reducing uncertainty in the ability to predict the capture zone of PM-5 (Vesselinov et al. 2002b). A conceptual particle plume was released at a single location at the water table beneath Mortandad Canyon to simulate the transport away from the site. The calibrated model predicted that the particles traveling along the mean pathway would arrive at PM-5 (orange line, Figure 4-36). This model predicted that ~80% of the particles would arrive at PM-5. By varying recharge parameters and aquifer properties in a large number of possible combinations, within calibration constraints, a wide range of possible model predictions was generated. This analysis showed that parameter uncertainty was sufficiently great so that either 0% or 100% capture was also possible (blue and green lines, respectively, on Figure 4-36). Figure 4-37 illustrates the full plume migration in the 0% capture scenario. The analysis determined that better information on recharge rates in Mortandad Canyon would have the most benefit to reducing predictive uncertainty. The caveats to this study include the following: (1) possible recharge rates were not constrained to be within the bounds provided by existing studies of recharge, and (2) the method of modeling recharge probably overestimates the impact of local recharge on local head gradients.

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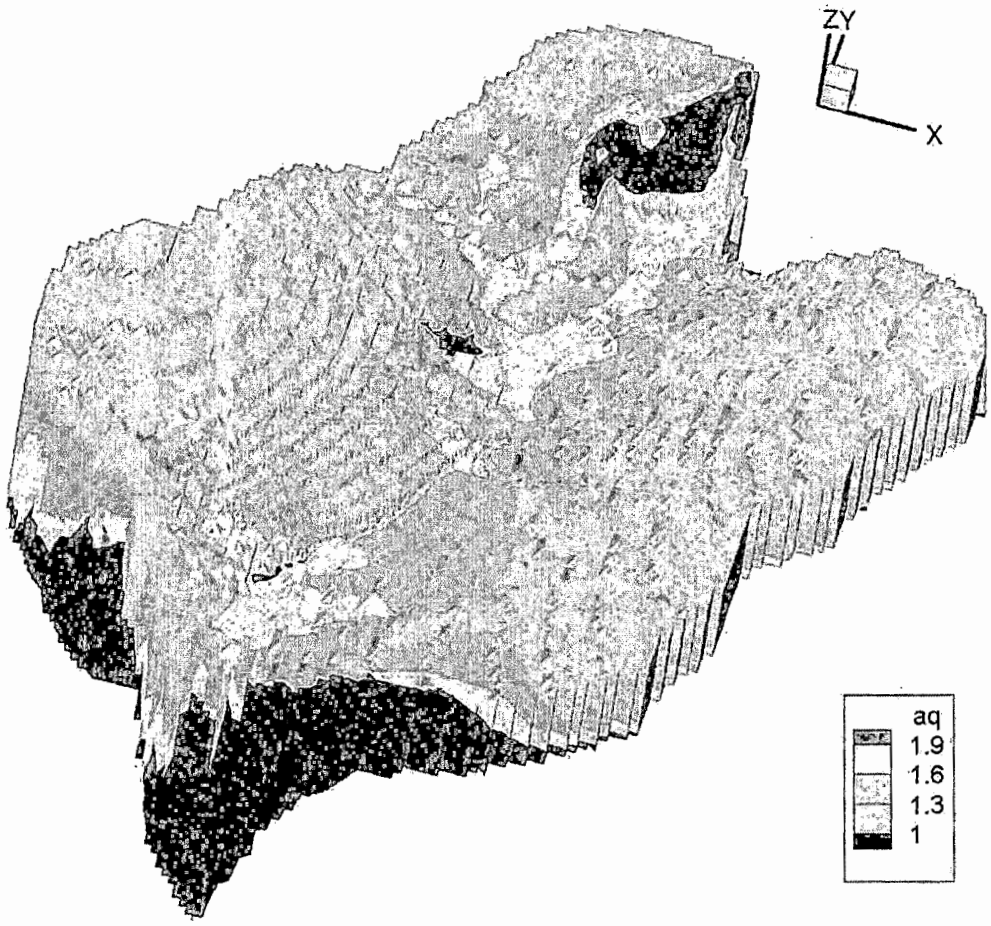

Figure 4-34. Predicted total dissolved salts in the groundwater at steady state, using a simple model of mineral dissolution. Red areas show the zones of relatively old water that are not mixing with fresh water.

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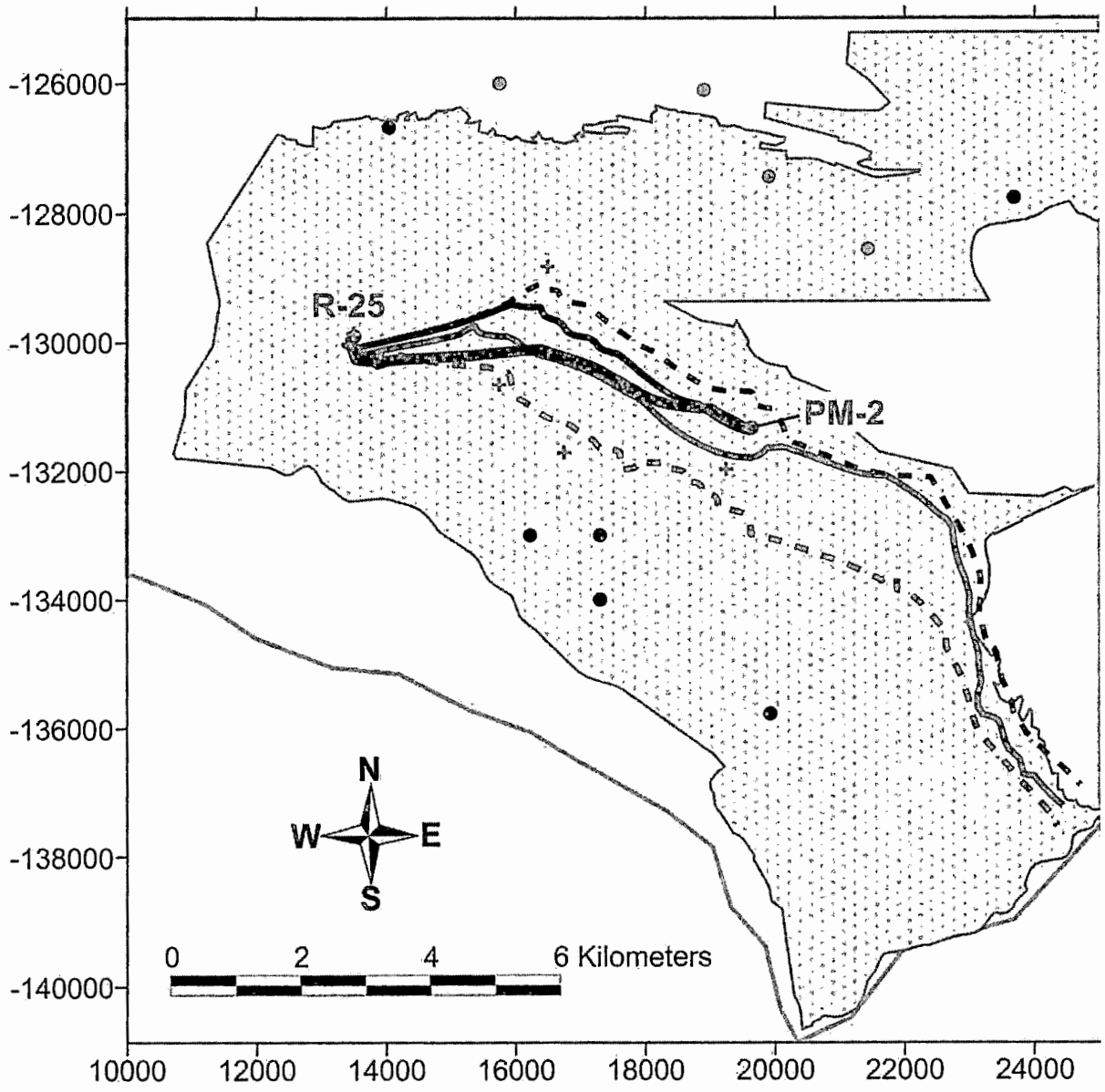

Note: The Purple line is the "calibrated" model result
The blue and red lines are min/max:
The dotted lines are most southern and most northern trajectories;
The solid lines are most shallow and most deep trajectories

- Well with steady-state water level observation
- Well with steady-state and water level and drawdown observations
- Potential location for new data (we assume that each well has multiple screens)
- Plane along which Y is calculated for predictive analysis

Figure 4-35. Location of hypothetical wells (green crosses) used to evaluate the potential value of head data in reducing uncertainty in flow directions. Solid and dotted lines show range of uncertainty in flow direction (north/south) and flow depth.

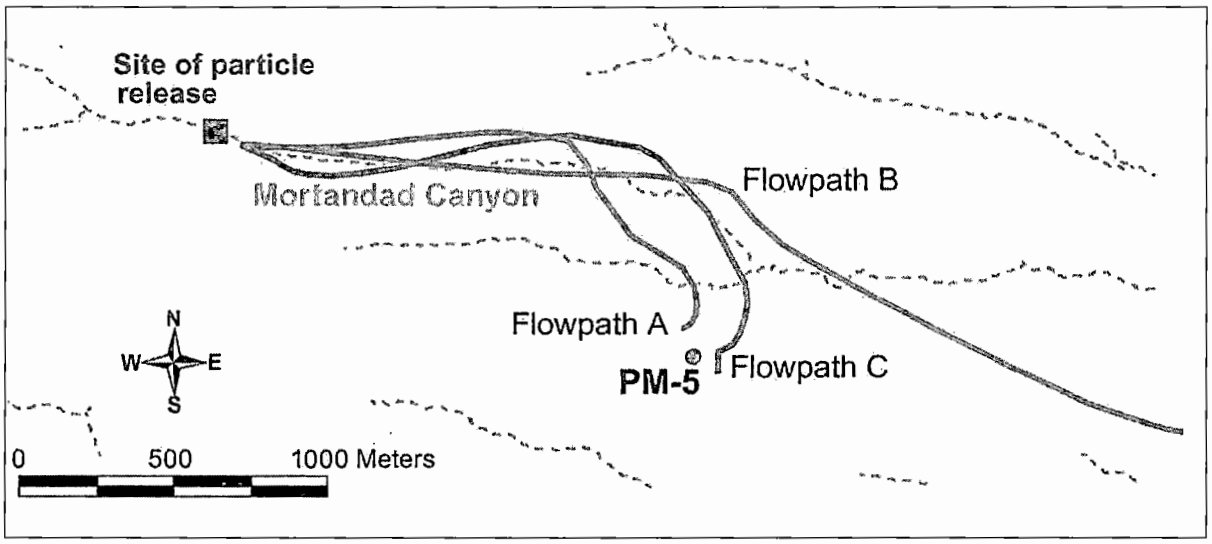

Figure 4-36. Mean flowpath for three simulations of plume migration away from Mortandad Canyon: orange-best calibrated model; green – maximum capture by PM-5; blue – minimum capture by PM-5.

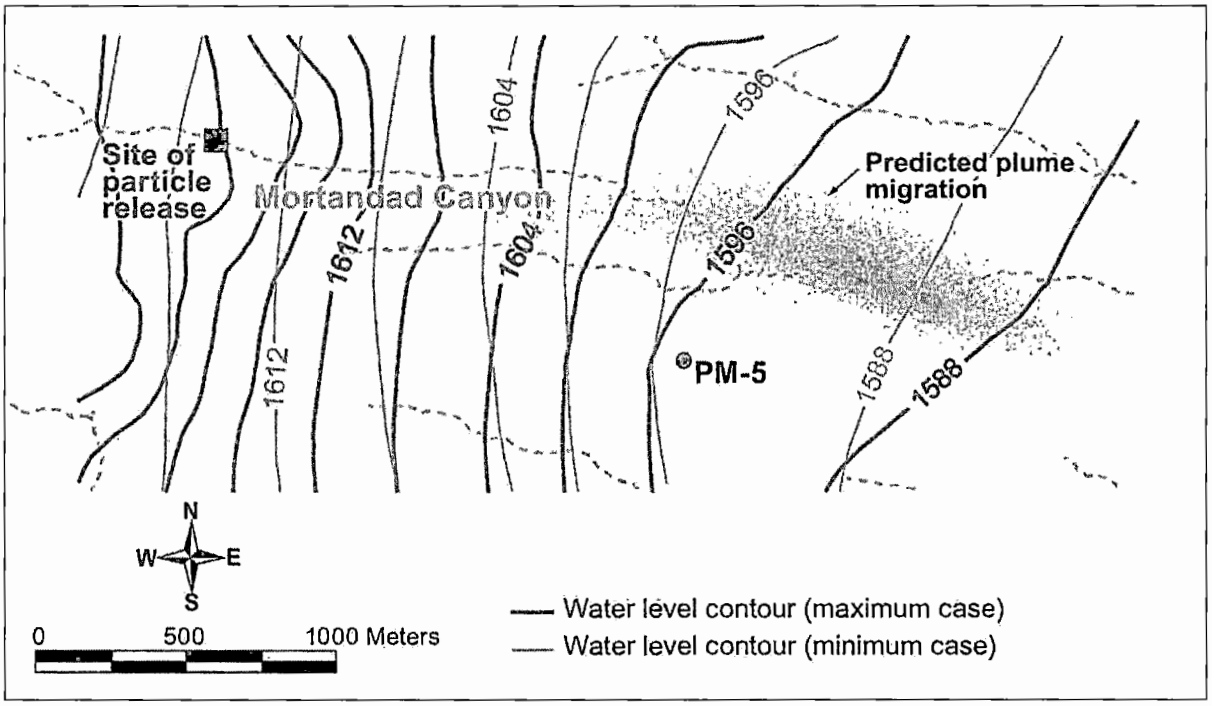

Figure 4-37. Illustration of plume migration for minimum capture by PM 5 (0%). Also shown are the two water table elevations predicted by the minimum and maximum cases.

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3. Proposed pump test at O-1. The best way to characterize the hydraulic properties of the aquifer is to conduct a pump test with one or more monitoring wells. It was proposed that characterization well R-5 be drilled very close to O-1 so that a pump test could be conducted. A 2-D radial model was used, with the 3-D geologic model interpolated onto the grid to represent aquifer heterogeneity, to determine the optimal distance the characterization well should be drilled from O-1. Figure 4-38 shows the radial grid, and the predicted drawdowns as a function of distance from O-1, using a variety of model assumptions and parameters (8 cases). The range of suggested distances from the well that came from this analysis was 100–400 m. Ultimately, the well was sited at a greater distance for other purposes and no pump test was conducted. This test will be feasible when well R-3 is constructed closer to O-1.

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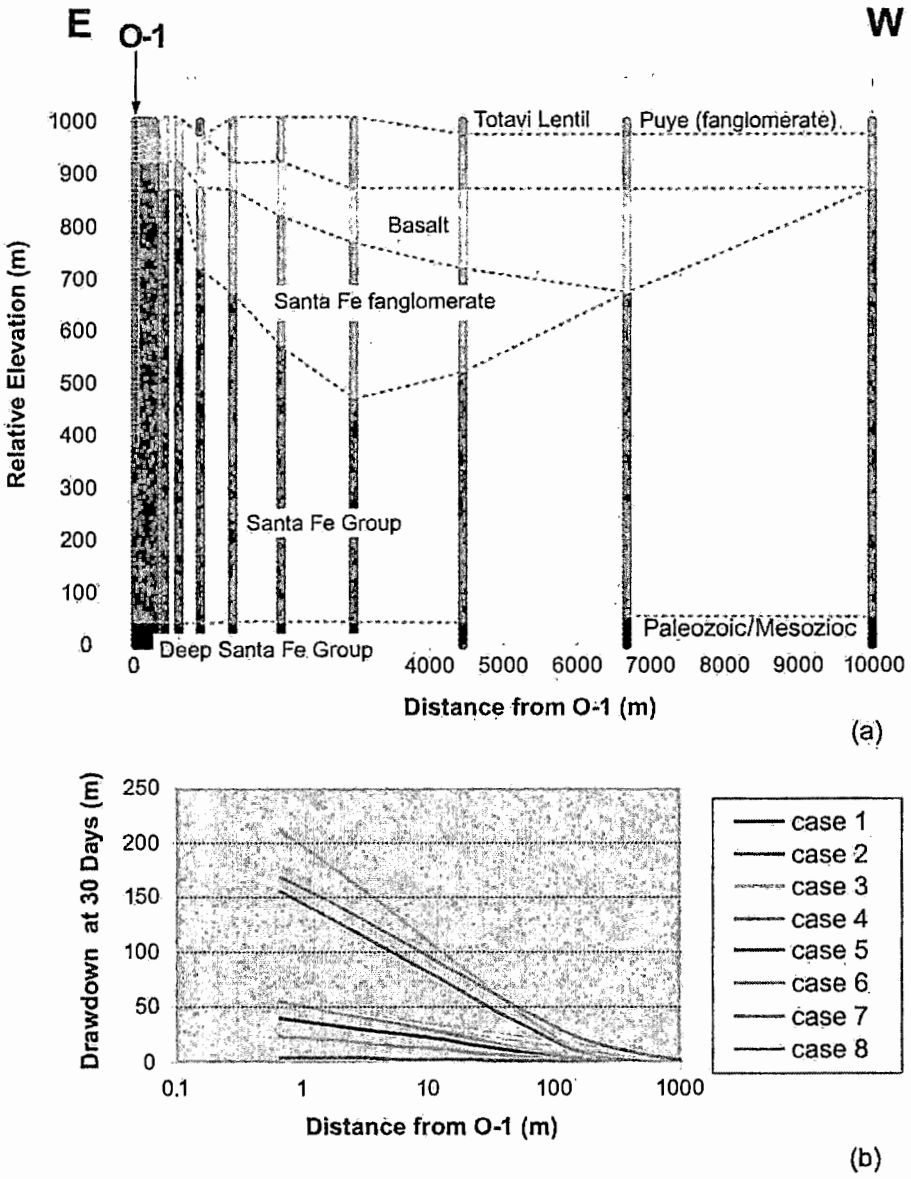

Figure 4-38. (a) Hydrostratigraphic units in the vicinity of well O-1, interpolated onto radial grid; (b) Predicted drawdowns at the top of the aquifer, for eight cases.

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5.0 CONCLUSIONS

5.1 Summary

This report has described the geology, hydrology, and geochemistry of the Pajarito Plateau, based on empirical observations and modeling analyses. The purpose of this description is to provide a basis for evaluating and, and if necessary, designing an enhanced monitoring network capable of detecting contaminants. In order for a monitoring system to detect contaminants, an understanding of how contaminants reach groundwater and how contaminants move through groundwater is required. This section draws together the information present in the previous sections to establish a conceptual model of contaminant transport through the hydrogeologic system. This conceptual model is the basis for relating the work to evaluation of risk (Section 5.2) and the monitoring implications described in Section 5.3.

In overview, the contaminant transport conceptual model is one in which contaminants reach points of potential exposure in the regional aquifer only if the following conditions are met:

- Mobile contaminants have been released to the environment
- There are natural or anthropogenic water inputs to carry contaminants downward
- Vadose zone hydrogeologic controls are present, including enhanced infiltration and lateral pathways
- Flow-field modifications are present to influence transport of contaminants in the regional aquifer.

The following subsections draw together the observations and analyses that explain and support these conditions for contaminant transport.

5.1.1 Presence of Contaminants

Imprinted on the natural variations in chemistry is the presence of contaminants historically released since the early 1940s when Laboratory operations commenced. While the contaminants are at concentrations largely below regulatory standards or risk levels, they demonstrate the presence of pathways for groundwater flow and contaminant transport from the surface to deeper groundwater. The impacts to groundwater at the Laboratory have occurred mainly where effluent discharges have caused increased infiltration of water. The depth to which chemical constituents move in the subsurface is determined partly by their chemical behavior: nonreactive constituents move readily with groundwater, while reactive or adsorbing constituents move a shorter distance.

In most cases where effluent sources have been eliminated, groundwater concentrations of non-reactive discharged contaminants have decreased far below previous levels (e.g., nitrate, tritium, and perchlorate) in alluvial groundwater. These mobile contaminants move readily through the subsurface and are detected within perched intermediate zones and at the regional water table beneath several canyons, including Pueblo Canyon, Los Alamos Canyon, Sandia Canyon, Mortandad Canyon, and Cañon de Valle. In the case of reactive or adsorbing chemicals, the concentrations in the alluvial groundwater remain elevated significantly above background levels

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after elimination of discharges or other contaminant source terms (e.g., excavation and removal of contaminated sediments). These include constituents such as strontium-90 and the actinides (americium-241, plutonium-238, and plutonium-239, 240) (Section 3.1.2).

Lateral flow and transport through surface water and in the alluvial systems are rapid with respect to other subsurface hydrologic processes on the plateau. Rates of lateral transport are even higher during surface flow events, which occur more frequently in the larger wet watersheds than in other areas of the plateau. Sorbing species transport slowly in alluvial waters and more commonly migrate down the canyon floor by sediment transport (LANL, 2004a; Lopes and Dionne, 1998; Solomons and Forstner, 1984; and Watters et al., 1983). Since some of the wet canyons that cross Laboratory land have received liquid-waste discharges from outfalls, the alluvial systems act as line sources for both water and contaminants to the deeper vadose zone beneath such canyons (Section 2.5.2.2).

Data for conservative (nonreactive) constituents (tritium, nitrate, perchlorate) in alluvial groundwater support the conceptual model that this groundwater has a short residence time and conservative contaminants do not accumulate in alluvial groundwater. The time-trend pattern for these contaminants shows a high level when they were being released, followed by a sharp decline in concentration to nearly nondetectable levels when the source was eliminated. Past values of tritium and nitrate in alluvial groundwater in DP, Los Alamos, Pueblo, and Mortandad Canyons exceeded the 20,000 pCi/L mean concentration level (MCL) (Rogers 1998). Because of improvement in effluent quality, values this high do not occur today in these locations (Section 3.2.3.1).

Data for adsorbing constituents (strontium-90, plutonium-239, 240) illustrate the conceptual model of contaminant adsorption onto alluvial sediments. The time- trend pattern for the adsorbing contaminants shows a decline in concentration when the source is cut off, followed by maintaining a fairly constant low concentration in the groundwater due to cation exchange. The highest measured strontium-90 activity was approximately 500 pCi/L in Acid Canyon surface water in 1960. With no present source, levels have dropped dramatically and strontium-90 is now consistently detected at low activities, below 1 pCi/L in alluvial groundwater (Section 3.2.3.1).

Data showing low levels of tritium activity in intermediate perched groundwater support the conceptual model that alluvial groundwater affected by effluent discharges is a principal source of recharge and contaminants for the intermediate perched groundwater. The highest values of tritium in intermediate perched groundwater are found where effluent discharges have occurred. Tritium time-series data also support a conceptual model that groundwater in the intermediate perched zones may have short residence time. In the absence of effluent discharge from TA-45 as a tritium source in Pueblo Canyon, tritium in the intermediate perched zone sampled by well TW-2A fell rapidly during the 1980s (Figure 3-13). This suggests that tritium associated with the former TA-45 treatment plant infiltrated the canyon floor and migrated vertically, at least to the depth of the intermediate perched zone at TW-2A, but had no continuing source when the TA-45 treatment plant was shut down (Section 3.2.3.2).

The distribution of tritium in the regional aquifer supports the conceptual model that surface effluent discharges have caused the instances where Laboratory contaminants are found at depth.

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In most cases, the highest regional aquifer tritium values are found near where effluent discharges have occurred, but are much lower than values observed in overlying alluvial or intermediate perched groundwater. Elevated 3H in regional aquifer samples has been observed at wells O-1, TW-1, TW-3, TW-8, LA-1A and LA-2 (Rogers et al. 1996b), as well as in several wells drilled during the hydrogeologic characterization program (Section 2.7.3.1.1).

The fundamental condition that contaminants should have been released for groundwater contamination to occur is illustrated by the distribution of conservative (that is, nonreactive) groundwater contaminants. Generally, compounds like RDX, tritium, perchlorate, and nitrate move readily with the groundwater because chemical reactions do not retard the movement of these compounds or decrease their concentrations, although the activity of tritium does decrease due to radioactive decay. Semireactive constituents (uranium, strontium-90, barium, some HE compounds, and solvents) whose movement is slowed or their concentrations are decreased by geochemical processes and strongly reacting constituents (americium-241, plutonium, and cesium-137) that are nearly immobile are not found above background levels in intermediate perched groundwater or the regional aquifer (Section 3.2.1).

5.1.2 Water Inputs

Sufficient water input in a canyon system is a critical condition for transporting anthropogenic constituents. In most cases where Laboratory anthropogenic constituents are found at depth, the setting is either:

- Canyons where natural water input is high (Pajarito, Water, and Cañon de Valle)
- Canyons where anthropogenic water input is high (Pueblo, Los Alamos, Sandia, Mortandad)
- Mesa-top sites where large amounts of liquid effluent have been discharged (such as retention ponds or outfalls) (Cañon de Valle and Water canyons) (Section 3.2.2).

Wet canyons receive large runoff volumes, either through channeling of precipitation or through wastewater discharges. This runoff, in turn, creates surface-water flow along canyon bottoms, which subsequently infiltrates to form near-surface, alluvial water bodies (Section 2.4.2.1). The highest net infiltration rates are estimated to occur in canyons, especially those that head in the mountains, with magnitudes of up to a few hundred millimeters per year caused by channelized runoff. In contrast, much lower net infiltration rates occur across mesas and in the smaller canyons that head on the plateau (Section 2.4.2.1).

The infiltration rate estimates from canyon-bottom alluvium and mesa-top sites are consistent with the estimated infiltration rates inferred from moisture content profiles. In Section 4.1.3.2, numerical models for wells LADP-3 and LADP-4 in Los Alamos canyon are presented showing that moisture profiles reflect the conceptual model of high infiltration in canyons and low infiltration on mesas. That analysis also shows that the uncertainties associated with such estimates are quite high (in the range of a factor of 3). However, by combining moisture content, tracer or contaminant profiles, and water budget information, a more constrained estimate has been achieved (Section 2.5.1). The resulting net percolation rates beneath the alluvial systems of

wet canyons to the underlying unsaturated zone are expected to be among the highest across the plateau, approaching meters per year (100–1000 mm/yr) (Kwicklis et al. 2005) (Section 2.5.2.2).

The alluvial groundwater present in several canyons has a small volume relative to the annual volume of runoff or effluents, does not extend beyond the LANL boundary, and is generally completely refreshed by recharge on a time scale of about a year (Section 3.2.3.1). The Kwicklis et al. (2005) study shows that about 23% of the infiltration occurs from canyon bottoms on the plateau at lower elevations, including 14% of the total in streams that flow at least partly within LANL boundaries.

Although relatively small volumetrically compared to mountain recharge to the west, aquifer recharge occurring locally on the plateau is important to the assessment of flow paths of potentially contaminated water. Tritium data confirms that relatively young water is present in the aquifer (Rogers et al. 1996b), indicating fast pathways through the vadose zone beneath LANL. Kwicklis et al. (2005) used vadose zone occurrences of ^{3}H to estimate the time-dependent transport velocities from which they derived the infiltration rates to the regional aquifer. They found that, in Mortandad Canyon, infiltration rates as high as 2000 mm/yr during periods of large volumes of effluent discharge decreased to 100–200 mm/yr when effluent discharge flow rates were reduced. These observations and analyses confirm that local recharge in canyons is an important component of the recharge distribution for the plateau (Section 2.7.3.1.1).

The presence of water, either natural or from the discharge of effluents to canyons or mesa-top locations in the Laboratory's semiarid setting, initiates or increases downward percolation of water. Even under unsaturated flow conditions, this percolation may move significant volumes of water to the regional aquifer within a few decades.

5.1.3 Vadose Zone Hydrogeologic Controls

The third condition that controls the distribution of groundwater contaminants is the presence of vadose zone hydrogeologic controls. The controls considered most important in influencing contaminant distribution and transport are: near- surface circumstances that enhance infiltration, potential pathways in the vadose zone (e.g., basalts), and transport through intermediate perched groundwater.

Infiltration rate affects the movement of anthropogenic constituents from the surface to groundwater. As described in Section 2.5.3, undisturbed Bandelier Tuff has a very low infiltration rate. On mesas, the predicted travel times are variable, but for the most part are greater than 1000 years, ranging from 1000 to 5000 years on the eastern portions of the Laboratory to 20,000 to 30,000 years in the western region. Areas that have other geologic units (particularly basalt units or Puye Formation) or fractured units exposed in the canyon bottom have higher, or enhanced, infiltration rates. In addition, the vadose-zone thickness decreases with increasing distance down canyon, due to thinning of the Bandelier Tuff (Section 2.2.9). Where the Otowi Member of the Bandelier Tuff is thick, infiltration rates are quite low. However, on the eastern side of the plateau, the Otowi Member thins to 0 to 100 feet, reflecting both the general thinning of the Otowi Member away from its caldera source and thinning of the ash-flow

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tuffs over the Cerros del Rio highland on the east side of the plateau (Section 2.2.9.1). The eastern portions of canyons with thinned or absent Otowi Member have enhanced infiltration. Infiltration rates of 1500 to 2000 mm/yr are estimated for the confluence of Los Alamos and Pueblo Canyons, a consequence of infiltration directly onto Puye fanglomerates or fractured basalts (Section 2.7.3.1.1.).

Enhanced infiltration is especially true for the eastern portion of deep wet canyons because their canyon bottom elevations are 45 to 60 m lower than smaller canyon systems on the plateau. Thus, the deepest canyons extend to stratigraphic horizons having higher infiltration rates because of increased fracture flow. Contaminants transported down canyon via surface flow or through the alluvial groundwater system often percolate through a geologic column consisting primarily of basalt and Puye Formation fanglomerate with little or no overlying tuff. Downward percolation is believed to be more rapid in the basalt than through moderately welded tuff (Section 2.2.8). Thus, these wet canyons have thinner vadose zones and a smaller portion of the flow path with matrix-dominated flow. Los Alamos and Pueblo Canyons have regions in the vicinity of their confluence in which the Bandelier Tuff is thin or nonexistent. Water infiltrates directly onto basaltic rocks or the Puye Formation, thereby yielding rapidly downward flow through fractures or preferential flow channels. The predicted travel times are especially short (5 to 10 years) in these locations (Section 4.1.2.1).

Other instances of enhanced infiltration include the Cañon de Valle and Water Canyon, where rates up to 1000 mm/yr are estimated for areas associated with the Pajarito fault zone. Anthropogenic alterations can also enhance infiltration, for example sediment ponds in Mortandad Canyon and ponds in Cañon de Valle.

In contrast to the Bandelier Tuff, the basaltic rocks clearly exhibit rapid flow through fractures and other fast pathways, so that the permeability of the matrix rock is essentially irrelevant to the rates of water percolation (Stauffer and Stone 2005). Fracture flow occurs because of the orders-of-magnitude lower matrix permeabilities of these rocks, compared to the Bandelier Tuff (Section 2.4.1). The upper surface of the Cerros del Rio basalt is irregular, with a broad highland that extends from north to south under the east-central portion of the Laboratory, largely buried beneath the Bandelier Tuff. The presence of the Cerros del Rio basalt in the vadose zone provides potential lateral fast pathways in the vadose zone (Section 2.2.8). These hydrogeologic factors, compounded by the relatively high deep-percolation rate in wet canyons, likely yield the fastest vadose-zone travel times for contaminants from the land surface of the plateau to the regional aquifer. Transport to the regional aquifer beneath wet canyons is predicted to be on the order of decades to hundreds of years (Section 2.5.2.2).

The water-quality impacts by effluent releases on alluvial groundwater extend in a few known cases to intermediate perched groundwater at depths of a few hundred feet beneath these canyons. Since the contaminated alluvial groundwater bodies are separated from the intermediate perched groundwater by hundreds of feet of dry rock, pathways within the vadose zone are likely present in those canyons. There are two end-member conceptual models for flow within an intermediate perched water zone:

- *Low-velocity, virtually stagnant water resting in a perching horizon within a local structural or stratigraphic depression.* Water percolates very slowly out the bottom of

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this zone or spills over the sides of the depression. This configuration views perching horizons as barriers that slow the downward percolation of water. In several wells, intermediate saturated zones thought to represent perched groundwater were screened but failed to produce significant water. These occurrences may represent cases where zones of limited extent were substantially drained when the perching horizon was penetrated during drilling. Once the stagnant water is depleted in an initial round of sampling, there is insufficient recharge upstream to keep the zone saturated.

- *High-velocity, laterally migrating water that travels on top of the perching horizon.* This conceptualization suggests that once groundwater reaches a perched zone, it rapidly percolates laterally along high-permeability pathways until the perching horizon pinches out or is breached by high-permeability features, such as fractures or lateral changes in lithology. In this scenario, water could move in stair-step fashion from one perching horizon to another. There are no confirmed instances of large-scale, lateral vadose zone pathways beneath the Pajarito Plateau at depths greater than the alluvial groundwater. However, the case of lateral flow through the wet, mountain-front mesas at TA-16 suggests that this possibility does exist at greater depths. Although the TA-16 observations are categorized as shallow for the purposes of this discussion because they discharge via springs in the local canyons, it could be argued that deep pathways with flow geometries similar to those of the mountain-front mesa or today's alluvial groundwater zones are evidence for the possibility of deeper fast pathways elsewhere (Section 2.6.2.4).

The site-wide vadose zone transport model predicts that regions of relatively rapid travel times are present 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 (Section 4.1.2.3).

Hydrogeologic controls influence movement of anthropogenic constituents through the vadose zone. The presence of geologic units that enhance infiltration, that act as pathways, or are conducive to perching groundwater and forming intermediate perched groundwater appears to be an important condition for groundwater contaminants to be transported to the regional aquifer.

5.1.4 Regional Aquifer Transport

Relatively little contamination reaches the regional aquifer from the alluvial groundwater bodies, and water quality impacts on the regional aquifer, though present, are low. Flow field modification is considered important in controlling anthropogenic constituent distribution in the regional aquifer. Anthropogenic constituents that enter the regional aquifer near pumping wells are predicted to have much shorter travel times than those outside the influence of pumping.

The LANL regional aquifer model was used to produce a map of velocities at the water table. These velocities are *highly uncertain* and are used only to illustrate a few key points. First, given the heterogeneous nature of the aquifer, groundwater velocity is likely to vary considerably over short distances. There are two areas with relatively high permeability ($K > 3$ m/day): the north-central aquifer beneath LANL (wells TW-2, R-4, TW-3, R-11, R-28, and R-13) and the south-central aquifer beneath LANL (R-19, screen 6, DT-10, DT-9) (Section 2.4.2.3).

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The fastest velocities are in the basalts where fracture flow (very low porosity) is assumed. Basalt straddles the water table in two areas. The most extensive is located in the south-central part of the plateau, where as much as 195 ft of saturated Pliocene Cerros del Rio basalt occurs at the top of the regional zone of saturation in well DT-10 and 290 ft occurs in well R-22 (Figure 2-10). A smaller region of older Miocene basalts straddles the water table in a north-trending zone extending between wells R-12 to R-5.

Second, flow on the eastern portion of LANL is predicted to be *very* slow. This is due to the very low permeability of the Santa Fe Group, which is prevalent at the water table east of LANL (Section 4.2.12.1). The Tesuque Formation is the primary rock unit making up the regional aquifer in the eastern part of the plateau and in the Buckman wellfield east of the Rio Grande. Bedding within the Santa Fe Group and the Puye Formation is likely to cause higher permeability parallel to the beds than perpendicular to the beds. Large vertical head gradients measured in R wells are evidence of anisotropy. The beds within the Puye Formation range from centimeters to meters in thickness. Most are very low angle, dipping to the east. In contrast, beds within the pumiceous volcaniclastic rocks tend to dip to the southwest (R-20, R-2, R-7, R-19, and R-33). Beds within the Santa Fe Group exposed on the western margin of the plateau dip approximately 2–5° to the west (Golombek et al. 1983). Data from R-16 suggest that shallow layers are very low-angle, but deeper layers dip as much as 25° to the west. Hydrologic modeling and pump test analysis suggests that vertical permeability is 100 to 1000 times lower than horizontal permeability in the Santa Fe Group (Hearne 1985; McAda and Wasiolek 1988; Keating et al. 2003). (Section 2.4.2.3)

The regional aquifer conceptual model incorporates data from recent large-scale (30-day) pumping tests. Individual drawdown and recovery water levels in responsive wells demonstrate that the regional aquifer surrounding PM-2 is vertically anisotropic with pronounced resistance to vertical propagation of drawdown at shallower depths. Hydraulically, the aquifer behaves like a semiconfined aquifer at depth with leaky units located above (and perhaps below) a highly conductive layer (Section 2.7.5). It appears that there are water-table conditions near the water table, but leaky-confined aquifer behavior deeper down, although the degree to which the uppermost phreatic zone and the deeper, leaky-confined aquifer are hydrologically connected is unknown. The regional aquifer can be thought of as a compartmentalized aquifer with water from plateau recharge traveling laterally in the phreatic zone as the upper compartment and a lower compartment, which contains deeper groundwater flow as the leaky-confined aquifer that is isolated to some degree from the overlying compartment.

The contaminant pathways in the regional aquifer depend heavily on the strength of the hydrologic separation of the two compartments, which translates into how efficiently the pressure drawdown caused by the pumping wells propagates to the water table. Two conceptual alternatives are end members on a spectrum of potential configurations and thus capture the total potential variability.

- Weak hydraulic separation between the shallow (phreatic; water-table) and deep (leaky-confined; pumped) zones does allow pumping drawdown to reach the water table. Hydraulic gradients in the phreatic zone are affected by the pumping and contaminants

are drawn toward the wells. Contaminants are primarily predicted to arrive at water supply wells with a travel time of less than 50 years.

- Strong hydraulic separation between the shallow (phreatic; water-table) and deep (leaky-confined; pumped) zones does NOT allow the pumping drawdowns to reach the water table. Hydraulic gradients in the phreatic zone are NOT affected by the pumping. Contaminants are predicted to bypass the water supply wells and will arrive at the springs with travel time of about 200 years.

Compartmentalized flow with variably separated shallow and deep zones is supported by observations. The recent pumping tests suggest strong hydraulic separation exists, as described in the "strong separation" regional aquifer conceptual alternative. However, it is likely that some downward movement of water and contaminants does occur due to pumping of water supply wells at depth. Occurrences of tritium and perchlorate in O-1 illustrate the point that flow paths between the shallow and deep aquifer water can exist during production. This observation supports deeper pathways near water supply wells, conforming to the "weak separation" regional aquifer conceptual alternative. However, the extent of vertical transport is undoubtedly a function of the local permeability structure between the water table and the pumping interval in the water supply well, which may vary spatially across the plateau.

It is unclear whether it is important to monitoring goals to distinguish between these two alternatives. The first priority is to enable prediction of contaminant transport velocities sufficiently accurately to design an enhanced monitoring network and interpret the results. Either alternative results in lateral transport of contaminants reaching the water table, especially at locations relatively unaffected by municipal water well pumping. It is possible that the more strongly compartmentalized, two-zone aquifer conceptualization might yield more rapid contaminant transport near the water table, with transport pathways that are more lateral and less influenced by municipal water supply well pumping than the weak separation, more uniformly anisotropic case.

5.2 Relation of Hydrogeologic Workplan Results to Risk Assessment

The data, conceptual models, and numerical models resulting from work performed during implementation of the Hydrogeologic Workplan will be used, in combination with data gathered by the Environmental Restoration Program, to perform groundwater risk assessments for LANL-contaminated sites. The risk assessments will synthesize information (and uncertainty) about source term, vadose-zone flow and contaminant transport, and saturated-zone flow and contaminant transport to predict future health effects at receptor locations. They will be performed using a probabilistic approach that incorporates parameter uncertainty and variability, as well as conceptual model uncertainty. Data sets and site information gathered thus far will be used to define uncertainties in the form of parameter distributions and well-defined alternative conceptual models of groundwater flow and contaminant transport. These uncertainties will be propagated through groundwater models and then used in a risk-based decision analysis to identify and rank alternative actions to protect people from potential impacts of groundwater contamination from various release sites.

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To construct the probabilistic risk assessment and associated decision analysis, several steps are employed. When using these steps we assume that we have already acquired general knowledge about the site. This assumption is, in general, valid for the main contamination issues on the plateau, based on background information gained during the Hydrogeologic Workplan and Environmental Restoration activities of the past 10 years.

1. *Define the question to be answered.* Examples of the questions might be, "What is the potential, future health risk for water users of municipal supply wells associated with historic effluent releases in canyon X? How can these risks be decreased?"
2. *Define input parameters and construct parameter distributions.* Estimates in the range of model input parameters are made based on field data, historic records and expert judgment. Example distributions might include uncertainty in contaminant masses released as a function of time in geologic and/or in hydrologic properties.
3. *Define conceptual models.* These could be related to source release, to vadose zone and groundwater flow, and to contaminant transport.
4. *Construct numerical models based on information from Steps 1 through 3.* Such models will generally include a vadose-zone and a saturated-zone model.
5. *Sample parameter sets to be used as input for a series of Monte Carlo simulations that capture the ranges of model and parameter uncertainties defined.*
6. *Run probabilistic flow and transport simulations using the numerical models and the parameter sets.*
7. *Use output from flow and transport simulations to calculate health effects or to answer other questions defined in Step 1.*
8. *Perform sensitivity analyses to determine parameters or conceptual models that produce model results indicating potential adverse health effects.*

Steps 2, 3 and 4 rely extensively on work performed for the Hydrogeologic Workplan. Predicted results are compared to field data (concentrations, heads, water content) to verify that model results are reasonable. In addition, in order to create regulator and stakeholder trust in this process and its results, stakeholder input concerning parameter distributions and conceptual models is encouraged.

Based on the sensitivity analysis described in Step 8 above, decision analysis is applied to define the optimal course(s) of action at a particular contaminated site. Such actions may include some combination of cleanup, stabilization, additional characterization, and monitoring. If additional characterization is identified as an action that can reduce risk, the sensitivity analysis yields information not only about which parameters should be better characterized, but also to what degree the uncertainty or variability in a specific parameter should be reduced. If the uncertainty were reduced to within the defined limits through characterization, then an updated risk assessment would calculate reduced risk. The decision analysis may help decrease the cost of future characterization by identifying parameters that do not need to be better characterized. Also, if experts feel that further characterization will not result in decreased uncertainty in a parameter identified in the sensitivity analysis, then that characterization effort might be rejected and an action with a higher probability of success may be pursued instead.

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The generic process outlined above will be implemented on a canyon-by-canyon, or site-by-site basis in the future, using information learned from the Workplan and ER activities as a foundation. The conceptual, and for certain sites, numerical models will be formulated based on the knowledge gained and described in Sections 2 and 4 of this report. Thus, the past work becomes the springboard for future risk assessment and decision analysis activities related to groundwater at the LANL site.

5.3 Implications of Hydrogeologic Workplan Findings for Monitoring

The principal motivation for embarking on the Hydrogeologic Workplan was to provide the underlying scientific basis needed to make informed decisions regarding monitoring, remediation, or other actions to provide assurance that the groundwater beneath the Laboratory is protected. The site-wide approach taken in the investigation, both in terms of field-based characterization and modeling, has filled in many gaps in our understanding of the groundwater behavior and pathway directions and rates of migration of contaminants. Characterization wells were drilled for a range of objectives, from the collection of basic hydrogeologic information about the regional aquifer to serving as contaminant-specific and unit-specific sampling wells.

This investigation has led to a vastly improved conceptual understanding of the groundwater systems of the Pajarito Plateau: new concepts have been developed, and previous hypotheses have been confirmed or refined. Although wells have been drilled in a manner that does not preclude their being used in an enhanced monitoring network, the goal was to gather general information required to confirm or refine our conceptual models for groundwater flow and transport. Additional information may be necessary to predict contaminant transport in a particular setting: all sites are unique and require site-specific measurements to reduce uncertainties. However, armed with the improved understanding gained from the Hydrogeologic Workplan activities, we are now able to develop improved groundwater monitoring strategies or conduct more cost-effective detailed studies of individual canyons where initial studies have suggested that groundwater risk may exist.

In this section, we place the results of the findings of the Hydrogeologic Workplan into context by discussing the impact of the conceptual model elements learned in the study to the following questions: How does a particular conceptual model element impact -

- the design of an enhanced groundwater monitoring plan?
- the conduct of a detailed contaminant nature and extent study?
- the application of a remediation strategy?

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5.3.1 Alluvial Groundwater

The alluvial system potentially provides a significant pathway for lateral transport at high velocity over great distances. Travel times on the order of a few years are expected in some canyons for contaminants to travel several kilometers from the release location. Tracer tests in Mortandad Canyon and contaminant migration measurements in Los Alamos and Mortandad canyons illustrate this point. A corollary is that within a few years of reducing the source term (reducing the effluent concentration, removing a solid source through remediation, etc.), concentrations of nonsorbing contaminants decrease due to flushing of the alluvial groundwater. These contaminants can enter the underlying vadose zone. Some contaminants such as Sr-90 travel much more slowly in the alluvial system due to retardation resulting from sorption. The contaminant inventory for these constituents is expected to reside mainly in the alluvial groundwater and on sediments (see Section 3).

A number of attenuation processes act to slow or impede the movement of contaminants, but ultimately the spatial extent of contamination within the canyon is limited by the distance traveled by surface and subsurface water. This distance varies seasonally with rainfall and runoff variability, and can be significantly changed from natural conditions by the input of anthropogenic water sources such as LANL effluent discharges or municipal water treatment facilities.

Alluvial groundwater is the potential source for water and contaminants to the deeper vadose zone. Percolation rates to the deeper vadose zone are temporally and spatially variable. Zones of preferential percolation exist, and it is difficult to predict their locations a priori. These zones are probably controlled by the nature of the hydrogeologic properties at the base of the alluvium, topographic conditions of the canyon, and the degree of fracturing of the underlying basement rock. For example, relatively high recharge is thought to be associated with fractures in Los Alamos Canyon near the Guaje Mountain Fault zone and in locations in the vicinity of the low-head weir, where water infiltrates directly into fractured basalts.

Implications of this conceptual model for nature-and extent studies, groundwater monitoring strategies, and remediation are:

- Long-term monitoring of the alluvial groundwater should focus on nonsorbing contaminants such as tritium, perchlorate, and aqueous HE compounds.
- To monitor changes in contaminant concentrations in response to changes in operations or after remediation, frequent samples must be taken to track progress.
- The absence of a contaminant known through historical records to have been introduced into a canyon likely means that the contaminant resides deeper in the system, and has been flushed out of the shallow system once the release was terminated.
- A relatively complete mass balance of released sorbing contaminants can be achieved by focusing on the alluvial sediments and groundwater.
- If a nonsorbing contaminant has been released for many years into a canyon, most of the inventory probably resides in strata below the alluvial system, so remediation techniques

such as permeable reactive barriers in the alluvial system will be addressing only a small fraction of the inventory.

- Sorbing contaminants are accessible to remediation technologies applied to the alluvial system. Technologies requiring a flux of contaminant, such as a permeable reactive barrier, are likely to work slowly, but may be useful, should some type of vadose zone remediation be required.
- In nature-and-extent studies for nonsorbing contaminants, zones of enhanced infiltration must be located using hydrologic studies to understand the different terms in the water budget. Surface water flow data, piezometric measurements of alluvial groundwater heads, and shallow borings that penetrate the underlying bedrock are useful to identify these zones.
- Numerical models of the surface-water/alluvial groundwater system are useful for constraining the estimates of percolation rates to the deeper vadose zone.

5.3.2 Vadose Zone

Transport velocities for nonsorbing contaminants in the deeper vadose zone (below the alluvial systems) are much larger in canyon bottoms than on mesa tops, suggesting that effluent discharges into canyons are the principle threats to the deep groundwater. Localized zones of high water flux from mesas are possible, such as in locations where the surface has been disturbed by human activities, or in faulted regions in close proximity to the Pajarito fault zone. However, most mesas show little, if any, evidence of transport of large quantities of contaminants to great depths. Numerical models of unsaturated zone transport in mesas are consistent with this observation.

Transport of contaminants from the alluvial groundwater zones to the deeper vadose zone can occur in two main rock types: Bandelier Tuff and basalts. Water percolates principally through the matrix pores in the Bandelier Tuff, but drains quickly through fractures and other open void space in the basalts. Fractures in the Tshirege Member of the Bandelier Tuff at the base of the alluvial systems probably serve as preferential pathways for downward percolation, but water quickly imbibes into the rock matrix, and matrix flow is even more likely in the more homogeneous Otowi Member. The subsurface location of contaminants in the vadose zone is controlled by the local percolation rate from the alluvial system. Although contaminants might be present in the rock pores along the entire reach of a contaminated canyon, the greatest quantities of nonsorbing contaminants will likely be present in zones of enhanced percolation. As discussed in the previous subsection, the locations of these zones are difficult to predict in the absence of detailed studies of the alluvial system.

Where Bandelier Tuff is present, travel times to the regional aquifer are controlled by the percolation flux and the total thickness of the underlying tuff units. Travel times through the tuff units probably range from a few decades to several hundred years. This means that most of the inventory of nonsorbing contaminants probably still resides in the vadose zone. In many vadose zone wells, the location of the contaminant front in the vadose zone has been located in the Bandelier Tuff. However, even where a well defined front exists, contamination is also found in deeper perched zones in the same well or in nearby wells. This suggests that a zone of higher percolation flux supplies the zone, and some lateral flow occurs. This lateral flow may be along

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the canyon, but it is just as likely that the well is located nearby, but offset from the zone of highest percolation, and the lateral transport occurs a short distance perpendicular to the strike of the canyon.

Where infiltration occurs directly onto basalts, higher percolation rates are expected, along with much more rapid transport of contaminants to depth. Travel times through the basalts are expected to be a few years. Beneath the basalts and the Bandelier Tuff, the Puye Formation represents a highly heterogeneous vadose zone medium in which preferential pathways are likely. Travel times through the Puye Formation are therefore likely to be small for nonsorbing contaminants.

Sorbing contaminants are rarely detected at depths below the alluvial groundwater, even in locations where they were released coincident with nonsorbing contaminants that are found at depth. Retardation due to sorption is a key delay mechanism in the system. Detailed sampling has not been conducted in the few feet of rock immediately below the alluvial groundwater zone, but it is likely that any sorbing contaminants that have escaped the alluvial system have only migrated a very short distance into the bedrock.

Perched water is commonly found beneath naturally wet canyons or canyons with significant water input from anthropogenic sources. Generally, the perched water is not found to flow underneath the adjacent mesas, although data are somewhat limited. Perching is caused by low-permeability horizons: the downward percolation rate exceeds the saturated hydraulic conductivity of the perching horizon, and water collects or is diverted laterally. The degree of lateral flow within perched zones is uncertain. Lateral diversion will force contaminants to reach the water table at a different location than it entered the deeper vadose zone, but it is unlikely that this location will fall significantly outside the uncertainty zone defined by the alluvial groundwater zone. Travel times are not dramatically affected by the nature of flow in the perched zone. Travel times are controlled by percolation through the Bandelier Tuff, and the details of the flow path beneath these units are relatively unimportant in determining the total travel time to the regional aquifer. Finally, perching horizons provide a convenient means for monitoring the extent of transport of contaminants in the vadose zone.

Implications of this conceptual model for nature-and extent studies, groundwater monitoring strategies, and remediation are:

- Monitoring of the performance of waste sites located on mesas will probably turn up little contamination at great depth: sampling ports located in the vadose zone directly beneath the waste are probably required to detect contaminants. Given that regional aquifer monitoring to ensure the validity of this conclusion will probably be required, we should attempt to combine monitoring with characterization or other goals to maximize the utility of the well.
- Wet canyons with contaminants are the locations to focus monitoring.
- In zones where contaminants percolate directly into basalts, contamination has traversed the vadose zone, and characterization efforts should focus on the regional aquifer. Further characterization of nature and extent in the basalts of the vadose zone will not yield as

useful information in locations where contaminants have already reached the regional aquifer.

- Long-term monitoring of the intermediate groundwater should focus on nonsorbing contaminants such as tritium, perchlorate, and aqueous HE compounds.
- Sorbing contaminants can be checked on a less frequent basis because to date they have not traveled to significant depths, making the rapid breakthrough of high concentrations to the perched zones or the regional aquifer very unlikely.
- Given the range of travel times through the vadose zone, it is critical, if risk-based approaches are taken, that decision makers settle on the time period of regulatory interest. Without this definition, studies will not be appropriately focused, and misplaced characterization activities are likely to be the result.
- Although downward migration along the entire length of a wet canyon may occur, unequal percolation rates along the canyon lead to zones where greater depths of penetration of contaminated water has occurred, including all the way to the water table. Uncontaminated regional aquifer water at one location does not guarantee that the regional aquifer is clean at another location in the same canyon.
- Monitoring wells should be located near or downgradient of zones of preferential percolation determined from alluvial and vadose zone studies. In canyons posing significant risk, a higher density of shallow intermediate wells should be considered to pinpoint the preferential transport pathways than in canyons with lower risk potential.
- Given that the lateral displacement of contaminants in perched zones will not add large additional uncertainty to the location of contaminant arrivals at the water table, nor will travel times be much affected, there is no compelling reason to study in detail the nature of flow and transport in the perched zones if the regional aquifer water is ultimately of greatest interest for groundwater protection. Characterization of pathways closer to the surface is more cost effective and definitive, and should bound the lateral extent of transport above the regional aquifer.
- Contaminant inventories are likely to be small in most perched zones compared to the thick, unsaturated regions in which contaminated water is held in the matrix pores. Therefore, the perched zones are not good candidates for remediation by pump-and-treat methods because only a small fraction of the inventory will be accessed. An exception might be the large perched zone containing HE contamination at TA-16. If such a technique is attempted, better hydrologic characterization of the intermediate zones are required than we have obtained to date.
- Perched zones are targets of opportunity for acquiring contaminant concentration data, making them useful in nature and extent studies.
- Remediation of contaminants in the unsaturated rock of the vadose zone is not likely to be successful using available technologies. Water residing in matrix pores cannot be pumped, and most contaminants of interest are not volatile. Gas-phase nutrients could possibly be delivered to increase biological activity and induce bioremediation of organic contaminants, but the large spatial extent of contamination in the vadose zone probably renders such concepts impractical unless a single zone of preferential flow and transport is discovered.

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5.3.3 Regional Aquifer

The regional aquifer represents the most likely groundwater accessible to humans via the municipal water supply wells and the springs that discharge at the Rio Grande in White Rock Canyon. The focus of this summary is on the elements of the conceptual model most directly connected to the migration of contaminants in the regional aquifer. Aquifer processes and measurements in the broader regional context were established in Section 2.7 and models were presented in Section 4.2.

Local recharge on the plateau on Laboratory property is a relatively small fraction of the total recharge, but is critical to understand for its implications for contamination from historical and current Laboratory operations. Some of the recharge focused along canyons contains contaminants from the Laboratory. This water potentially represents a source term for regional aquifer contamination.

To date, several observations have been made of contaminants reaching the regional aquifer. Conditions facilitating possible rapid downward migration to the regional aquifer are described in the previous subsections. High percolation rates, typically enhanced by anthropogenic water sources, and/or relatively thin or non-existent Bandelier Tuff at the surface are the conditions most likely to result in present-day regional aquifer contamination of nonsorbing constituents. Future contamination at additional locations is expected over a period of decades to centuries as more of the contaminant inventory reaches the water table.

There are no definitive observations of sorbing contaminants having reached the regional aquifer via a groundwater pathway. This fact further supports the concept of retardation due to sorption as the principal retardation mechanism for many contaminants.

Measured concentrations of nonsorbing contaminants in the regional aquifer are much lower than their concentrations in the effluent discharges or in the alluvial groundwater. This is the case even for samples collected near the top of the regional aquifer, where it might be expected that dilution due to dispersive mixing with regional aquifer water would not have taken place to as great a degree as further downgradient and at greater depth. Significant dilution of these plumes has occurred, assuming that samples are representative of the maximum concentrations and are not affected by mixing in the borehole. Borehole mixing and dilution is expected in municipal water supply wells, but is likely to be less prevalent in characterization-well samples with short screens.

Lateral flow directions in the regional aquifer are defined by the potentiometric surface constructed on the basis of new measurements in the shallow regional aquifer in characterization wells drilled during the characterization program. Flow directions are generally west to east or southeast across the plateau. Detailed gradients at scales smaller than the distance between wells are more uncertain, and might be affected by local recharge conditions and pumping of nearby water supply wells. Deeper in the aquifer, gradients and flow directions are uncertain due to lack of deep wells. Different conceptual models lead to either (1) easterly flow paths with water upwelling and discharging at the Rio Grande, or (2) more southerly flow

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paths with water leaving the Española Basin via interbasin flow to the Albuquerque Basin. Data to distinguish between these two mechanisms are lacking.

Heads decrease with depth in most characterization wells on the plateau, and this condition is probably magnified by pumping of municipal water supply wells, whose screens are located well below the water table. While this condition might imply that contaminants at the water table should move downward, the hydrodynamics of the system are a function of the rock properties as well as the gradient. At some locations we find significant resistance to flow in the vertical direction, leading to compartmentalized zones that are connected only weakly to each other. Phreatic (unconfined water-table) conditions are present near the water table, whereas the aquifer exhibits behavior consistent with leaky-confined conditions at greater depths. The common observation of water-table conditions on the plateau, the depth-dependent response to pumping during multiple-well hydrologic tests, and the persistent head declines in the deeper aquifer in response to pumping are evidence of this behavior. More information is needed to determine if this is a ubiquitous feature of the aquifer.

This conceptual model means that contaminant transport pathways are not necessarily downward in the regional aquifer. In the extreme, a ubiquitous low-permeability barrier separating the phreatic zone from the deeper zone would render the downward component of the gradient meaningless: downward flow would be negligible, and contaminants hitting the regional aquifer would travel laterally along the streamlines defined by the potentiometric surface. The reality is almost certainly more complex, with thin (in the vertical), laterally discontinuous, low-permeability heterogeneities creating increasingly confined conditions with depth. In such a situation, pathways to the depths of water supply well screens are also likely.

Linear transport velocities are a function of the effective porosity of the medium as well as the groundwater flux. Porosity estimates are best made using interwell tracer tests, but these tests have not yet been conducted in the regional aquifer. Heterogeneous flow at larger scales will tend to result in lower effective porosity estimates than what is measured in cores or with borehole logging tools due to preferential flow. All else being equal, lower effective porosity leads to higher velocities and shorter travel times.

Implications of this conceptual model for nature-and extent studies, groundwater monitoring strategies, and remediation are:

- Contaminant detections in the regional aquifer are spatially variable, with detects and non-detects in the same canyon. Given that contamination has probably arrived at the regional aquifer only at a few locations, contaminant monitoring locations in the regional aquifer must be selected using an approach that integrates information of alluvial, vadose zone, and regional aquifer.
- More detailed investigations along canyons with risk-significant contamination are needed to pinpoint the spatial locations of the fastest pathways to the regional aquifer. Locations within or downgradient of these zones are good locations for contamination monitoring. The concept that the canyons are a line source of recharge is a good starting point, but more detailed information is needed to place monitoring wells.

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- Contaminant detections in the regional aquifer will probably continue to be at low concentrations, and changes in time of these values will be gradual. Sampling frequency can thus be relatively long without missing important information.
- Long-term monitoring of the regional aquifer groundwater should focus on non-sorbing contaminants such as tritium, perchlorate, and aqueous HE compounds.
- Sorbing contaminants can be checked on a less frequent basis because to date they have not been detected with certainty in the regional aquifer.
- Contaminants reaching the regional aquifer most likely will travel laterally from their point of entry into the aquifer at the water table. Tortuous pathways to greater depths are also possible, with perhaps only a fraction of the contaminant taking this deeper path, and the rest continuing to travel laterally. Sampling screens in the shallowest portion of the regional aquifer are thus most likely to be well placed to detect contamination. Permeable zones within the first 100 ft or so of the regional aquifer should be the targets for monitoring locations.
- If the water discharging the regional aquifer at the springs in White Rock Canyon is principally water that recharged locally on the plateau, then continued monitoring of these springs for contamination is appropriate. Changes in concentrations are expected to be very gradual, so relatively infrequent sampling is sufficient.
- The extent of downward contaminant migration induced by water supply well pumping is uncertain, ranging from capture of the plume by the supply wells to a shallow, laterally migrating plume unaffected by pumping. Observations at O-1 prove that capture by a water supply well can occur. However, at other locations, weak or non-existent pressure responses in the shallowest screens to pumping from the deeper aquifer suggest that pathways may not exist that connect the shallow and deeper system.
- Given this variability and uncertainty, the concept of a "sentinel well," that is, a well designed to provide advanced warning of supply well contamination, will be difficult to implement. A shallow screen would miss a contaminant transport pathway in which the vertical downward migration occurs upstream of it, whereas a screen at the elevation of the producing zone might miss a vertical pathway located downstream of the monitoring well (including a situation in which the supply well itself is a pathway).
- Monitoring wells designed to be used as sentinel wells must attempt to provide coverage for both types of flow paths. Shallow screens will probably be the best sampling locations for water ultimately discharging at the Rio Grande.
- If pump-and-treat is proposed for a contaminant in the regional aquifer, the system should focus on the uppermost portion of the aquifer, where regional aquifer contaminants are known to reside. More detailed measurements of the hydrologic conditions in the shallow regional aquifer are required to better design monitoring or remediation systems.
- Pumping tests using the water supply wells to induce the pressure response are extremely informative, and should be continued as opportunities present themselves. Each pumped well provides information in the vicinity of that well, so to gain the site-wide knowledge needed, continued testing is required. The tests are not duplicative or redundant: rather, each test provides unique information.

- Tracer tests are the best way to determine the effective porosity of the medium at the field scale. This parameter is needed to convert groundwater flux estimates to a contaminant transport velocity estimate. The Puye Formation and the Cerros del Rio basalts are the most important units in which to conduct these tests, since these are the units encountered at the water table in regions where Laboratory contamination is a concern.
- The regional aquifer flow and transport model must continue to be improved by incorporating new data and concepts. Use of the model to interpret the hydrologic response of the system, to design and interpret the results of the future monitoring program, and in contaminant transport predictive studies requires that models keep up with the new data that will be collected. In the shorter term, available data sets not used in the model development to date, including the pumping tests discussed above, geochemical data, and thermal data, should be incorporated into updated versions of the model.
- For all modeling, including the regional aquifer model, continued exploration of alternative hypotheses should be continued. This statement applies for all aspects of the groundwater model, including those elements not obviously tied to questions of contaminant transport. Groundwater model development is a process in which feedbacks of changes in one portion of the system can affect model performance in unforeseen ways. A philosophy of continuous model improvement should continue to be used to enable higher fidelity predictions as improvements are made.
- Future studies should go beyond current approaches to include a data collection and modeling processes that make the greatest use of opportunities to investigate large portions of the aquifer. These opportunities may include: (1) passive monitoring of aquifer pressures in response to inputs (recharge) and withdrawals (supply well pumping) that occur as a matter of course; (2) incorporation of that information into refined versions of the regional aquifer model; and (3) increasing use of remote data that provides information on large-scale aquifer conditions and properties, including INSAR, airborne electromagnetic data, or gravity data, if initial investigations demonstrate that these techniques provide useful information.

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APPENDIX 1-A. REGULATORY FRAMEWORK

1-A-1. Hydrogeologic Workplan Background

The Hydrogeologic Workplan was intended to collect data necessary to comprehensively address DOE, federal, and state groundwater requirements. The groundwater requirements are for characterization and monitoring. The intent of the Hydrogeologic Workplan was to characterize the hydrogeologic setting to the degree necessary to evaluate the existing monitoring network and design an enhanced network, if necessary.

1-A-1.1. DOE Orders

LANL, in compliance with DOE Order 5400.1, published a Groundwater Protection Management Program Plan (GWPMP) on March 6, 1995 (LANL 1995a). A subsequent draft of the plan including revisions and dated January 31, 1996, was approved by DOE/AL on March 15, 1996 (LANL 1996a). The GWPMP provides background information on the hydrologic setting and programs in place at LANL; describes groundwater issues and solutions; and lays out business and implementation plans. The GWPMP concluded that the number and distribution of wells was insufficient to monitor the groundwater beneath LANL. The Hydrogeologic Workplan (LANL 1998) was intended in part to address the monitoring network issue by collecting data necessary to design an enhanced monitoring network.

1-A-1.2. RCRA Permit and HSWA Requirements

In 1986, the Environmental Protection Agency (EPA) authorized the State of New Mexico to operate a hazardous waste management program under the RCRA. The New Mexico Environment Department (NMED) issued a Hazardous Waste Facility Permit (Permit NMD890010515) to the Laboratory on November 8, 1989. At that time, both EPA and NMED retained administrative authority for the permit: EPA for the portions of the permit that were affected by the RCRA Hazardous and Solid Waste Amendments (HSWA) enacted in 1984, and NMED, for the parts of the permit that were unaffected by HSWA. In March 1990, the EPA issued a HSWA module to LANL's permit (known as Module VIII) and, in January of 1996, authorized NMED to act as administrative authority for that module. Thus in 1996 NMED became the sole administrative authority for the Laboratory's Hazardous Waste Facility permit.

The activities described in the Hydrogeologic Workplan support the appropriate Resource Conservation and Recovery Act (RCRA) and the New Mexico Hazardous Waste Act monitoring and corrective action decisions that have yet to be made at LANL. This investigation phase comes before and provides the basis for formal RCRA monitoring that may be warranted. The general RCRA requirements for characterization and monitoring are provided in the following sections.

1-A-1.3. RCRA Monitoring Requirements

LANL is currently in compliance with RCRA groundwater monitoring requirements. The monitoring requirements under RCRA are different for "regulated units" and for other "solid

waste management units" (SWMUs). This discussion will address both types of monitoring requirements.

RCRA Monitoring Requirements for Regulated Units

"Regulated units" are surface impoundments, waste piles, land treatment units, and landfills that received hazardous waste after July 26, 1982. The "regulated units" that remain at LANL and have not undergone clean closure (all hazardous waste residues and contamination have been removed) are

- Area G in Technical Area 54 (TA-54),
- Area H in Technical Area 54 (TA-54), and
- Area L in Technical Area 54 (TA-54).

(Note: Open Burning/Open Detonation units in the High Explosives corridor at LANL, although not considered "regulated units", once permitted may be subject to similar groundwater monitoring requirements as "regulated units" if they pose a threat to groundwater).

The monitoring requirements for regulated units are described in the RCRA regulations in sections 40 CFR 264.90 to 40 CFR 264.100. The monitoring for regulated units is divided into three structured, sequential monitoring programs: (1) a program for detection, (2) a program for compliance, and (3) a corrective action program. The requirements of these monitoring programs are summarized generally in Table 1-A-1. According to the regulations, monitoring of these units may be waived under the following conditions:

- The unit presents no potential impact to groundwater.
- The unit has been clean closed.
- The regional administrator/state director has granted a groundwater monitoring waiver.

Groundwater-monitoring waiver demonstrations for all of LANL's "regulated units" (including those that had not yet been clean-closed) were submitted to NMED in the 1980s and early 1990s. In May 1995, the NMED issued a letter to LANL indicating that there was insufficient information on the hydrogeologic setting upon which to base approval of the groundwater-monitoring waiver demonstrations, and the waiver demonstrations were denied (NMED, 1995a). By letter dated August 17, 1995 NMED required that a site-wide hydrogeologic characterization be completed that would satisfy both the RCRA "regulated units" and the HSWA module requirements. (Section III. A. 1 of the HSWA portion of the RCRA permit requires that the hydrogeologic setting be characterized) (NMED, 1995b). Thus, groundwater monitoring requirements for LANL's "regulated units" can be addressed by the completion of the site-wide hydrogeologic characterization described in the Hydrogeologic Workplan.

In response to the NMED letters, the Laboratory submitted the Hydrogeologic Workplan to NMED in 1996 and received NMED approval on May 22, 1998. The Hydrogeologic Workplan describes a 7-year characterization effort for groundwater on a Lab-wide basis with the objective of developing sufficient understanding of the hydrogeology to design an adequate detection monitoring network or to resubmit waiver demonstrations for some or all of the units.

Table 1-A-1.
RCRA Groundwater Monitoring Programs for Regulated Units

Monitoring Program	Triggered by	Purpose	Requirements	Definition	Result
Detection (40 CFR 264.98)	Required for all owners/operators of facilities that treat, store, or dispose of hazardous waste 40 CFR 264.91(4), unless exempt by waiver	Detect releases that are a threat to human health or the environment	Monitor for indicator parameters, constituents, or reaction products. Monitoring to be based on the type, quantity, and concentration of waste constituents in the unit; mobility, stability, and persistence in unsaturated zone; detectability in groundwater; and concentration in background	"Detected" defined as statistically significant evidence of contamination based on comparison of groundwater quality upgradient and unaffected by unit to groundwater that passes beneath the unit measured at the point of compliance	If "detected", institute compliance monitoring program
Compliance (40 CFR 264.99)	Whenever hazardous constituents to which the ground water protection standard applies are detected at a compliance point 40 CFR 264.91(1)	Document that a release from a unit is above a standard. Determine compliance with ground water protection standard	To determine whether regulated units are in compliance with the groundwater protection standard by monitoring constituents and their associated concentrations specified in the permit at the POC for the prescribed period. The groundwater protection standard specifies: list of constituents; concentration limits; point of compliance; period of compliance	"Exceeded" defined as statistically significant evidence of increased contamination	If ground water protection standard concentration limits are being exceeded, institute corrective action program
Corrective Action (40 CFR 264.100)	Whenever the groundwater protection standard is exceeded 40 CFR 264.91(2) & (3)	To ensure that corrective action has successfully brought regulated units into compliance with the groundwater protection standard	Requires action taken to prevent hazardous constituents from exceeding concentration limits and a groundwater monitoring program established to demonstrate effectiveness	Same as for Compliance Monitoring Program	If concentrations are being exceeded, re-evaluate corrective action

Monitoring Requirements for Solid Waste Management Units

The applicability of RCRA groundwater monitoring requirements to units not defined as "regulated units" at 40CFR264.90 (or subpart X units that pose a threat to groundwater) is described at 40 CFR 264.101. For these types of solid waste management units (SWMU), there are no specific monitoring requirements; however, preamble language suggests that repetitive monitoring may be necessary to determine the efficacy of a remedy in the event a release is determined to be a threat to human health or the environment. In addition, characterization to determine if a release to groundwater has occurred and to what extent, if any, such release threatens human health or the environment may be necessary. LANL's ENV-ERS Project conducts the investigations necessary to determine if releases have occurred and if a release represents an unacceptable risk to human health and the environment.

There is a requirement for hydrogeologic characterization at Section III.A.1 of the HSWA module of the RCRA operating permit. The work conducted under the Hydrogeologic Workplan was intended to fulfill this requirement for characterization, in addition to the requirements for "regulated units".

In summary, there are no RCRA monitoring requirements for SWMUs that are not "regulated units", unless a release requiring corrective action is identified through characterization. LANL was in the process of characterizing the hydrogeologic setting, identifying releases, determining the extent of any releases, and evaluating the risk posed by any releases through activities associated with the HWP and Module III of the HSWA module.

In 2005, NMED, DOE, and UC signed a Compliance Order on Consent (NMED 2005). The order replaces the site-wide characterization requirements of the Hydrogeologic Workplan with wells intended to investigate the nature and extent of contaminant releases from sources. The data and information gained through implementation of the Hydrogeologic Workplan are invaluable to planning and implementing the site-specific corrective action investigations required by the Order on Consent (NMED 2005).

1-A-2. Technical Objectives of the Hydrogeologic Workplan

As previously stated, the Hydrogeologic Workplan was developed in response to NMED letters requiring a better understanding of the hydrogeologic regime in order to evaluate the need for groundwater monitoring. Specifically, NMED identified four issues that needed to be resolved (NMED 1995b):

- Individual zones of saturation beneath LANL have not been adequately delineated and the "hydraulic interconnection" between these is not understood.
- The recharge area(s) for the regional and intermediate aquifers and any associated effects of fracture-fault zones with regard to contaminant transport and hydrology have not been identified.
- The groundwater flow direction(s) of the regional aquifer and intermediate aquifers, as influenced by pumping of production wells, are unknown.
- Aquifer characteristics cannot be determined without additional monitoring wells installed within specific intervals of the various aquifers beneath the facility.

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In addition, the Hydrogeologic Workplan was intended to satisfy the characterization requirements in the HSWA module. Table 1-1 is a crosswalk of HSWA module requirements, how they have been addressed, and which sections of this report contain that information. The technical objectives of the Hydrogeologic Workplan were intended to be comprehensive with respect to groundwater regulatory requirements for characterization and potential future monitoring.

The questions posed by the NMED were large-scale hydrogeologic questions that were open-ended – it was unclear how much data would be required to resolve them. To address this issue, the Hydrogeologic Workplan focused the hydrogeologic investigations on information needed to understand potential contaminant transport and exposure from "aggregates": groups of potential release sites (PRS) that are geographically close and had similar waste-generating processes. The Data Quality Objective (DQO) process was employed to develop the data collection and analysis portions of the Hydrogeologic Workplan. The DQO process was developed by the Environmental Protection Agency to ensure that data collected are adequate for decision-making (EPA, 1994). The first step in applying the DQO process was developing a decision flow chart that specified the decisions for which data were necessary (Figure 1-A-1). The decision statements were in answer to the following questions:

- Are the alluvial groundwaters and uppermost subsurface waters at contaminant concentrations greater than a regulatory limit or risk level?
- Is the intermediate perched zone groundwater at contaminant concentrations greater than some regulatory limit or risk level?
- Is the regional aquifer, as affected by canyon systems, impacted by contaminant concentrations greater than some regulatory limit or risk level?
- What are the pathways for exposure to contaminants from sediments associated with alluvial groundwater and uppermost subsurface water?
- Are there sufficient source terms to cause contamination if moved along pathways to the regional aquifer within a compliance time frame?

The first three decisions are used to determine whether groundwater currently exceeds standards. The last two decisions establish whether pathways exist that may allow contamination to occur in the future. Each decision had several subordinate questions that required some data to answer. The decisions cannot be resolved until data sufficient to answer each subordinate question is available. For example, for the decision: "what are the pathways for exposure to contaminants from alluvial sediments and uppermost subsurface water?" the subordinate questions are as follows:

- Does significant recharge occur from near surface to underlying groundwater bodies?
- Do we know the hydraulic properties of the alluvium?
- What are the retardation factors of alluvial sediments?
- Do we understand groundwater movement from alluvial water to intermediate perched zones?

- Do we understand groundwater movement from intermediate perched zones to the regional aquifer?
- Are fractures and faults important contaminant transport pathways for liquids in canyons?

Although there were numerous subordinate questions and decisions, the data needed to resolve them were primarily water quality information from alluvial, intermediate, and regional aquifer groundwater, hydrologic properties, and geochemistry. Modeling tools were identified as critical to analyzing the data collected and to guide further data collection.

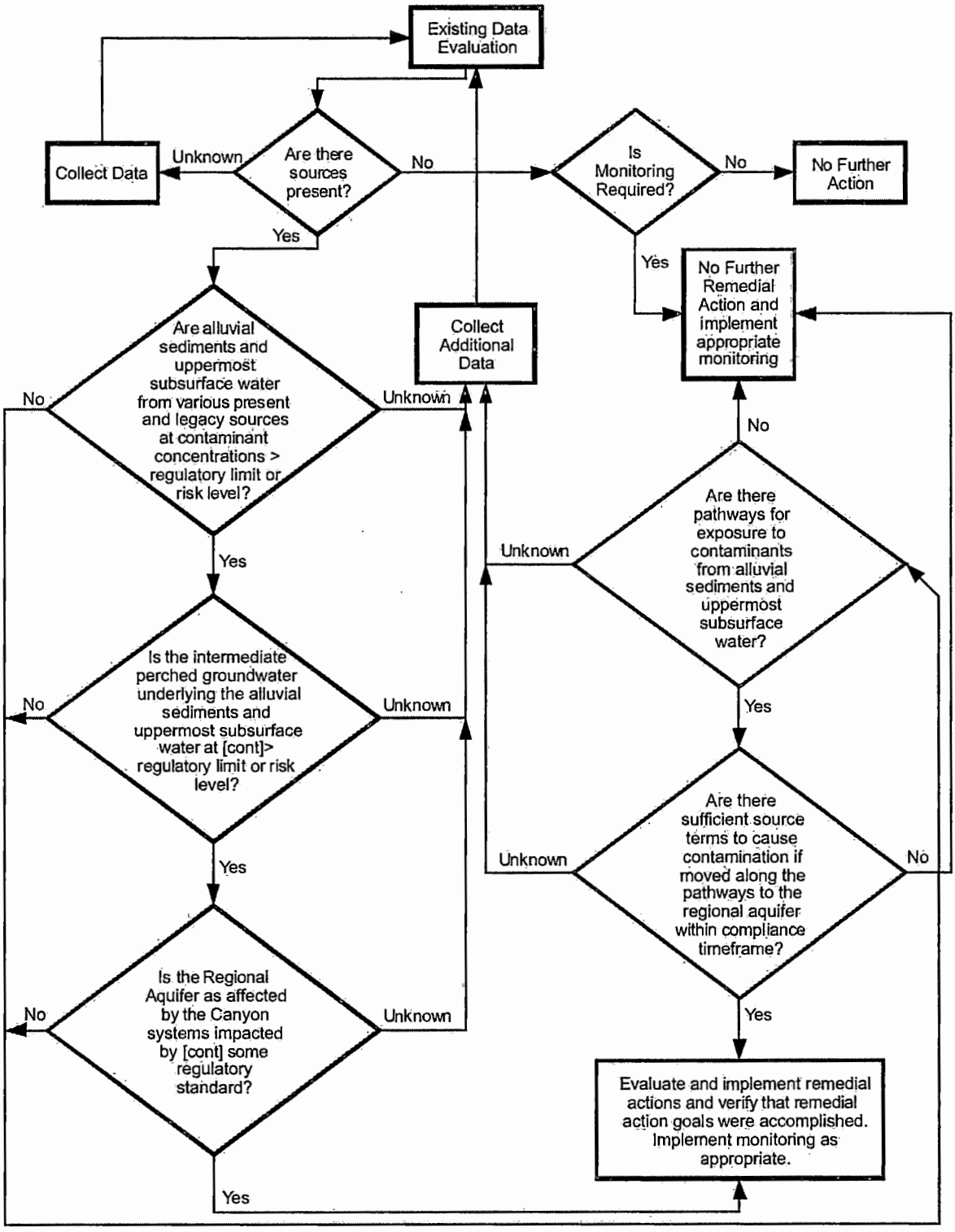

Figure 1-A-1. Flow chart used for hydrogeologic characterization decisions (LANL, 1998).

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1-A-3. Hydrogeologic Workplan Data Collection Approach

The data collection approach described in the Hydrogeologic Workplan utilized an iterative approach that incorporated new information and data into the site conceptual model as it became available. This method enabled effective decision-making for aggregates to occur in the characterization process on a step-by-step basis. This approach was developed, in part, to resemble EPA's concept of the limit of the waste management area as described in the definition of the point of compliance. In this definition, it is acceptable to circumscribe several units with an imaginary line when locating the point of compliance, a vertical surface at the hydraulically downgradient limit of the waste management area at which the groundwater protection standards apply (New Mexico Annotated Code, Title 20, Chapter 4, Part 1, (20 NMAC 4.1) Subpart VI, 264.95(2)). The aggregate approach bounded similar areas in a manner that supported not only logical hydrogeologic characterization but process and regulatory application as well.

Eight aggregates were defined and data collection locations were selected to resolve the subordinate questions and decisions. In aggregates where there were existing data and known contaminant sources, wells were placed where they were most likely to encounter contaminants and to assess contaminant transport pathways. In aggregates with little existing hydrologic data and known contaminant sources, wells were located proximal and down gradient from contaminant sources. In aggregates where there were little existing data and small or no contaminant sources, wells were placed to reduce uncertainties in the hydrologic setting and to confirm the assumption of no groundwater impact.

The original Hydrogeologic Workplan proposed to characterize the hydrogeologic setting by drilling, logging, installing, and sampling wells to the regional aquifer without installing separate intermediate-depth wells. This approach was expected to provide the greatest amount of characterization data and was agreed to by NMED, as documented in a letter sent to NMED (LANL 1996b). This approach was formulated based on the following technical rationale:

- The presence of intermediate zone(s) is controlled by geologic structure and the geology across LANL is extremely variable. Understanding the geologic setting from the surface to the regional aquifer is more important in predicting flow than measurements in individual intermediate zones.
- If a well were installed at the first intermediate zone encountered, there would be a gap in the information between the upper intermediate zone and the top of the regional aquifer. Furthermore, wells installed in the first intermediate zone will not provide any information on the underlying less permeable perching layer. The characteristics of the perching layer must be understood in order to assess the impact to the regional aquifer. The perching layer stratigraphy is as important to evaluating potential pathways as the hydrologic characteristics of the saturated zone itself.
- The data collection described in the Hydrogeologic Workplan is intended to characterize the hydrogeologic setting to a sufficient degree to develop an adequate detection monitoring system or groundwater monitoring waiver, if appropriate. Wells that may be needed to monitor the intermediate zone(s) will be considered as part of the monitoring system design.

1-A-3.1 Revision to Hydrogeologic Workplan Data Collection Approach

The characterization approach was modified as the Hydrogeologic Workplan was implemented. A major drilling program change was prompted by an NMED letter (NMED 1999) with two key points: (1) water samples taken from boreholes during the drilling operation would not be adequate for regulatory decisions; and (2) perched zones did not have to be sealed off during drilling, but could be left open until the well was constructed. The practical result of these requirements was that intermediate perched zones could not be characterized by obtaining one sample during drilling. Instead, a dedicated sampling location must be installed to characterize the intermediate perched zones over time. Initially, wells that encountered intermediate perched zones were built with multiple completions. Eventually separate intermediate wells were constructed to be able to monitor the intermediate perched zones. The second point in the 1999 NMED letter, to be able to leave intermediate perched zones open, allowed the wells to be drilled faster because there was no longer a need to telescope down well casing sizes to seal off intermediate perched groundwater zones.

Another modification from the Hydrogeologic Workplan was the use of fluids in drilling. The original Hydrogeologic Workplan called for drilling with no additives in order to collect pristine samples while drilling. The earliest wells were drilled using air-rotary drilling methods with casing advance and the minimal use of fluids other than air. Because of significant problems associated with stuck casing, unstable boreholes, and lost circulation, small amounts of drilling fluids were used to improve lubricity, borehole stabilization, and cuttings circulation. Continuing drilling problems made total reliance on air-rotary drilling with casing advance impracticable for meeting drilling objectives. It became apparent that the depth of the wells and the difficult drilling environment required that more drilling techniques be added to the drilling "tool box" in order to respond to the complex hydrogeologic conditions that characterize the Pajarito Plateau. All of the drilling methods used at LANL are used in standard environmental industry practice and are described by the American Society for Testing and Materials (ASTM). Table 1-A-2 briefly describes the drilling methods used since the beginning of the drilling program.

1-A-3.2 Alluvial Groundwater Investigations

Beginning in the mid-1990s, detailed investigations were begun for the ENV-ERS Project, which is driven by the Laboratory's HSWA module to the RCRA operating permit. The first watershed investigation to be implemented was in the Los Alamos and Pueblo Canyon watershed to fulfill request for information requirements presented in the Task/Site Work Plan for Los Alamos and Pueblo Canyons, OU 1049 (LANL 1995b) and the subsequent addendum, Surface Water and Alluvial Groundwater Sampling and Analysis Plan (LANL 2002). The watershed-scale investigations conducted under the ENV-ERS Project are designed to collect data sufficient to evaluate human-health and ecological risk at a watershed scale. In accordance with existing canyons work plans, the Compliance Order on Consent, and the Federal Facility Compliance Agreement for storm water, surface water and alluvial groundwater investigations are conducted in a coupled manner in order to facilitate the development of conceptual models of the relationship between these waters.

Table 1-A-2.
Drilling Methods Used for Hydrogeologic Characterization Wells at Los Alamos National Laboratory

Drilling Method	Description	Benefits	Drawbacks
Air rotary ASTM D5782-95; D5781-95 (ASTM, 2000a; ASTM, 2000b)	A drill pipe or drill stem is coupled to a drill bit that rotates and cuts through soils, alluvium, and rock. The cuttings produced from the rotation of the drilling bit are transported to the surface by compressed air or by compressed air augmented by municipal water mixed with drilling additives. In conventional air-rotary drilling, the compressed air is forced down the borehole through the drill pipe and returns to the surface up through the annular space. In reverse air rotary, a dual tube drilling system is used and drilling fluids are forced down the outer tube and return up the center tube, where the cuttings are discharged through a cyclone velocity dissipater. The circulation of drilling fluids not only removes cuttings from the borehole but also cools the drill bit.	The air rotary drilling method, employed in an open hole, is the fastest and least expensive drilling method in the unsaturated zone. It is best suited for stable, hard rock formations with good circulation characteristics (in which there is minimal loss of fluids into the formations). Open hole drilling allows for the collection of an extensive suite of geophysical logs for the characterization of hydrogeologic properties.	Experience gained in the early part of the drilling program showed that air rotary drilling in an open hole is not always a suitable method for drilling at depths greater than 150 feet below the regional aquifer water table. The use of municipal water with drilling additives is almost always required to improve borehole stability and circulation of cuttings. Use of these drilling fluids can alter the natural properties of the rocks and it is not possible to collect pristine water samples while drilling. Generation of dust at the surface is a problem unless dust-suppression equipment is used and/or municipal water is added to the circulation fluid.
Casing advance ASTM D5876-95 (ASTM, 2000c)	Air-rotary drilling using an under reamer cutting system (rotary bits or downhole hammer) to create a hole large enough for a heavy-walled casing to slide down behind the drill bit. The casing is advanced simultaneously while drilling the hole. Compressed air or compressed air augmented by municipal water mixed with drilling additives is used to remove the cuttings from the bottom of the borehole. When the borehole has reached total depth, the well is constructed inside the heavy walled casing, as the casing is incrementally removed.	The drill casing stabilizes the borehole when drilling through poorly consolidated materials and improves circulation in highly porous or fractured rocks. The cased hole provides a stable environment for the construction of the well. There is relatively little disturbance to the borehole walls and relatively undisturbed samples of rock and water are obtained during drilling.	The heavy-wall casing frequently becomes stuck and is difficult to extract from the borehole. Casing that can not be extracted must be abandoned in the hole, possibly impacting the use of some well screens. The cost is high and drilling rates are often very slow. The use of municipal water with drilling additives is almost always required to provide lubricity between the casing and the borehole wall and to improve borehole stability and the circulation of cuttings. Use of heavy-walled casing severely limits the geophysical methods that can be used for hydrogeologic characterization.
Mud rotary ASTM D5783-95 (ASTM, 2000d)	A bit is rotated to cut through the rock while mud is the circulating fluid pumped down through the drill pipe and returned back up the borehole through the annular space. The mud-filled hole stabilizes the borehole wall and cools the drill bit. Circulation of the mud carries the cuttings up to the surface.	Rapid and effective drilling methods. Can be used to maintain borehole stability in poorly consolidated sediments of the saturated zone. Open hole drilling allows for the collection of an extensive suite of geophysical logs for the characterization of hydrogeologic properties.	Does not work well in vadose zone due to lost circulation zones in fractured basalts and in highly porous tuffs and sediments. Masks the recognition of water-bearing zones while drilling. Slow circulation of mud mixes cuttings from throughout the borehole, hampering geologic characterization. Addition of drilling muds and fluids changes the geochemical environment around the borehole. Requires extensive development to remove residual muds and drilling fluids, and to restore the aquifer's hydraulic and geochemical properties to natural conditions.

The scope of investigation in the Los Alamos/Pueblo watershed (other watershed work plans have similar scope) consisted of 4 sampling rounds collected through one year across a representative range of hydrologic conditions (e.g., higher water levels and more extensive saturation typical of spring snowmelt conditions; and low groundwater levels that commonly occur in the fall), detailed water-level measurements collected using dedicated pressure transducers, measurement of field parameters, a water balance study, and field observations on extent and persistence of surface water. These data were used to develop a conceptual model to describe the occurrence and temporal context of groundwater contamination in support of the risk assessment. The report for the Los Alamos and Pueblo Canyon investigation was submitted to the NMED in April, 2004. The Mortandad Canyon investigation is underway, and the report is scheduled for completion in 2006. Subsequent watershed-scale investigations will be completed in order of priority.

1-A-4. Independent Peer Review of the Hydrogeologic Workplan

In 1999, an External Advisory Group (EAG) was formed to provide an independent review of the implementation of LANL's Hydrogeologic Workplan. The EAG consisted of six members with diverse technical and professional backgrounds to provide a broad technical and managerial review of LANL's Hydrogeologic Workplan activities and methods. The EAG was provided semi-annual updates on the program status. The EAG provided a report of findings and observations based on the semi-annual reviews (External Advisory Group 1999a, 1999b, 2000a, 2000b, 2001a, 2001b, 2002; External Evaluation Group 1998). In response, action plans were developed that specified how the recommendations of the EAG were incorporated into the program.

In addition to the semi-annual reviews, the EAG provided technical assistance when requested. In FY99, two EAG members provided invaluable assistance in repairing the well R-25 collapsed screen #3. Numerous problems encountered in the repair process were overcome with the advice and guidance of the EAG members. The "hands on" assistance was critical in completing the characterization well.

1-A-5. Outreach Activities

The original Hydrogeologic Workplan (LANL 1998) specified a communications approach that included three quarterly meetings, one annual meeting, and an annual status report to update regulators on the characterization progress. The primary purpose of the quarterly meetings was to report on progress and findings from the previous quarter. The annual meeting was intended to provide more of a synthesis of data collected in the previous year and to allow regulators to provide their input to the planned activities for the coming year. One objective of the annual meeting was to reach a DOE, LANL, NMED consensus on the activities for the following year in time to influence budget requests. The annual report was published as a prelude to the annual meeting and provided the written synthesis of the data collected and interpreted over the year. The first annual meeting was held in March 1998 and participants were limited to representatives of the DOE, LANL, and NMED. Annual meetings were held in 1999, 2000, 2001, 2002, 2003, 2004, and the last annual meeting was held in 2005.

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Extensive information has been presented and discussed with regulators and the public in several ways since the Hydrogeologic Workplan was completed in 1997 (Table 1-A-3):

- Three quarterly meetings and one annual meeting held every year (27 documented meetings) with distribution of meeting minutes to an extensive mailing list
- Annual status reports summarizing the work accomplished in the previous year
- Well completion reports
- Geochemistry reports
- Hydrologic testing reports
- Water quality data, which are available over the internet at http://wqdbworld.lanl.gov.
- Annual environmental surveillance reports, which provide the analytical results of surface water and groundwater sampling at LANL and in northern New Mexico.

Table 1-A-3.
Documents Relevant to the Hydrogeologic Workplan

Type of Document	Subject	Reference
Meeting Minutes	Annual Meeting 3/30/98	Letter, DOE/LASO file number LAAME 6BK-010
	Annual Meeting 3/29/99	Letter, LANL file number ESH-18/WQ&H: 99-0162
	Annual Meeting 3/29/00	Letter, LANL file number ESH-18/WQ&H: 00-0267
	Annual Meeting 3/20/01	Letter LANL file number ESH-18/WQ&H: 01-126
	Annual Meeting 4/10/02	Letter LANL file number RRES-DO: 02-25
	Annual Meeting 3/18/03	Letter LANL file number RES-GPP-03-053
	Annual Meeting 4/12/04	Letter LANL file number RRES-GPP-04-0023
	Quarterly Meeting 6/29/98	Letter LANL file number ESH-18/WQ&H: 98-0233
	Quarterly Meeting 10/27/98	Letter LANL file number ESH-18/WQ&H: 98-0443
	Quarterly Meeting 2/9/99	Letter LANL file number ESH-18/WQ&H: 99-0066
	Quarterly Meeting 6/23/99	Letter LANL file number ESH-18/WQ&H: 99-0275
	Quarterly Meeting 10/13/99	Letter LANL file number ESH-18/WQ&H: 99-0451)
	Quarterly Meeting 1/27/00	Letter LANL file number ESH-18/WQ&H: 00-0056
	Quarterly Meeting 6/22/00	Letter LANL file number ESH-18/WQ&H: 00-0425
	Quarterly Meeting 10/3/00	Letter LANL file number ESH-18/WQ&H: 00-0403
	Quarterly Meeting 1/30/01	Letter LANL file number ESH-18/WQ&H: 01-051
	Quarterly Meeting 6/27/01	Letter LANL file number ESH-18/WQ&H: 01-284
	Quarterly Meeting 10/16/01	Letter LANL file number ESH-18/WQ&H: 01-410
	Quarterly Meeting 1/30/02	Letter LANL file number ESH-18/WQ&H: 02-114
	Quarterly Meeting 7/24/02	Letter LANL file number RRES-GWPP: 02-03
	Quarterly Meeting 10/29/02	Letter LANL file number RES-GPP-02-021)
	Quarterly Meeting 1/22/03	Letter LANL file number RES-GPP-03-013
	Quarterly Meeting 10/27/03	Letter LANL file number RRES-GPP-03-101
	Quarterly Meeting 1/28/04	Letter LANL file number RES-GPP-04-0023
	Quarterly Meeting 7/13/04	Letter LANL file number RRES-GWPP:04-0045
	Quarterly Meeting 10/25/04	Letter LANL file number ENV-GPP:04-0051
	Quarterly Meeting 2/2/05	Letter LANL file number ENV-GPP:05-0007

Table 1-A-3.
Documents Relevant to the Hydrogeologic Workplan (continued)

Type of Document	Subject	Reference
Ground-water Annual Status Reports	Annual Report for FY97	Nylander, C.L., et al., 1998.
	Annual Report for FY98	Nylander, C.L., et al., 1999.
	Annual Report for FY99	Nylander, C.L., et al., 2000.
	Annual Report for FY00	Nylander, C.L., et al., 2001.
	Annual Report for FY01	Nylander, C.L., et al., 2002.
	Annual Report for FY02	Nylander, C.L., et al., 2003.
Well Completion Reports	Well Completion Report for R-1	Kleinfelder, Well R-1, 2004c.
	Well Completion Report for R-2	Kleinfelder, Well R-2, 2004b.
	Well Completion Report for R-4	Kleinfelder, 2004a, Well R-4, 2004a.
	Well Completion Report for R-5	LANL, Well R-5, 2003a.
	Well Completion Report for R-7	Stone, W., et al., Well R-7, 2002.
	Well Completion Report for R-8	LANL, Well R-8, 2003b.
	Well Completion Report for R-9	Broxton, D.E., et al., Well R-9, 2001a.
	Well Completion Report for R-11	Kleinfelder, Well R-11, 2004c.
	Well Completion Report for R-12	Broxton, D.E., et al., Well R-12, 2001b.
	Well Completion Report for R-13	LANL, Well R-13, 2003a.
	Well Completion Report for R-14	LANL, Well R-14, 2003.
	Well Completion Report for R-15	Longmire, P., et al., Well R-15, 2000.
	Well Completion Report for R-16	LANL, Well R-16, 2003e.
	Well Completion Report for R-19	Broxton, D., et al., Well R-19, 2001d.
	Well Completion Report for CdV-R-15-3	Kopp, B., et al., Well CdV-R-15-3, 2002.
	Well Completion Report for CdV-R-37-2	Kopp, B., et al., Well CdV-R-37-2, 2003.
	Well Completion Report for R-20	LANL, Well R-20, 2003f.
	Well Completion Report for R-21	Kleinfelder, Well R-21, 2003f.
	Well Completion Report for R-22	Ball, T. et al., Well R-22, 2002.
	Well Completion Report for R-23	LANL, Well R-23, 2003g.
	Well Completion Report for R-25	Broxton, D., et al. Well R-25, 2001e.
	Well Completion Report for R-26	Kleinfelder, Well R-26, 2004f.
	Well Completion Report for R-28	Kleinfelder, Well R-28, 2004d.
	Well Completion Report for R-31	Vaniman, D., et al. Well R-31, 2002.
	Well Completion Report for R-32	LANL, Well R-32, 2003h.

Table 1-A-3.
Documents Relevant to the Hydrogeologic Workplan (continued)

Type of Document	Subject	Reference
	Well Completion Report for MCOBT-4.4	Broxton, D., et al., 2002.
	Well Completion Report for MCOBT-8.5	Broxton, D., et al., 2002.
	Well Completion Report for R-9i	Broxton, D., et al., 2001c.
	Well Completion Report for CdV-16-1(i)	(Completion report not available)
	Well Completion Report for CdV-16-2(i)	(Completion report not available)
	Well Completion Report for CdV-16-3(i)	(Completion report not available)
Geo-chemistry Reports	Geochemistry Report for R-7	Longmire, P., et al., Well R-7, 2002.
	Geochemistry Report for R-9	Longmire, P., Well R-9, 2002b.
	Geochemistry Report for R-9i	Longmire, P., Well R-9i, 2002b.
	Geochemistry Report for R-12	Longmire, P., Well R-12, 2002d.
	Geochemistry Report for R-15	Longmire, P., Well R-15, 2002a.
	Geochemistry Report for R-19	Longmire, P., Well R-19, 2002e.
	Geochemistry Report for R-22	Longmire, P., Well R-22, 2002c.
	Geochemistry Report for R-25	Longmire, P., Well R-25, 2005.
Hydro-logic Testing Reports	Hydrologic Testing Report for R-9, R-12, and R-25	Stone, W. J., Wells R-9, R-12, and R-25, 2000.
	Hydrologic Testing Report for R-9i, R-13, R-19, R-22, R-31	Stone, W.J., et al., Wells R-9i, R-13, R-19, R-22, R-31, 2003.
	Hydrologic Testing Report R-15	McLin, S.G., Well R-15, 2004.

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APPENDIX 1-B. WELL COMPLETION FACT SHEETS

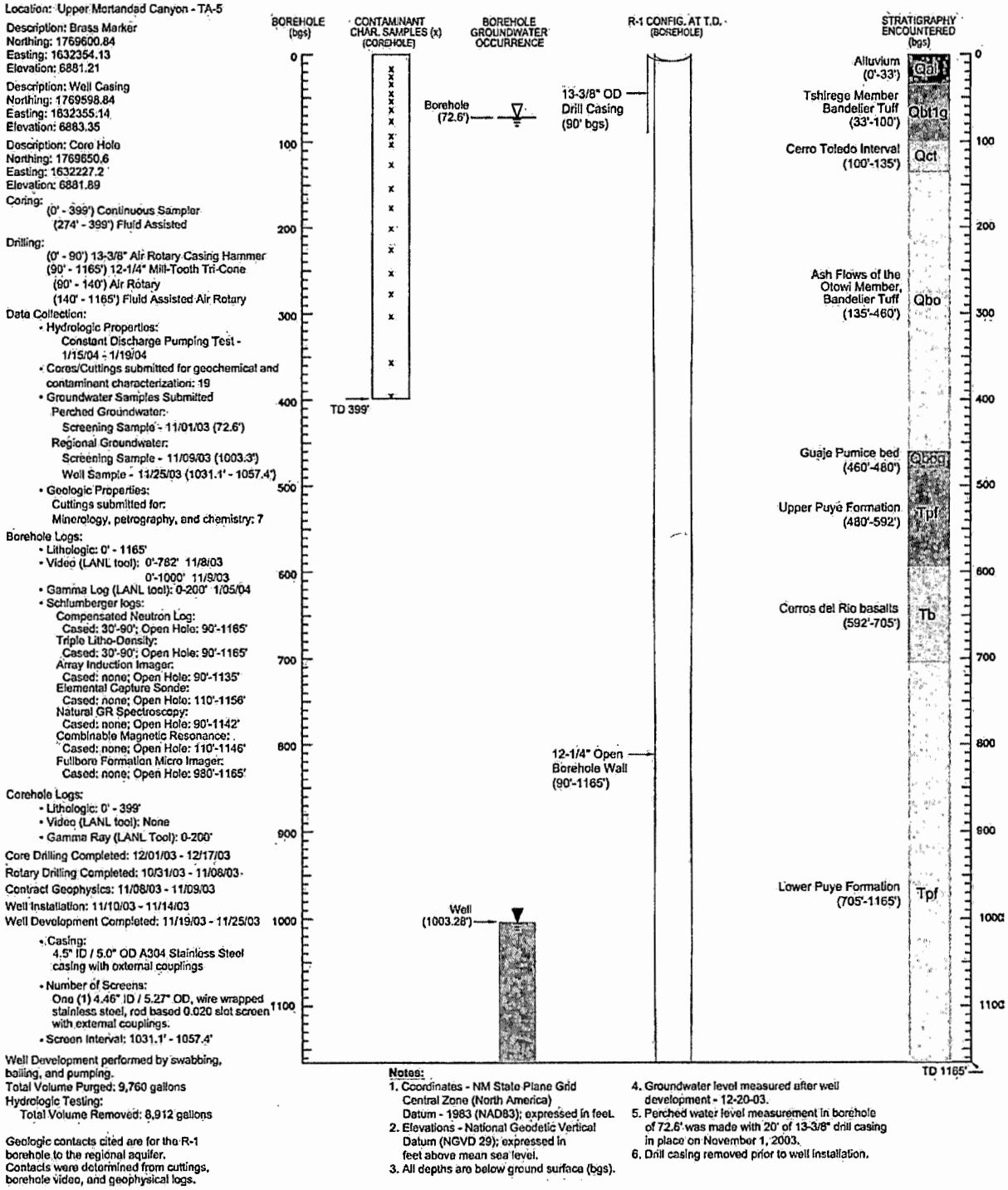

Figure 1-B-1. Completion diagram for well R-1 (Kleinfelder 2004e).

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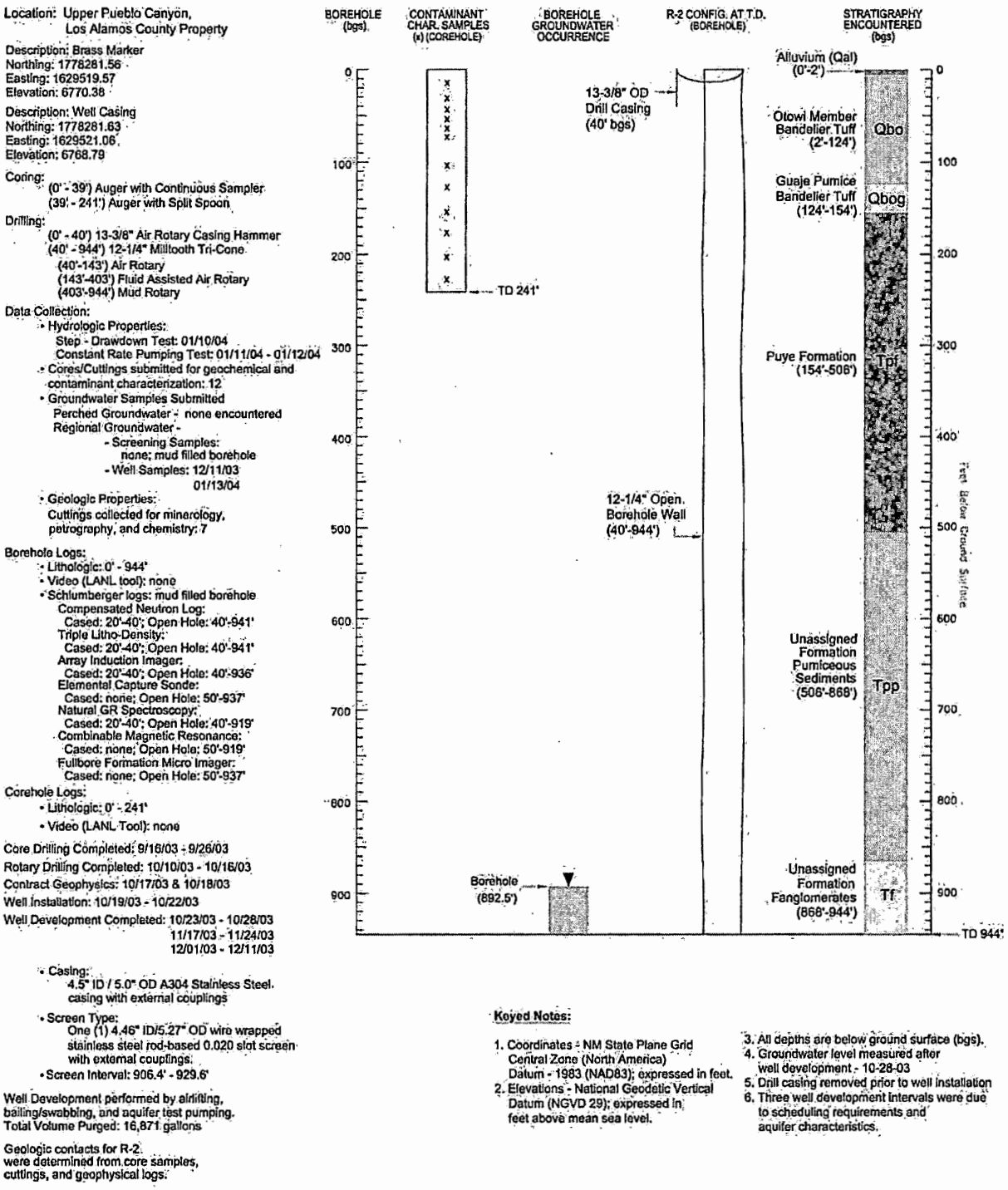

Figure 1-B-2. Completion diagram for well R-2 (Kleinfelder 2004b).

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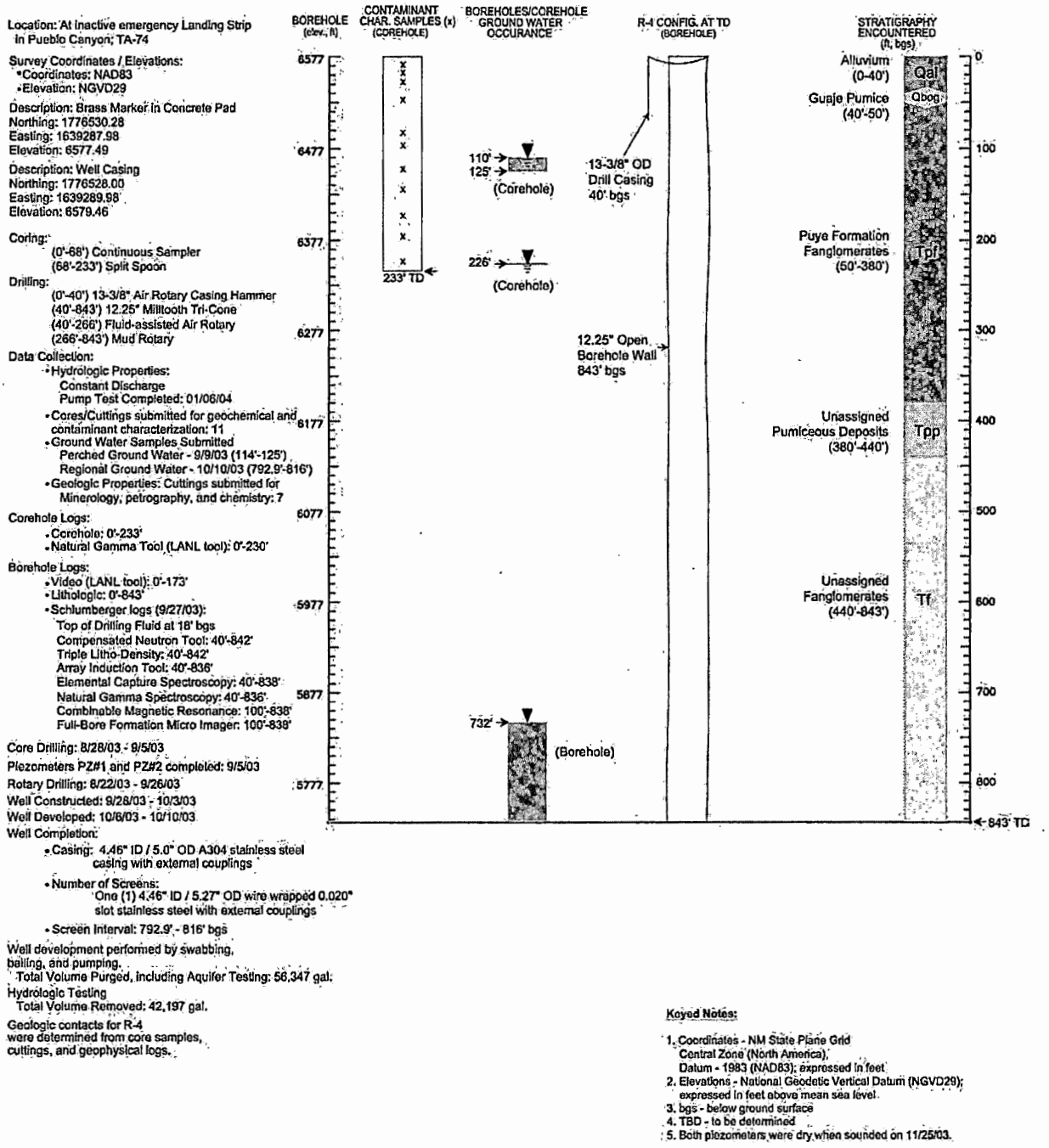

Figure 1-B-3. Completion diagram for well R-4 (Kleinfelder 2004a).

05908

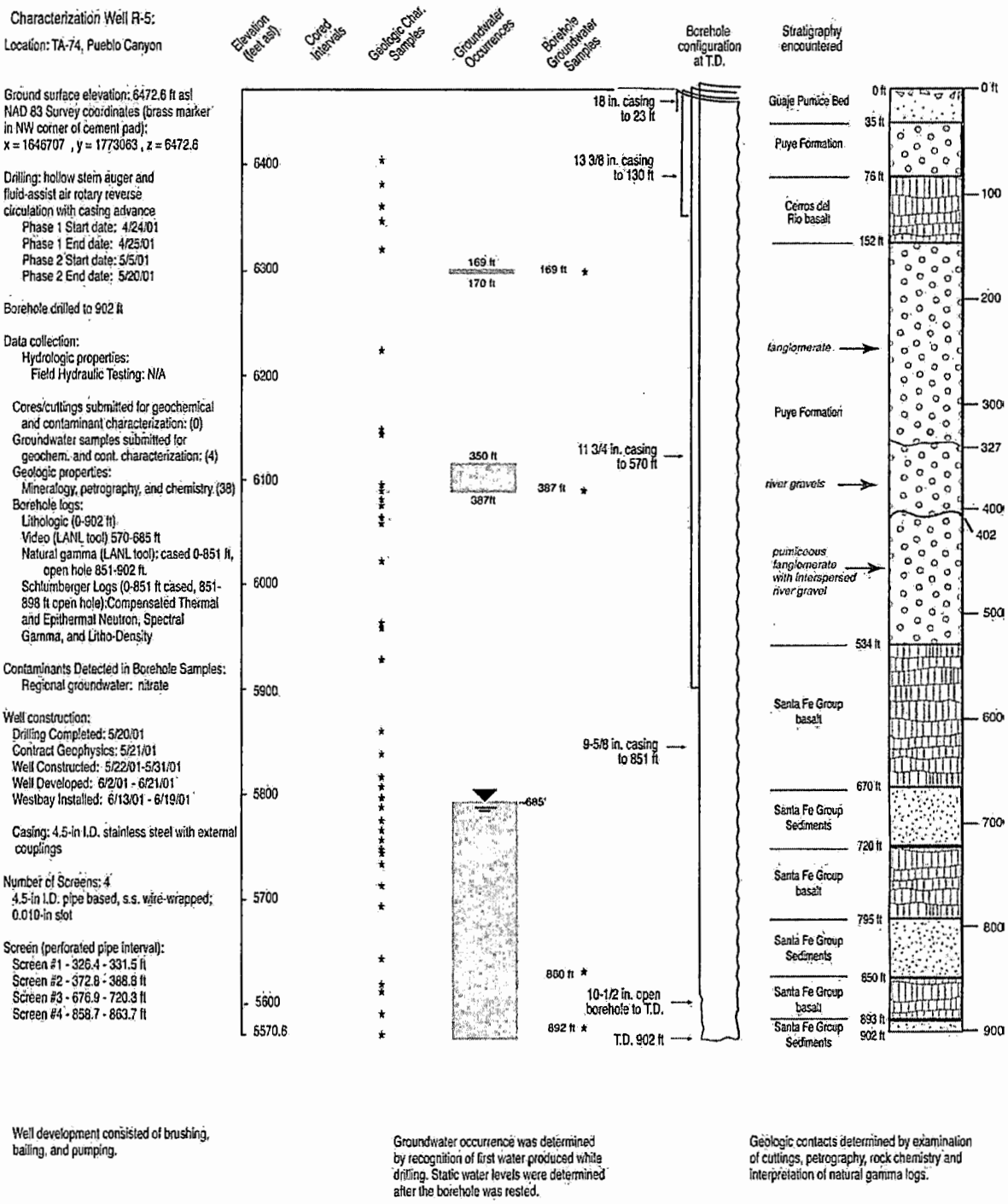

Figure 1-B-4. Completion diagram for well R-5 (LANL 2003a).

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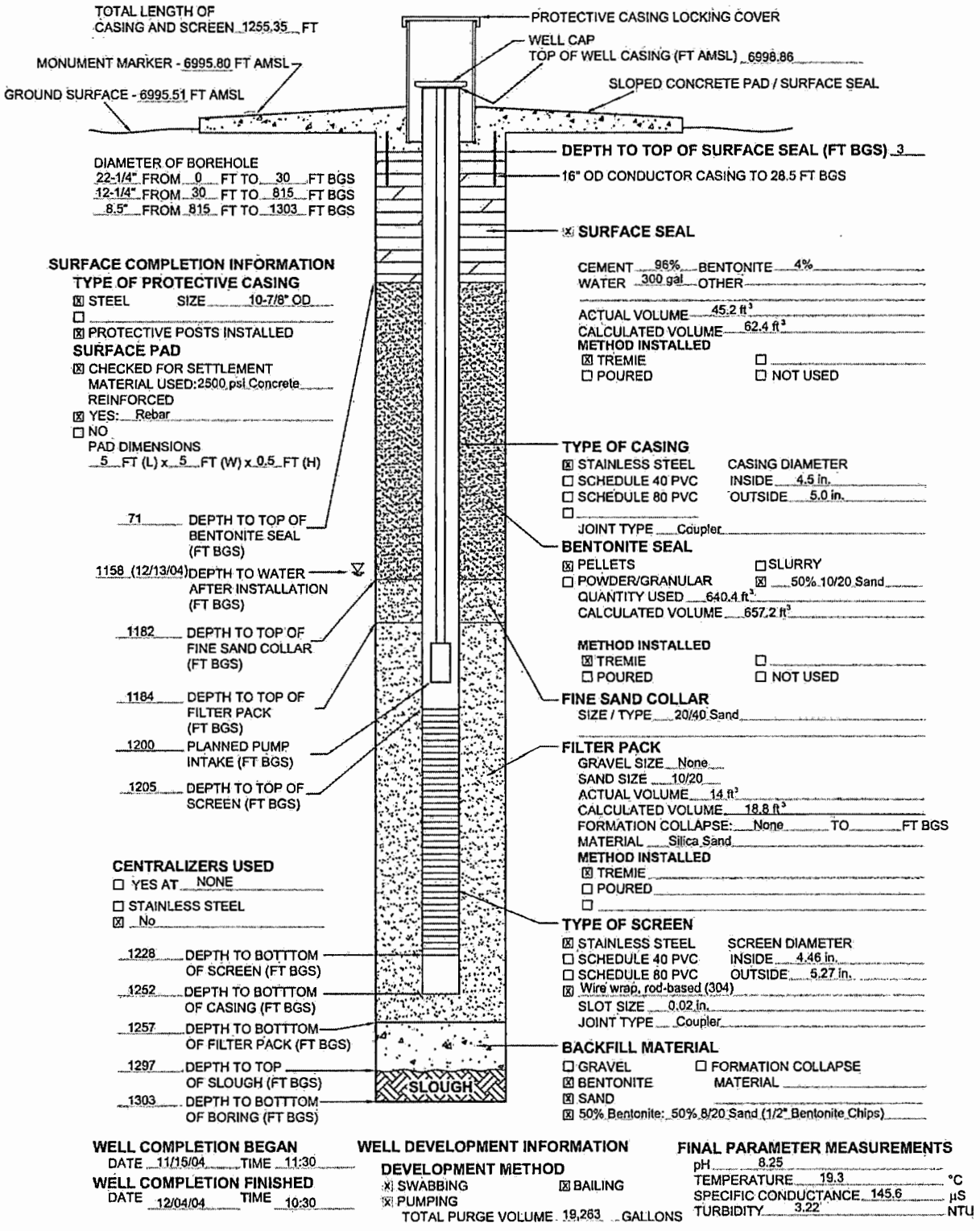

Figure 1-B-5. Completion diagram for well R-6 (Note: no report available for R-6).

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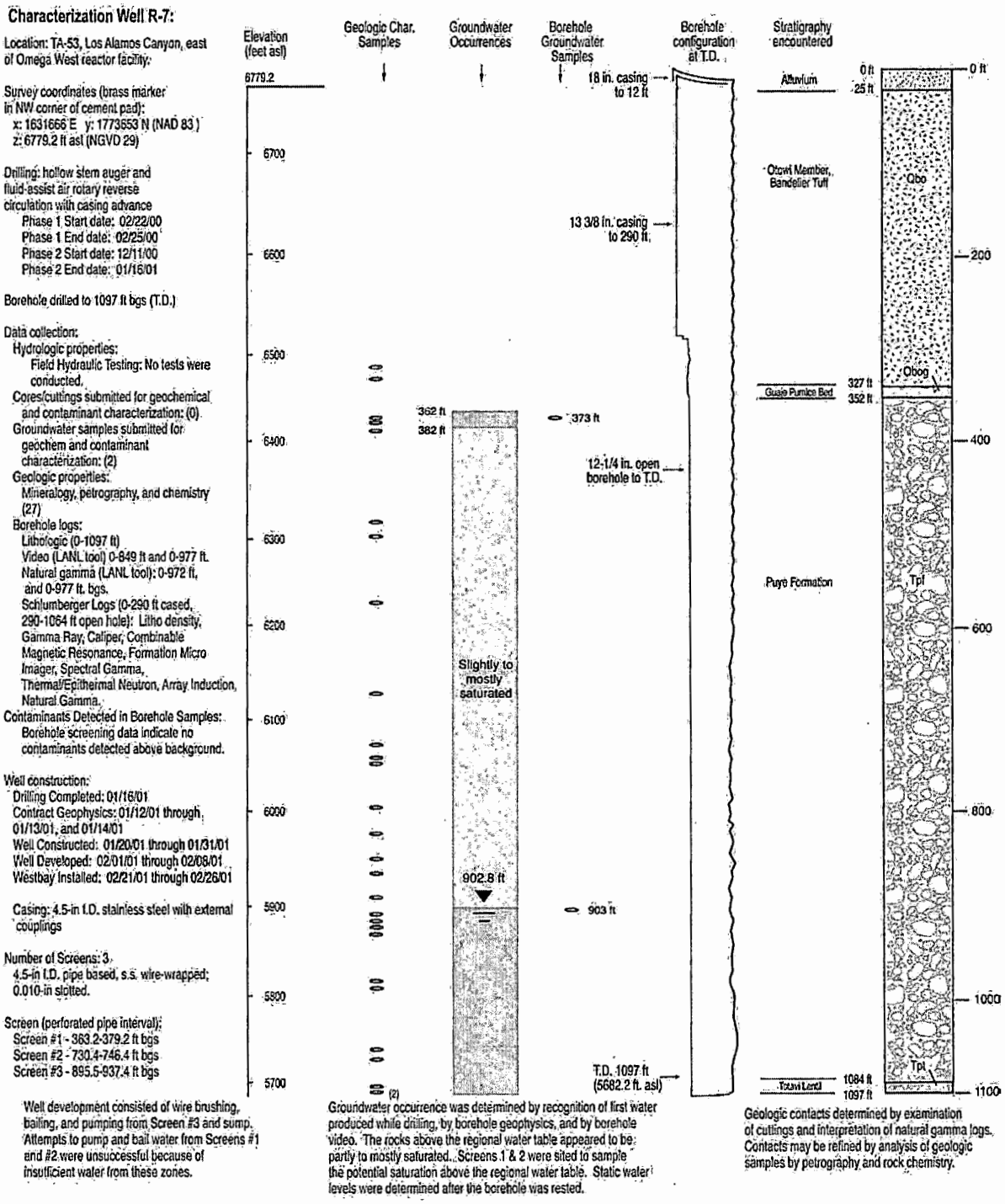

Figure 1-B-6. Completion diagram for well R-7 (Stone et al. 2002).

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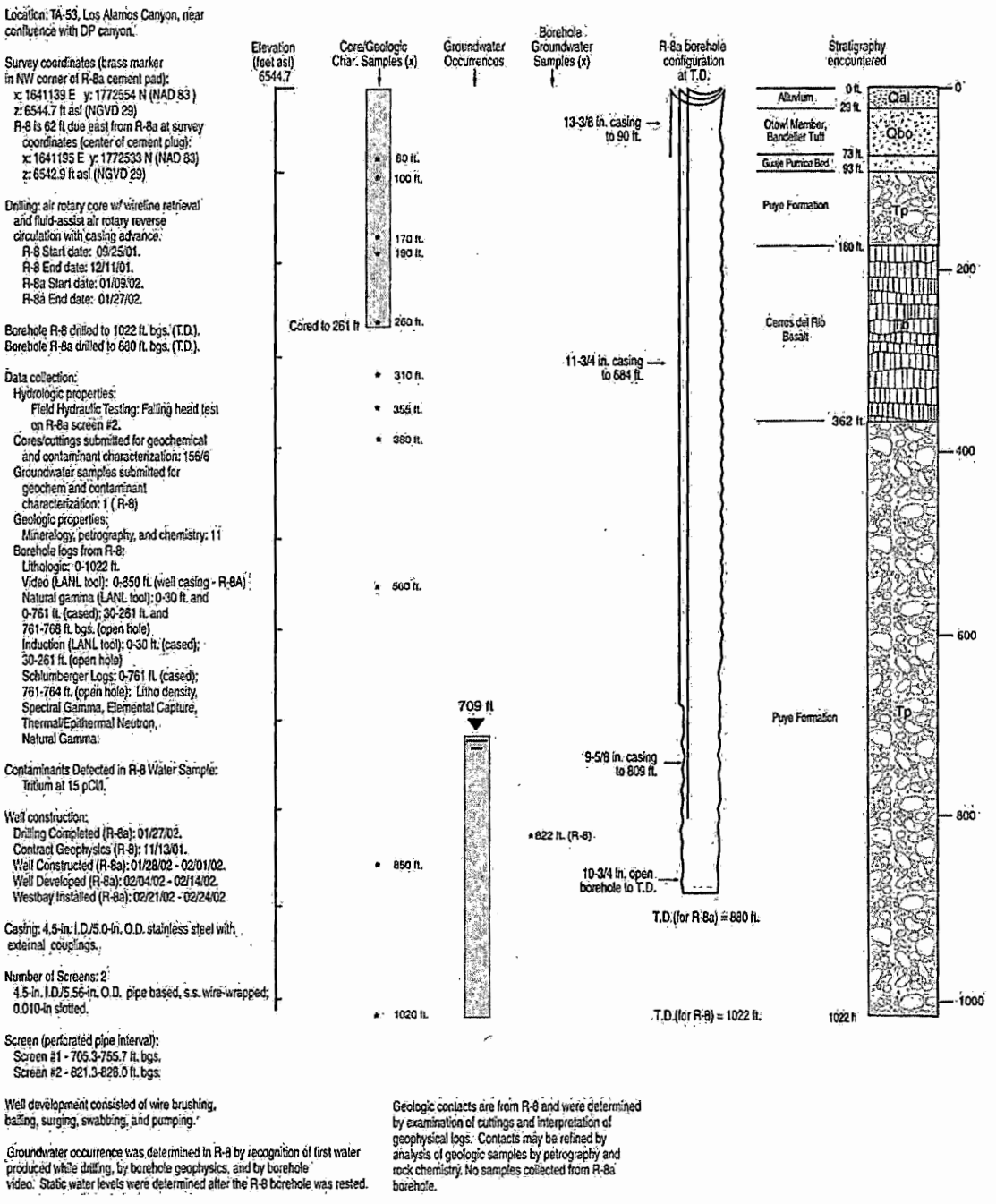

Figure 1-B-7. Completion diagram for wells R-8 and R-8a (LANL 2003b).

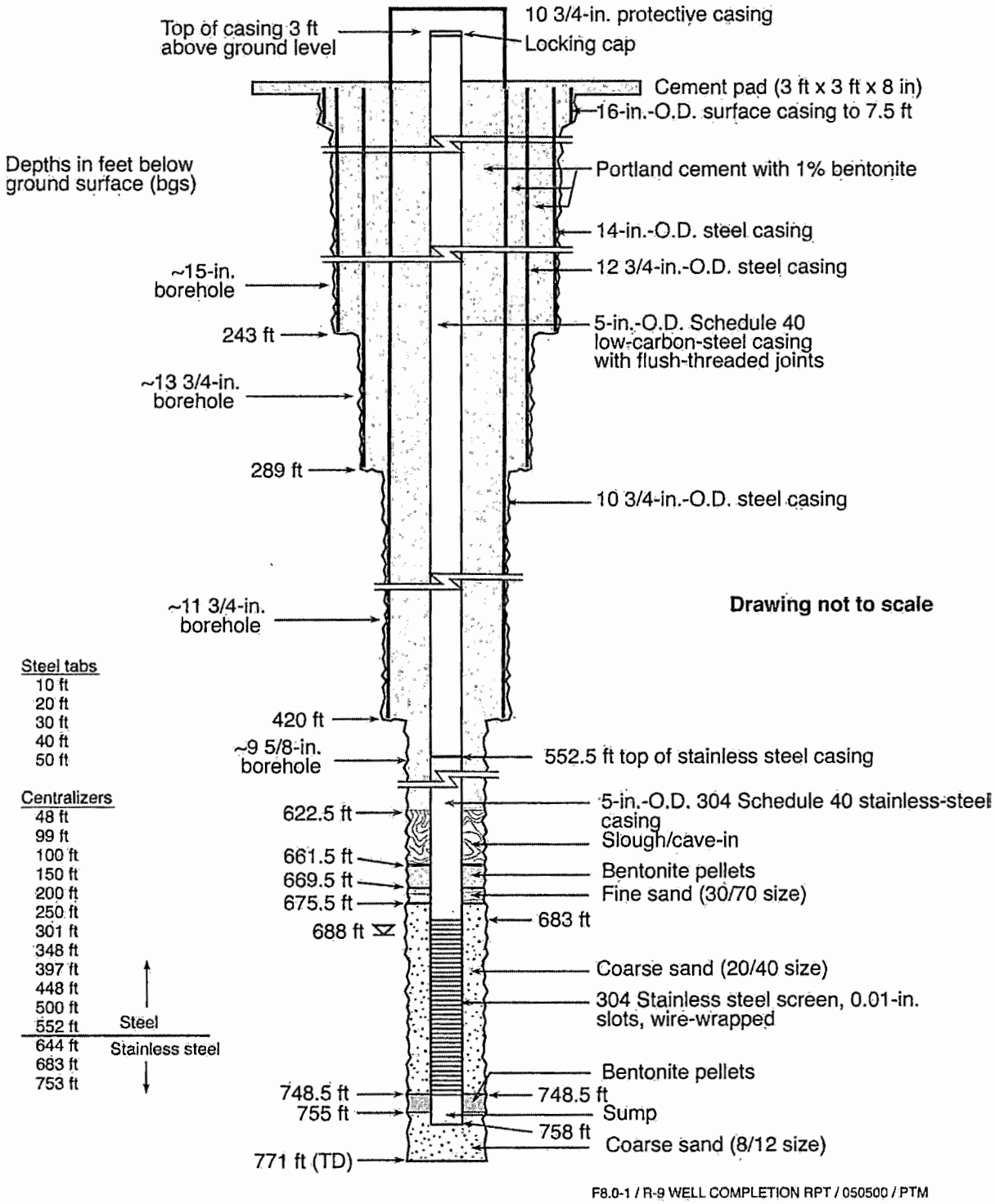

Figure 1-B-8. Completion diagram for well R-9 (Broxton et al. 2001d).

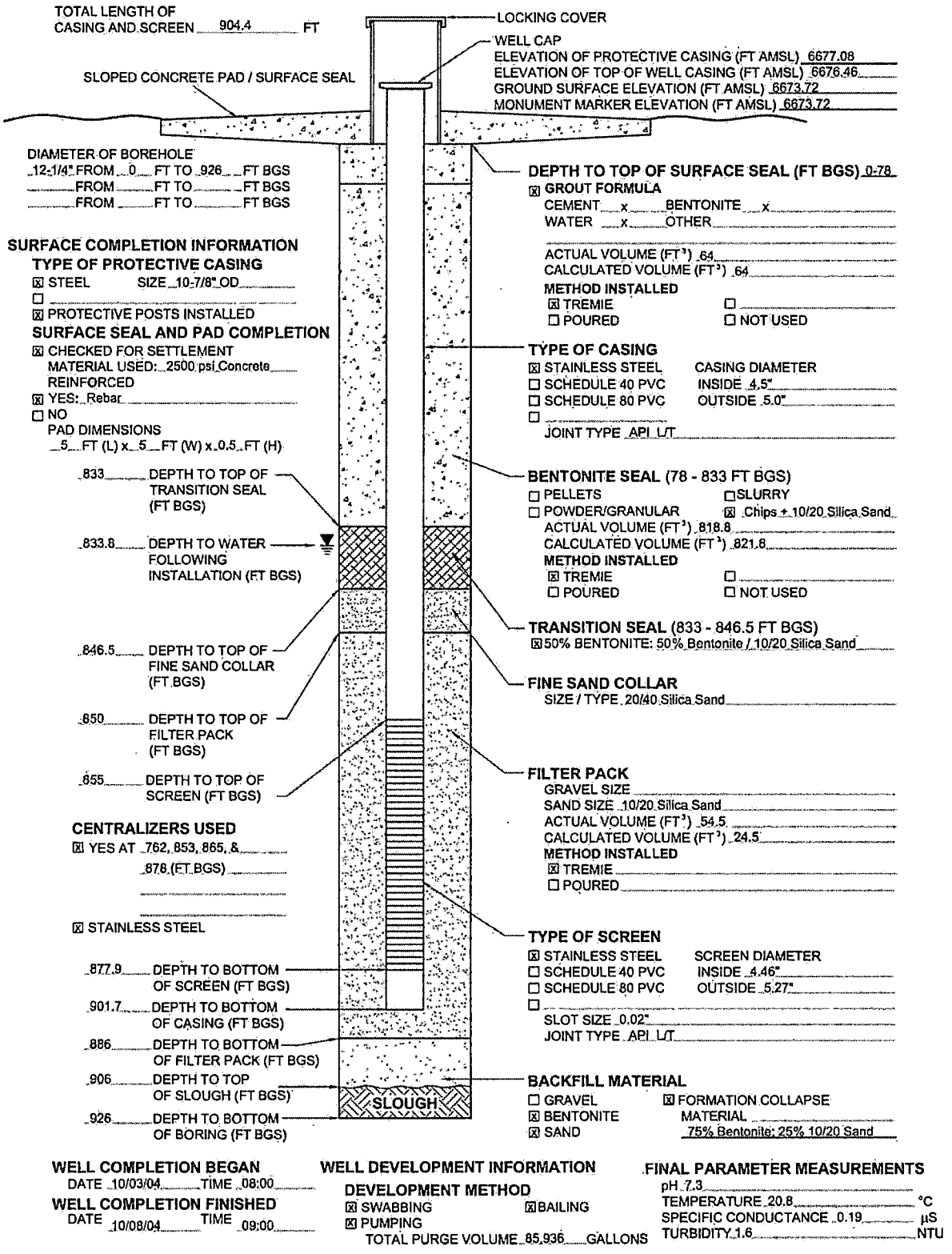

Figure 1-B-9. Completion diagram for well R-11 (Kleinfelder 2004c).

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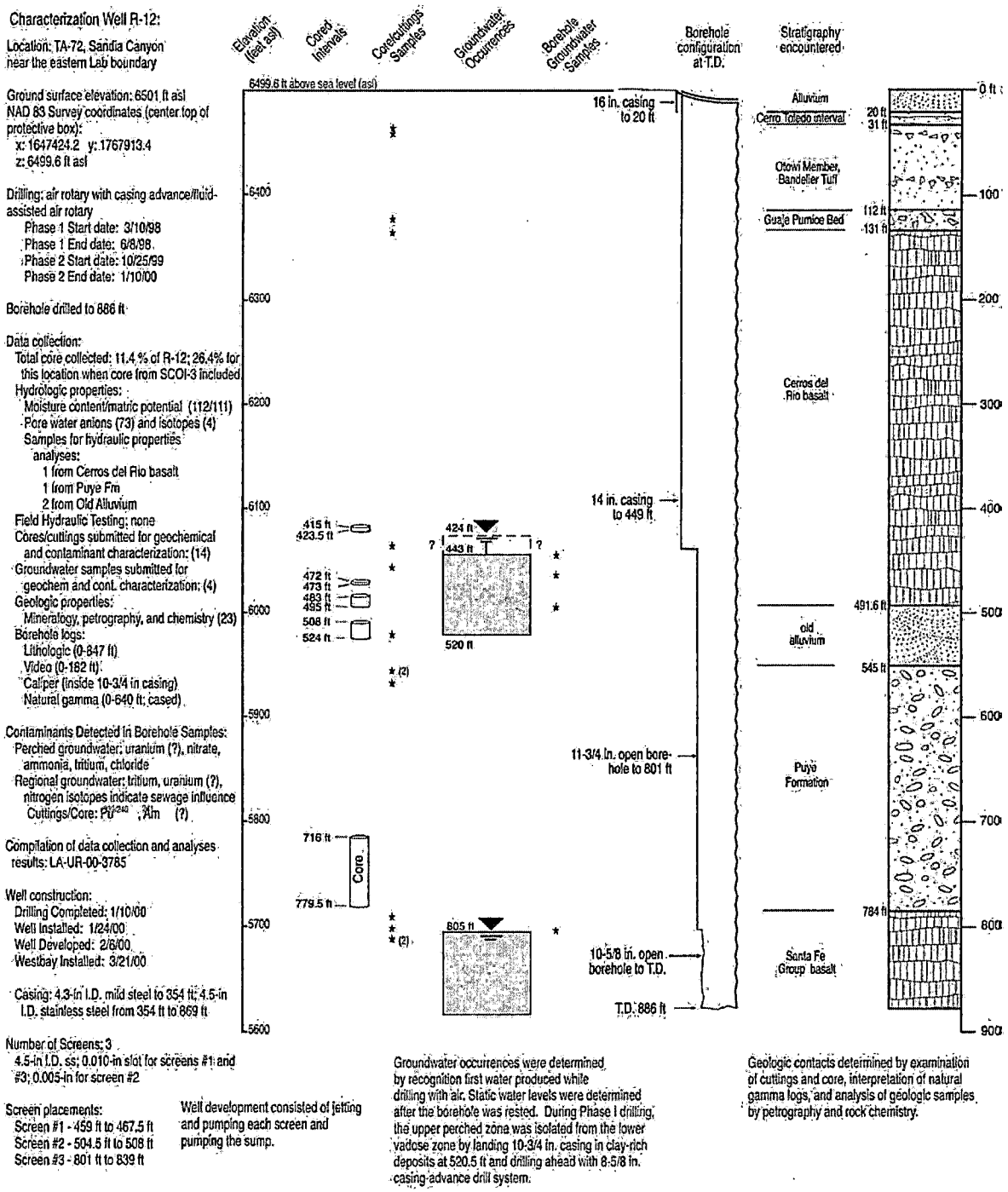

Figure 1-B-10. Completion diagram for well R-12 (Broxton et al. 2001b).

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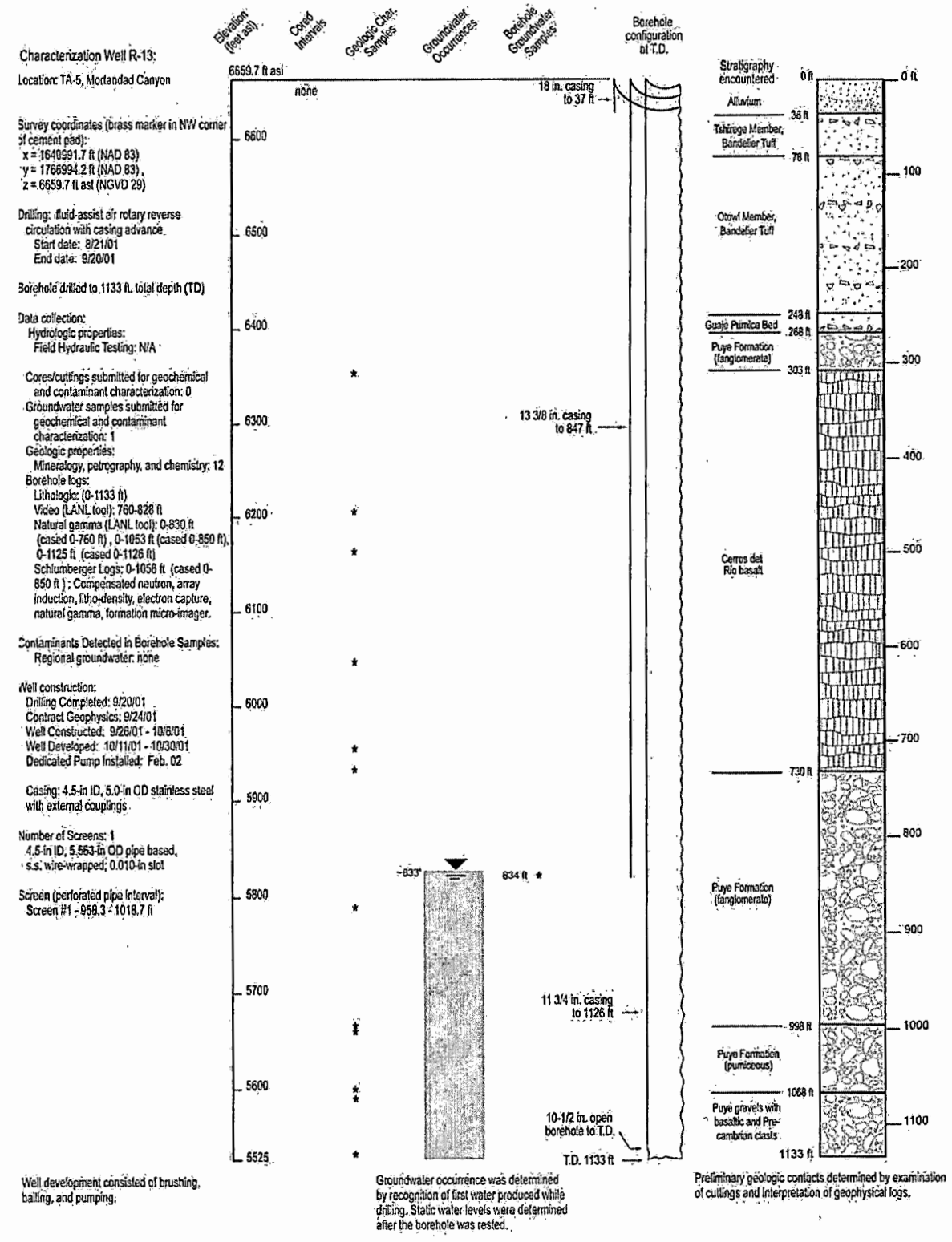

Figure 1-B-11. Completion diagram for well R-13 (LANL 2003c).

05916

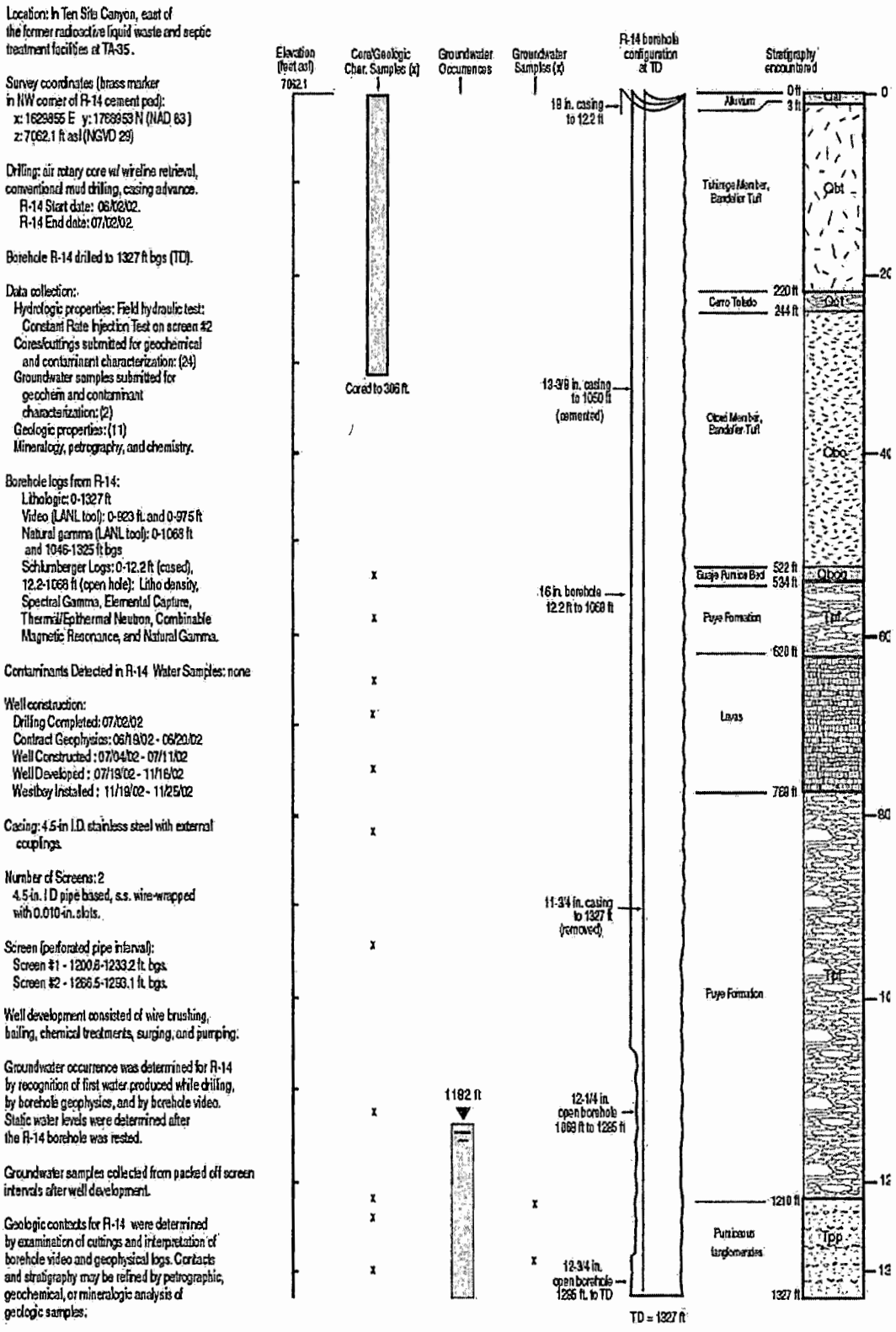

Figure 1-B-12. Completion diagram for well R-14 (LANL 2003d).

05917

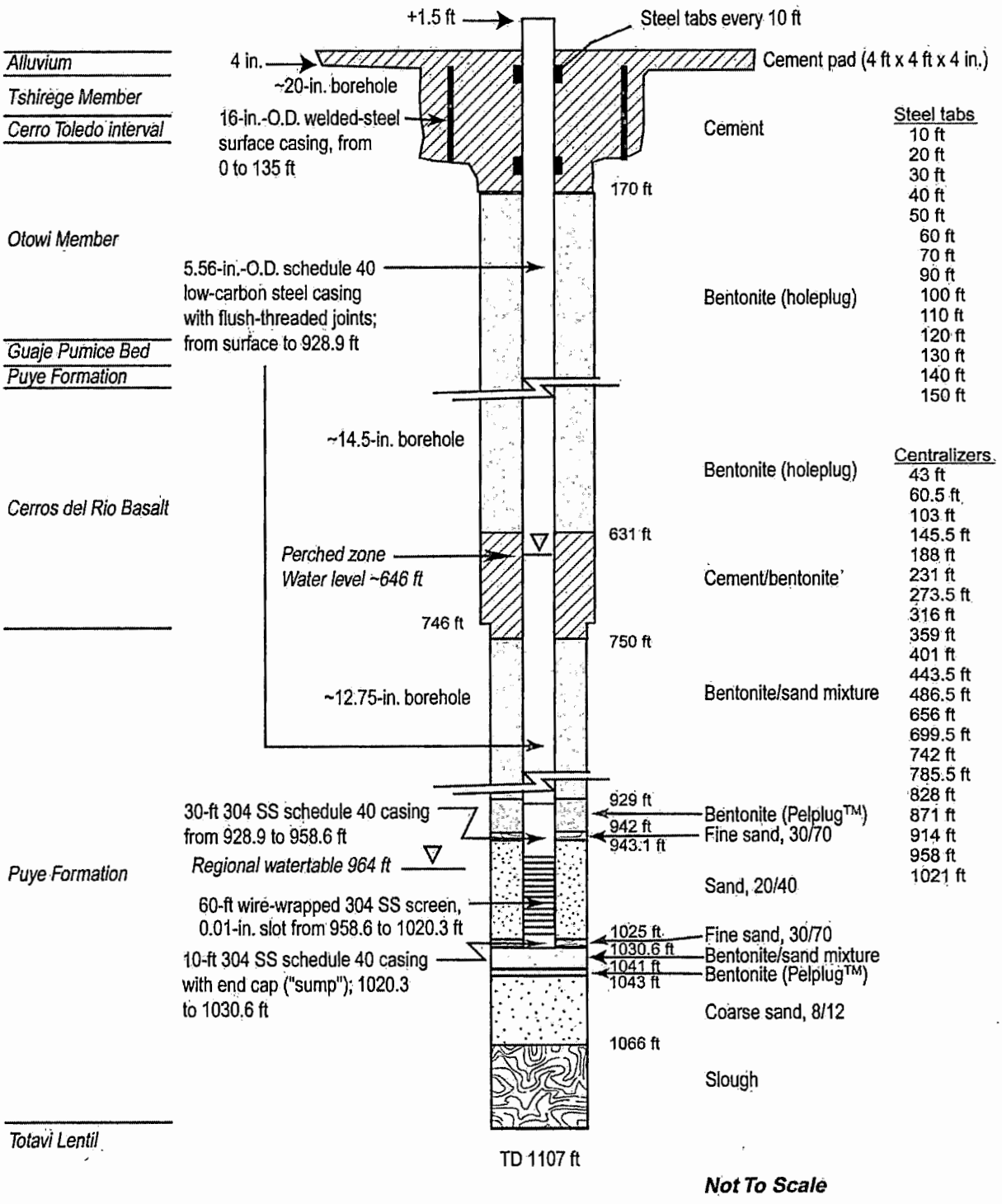

Figure 1-B-13. Completion diagram for well R-15 (Longmire et al. 2000).

05918

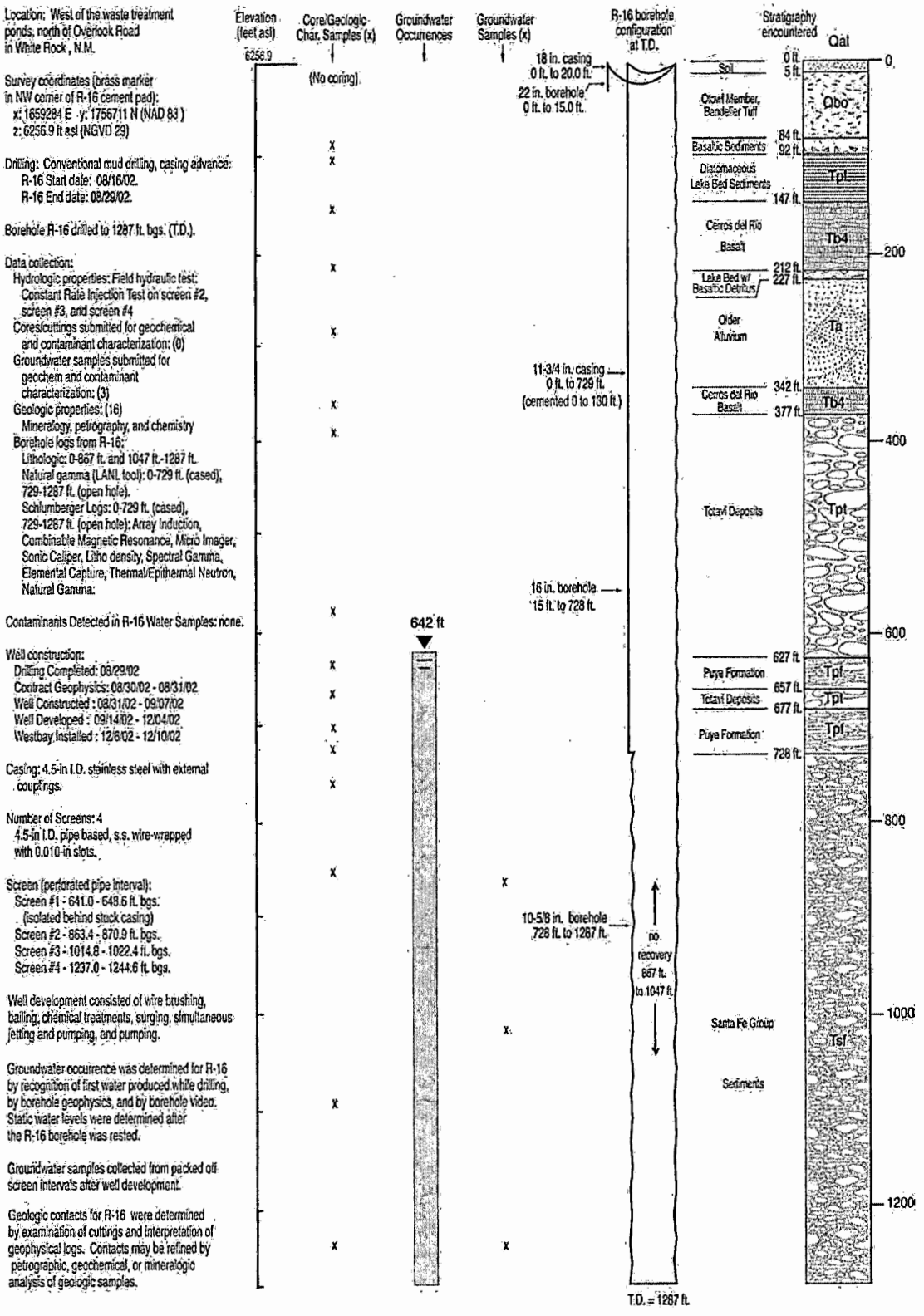

Figure 1-B-14. Completion diagram for well R-16 (LANL 2003e).

05919

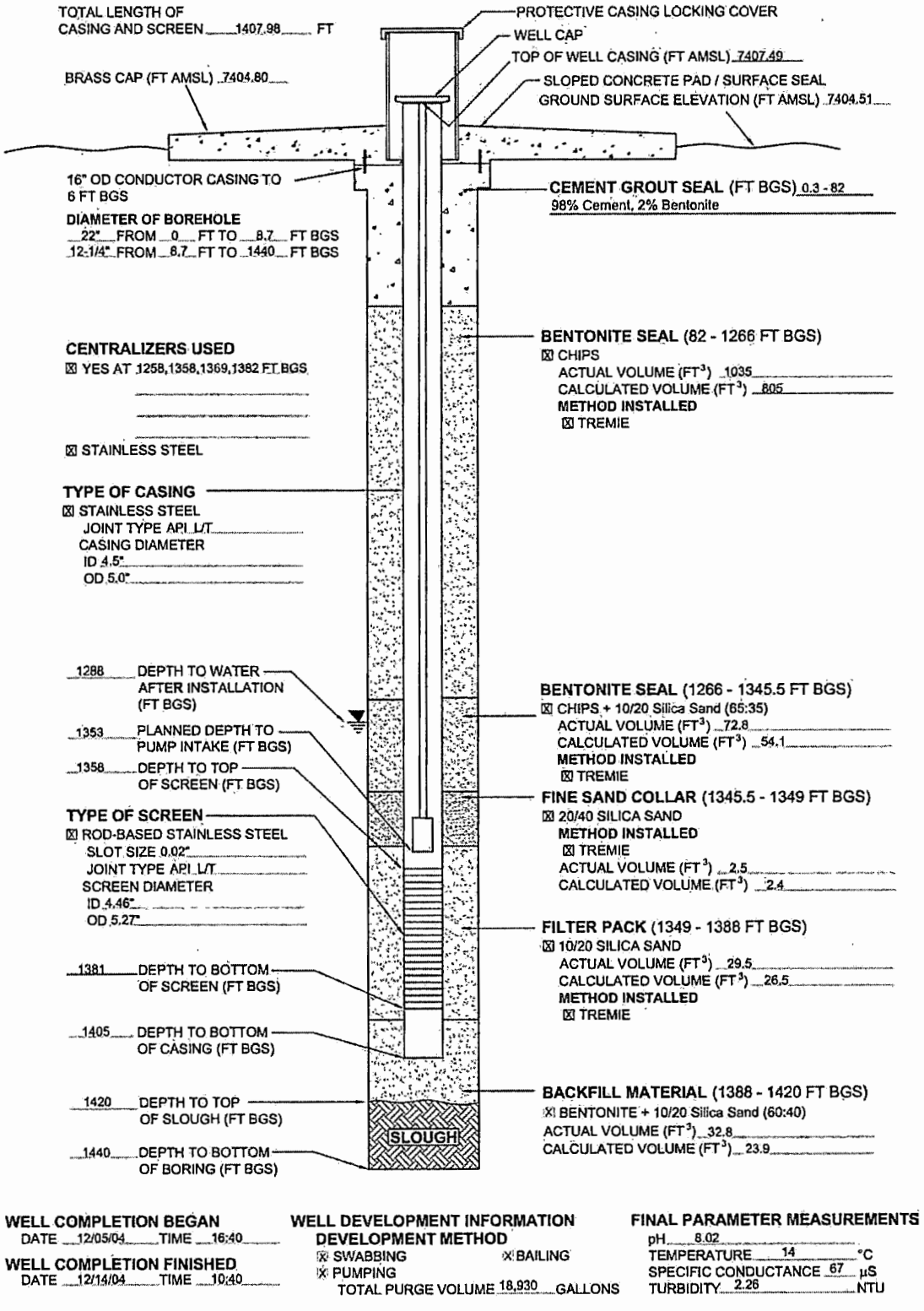

Figure 1-B-15. Completion diagram for well R-18 (Note: well completion report not available).

05920

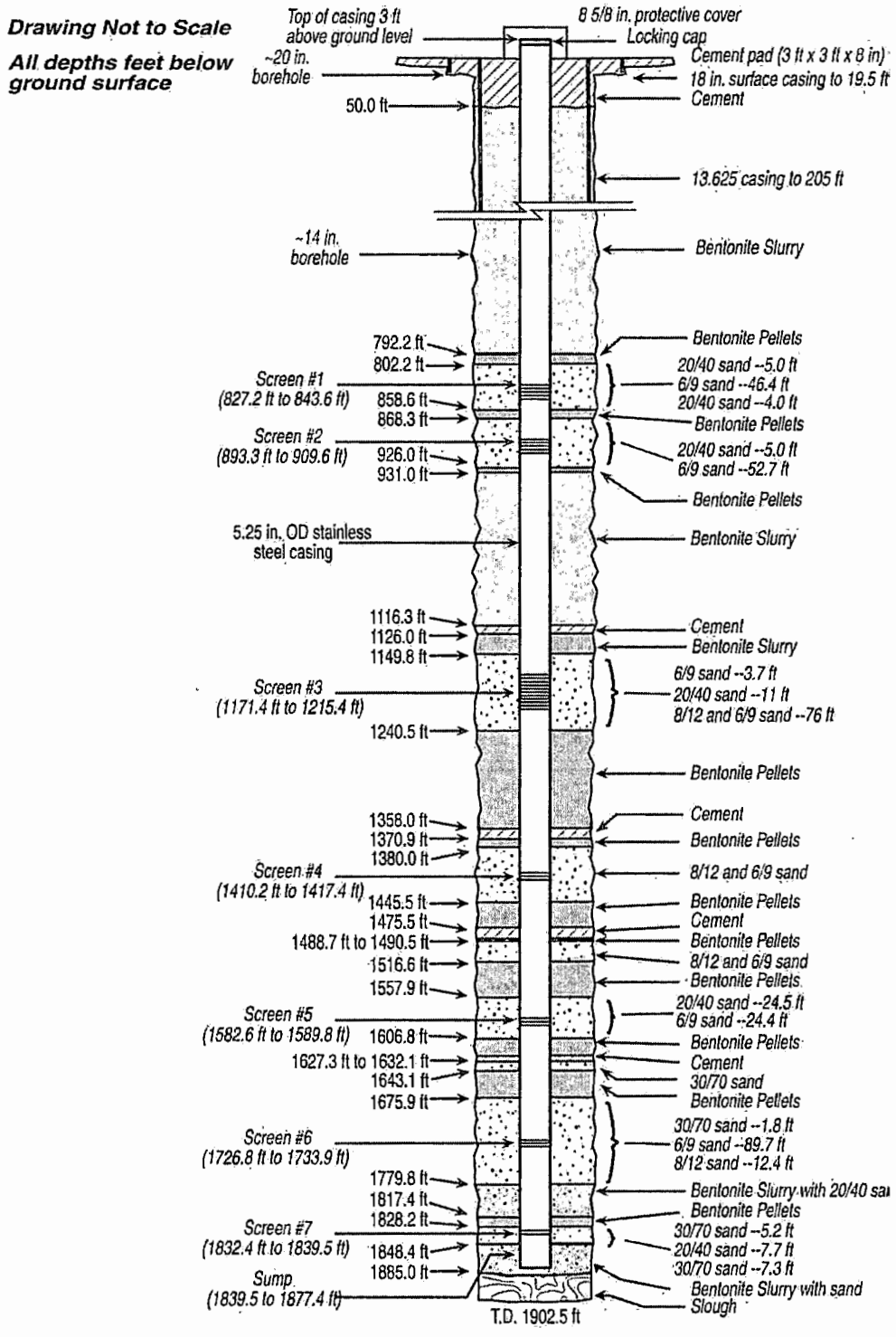

Figure 1-B-16. Completion diagram for well R-19 (Broxton et al. 2001d).

05921

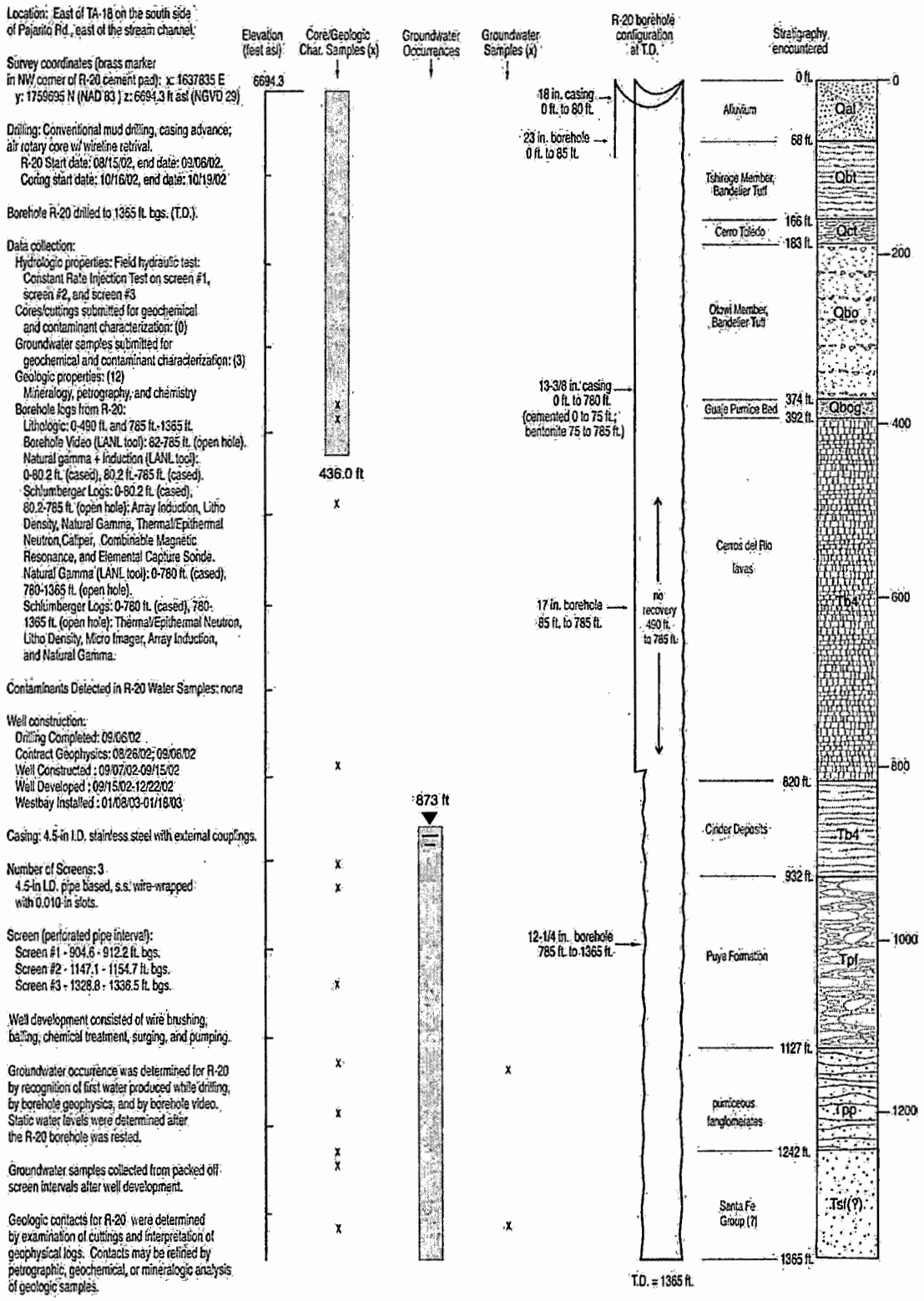

Figure 1-B-17. Completion diagram for well R-20 (LANL 2003f).

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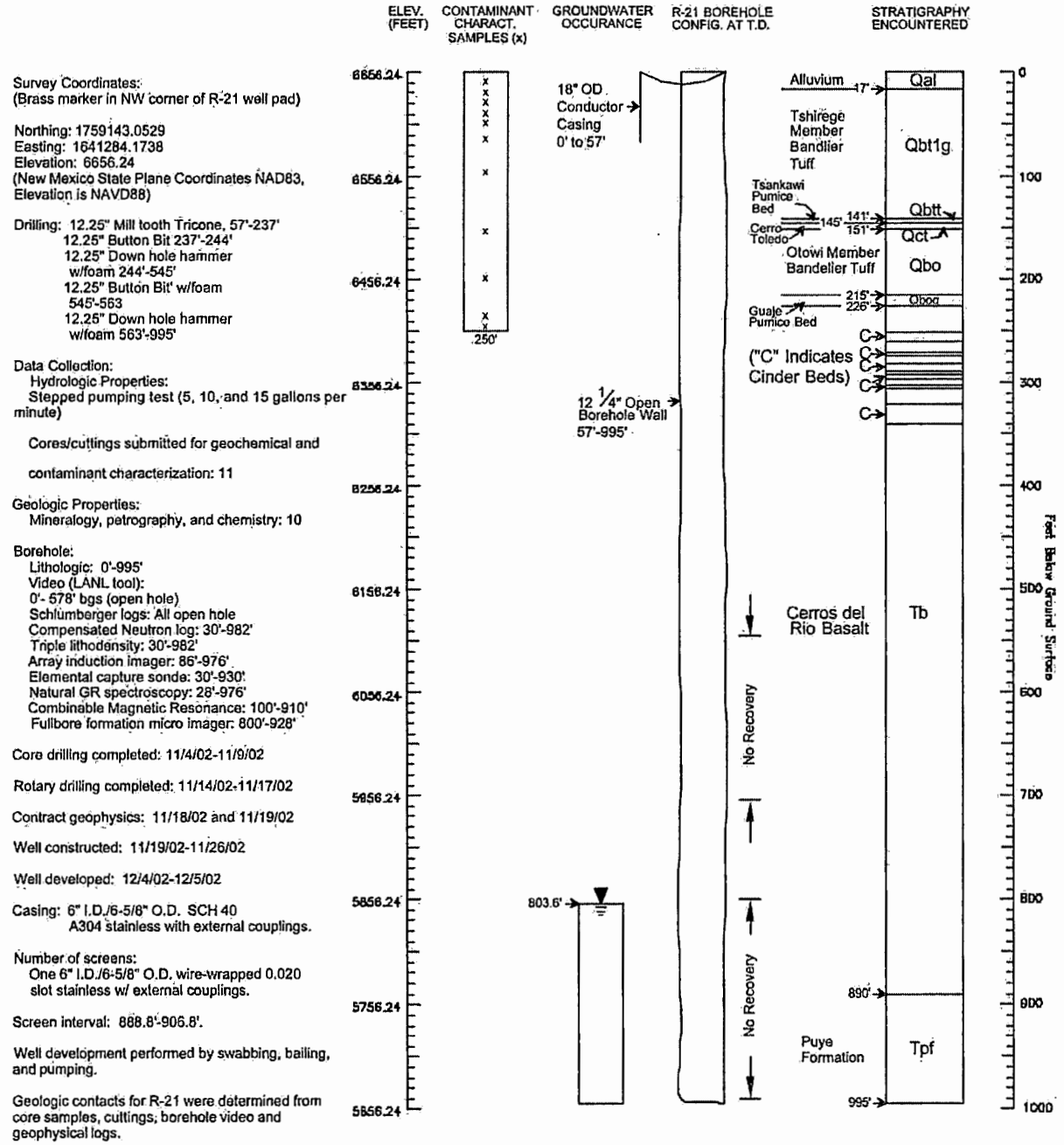

Figure 1-B-18. Completion diagram for well R-21 (Kleinfelder 2003f).

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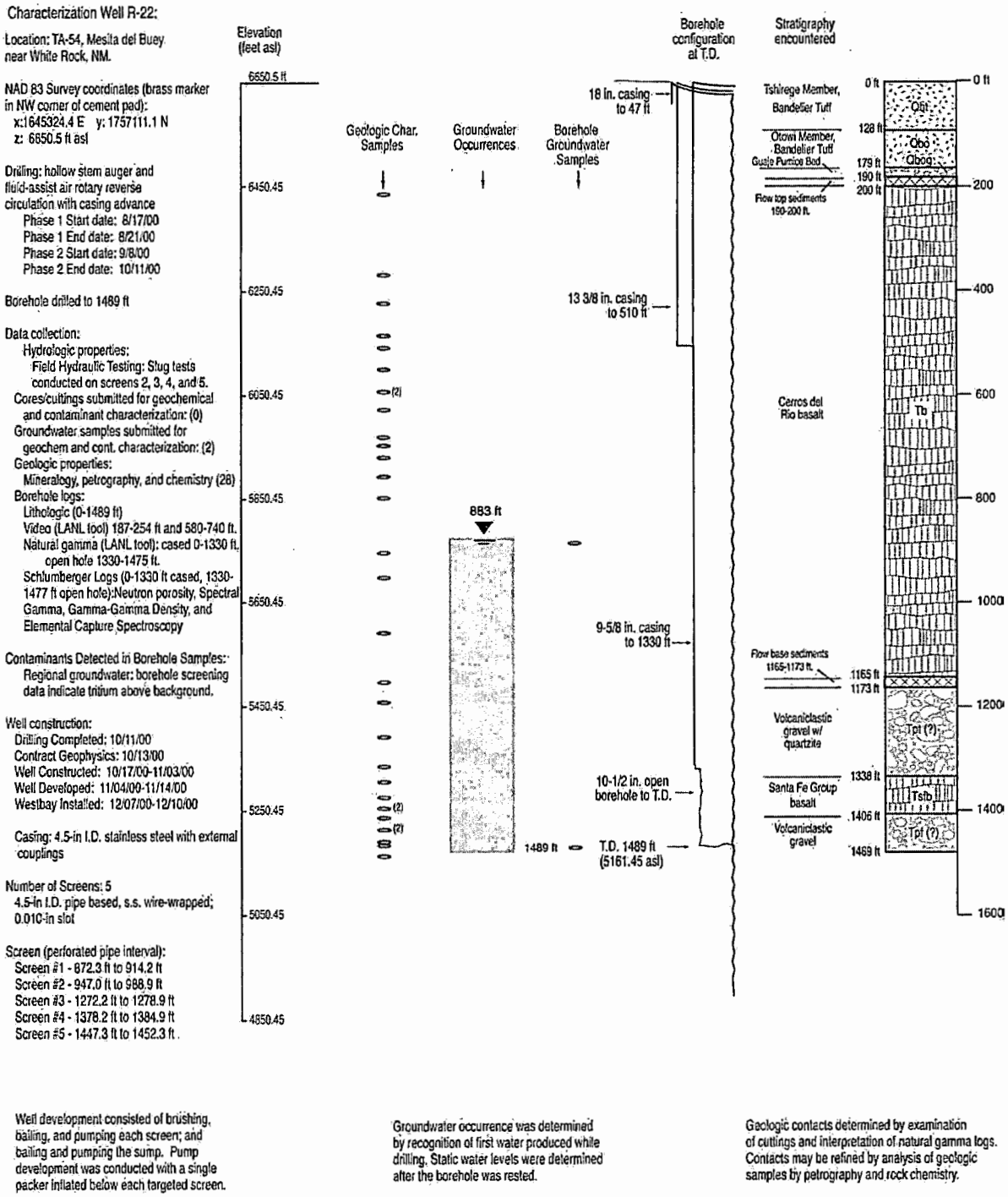

Figure 1-B-19. Completion diagram for well R-22 (Ball et al. 2002).

05924

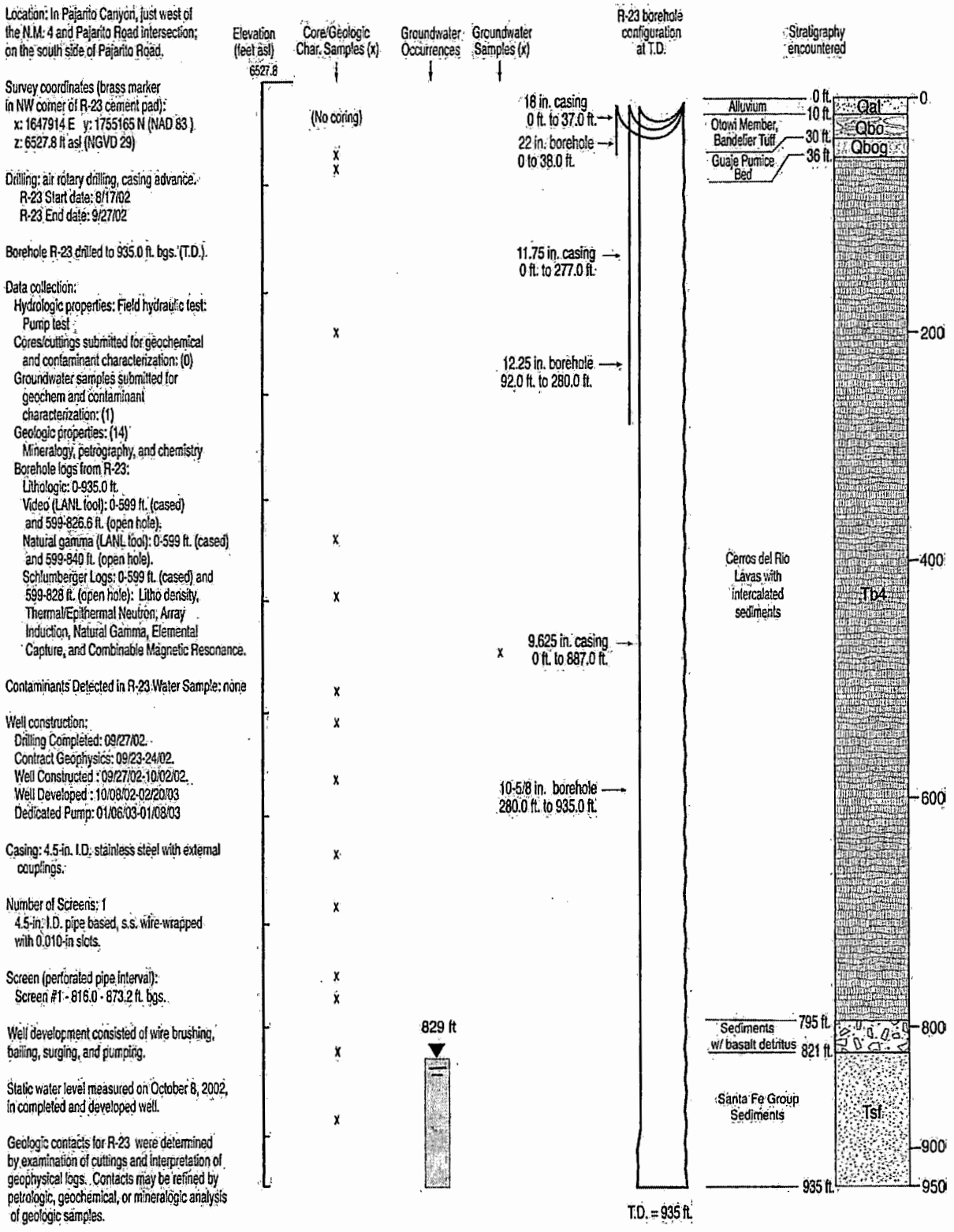

Figure 1-B-20. Completion diagram for well R-23 (LANL 2003g).

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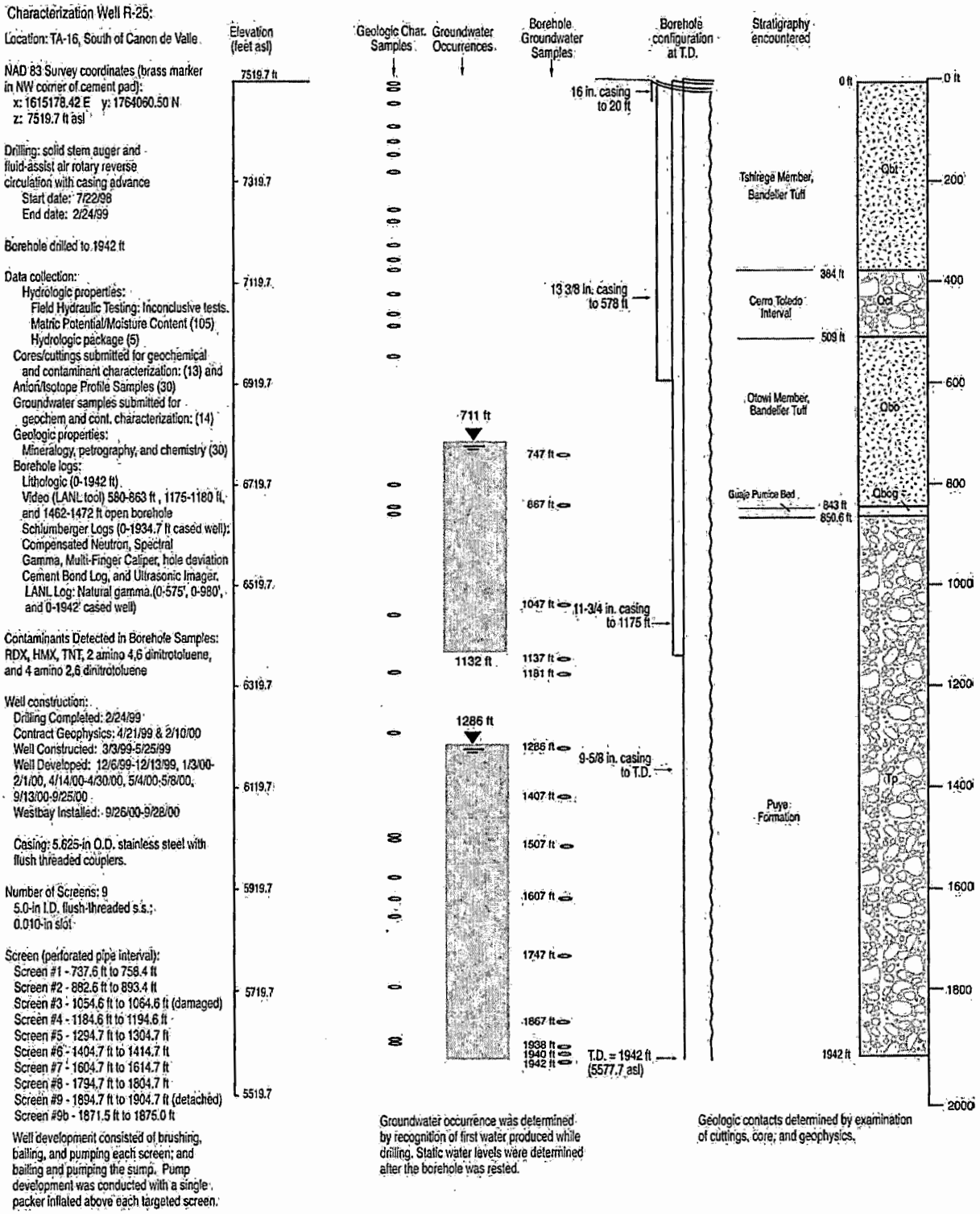

Figure 1-B-21. Completion diagram for well R-25 (Broxton et al. 2001e).

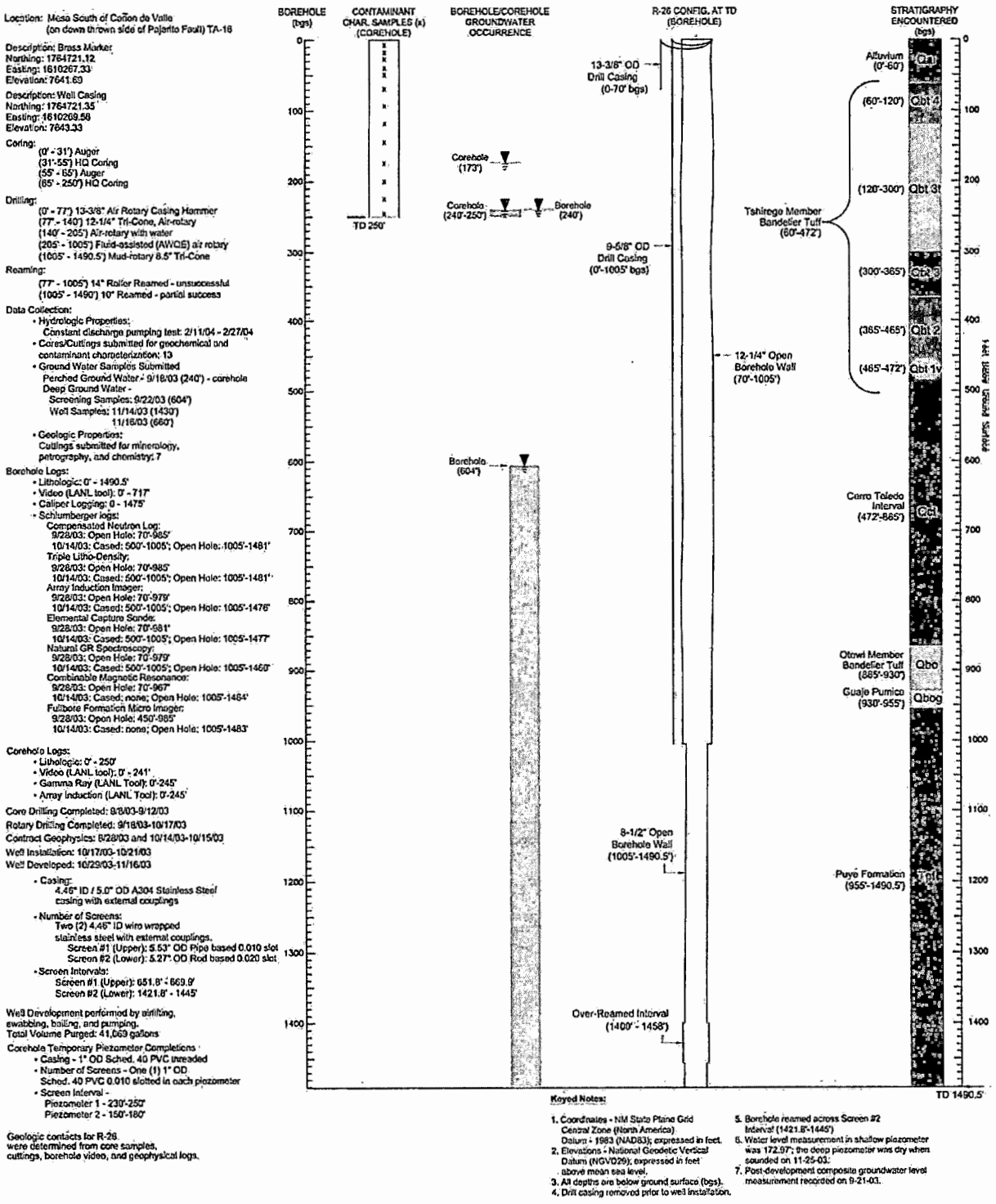

Figure 1-B-22. Completion diagram for well R-26 (Kleinfelder 2004f).

05927

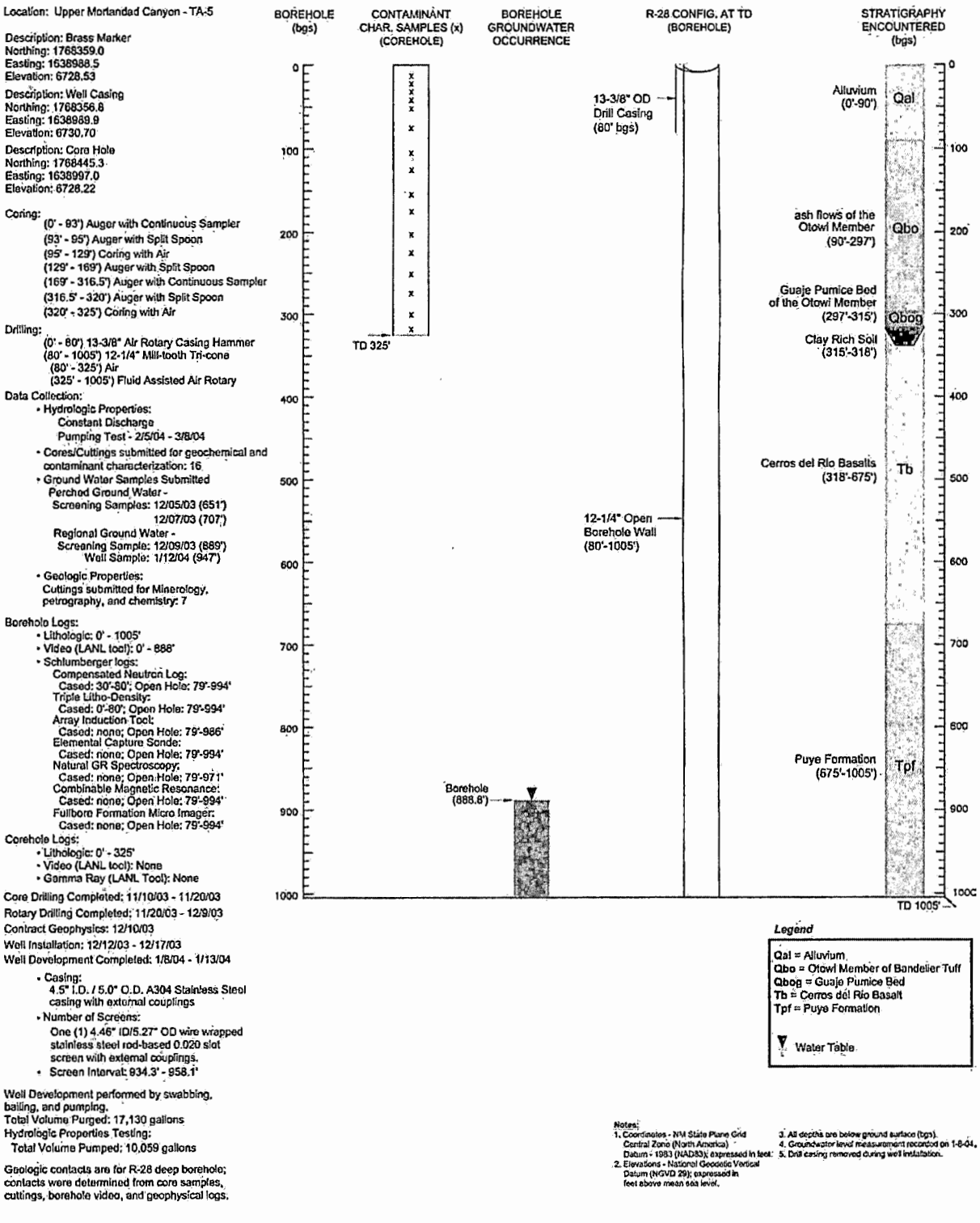

Figure 1-B-23. Completion diagram for well R-28 (Kleinfelder 2004d).

05928

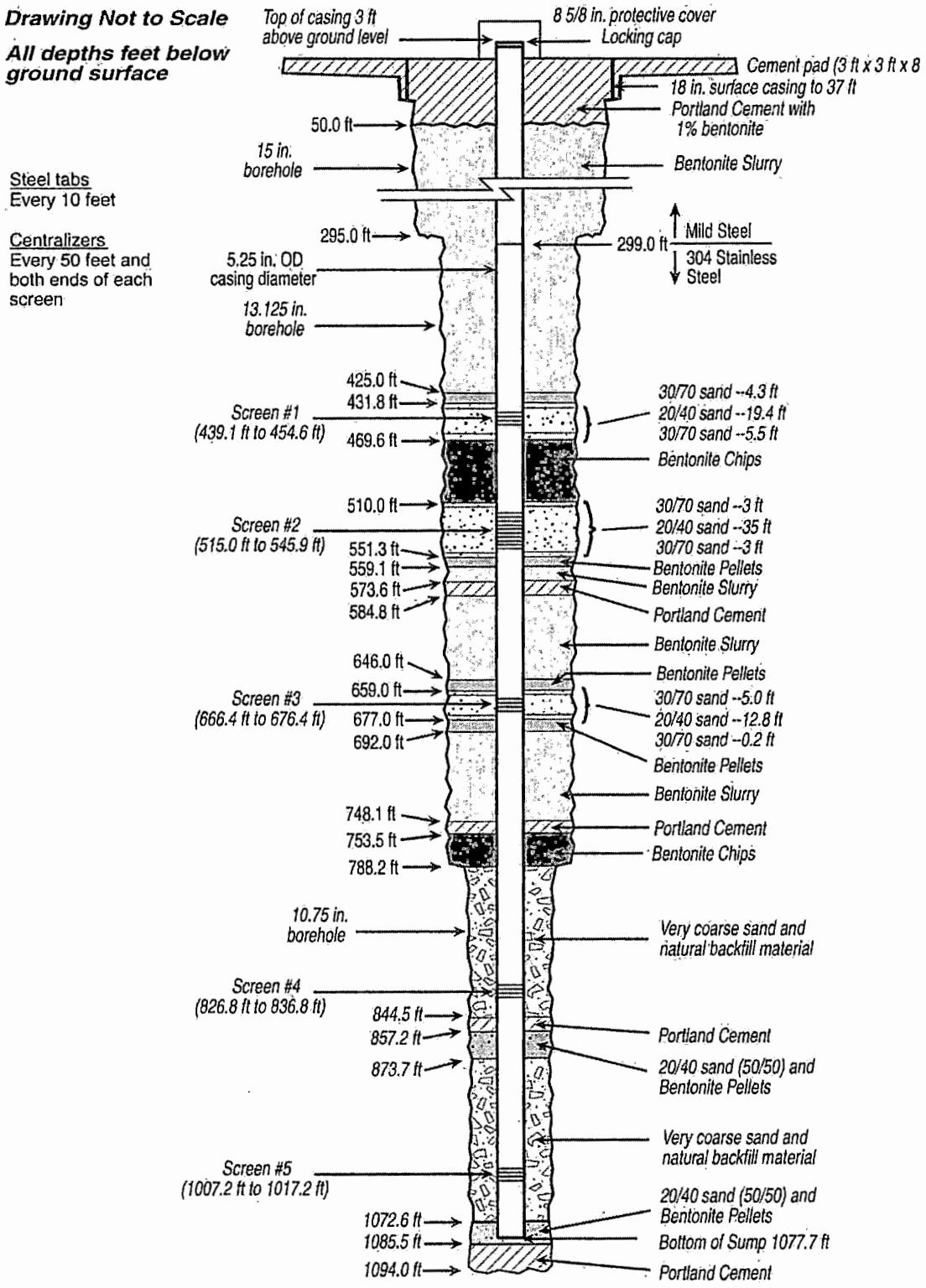

Figure 1-B-24. Completion diagram for well R-31 (Vaniman et al. 2002).

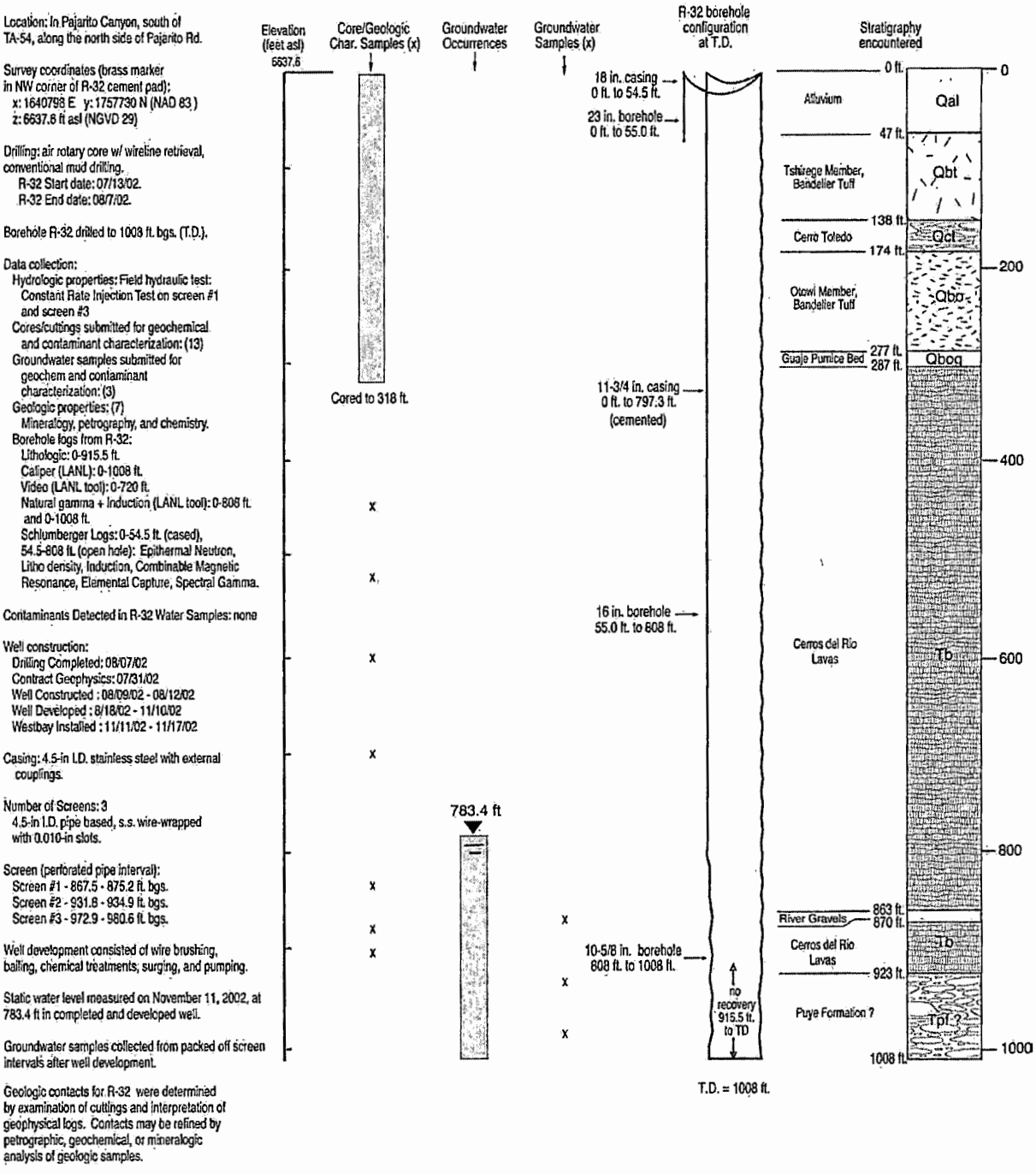

Figure 1-B-25. Completion diagram for well R-32 (LANL 2003h).

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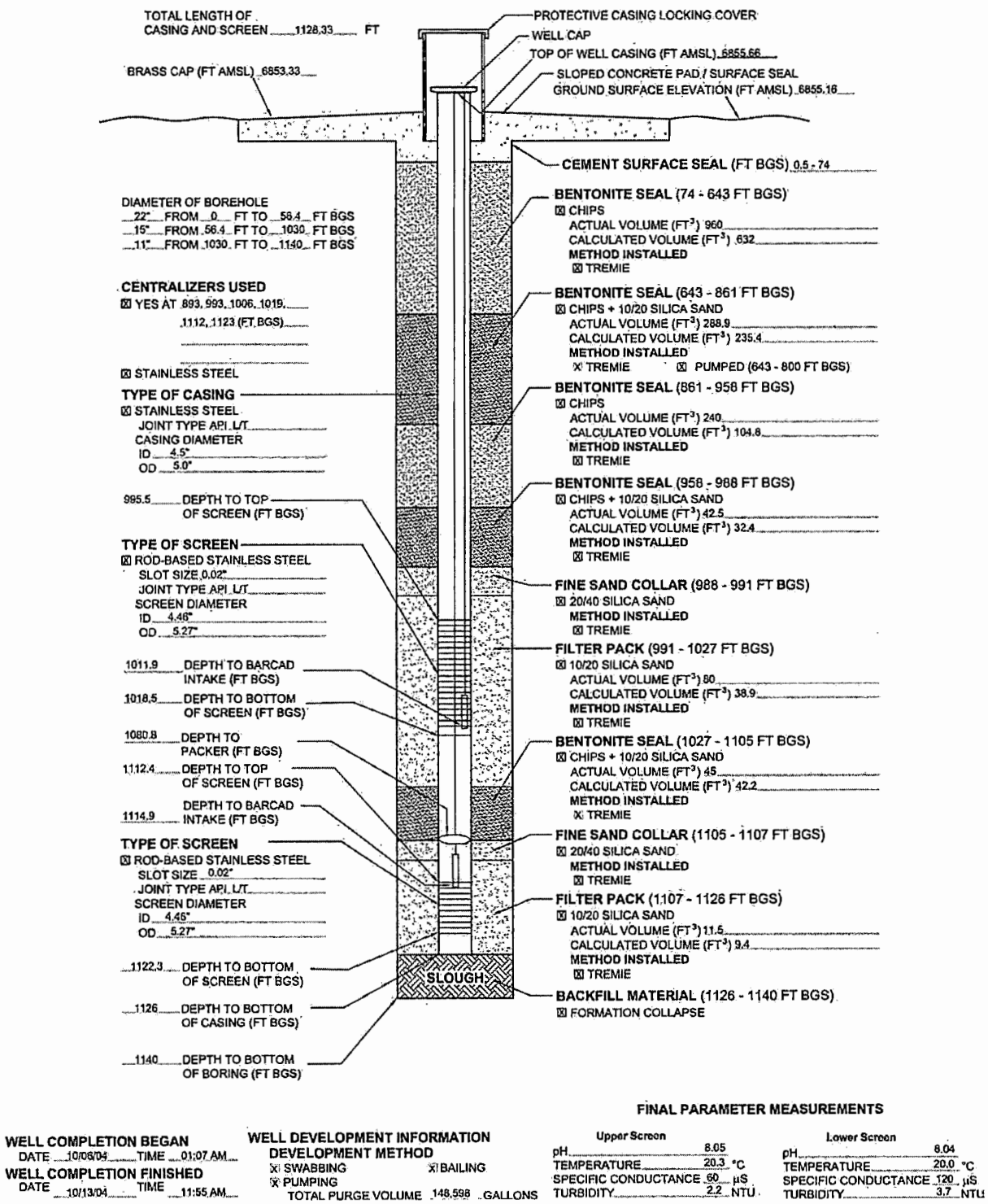

Figure 1-B-26. Completion diagram for well R-33 (Note: well completion report not available).

05931

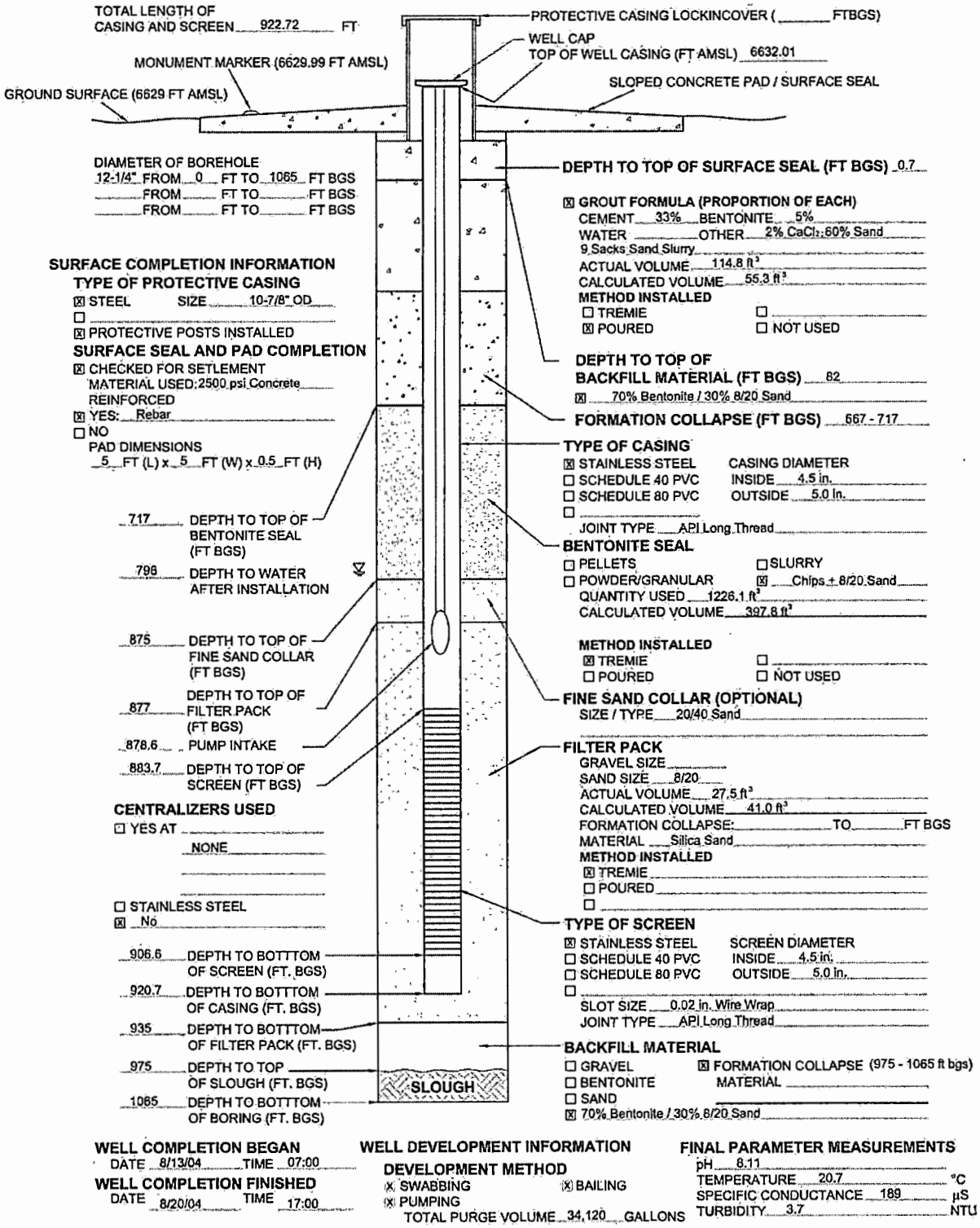

Figure 1-B-27. Completion diagram for well R-34 (Note: well completion report not available).

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APPENDIX 2-A. GEOLOGIC INFORMATION USED TO DEFINE THE CONTROLS ON HYDROLOGY

2-A-1. Lithologic Information from Cuttings and Core

Drill cuttings and core were collected in all boreholes to meet the regional hydrogeologic characterization requirements described in Section 4.2 of the Hydrogeologic Workplan (LANL, 1998). Cuttings and core provide the most direct evidence for the vertical distribution of hydrogeologic units at each borehole. Correlations of rock units among boreholes are key components of the site-wide 3-D geologic model for the plateau.

Drill cuttings were the most common type of geologic samples produced during the drilling program. Approximately 500 to 700 ml of bulk drill cuttings were collected every 5 ft, as conditions permitted, to the total depth (TD) of each boring. Cuttings were stored in plastic bags labeled with the well name and footage range representing the depth interval at which the cuttings were collected. A subset of unsieved and sieved samples were collected from each cuttings interval and stored in plastic chip trays for geologic examination. The quality and representativeness of cuttings depended on a number of drilling variables including type of circulation fluids used (air, water, foam, mud), circulation type (conventional, reverse), and drill-bit pressure.

Core was collected from dedicated core holes where it was often paired with deeper drill holes. Core was also collected from selected intervals in some regional aquifer boreholes. Core was collected to fulfill a number of characterization objectives, including:

- Geologic characterization of groundwater-bearing zones and aquitards in perched groundwater systems
- Collection of moisture-sensitive samples for hydrologic and chemical analyses of vadose-zone samples (e.g. moisture, anions)
- Collection of intact rock samples to determine hydraulic properties of selected hydrogeologic units.

Rock lithologies, alteration features, and stratigraphic contacts for each borehole are summarized in lithologic logs based on visual examination of cuttings and core. A small subset of core and cuttings was selected for additional characterization to better understand alteration features relevant to rock-water interactions and to aid correlation of rock units between boreholes. The additional characterization primarily consisted of X-ray diffraction for mineralogy, X-ray fluorescence for rock chemistry, thin-section petrography, and $^{40}Ar/^{39}Ar$ age dating. The lithologic logs also incorporated information about stratigraphic contacts and rock properties based on interpretations of borehole geophysical logs.

Core and cuttings are currently archived at the ENV Division Sample Management Facility located at Technical Area 3, building 03-0271-101. All borehole materials are stored in core boxes labeled with the well name, box number, and footage range for the box.

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2-A-2. Borehole Geophysical Data

Borehole geophysical data were collected to determine the geologic and hydrologic characteristics of the vadose zone, perched saturated zones, and the regional aquifer as specified in Section 4.1.6 of the workplan. A listing of geophysical logs collected during installation of Hydrogeologic Workplan wells is given in the well completion reports associated with those wells. Borehole geophysical data were obtained from two sources. Laboratory/contractor personnel collected caliper, spontaneous potential, single-point resistance and induction, and natural gamma radiation logs using the Laboratory's geophysical logging equipment, usually during breaks in the drilling process when conditions permitted the collection of open-borehole data. A wire-line logging service was contracted to obtain a more extensive suite of borehole geophysical logs once the borehole reached total depth.

The number and types of contracted wire-line geophysical logs varied as a function of borehole condition, the presence or absence of drill or well casing, whether the borehole was air or fluid filled, and technical issues addressed by a particular logging run. Drilling conditions determined whether the borehole was open or cased at the time of logging. Table 2-A-1 gives the typical suites of logs that have been run by wire-line logging services in cased and open boreholes. General logging information and borehole conditions at the time of logging were documented by site personnel.

Preliminary results of geophysical logs were generated in the logging truck at the time the geophysical services were performed. These preliminary logs were used by contractor, DOE, and LANL personnel to help select well screen locations and to evaluate borehole conditions prior to well construction.

The geophysical contractor reprocessed the field measurements to correct for borehole and formation environmental conditions, to perform an integrated analysis of the log measurements so that they were all coherent, and to combine the logs into a single presentation enabling integrated interpretation. The contractor then prepared an interpretive report that was included as an appendix in the well completion reports. The interpretive report includes information about the hydrogeologic characteristics of the rocks penetrated by the boreholes, moisture distributions as a function of depth, the location of the regional water table, borehole diameter, deviation as a function of depth, and degree of drilling fluid invasion. Depending on the suite of logs collected, the interpretive report may include information about

- total and effective water-filled porosity and pore size distribution, from which an estimate of hydraulic conductivity is made,
- bulk density and photoelectric effect, the latter of which is particularly sensitive to lithology,
- electrical resistivity at multiple depths of investigation,
- concentrations of a number of elements,
- spectral natural gamma ray, including potassium, thorium, and uranium concentrations,
- bedding orientation and geologic texture,
- borehole inclination and azimuth, and
- borehole diameter.

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2-A-3. Borehole Video Logs

Borehole video logs were run in open boreholes to obtain lithologic information and to help determine stratigraphic contacts for the geologic units penetrated, to allow visual examination of borehole walls for evidence of perched saturation, and to document water levels in the boreholes. Video logs also were run when wells were completed to document the as-built condition of installed well components. Additional videos were sometimes run during and after well development to assess the effectiveness of development techniques. Finally, the borehole video logs were used during drilling operations to assess problematic borehole conditions and to guide fishing operations for tools and equipment lost downhole.

One of the principal uses of the borehole video logs was to identify potential groundwater pathways. For example, when used in conjunction with geophysical logs, video logs were an important method for locating highly porous interflow breccias sandwiched between massive basalt flows. These interflow breccias were important for determining the locations of perched zones in some boreholes. The video logs also showed whether the porosity of these interflow breccias was open or modified by deposition of extensive secondary clay minerals. Fractures are potential pathways in the massive flow interiors. Fracture density, fracture dips, and open verses sealed fractures were assessed using video logs.

2-A-4. Surface Geophysical Data

Surface geophysical data were used to help constrain the site-wide geologic model. These data include regional gravity data, airborne electromagnetic data, high-resolution resistivity, and magnetotellurics. Gravity data were used to help define regional structure beneath the Pajarito Plateau. Airborne electromagnetic data, high-resolution resistivity, and magnetotelluric data were used to focus groundwater investigations by defining the conductivity structure beneath the plateau. The remainder of this section describes the airborne electromagnetic data in more detail.

An electromagnetic (EM) and magnetic survey was flown over the Pajarito Plateau in early September 2001 by the Fugro Airborne Surveys Corporation on behalf of LANL. A total of 762 line kilometers of MegaTEM® time domain EM data and magnetic data were collected. Flight lines were spaced at 333.3 ft (105 m) within the Laboratory boundaries, and at 666.7 ft (210 m) in buffer zones adjacent to the Laboratory, oriented N20E: with tie lines at an approximate 2000-meter spacing. Because of security constraints stemming from the events of September 11, 2001, flight lines in the western 20% of the Lab, and the two tie lines in the northern portion of the Laboratory were not flown.

The contractor provided maps of Residual Magnetic Intensity (RMI), apparent conductance and conductivity depth slices at various depths, multiparameter profiles with conductivity-depth-transform (CDT) sections for flight lines and digital archives of line and grid data. The digital EM data were analyzed at a later time (end of FY01) by Condor Consulting, Inc. This analysis resulted in two additional models of CDTs along the flight paths. All of the processing assumed a "layered-earth" model, and all of the inversions were restricted to single points/multiple depths (1-D), multiple depths along individual flight lines (2-D), or a constant depth on multiple flight lines (2-D); there was no true 3-D inversion performed on the data set. Data from the existing

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3-D geologic model, identifying zones of expected similar hydrologic properties, were provided to Condor and are part of the initial data analysis. Borehole geophysical logs were also provided to Condor to assist in calibrating their models. The results of all three models for each flight line are available. At some future time, a constrained 3-D inversion, utilizing the 3-D hydrogeologic model, may allow better resolution of the conductance inversion results.

Visual correlation of conductance and observed groundwater can be obtained through study of the "multiplots" of the flight lines closest to groundwater occurrences. An effort has been made to allow creation of 3-D conductance models for each of the CDT data sets. Interpolation of flight line data is accomplished through scaled interpolation within an oriented ellipsoid that samples a similar number of points in the directions: vertical, along-flight-line, and between-flight-line. Many 3-D visualization packages are capable of displaying and scaling 3-D grid data. As much of the error/uncertainty of the conductance model occurs in the depth/thickness value, real-time scaling and offsetting the z-axis of the conductance grid can allow correlation with known groundwater locations obtained from drill holes; and thus allow a projection/extrapolation of the groundwater surface beyond the limits of direct observation.

The two tie lines of the survey provide conductance signatures that correlate well with the major faults in the western portion of the Laboratory and could perhaps provide some information regarding their dips. These survey lines indicate other localities with signatures similar to those of the mapped faults, which may indicate buried faults or conductive fracture zones further to the east.

2-A-5. Drilling Information

Observations about drilling characteristics by the drillers and on-site geologists contributed to understanding the hydrogeology of the boreholes. These observational data were recorded in field logs, and they provided supplemental information that aided the interpretation of hydrogeologic data from other sources such as cuttings and geophysical logs.

Because of the heterogeneous nature of the rocks beneath the plateau, major lithologic and stratigraphic contacts were commonly marked by significant changes in drill penetration rates. Drilling rates were affected by a number of factors, but chief among them was the competency of the rocks being penetrated. Hard rock units such as strongly welded tuffs, lava flows, and boulder-rich fanglomerate deposits were characterized by slow drilling rates, whereas less competent rocks such as nonwelded tuffs and poorly indurated sands, silts, and clays drilled more rapidly. For example, drill penetration rates normally decreased downhole when going from the nonwelded tuffs at the base of Qbt 3 into the welded tuffs at the top of Qbt 2 and from the Guaje Pumice Bed into Puye Formation and/or Cerros del Rio basalt.

Information about borehole stability and lost-circulation zones also provided important site-specific information about subsurface conditions. For example, open borehole drilling at R-22 was complicated by caving conditions and by difficulty in maintaining free rotation of the drill string though thick sequences of basalt. Normally, the interiors of basalt flows are strongly competent and yield gun-barrel smooth boreholes, but the conditions at R-22 suggested that loose blocks of basalt were caving into the borehole and binding up the drill string. Subsequent

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borehole video logs showed that dense networks of fractures intersected the R-22 borehole resulting in an unstable borehole. Similarly, lost circulation zones generally indicated that drilling fluids had escaped into highly porous fractures or scoria zones intersected by the borehole. At R-34, significant zones of lost circulation were associated with thick beds of loose basaltic scoria. Some cavities observed in borehole videos might be small-scale lava tubes or caverns similar to those known to occur in the Cerros del Rio volcanic field east of the Rio Grande.

Important information about water-bearing strata was obtained when drillers noted changes in the drilling fluids circulating through the borehole. Perched water and the top of the regional zone of saturation were readily recognized when water and wet cuttings were returned to the surface using air-rotary drilling methods. Water-bearing zones were identified even when using fluid-assisted air-rotary methods that involved the use of air, municipal water, foam, and other additives for circulation. When using such methods, surplus production of water and thinning of drilling foam often was associated with the intersection of groundwater.

2-A-6. Data Generated by Other Projects

Numerous local and regional mapping projects and geological studies have provided important information supporting development of geologic conceptual models and digital realizations of these models. Pioneering work by geologists of the U.S. Geological Survey (USGS) helped define the tectonic setting and the major hydrogeologic units of the region (Smith, 1960a and 1960b, Griggs, 1964; Smith and Bailey, 1966; Bailey et al., 1969; Smith et al., 1970). Regional and local studies of rock unit ages, many of which were supported by the Laboratory, provided a time scale to calibrate the timing of the volcano-tectonic development of the site: faulting and volcanism, and emplacement of the resultant volcanic flows and sedimentary units (Gardner and Goff, 1984, Gardner et al., 1986; Loeffler et al., 1988; Turbeville et al., 1989; Izett and Obradovich, 1994; Spell et al., 1990; Spell and Harrison, 1993; Spell et al., 1996; Toyoda et al., 1995; McIntosh and Quade, 1995; WoldeGabriel et al, 1996; Reneau et al., 1996; Smith, 2001; WoldeGabriel et al., 2001; Goff and Gardner, 2004). Understanding the nature of the evolving tectonic regime allowed development of models to define the conceptual, spatial distribution of hydrogeologic units, as well as explanations of their post-deposition evolution.

The New Mexico state mapping program, supported by the USGS and the New Mexico Bureau of Geology and Mineral Resources, with help from LANL scientists, produced 1:24,000-scale, surface geologic maps and accompanying cross sections for the Frijoles (Goff et al., 2002), White Rock (Dethier, 1997), Puye (Dethier, 2003), and Guaje Mountain (Kempter and Kelley, 2002) quadrangles. These four maps encompass the Laboratory site with a significant buffer zone, allowing the integration of site and regional geologic features. Other geological maps, some with cross sections, covering portions of the LANL include those by Baltz et al., (1963); Goff et al., (1990); Rogers, (1995); Vaniman and Wohletz, (1990); Reneau et al., (1995); Goff, (1995); Lewis et al., (2002); and Lavine et al., (2003).

Española Basin workshops were hosted annually by the Española Basin Technical Advisory Group and sponsored by the U.S. Geological Survey, the New Mexico Bureau of Geology and Mineral Resources, Los Alamos National Laboratory, and the city of Santa Fe. These workshops

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were important forums for disseminating results of ongoing technical studies of the hydrogeologic framework of the Española Basin.

The seismic hazards program at LANL was an important source of information about faults and fractures in the vicinity of the Laboratory (Gardner and House, 1987; Gardner et al., 1990, 1993, 1999, 2001; Lewis et al., 2002; and Lavine et al., 2003). Their high-resolution, surface mapping of subunits of the Bandelier Tuff provided new information about the distribution and nature of faulting on the Pajarito Plateau and made estimates about amounts and rates of offset of geologic units. Numerous other Laboratory projects and programs helped to develop geologic information supporting geologic conceptual models. The Environmental Restoration project funded numerous projects as part of its RCRA facilities investigations that provided information about geologic framework of the site and hydrologic properties of geologic units.

Students and their advisors from the graduate programs from the University of New Mexico, New Mexico State University, and New Mexico Institute of Mining and Technology have provided additional hydrogeologic information for the Jemez volcanic field and Española Basin. Studies by graduate students from the University of Texas (e.g., Turbeville et al., 1989) were especially useful for understanding the Puye Formation.

Table 2-A-1.
Typical Wire-Line Geophysical Logging Tools

Cased Hole	Cased Hole	Open Hole	Comments
Array Induction Tool (AIT)		X	Measures open-hole formation conductivity with multiple depths of investigation at varied vertical resolution
Triple Litho Density Tool (TLD)	X	X	Evaluates formation porosity where grain density can be estimated
Combinable Magnetic Resonance Tool (CMR)		X	Provides information on water content and relative abundance of hydrous minerals and capillary-bound versus mobile water
Natural Gamma Tool	X	X	Used to distinguish lithologies by their gross gamma signature; also used to calibrate depth of other geophysical tool readings
Natural Gamma Ray Spectrometry Tool (also called the spectral gamma tool)[1]	X	X	Used to distinguish lithologies where formations vary in relative and overall concentrations of potassium, thorium and/or uranium
Epithermal Compensated Neutron Log (CNL)	X	X	Measures moisture content in unsaturated conditions and porosity in saturated conditions
Caliper		X	Measures rugosity of borehole wall
Fullbore Formation Microimager (FMI)		X	Provides high-quality image of borehole based on electrical properties; used to determine lithologies, bedding attitudes, fracture characteristics, and borehole deviation
Elemental Capture Spectrometer (ECS)	X	X	Determines formation lithology from bulk geochemistry; used primarily to determine elemental concentrations of silicon, calcium, iron, titanium, and gadolinium

[1]A total gamma log was collected with each geophysical suite to correlate separate logging runs within a borehole.

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APPENDIX 2-B. PERCHED WATER OCCURRENCES

This appendix documents the field observations of the 33 occurrences of perched groundwater detected in 29 boreholes across the Pajarito Plateau. Characteristics of deep perched groundwater zones encountered in wells on the Pajarito Plateau are listed in Table 2-B-1.

In the western part of Los Alamos Canyon, perched groundwater occurs at depths of 89 to 137 m (293 to 450 ft) in the Guaje Pumice Bed and in underlying Puye Formation fanglomerate. Saturated thicknesses for these occurrences range from about 6.7 m (22 ft) in the west to about 1 m (3 ft) in the east. These groundwater occurrences in the Guaje Pumice Bed may represent a related groundwater system because of their similar geologic and geographic settings, however, in one well, R-7 (Figure 2-37), perched groundwater occurs immediately beneath the Guaje Pumice Bed, in the underlying Puye Formation. The east-west extent of perched groundwater in the Guaje Pumice Bed is about 5.6 km (3.7 mi). Little is known about the extent of perched groundwater beneath the adjacent mesas, but a dry borehole extending to the Guaje Pumice Bed (borehole 21-2523) suggests that saturation does not extend beneath the mesa north of Los Alamos Canyon. The perched groundwater is free of contamination in the central part of the canyon (e.g. well LAO(I)A-1.1) but contained 3000 pCi/L tritium in 1995 at LADP-3 (Broxton et al, 1995), the easternmost well penetrating this groundwater body. The movement of groundwater in the Guaje Pumice Bed may be controlled by paleotopography on top of the underlying Puye Formation. Structure contours indicate that the down-dip direction for the base of Guaje Pumice Bed beneath Los Alamos Canyon is towards the south and east (Section 2.2.9).

Eastward in Los Alamos Canyon, perched zones are generally thicker and occur at multiple depths. In well R-9 for example, three perched systems were encountered: 1) in the central part of the Cerros del Rio basalt, 2) in the basal part of the Cerros del Rio basalt, and 3) in pumice-rich deposits in the lower part of the Puye Formation. Saturated thicknesses for the top and bottom zones range from about 13.7 to 31.4 m (45 to 103 ft), and the middle zone was 2.1 m (7 ft) thick. The top and middle perched zones in R-9 are also present in well LAWS-1, located 396 m (1300 ft) to the east, but their lateral extent is likely to be much greater. The occurrence of more extensive perched groundwater in the eastern part of Los Alamos Canyon may be due to enhanced infiltration where the canyon floor is underlain by Puye fanglomerate and Cerros del Rio basalt rather than by Bandelier Tuff. Tritium activities of 69 to 246 pCi/L for these perched groundwaters are elevated relative to the cosmogenic baseline of 1 pCi/L, suggesting that these zones contain a component of young water that postdates the advent of atmospheric nuclear testing 60 years ago (Longmire, 2002).

Table 2-B-1.
Characteristics of Deep Perched Groundwater Zones Encountered in Wells on the Pajarito Plateau

Watershed	Well Name, Borehole Depth (ft), Surface Elev. (ft)	Depth to Water (ft)	Saturated Thickness (ft)	Groundwater Host Rock	Nature of Perching Layer	Anthropogenic Chemicals Detected	Comments
Pueblo Canyon	TW-2a 133 6646	110	>23	Puye Fm. fanglomerate	Within Puye Fm. fanglomerate; perching lithology not known	Tritium, nitrate	A single-screen well was installed in this zone (Griggs, 1964, Purtymun, 1995).
Pueblo Canyon	R-5 902 6473	~380	~37	Puye Fm. dacitic sands and gravels mixed with 5-15% rounded quartzite and granite river gravels	Within Puye Fm. fanglomerate; perching lithology not known	Nitrate, fluoride, chloride, uranium, and sulphate	A canyon-floor well was installed with four isolated screens (LANL, 2003). Screen #2 is complete in this perched zone. The vertical extent of this zone is poorly known.
Pueblo Canyon	TW-1a 225 6370	188-225 (?)	±37 (?)	Interflow breccia and siltstone in Cerros del Rio basalt	Possibly unfractured massive basalt	Nitrate, phosphate, chloride, boron, and uranium	Groundwater was first encountered near the top of Cerros del Rio basalts in a zone from 212- to 215-ft-deep (Griggs, 1955). Groundwater may be confined because the water level stabilized at 188 ft (Purtymun, 1995). Well screen placed from 215 to 225 ft deep.
Pueblo Canyon	POI-4 181 6372	160	>21	Cerros del Rio fractured basalt	Confining layer not penetrated	Nitrate, phosphate, chloride, boron,	Groundwater occurs in massive basalt cut by high-angle fractures. A single-screen well was installed in this zone.

Table 2-B-1.
Characteristics of Deep Perched Groundwater Zones Encountered in Wells on the Pajarito Plateau (continued)

Watershed	Well Name, Borehole Depth (ft), Surface Elev. (ft)	Depth to Water (ft)	Saturated Thickness (ft)	Groundwater Host Rock	Nature of Perching Layer	Anthropogenic Chemicals Detected	Comments
Los Alamos Canyon	H-19 2000 7172	450	22	Porous, well-bedded and well-sorted fall deposits of the Guaje Pumice Bed	Tschicoma Fm. lava flow top	Not sampled	Saturation in this zone was noted while drilling to reach the regional aquifer (Griggs, 1964). The perched zone was not screened, and the regional well was later abandoned.
Los Alamos Canyon	LAOI(A)1.1 323 6833	289	27	Porous, well-bedded and well-sorted fall deposits of the Guaje Pumice Bed	Top of Puye Formation; possible clay-rich soil horizon – see description for well LADP-3	None	A single-screen well was installed in this zone.
Los Alamos Canyon	R-7 1097 6779	373	9	Puye Fm. silty, clayey, and sandy gravels	Clay-rich gravels from 382 to 397 ft deep in the Puye Formation	None	A canyon-floor well was installed with three isolated screens (Stone et al., 2002). Screen #1 in well R-7 is completed in this perched zone.
Los Alamos Canyon	R-7 1097 6779	744	~23	Puye Fm. sandy gravel with abundant pumice clasts	Puye Fm.; possible perching layer from 767 to 772 ft in silty pebble gravel or from 772 to 777 ft in clayey pumiceous sands.	None	Screen #2 in well R-7 is completed in this zone. Geophysical logs and borehole videos suggest additional perched groundwater zones were encountered when the R-7 borehole was drilled.
Los Alamos Canyon	LADP-3 349 6756	320	9	Porous, well-bedded and well-sorted fall deposits of the Guaje Pumice Bed	Smectite- and kaolinite-rich soil a few inches thick at top of Puye Formation	Tritium	Soil development occurs at top of the Puye Formation in outcrops and in boreholes elsewhere. A single-screen well was installed in this zone. (Broxton et al., 1995).

Table 2-B-1.
Characteristics of Deep Perched Groundwater Zones Encountered in Wells on the Pajarito Plateau (continued)

Watershed	Well Name, Borehole Depth (ft), Surface Elev. (ft)	Depth to Water (ft)	Saturated Thickness (ft)	Groundwater Host Rock	Nature of Perching Layer	Anthropogenic Chemicals Detected	Comments
Los Alamos Canyon	LAOI-3.2a 165.5 ~6620	134	>31	Basal ash-flow tuffs of the Otowi Member and porous, well-bedded and well-sorted fall deposits of the Guaje Pumice Bed	The perched zone was not fully penetrated during drilling; perching lithology not known	Nitrate, perchlorate, chloride	Perched groundwater was detected while coring through the lowermost part of the Bandelier Tuff. The bottom of saturation was not penetrated by the borehole. A single-screen well was installed in this zone.
Los Alamos Canyon	Otowi 4 2806 6639	~253	Not known	Puye Fm. gravels	Within Puye Fm. fanglomerate; perching lithology not known	Not sampled	Saturation in this zone was noted while drilling to install a municipal supply well in the regional aquifer (Stoker et al. (1992). The geologic log notes: "Some perched water was visible in a video log of the 48-in hole at about 253 ft where water cascaded in from a large gravel." This perched zone is not accessed by a well screen in Otowi 4.
Los Alamos Canyon	R-6i 660 ~6995	592	23	Puye Fm. gravels	Poorly sorted fanglomerate with a silty matrix	Nitrate and perchlorate	This zone occurs at the same elevation and may be related to the perched zone identified by borehole video in nearby supply well Otowi 4 during drilling. A single-screen well was installed in this zone.

Table 2-B-1.
Characteristics of Deep Perched Groundwater Zones Encountered in Wells on the Pajarito Plateau (continued)

Watershed	Well Name, Borehole Depth (ft), Surface Elev. (ft)	Depth to Water (ft)	Saturated Thickness (ft)	Groundwater Host Rock	Nature of Perching Layer	Anthropogenic Chemicals Detected	Comments
Los Alamos Canyon	R-9i 322 6383 and LAWS-01 281.5 6305	137	45-99	Cerros del Rio basalt interflow breccia and highly fractured basalt	Massive basalt with few fractures	Tritium	Groundwater was first encountered at a depth of 180 ft, but the water level quickly rose to 137 ft, indicating possible confinement. At R-9i a canyon-floor well was installed with two isolated screens (Broxton et al., 2001a,b). Screen #1 of R-9i is complete in this zone. In LAWS-01, this zone is sampled via a flexible liner with sampling ports (Stone and Newell, 2002).
Los Alamos Canyon	R-9i 322 6383 and LAWS-01 281.5 6305	275	7	Cerros del Rio basalt brecciated flow base	Clay-rich, stratified, basaltic tephra (maar deposits) from 282 to 289.8 ft	Tritium	Water first encountered at 275 ft. The water level stabilized at 264 ft and may be confined (Broxton et al., 2001a,b). Screen #2 in well R-9i is complete in this zone. In LAWS-01, this zone is sampled via a flexible liner with sampling ports (Stone and Newell, 2002).
Los Alamos Canyon	R-9 771 6383	524	48 to 103	Puye Formation sands and gravels	Clay-rich tuffaceous sands and gravels	Tritium	Three stringers of sands and gravels at 579-580.5 ft, 615 ft, and 624-626.8 ft produced perched groundwater (Broxton et al., 2001a). These occurrences probably constitute a single saturated zone because when isolated each yielded the same

Table 2-B-1.
Characteristics of Deep Perched Groundwater Zones Encountered in Wells on the Pajarito Plateau (continued)

Watershed	Well Name, Borehole Depth (ft), Surface Elev. (ft)	Depth to Water (ft)	Saturated Thickness (ft)	Groundwater Host Rock	Nature of Perching Layer	Anthropogenic Chemicals Detected	Comments
							depth-to-water of 524 ft. The water-bearing stringers are enclosed by clay-rich tuffaceous sands and gravels that may be confining units or may simply be unproductive. No well screens were installed in this saturated zone.
Sandia Canyon	PM-1 2501 6513	450	Not Known	Cerros del Rio basalt	Not known	Not sampled	During installation of supply well PM-1, the geologic log notes that water was present in brecciated Cerros del Rio basalt at a depth of 450 ft (Cooper et al., 1965). No other information was given about this zone.
Sandia Canyon	R-12 886 6500	424	76-95	Fractured Cerros del Rio basalt and underlying fluvial sands and silts, and riverine gravels of the lacustrine facies of the Puye Fm.	Clay-rich lake beds of the lacustrine facies of the Puye Fm. from 519-535 ft	Tritium, nitrate	This is probably the same perched groundwater as that encountered in PM-1. Groundwater was first encountered at a depth of 443 ft, but the water level quickly rose to 424 ft before stabilizing, indicating possible confinement. A well was installed with three isolated screens (Broxton et al., 2001c). Screens #1 and #2 are complete in this perched zone.

Table 2-B-1.
Characteristics of Deep Perched Groundwater Zones Encountered in Wells on the Pajarito Plateau (continued)

Watershed	Well Name, Borehole Depth (ft), Surface Elev. (ft)	Depth to Water (ft)	Saturated Thickness (ft)	Groundwater Host Rock	Nature of Perching Layer	Anthropogenic Chemicals Detected	Comments
Mortandad Canyon	I-8 745	675, water level is at top of well sump	Saturated thickness is unknown, but the zone is probably very thin	Fractured Cerros del Rio basalt	Nature of confining bed is unknown	None	A small amount of water was observed trickling from a fracture at 669 ft bgs in the borehole video. A single-screen well was installed, but only a small amount of water has accumulated in the well sump.
Mortandad Canyon	MCOBT-4.4 767 6836	520	2-4 currently	Puye Fm. pebble gravel and silty sands	Top of Cerros del Rio basalt	Tritium, nitrate, perchlorate	Initial depth-to-water was 493 ft, but it has since declined to 520 ft. A single-screen well was installed in this zone (Broxton et al., 2002a).
Mortandad Canyon	I-4 540	520	2-4	Puye Fm. pebble gravel and silty sands	Top of Cerros del Rio basalt	Tritium, nitrate, perchlorate	A single-screen well was installed in this zone. This well was installed as a possible replacement well for MCOBT-4.4.
Mortandad Canyon	R-15 1107 6820	646	~99 (?)	Fractured Cerros del Rio basalt	Clay-rich flow-base rubble or underlying silty basaltic sand (745-746.7 ft)	Tritium, nitrate, perchlorate	Saturation in this zone was noted while drilling to reach the regional aquifer (Longmire et al., 2001). Saturation was first encountered at a depth 646 ft, but a zone of increased water production was noted by the driller from 707-717 ft. It is uncertain whether this occurrence represents one zone or multiple, stacked zones.

Table 2-B-1.
Characteristics of Deep Perched Groundwater Zones Encountered in Wells on the Pajarito Plateau (continued)

Watershed	Well Name, Borehole Depth (ft), Surface Elev. (ft)	Depth to Water (ft)	Saturated Thickness (ft)	Groundwater Host Rock	Nature of Perching Layer	Anthropogenic Chemicals Detected	Comments
Mortandad Canyon	I-5 717 6820	687	20	Interflow breccia in Cerros del Rio basalt	Possible confining unit in massive basalt in lower part of Cerros del Rio basalt	Tritium, nitrate, perchlorate	This well was installed adjacent to R-15 and targeted the water production zone from 707 to 717 ft that was noted in that borehole. A single-screen well was installed in this zone. It is uncertain whether the perched zone was fully penetrated by the borehole.
Mortandad Canyon	I-6 722 6811	662	43	Interflow breccia and fractured basalt in Cerros del Rio basalt	Possible confining unit in massive basalt in lower part of Cerros del Rio basalt	Tritium, nitrate, perchlorate	This well is 150 ft north of R-15 and I-5, near the Mortandad Canyon stream channel. A single completion well was installed in this zone. The elevation of the SWL is 16 ft higher than at I-5. It is uncertain whether the perched zone was fully penetrated by the borehole.
Pajarito Canyon	R-23 935 6528	Not known	Not known	Cerros del Rio basalt	Not known	Not sampled	Perched groundwater was probably encountered while drilling R-23 to the regional aquifer. Water accumulated in the annulus between the drill casing and the borehole wall above a clay-rich bridge. The accumulated water is probably from a perched zone within the Cerros del Rio basalt. The perched zone was not screened.

Table 2-B-1.
Characteristics of Deep Perched Groundwater Zones Encountered in Wells on the Pajarito Plateau (continued)

Watershed	Well Name, Borehole Depth (ft), Surface Elev. (ft)	Depth to Water (ft)	Saturated Thickness (ft)	Groundwater Host Rock	Nature of Perching Layer	Anthropogenic Chemicals Detected	Comments
Pajarito Canyon	R-19 1902.5 7066	894	18	Puye Fm. sand and gravel beds	Puye Fm. low-porosity sedimentary deposits.	None	R-19 was installed on the mesa south of Threemile Canyon. A perched zone was encountered in Puye Formation fanglomerate overlying Cerros del Rio basalt. Borehole geophysical logs indicate the perched zone is made up of high-porosity sediments overlying low-porosity sediments. A well was installed with seven isolated screens at this site (Broxton et al., 2001d). Screen #2 is complete in this perched zone.
Cañon de Valle	R-25 1942 7516	723	~409	Otowi ash-flow tuff, Guaje Pumice bed, and Puye Fm. fanglomerate	Confining layer occurs in Puye Fm. sedimentary deposits. From 1132 to 1137 ft, cuttings of fine-grained sand and silt are interbedded with gravels and cobbles. Alternating wet and dry sediments occur below this zone to a depth of 1286 ft.	High-explosive compounds and their degradation products, trichloroethene, tetrachloro-ethene	This large saturated zone is separated from the regional aquifer (depth at 1286 ft) by 154 ft of alternating wet and dry fanglomerate deposits. This upper saturated zone is currently interpreted as a perched zone with a leaky confining layer. The top of the same upper saturated zone was penetrated in nearby well CDV-16-1(i) which is located in adjacent Cañon de Valle. A multi-screen mesa-top well was installed at R-25 (Broxton et al., 2002b). Four screens are complete in this thick perched zone.

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Table 2-B-1.
Characteristics of Deep Perched Groundwater Zones Encountered in Wells on the Pajarito Plateau (continued)

Watershed	Well Name, Borehole Depth (ft), Surface Elev. (ft)	Depth to Water (ft)	Saturated Thickness (ft)	Groundwater Host Rock	Nature of Perching Layer	Anthropogenic Chemicals Detected	Comments
Cañon de Valle	CDV-16-1(i) 683 7382	563	>120 ft; not fully penetrated	Otowi ash-flow tuff	Perching horizon not known; below drill hole depth	High-explosive compounds	Because of the proximity of CDV-16-1(i) and R-25 (~375 ft), the upper saturated zone in these wells is probably laterally connected. The top of the upper saturated zone is 28 ft higher in CDV-16-1(i) (elev. 6821 ft) compared with R-25 (elev. 6793 ft). A single-screen well was installed in this zone.
Cañon de Valle	CDV-16-2(i) 1063.1 7467	827 (?)	Not known	Puye Fm. fanglomerate	Within Puye Fm. fanglomerate; perching lithology not known	High-explosive compounds	The nature of this perched zone is currently under investigation. Borehole video logs, water level measurements, and the presence of high explosives in groundwater samples indicate that perched water is present. However, efforts to install a well in this zone(s) have not been successful.
Cañon de Valle	R-26 1490.5 7642	173	Zones of thin, dis-continuous saturation associated with fractures	Fractured densely-welded tuff in unit Qbt 3t of the Tshirege Member	Water production associated with fractures	Analyses pending	A piezometer was installed in a borehole adjaent to well R-26 to monitor water levels in this perched zone. The piezometer is screened from 175 to 185 ft deep, and the depth to water is 173 ft. Saturation appears to be associated with low-angle platy fractures in the ash-flow tuff.

Table 2-B-1.
Characteristics of Deep Perched Groundwater Zones Encountered in Wells on the Pajarito Plateau (continued)

Watershed	Well Name, Borehole Depth (ft), Surface Elev. (ft)	Depth to Water (ft)	Saturated Thickness (ft)	Groundwater Host Rock	Nature of Perching Layer	Anthropogenic Chemicals Detected	Comments
Cañon de Valle	R-26 1490.5 7642	About 604	See comments	Cerro Toledo interval	See comments	Analyses pending	R-26 was recently drilled and interpretation of perched water in this zone is preliminary. Borehole geophysical logs suggest high moisture contents below 575 ft to the top of regional saturation at 954 ft. Perched water appears most likely at depths of 580 to 662 ft and 780 to 827 ft. A water level at 604 ft depth was measured during drilling while the borehole was at a depth of 720 ft. Well R-26 was completed with two isolated well screens with the upper screen placed within the perched zone and the lower screen in the regional zone of saturation.
Water Canyon	SHB-3 860 7608	663	> 197 ft (?), probably not fully penetrated	Otowi ash-flow tuff, Guaje Pumice bed, and Puye Fm. fanglomerate	Confining layer probably not penetrated	None	Saturation occurs in the lower Bandelier Tuff and upper Puye Formation. A temporary mesa-top well was installed in the perched zone (Gardner et al., 1993).

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In Pueblo Canyon perched water was identified in four wells. At wells TW-2a and R-5, perched water occurs within fanglomerate of the Puye Formation and has a saturated thickness of >7 and about 11.3 m (>23 and about 37 ft), respectively. Depth to water is 33.5 m (110 ft) at TW-2a and about 115.8 m (380 ft) at R-5. These perched zones probably represent relatively small, unrelated water bodies because of their distance from one another (4 km [2.5 mi]), the lateral heterogeneity of Puye Formation deposits, and their varying depths beneath the canyon floor. Wells TW-1a and POI-4 encountered perched water at depths of 36 to 48.8 m (118 to 160 ft), respectively, in Cerros del Rio basalt. The saturated thickness is about 11 m (37 ft) at TW-1a and 6.4 m (>21 ft) at POI-4. Saturation is associated with interflow breccia and sediments in TW-1a and with fractured basalt at POI-4.

In Sandia and Mortandad Canyons perched water was found in Cerros del Rio basalt and the Puye Formation. The water quality of these perched zones includes a component of treated waste-water effluent released to the canyons via outfalls (Longmire et al., 2001; Longmire, 2002; Broxton et al., 2002b). Depth to water is also similar, ranging from 129 to 152 m (424 to 500 ft) in Sandia Canyon and 150 to 197 m (493 to 646 ft) in Mortandad Canyon.

In Sandia Canyon, well R-12 encountered perched water from depths of 135 to 158 m (443 to 519 ft). Saturation occurs in the lower part of the Cerros del Rio basalt and extends downward into underlying lacustrine facies of the Puye Formation (Broxton et al., 2001a). The perched water in this zone may be confined because the borehole was dry until a depth of 135 m (443 ft) was reached, but the water level rose to a depth of 129 m (424 ft) once saturation was encountered. The apparent confining layer at the top of this zone is a massive basalt flow with few fractures. An alternative explanation for the observed rise in water level is that the groundwater is unconfined, but water-bearing interconnected fracture systems were not intersected by the borehole until a depth of 135 m (443 ft). The perching layer consists of clay- and silt-rich lacustrine deposits 5 m (16.5 ft) thick. The saturated thickness of this groundwater body is at least 23 m (75 ft), making it one of the thickest perched groundwater bodies identified in the eastern part of the Pajarito Plateau.

In Mortandad Canyon perched water was encountered in three boreholes. At well MCOBT-4.4, the top of perched groundwater zone occurs at a depth of about 150 m (493 ft), within pebble gravel made up of dacitic volcanic detritus in the Puye Formation. The saturated thickness of this zone is between 3 and 6 m (10 and 30 ft). The perching layer includes one or more of the following lithologies: 1) silty sands and gravels in the lower part the Puye sequence (153.3 to 157.6 m [503 to 517 ft]), 2) clay-rich brecciated rubble at the top of Cerros del Rio basalt (157.6 to 159.3 m [517 to 522.5 ft]), or 3) the massive, unfractured interior of the uppermost Cerros del Rio flow (approximately 159.3 to 163.1 m [522.5 ft to 535 ft]). At wells R-15 and I-5, located 347 m (1140 ft) down canyon of MCOBT-4.4, perched water occurs within the lower part of a thick sequence of Cerros del Rio basalts. The depth to water is 197 m (646 ft) in R-15 and 209 m (686 ft) in the adjacent well I-5 which is offset 20 m (66 ft). Saturation in both wells occurs in fractured lava flows and interflow breccias. The variable elevations of the top of perched saturation and varied saturated thicknesses of 30 m (99 ft) in R-15 and 8+ m (26+ ft) in I-5 illustrate the hetergeneous nature of perched bodies located within basaltic rocks. In R-15, the perching horizon is clay-rich flow-base rubble or underlying silty basaltic sands; the perched water at I-5 was not fully penetrated. Because of their different geologic settings, the perched

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groundwater at MCOBT-4.4 and R-15/I-5 probably represent unrelated groundwater bodies of limited lateral extent. Other deep boreholes in Mortandad Canyon did not encounter perched groundwater. Based on the distribution of available boreholes, the lateral extent of individual perched groundwater bodies is probably less than 460 m (1500 ft).

Both perched water occurrences in Mortandad Canyon contain elevated tritium, nitrate, and perchlorate. The highest contaminant levels occur in MCOBT-4.4, which contains 14,750 pCi/L tritium, 12.5 mg/L nitrate plus nitrite (as N), and 179 ppb perchlorate (Longmire, 2002, personal communication). Since 1963, these contaminants were released to the canyon as liquid effluent by a waste treatment facility in the upper part of the canyon. The presence of contaminants in perched groundwater beneath Mortandad Canyon indicates that vertical transport through the vadose zone occurs on the timescale of decades.

A large area of complex perched groundwater occurrences is found in the region bounded by Cañon de Valle on the north and Water Canyon on the south in the southwest part of LANL. Five deep boreholes encountered significant zones of groundwater over a 2.6 km^2 (1 mi^2) area located just east of the Pajarito fault zone. These boreholes included R-25, R-26, CdV-16-1(i), CdV-16-2(i), and SHB-3. Depth to water in these perched zones range from about 183 m (600 ft) just east of the Pajarito fault to about 244 m (800 ft) 2.3 km (1.4 mi) farther east of the fault. Only wells R-25 and R-26 fully penetrate the perched water zones.

At R-26, a water-level measurement of 184 m (604 ft) was obtained when the borehole was 219 m (720 ft) deep. The borehole was eventually completed to a total depth of 454.3 m (1490.5 ft) with the regional water table occurring at a depth of approximately 291 m (954 ft). Borehole neutron, magnetic resonance, and induction logs indicate that high moisture contents occur in rocks below 175 m (575 ft), with perched water most likely at depths of 177 to 202 m (580 to 662 ft) and 238 to 252 m (780 to 827 ft). These perched zones occur within stratified volcaniclastic sediments of the Cerro Toledo interval. Low-permeability sediments within the Cerro Toledo interval probably provide the perching horizons.

R-25, located 1524 m (5000 ft) east of R-26, has two distinct zones of saturation separated by 47 m (154 ft) of partially saturated rocks. The upper zone, which is interpreted as a perched zone, occurs between depths of about 217 to 345 m (711 to 1132 ft) within the Otowi Member and in the upper part of the Puye Formation. An interval of partial saturation occurs below the perched zone from 345 to 392 m (1132 to 1286 ft) depth. Partial saturation was defined by casing off the perched zone and drilling through alternating zones of dry and wet rocks by coring and air-rotary methods. From 392 m (1286 ft) to the total depth of 592 m (1942 ft), continuous saturation representing regional groundwater was encountered within Puye deposits. R-25 was constructed with 9 screens separated by packers using a Westbay™ sampling system. Hydraulic head measurements in isolated screens decrease with depth, indicating downward vertical gradients. Isotopic and water quality data suggest the upper and lower zones of saturation at R-25 represent separate groundwater systems (Longmire, 2003, personal communication).

Table 3-A-1.
Guaje Canyon Watershed Description

Hydrogeologic Element	Characteristic	Description
Surface Water	Flow	Guaje Canyon heads in the Sierra de los Valles on Forest Service land, enters San Ildefonso Pueblo land, and continues to its confluence with lower Los Alamos Canyon approximately a mile west of the Rio Grande (Figure 3-A-1, Figure 3-A-2). Guaje Canyon is part of the Los Alamos Canyon watershed, but is covered separately because it is a large drainage that is largely unaffected by LANL activities. Guaje Canyon contains an interrupted stream with a perennial reach extending from springs located upstream of Guaje Reservoir to some distance downstream of the reservoir. An intermittent reach extends farther downstream to the confluence with lower Los Alamos Canyon. Snowmelt runoff does not reach the Rio Grande. Rendija Canyon heads on the flanks of the Sierra de los Valles and contains an ephemeral stream. Barrancas Canyon heads on the Pajarito Plateau and has intermittent and ephemeral flow.
	Quality	There are no known water quality effects of LANL activities.
Springs	Name	No springs have been found in any of these canyons.
	Quality	See above.
Alluvial Groundwater	Extent	Little or no alluvial groundwater is present in these canyons. Only two alluvial wells have been installed in Guaje Canyon to investigate the presence of alluvial groundwater. These wells were completed in the perennial reach of the canyon and alluvial groundwater was encountered near the stream level. For Rendija Canyon and Barrancas Canyon, no alluvial wells have been installed and no alluvial groundwater is known to exist.
	Depth/Thickness	See above.
	Quality	No impacts of LANL activities on this water are known.
Intermediate Groundwater	Extent/Hydrology	No intermediate groundwater wells have been installed and no groundwater is known to occur in these canyons. Drilling of the water supply wells in Rendija Canyon and Guaje Canyon did not find any intermediate groundwater.
	Depth/Thickness	See above.
	Quality	No LANL liquid discharges have occurred.

Table 3-A-1.
Guaje Canyon Watershed Description (continued)

Hydrogeologic Element	Characteristic	Description
Regional Aquifer	Depth/Hydrology	The regional aquifer occurs in the Puye Formation and the Santa Fe Group in the vicinity of Guaje Canyon. The regional aquifer probably includes rocks of the Tschicoma Formation in the western part of the canyon. The regional aquifer supplies water to the supply wells of the Guaje wellfield. Groundwater flow in the regional aquifer is from the northwest, so no Laboratory contaminant sources are located upgradient of Guaje Canyon sites. The aquifer lies at depths of about 230 to 570 ft in the Guaje wellfield.
	Quality	The water is of generally good quality except for high levels of naturally occurring arsenic—up to 40 µg/L in older, now-abandoned wells. The EPA MCL for arsenic is 10 µg/L.
Contaminants	Potential Sources	These canyons are located north of the Laboratory, mainly on Forest Service land and on San Ildefonso Pueblo. The primary Laboratory activities in the canyons have involved water supply: the Guaje reservoir is no longer in use, and the Guaje wellfield (now operated by Los Alamos County) currently includes five water supply wells. The wells in this field also extend to lower Rendija Canyon. Rendija Canyon contained a small-arms firing range and several sites used as mortar impact areas. Past Laboratory activities are described in more detail in an RFI Work Plan for the North Canyons and an RFI Work Plan for OU 1071.
	Type	
References: LANL 2001a; LANL 1992g.		

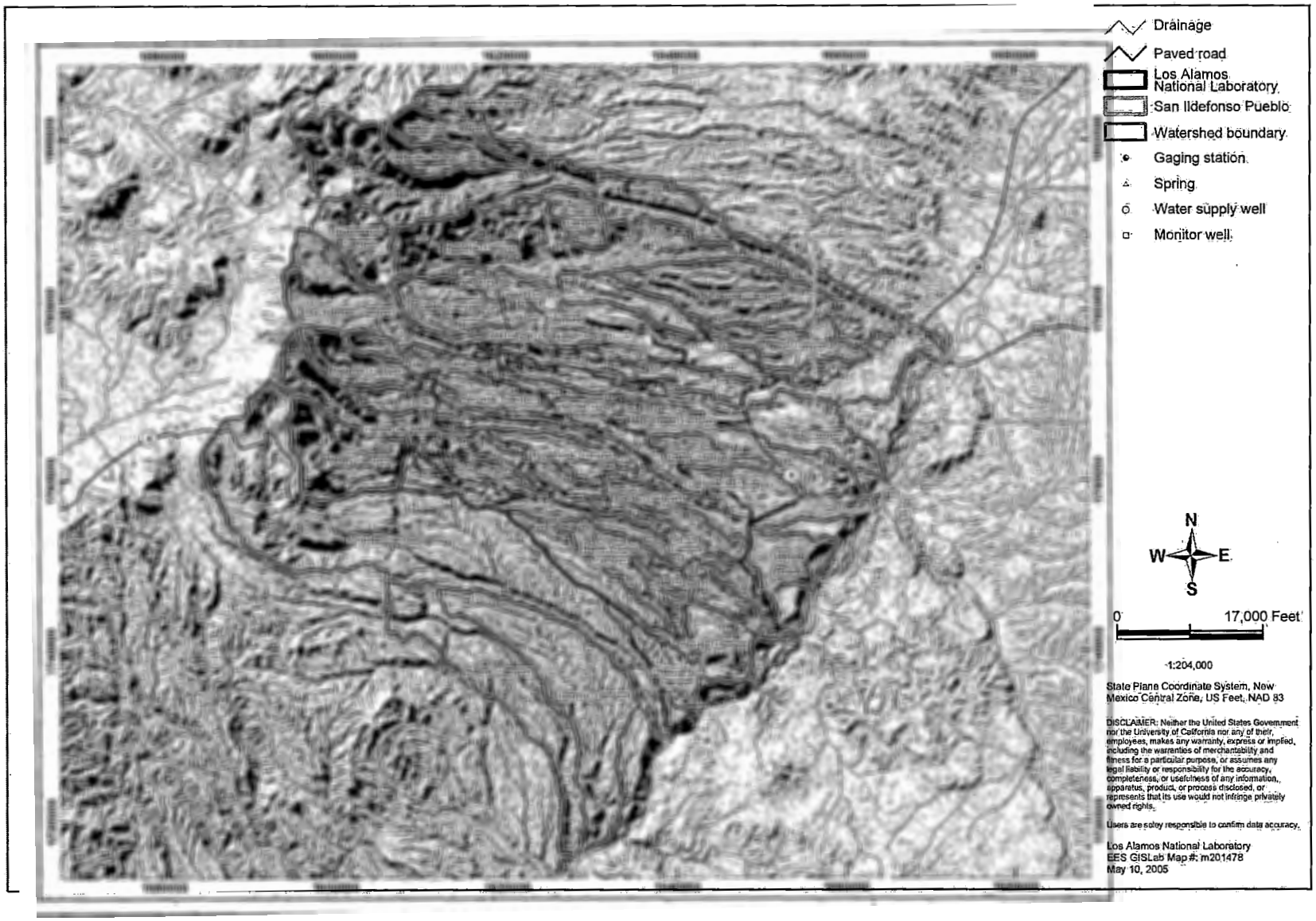

Figure 3-A-1. Watersheds on the Pajarito Plateau in the vicinity of Los Alamos National Laboratory.

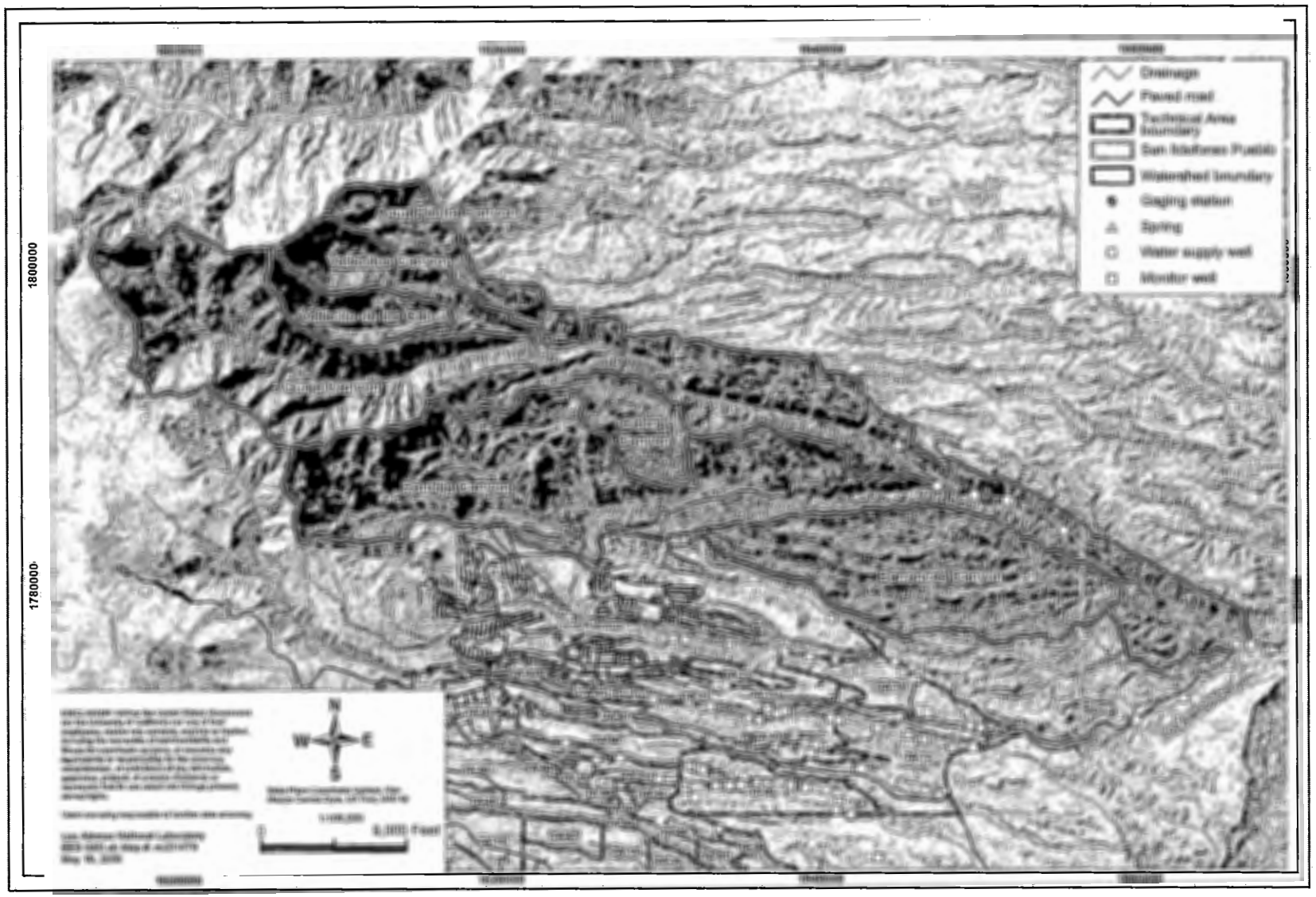

Figure 3-A-2. Guaje Canyon watershed.

Table 3-A-2.
Los Alamos Canyon Watershed Description

Hydrogeologic Element	Characteristic	Bayo Canyon	Acid and Pueblo Canyons	DP and Los Alamos Canyons
Surface Water	Flow	Bayo Canyon heads on the Pajarito Plateau on land owned by Los Alamos County and extends across the northeast portion of the Laboratory (TA-74), crosses San Ildefonso Pueblo land to the east, and terminates at its confluence with lower Los Alamos Canyon near Totavi (Figure 3-A-1, Figure 3-A-3). The drainage area of Bayo Canyon is about 4 square miles. Surface water flow in Bayo Canyon is ephemeral and intermittent and there are no springs in the vicinity. Stream losses caused by infiltration into the underlying alluvium and evapotranspiration typically prevent surface flow from reaching Los Alamos Canyon. No alluvial or intermediate groundwater was encountered during drilling of about 90 boreholes at the TA-10 site in upper Bayo Canyon. Drilling at TA-10 has not found	Pueblo Canyon heads on USFS land, crosses Los Alamos County land, then Laboratory land where it joins Los Alamos Canyon just upstream of the San Ildefonso Pueblo boundary (Figure 3-A-1; Figure 3-A-3). The draingage area of Pueblo Canyon is about 6.5 square miles, including Acid Canyon. Surface water in Pueblo Canyon occurs as ephemeral runoff from precipitation and as perennial flow supported by effluent discharge from the Los Alamos County Sewage Treatment Plant. Generally, ephemeral surface water occurs in the upper portion of Pueblo Canyon following summer rains and snowmelt events, and perennial surface water occurs in the lower portion of Pueblo Canyon because of discharges from the Los Alamos County Sewage Treatment Plant. Surface water in Pueblo Canyon rarely flows across the length of the Laboratory. Acid Canyon heads on the Pajarito Plateau in the southwestern portion of the Los Alamos townsite and extends east-northeasterly to its confluence with Pueblo Canyon. The South Fork of Acid Canyon is a short north-trending	Los Alamos Canyon heads on USFS land, crosses Laboratory land, then San Ildefonso Pueblo land before joining the Rio Grande (Figure 3-A-1; Figure 3-A-3). Surface water occurs in Los Alamos Canyon as perennial flow in the upper reaches west of the Los Alamos Reservoir located west of DOE property, and in the lower reaches east of the confluence with Pueblo Canyon. The drainage area of Los Alamos Canyon is about 11.6 square miles, including DP Canyon. Typically, the overflow of water from the reservoir during spring snowmelt results in nearly continuous surface water flow between the western Laboratory boundary and the vicinity of TA-2 for several weeks to several months each year. For most of the year, the only surface flow in Los Alamos Canyon is in lower Los Alamos Canyon due to discharge from the Los Alamos County Sewage Treatment Plant and flow from Basalt and Los Alamos Springs east of the Laboratory boundary. Surface water in Los Alamos Canyon rarely flows across the length of the Laboratory except during snowmelt and summer storm events. Most often, surface waters are depleted by infiltration into canyon alluvium creating saturated zones of seasonally variable extent. DP Canyon heads on the Pajarito Plateau in the southeastern portion of the Los Alamos townsite and extends east-southeasterly to its confluence with Los Alamos Canyon. DP Canyon is located entirely within DOE-owned land except for a short segment at the head of the canyon on land owned by Los Alamos County. Surface flow in DP Canyon is generated by rainfall and snowmelt events. DP

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Table 3-A-2.
Los Alamos Canyon Watershed Description

Hydrogeologic Element	Characteristic	Bayo Canyon	Acid and Pueblo Canyons	DP and Los Alamos Canyons
		contamination that extends more than a few feet beneath former release sites. Groundwater in the regional aquifer is as described for Guaje Canyon.	tributary to Acid Canyon. Both of these canyons are entirely within land owned by Los Alamos County. These two canyons drain a surface area that is largely paved and developed.	Spring, located in DP Canyon, discharges continuously except for dry periods, such as during the winter and spring of 1996.
	Quality	TA-10 was used as a firing site from 1943 to 1961, for tests with high explosives and radioactive materials. The site included a radiochemistry laboratory. While in operation, the TA-10 sites in Bayo Canyon were investigated for environmental impacts. The site was decontaminated and decommissioned in 1960. TA-10 was the site of an extensive Formerly Utilized Sites Remedial Action Program investigation in 1976. In the mid-1990s the site was studied under a RFI Work Plan for Operable Unit 1079. RFI activities included shrapnel removal and investigation, remediation, or deferred action for several potential release sites. A second RFI work plan was written in 2001.	Key contaminants in Acid Canyon surface water include metals (arsenic, cadmium, manganese, zinc, and cyanide), PAHs (e.g., benzo-a-pyrene, dibenz-a-h-anthracene), and radionuclides (Pu-239, -240, strontium-90, and uranium-234). The metals COPCs are dominated by naturally occurring constituents, or constituents associated with urban runoff. The PAHs are also believed to be associated with runoff from developed areas with the Los Alamos townsite. The radionuclides were detected in bedrock pools in the South Fork of Acid Canyon and are consistent with contaminants found in sediment within the canyon from historical releases from TA-45. The radionuclide contamination generally does not extend beyond the Acid/Pueblo Canyon confluence in detectable concentrations, with the exception of Pu-239, -240 in unfiltered samples.	Key contaminants in upper Los Alamos Canyon surface water include metals (arsenic, manganese, iron, selenium, and cyanide), pesticides, and plutonium-239, -240. The metals are generally considered naturally occurring, although some minor contribution from historical Laboratory releases is possible. The cyanide detects in upper Los Alamos Canyon are believed to be related to combustion of organic matter during the Cerro Grande fire and may also be related to anti-caking and anti-corrosion agents contained in fire retardant. Pesticides are predominantly related to historical use in the Santa Fe National Forest and to use within the Los Alamos townsite. The plutonium-239 is related to outfalls (likely Hillsides 137 and 138) in former TA-1. The Pu-239 is a COPC only for the unfiltered samples indicating the potential that the sample(s) with detections may have contained suspended sediment. Key contaminants in DP Canyon surface water and springs include metals (arsenic, copper, lead, manganese, zinc, and cyanide), pesticides, and radionuclides (americium-241, and strontium-90). Chloride is also present. The metals are either naturally occurring or likely related to townsite runoff, since none of the PRSs in DP Canyon are known for metals contamination, the exception

Table 3-A-2.
Los Alamos Canyon Watershed Description

Hydrogeologic Element	Characteristic	Bayo Canyon	Acid and Pueblo Canyons	DP and Los Alamos Canyons
			Surface water in Pueblo Canyon above the confluence with Acid Canyon also has metals COPCs and PAHs that are considered to have a source in townsite runoff. Surface water in Pueblo Canyon below the confluence with Acid Canyon shows metals COPCs (arsenic, manganese, selenium, and cyanide), and organics COPCs (pesticides and PAHs) that are both likely from townsite, national forest, or Cerro Grande fire sources. Radionuclides include Pu-239, -240, americium-241, and cobalt-60.	being the DP Tank Farm (DPTF, SWMU 21-029) which had lead contamination associated with leaks from the tanks. However, no other of the COPCs from the DPTF are present. The cyanide detections in DP Canyon are from DP Spring and a location at the very head of DP Canyon suggesting a source other than Laboratory operations. The radionuclides are COPCs only for the unfiltered samples indicating the potential that the detections are related to the presence of suspended sediment in the samples. DP Spring consistently shows elevated strontium-90 concentrations related to surface water and alluvial groundwater discharge from Reach DP-2 where strontium-90 is present throughout the sediment due to historical releases from SWMU 21-011(k). Key COPCs in surface water and springs in lower Los Alamos Canyon include metals (antimony, arsenic, beryllium, copper, possibly mercury, molybdenum, nickel, selenium, thallium, and cyanide), PAHs (benzo_k_fluoranthene), and pesticides (DDE_4_4_, and DDP_4_4_), and only strontium-90 from unfiltered surface water. The constituents present in lower Low Alamos Canyon appear to be primarily naturally occurring or related to sources other than Laboratory operations. Of the metals identified as COPCs for lower Los Alamos Canyon, only molybdenum (and mercury?) have known Laboratory sources up canyon. The cyanide is believed to be related to the combustion of organic matter during the Cerro Grande fire. Detections of cyanide in the lower canyon are thought to be related to transport of ash from burn areas in the upper watershed during floods. Strontium-90 could be

Table 3-A-2.
Los Alamos Canyon Watershed Description

Hydrogeologic Element	Characteristic	Bayo Canyon	Acid and Pueblo Canyons	DP and Los Alamos Canyons
				from either Los Alamos or Pueblo Canyon, but based on estimated inventories of strontium-90, it is most likely associated with Los Alamos Canyon (specifically SWMU 21-011(k).
Springs	Name	There are no springs in Bayo Canyon.	There are no springs in Acid and Pueblo Canyons,	Discharge at DP Spring is highly variable, generally ranging from dry to less than one gallon per minute, and has been observed to respond rapidly to storm-water runoff from upper DP Canyon. Surface water flow generally extends for less than 50 ft down canyon from the point where spring flow joins the stream channel. Basalt Spring is recharged by water from the County Sewage Treatment Plant in Pueblo Canyon. It has variable estimated discharge rates from 1 to 10 gallons per minute. LA Spring discharges along the south slope of the canyon approximately 300 meters downstream of Basalt Spring.
	Quality	See above.	See above.	Chloride, sodium, and manganese, barium, boron, HE, and solvents at concentrations above background.
Alluvial Groundwater	Extent		Two saturated zones are known to occur in the alluvium of Pueblo Canyon. The first is in the upper reach from the headwaters to approximately the Rendija Canyon Fault. The eastern limit of this saturated zone has not been clearly defined and it may extend further down canyon. The second is in the lower reach downstream of the Los Alamos County Sewage Treatment Plant where saturated conditions are supported year-round due to effluent	Two saturated zones are known to occur in the alluvium of Los Alamos Canyon. The first is in the upper part of Los Alamos Canyon and extends eastward from the Los Alamos Reservoir to the vicinity of observation well LAO-4.5 west of State Rte. 4. The second is in the lower part of Los Alamos Canyon and extends from Basalt Spring to the Rio Grande. Alluvial groundwater in lower Los Alamos Canyon near Basalt and Los Alamos Springs is chemically similar to surface water flow supported by these springs. The chemistry of the water discharging from Basalt Spring is

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Table 3-A-2.
Los Alamos Canyon Watershed Description

Hydrogeologic Element	Characteristic	Bayo Canyon	Acid and Pueblo Canyons	DP and Los Alamos Canyons
			releases from the sewage treatment plant. The extent of saturation is variable due to fluctuation in runoff and volume of effluent released during the year. The volume of effluent released into the canyon typically decreases during the spring and early summer months as wastewater from the plant is pumped up canyon for irrigation use on the municipal golf course. From 1951 to 1964, surface flow in the mid-reach of Pueblo Canyon was augmented by liquid effluent from the former TA-45 radioactive liquid waste treatment facility via Acid Canyon. In addition, Los Alamos County operated a sewage treatment plant in upper Pueblo Canyon (known as the Pueblo Sewage Treatment Plant) until the current Los Alamos County Sewage Treatment Plant came on-line in 1963. Effluent from these past sources likely supported sustained saturated conditions throughout the mid-reach of Pueblo Canyon as well as shallow bedrock springs such as Hamilton Bend Spring, just west of the current Los Alamos County Sewage Treatment Plant. The sewage treatment plants are sources of boron and nitrate. This	similar to effluent from the Los Alamos County Sewage Treatment Plant. The chemistry of water discharging from Los Alamos Spring may represent an isolated perched system as it does not contain characteristic major ions indicative of sewage effluent. Alluvial groundwater in lower Los Alamos Canyon, from the confluence of Guaje Canyon and Los Alamos Canyon to the Rio Grande, shows chemical similarity to both regional aquifer water and surface water from the Rio Grande (LANL, 2004b, 2002, 2001a).

Table 3-A-2.
Los Alamos Canyon Watershed Description

Hydrogeologic Element	Characteristic	Bayo Canyon	Acid and Pueblo Canyons	DP and Los Alamos Canyons
			alluvial groundwater may have provided the source for infiltration to intermediate perched zone groundwater or the regional aquifer. Shallow spring flow (including Hamilton Bend Spring) ended following closure of TA-45 and the Pueblo Sewage Treatment Plant.	
	Depth/ Thickness		See above.	In middle and upper Los Alamos Canyon, the saturated thickness in the alluvium varies seasonally from a few feet in the winter months to 25 ft in the spring and summer months when recharge is the greatest. The alluvial groundwater provides recharge to intermediate perched zones by infiltrating along preferential pathways such as faults or permeable bedrock units.
	Quality		Known contaminants at former TA-45 include nitrate, perchlorate, tritium, isotopes of uranium and plutonium, strontium-90, cesium-137, and gross-alpha radiation. The contaminant histories for nitrate, tritium, and strontium-90 illustrate trends in Pueblo Canyon surface water and groundwater. Nitrate has been present from Laboratory radioactive liquid waste effluents and from Los Alamos County Sewage Treatment Plant sanitary effluent. The highest values were found in surface water in the 1950s and 1960s, possibly related to both types of sources. With decommissioning of the radioactive outfall in 1964 and moving	Alluvial groundwater has been found in DP Canyon at wells LAUZ-1 and LAUZ-2, installed for the ER investigation at TA-21. Strontium-90, tritium, and some organic compounds have been detected at LAUZ-1. Time series plots of nitrate, tritium, plutonium-239, strontium-90, and molybdenum provide a picture of contaminant trends in Los Alamos Canyon groundwater. Nitrate in discharges into DP Canyon from TA-21 caused surface water and alluvial groundwater concentrations to exceed 100 mg/L (nitrate as nitrogen), or 10 times the MCL, until discharges ceased in 1986. Nitrate concentrations have returned to background since discharges ended. TA-21 effluent caused tritium activities in surface water and alluvial groundwater in and downstream of DP Canyon

Table 3-A-2.
Los Alamos Canyon Watershed Description

Hydrogeologic Element	Characteristic	Bayo Canyon	Acid and Pueblo Canyons	DP and Los Alamos Canyons
			the sanitary discharge downstream to the Bayo Treatment Plant, less water and less nitrate are present in the upper portion of the drainage in recent years. Tritium and strontium-90 histories characterize the radioactive effluent releases into Acid Canyon. Tritium persisted in surface water and alluvial groundwater at fairly high levels for about a decade after effluent releases ceased, but has dropped to background levels since. The highest measured strontium-90 activity was about 500 pCi/L in Acid Canyon surface water in 1960. With no present source, levels have dropped dramatically and strontium-90 is now seen only at low activities, below 1 pCi/L in alluvial groundwater.	to reach values up to 5,000,000 pCi/L or 250 times the MCL. As with nitrate, tritium activities decreased greatly after discharges ceased. In Los Alamos Canyon above the mouth of DP Canyon, the Omega West Reactor cooling line leaked water containing tritium from 1956 to 1993. As a result of this leak, tritium activity in alluvial groundwater remained at values around 10,000 pCi/L or half of the MCL. Once the leak was shut off, tritium levels in Los Alamos Canyon water returned to background. Strontium-90 contamination in surface water and alluvial groundwater came from reactor sources at TA-2 and effluent discharges from TA-21. The strontium-90 activity in DP Canyon surface water reached 28,600 pCi/L. There is no present source, and activities of this isotope have dropped greatly after discharges ceased. However, strontium-90 persists in alluvial groundwater at levels above the EPA MCL of 8 pCi/L due to the large inventory in alluvial sediment, providing a source to groundwater. Migration of strontium-90 is considered to be controlled by cation exchange. Effects of Manhattan Project releases in upper Los Alamos Canyon cause plutonium-239, -240 activity in alluvial groundwater to remain at about 25% of the DOE 4 mrem drinking water derived concentration guide (DCG) of 1.2 pCi/L. Discharges from TA-21 resulted in plutonium-239, -240 activity in surface water much above the DOE 4 mrem DCG, even exceeding the 100 mrem DCG of 30 pCi/L in the late 1960s. Plutonium activity has decreased substantially with the end of discharges in 1986, but is still

Table 3-A-2.
Los Alamos Canyon Watershed Description

Hydrogeologic Element	Characteristic	Bayo Canyon	Acid and Pueblo Canyons	DP and Los Alamos Canyons
				occasionally detected in surface water and alluvial groundwater below the former outfall. A short section of alluvial groundwater in Los Alamos Canyon has molybdenum concentrations near or above the New Mexico groundwater standard of 1,000 µg/L. In the early 1990s, molybdenum concentrations in Los Alamos Canyon alluvial groundwater rose sharply above background and exceeded the New Mexico groundwater limit in 2000. The source of this molybdenum is sodium molybdate, a water-treatment chemical commonly used in cooling towers at TA-53. The Laboratory discontinued use of sodium molybdate in June 2002.
Intermediate Groundwater	Extent/ Hydrology		Intermediate perched zones have been identified in two areas beneath Pueblo Canyon. One zone is in the middle reach of Pueblo Canyon where test well (TW)-2A is completed within fanglomerates of the Puye Formation. The perched zone occurs at a depth of about 120 ft. The second is in lower Pueblo Canyon (wells TW-1A and POI-4) within a thick sequence of Cerros del Rio basalts, at a depth of about 188 ft. This intermediate perched zone may be one source of water contributing to the flow from Basalt Spring in Los Alamos Canyon. Fairly rapid communication from Pueblo Canyon surface water and alluvial groundwater to the intermediate perched groundwater was interpreted	Several intermediate perched zones have been encountered in Los Alamos Canyon between TA-2 and State Road 4. A perched zone was encountered at well R-6i east of the facilities at TA-21 on the mesa top. The zone occurs within the Puye Formation at a depth of 593 ft.

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Table 3-A-2.
Los Alamos Canyon Watershed Description

Hydrogeologic Element	Characteristic	Bayo Canyon	Acid and Pueblo Canyons	DP and Los Alamos Canyons
			by the USGS based on water level measurements and similarities in water quality.	
	Depth/Thickness		See above.	The upper intermediate perched zone occurs within the Guaje Pumice Bed. This zone was encountered in borehole LADP-3 (at 325 ft). This same zone may have been penetrated by test hole H-19, west of the Los Alamos Canyon Bridge. The saturated thickness of this zone decreases from west to east, ranging from 22-ft at LAOI(A)-1.1 to 5-ft at LADP-3. A deeper intermediate perched zone was encountered in LAOI(A)-1.1 in the Puye Formation at about 317 ft. Another hole was drilled from the mesa top at MDA V in TA-21 which is approximately midway between LAOI(A)-1.1 and LADP-3 to investigate the lateral extent of the Guaje Pumice intermediate perched zone under DP Mesa. The MDA V Deep Hole (borehole 21-2523) did not find saturated conditions in the Guaje Pumice Bed at this location, indicating that this intermediate perched zone does not extend northward under DP Mesa. Other intermediate perched zones have been found in the basalt at R-9 near SR-4 at 180 and 275 ft. This well also found three possible saturated zones between depths of 570 and 626 ft, about 100 ft above the regional aquifer.
	Quality		Analysis of water samples from well TW-2A show that this perched zone contains elevated activities of tritium (2,228 pCi/L). This suggests that tritium associated with the former TA-45 treatment plant has infiltrated the canyon floor and migrated vertically, at	Average activities of tritium were 2.98 pCi/L in the perched zone, within the upper Puye Formation at well R-7 east of well LAOI(A)-1.1. Tritium was initially found in LADP-3 at 5500 pCi/L but activity has declined greatly since then, probably related to cessation of the Omega West Reactor cooling line leak in 1993. Average activities of tritium in the two intermediate perched zones at R-9i were 200 pCi/L at

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Table 3-A-2.
Los Alamos Canyon Watershed Description

Hydrogeologic Element	Characteristic	Bayo Canyon	Acid and Pueblo Canyons	DP and Los Alamos Canyons
			least to the depth of the intermediate perched zone at TW-2A. The tritium history for TW-2A shows a steep decrease the early 1980s, related to the cessation of discharges into Acid Canyon in 1964. Elsewhere in intermediate perched groundwater, tritium has been detected mainly at trace levels. In core from drilling of well R-2, perchlorate was found in more than 50% of the samples. Nitrate histories show that concentrations in TW-1A have often been up the 10 mg/L MCL. The high nitrate value in this and other wells in 1994 resulted from a sample preservation error. In about 1980, the Los Alamos County Bayo Sanitary Wastewater Treatment Plant, which discharges into Pueblo Canyon upstream of TW-1, greatly increased discharges. This increase in flow and infiltration apparently resulted in the higher concentrations of nitrate and chloride in TW-1 beginning about 1981. Nitrate (as nitrogen) concentrations in TW-2A, upstream of the Bayo treatment plant, have been 3 mg/L or less. Strontium-90 has not been consistently detected in intermediate perched	180 ft and 132 pCi/L at 275 ft during characterization sampling. Activities of tritium were 3802 pCi/L and concentrations of nitrate (as nitrogen) were 4.20 mg/L. Recharge from DP Canyon is most likely the dominant source of water to this perched intermediate zone. Perchlorate has been detected in unsaturated core samples from LADP-3 and R-8. However, perchlorate appears to have a very restricted vertical extent (<15 ft thick) in LA Canyon based on these boreholes. No other perchlorate detections occurred over the 200-350 ft sampling depth in the two boreholes. A similar situation occurs in DP canyon where LAUZ-1 perchlorate is also restricted to a narrow vertical depth range. In this borehole, all but one of the samples were non-detects for perchlorate. Vadose zone cores from DP Mesa boreholes LADP-4 (drilled on a bench above the DP canyon bottom near the former TA-21 radioactive liquid effluent outfall) and borehole 21-2523 (drilled east of MDA V), show a more extensive zone (>200 ft) of perchlorate contamination than occurs in the bottom of Los Alamos or DP canyon. In addition, both of these core holes show co-contamination of chlorate and nitrate. Chlorate has been detected in DP Spring, but chlorate and perchlorate have not been detected in other Los Alamos Canyon surface or groundwater samples.

Table 3-A-2.
Los Alamos Canyon Watershed Description

Hydrogeologic Element	Characteristic	Bayo Canyon	Acid and Pueblo Canyons	DP and Los Alamos Canyons
			groundwater.	
Regional Aquifer	Depth/ Hydrology		Depth to the regional aquifer is known in several locations in Pueblo Canyon, including TW-4 in upper Pueblo Canyon, at well TW-2 in the middle reach, and at wells TW-1 and O-1 near the confluence with Los Alamos Canyon. Water level measurements show depths to water to be 1173 ft in 2003 at TW-4, 807 ft in 2001 at TW-2, and 686 ft in 2001 at O-1. Based on Laboratory water-level maps, the general direction of groundwater flow in the regional aquifer is east in the vicinity of Pueblo Canyon. East of the Rendija Canyon Fault, the top of the regional aquifer is within the Totavi Lentil of the Puye Formation.	Depth to the regional aquifer is known in several locations in Los Alamos Canyon; at TW-3 and O-4, at O-1 near the confluence with Pueblo Canyon, and at LA-5 and LA-1B in the lower reach. Water level measurements show depths to water to be 784 ft in 2001 at TW-3, 68 ft in 2001 at O-1, 762 ft in O-4 in 1995, and -18 ft (artesian) in 1996 at LA-1B. Based on Laboratory water-level maps, the general direction of groundwater flow in the regional aquifer is east in the vicinity of Los Alamos Canyon.
	Quality		Contaminants have been detected in the regional aquifer, particularly nitrate in TW-1, indicating that the pathways for contaminant migration may be active at least along the lower portion of the canyon. Tritium has been found in TW-1 at up to 360 pCi/L though recent levels are lower at 140 pCi/L. Perchlorate is found within the regional aquifer in Pueblo Canyon, notably in water supply well O-1 at 2.8 ppb using the LC/MS/MS analytical method. Well O-1	Tritium has been detected in the regional aquifer at up to 80 pCi/L in TW-3 (though recent samples are nondetects) and 24 pCi/L in R-9. In TW-3 nitrate (as nitrogen) values were below 0.3 mg/L prior to 1967, but have averaged above 0.6 mg/L since 1981 with values up to 0.97 mg/L in 1994. Activities of tritium were 181 pCi/L in the regional aquifer at well R-6 during development. Concentrations of nitrate (as nitrogen) were 0.49 mg/L at the well. Concentrations of perchlorate were less than detection (0.0005 ppm) using the ion chromatography method. Because tritium was detected and nitrate concentration is within background, a component of young water containing

Table 3-A-2.
Los Alamos Canyon Watershed Description

Hydrogeologic Element	Characteristic	Bayo Canyon	Acid and Pueblo Canyons	DP and Los Alamos Canyons
			also contains a consistent 35-45 pCi/L of tritium and higher nitrate (as nitrogen) than any other regional aquifer well, excluding TW-1. Nitrate (as nitrogen) has been about 1.7 mg/L at well O-1 compared with approximately 0.5 mg/L in other water supply wells. Characterization well R-4, west of the Bayo Canyon and Pueblo Canyon confluence, contained 19.49 pCi/L of tritium and 1.39 ppm of nitrate (as nitrogen). These results indicate that the regional aquifer has experienced recent recharge that is most likely the result of past discharges to Acid Canyon to the west of well R-4.	tritium may have originated from a different source other than TA-21. This assumes that tritium, nitrate, and perchlorate were released to the environment at the same time.
Contaminants	Potential Sources		Contaminant sources affecting Pueblo Canyon include two inactive TAs (TA-1 and TA-45). TA-1 included the portion of the present-day Los Alamos townsite where the majority of the theoretical and technical work was accomplished at the Laboratory from 1943–1954. Acid Canyon was the original disposal site for liquid wastes generated by research on nuclear materials for the World War II Manhattan Engineer District atomic bomb project. From 1943 to 1951, Acid Canyon received untreated radioactive industrial effluent from the TA-1	Several contaminant sources affected upper Los Alamos Canyon. TA-2, located in upper Los Alamos Canyon, was the location of a series of nuclear reactors. The cooling line for the Omega West Reactor leaked water with tritium activity of at least 100,000 pCi/L into the alluvium, probably from 1956 until 1993. TA-21, which is on DP Mesa, north of Los Alamos Canyon, was the site of plutonium processing facilities. The site discharged treated liquid radioactive effluent into DP Canyon from 1952 to 1986 and includes Material Disposal Areas A, B, T, U, and V. TA-41, located in upper Los Alamos Canyon, was used for testing of nuclear weapons components. TA-53, the site of the Los Alamos Neutron Science Center (LANSCE) linear accelerator facility, lies on the mesa south of the canyon.

Table 3-A-2.
Los Alamos Canyon Watershed Description

Hydrogeologic Element	Characteristic	Bayo Canyon	Acid and Pueblo Canyons	DP and Los Alamos Canyons
			research activities. The TA-45 treatment plant was completed in 1951 and discharged treated effluents containing residual radionuclides into Acid Canyon from 1951 to 1964. TA-73 is the site of the DOE airport and former landfill, above Pueblo Canyon. Pueblo Canyon also receives sanitary effluent from Los Alamos County Sewage Treatment Plant in Bayo Canyon. The county operated two other sewage treatment plants along Pueblo Canyon in the past. More detailed information about these sites can be found in the Task/Site Work Plan for Operable Unit 1049, Los Alamos Canyon and Pueblo Canyon, and the RFI Work Plans for Operable Units 1078, 1079, 1100, and 1106.	Water from National Pollutant Discharge Elimination System (NPDES) permitted outfalls, sanitary treatment, and reactor beam cooling water ponds flowed to Los Alamos Canyon. TA-1 included the portion of the present-day Los Alamos townsite where the majority of the theoretical and technical work was accomplished at the Laboratory from 1943 to 1954. Several facilities discharged untreated chemical waste streams into the canyon.
	Type		Septic tank outfall located on the south rim of Acid Canyon in the 1940s containing plutonium-239, -240 and PCBs. Former Pueblo Canyon WWTP operated from 1951 until 1991. Sludge from the Pueblo Canyon Sewage Treatment Plant contained metals at levels above background. Former Central Sewage Treatment Plant operated from 1947 until 1961. Metals and organic chemicals, including mercury and DDT, were contaminants	TA-1 Hillsides 137, 138, and 140 received discharges from septic tank outfalls from 1943 until the late 1950s. Radionuclides are the primary contaminants at these hillside sites, although some metals contamination is also present). TA-2 housed a series of research nuclear reactors, including the Omega West Reactor, which was a source of tritium releases into alluvial groundwater. Other SWMUs at TA-2 include leach fields for water boiler reactors. Cesium-137 and strontium-90 are primary contaminants associated with the leach fields, and strontium-90 has historically been detected in alluvial groundwater monitoring wells

Table 3-A-2.
Los Alamos Canyon Watershed Description

Hydrogeologic Element	Characteristic	Bayo Canyon	Acid and Pueblo Canyons	DP and Los Alamos Canyons
			identified at the outfalls. Outfalls from former TA-1 and former TA-45. TA-45 was the site of the first radioactive liquid waste treatment facility. TA-1 outfalls into Acid Canyon were not treated. These outfalls were the most significant sources of radionuclide and other contamination in Acid and Pueblo Canyons. Plutonium-239,-240 is the primary contaminant, although other radionuclides, metals, and some organic chemicals are also present.	down canyon of the site. TA-41 was used for weapons development and long-term studies of weapon subsystems. The primary contaminant sources are a septic system and a sewage treatment plant. Initial data from these SWMUs indicate radionuclides at levels above background, but characterization of TA-41 is incomplete. TA-21 was the site of a plutonium processing plant and polonium and tritium research laboratories. Outfalls were the primary source of radionuclide contaminants in DP and upper Los Alamos Canyons. Radionuclides, particularly cesium-137, and strontium-90, are the primary contaminants discharged from this outfall. TA-53 includes a proton accelerator and associated experimental and support buildings used for research with subatomic particles; it is the current site of the Los Alamos Neutron Science Center (LANSCE). The accelerator became fully operational in 1974. Occasional releases occurred from three surface impoundments at the east end of TA-53, referred to as consolidated SWMU 53-002(a)-99, which have contributed contamination to an unnamed tributary drainage to Los Alamos Canyon. The impoundments received sanitary, radioactive, and industrial wastewater from various TA-53 buildings as well as septic tank sludge from other Laboratory buildings. The northern impoundments were active from the early 1970s until 1993. The southern impoundment was active from 1985 until 1998. Inorganic chemicals, organic chemicals, and radionuclide COPCs have been identified at the

Table 3-A-2.
Los Alamos Canyon Watershed Description

Hydrogeologic Element	Characteristic	Bayo Canyon	Acid and Pueblo Canyons	DP and Los Alamos Canyons
				impoundments and in the drainage. SWMU 21-018(a), Material Disposal Area (MDA) V, received liquid waste effluent from laundry operations and includes three absorption beds on the south side of DP Mesa that sometimes overflowed into Los Alamos Canyon. Sediment sampling in 1946 documented that plutonium from this source was entering the main channel in Los Alamos. Additional outfalls that discharged off the south rim of DP Mesa include SWMUs 21-023(c), 21-024(b), 21-024(c), 21-024(i), and 21-027(a). SWMU 21-029, the DP Tank Farm, was a fuel distribution station with aboveground and underground fuel tanks from 1946 to 1985. Diesel range organic (DRO) and gasoline range organic (GRO) hydrocarbon contamination was identified at two areas of bedrock seeps in the DP Canyon channel and observed to periodically form a sheen in surface water adjacent to the site. The MDAs at TA-21 are not considered to be important from the perspective of releases to the canyons.

References:

Broxton et al. 1995; Broxton et al. 2001a; Davis et al. 1996; Gallaher 2000; Glasco 2000; Griggs 1964; Kingsley 1947; Kleinfelder 2004a; Koch et al. 2004; Koch and Rogers 2003; LANL 1981; LANL 1991; LANL 1992a; LANL 1992c; LANL 1994b; LANL 1995; LANL 1996; LANL 1998b; LANL 2001a; LANL 2004a; LANL, 2004b; LASL 1963; Longmire 2002a; Longmire and Goff 2002; Mayfield et al. 1979; Newman 2003; Purtymun and Rogers 2002; Rogers 1998.

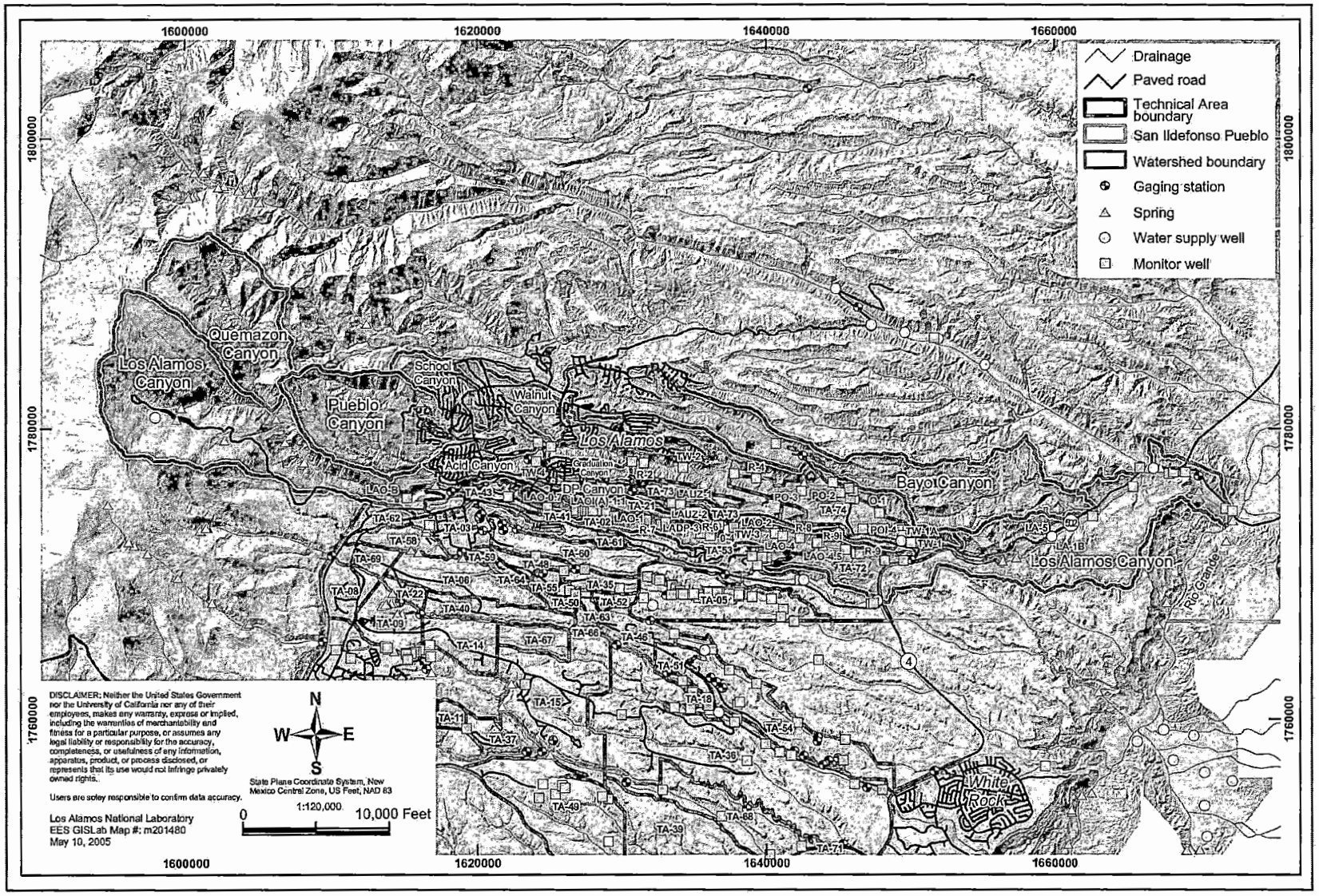

Figure 3-A-3. Los Alamos Canyon watershed, including Los Alamos Canyon, Bayo Canyon, Acid Canyon, Pueblo Canyon, and DP Canyon.

Table 3-A-3.
Sandia Canyon Watershed Description

Hydrogeologic Element	Characteristic	Description
Surface Water	Flow	Sandia Canyon is located on the plateau within the central part of the Laboratory (Figure 3-A-1, Figure 3-A-4). The canyon heads on Laboratory property within TA-3 at an elevation of approximately 7300 ft and trends east-southeast across the Laboratory, Bandelier National Monument, and San Ildefonso Pueblo land, and reaches the Rio Grande in White Rock Canyon at an elevation of 5450 ft. Sandia Canyon has a relatively small total drainage area of about 5.5 mi^2. Surface water occurs in Sandia Canyon as ephemeral runoff from precipitation and as NPDES-permitted effluent discharge from the Laboratory sanitary wastewater sewage treatment plant and the TA-3 power plant. On a volume basis, baseflow in Sandia Canyon represents one of the largest potential non-natural groundwater recharge sources at the Laboratory. The NPDES outfalls support perennial and intermittent flow within the upper 2.5 miles of the canyon, and a wetland has developed because of the artificial flows. The lower 9.5 miles of channel is ephemeral.
	Quality	Surface water quality reflects sewage effluent with nitrate, chloride, and metals slightly above background by approximately 2 to 5 times. Stream sediments contain PCBs and they are detected in surface water at low levels.
Springs	Name	Sandia Spring discharges about 1 gpm approximately 0.5 mile from the Rio Grande.
	Quality	Contaminant levels are at detection or background levels.
Alluvial Groundwater	Extent	Little is known about the occurrence of alluvial groundwater in Sandia Canyon. Most likely, infiltration of surface water creates a saturated zone of seasonally variable extent within the alluvium in the upper reach of the canyon. However, the extent and thickness of alluvial groundwater has not been characterized. Two wells were installed in 1990 to look for alluvial groundwater near the eastern Laboratory boundary as part of the HSWA permit special conditions. Both wells, SCO-1 and SCO-2, were dry at the time of installation. Periodic attempts to sample these wells as part of the Laboratory's annual environmental surveillance activities have found no water in the wells.
	Depth/Thickness	See above.
	Quality	NA

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Table 3-A-3.
Sandia Canyon Watershed Description (continued)

Hydrogeologic Element	Characteristic	Description
Intermediate Groundwater	Extent/Hydrology	An intermediate perched zone was found within basalts near SR-4.
	Depth/Thickness	The perched zone is at about 440 ft in well R-12.
	Quality	The perched zone has tritium above background (60 to 160 pCi/L). In the borehole for R-11, nitrate (as nitrogen) was above background, at about 4.9 mg/L of nitrate (as nitrogen) at a depth of 443 ft bgs.
Regional Aquifer	Depth/Hydrology	The regional aquifer lies at about 800 ft depth below Sandia Canyon near SR-4.
	Quality	Tritium in well R-12 is about 45 pCi/L, and is above background. Concentrations of nitrate (as nitrogen) were 0.5 ppm at the regional water table during drilling. Characterization well R-11 west of supply PM-3 contained 12.8 pCi/L of tritium and 4.91 ppm of nitrate (as nitrogen), indicating that this well has experienced recent recharge. The $\delta^{15}N_{air}$ of nitrate values were +0.5 and +0.7% for the sample, which suggests that nitrate has not undergone fractionation, and the two values are very consistent with that of nitrate derived from neutralized nitric acid. The most likely source of this unique nitrate at well R-11 is Mortandad Canyon, which has a long history of discharges containing nitrate derived from neutralized nitric acid.
Contaminants	Potential Sources	Potential Release Sites (PRS) within the watershed are located at TAs-3, -53, -60, -61, -72, and former TA-20. The Laboratory started use of Sandia Canyon lands during the 1940s. The Laboratory's primary use of Sandia Canyon has been for liquid waste disposal from industrial and sanitary systems, particularly the treated effluents from the TA-46 Sewage Treatment Plant and cooling tower blowdown from the TA-3 power plant. Other sources include discharges from the TA-53 accelerator, the protective force small arms live firing range at TA-72, and a small high explosives firing site near TA-3 (former TA-20).
	Type	Nitrate, perchlorate, chromium, copper, PCBs in sediments, HE compounds, tritium, isotopes of uranium and plutonium, lead in surface soils.

References:
Broxton et al. 2001b; Kleinfelder 2004c; LANL 1996; Longmire 2002c; Purtymun and Stoker 1990.

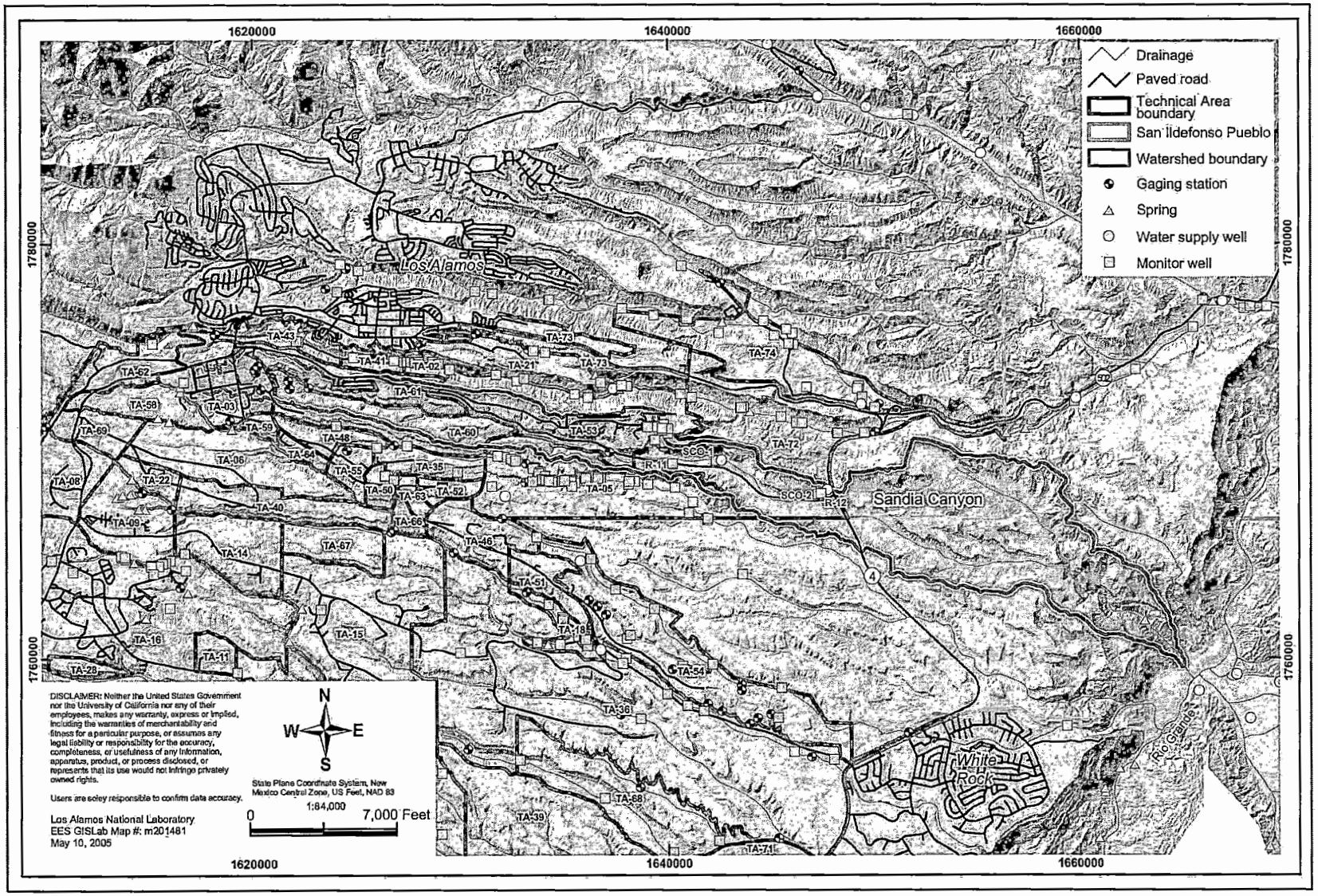

Figure 3-A-4. Sandia Canyon watershed.

Table 3-A-4.
Mortandad Canyon Watershed Description

Hydrogeologic Element	Characteristic	Mortandad Canyon	Cañada del Buey
Surface Water	Flow	Mortandad Canyon is an east to southeast trending canyon that heads on the Pajarito Plateau near the main Laboratory complex at TA-3 at an elevation of 7380 ft above sea level (Figure 3-A-1, Figure 3-A-5). The drainage extends about 9.6 mi from the headwaters to its confluence with the Rio Grande at an elevation of 5440 ft asl covering an area of 5 square miles. The canyon crosses San Ildefonso Pueblo land for several miles before joining the Rio Grande. Tributary canyons to the Mortandad Canyon drainage include Effluent Canyon, Ten Site Canyon, Cedro Canyon, and Cañada del Buey. Surface water in Mortandad Canyon is ephemeral; however, there are two segments that are effluent-dependent. The ephemeral segments flow only in response to precipitation. Historical Environmental Surveillance Program (ESP) data indicate that persistent surface flow occurs in the effluent-dependent segments at the surface water stations down canyon from the Radioactive Liquid Waste Treatment Facility (RLWTF) outfall (measured at gage E200, Mortandad below Effluent Canyon) and the Los Alamos County sewage treatment plant outfall in White Rock.	Cañada del Buey has a drainage area of 4.2 square miles and within the Laboratory boundary, it is ephemeral in character, based on flow data from three gages: E218 (Cañada del Buey near TA-46), E230 (Cañada del Buey above SR-4), and E225 (Cañada del Buey near MDA G). In the period from 1995 to 2002, the number of days of flow per year ranged from 38 at the gage near TA-46 to zero near MDA G. East of LANL in White Rock, Cañada del Buey has effluent-supported flow from the Los Alamos County sewage treatment plant, which discharges into Cañada del Buey about 2 mi upstream of its confluence with Mortandad Canyon and results in effluent-supported surface flow that regularly extends to the Rio Grande.
	Quality	Historically, the following constituents have been detected in Mortandad Canyon surface water at significant levels relative to standards: americium-241, plutonium-238 and plutonium-239, -240, strontium-90, tritium, nitrate, perchlorate, and fluoride.	Operational NPDES-permitted outfalls associated with Cañada del Buey include: 13S associated with the TA-46 SWSC Plant (effluent is sampled at 13S but not discharged; all SWSC effluent is routed to TA-3); and 04A-118 associated with water supply well Pajarito Mesa #4.

Table 3-A-4.
Mortandad Canyon Watershed Description (continued)

Hydrogeologic Element	Characteristic	Mortandad Canyon	Cañada del Buey
Springs	Name	No springs are present in Mortandad Canyon. However, some wetland areas occur in Pratt Canyon and occur locally downstream.	No springs are present in Cañada del Buey.
	Quality	See above.	See above.
Alluvial Groundwater	Extent	The extent, quality, and flow of alluvial groundwater in Mortandad Canyon is known from years of investigations. Major recharge to the alluvium occurs from effluent released in the upper canyon. The alluvial groundwater extends about 2 mi downstream from the TA-50 outfall.	Cañada del Buey contains a shallow perched alluvial groundwater system of limited extent, and only two observation wells here have ever contained water. Purtymun (1995) suggested that the primary source of the alluvial water is purge water from supply well PM-4, although storm water and snowmelt runoff augment the alluvial groundwater. However, the presence of water in the alluvium does not correspond to releases from the water supply wells.
	Depth/Thickness	The saturated portion of the Mortandad Canyon alluvium is generally less than 10 feet thick and there is considerable variation in saturated thickness depending on the amount of precipitation and runoff in any particular year. Groundwater flow velocity in the alluvium varies from about 60 ft/day in the upper canyon to about 7 ft/day in the lower canyon and has been estimated to be 30 to 40 ft/day between MCO-5 and MCO-8.2.	See above.
	Quality	Historically, the following constituents have been detected in alluvial groundwater in Mortandad Canyon at significant levels relative to standards: americium-241; plutonium-238 and plutonium-239, -240; strontium-90; tritium; nitrate; perchlorate; and fluoride. Nitrate (as N) concentrations in alluvial groundwater have generally reflected the concentration in RLWTF effluent. The nitrate concentration in the effluent decreased in 1999 due to improved treatment in the RLWTF,	Some alluvial groundwater samples have contained high levels of gross alpha and gross beta, but have no regular detection of any measured radioisotopes.

Table 3-A-4.
Mortandad Canyon Watershed Description (continued)

Hydrogeologic Element	Characteristic	Mortandad Canyon	Cañada del Buey
		and alluvial groundwater concentrations have fallen below the NM groundwater standard of 10 mg/L as a result. Perchlorate measurements are available since about 2000. The RLWTF started operating a system for removing perchlorate from the plant effluent on March 26, 2002. Prior to removal, perchlorate was measured in RLWTF effluent at an annual average concentration of 169 ppb in 2001; it has not been detected above 4 ppb since. Alluvial groundwater concentrations have fallen rapidly due to effluent improvement. During the last 10 years, tritium has been found above the 20,000 pCi/L EPA MCL at the Laboratory only in alluvial groundwater in Mortandad Canyon. At the end of 2000, the RLWTF adopted a voluntary goal of having tritium activity in its effluent below 20,000 pCi/L, and tritium activity in the effluent dropped below that in 2001 and was 10,400 pCi/L in 2003. Tritium activity in alluvial groundwater downstream has dropped correspondingly with a maximum value of 8,770 pCi/L in 2003. The discharge from the RLWTF into Mortandad Canyon creates a localized area of alluvial groundwater where strontium-90 persists at activities above the 8-pCi/L EPA drinking-water MCL. The radionuclides plutonium-238; plutonium-239, -240; and americium-241 are also present above the 4-mrem DOE DCG for drinking water.	
Intermediate Groundwater	Extent/Hydrology	Perched groundwater was encountered during drilling of R-15 and MCOBT-4.4 in different stratigraphic zones within the	No intermediate perched groundwater has been found in wells drilled near Cañada del Buey. These wells include

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Table 3-A-4.
Mortandad Canyon Watershed Description (continued)

Hydrogeologic Element	Characteristic	Mortandad Canyon	Cañada del Buey
		Cerros del Rio basalt. The lateral extent of these intermediate depth perched zones is unknown.	PM-4, R-21, and R-22, as well as numerous wells drilled to investigate conditions beneath MDA L and MDA G.
	Depth/Thickness	Intermediate perched groundwater was found at MCOBT-4.4, where a single screen was set in a perched zone within the upper Puye Formation/Cerros del Rio basalt at a depth of 524 ft below ground surface (bgs). In R-15, perched groundwater was encountered at a depth of 646 ft bgs in the lower portion of the Cerros del Rio basalt.	See above.
	Quality	Measurements from core samples in several wells indicate that there is a large inventory of perchlorate and nitrate in the unsaturated Bandelier Tuff, extending to distances of 400 feet below the floor of Mortandad Canyon. Preliminary estimates suggest there is 415 to 1250 kg of perchlorate in the upper 300 ft of the vadose zone. Analytical results from groundwater samples collected from MCOBT-4.4 showed 12,797 pCi/L tritium, 13.2 mg/L nitrate plus nitrite (as N), and 142 ppb perchlorate. Perched groundwater encountered during the drilling of R-15 contained 3770 pCi/L tritium and 12 ppb perchlorate. Five additional intermediate-depth wells have been drilled and groundwater samples collected from the boreholes near the sediment traps. They contained nitrate, perchlorate, and tritium at concentrations similar to, but less than, those measured at well MCOBT-4.4.	See above.
Regional Aquifer	Depth/Hydrology	The regional water table occurs within the Puye Formation in the four wells that encounter the regional aquifer in the Mortandad Canyon watershed. In Ten Site Canyon, approximately 3700 ft west of the confluence with Mortandad Canyon, the regional aquifer was encountered at a depth of	Regional aquifer conditions for Cañada del Buey are covered in the column for Mortandad Canyon and the table for Pajarito Canyon.

Table 3-A-4.
Mortandad Canyon Watershed Description (continued)

Hydrogeologic Element	Characteristic	Mortandad Canyon	Cañada del Buey
		1182 ft in well R-14. In Test Well 8 the regional aquifer occurs at a depth of 994 ft. The regional aquifer was encountered at a depth of 964 ft in R-15, located in Mortandad Canyon approximately 2000 ft east of the confluence with Ten Site Canyon. In well R-13, located approximately 5800 feet ESE of R-15, the regional aquifer was encountered at a depth of 833 ft. Well R-28 lies between R-15 and R-13 and the regional water table occurs at 889 ft. Flow in the regional aquifer is generally west to east; some deviation may be present due to pumping in the Pajarito Mesa well field. Average flow velocity for the regional aquifer in the vicinity of Mortandad Canyon is estimated to be about 95 ft/yr.	
	Quality	Wells R-13 and R-14 have not shown contamination in the regional aquifer from samples collected during drilling and/or subsequent characterization. Regional aquifer well R-15 contained 2.4 mg/L nitrate (as N), 18 pCi/L tritium, and up to 4.2 ppb perchlorate in groundwater sampled at a depth of 1019 ft bgs. Well R-28 contains 7.2 mg/L of nitrate (as N) in a borehole sample, and 114 pCi/L of tritium.	Well R-21 contained 0.42 pCi/L of tritium and 0.299 µg/L of perchlorate (using liquid chromatography/mass spectrometry. Well R-21 is not impacted from Laboratory discharges.
Contaminants	Potential Sources	The source of contaminants to Mortandad Canyon has been from two liquid waste treatment plants. One is the NPDES-permitted outfall from the TA-50 Radioactive Liquid Waste Treatment Facility. It has been used to treat liquid radioactive waste from Laboratory operations from 1963 to the present. A second radioactive wastewater treatment plant at TA-35 treated wastes from reactor experiments from 1951 to 1963. It did not operate well, and large volumes of wastewater were released into Ten Site Canyon. Other mesa-top sites that could impact Mortandad Canyon	Cañada del Buey is bordered on the south by Material Disposal Areas G and L at TA-54.

Table 3-A-4.
Mortandad Canyon Watershed Description (continued)

Hydrogeologic Element	Characteristic	Mortandad Canyon	Cañada del Buey
		include MDA C near TA-50 and three waste oil surface impoundments at TA-35 closed in 1989. More information about the history of these sites and planned investigations can be found in the RFI Work Plans for OU 1129 and OU 1147.	
	Type	The effluents discharged from TA-3, TA-35, TA-48, and TA-50 have contained a variety of contaminants, including nitrate, perchlorate, tritium, cesium-137, strontium-90, americium-241, and several isotopes of uranium and plutonium.	Past discharges included accidental releases from experimental reactors and laboratories at TA-46. The Los Alamos County sewage treatment plant contributes flow to the lower portion of Cañada del Buey.

References:

Baltz et al. 1963; Broxton et al. 2002; Kleinfelder 2004d; LANL 1992b; LANL 1992h; LANL 1997; LANL 2000a; LANL 2001a; LANL 2002; LANL, 2003a; Longmire et al. 2001a; Newman 2003; Purtymun et al. 1983; Purtymun 1995.

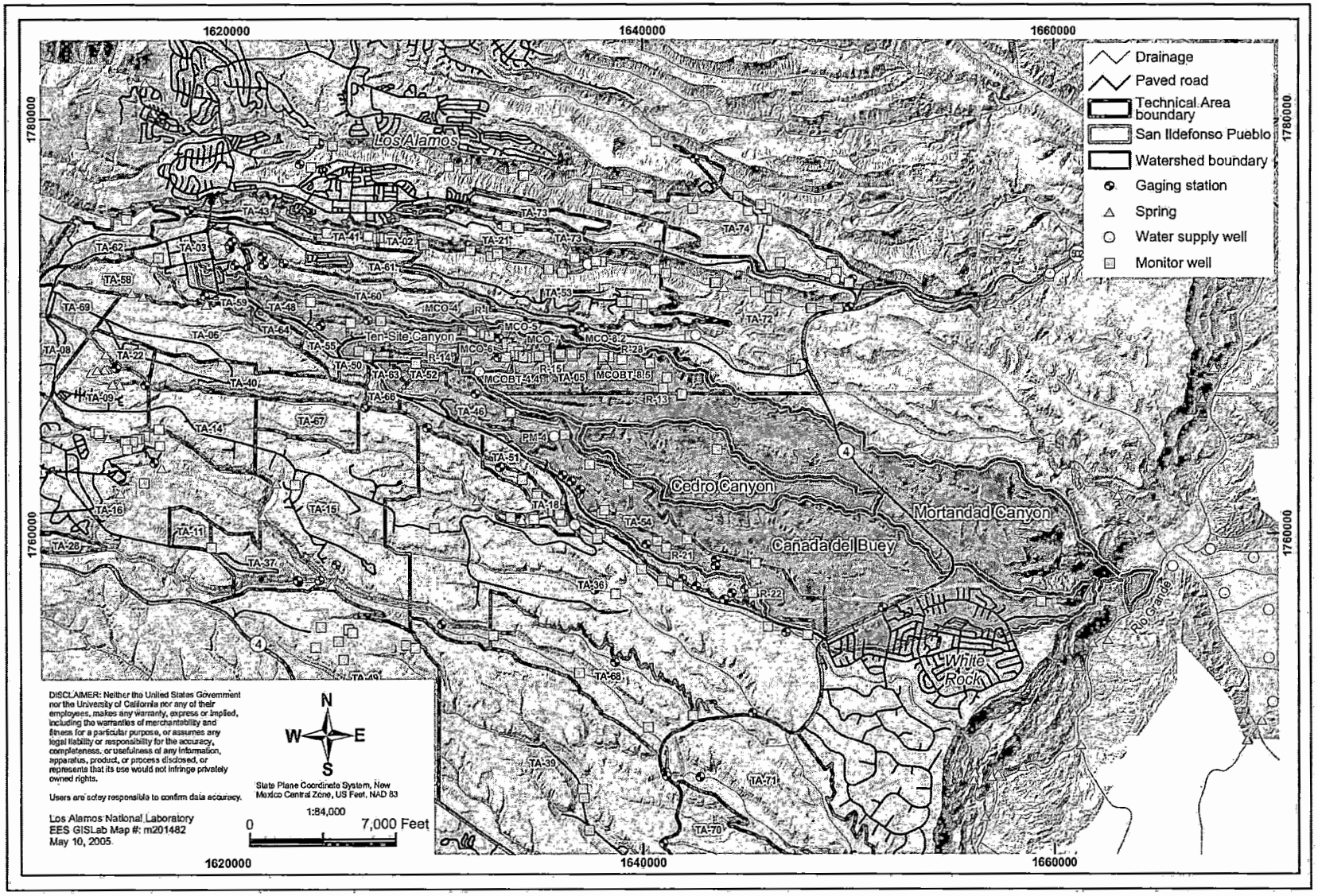

Figure 3-A-5. Mortandad Canyon Watershed including Mortandad Canyon and Cañada del Buey.

Table 3-A-5.
Pajarito Canyon Watershed Description

Hydrogeologic Element	Characteristic	Description
Surface Water	Flow	Pajarito Canyon is located on the Pajarito Plateau in the central part of the Laboratory (Figure 3-A-1; Figure 3-A-6). The canyon heads in the Santa Fe National Forest west of the Laboratory boundary at an elevation of approximately 10,434 ft and trends east-southeast across the Laboratory and Los Alamos County. It empties into the Rio Grande in White Rock Canyon at an elevation of 5422 ft. The drainage area of the Pajarito Canyon watershed is about 12 square miles. Surface water occurs in Pajarito Canyon mostly as intermittent flow. Short reaches of perennial flow occur downstream of spring discharges in Starmers Gulch and below Spring 4A in White Rock Canyon. Surface water flow is ephemeral in central Pajarito Canyon between the confluences with Twomile and Threemile Canyons. Flow is also ephemeral through White Rock. In Twomile Canyon, flow is ephemeral west of TA-3 and is possibly intermittent from TA-3 to the confluence with Pajarito Canyon. Three-mile Canyon is ephemeral except for a possible intermittent reach supported by springs above the confluence of Three-mile and Pajarito Canyons.
	Quality	High explosive compounds and metals have been detected in surface water in upper and middle Pajarito Canyon. There are no surface water chemistry results for Twomile Canyon except for a small tributary near building SM-30 in TA-3. Samples from the tributary show elevated arsenic and mercury in nonfiltered samples. RDX, SVOCs, and pesticides have been detected in a surface water sample in Threemile Canyon.
Springs	Name	Short reaches of perennial flow occur down stream of spring discharges in Starmers Gulch and below Spring 4A in White Rock Canyon. In the western portion of Pajarito Canyon, springs discharge from canyon slopes above the alluvium. The probable source of these springs is groundwater perched within the upper part of the Tshirege Member of the Bandelier Tuff. Typical discharge rates are approximately 1 to 15 gallons per minute. Springs include PC, Homestead, Upper Starmer, Charlies, Garvey, Perkins, Starmer, Josie, Keiling, and Bulldog Springs. Springs issue from the canyon floor of upper Twomile Canyon in TA-3 and TA-58. These springs include Hanlon, Anderson, SM-30, SM-30A, and TW-1.72 Springs. There are two springs in the floor of Threemile Canyon (Threemile and TA-18 Springs).

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Table 3-A-5.
Pajarito Canyon Watershed Description (continued)

Hydrogeologic Element	Characteristic	Description
	Quality	HE compounds have been detected in spring water at TA-8 and TA-9. There are no screening data for springs in Twomile Canyon. HE compounds have been detected in Threemile Canyon.
Alluvial Groundwater	Extent	There are no alluvial wells in Pajarito Canyon upstream of TA-18. Therefore, information about the nature and extent of alluvial groundwater is limited. Most likely, infiltration of surface water creates a continuous saturated zone within the alluvium that extends from the Pajarito fault zone across the Laboratory to White Rock. Alluvial wells have been installed between TA-18 and state road NM4, which demonstrate the presence of alluvial groundwater in this part of Pajarito Canyon. The drilling of seven test holes in 1985 showed that the saturation in lower Pajarito Canyon does not extend laterally under Mesita del Buey near MDAs G and L. Three of the alluvial test holes were completed as groundwater monitoring wells (PCO-1, -2, -3). An additional 20 alluvial wells were installed between 1990 and 1998 by the Environmental Restoration Project as part of the RFI for TA-18. There are no alluvial wells in Twomile Canyon and the extent of alluvial groundwater, if present, is unknown. There are no alluvial wells in Twomile Canyon and the extent of alluvial groundwater, if present, is unknown. Alluvial groundwater has been documented in lower Threemile Canyon at 18-BG-1 and 18-MW-8.
	Depth/Thickness	Wells PCO-1, -2, and -3 are probably representative of alluvial groundwater between TA-18 and state road NM-4. When installed during 1985, depth to water was 1.3 ft in PCO-1, 6.3 ft in PCO-2, and 3.1 ft in PCO-3. Assuming continuous saturation in the alluvium, the saturated thickness is about 9.7 ft in PCO-1, 2.7 ft in PCO-2, and 8.9 ft in PCO-3. The saturated thickness and presence of water in these wells vary seasonally. Due to drought, these wells have had little water since 2000. At well 18-BG-4 in Threemile Canyon, the water level was 2.5 ft bgs.
	Quality	Data indicate the presence of metals, radionuclides, high explosives, VOCs, and anions in alluvial groundwater. Except for VOCs and some radionuclides in wells near TA-18, occurrence of these constituents is irregular and at low levels. There are no water quality data for alluvial groundwater in Twomile Canyon. Alluvial groundwater has been documented in lower Threemile Canyon at 18-BG-1 and 18-MW-8. In lower Threemile Canyon RDX and VOCs have been detected in 18-MW-8.
Intermediate Groundwater	Extent/Hydrology	Intermediate perched water is likely to occur beneath Pajarito Canyon, but knowledge of its extent and quality is incomplete. No water quality data for perched intermediate systems are available with current wells. Perched water was suggested during the drilling of PM-2 and SHB-4 in the vicinity of TA-18. At PM-2, a "show of water at 335 ft" was noted in the Otowi Member of the Bandelier Tuff during the cable-tool drilling. In SHB-4, the core tube and core from the top of the

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Table 3-A-5.
Pajarito Canyon Watershed Description (continued)

Hydrogeologic Element	Characteristic	Description
		Otowi Member from about 125 ft to 145 ft came out of the hole wet. Test Holes 5 and 6 were drilled in 1950 to investigate perched groundwater in Pajarito Canyon south of TA-54. Test Hole 5 was drilled through the Bandelier Tuff and into basalts at a total depth of 263 ft. Test Hole 6 was also drilled through the tuff and into basalts to a total depth of 300 ft. These dry test holes indicate that perched water does not occur in the upper part of the vadose zone in this part of the canyon. Between 2000 and 2002 regional wells R-20, R-22, R-23, and R-32 were installed in lower Pajarito Canyon. Perched intermediate water was not identified during the drilling of wells R-20, R-22, and R-32. At R-23, near the eastern Laboratory boundary, there were indications that perched intermediate water may be present in Cerros del Rio basalt. However, R-23 is only screened in the regional aquifer. In Twomile Canyon, well 03-MW-1 is a 28-ft-deep mesa top well that samples shallow intermediate perched water near building SM-30 at TA-3. A thin zone of saturation occurs in the upper Tshirege Member. Characterization well R-19, located on the mesa south of Threemile Canyon, had indications of possible perched water at depths of 834 to 840 ft and 894 to 912 ft. Both zones were screened in the completed well, but only the 894 to 912 ft interval (screen 2) in the Puye Formation yields water.
	Depth/Thickness	See above.
	Quality	Characterization sampling for 03-MW-1 found elevated concentrations of Hg, tritium, and VOCs. A RFI Work Plan is being prepared to determine the extent of this perched zone. Four rounds of characterization sampling for R-19 indicate there are no impacts to the intermediate perched water from Laboratory operations. Less than detection activities of tritium indicate that groundwater in the perched zone pre-dates atmospheric nuclear testing.
Regional Aquifer	Depth/Hydrology	Water-level maps indicate that in the vicinity of Pajarito Canyon the general direction of groundwater flow in the regional aquifer is east to southeast. Depth to the regional aquifer is known in Pajarito Canyon at supply well PM-2 and in characterization wells R-20, R-22, R-23, and R-32. The nonpumping water level for PM-2 in 2001 was at a depth of 855 ft. In 2002, the regional water table was at a depth of 826 ft in R-20, 890 ft in R-22, 828 ft in R-23, and 776 ft in R-32. R-23 is completed with a single well screen, R-20 and R-32 have three well screens, and R-22 has five well screens. The regional aquifer probably discharges at Spring 4A and other springs along White Rock Canyon. There are no regional aquifer wells associated with Twomile Canyon. Well R-19 is located on the mesa south of Threemile

Table 3-A-5.
Pajarito Canyon Watershed Description (continued)

Hydrogeologic Element	Characteristic	Description
		Canyon. It is down gradient from firing site IJ in TA-36 and is up gradient of TA-18. In addition to two screens in the vadose zone (described above), R-19 has five screens in the regional aquifer.
	Quality	Water quality of the regional aquifer beneath eastern Pajarito Canyon shows little, if any, impacts from LANL operations. Four rounds of characterization sampling at R-22 yielded possible detects of Tc-99 in the first sampling round for screens 3 and 4, but it was not detected in any of the screens during subsequent sampling rounds. Tritium was detected above background (~1 pCi/L) in screen 2 (76.6 pCi/L) during the first sampling round, but was at background for subsequent sampling rounds. Tritium activities in screen 5 were slightly elevated relative to background in the four characterization sampling rounds (3.5 to 18.5 pCi/L). Surveillance sampling of PM-2 shows the groundwater meets regulatory standards. Wells R-20 and R-32 contained low levels of tritium less than 3 pCi/L (1.98 pCi/L of tritium for well R-20 and 2.84 pCi/L for well R-32). Followup sampling at well R-32 did not confirm the presence of low-level tritium. Low-level perchlorate was not detected at well R-20 and was detected at wells R-23 (0.21 to 0.41 µg/L) and well R-32 (0.21 to 0.29 µg/L). Results for both low-level tritium and low-level perchlorate for these three wells suggest that the regional aquifer is not significantly impacted from Laboratory discharges. The dominant fraction of groundwater in the regional aquifer is greater than 61 years of age, based on the non-detectable tritium. Four rounds of characterization sampling at R-19 indicate there are no impacts to the regional groundwater from Laboratory operations. Less than detection activity of tritium at R-19 indicate that the regional groundwater pre-dates nuclear testing.
Contaminants	Potential Sources	The primary Laboratory use of Pajarito Canyon watershed has been as the canyon-bottom location for the Los Alamos Critical Experiments Facility (LACEF) at TA-18 and for mesa-top surface and subsurface material disposal areas (MDAs) F at TA-6, Q at TA-8, MDA M at TA-9, and MDAs G, H, J, and L at TA-54. Runoff from firing sites in TA-15 and TA-36 may also be a contaminant source. A detailed description and data summary for Pajarito Canyon potential contaminants is contained within the work plan for Pajarito Canyon.
	Type	Pajarito Canyon: metals, radionuclides, HE compounds, VOCs, anions; Twomile Canyon: mercury, tritium, VOCs; Threemile Canyon: HE compounds, VOCs.

References:

Broxton et al. 2001c; Cooper et al. 1965; Devaurs 1985; Devaurs and Purtymun 1985; Gardner et al. 1993; Griggs 1955; Griggs 1964; LANL 1998a; LANL 2000b; Longmire 2002d; Longmire 2002e; Purtymun 1995.

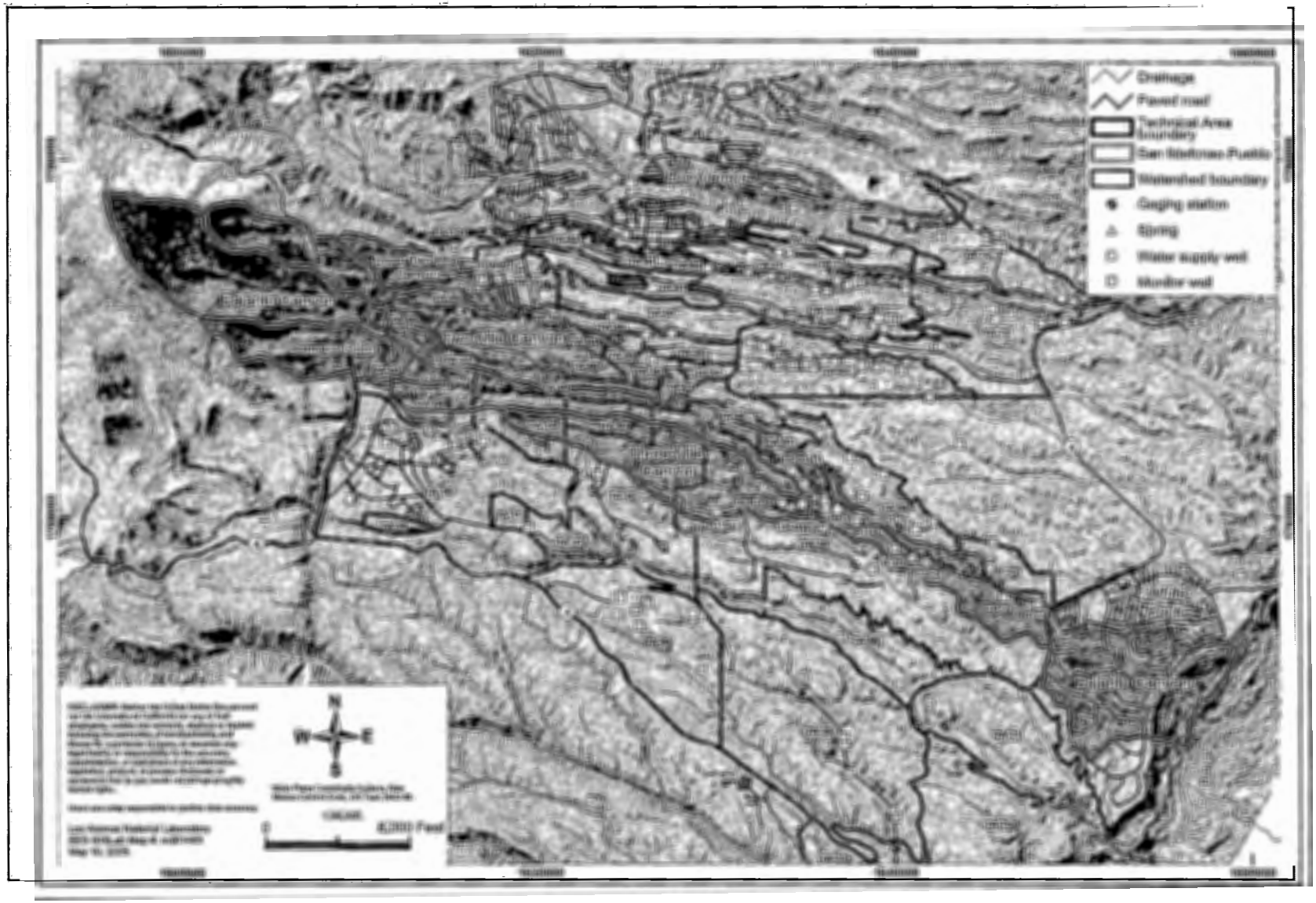

Figure 3-A-6. Pajarito Canyon watershed.

Table 3-A-6.
Water Canyon Watershed Description

Hydrogeologic Element	Characteristic	Water Canyon	Cañon de Valle	Potrillo and Fence Canyons
Surface Water	Flow	The Water Canyon drainage area is about 6 square miles. Surface water flow in upper Water Canyon is perennial from SR 501 to the eastern edge of TA-28 (Figure 3-A-1, Figure 3-A-7). Intermittent surface water occurs in upper Water Canyon (gage E252, Water above SR-501), primarily in the spring. In middle Water Canyon, flow is ephemeral at gage station E265.2 (Water below SR-4). Lower Water Canyon is ephemeral.	Cañon de Valle has a drainage area of 4 square miles and surface water is perennial from Burning Ground spring to gage E256 (Cañon de Valle below MDA P). Intermittent surface water occurs from natural and anthropogenic sources to gage E262 (Cañon de Valle above Water) Figure 3-A-1, Figure 3-A-7).	The drainage area of Potrillo Canyon and Fence Canyon together is about 4.5 square miles and the surface water flow is entirely ephemeral.

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Table 3-A-6.
Water Canyon Watershed Description (continued)

Hydrogeologic Element	Characteristic	Water Canyon	Cañon de Valle	Potrillo and Fence Canyons
	Quality	Except for flow from the Water Canyon Gallery, no surface water quality data are available for upper Water Canyon. In middle Water Canyon, surface water chemistry results show contaminant levels are at detection or background levels. In lower Water Canyon, uranium is significantly greater than background in surface water (>10 ppb) near the firing sites, yet no significant elevation in concentration is seen at State Road 4.	Surface water concentrations of barium are 2-3 mg/L and concentrations of RDX are more than 100 µg/L or ppb.	See above.
Springs	Name	Water Canyon Gallery is a spring that issues from the Bandelier Tuff west of LANL in Water Canyon. Spring 5A is in lower Water Canyon.	Several springs issue from the Bandelier Tuff in the upper reaches of Cañon de Valle: Armistead Spring, American Spring (west of LANL) and SWSC, Burning Ground, Martin, and Hollow Springs, and others (in LANL). Note that Martin Spring actually flows into Water Canyon. It is included here because of its close location to the Cañon de Valle springs, and similar contaminant constituents.	There are no springs in Potrillo Canyon or Fence Canyon.
	Quality	Water quality data indicate that concentrations of constituents are consistent with other springs within the Sierra de los Valles.	For the on site springs, chloride, sodium, manganese, nitrate, barium, boron, HE compounds, and solvents are at concentrations above background. As in the alluvial system, the main contaminants of concern are HE compounds and barium. HMX, RDX, and TNT concentrations range	See above.

Table 3-A-6.
Water Canyon Watershed Description (continued)

Hydrogeologic Element	Characteristic	Water Canyon	Cañon de Valle	Potrillo and Fence Canyons
			up to 32, 330, and 3 µg/L, respectively. Barium concentrations range up to 1310 µg/L. Martin and Fishladder canyons are above 6.1 ppb RDX as well.	
Alluvial Groundwater	Extent	In upper Water Canyon, some alluvial groundwater is likely to occur near the headwaters. The occurrence and duration of alluvial groundwater likely decreases down canyon, given limited addition of water, lack of springs and seeps, and rare discharge from tributary canyons. Alluvial groundwater in Martin Canyon (a small tributary canyon to Water Canyon) is intermittent. In middle Water Canyon, alluvial groundwater is present in WCM-1 and WCM-2, but no water is present in WCO-1, WCO-2, and WCO-3. The downstream extent of alluvial groundwater may be between the WCM-2 and WCO-1.	A thin (typically <10 ft thick) alluvial system in Cañon de Valle near SWSC and Burning Ground Springs has perennial saturation. However, alluvial saturation does not extend to the confluence with Water Canyon. The down-canyon extent of saturation is highly variable and fluctuates depending on weather conditions. Saturation is also restricted by the limited extent of alluvium in the canyon. Six alluvial wells are used for water level monitoring and for alluvial water sampling.	In Potrillo Canyon, there is one known occurrence of alluvial groundwater in moisture access hole POTM-2. Several other boreholes have been drilled near this area to define the extent of the groundwater found in POTM-2 but all are dry. In Fence Canyon, no occurrences of alluvial groundwater have been documented. However, only one well was installed, well FCO-1, located near State Road 4. Based on physiography, no alluvial groundwater is expected at that location.
	Depth/Thickness	The alluvium is typically less than 10 ft thick.	See above.	See above.
	Quality	Groundwater quality in Martin Canyon shows primarily barium and high explosives as contaminants but also nitrate, many metals and organics, including values above WQCC standards.	Groundwater quality shows primarily barium and HE compounds including HMX, RDX, and TNT as contaminants. HMX, RDX, and TNT concentrations have been measured up to 610, 759, and 46 µg/L, respectively. High explosive degradation products and perchlorate	See above.

Table 3-A-6.
Water Canyon Watershed Description (continued)

Hydrogeologic Element	Characteristic	Water Canyon	Cañon de Valle	Potrillo and Fence Canyons
			have also been detected. Barium concentrations range up to 18,000 µg/L.	
Intermediate Groundwater	Extent/Hydrology	No perched water was encountered in any of the holes and all holes have remained dry with the exception of core hole CH-2. DT-5, DT-5P, and four core holes (CH-1, CH-2, CH-3, and CH-4) were drilled to depths of 300 to 500 ft at the main experimental area and more than 50 experimental holes were drilled as deep as 142 ft in Areas 1, 2, 2A, 2B, 3, and 4 from 1959 to 1961. CH-2 may have an undetected natural perched zone; however, this seems unlikely because this recharge pathway apparently developed more than a decade after the hole was completed.	At depths of a few hundred feet, transient zones of perched saturation within the Bandelier Tuff have been identified in two boreholes beneath the TA-16 mesa between Water Canyon and Cañon de Valle. These zones may be related to the perched water that feeds the numerous Cañon de Valle springs.	No perched zones are known in the area of these canyons, although little drilling has been done.
	Depth/Thickness	See above.	Wells R-25 and SHB-3 encountered a thick perched zone in the lower Otowi and upper Puye that apparently extends beneath a large portion of the mesa; at R-25 the perched zone extends in depth from 711 to 1132 ft. The lateral extent of this perched zone has not been determined, however.	See above.
	Quality	See above.	The transient saturation contains HE and barium contamination and appears to be from former and active HE waste water lagoons on the mesa top rather than to the building 260	See above.

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Table 3-A-6.
Water Canyon Watershed Description (continued)

Hydrogeologic Element	Characteristic	Water Canyon	Cañon de Valle	Potrillo and Fence Canyons
			outfall. HMX, RDX, and TNT concentrations range up to 21, 2 490, and 1.3 µg/L, respectively. Barium concentrations range up to 1790 µg/L. High explosive compounds (for example, 84 µg/L RDX), HE degradation intermediates (2-amino-4,6-dinitro-toluene and 4-amino-2,6-dinitrotoluene), chlorinated solvents, and boron were detected in the perched zone at R-25. The tritium activity in this well is up to 140 pCi/L in the intermediate perched zone, indicating a component of recharge within the last 50 years. The unsaturated soils and tuff that make up the TA-16 mesa, and the alluvial sediments and soils of Cañon de Valle and Martin Canyon contain variable and localized inventories of HE and barium. Core holes in the vicinity of the 260 outfall in particular show detections of these contaminants in the upper few hundred feet of the vadose zone.	
Regional Aquifer	Depth/Hydrology	Information on the regional aquifer near Water Canyon is discussed in the table for Ancho Canyon.	Well R-25 encountered the regional aquifer at 1286 ft.	By projecting depths from water supply well PM-2, the regional aquifer lies 730 ft below the bottom of Potrillo Canyon and 620 ft below the bottom of Fence Canyon.
	Quality	See above.	High explosives were detected in R-25 although this may have been from	See above.

Table 3-A-6.
Water Canyon Watershed Description (continued)

Hydrogeologic Element	Characteristic	Water Canyon	Cañon de Valle	Potrillo and Fence Canyons
			cross contamination from the upper saturated zone above, which occurred during drilling (Longmire 2005). High explosives concentrations are decreasing in the regional aquifer samples with time, while they are remaining relatively constant in the upper saturated zone. Tritium activity has decreased during sampling, remaining above 2 pCi/L, suggesting a component of recharge in the past 61 years. Well R-18 located north of well R-25 contained less than -0.32 pCi/L of tritium, less than 0.001 ppm of perchlorate, and concentrations of HE compounds and degradation intermediates were less than detection (0.48 to 1.5 µg/L method detection limit). Well R-18 has not experienced recharges within the past 61 years and the well is not impacted from Laboratory discharges.	
Contaminants	Potential Sources	In upper Water Canyon, potential contaminant sources include TA-11, TA-15, and TA-16. Potential contaminants include HE compounds, barium, and solvents. In middle Water Canyon, TA-49 is a potential contaminant source possibly contributing isotopes of uranium and plutonium, lead, beryllium, and HE compounds such as TNT, RDX, HMX,	In Cañon de Valle, potential contaminant sources include TA-8, TA-9, TA-11, TA-14, TA-15, and TA-16.	In Fence Canyon and Potrillo Canyon, firing sites at TA-36 are potential sources of contaminants.

Table 3-A-6.
Water Canyon Watershed Description (continued)

Hydrogeologic Element	Characteristic	Water Canyon	Cañon de Valle	Potrillo and Fence Canyons
		and barium nitrate. For lower Water Canyon, TA-14, TA-15, and TA-36 are potential sources of high explosives such as TNT, nitrocellulose, trinitramines (RDX), and pentaerythritol tetranitrate (PETN). Metals may also be associated with the explosives (uranium, barium, beryllium, lithium hydride, lead, mercury, copper, and zinc).		
	Type	Soils in several of these operational areas have high levels of uranium contamination. More information for upper Water Canyon may be found in the RFI Work Plan for Operable Unit 1082. For middle and lower Water Canyon, additional detail is contained in the RFI Work Plan for Operable Unit 1144 and RFI Work Plans for Operable Units 1085, 1086, and 1130.	Potential contaminants include HE compounds, barium, nitrate, and solvents. More information may be found in the RFI Work Plan for Operable Unit 1082 and the associated RFI reports.	TNT, nitrocellulose, trinitramines (RDX), and PETN. Metals may also be associated with the explosives (uranium, barium, beryllium, lithium hydride, lead, mercury, copper, and zinc). Soils in several of these operational areas have high levels of uranium contamination.

References:
LANL 1992f; LANL 1993a; LANL 1993d; LANL 1993e; LANL 1994a; LANL 1998b; LANL 2003b.

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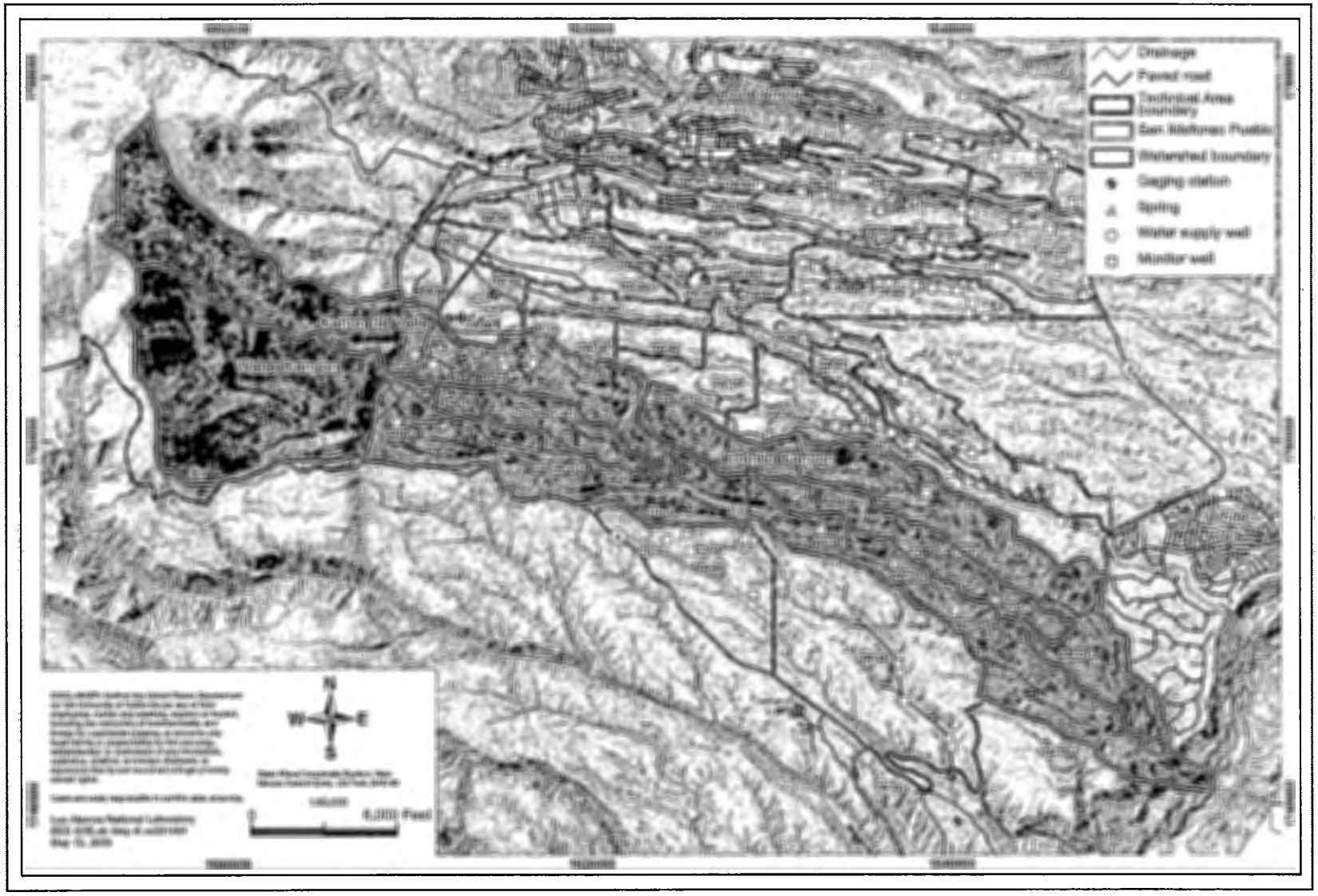

Figure 3-A-7. Water Canyon watershed including Pajarito Canyon, Cañon de Valle, Potrillo Canyon, and Fence Canyon.

Table 3-A-7.
Ancho Canyon Watershed Description

Hydrogeologic Element	Characteristic	Description
Surface Water	Flow	Ancho Canyon lies in the southeastern part of the Laboratory (Figure 3-A-1; Figure 3-A-8) and has a drainage area of 6.7 square miles. Ancho Canyon heads on the Pajarito Plateau and for the most part has ephemeral flow. The canyon has two main branches. Beginning less than a mile above the Rio Grande, flow in Ancho Canyon is perennial, fed by Ancho Spring, a regional aquifer spring.
	Quality	
Springs	Name	Ancho Spring
	Quality	Analysis of water at Ancho Spring by the Environmental Surveillance Program indicates occasional presence of HE compounds and trace levels of depleted uranium. Because the spring issues from the canyon floor, it is uncertain whether these contaminants are being transported by groundwater or if they are being mobilized from sediments in the canyon. Ancho Spring is downgradient of explosives testing sites.
Alluvial Groundwater	Extent	Little is known about the presence of alluvial groundwater in Ancho Canyon. Ancho Canyon contains thick alluvium that could host perched groundwater.
	Depth/Thickness	Three boreholes (ASC-15, ASC-16, and ASC-18) drilled by the ER Project encountered 4 ft to 9 ft of saturation in alluvium below MDA Y, but no contamination. Several boreholes drilled downgradient of MDA Y did not encounter alluvial groundwater, suggesting that the occurrence of alluvial groundwater in this area is limited in extent.
	Quality	See above.
Intermediate Groundwater	Extent/Hydrology	No intermediate perched zones have been found beneath Ancho Canyon. ER borehole DMB-1, drilled between building 69 and the Administrative Area at TA-39, penetrated 119 ft of Bandelier Tuff and 5 ft of Cerros del Rio basalts. No intermediate-depth perched water was encountered in this hole, but clay-lined fractures and vesicles in the basalt suggest that the periodic passage of groundwater through these rocks may occur. A test hole (TH-7) drilled 10 ft into basalts in Ancho Canyon below State Road 4 was dry. The hole was drilled in 1950 and has been plugged.
	Depth/Thickness	R-31 was drilled in TA-39 in the north fork of Ancho Canyon. A screen was placed from 439 to 454 ft at a possible perched zone, based on water seen in a borehole video. The zone has been dry since and no water samples have been collected from it.

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Table 3-A-7.
Ancho Canyon Watershed Description (continued)

Hydrogeologic Element	Characteristic	Description
	Quality	See above.
Regional Aquifer	Depth/Hydrology	Groundwater flow in the regional aquifer beneath Ancho Canyon is to the east and southeast, towards the Rio Grande. The regional aquifer lies at about 1000 to 1170 ft beneath the mesa at TA-49, and is within the Cerros del Rio basalt, the underlying Puye Fanglomerate, "Totavi" gravels, and possibly the Santa Fe Group (Section 2.3.1). The regional water table, at well R-31 in TA-39, was encountered at about 530 ft within the Cerros del Rio basalt, the underlying Puye Fanglomerate, and "Totavi" gravels.
	Quality	Three regional aquifer wells at TA-49 have been sampled since the 1960s to monitor for effects of testing at that site. In general, no contaminants have been consistently found. High metal concentrations (lead, zinc, iron, manganese) in samples are related to metal well casing and fittings. Occasional detections of organic compounds are not supported by follow up sampling. Post-drilling water quality sampling has not been completed at well R-31.
Contaminants	Potential Sources	Located south of Ancho Canyon on a mesa near the Rio Grande, TA-33 was used as a firing site and for production of tritium. PRSs include landfills, septic systems, and burn areas. It is situated on a mesa top and is being investigated by the ER Project as OU 1122. TA-39 is located on the floor of middle Ancho Canyon, and it was used for open-air testing of high explosives. PRSs in this technical area include five firing sites, a number of landfills, and septic systems. The ER Project is investigating this technical area as OU 1132. More detailed information about the operational history and the PRSs can be found in the RFI Work Plans for OUs 1122 and 1132. TA-49 lies on a mesa in the upper part of the Ancho Canyon drainage. TA-49 was used for underground hydronuclear testing in the early 1960s. The testing consisted of criticality, equation of state, and calibration experiments involving special nuclear materials. The RFI Work Plan for Operable Unit 1144 describes the planned ER investigations that focus on identifying and quantifying migration of contaminants from the shafts.
	Type	There are large inventories of radioactive and hazardous materials such as isotopes of uranium and plutonium, lead, beryllium, TNT, RDX, HMX, and barium nitrate. Much of this material was left in shafts drilled into the mesa top.

References:
LANL 1992d; LANL 1992f; LANL 1993b; Purtymun and Stoker 1987.

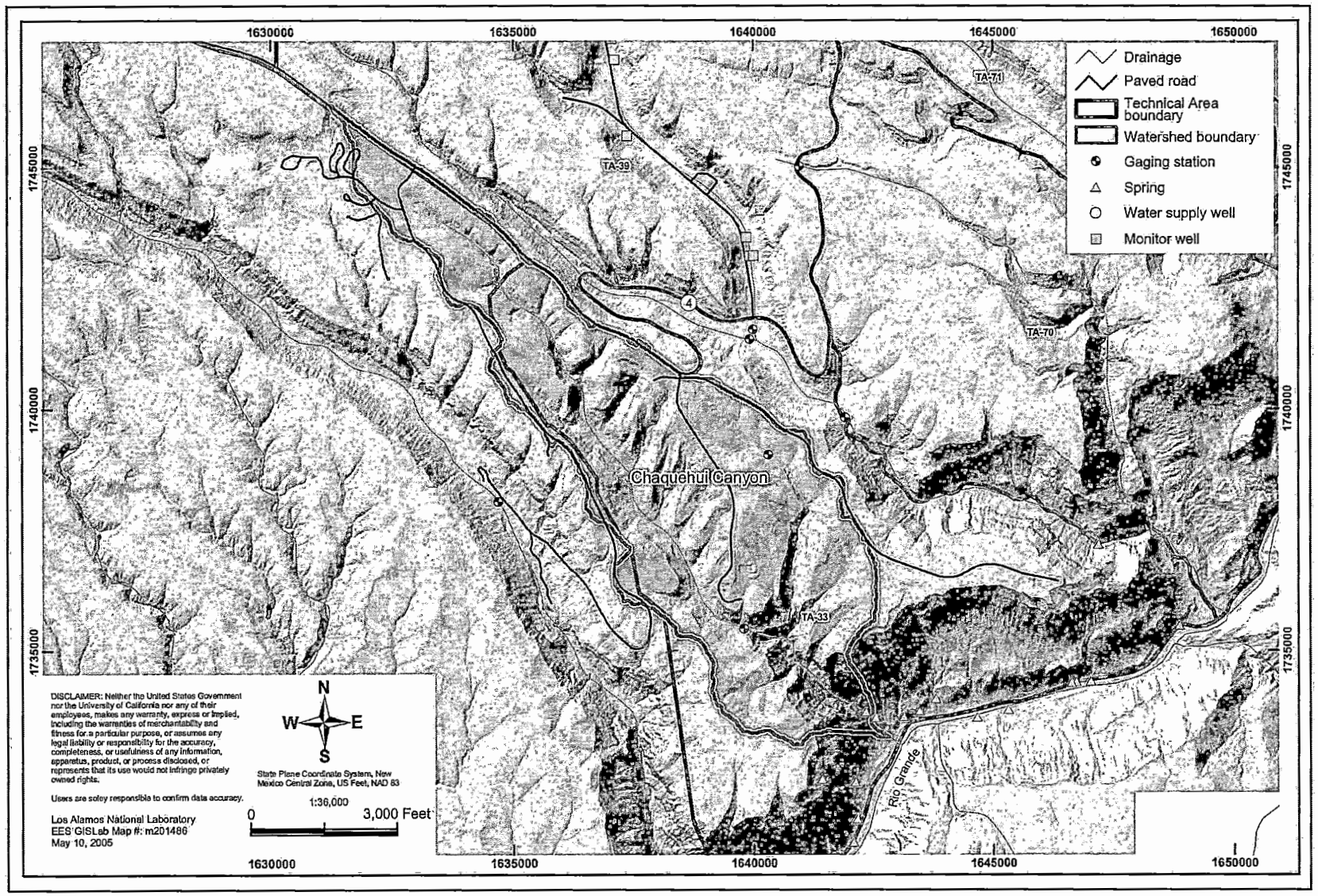

Figure 3-A-8. Ancho Canyon watershed.

Table 3-A-8.
Chaquehui Canyon Watershed Description

Hydrogeologic Element	Characteristic	Description
Surface Water	Flow	Chaquehui Canyon heads on the Pajarito Plateau and has a drainage area of about 2 square miles. It contains an ephemeral stream in its upper portion (Figure 3-A-1, Figure 3-A-9).
	Quality	
Springs	Name	Springs issue from basalts near the Rio Grande in the area of Chaquehui Canyon (Springs 8A, 9, 9A, 9B, and Doe Spring). These springs are located 130-200 ft above the Rio Grande. About 0.5 mile above the Rio Grande, Doe Spring, a regional aquifer spring, maintains a short perennial reach. Farther down the drainage, Springs 9, 9A and 9B maintain perennial flow that extends 0.25 mile to the Rio Grande.
	Quality	
Alluvial Groundwater	Extent	Little is known about the presence of alluvial groundwater in Chaquehui Canyon. Much of Chaquehui Canyon is unlikely to contain perched alluvial groundwater because most of its course forms a steep narrow drainage through basalts that are swept free of alluvium by runoff. Purtymun reported that there was water perched locally in the alluvium but provided no basis for this statement. Purtymun probably refers to alluvium downstream of Doe Spring and Springs 9 and 9A.
	Depth/Thickness	See above.
	Quality	See above.
Intermediate Groundwater	Extent/Hydrology	No intermediate groundwater is known in Chaquehui Canyon; however there has been no drilling in the area.
	Depth/Thickness	See above.
	Quality	See above.
Regional Aquifer	Depth/Hydrology	The springs may represent discharge from the regional aquifer in White Rock Canyon. Well R-31 in TA-39 (Ancho Canyon) found the regional aquifer at about 530 ft within the Cerros del Rio basalt, the underlying Puye Fanglomerate, and "Totavi" gravels.
	Quality	
Contaminants	Potential Sources	Chaquehui Canyon lies south of the mesa occupied by TA-33. TA-33 was used as a firing site and for production of tritium. PRSs include landfills, septic systems, and burn areas. TA-33 is situated on a mesa top and is being investigated by the ER Project as Operable Unit (OU) 1122.
	Type	

References:
LANL 1992d; Purtymun and Rogers 2002.

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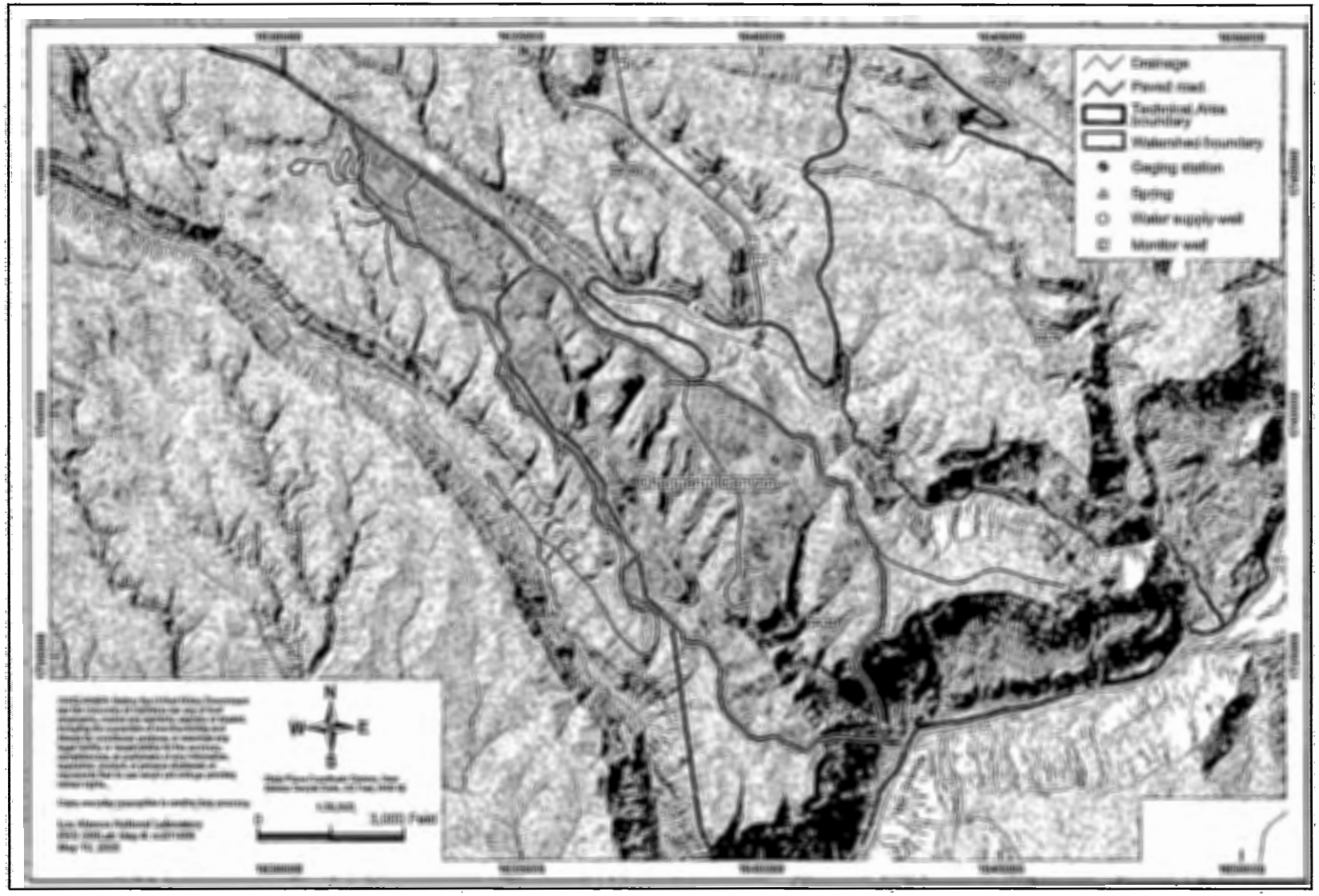

Figure 3-A-9. Chaquehui Canyon watershed.

Table 3-A-9.
Frijoles Canyon Watershed Description

Hydrogeologic Element	Characteristic	Description
Surface Water	Flow	Frijoles Canyon lies on US Forest Service and US Park Service lands south of Laboratory land and heads within the Sierra de los Valles (Figure 3-A-1; Figure 3-A-10) with a drainage area of about 19 square miles. Rito de los Frijoles is a perennial stream that originates in the upper canyon and extends to the Rio Grande.
	Quality	The Laboratory has monitored surface water quality at two locations for several decades, one near the park headquarters and one just above the Rio Grande. In general, no Laboratory-derived contamination has been observed. The National Park Service has monitored surface water quality extensively in Frijoles Canyon. High fecal coliform bacteria counts originating from local sanitary sources and horse corrals have been a major issue in surface water quality.
Springs	Name	Rito de los Frijoles originates from springs in upper Frijoles Canyon. One regional aquifer spring, Spring 10, discharges at the edge of the Rio Grande south of Frijoles stream. The spring has a very low discharge and is difficult to sample separately from adjacent river water.
	Quality	
Alluvial Groundwater	Extent	No wells have been drilled into the alluvium in Frijoles Canyon. The presence of perennial surface flow suggests a large extent of alluvial saturation.
	Depth/Thickness	The alluvium is probably thin, on the order of 6 m or less.
	Quality	See above.
Intermediate Groundwater	Extent/Hydrology	No intermediate groundwater is known to exist in the area of Frijoles Canyon; however no wells have been drilled.
	Depth/Thickness	See above.
	Quality	See above.
Regional Aquifer	Depth/Hydrology	No regional aquifer wells are located in Bandelier National Monument. The nearest wells are in Ancho Canyon.
	Quality	See above.
Contaminants	Potential Sources	Frijoles Canyon lies south of the Laboratory boundary near the Rio Grande, but is separated from TA-33 by Chaquehui Canyon. Local sanitary sources and horse corrals have been potential source of contamination.
	Type	There is a high fecal coliform bacteria count in surface water.

References:
Mott 1999; Purtymun and Adams 1980.

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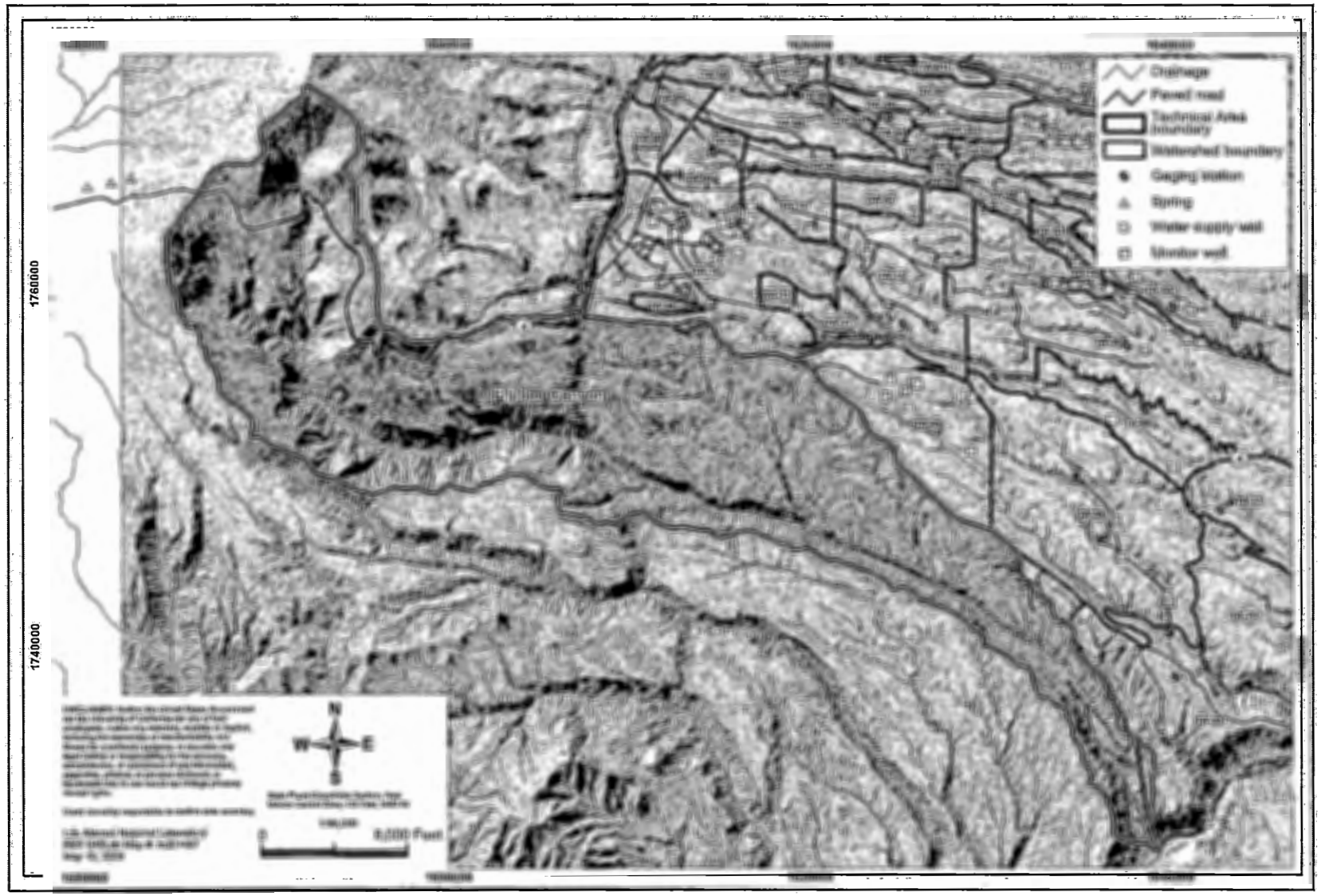

Figure 3-A-10. Frijoles Canyon watershed.

Table 3-A-10.
White Rock Canyon Watershed Description

Hydrogeologic Element	Characteristic	Description
Surface Water	Flow	Flow from regional aquifer springs supports perennial surface water flow in several canyons just above where they reach the Rio Grande: Sandia, Pajarito, Ancho, and Chaquehui canyons (Figure 3-A-1, Figure 3-A-11). Except for Sandia Canyon, these flows reach the Rio Grande. The Los Alamos County White Rock Sewage Treatment Plant discharges effluent into Mortandad Canyon just above the river at the northern county boundary.
	Quality	The discharge from the White Rock Sewage Treatment Plant is the primary surface water source and has a strong impact on the chemistry of the water that enters the Rio Grande from Mortandad Canyon, leading to higher TDS, nitrate, chloride, sulfate, and some metals. Water quality of the other streams is mainly determined by chemistry of their contributing springs (summarized in the regional aquifer description below). Purtymun (1995) and Purtymun et al. (1980) summarize flow and water quality from the White Rock Canyon springs and surface water.

Table 3-A-10.
White Rock Canyon Watershed Description (continued)

Hydrogeologic Element	Characteristic	Description
Springs	Name	Springs near the Rio Grande represent natural discharge from the regional aquifer. The springs discharge from two geologic units, the Tesuque Formation and the Totavi Lentil (the lower part of the Puye Formation). The Tesuque Formation consists of sandstones, siltstones, and interbedded basalts. The Totavi Lentil is a channel fill deposit made up of grain sizes ranging from gravel to boulders. Most of the springs discharge close to the elevation of the Rio Grande, though some springs discharge at elevations several tens of feet above the Rio Grande. The springs can be divided into four groups: **Group I springs** discharge from the Totavi Lentil on the west side of the river. The spring water is dominated by calcium bicarbonate with sulfate and chloride of about 4 mg/L and TDS averages 163 mg/L. **Group II springs** discharge from coarse-grained Tesuque Formation sediments on both sides of the river. These springs have sodium bicarbonate water with about 3 mg/L of sulfate and chloride, and TDS averages 183 mg/L. **Group III springs** discharge from fine-grained Tesuque Formation sediments on the west side of the river. These springs also have sodium bicarbonate water with about 10 mg/L of sulfate, 3 mg/L of chloride and TDS averages 215 mg/L. **Group IV springs** discharge from fine-grained Tesuque Formation sediments on the east side of the river near faults and basalt flows. These springs have varied chemistry with higher TDS than the other springs, of 270 to 500 mg/L. The springs discharging from the Totavi Lentil (Group I springs) follow the outcrop of this formation, increasing their elevation above the river in a downstream direction. These higher elevation springs generally occur on the flanks of or in the bottom of canyons where erosion has exposed the Totavi Lentil. The elevation of springs above the river could reflect channeling of discharge from the regional aquifer along the higher-permeability Totavi Lentil, combined with the increase in elevation of the water table with distance west of the river. An alternative hypothesis about spring origin is that the elevation of some springs (Spring 4A) above the river indicates that they discharge from perched groundwater located above the regional aquifer. As well, the elevation of springs above the river could reflect complex flow paths resulting from local variations in geology and permeability related to numerous large-scale landslides along the canyon walls.
	Quality	The US Geological Survey and the Laboratory have monitored chemistry of the White Rock Springs since the 1960s; the springs show no clear impact of Laboratory contamination. Tritium values in the springs are either in the range of regional aquifer values, namely less than 3 pCi/L, or up to 40 pCi/L, which could indicate either Laboratory impact or a component of precipitation. A few springs have relatively high natural uranium. These springs lie mainly on the east side of the river

Table 3-A-10.
White Rock Canyon Watershed Description (continued)

Hydrogeologic Element	Characteristic	Description
		near and north of the Buckman wellfield. Some springs (1, 3, 3A, 4, 5) also show subtle increases in nitrate over 20 years. These increases could be due to the impact of feral cattle grazing near the springs over time as well as to some change in groundwater quality. Perchlorate has been measured at low levels in some springs, but the source is not clear.
Alluvial Groundwater	Extent	Alluvial groundwater is not present in the White Rock Canyon area. However, household wells in Los Alamos Canyon (Halladay and Otowi) and household wells nearer the Rio Grande probably draw their water from Santa Fe Group sediments but may draw water in part from alluvium in these drainages.
	Depth/Thickness	See above.
	Quality	See above.
Intermediate Groundwater	Extent/Hydrology	Perched intermediate groundwater may not be present in the White Rock Canyon area. However, an alternative hypothesis about White Rock Canyon spring origin is that the elevation of some springs above the river indicates that they discharge from perched groundwater located above the regional aquifer.
	Depth/Thickness	See above.
	Quality	See above.
Regional Aquifer	Depth/Hydrology	The Rio Grande is the major groundwater discharge zone for the regional aquifer underlying the Pajarito Plateau. The river gains flow through White Rock Canyon, indicating that the local water table (the regional aquifer) lies above the river. The City of Santa Fe operates the Buckman wellfield on the east side of the Rio Grande across from White Rock (Figure 3-A-11). The wellfield includes eight pumping wells. These wells draw their water from Santa Fe Group sediments. Vesselinov and Keating (2002) concluded from a modeling study that under long-term steady state conditions, these wells might one day draw perhaps a third of their water from beneath LANL on the west side of the Rio Grande. As a result, LANL has sampled three of the Buckman wells (1, 2, and 8) since 2001 for its Environmental Surveillance Program. Water in these wells is quite old, having passed through the deeper portion of the basin fill sediments where it acquired a higher load of dissolved solutes. San Ildefonso Pueblo draws water from more than 10 community and household wells located on both sides of the Rio Grande. Little information on depth or geology for these wells is available. Many of these wells probably draw their water from Santa Fe Group sediments. At least two of the San Ildefonso wells are uncapped artesian wells.
	Quality	The US Geological Survey and the Laboratory have monitored chemistry of the White Rock Springs since the 1960s; the springs do not show a definitive impact of Laboratory contamination. Tritium activities in the springs are either in the range

Table 3-A-10.
White Rock Canyon Watershed Description (continued)

Hydrogeologic Element	Characteristic	Description
		of regional aquifer values, namely less than 3 pCi/L, or range from 10 to 50 pCi/L, which could indicate either Laboratory impact or a component of local precipitation—more likely the latter given spring locations. A few springs have relatively high natural uranium. These springs lie mainly on the east side of the river near and north of the Buckman well field. Some springs (1, 3, 3A, 4, 5) also show subtle increases in nitrate over 20 years. These increases could be due to the impact of feral cattle grazing near the springs over time, natural source, and seepage from impoundments within Pajarito Canyon and past effluents released in several canyons. Perchlorate has been measured at low levels in some springs, but the source is not clear. The measured perchlorate values are similar to those found in wells distant from LANL. Spring 2B below and east of the White Rock Overlook shows higher concentrations of uranium, chloride, boron, and nitrate than other springs. This spring's chemistry (except for uranium) is similar to the nearby stream in Mortandad Canyon, which is fed by effluent from the White Rock sanitary treatment plant. This similarity in chemistry, along with nitrogen isotope results that indicate a sewage source for both waters, suggests that a large part of the water from Spring 2B comes from the treatment plant effluent in lower Mortandad Canyon. It is possible that natural uranium within the Santa Fe Group sediments has been leached from mineral surfaces in contact with the bicarbonate-rich groundwater. Increasing concentrations of carbonate alkalinity are from the treated sewage effluent discharged upgradient from the spring. Some Buckman wells have exceptionally high uranium (up to 230 ppb, compared to the new EPA MCL of 30 ppb). Such naturally occurring uranium is common in the Pojoaque and Tesuque area. The Buckman wells also have high sodium, carbonate alkalinity, and TDS.
Contaminants	Potential Sources	TA-33 borders the Rio Grande at the southern end of LANL along White Rock Canyon. The RFI Workplan for OU 1122 describes environmental concerns at TA-33. To the north of TA-33 lies TA-70, a buffer area where no Laboratory activities have occurred. Adjoining TA-70 to the north, Los Alamos County land comprises the low to moderate-density residential area of White Rock. Los Alamos County formerly operated sanitary effluent lagoons near the edge of the canyon just south of Pajarito Canyon. A municipal sanitary treatment plant discharges effluent into Mortandad Canyon just above the river at the northern county boundary. This discharge is the main surface water source and has a strong impact on the chemistry of the water that enters the Rio Grande from Mortandad Canyon, leading to higher concentrations of TDS, nitrate, chloride, sulfate, and some metals. To the north of White Rock is undeveloped San Ildefonso property.

Table 3-A-10.
White Rock Canyon Watershed Description (continued)

Hydrogeologic Element	Characteristic	Description
		Los Alamos Canyon lies at the northern end of White Rock Canyon. LANL effluents have moved down Los Alamos Canyon either adsorbed onto sediments or dissolved in stream flow, affecting sediment and shallow groundwater quality in the lower portion of the canyon (Section 2.4).
	Type	TA-33 was used as a firing site and for production of tritium. PRSs include landfills, septic systems, and burn areas. It is situated on a mesa top and is being investigated by the ER Project as Operable Unit (OU) 1122. If contaminants are released from TA-33, they may impact Ancho Canyon, Chaquehui Canyon, or the Rio Grande. The discharge from the municipal treatment plant is the primary surface water source and has a strong impact on the chemistry of the water that enters the Rio Grande from Mortandad Canyon, leading to higher levels of TDS, nitrate, chloride, sulfate, and some metals.

References:
LANL 1992d; Purtymun et al. 1980; Purtymun 1995; Vesselinov and Keating 2002; LANL, 2004a.

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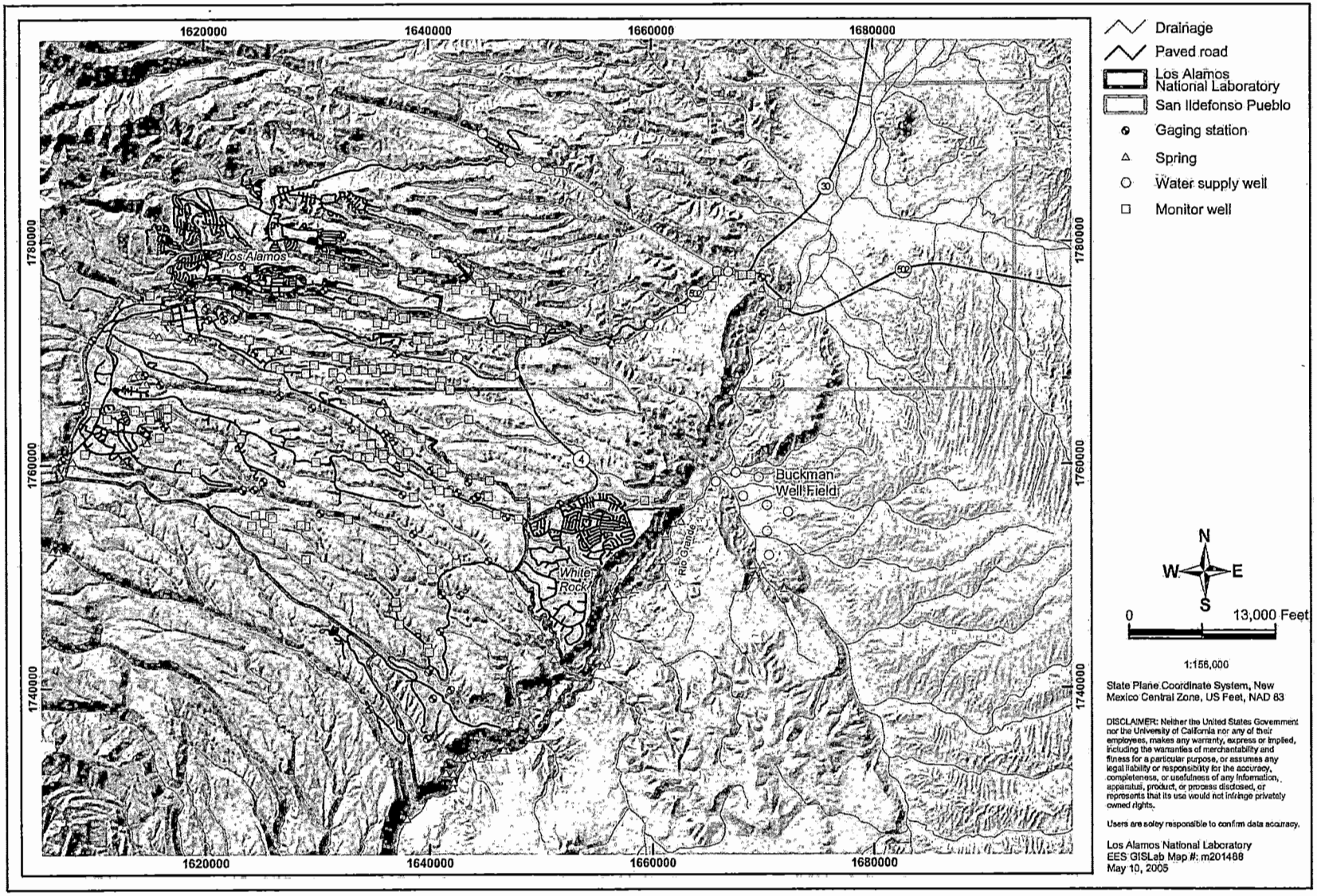

Figure 3-A-11. White Rock Canyon.

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3-B. Alternative Conceptual Models of Contaminant Transport

The purpose of this section is to discuss two alternative interpretations of how water flows and contaminants behave on the Pajarito Plateau. With the uncertainty that is inherent to all subsurface investigations, it is important to examine the strengths and weaknesses of other possible interpretations of the available data. This section explores alternative conceptual models by first providing a description of the alternative model. Second the strengths and limitations of the alternative are summarized. An assessment of how the alternative conceptual model would change the current conceptual model or how risk is assessed is presented. Finally, a discussion of how the alternative conceptual model could be tested is provided.

3-B-1. Colloid-Facilitated Transport

The movement of small particles in groundwater flow systems can represent an alternate mechanism for contaminant transport. While generally not as significant overall as the movement of dissolved or immiscible species, the movement of small particles can increase the magnitude of mass transport. This section will focus on colloids, a special class of particles with properties the lie between that of the dissolved state and the solid state.

Historically, researchers have applied the term colloid to particles with a size range of 0.001 to 1 micron (1 micron is 0.001 millimeter). The colloids can be mineral particles, particulate organic matter, biological (for example, bacteria), or even microemulsions of hydrocarbons. The surface area per unit mass is very high for colloids, which greatly affects their mass transport. Contaminants can be transported as colloids resulting in unexpected mobility. This is because the transport of contaminants adsorbed to colloids is determined by the physical/chemical properties of the colloid, rather than properties of the contaminant. Work at the Nevada Test Site suggests that plutonium can be transported over significant lateral distances (~1.3 km) by colloids (Kersting et al. 1999). Predicting colloid transport is extremely difficult, however. Colloid stability and filtration depends on a complex array of factors including density, size, surface chemistry, water chemistry, water flow rates, and pore size distribution of the soil matrix. Table 3-B-1 discusses strengths and weaknesses of a colloid-facilitated transport model.

3-B-1.1 Strengths and Limitations of the Colloid-Facilitated Transport Model

Table 3-B-1.
Colloid-Facilitated Alternative Transport Model

Strengths	Limitations
Since the start of discharges in May 1963, the RLWTF has used the flocculate "calcium hydroxide" and "ferric sulfate" as a part of the treatment process, and it is likely that a continual stream of residual colloids was discharged to the canyon floor.	Bulk of radionuclide inventory appears adsorbed to stream sediments.
Work by Penrose et al. (1990) demonstrated the presence of colloids with plutonium and americium along a 3400 m segment of the perched alluvial groundwater system in Mortandad Canyon. The study concluded that the horizontal dispersal of the radionuclides through the groundwater system was due to colloid transport in the subsurface.	That conclusion was challenged, however, by a subsequent review that concluded that the radionuclide transport within the canyon was principally due to surface water, rather than groundwater transport (Marty et al. 1997).
At a mesa top site at TA-21, some of these radionuclides occur at much greater depths in the field than expected. Work by Nyhan et al. (1985) suggests that substantial hydraulic loading can enhance the vertical penetration depth. The study examined the distribution of plutonium, americium-241 and water in Bandelier Tuff beneath former liquid waste disposal sites at TA-21. Nyhan et al. (1985) found that after 17 years of migration, the Am-241 was mobilized under heavy hydraulic loading to 30 m. It is possible that the radionuclides are mobilized by other chemicals or possibly by colloid transport in preferential flow paths.	While colloids have been shown to be abundant in the alluvial groundwater, coring has not shown appreciable vertical movement (less than five feet) of plutonium or americium in the vadose zone below the alluvium (Stoker et al. 1991). Studies show that 99% of the plutonium inventory is adsorbed on alluvium and little is in the water column; the colloidal fraction in groundwater represents less than 1 percent of the total plutonium inventory in the canyon (Purtymun et al. 1984; Stoker et al. 1991). These results suggest that vertical transport of the radiocolloids has been minimal in the Bandelier Tuff beneath the canyon floor, even after decades of continual liquid release.
Occasional Pu-239, -240 detects in samples from water supply wells (1970s and 1980s mostly) may be colloid related.	No plutonium detects in recent years and earlier detections primarily limited to water supply wells---few in monitoring wells. Unable to validate earlier results because of limitations in existing records.

3-B-1.2 Effect on Current Conceptual Model and Assessment of Risk

Many radionuclides and metals are currently conceptualized to be relatively immobile at the site. If colloid-facilitated transport is significant, the subsurface travel times for these constituents to the accessible environment will be reduced. Health risks from colloid-facilitated transport, however, likely will not be greatly different from the levels presently recognized: sampling of the groundwater systems account for the total contaminant concentrations and already include any colloid contributions, if present. Monitoring of the shallower groundwater at the site, the depths where contaminated colloids should be most abundant, has identified few areas with concentrations above a regulatory standard. Given the vadose zone thickness and likely reduction in contaminated colloid concentrations with depth, contaminant concentrations due to colloid-facilitated transport in the regional aquifer are also expected to meet regulatory standards.

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3-B-2. Cs-137 "Groundwater Transport" to the Rio Grande

A report written by Norm Buske (2003) for the RadioActivist Campaign (TRAC) and Concerned Citizens for Nuclear Safety (CCNS) in late October 2003 cites samples of aquatic moss from Spring 4A and the Pajarito Stream containing "...consistently low levels of cesium-137 *of LANL* origin [emphasis added]. This is the first confirmed detection of LANL radioactivity from a groundwater pathway." The report also cited moss samples from other sites, as testing positive for Cs-137 and said samples showed Cs-137 "in the range of 0.01 to 6 picocuries/kilogram...Cesium-137...is...at levels far too low to be considered a public health concern." Table 3-B-2 discusses strengths and limitations of a Cs-137 transport model.

3-B-2.1 Strengths and Limitations of Cs-137 Groundwater Transport Alternative Model

Table 3-B-2.
Cs-137 Groundwater Transport Alternative Model

Strengths	Limitations
Detections of tritium and perchlorate in other White Rock Canyon springs support this model.	Levels of these constituents may be within natural ranges. When converted to an equivalent weight basis, the amount of cesium measured by Buske (2003) in the moss samples is within the background concentrations for plants in northern New Mexico.
Cesium-137 is a major Laboratory contaminant in Los Alamos and Mortandad Canyons radioactive effluent discharges.	Cesium-137 is a common fallout radionuclide that was distributed globally during atmospheric nuclear tests. It is considerably more probable that the moss accumulated cesium from worldwide fallout rather than from groundwater. Fallout cesium-137 is universally present in surface soils and soil concentrations are one hundred times greater those found in study.
	The Buske (2003) results were very close to detection levels, in the range of 0.01 to 6 pCi/Kg wet, and the study did not include control samples (upstream) so that Cs-137 from fallout sources could not be compared.
	If Cs-137 traveled through groundwater to a spring along the Rio Grande, several non-adsorbing chemical constituents that usually reflect groundwater contamination, such as nitrate or tritium, likely would accompany and precede Cs-137. Tritium and nitrate values in Spring 4A indicate the spring water reflects background aquifer conditions unaffected by Laboratory discharges.
	From 1995 through 2003, LANL has made 121 Cs-137 measurements in White Rock Canyon springs, with only two detections in the data set. Nine of these measurements (with only one detection) were from Spring 4A. Thus, the body of data does not support the presence of Cs-137 in any White Rock spring, at an average detection limit of 3 pCi/L. In addition, Cs-137 is not detectable in regional aquifer monitoring wells upgradient of the springs.

3-B-2.2 Effect on Current Conceptual Model and Assessment of Risk

If real, the groundwater transport of Cs-137 alternative conceptual model would indicate that relatively immobile radionuclides or metals may potentially move through groundwater to the accessible environment at a faster rate than recognized. Assessment of water quality changes at those locations would continue in the future. The current monitoring results from across the regional aquifer do not indicate any location where the concentrations of these constituents are greater than regulatory standards. Given this pattern, it is highly unlikely that concentrations greater than standards would be observed in the future. Contaminant transport models that only take into account sorption and solubility may underestimate the extent a colloid-bound species is able to migrate in groundwater.

A study is being conducted by a LANL team to assess the distribution and concentrations of cesium in moss throughout northern New Mexico. The objective is to collect various moss sample specimens from springs located in northern New Mexico and southern Colorado (a great distance from LANL) and analyze them for Cs-137 activity. This program will collect the data necessary to evaluate whether Cs-137 concentrations near the Laboratory are anomalous. Additional monitoring of wells and springs in the Los Alamos area will continue to look for evidence of rapid movement of cesium (and other contaminants) through the groundwater system.

APPENDIX 4-A. METHOD FOR ESTIMATING INFILTRATION RATE IN CANYONS

Net infiltration is defined as the flux of water that percolates to depths greater than the zone in which evapotranspiration (ET) processes take place. A complete site-wide study of net infiltration has recently been completed (Kwicklis et al. 2005). That study presents estimates of net infiltration determinations with a variety of estimation techniques, including Darcy's Law, chloride mass-balance and water-balance methods. The study extrapolates these estimates to other areas within the site for which estimates do not exist. Factors used to make this extrapolation include topography, soil type, vegetation, and bedrock type. The Kwicklis et al. (2005) publication was not ready in time to be used in model predictions presented elsewhere in this report. Previous modeling analyses should be updated to include the detail from the site-wide net infiltration study, as appropriate.

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 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 (Section 2.6.1). More variability is added to the map for canyon locations because the canyons are the main source of recharge across the plateau, and also 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 net infiltration index ranges in value from one to five, with one representing the lowest and five representing the highest infiltration potential. The NII is based on a number of physical factors, as shown in Table 4-A-1:

- The location of the headwaters is the first factor because those 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. Those canyons with perennial streams are expected to generate higher net infiltration than those with ephemeral or intermittent streams, and therefore receive a higher ranking.
- Observation of alluvial water is the final factor used to define the NII. Some canyons have alluvial groundwater of significant depth while others have limited or no alluvial water. Those canyons with deeper alluvial groundwaters receive a higher net infiltration index than those without.

Note that the factors contributing to the NII are used to define a set of net infiltration indices that may be updated with site-specific observations and data. However, as a general approach for supporting a plateau-wide modeling effort, the NII is a reasonable simplification. 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 of this 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 alternative

hypotheses, the model assumes a higher NII in the wetter areas, so that it errs on the side of predicting more rapid transport. Once areas with potential fast paths are identified, more site-specific and detailed net infiltration studies can be performed to refine the predictions.

Table 4-A-1 also includes the net infiltration assumed for each NII. These estimates exhibit approximately three orders of magnitude variation in net infiltration between the driest and the wettest canyons. To assess uncertainty in infiltration, different sets of net infiltration estimates are also included in this study.

Once the NII and the associated infiltration rates for each NII have been defined, the next step is to assign net infiltration indices of canyons or portions of canyons across the Pajarito Plateau. This task was accomplished by compiling information from the LANL Hydrogeologic Workplan about the descriptive factors listed in Table 4-A-1. 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 particular canyon is split into sections because the hydrologic factors change as one moves down the canyon. The characteristics of these canyons or portions of canyons are shown in Table 4-A-1, along with the resulting net infiltration index for each section. The net infiltration index is determined by comparing the characteristics in Table 4-A-1 to the net infiltration factors in Table 4-A-1.

Figure 4-A-1 shows the resulting NII map for the study area with respect to the LANL boundary. Canyons with no portion of their reach inside the site area, in the gray area of this figure, are not assigned a NII as part of this study because laboratory-derived contaminants are not present in these canyons. Infiltration rates converted from the values in Table 4-A-1 were used as the upper water-flux boundary conditions for the series of one-dimensional vadose-zone flow and particle tracking runs.

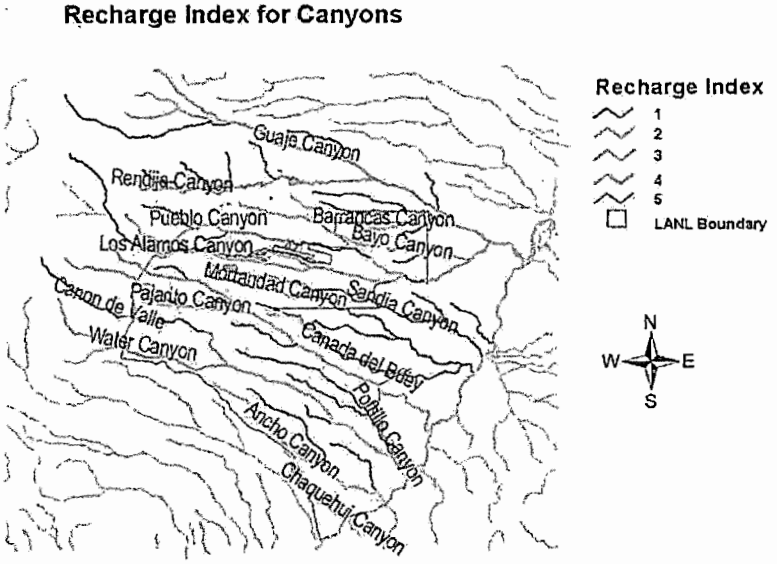

Figure 4-A-1. Infiltration on the Pajarito Plateau: result of analysis to determine the Net Infiltration Index (NII) indicator parameter across the Pajarito Plateau and surrounding region of the study area.

Table 4-A-1.
Determination of Net Infiltration
Index for Sections of Canyons on the Pajarito Plateau

Canyon/ ArcView Identifier	Reach	Headwaters (drainage <5 mi² 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		LANL (1998) p. 4-41, 4-42	4
Pueblo (Pueb2)	Below Guaje Mountain Fault, above sewage treatment plant	Mountains	Ephemeral	May or may not be saturated		LANL (1998) p. 4-41, 4-42	3
Pueblo (Pueb3)	Below sewage treatment plant to halfway across Lab land	Mountains and anthropogenic source	Perennial	Saturated		LANL (1998) p. 4-41, 4-42	5
Pueblo (Pueb4)	Half way across Lab land to confluence with LA Canyon	Mountains	Intermittent	Saturated		LANL (1998) p. 4-41, 4-42	4
Pueblo (Historic)	Mid (below TA-45) and upper (old sewage) canyon	Mountains	Possible historic perennial flow	Possible historic 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		LANL (1998) p. 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) Table 8 714, 213, 566, 1076 mm/yr	LANL (1998) p. 4-48	4
Los Alamos (LA3)	TA-2 to confluence of Pueblo Canyon	Mountains	Ephemeral	Saturated (same as above)	222, 408 mm/yr	LANL (1998) p. 4-48	4

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Table 4-A-1.
Determination of Net Infiltration
Index for Sections of Canyons on the Pajarito Plateau (continued)

Canyon/ ArcView Identifier	Reach	Headwaters (drainage <5 mi² unless noted)	Surface Water	Alluvial Water	Published Net Infiltration	Notes	NII
Los Alamos (LA4)	Confluence of Pueblo Canyon to LAO-4.5	Mountains	Perennial	Saturated	399 mm/yr	LANL (1998) p. 4-48	5
Los Alamos (LA5)	LAO-4.5 to Basalt Spring	Mountains	Ephemeral	Not Saturated	362 mm/yr	LANL (1998) p. 4-48	3
Los Alamos (LA6)	Lower; Basalt Spring to Rio Grande	Mountains	Ephemeral	Saturated	325 mm/yr	LANL (1998) p. 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 ?)		LANL (1998) p. 4-48	3
Sandia (San1)	Headwaters to TA-72	Plateau with small anthropogenic source	Ephemeral	Not character-ized (likely saturated portions)	Surface water source is precipitation and treatment plant water (not much snow melt)	LANL (1998) p. 4-53	3
Sandia (San2)	Below TA-72	Plateau	Not present	Not character-ized (eastern part near SCO-1 & SCO-2 dry since 1990)		LANL (1998) p. 4-53	1
Cañada del Buey (CdB1)	All else	Plateau	Ephemeral (with snow-melt and thunder-storms)	Not saturated	<0 (Rogers et al. 1996)	LANL (1998) p. 4-59, 4-61	1
Cañada del Buey (CdB2)	Between CDBO-6 & CDBO-7	Plateau	Ephemeral (with snowmelt and thunder-storms)	Sometimes saturated within weathered tuff (near discharge of PM-4)		LANL (1998) p. 4-61	2
Pajarito (Paj1)	West of Homestead Spring	Mountains (drainage >10 mi²)	Occurs as springs above alluvium (1-15 gpm)	Saturated alluvium (perched to ~10 ft depth)		LANL (1998) p. 4-61, 4-62	4
Pajarito (Paj2)	Several 100 yards near Homestead Spring	Mountains	Perennial	Saturated alluvium (perched to ~10 ft depth)		LANL (1998) p. 4-61, 4-62	5

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Table 4-A-1.
Determination of Net Infiltration
Index for Sections of Canyons on the Pajarito Plateau (continued)

Canyon/ ArcView Identifier	Reach	Headwaters (drainage <5 mi² unless noted)	Surface Water	Alluvial Water	Published Net Infiltration	Notes	NII
Pajarito (Paj3)	Below Homestead Spring to above Three-Mile Canyon	Mountains	Intermittent to ephemeral	Saturated alluvium (perched to ~10 ft depth)		LANL (1998) p. 4-61, 4-62	4
Pajarito (Paj4)	Three-mile Canyon to eastern LANL boundary	Mountains	Ephemeral	Saturated alluvium (perched to ~10 ft depth)		LANL (1998) p. 4-61, 4-62	4
Pajarito (Paj5)	East of LANL boundary to Rio Grande	Mountains	(Not discussed) Assumed ephemeral	Not saturated		LANL (1998) p. 4-61, 4-62, 4-60	2
Ancho (Ancho)	All	Plateau	Ephemeral from precipitation (sometimes severe)	Little known (possible shallow perched zone)		LANL (1998) p. 4-69	2
Chaq-uehui (Cheq1)	Headwaters to 0.5 mile from Rio Grande	Plateau	Ephemeral	Little known (However, observed infiltration into tuff at TA-33, tritium at 100-170 ft)		LANL (1998) p. 4-74	2
Chaq-uehui (Cheq2)	0.5 miles from/to Rio Grande	Plateau	Perennial for short distance	Little known		LANL (1998) p. 4-74	2
Cañon de Valle (CdV1)	Headwaters to Pajarito Fault	Mountains	Perennial	Saturated		LANL (1998) p. 4-78, 4-79	5
Cañon de Valle (CdV2)	Pajarito Fault to 260 Outfall	Mountains	Intermittent	Saturated		LANL (1998) 4-78,4-79	4
Cañon de Valle (CdV3)	260 Outfall to MDA P	Mountains and Anthropogenic source	Perennial	Saturated		LANL (1998) p. 4-78, 4-79	5
Cañon de Valle (CdV4)	MDA P to Water Canyon	Mountains	Intermittent	Saturated		LANL (1998) p. 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. 1996a)	LANL (1998) p. 4-85	1

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Table 4-A-1.
Determination of Net Infiltration
Index for Sections of Canyons on the Pajarito Plateau (continued)

Canyon/ ArcView Identifier	Reach	Headwaters (drainage <5 mi² unless noted)	Surface Water	Alluvial Water	Published Net Infiltration	Notes	Nil
Potrillo (Pot2)	POTM-wells to Water Canyon	Plateau	Rare	Not expected		LANL (1998) p. 4-85	1
Fence (Fen1)	All	Plateau	Ephemeral (no significant snowmelt)	Little known, dry at State Rt. 4		LANL (1998) p. 4-86	1
Water (Wat1)	Headwaters to west of LANL boundary	Mountains	Mostly perennial	Assumed saturated		LANL (1998) p. 4-87, 4-79	4
Water (Wat2)	Western LANL boundary to Cañon de Valle	Mountains	Unknown	Unknown		LANL (1998) p. 4-87, 4-79	3
Water (Wat3)	Cañon de Valle to well DT-10	Mountains	Intermittent and Ephemeral	Saturated		LANL (1998) p. 4-87, 4-79	4
Water (Wat4)	DT-10 to spring 5AA	Mountains	Ephemeral	Not saturated		LANL (1998) p. 4-87, 4-79	2
Water (Wat5)	At spring 5AA	Mountains	Short perennial reach	Possibly saturated		LANL (1998) p. 4-87, 4-79	4
Water (Wat6)	Beneath 5AA to Rio Grande	Mountains	Ephemeral	Not saturated		LANL (1998) p. 4-87, 4-79	2
Mortandad (Mort1)	Headwaters to TA-50 outfall	Plateau	Ephemeral and Intermittent	Not saturated	See LANL (1998) p.4-92 for surface water loss estimates	LANL (1998) p. 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	LANL (1998) p. 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		LANL (1998) p. 4-89, 4-91	4

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Table 4-A-1.
Determination of Net Infiltration
Index for Sections of Canyons on the Pajarito Plateau (continued)

Canyon/ ArcView Identifier	Reach	Headwaters (drainage <5 mi² unless noted)	Surface Water	Alluvial Water	Published Net Infiltration	Notes	NII
Mortandad (Mort4)	From just above boundary with San Ildefonso land to the Rio Grande	Plateau	Ephemeral	Not saturated		LANL (1998) p. 4-89, 4-91	1
Guaje (Guaje1)	Upstream (near springs) to downstream from the Guaje Reservoir	Mountains	Perennial	Saturated		LANL (1998) p. 4-95	5
Guaje (Guaje2)	Downstream from Guaje Reservoir to LA Canyon	Mountains	Intermittent	Possible seasonal saturation		LANL (1998) p. 4-95	3
Rendija (Ren1)	All	Mountains	Ephemeral	Unknown			3
Barrancas (Barr1)	All	Plateau	Intermittent and Ephemeral	Potentially saturated		LANL (1998) p. 4-96, 4-97	2
Bayo (Bayo)		Plateau	Intermittent and Ephemeral	Potentially saturated (90 boreholes in former TA-10, found no alluvial water)		LANL (1998) p. 4-97	2
Three-Mile (Three)	All	Plateau	?	?		Assume like Potrillo	1
Two-Mile (Two)	All	Mountain	Assumed ephemeral	Assumed saturated		LANL, (1998) p. 4-60	3

APPENDIX 4-B. MDA G MODEL

This appendix summarizes modeling work previously reported in Birdsell et al. (2000). The purpose of this modeling presentation is to demonstrate the use of the vadose zone concepts outlined in this report and to present representative modeling results for a relatively dry mesa. This system is therefore one end member of the different types of vadose-zone behavior expected for the plateau. A model for the other extreme, a wet canyon, is presented for Los Alamos Canyon in Appendix 4-C.

4-B-1. Introduction and Motivation

Performance assessment (PA) is required to site and authorize permanent disposal facilities for radioactive waste. The purpose of the PA is to demonstrate that performance measures related to protection of human health and the environment are not likely to be exceeded for a specified period of time. Performance objectives and periods of compliance vary according to the characteristics of the radioactive waste being disposed, but groundwater protection for U.S. sites is always explicitly required for at least 1000 years. This study presents an integrated case study that predicts the groundwater pathway dose in support of the performance assessment PA of the active, low-level, solid radioactive waste site located at the Laboratory, shown in Figure 4-4 (from Figure 1 of Birdsell et al. 2000). In contrast to the modeling study of Los Alamos Canyon presented in Appendix 4-C, this model illustrates aqueous contaminant transport from a relatively dry mesa, as opposed to a canyon bottom.

The three-dimensional unsaturated zone flow and transport model captures the complex hydrogeology and topography of the site and yields radionuclide flux estimates to the regional aquifer. Within the unsaturated zone model, the source release of radionuclides is computed for 38 waste disposal pits and four shaft fields (Figure 4-5, from Figure 3 of Birdsell et al. 2000), each contributing to the total inventory. The continued migration of radionuclides through the aquifer is calculated by using a three-dimensional model designed to maintain the temporally and spatially varying distribution of radionuclide flux from the unsaturated zone.

4-B-2. Hydrostratigraphy and Hydraulic Properties

The strata that underlie the LANL waste site are composed of a series of nonwelded to moderately welded rhyolitic ash-flow and ash-fall tuffs underlain by a thin pumice bed (Guaje Pumice), a thick basalt (Cerros del Rio Basalt), and a fanglomerate (Puye Formation), as shown in Figure 4-B-1 (from Figure 3 of Birdsell et al. 2000). The tuff has eroded to leave a system of alternating finger-shaped mesas and canyons. LANL's low-level waste disposal facility is located atop one such mesa with the waste buried in disposal pits and shafts to a depth of approximately 20 m. The surrounding canyons lie 30 m below the steep-sided mesa, and the water table is located approximately 250 to 300 m below the disposal pits.

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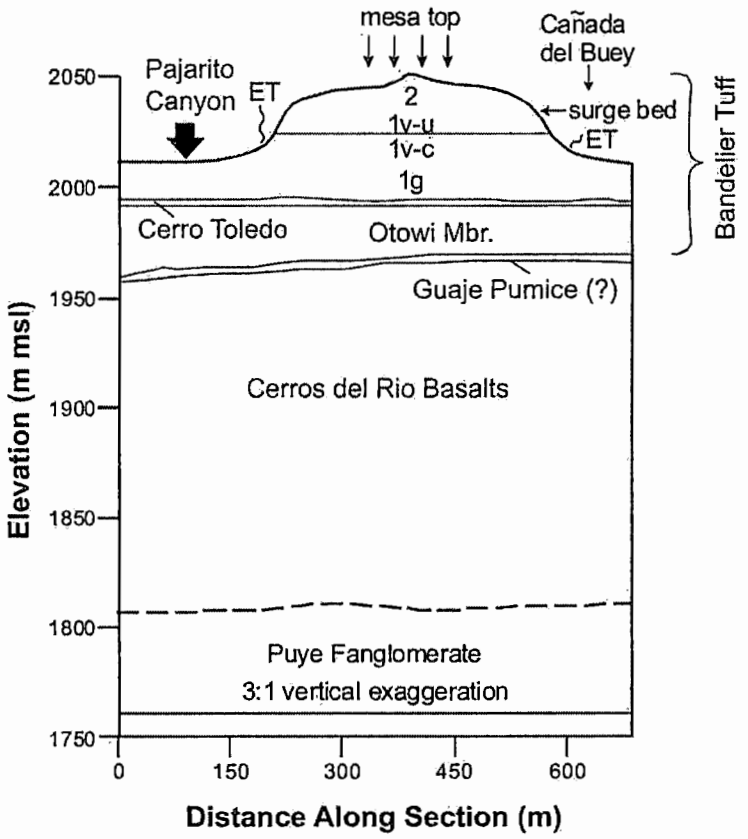

Figure 4-B-1. Conceptual model of hydrostratigraphy of the unsaturated zone for the MDA G Performance Assessment Model.

The stratigraphy at this site has several important features. The Bandelier Tuff, which composes the upper six stratigraphic units (See Figure 4-B-1), dips gently and thins toward the eastern end of the site. The top tuff layer, Unit 2, and the upper few meters of the second layer, Unit 1v-u, are extensively fractured and are separated by a thin surge bed (Krier et al. 1997). Fractures in the deeper tuff units have also been observed in outcrop (Krier et al. 1997). In addition, the Cerros del Rio Basalts, which comprise over 50% of the unsaturated zone, display significant variability (Turin, 1995). The basalts range from extremely dense with no apparent porosity, to highly fractured, to so vesicular as to appear scoriaceous. Finally, the Puye Fanglomerate lies at the base of the unsaturated zone and extends into the saturated zone. The fanglomerate consists of cobbles and boulders of volcanic debris in a matrix of silts, clays, and sands (Purtymun, 1995). Clay, silt and pumice lenses, and interbedded Cerros del Rio basalt are also common.

The van Genuchten model (van Genuchten, 1980), is used to represent the moisture retention characteristic curves for all units in the unsaturated-zone model. Birdsell et al. 2000 summarizes the hydrologic parameters used for all of the units in the unsaturated-zone flow and transport model. The parameters for the van Genuchten model (saturated permeability, porosity, inverse air entry pressure, etc.) are fairly well characterized for the six Bandelier Tuff units and for the crushed-tuff backfill but not for the deeper units. The properties for the tuff units (Krier et al.

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1997), the crushed tuff, and the Guaje Pumice were measured on core samples of matrix material. Estimated values for the saturated conductivity and porosity of the Puye Fanglomerate (Purtymun 1984) are used, and we assume that the van Genuchten fitting parameters are similar to those of coarse sands.

No hydrologic property data were available for the basalts at the time this study was performed. The basalt is modeled as a composite-continuum medium made up of both fractures and matrix material (Peters and Klavetter 1988). To ensure conservatism, we set the continuum porosity of the basalt to that of the fractures, thus forcing very low residence times of solutes in this unit for which there was no hydrogeologic characterization data.

4-B-3. Infiltration

Although the average precipitation rate for the area is 35.6 cm/year (Bowen, 1990), most of this precipitation is lost to runoff and evapotranspiration, resulting in a heterogeneous infiltration pattern that is controlled by the mesa/canyon setting of the site. Infiltration is thought to be seasonal with most occurring during spring snowmelt and, to a lesser extent, during the summer thunderstorm season (Rogers et al. 1996a). Figure 4-A-1 shows the different scales of infiltration across the plateau. Based on measured rock saturations and chloride data, a very low net infiltration rate (same as net infiltration, as used in Appendix 4-A) of 1 to 10 mm/year is thought to exist within the mesa. Pajarito Canyon is wetter with an estimated net infiltration rate of 10 to 100 mm/year, while Cañada del Buey is dry with a net infiltration rate similar to the mesa top. The steep mesa sides represent an evaporative region water sink rather than a source region. The coupling of the fractured units separated by the high-permeability surge bed with the mesa's topographic relief is thought to enhance air circulation and consequently lead to evaporative drying within the mesa interior.

4-B-4. Radionuclide Releases

The waste disposal facility occupies about 300,000 m^2 atop a finger-shaped mesa with waste buried in pits and shafts to a depth of approximately 20 m (Figure 4-5). Between 1957 and 1995, solid radioactive waste was buried in 34 disposal pits and in almost 200 shafts located in five shaft fields. The waste form buried at the site contains over 60 radionuclides with the majority of the waste being ^{235}U, ^{238}U, and ^{232}Th. Currently, only low-level radioactive waste is accepted, but prior to 1971, transuranic and mixed wastes were also accepted (Schuman 1997a). An expansion area with four large pits and another shaft field is planned for operation through 2044 and is included in this study.

The waste is categorized in terms of four disposal-unit classifications that are determined by the age of the wastes, because different regulations govern wastes disposed of during different time periods and because inventory records have improved with time. Detailed inventory information for the 1971–1988 waste and the 1988–1995 waste are obtained from disposal records. However, detailed inventory data are not available prior to 1971 and are uncertain for future activities. Therefore, the inventory in the 1957–1970 waste is extrapolated backwards based on disposal operations from 1971 to 1977, and the inventory for the 1996–2044 waste is projected based on current operations and expected future operations (Schuman 1997a; Vold and Shuman 1996).

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The release of radionuclides from the disposal units is represented by one of two release mechanisms: rapid release or solubility-limited release (Vold and Schuman 1996). The maximum porewater concentration of each nuclide is calculated based on its inventory, its waste volume and the moisture content in the pits. This concentration is then compared to the nuclide's solubility limit to determine which source-release model is appropriate for each nuclide in each disposal unit. That is, if the maximum porewater concentration exceeds the nuclide's solubility limit, the release concentration is held at the solubility limit until that nuclide's inventory has been exhausted. If the porewater concentration does not exceed the nuclide's solubility limit, the rapid-release model is used. Nuclides with very large solubility limits, such as ^{129}I and ^{99}Tc, are controlled by this mechanism throughout the site.

4-B-5. Computational Grids

The stratigraphic configuration used for the unsaturated zone model is derived from various sources including the then-current LANL site-wide geologic model (Vaniman et al. 1996), well-log picks, and surface observations. The data set is interpolated with the Stratagraphic Geocellular Modeling SGM Software Stratamodel to generate the three-dimensional geologic framework model. The three-dimensional unsaturated zone grid is generated with the Geomesh/X3D software (Gable et al. 1995) from this geologic framework model. An initial grid is constructed with the 45.7-m spacing of the geologic framework model and then resolved to include the 38 waste disposal pits and to better delineate the mesa sides. The final grid contains 41,542 nodes and 254,614 tetrahedral elements.

The saturated zone model extends from just west of the site to the Rio Grande. The grid is rectangular and oriented perpendicular to groundwater equipotentials. It is 9773 m long, 1280 m wide, and 100 m deep with 19,580 nodes and 102,960 tetrahedral elements. To better model the vertical dispersion of the contaminant plumes entering the aquifer from the unsaturated zone, the vertical element height is refined near the water table. The grid is also refined horizontally beneath the site to approximately 500 m downstream to accurately capture the spatial distribution of the radionuclides as they move toward the downstream compliance regions.

4-B-6. Model Implementation

Model implementation issues include how to assign the flow boundary conditions, initial conditions for transient flow, and hydraulic parameters in the model. We will also discuss some assumptions employed in model implementation.

To determine appropriate infiltration rates for the site, Birdsell et al. (2000) ran 5 two-dimensional simulations using different steady mesa-top infiltration rates of 10 mm/year, 1 mm/year, 0.1 mm/year, 0.01 mm/year and 0.0 mm/year, and compared the simulated saturation profiles to site field data. Figure 4-B-2 (adapted from Figure 5 of Birdsell et al. 2000) shows the calculated steady-state saturation profiles at the center of the mesa for the five infiltration rates along with the ranges of in situ saturation data measured in the six Bandelier Tuff units. The shape of the calculated saturation profiles shows the same trend as the data, e.g. saturations

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decrease from Unit 2 to Unit 1v-u and then increase again in Unit 1v-c, etc., but no single infiltration rate yields predicted saturation values that fit the entire data set. Based on their study, together with that of Newman (1996), Birdsell et al. (2000) used a range of mesa-top infiltration rates from 1 to 10 mm/year. The bottom boundary for the unsaturated zone model is the water table.

For the saturated-zone model, a steady flow field is calculated by applying a pressure head difference of 101 m (Purtymun 1995) across the east and west sides of the model. No-flow boundaries are used for the top, bottom, north and south sides. Recharge is believed to occur mainly to the west of the site, at higher elevations in the Jemez Mountains. A water-balance estimate shows that the volume of water entering the aquifer from the unsaturated zone at the site is negligible compared to the aquifer volume (Birdsell et al. 1999). Thus, water flowing from the unsaturated zone to the aquifer is not included.

Several assumptions have been made in implementing the simulation model, including steady infiltration rates and an equivalent continuum medium for the Cerros del Rio Basalts. Although the deep percolation is thought to be seasonal with most occurring during spring snow melt and to a lesser extent during the summer thunderstorm season (Rogers et al. 1996a), Birdsell et al. (1999) studied the effects of annual transients in percolation rate on unsaturated zone transport at the site. They found that simulated transient pulses are damped with depth so that the calculated cumulative contaminant flux at the base of the Bandelier Tuff is similar under transient and steady flow fields.

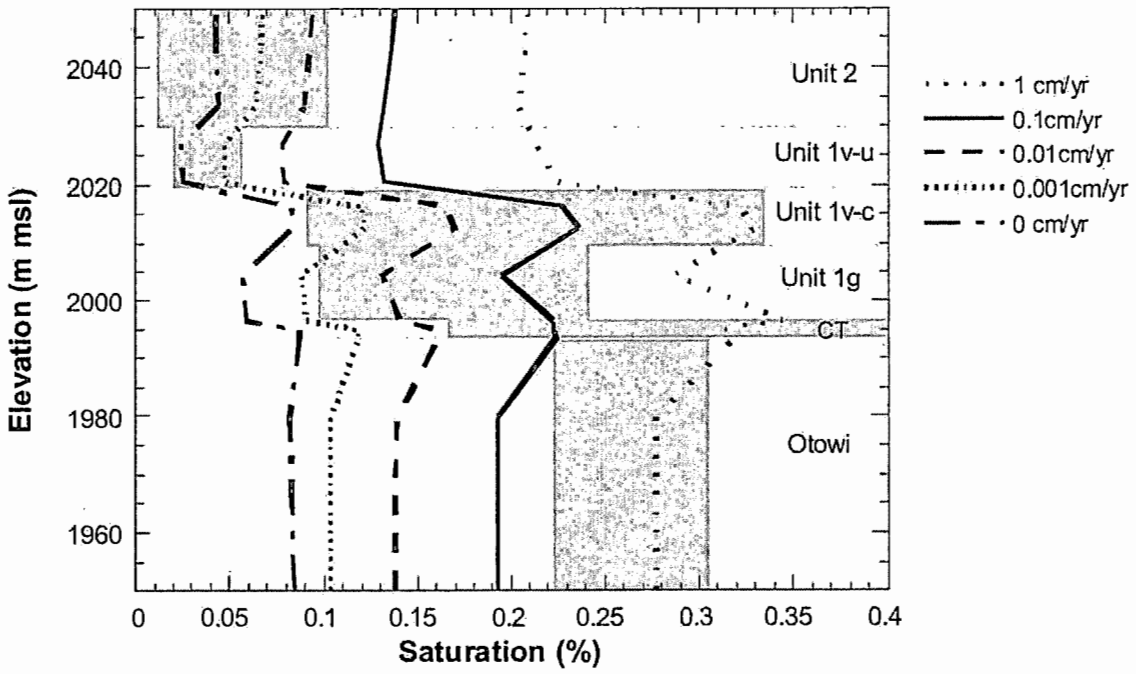

Figure 4-B-2. Comparison of site data (gray boxes) to calculated steady-state saturation profiles for several infiltration rates.

Another important assumption is that matrix flow dominates in the unsaturated tuff units at the site. This assumption is justified by considering that the pits are excavated completely through Unit 2, the most highly fractured tuff unit, thus excluding the fracture system and the likelihood of fracture flow through this unit. In addition, numerical studies of fracture flow for the site indicate that flow through fractured tuffs is difficult to maintain in low-saturation, high-capillarity systems (Soll and Birdsell 1998). Because the site in this study is a solid waste site, significant fracture flow through the unsaturated tuff units is unlikely.

Furthermore, the basalt is modeled as an equivalent continuum medium made up of both fractures and matrix material (Peters and Klavetter1988). Matrix properties are derived from analog basalts in Idaho (Bishop 1991). Fracture properties are chosen, through numerical sensitivity studies, so that no lateral diversion occurs at the top of the basalts in the simulations, even when the flow rate exceeds the matrix saturated hydraulic conductivity. The continuum porosity is set equal to the fracture volume fraction, 10^{-4}, to ensure rapid transport of 1 to 5 years through this unit, hence, foregoing any retardation due to matrix flow or sorption. Notice that this treatment of transport through the basalt yields a conservative result e.g., faster groundwater travel times and higher peak doses than actually expected.

It is evident that there is significant uncertainty in infiltration rates. For the purpose of sensitivity analyses, we defined a base-case set of infiltration rates as a reference, as listed in Table 4-B-1. Variations are made on the base-case infiltration rates to examine the impact of uncertain parameters on the model results.

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4-B-7. Representative Transport Result

Unsaturated zone transport calculations were run for ^{14}C, ^{129}I, ^{237}Np, ^{99}Tc, and ^{238}U using the base-case, steady flow field, 5_1_50 (nomenclature for these model results is defined in Table 4-B-1). These nuclides were chosen because of their low distribution coefficients, ranging from 0 to 2.43 for most of the unsaturated zone units. Using screening techniques developed by Birdsell et al. (1995), Birdsell et al. (2000) chose ^{14}C, ^{129}I, and ^{99}Tc, and eliminated the remaining nuclides from consideration in the dose assessment.

Figure 4-B-3 (adapted from Figure 8 of Birdsell et al. 2000) shows the simulated ^{129}I plumes in the unsaturated zone for the four age-dependent waste classes after 1000 years using the base-case flow field. Although the infiltration rate at each source region is the same (5 mm/year), the four plumes are quite different due to both inventory variations and differences in bed thickness. The inventory distribution in the disposal units is heterogeneous, leading to large variations in radionuclide flux from the disposal units to the unsaturated zone. For example, the 1971–1988 (Figure 4-B-3b) inventory dominates the total site release of ^{129}I to the aquifer at 1000 years. Also, the 1988–1995 shafts located near the southern edge of the mesa (Figure 4-B-3c) concentrate nearly 80% of the 1988–1995 ^{129}I inventory into a small area. This localized inventory produces a predominant plume at the southern portion of the mesa, while the pits to the north and west produce the less concentrated plumes. The location of the basalt unit and the effect on plume migration of the vertical, fracture-dominated flow through this unit is readily visible in these simulations. Once the solutes reach the basalt, they migrate quickly through the unit. In the 1996–2044 waste scenario (Figure 4-B-3d), only the plume's leading edge reaches the basalt after 1000 years because the Bandelier Tuff units are much thicker beneath this proposed expansion area.

To assess the effect of uncertainty in flow rate on transport results, Birdsell et al. (2000) examined the transport of the 1988–1995 ^{129}I inventory using different flow fields and compared the nuclide fluxes through the unsaturated zone. Figure 4-B-4 (from Figure 10 of Birdsell et al. 2000) shows the total flux of ^{129}I for the five flow fields described in Table 4-B-1. By comparing the 1_1_20 case, the 5_1_20 case, and the 10_1_20 case, it is seen that increased mesa percolation leads to faster breakthrough and increased solute flux through the unsaturated zone. This flow-rate dependency is compounded by the velocity-dependent rapid-release source term. The solute flux at 1000 years for the lowest flow case, 1_1_20, is five to seven orders of magnitude less than the other cases considered. This case is used to predict the lower-bound dose in the uncertainty analysis. Comparing the 5_1_20 case to the 5_1_50 case shows that additional flow through Pajarito Canyon results in faster breakthrough and increased solute flux to the saturated zone. The 10_5_100 case represents the wettest case and yields the fastest breakthrough and highest flux to the saturated zone and, consequently, the highest dose over the first 1000 years. This case is used to estimate an upper-bound dose for the uncertainty analysis.

Table 4-B-1.
Infiltration Rates (mm/year) Used as Upper Boundary Conditions for MDA G Performance Assessment

	Mesa Top	Cañada del Buey	Pajarito Canyon
1_1_20 (lowest flow case)	1	1	20
5_1_20	5	1	20
5_1_50 (base case)	5	1	50
10_1_20	5	1	20
10_5_100 (highest flow case)	10	5	100

Source: Birdsell et al. (2000).

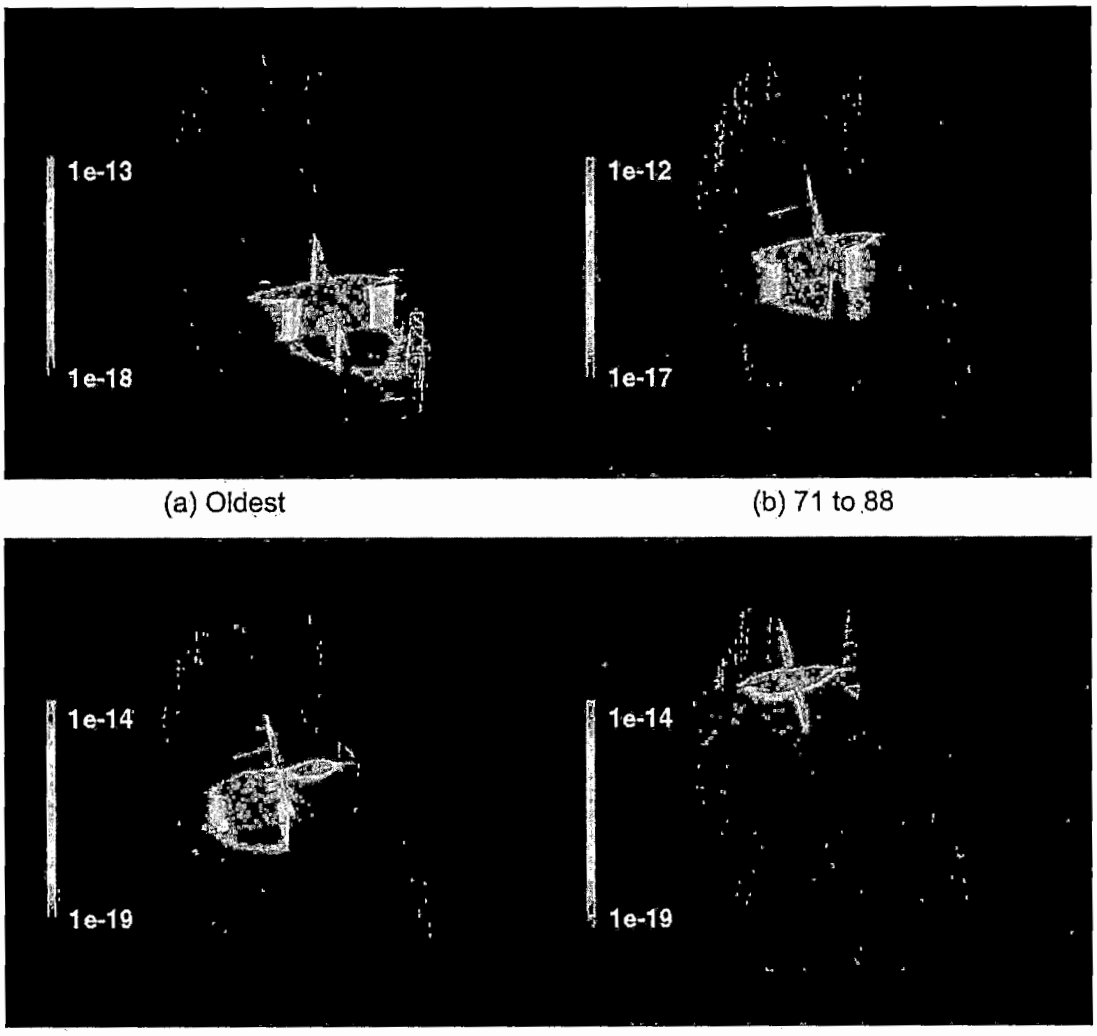

Figure 4-B-3. Iodine-129 plumes (concentration, moles/liter) in the vadose zone at 1000 years for the four different source regions, base-case flow field.

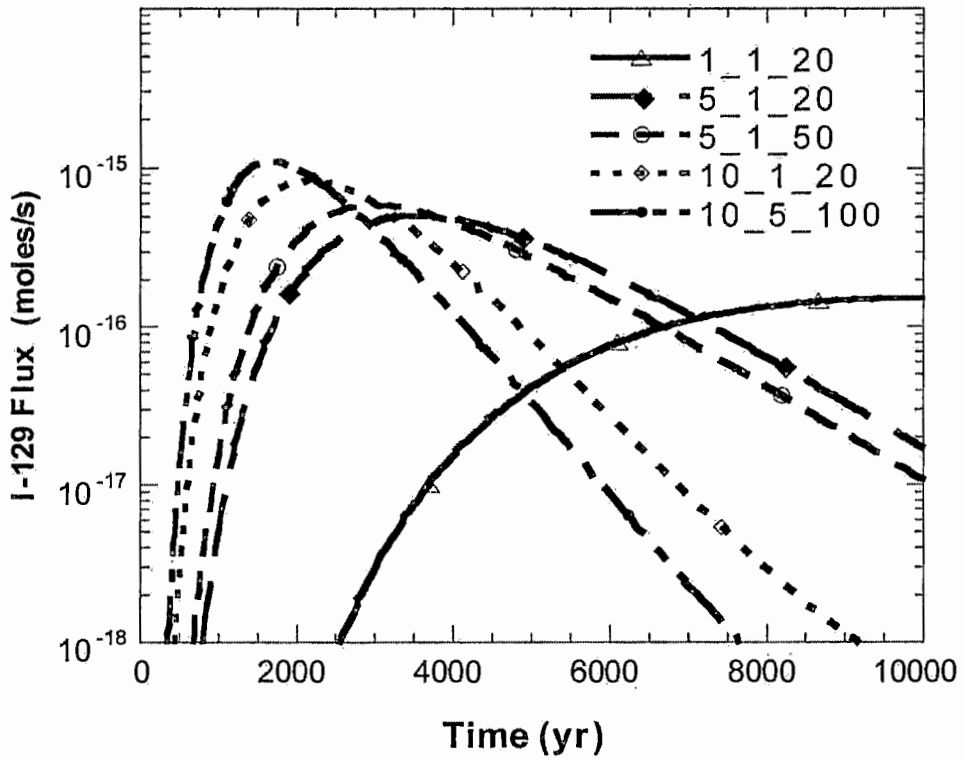

Figure 4-B-4. Total flux of the 1988–1995 ^{129}I inventory from the unsaturated zone to the saturated zone for various flow cases.

4-B-8. Discussion

Due to uncertainty in model parameters, the results of these transport simulations contain intrinsic uncertainty. The greatest uncertainties associated with predicting aquifer-related doses from the site, according to Birdsell et al. (2000), are related to the understanding of the mechanisms that control flow and transport within the unsaturated zone and our ability to model these mechanisms. At this point, they concluded that uncertainty related to the hydrologic processes themselves, i.e., conceptual model uncertainty, dominates the ability to make accurate predictions of transport at the site moreso than uncertainty related to the hydrologic and geochemical properties data. Importantly, however, predicted doses using parameters from the most conservative ends of the uncertain ranges are still well below regulatory concern.

The results of Birdsell et al. (2000) indicate that the mesa-top infiltration rate has the greatest impact on the simulated migration of waste through the unsaturated zone. It controls both the source release rate and subsequent downward solute migration. They bounded this uncertainty by considering a base-case flow field and high- and low-flow cases. As shown in Table 4-B-2, a variation in mesa-top infiltration rate from 1 to 10 mm/year results in a range of six orders of magnitude in the 1000-year groundwater-related doses. Clearly, a good understanding of this key parameter is important to the dose assessment. However, because doses are so much less than the performance objectives developed in Birdsell et al. (2000), conservative yet realistic infiltration rates seem adequate for this site. With respect to travel times, models of dry mesas such as that

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associated with MDA G generally predict travel times in the neighborhood of 1000 years or more. This basic result indicates that groundwater pathway risks associated with waste disposed under dry mesa conditions are expected to be risks that will present themselves far into the future, as opposed to there being a significant present-day risk. This result applies only to the groundwater: a complete pathway assessment should be conducted that includes other exposure scenarios in addition to groundwater.

Table 4-B-2.
Maximum Ground Water and
All Pathways Doses for the PA and CA Wastes,
Base Case Flow Field (mrem/yr) MDA G Performance Assessment.

	PA - Ground Water	PA - All Pathways	CA - All Pathways
Performance Objective	4	25	100
1000 yr (Base Case)	2.4×10^{-7}	6.5×10^{-7}	3.7×10^{-5}
Peak Dose (Base Case)	3×10^{-5} @ ~4500 yrs	1×10^{-4} @ ~4500 yrs	2×10^{-3} @ ~3000 yrs
1000 yr (high-flow case)	8.0×10^{-6}	2.2×10^{-5}	1.4×10^{-3}
1000 yr (low-flow case)	9×10^{-12}	2×10^{-11}	1×10^{-10}

Source: Birdsell et al. (2000).

Finally, there are residual uncertainties related to flow in the deeper unsaturated-zone units for which few hydrologic data are available. The simulations take virtually no credit for transport times through the Cerros del Rio basalts, which make up more than 50% of the unsaturated zone. The transport results are based on the steady-flow assumption and on the use of matrix, hydrologic properties for all tuff units at the site. The response of this fractured system to transient flow events is not completely known. Transient calculations (Birdsell et al. 1999) indicate that the steady-flow assumption is adequate because fluctuations in both saturation and contaminant flux rates dampen with depth even when including fractures in the upper two units. Fracture infiltration studies (Soll and Birdsell, 1998) lead to the conclusion that fracture flow is difficult to initiate and is short-lived in the upper two tuff units at the observed low field saturations. These conclusions are supported by modeling studies presented for Los Alamos Canyon in Appendix 4-C, as well as the findings of Robinson et al. (2005b).

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APPENDIX 4-C. LOS ALAMOS CANYON MODEL

4-C-1. Introduction and Motivation

Los Alamos Canyon, as shown in Figure 4-6, is one of the most complex sites at the Laboratory. A number of technical areas have been or are currently located in or adjacent to the canyon, resulting in multiple release locations along the canyon. This section examines, through a synthesis of available data and the development of numerical models, fluid flow and contaminant transport in the vadose zone beneath Los Alamos Canyon. The subsurface hydrology and transport in the vadose zone is also a challenging activity, given the wide range of infiltration rates, the presence of perched water, and the introduction of a host of contaminants of different chemical properties. Because the canyon serves as a collector of a wide range of contaminants, we decided that it was necessary to develop a model at the scale of the canyon, rather than at a smaller scale. The specific goals of the model are as follows:

- Synthesize the available data and conceptual understanding of the vadose zone hydrology beneath Los Alamos Canyon;
- Produce a "base-case" numerical model of the subsurface vadose zone hydrology that ultimately can be used to predict contaminant migration rates and concentrations in fluids reaching the regional aquifer beneath the canyon;
- Quantify the uncertainties associated with those predictions by establishing the bounds on system behavior through a suite of possible models, all of which are consistent with the available data, but which bracket the range of possible behavior;
- Provide a simulation tool for predicting the fate and transport of contaminants in Los Alamos Canyon under different assumed hydrologic and ER stewardship scenarios; and
- Demonstrate a model development methodology that can be used in studies of other canyons on the Pajarito Plateau.

This work focuses on the hydrology beneath Los Alamos Canyon, as a first step toward developing a predictive tool that can be used to simulate contaminant migration in the canyon. Since water is the carrier fluid for the contaminants of interest, constructing a realistic flow model that captures the most important hydrologic processes of the vadose zone is an essential first step in the development of a reliable model. Although we primarily restrict attention to flow issues, tritium transport in the vadose zone is also modeled here. Tritium, in the form of tritiated water, is an excellent tracer for groundwater, and hence is included in this modeling study as a constraint on the flow model. Although the work here is restricted to Los Alamos Canyon, we anticipate that the methodology and approach applied here can be used to develop models at other sites at the Laboratory.

4-C-2. Hydrostratigraphy

Accurate modeling of groundwater flow and transport in Los Alamos Canyon requires the integration of geologic model information with computational grids. Stratamodel was used to create a three-dimensional geologic framework model for Los Alamos Canyon. The geologic framework model consists of 20 distinct geologic units and is the product of a continuous process of model development and improvement in support of the Hydrogeologic Workplan

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(LANL 1998) activities, including the development of numerical flow and transport models such as the present study. The record of model development and improvement is documented in various LANL reports (Vaniman et al. 1996, Carey et al. 1999). The different versions of the geologic models are distinguished based on the fiscal year (FY) in which they were built. Several of the sensitivity analyses were performed with the FY98 version as the geologic basis, while most of simulations are done based on the FY99 version.

The defined stratigraphic units and their accepted designators are listed in Table 4-C-1. Figure 4-C-1 shows a two-dimensional cross section of the geologic model, illustrating the complexity of the current conceptualization of the subsurface. A characteristic of this two-dimensional stratigraphic model that is different than other models developed for sites on the Pajarito Plateau such as MDA G (Birdsell et al. 1999) and Mortandad Canyon (Dander 1998) is the absence of significant thickness of the Tshirege Member of the Bandelier Tuff. Los Alamos Canyon cuts deeply into the Bandelier Tuff such that the Otowi Member is the first unit encountered beneath the alluvium in the canyon bottom over much of the model domain. In the eastern portion of the model, the Otowi is not present, and instead the Cerros del Rio (Tb4) is the first unit encountered. This is the case at R-9, where the stratigraphic section consists only of basalts and the Puye Formation. Figure 4-C-2 depicts the full three-dimensional model stratigraphy, along with the locations of important wells and facilities referred to later.

Table 4-C-2 lists the hydrologic properties used for the Los Alamos Canyon model. Permeability and porosity values used for each unit are listed first, followed by the unsaturated hydrologic parameters for the van Genuchten (1980) formulation used in the present study. It is assumed in this study that hydrologic properties are homogeneous within each individual unit. Although the appropriate hydrologic properties for the various units are thought to be somewhat site dependent, these property values are representative averages of site-wide conditions and can be used as a starting point for vadose zone numerical simulations.

Table 4-C-1.
Stratigraphic Units Present in the Vicinity of Los Alamos Canyon

Group/Formation	Unit Name	Symbol
Tshirege Member of the Bandelier Tuff	Unit 5	Qbt5
	Unit 4	Qbt4
	Unit 3	Qbt3
	Unit 2	Qbt2
	Vapor-phase altered member of Unit 1	Qbt1v
	Glassy member of Unit 1	Qbt1g
	Tsankawi Pumice	Qbtt
Cerro Toledo Interval	Cerro Toledo	Qct
Otowi Member of the Bandelier Tuff	Otowi Member ash flow	Qbof
	Guaje Pumice bed	Qbog
Puye Formation	Puye fanglomerate	Tpf
	Totavi Lentil	Tpt
Cerros del Rio basalt	Basalt 4	Tb4
	Basalt 3	Tb3
	Basalt 2	Tb2
	Basalt 1	Tb1
Tschicoma Formation	Tschicoma latite	Tt2
	Tschicoma dacite	Tt1
Santa Fe Group	Chaquehui (volcaniclastic) aquifer unit	Tsfuv
	Santa Fe Group undifferentiated	Tsfu

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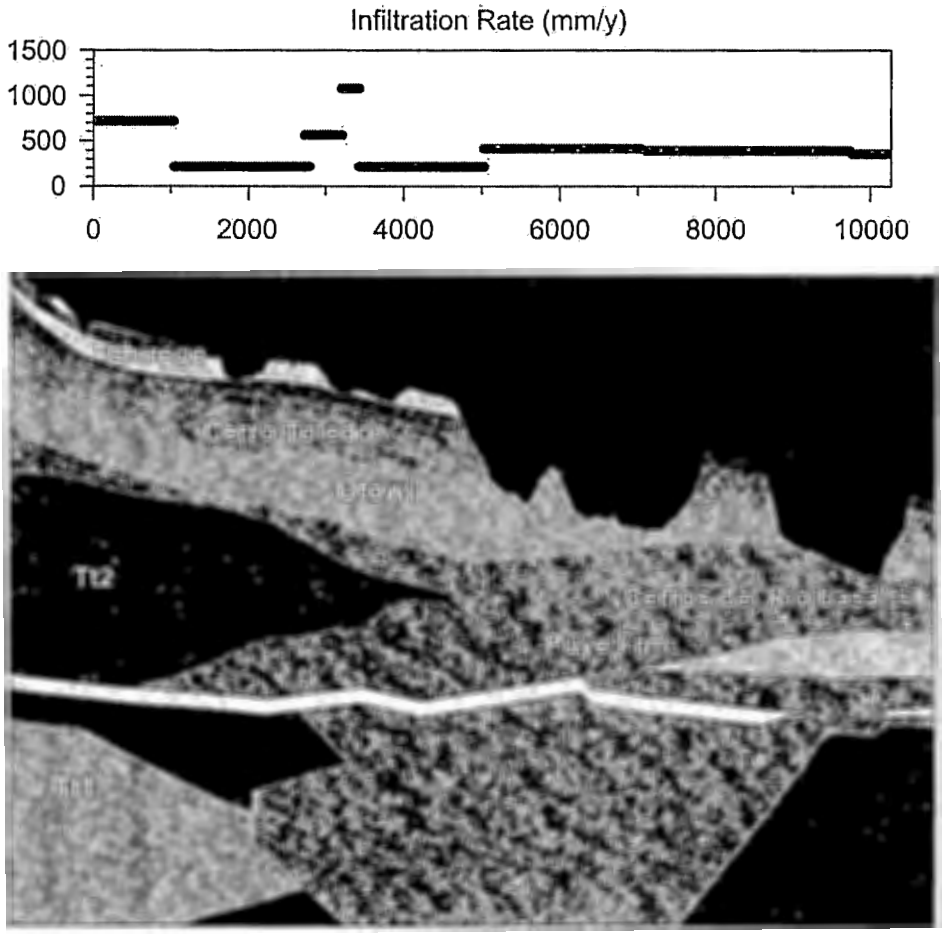

Figure 4-C-1. Cross section of stratigraphy in the vicinity of Los Alamos Canyon. Also shown is the infiltration map used along the canyon bottom (derived from water budget study of Gray 1997).

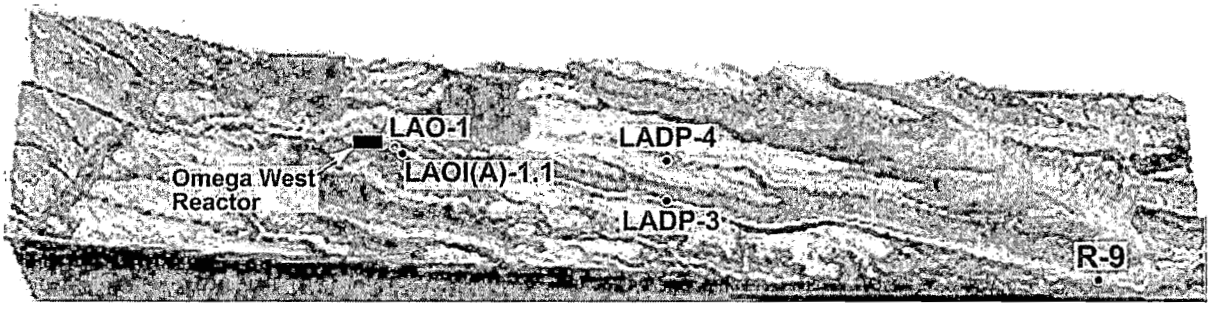

Figure 4-C-2. Three-dimensional depiction of the stratigraphic framework model used to construct the flow and transport model for Los Alamos Canyon. Important wells and the site of a nuclear reactor are also shown.

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Table 4-C-2.
Hydrologic Property Values in the Los Alamos Canyon Model

Hydrogeologic Unit	Geologic Designation	Permeability, m^2	Porosity	Van Genuchten α parameter, m^{-1}	Residual Moisture Content	Van Genuchten n parameter, unitless
Unit 3, Tshirege Member	Qbt3	1.01e-13	0.469	0.29	0.045	1.884
Unit 2, Tshirege Member	Qbt2	7.48e-13	0.479	0.66	0.032	2.09
Vitric unit, Tshirege Member	Qbt1v	1.96e-13	0.528	0.44	0.009	1.66
Glassy unit, Tshirege Member	Qbt1g	3.68e-13	0.509	2.22	0.018	1.592
Basal pumice unit, Tshirege Member	Qbtt	1.01e-12	0.473	1.52	0.01	1.506
Cerro Toledo Interval	Qct	8.82e-13	0.473	1.52	0.01	1.506
Otowi Member	Qbof	7.25e-13	0.469	0.66	0.026	1.711
Guaje Pumice Bed	Qbog	1.53e-13	0.667	0.081	0.01	4.026
Cerros del Rio Basalt, Puye Formation	Tb4	2.47e-12	0.3	0.1	0.066	2.
Tschicoma dacites	Tt2	2.96e-13	0.3	0.1	0.066	2.
Miocene basalts, Santa Fe Group	Tb3	2.96e-13	0.3	0.1	0.066	2.
Puye Formation	Tpf	4.73e-12	0.25	5.	0.01	2.68
Totavi Lentil	Tpt	4.73e-12	0.25	5.	0.01	2.68
Santa Fe Group	Tsfuv	2.65e-13	0.25	5.	0.01	2.68

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4-C-3. Infiltration Rates and Water Budget Model

The infiltration rate on the upper surface is one of the most important inputs in simulating flow and transport in the site. For the mesa areas, various hydrologic and chemical techniques have been employed to estimate infiltration rates in various settings. Rogers et al. (1996a) outlined an interpretive technique for estimating local infiltration rates based on measured hydrologic properties and water content values in samples collected from the vadose-zone tuffs. They obtained infiltration rates on mesas as low as 0.06 mm/yr with higher mesa values only found where surface conditions such as ponds were present. In more recent analyses, Birdsell et al. (1999) obtained a value on the order of 1 mm/yr for undisturbed mesa conditions at TA-49, and values estimated from 60-300 mm/yr beneath paved regions. At TA-16, chloride mass balance data collected by Newman (presented in Birdsell et al. 2005) were interpreted using the chloride mass balance method. Infiltration rates slightly higher than 1 mm/yr were obtained in this manner, which is consistent with the analyses of moisture content. Therefore, an infiltration rate of 1 mm/yr is assumed at all locations except the canyon bottom in the current model.

To estimate the infiltration rate along Los Alamos Canyon, we use the study of Gray (1997), who focuses on the water budget and fluid flow in the surface water stream and shallow alluvial aquifer in Los Alamos Canyon. The fundamental model equation used to evaluate the water budget is

$$I = P - R - ET - \Delta S$$

where I is infiltration, P is precipitation, R is runoff, ET is the evapotranspiration term, and ΔS is the change in fluid storage. Since there was no experimental basis for estimating ΔS, Gray assumes it to be zero, listing it as an uncertainty in his analysis. The water budget calculations employed data from several sources, including stream-flow data from three stream-flow gages that provide estimates of surface water flow rates, and meteorological data from five precipitation measurement stations. These data were used by Gray in both an overall water budget for the canyon and a detailed water budget calculation. Details can be found in Gray (1997).

Figure 15 of Gray (1997) shows the results from the overall water budget performed for Los Alamos Canyon. The key result from this aspect of Gray's work is the estimation of the relative amounts of ET, runoff, and infiltration to the deeper vadose zone. Over the three-year period of that study, Gray found that 71% to 83% of the water introduced into Los Alamos Canyon was lost to evapotranspiration. Gray points out many limitations and uncertainties in this estimate. Given the direct influence of this term in the water budget and indirectly on infiltration rate, a more comprehensive study of the processes is warranted. Most of the rest of the water not undergoing evapotranspiration is estimated to be recharging the deeper vadose zone, whereas runoff was found to be relatively small. Average infiltration rates applicable to the Los Alamos Canyon watershed were found to range from roughly 100 to 200 mm/yr for the period of study. These values are average values for the watershed, and might be expected to be higher locally directly beneath the stream channel.

In addition to the overall water budget, Gray (1997) conducted a detailed study using measured data and a numerical model to further break down the components of the water balance. A calibrated numerical flow model of the alluvial aquifer was developed to analyze the spatial and temporal distributions of infiltration in the canyon. Gray divided the canyon alluvial aquifer model into nine zones that corresponded to locations of the monitoring wells used in the model calibration. The model calibration procedure involved adjusting the drain conductance term that controlled the water flux leaving the alluvial aquifer (and entering the underlying bedrock) to match the water level data. The other terms in the water budget (excepting the storage term) were also included in the model, so that the calibration procedure provides a direct estimate of the spatially dependent infiltration rate along the canyon. Table 4-C-3 summarizes the results of this analysis. The highest infiltration rate of 1076 mm/yr occurs in Gray's Zone 4, corresponding to well LAO-0.8. This well falls near the southern projection of the Guaje Mountain fault zone, and was determined to have a strikingly low water level. This observation, and the numerical model calibrated to it, suggest high infiltration in this zone, perhaps due to an enhanced permeability due to fracturing. Zones 1 and 3 also exhibit higher than average infiltration. Gray postulates that Zone 3 may be higher because of its proximity to the Guaje Mountain fault, and Zone 1 infiltration may be high due to a greater saturated thickness in this portion of the canyon. The rest of the Los Alamos Canyon study area exhibited lower infiltration rates.

4-C-4. Contaminant Sources

A host of possible contaminant source sites exist for Los Alamos and DP canyons, resulting from past and present Laboratory operations. The most important of these for our purposes include TA-1 (Townsite), TA-41 (Weapons Development Facility), TA-2 (Omega West Reactor Site), TA-21 (DP Site), and TA-53 (LANSCE). In particular, the Omega West reactor site, located in Los Alamos Canyon, was used since 1943 to house and operate a series of research reactors. Early reactors were fueled by aqueous uranyl solutions, whereas other reactors were fueled by solid fuel elements. A variety of contaminants (mostly radionuclides) are suspected to have been released into the canyon. Most relevant to the present study is tritium, produced from a leak in the primary cooling water system at the reactor. The leak occurred from a break in a weld seam in a section of the delay line running from building TA-2-1 to the surge tank. This leak was discovered in 1993, and tritium was detected within a stretch of canyon corresponding to the southern projection of the Guaje Mountain fault zone. Typical concentrations in the cooling water ranged from 15.7×10^6 to 20.2×10^6 pCi/L. The duration of the leak is not documented, but measurements of tritium concentrations in alluvial aquifer well LAO-1 (located at the eastern boundary of TA-2) suggest that the leak may have begun between November 1969 and January 1970. This reactor was permanently shut down in 1994.

In the transport simulations, among all possible contaminants, we choose tritium, which, in the form of tritiated water, is among the simplest chemical constituents to model because its chemical state as a water molecule implies that it is a tracer for water. Other contaminants may undergo sorption, precipitation, and complex speciation processes that complicate the transport simulation.

Table 4-C-3.
Infiltration Rates for Various Portions of Los Alamos Canyon*

Zone	Location	Infiltration, mm/yr	ET, mm/yr	Downgradient Loss, mm/yr
1	LA Reservoir to 1100 ft east of bridge	714	464	56
2	End of Zone 1 to LAO-C	213	167	223
3	LAO-C to LAO-0.6	566	158	547
4	LAO-0.6 to LAO-0.8	1076	0	148
5	LAO-0.8 to LAO-1	222	195	93
6	LAO-1 to LAO-2	408	28	111
7	LAO-2 to LAO-6	399	93	46
8	State Rt. 4 to Lab boundary	362	139	19
9	East of Lab boundary	325	121	0

* Values from the analysis of Gray (1997)

4-C-5. Numerical Grids

To deal most efficiently with issues of computational demands and model accuracy, we have utilized both two- and three-dimensional models for various flow and transport model analyses. A major advantage of two-dimensional grids is the smaller number of nodes and elements. Calculations run very quickly, making the grid appropriate for scoping calculations and sensitivity studies. When very high spatial resolution is required, three-dimensional grids are also necessary. However, since the grid is two-dimensional, there are limitations as to what spatial variability of flow properties can be captured in the model. In two-dimensional simulations, the model domain implicitly assumes that flow is negligible in the direction normal to the grid. This problem is relaxed in the three-dimensional grid, at the cost of greater computational times and a somewhat reduced grid resolution. Computational grids have been built for both the two-dimensional and three-dimensional simulation models.

For the two-dimensional grid, the western boundary of the domain is located at New Mexico state plane coordinates (492916.5, 541257.7), just west of the Omega Bridge. Note that all state plane coordinates are specified in meters. The eastern boundary extends in a one-dimensional fashion from the western boundary to a coordinate location of (502959.6, 539688), just west of the intersection of State Route (SR) 4 and New Mexico State Highway (NMSH) 502. The extent of Los Alamos Canyon in the two-dimensional model is represented by drawing a one-dimensional line as closely as possible down the center of the canyon. To do this, the length of the canyon was traced from the western to the eastern boundary using a digital topographic map as a reference in Stratamodel (See Figure 4-6). The bends in Los Alamos Canyon are also accounted for. The final version of the two-dimensional grid for Los Alamos canyon consists of 57,004 nodes, 111,256 tetrahedral elements, and contains 11 materials.

In the process of selecting the simulation domain for the three-dimensional Los Alamos Canyon grid, we consider the historical information about contaminant releases and important sites along the canyon that may be relevant to contaminant transport issues in the canyon. It is deemed necessary that areas such as TA-21, TA-2 (the Omega West reactor), DP Canyon, and well R-9 be within the domain of the three-dimensional grid. The Los Alamos Canyon model domain is rectangular in shape and encompasses most of Los Alamos Canyon, DP Canyon, and some of the adjacent mesas to the north and south of Los Alamos Canyon. The model domain extends from the topographic surface to a depth of 1650 meters. Within this grid, we capture both the mesas and the canyon in the same grid, so that infiltration boundary conditions and contaminant releases can be applied correctly. One of the major constraints on the grid building process is to keep the total number of nodes as low as possible but, at the same time ensure that there is adequate resolution in the areas of interest. The final grid, shown in Figures 4-C-3 and 4-C-4, is a three-dimensional grid that is composed of 301,436 nodes, 1,688,457 elements, and 14 unique materials.

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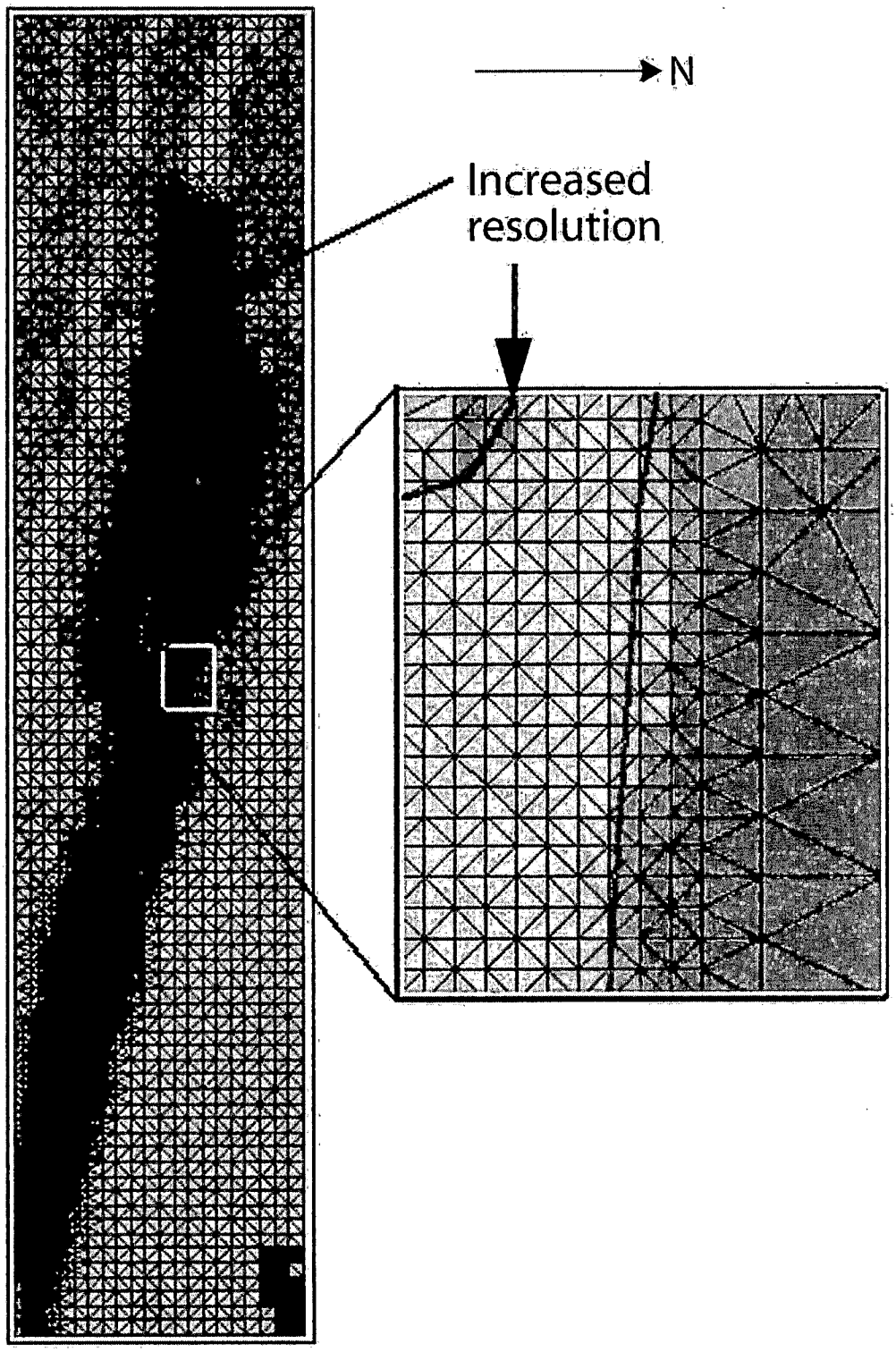

Figure 4-C-3. Three-dimensional model grid. Plan view showing the areas of enhanced grid resolution along Los Alamos and DP Canyons.

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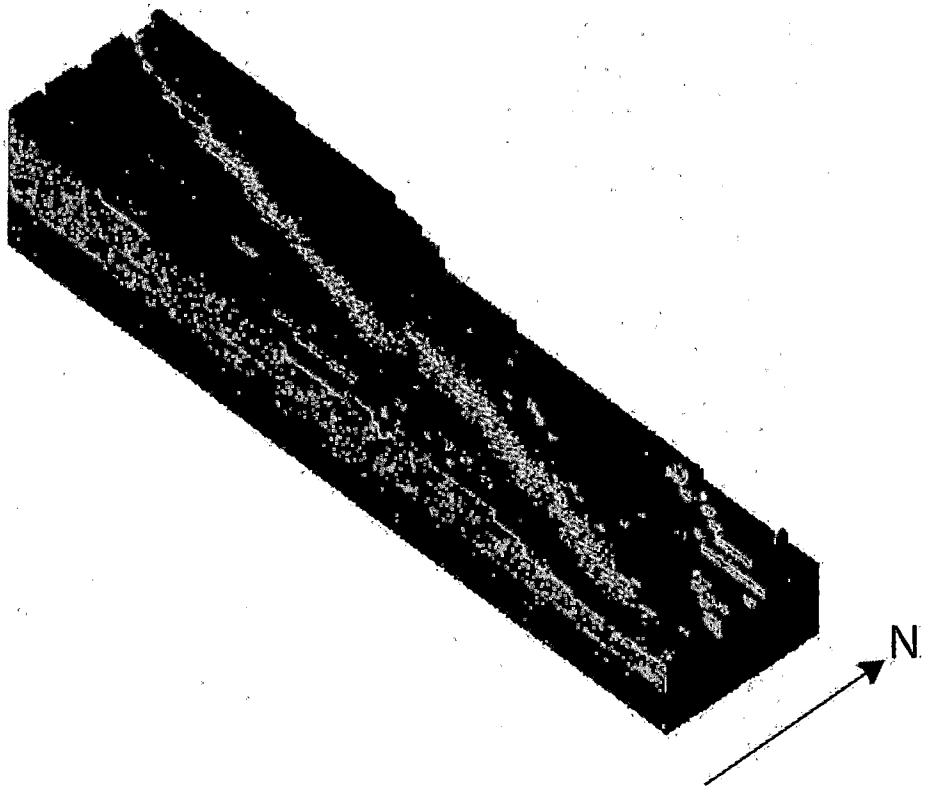

Figure 4-C-4. Three-dimensional view of the Los Alamos Canyon model numerical grid.

4-C-6. Model Implementation

Model implementation issues include how to assign the flow boundary conditions, initial conditions for transient flow, and hydraulic parameters in the model. We will also discuss some assumptions employed in model implementation.

The infiltration values obtained from Gray (1997) in Los Alamos Canyon were applied directly to the two- and three-dimensional models. In the three-dimensional model, it is relatively straightforward to apply an estimated infiltration rate on all grid nodes identified as representing the interface of the alluvium bottom and the bedrock. In a two-dimensional model, we implicitly assume that there are no variations in infiltration in the third dimension (the horizontal direction normal to the canyon). As a result, the appropriate flux to be input to the two-dimensional model is not necessarily the value along the canyon bottom. Figure 4-C-1 shows the infiltration map above the two-dimensional model domain. The infiltration rates so applied in two dimensions are expected to be maximum values. In this study, it is assumed that the relative flux entering the subsurface at different locations along the canyon remains the same, but the absolute value of infiltration is uncertain. The fluid mass flow rate at each top node is determined upon multiplying the infiltration rate at that node by the nodal area normal to the upper surface of the model (for an assumed 1 m thickness of the two-dimensional model domain).

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The bottom boundary condition represents the water table. The water table is estimated from results compiled by Keating (personal communication, 1999). Any node falling below this surface is assigned a value of saturation equal to 0.999 to represent the regional aquifer. Therefore, the vadose zone model domain extends only down to this surface, and the bottom region is simply a boundary condition rather than a calculated result.

The hydrologic properties at each grid node in the two- and three-dimensional models are determined by the properties of the unit in which the node falls. The hydrologic properties used for the Los Alamos Canyon model are listed in Table 4-C-2.

It is evident that there is significant uncertainty in the hydrologic properties and infiltration rates due to, for example, the true variability of medium properties, a limited number of measurements, and measurement errors. For the purpose of sensitivity analyses, we defined a base-case set of hydrologic properties and boundary conditions as a reference. In the base case, the values for the hydrologic properties are taken from Table 4-C-2 and the infiltration rate for the canyon is taken from Table 4-C-3 (1 mm/yr for the mesas). The base case parameter set used the mean values of the hydrologic parameters for all units. This practice has been used in other modeling studies on the Plateau, including Dander (1998) and Birdsell et al. (1999). Variations are made on the base-case parameters to examine the impact of uncertain parameters on the model results.

Once the hydrologic properties and initial and boundary conditions are selected, the flow and transport equations are solved using the finite element heat and mass (FEHM) code that simulates heat conduction, heat and mass transfer for multiphase flow within porous and permeable media, and noncondensible gas flow within porous and permeable media. The code handles model geometries in two or three dimensions, and has a variety of solute transport model options available for use. For details of the fundamental model equations solved by the code, see Zyvoloski et al. (1997).

4-C-7. Fluid Saturation Model Results

Figures 4-C-5 and 4-C-6 show a full three-dimensional view of fluid saturation and a series of two-dimensional vertical slices through the three-dimensional model. As expected, the figure shows wet conditions in the canyon, dry in surrounding mesas. As with the two-dimensional model, this model result shows the overriding importance of the stratigraphy in controlling the water contents in the rock. The local infiltration rate also exerts a strong control on the results. Directly beneath the canyon, fluid saturation is much higher within a given stratigraphic unit than in other parts of the model domain, a reflection of the high infiltration in the canyon.

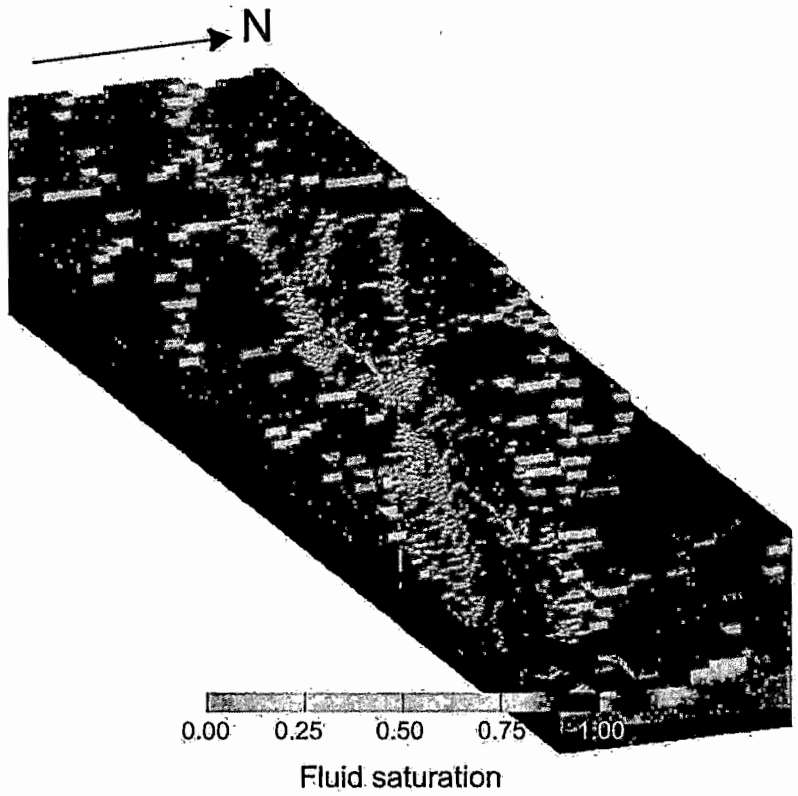

Figure 4-C-5. Full model three-dimensional flow results showing fluid saturation predictions through the model domain.

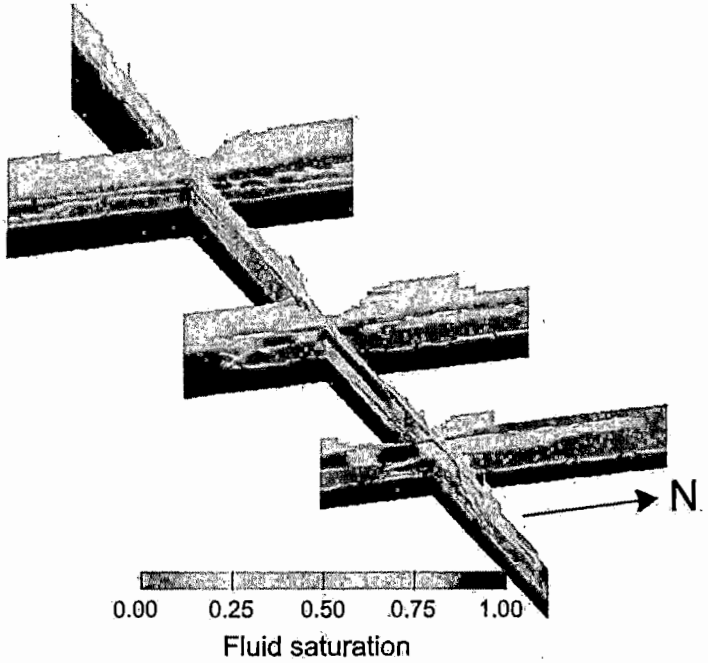

Figure 4-C-6. Fence diagram showing one north-south and three east-west cross-sections.

4-C-7.1 Moisture Comparisons to Data

We choose volumetric water content as the primary measurement used to evaluate the model results because adequate data on water content is available from virtually all vadose zone characterization wells. Robinson et al. (2005a) presents a detailed analysis of the comparisons of volumetric water contents predicted in the three-dimensional model to measured values in three wells located in Los Alamos Canyon: LADP-3, LAOI(A)-1.1, and R-9. Representative results are shown in Figures 4-C-7 and 4-C-8 for wells LADP-3 and LADP-4, respectively. The fits to the data are presented for three different levels of infiltration rates, i.e., the base-case infiltration map, a map with infiltration scaled down by a factor of three from the base map, and a map with infiltration scaled up by a factor of three. It is seen that the base infiltration map does an adequate job of jointly matching the water content profiles in these wells, despite the different stratigraphy and position relative to the canyon bottom. The good fit for LADP-4 illustrates the adequacy of the model in capturing the fluid saturations in the Tshirege Member (not present in the two-dimensional model), as well as in a region where infiltration rates are taken to be significantly lower than in Los Alamos Canyon at LADP-3. The need to apply significantly lower infiltration near LADP-4 is best understood by comparing the water content model and data for these two wells. The significantly wetter conditions in LADP-3 are simulated in the three-dimensional model through the setting of high infiltration in the canyon. It is evident from these comparisons that the model is able to capture the general features of data.

4-C-7.2 Sensitivity Analysis

As was discussed previously, there is significant uncertainty in the hydrologic property values and infiltration rates in the Los Alamos Canyon model. Therefore, it is important to investigate how the deviations of the parameter values from the base case affect the model predictions.

Sensitivity to flow transients. In model simulations presented thus far, it is assumed that the infiltration is time-independent. However, infiltration is likely to be a more transient phenomenon. Gray (1997) shows that in Los Alamos Canyon, water levels in alluvial aquifer wells fluctuate with season in response to summer storm events and spring runoff from snowmelt. It is not clear to what extent these transients are damped by the surface and alluvial aquifer flow processes. To test the potential influence on vadose zone water contents, we take a "worst-case" approach to bound the problem. In the first simulation, we test the sensitivity of the model to a very sharp impulse of water corresponding to the entire predicted infiltration of one-half year concentrated in a one-week time period. This bounding case is intended to model the case of all infiltration occurring in a single spring runoff event and a single summer storm event. Figure 4-C-9a shows the predicted water content profiles in LADP-3 in response to such an event. The influence is only felt in the uppermost ten meters or so of the vadose zone. The quantity of water input during the event, though intense, is insufficient to have a significant influence on the water content profile. These events would then be followed by a half-year of no infiltration, which would cause the profile to bounce back to nearly its original state. Therefore, the assumption of steady-state conditions over time scales of years should have no influence on the interpretation of the water content profiles in the observation wells, except possibly very close to the surface (alluvium-bedrock interface).

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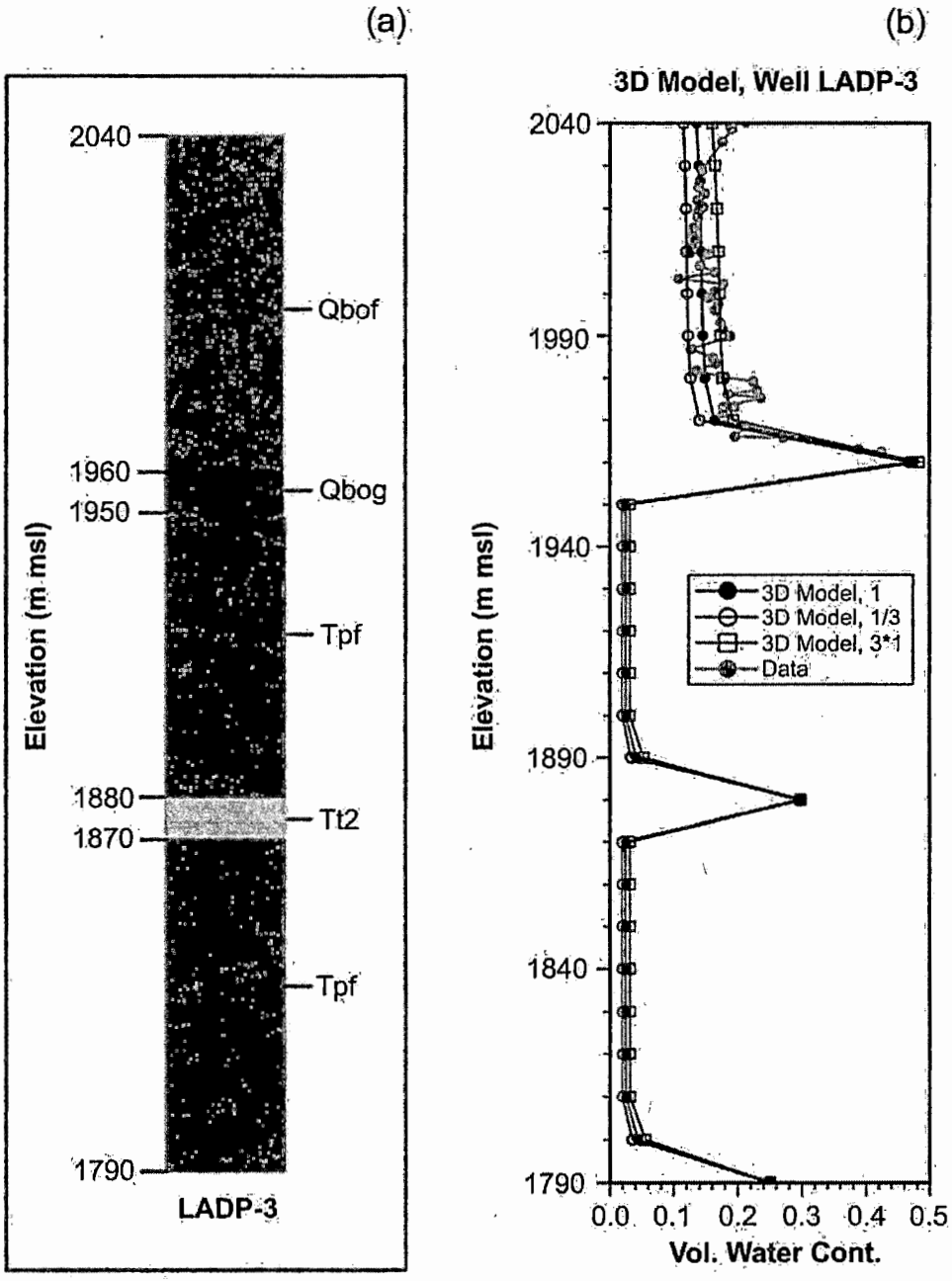

Figure 4-C-7. Comparison of data and three-dimensional model predictions for water contents in well LADP-3 (a. stratigraphy; b. data-model comparison).

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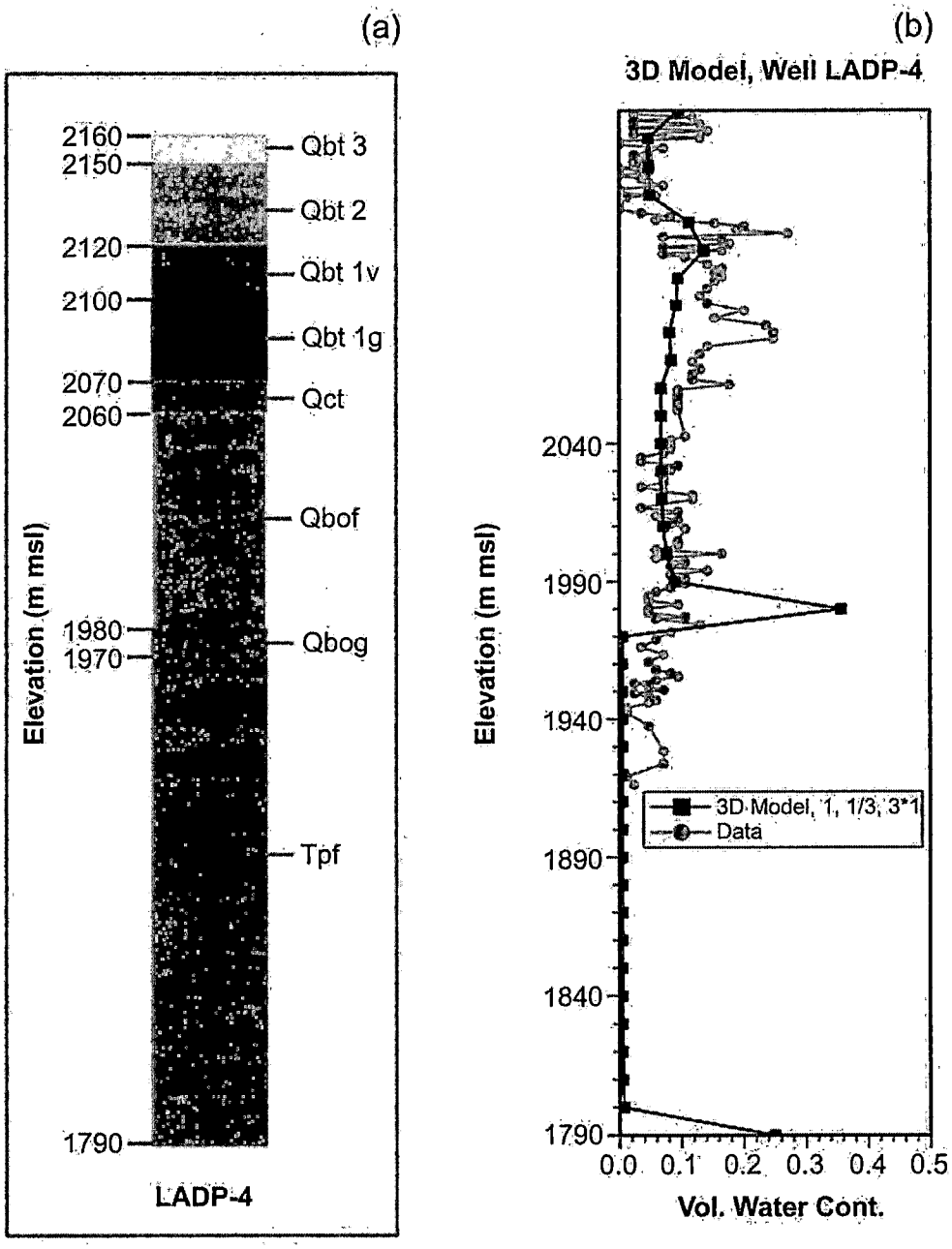

Figure 4-C-8. Comparison of data and three-dimensional model predictions for water contents in well LADP-4 (a. stratigraphy; b. data-model comparison).

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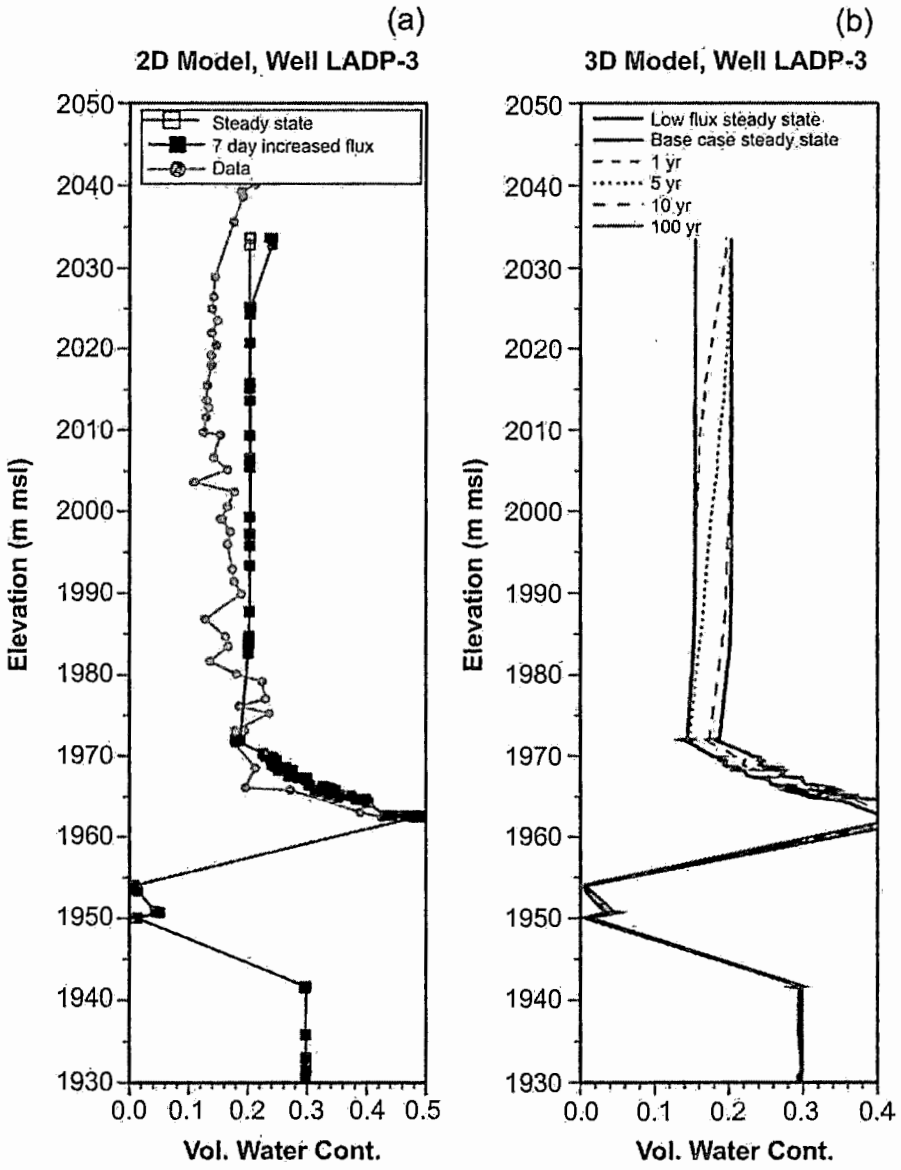

Figure 4-C-9. Two-dimensional model predictions for the water content in response to transient episodes of enhanced infiltration. (a) Well LADP-3, single one-week episode of enhanced infiltration. (b) Well LADP-3, prolonged period of enhanced infiltration (infiltration is increased by a factor of five starting at time 0).

Longer-term variability in the infiltration rate over years or decades could also complicate the interpretation of water content measurements, and thus need to be examined. Figure 4-C-9b shows the results of a simulation in which the infiltration steady state is used as an initial condition, and the rate is increased to the base-case infiltration map at time zero. The plot shows that over a time period of a few years, the water contents increase to significant depths. Within about a decade, the profile throughout the entire section of the Otowi Member reflects the new,

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higher infiltration rate. At times of one or a few years, the transient water content profile shows curvature similar to that seen in several of the observation wells, including LADP-3. This does not necessarily mean that the curvature is caused by such a transient, but simply that reasonable variability in infiltration rates over years to decades complicates the interpretation of the water content profiles. This simulation is meant to provide a caution against over-interpretation of the details of the water content profiles. Furthermore, it is recognized from this analysis that the match of a steady-state model to the data in Los Alamos Canyon represents the fluid flow characteristics of the system within the previous ten to 100 years leading up to the collection of the water content data. In general, this result is dependent on the hydrologic conditions of the particular model area. Wet canyon systems with high infiltration rates have transient time periods of this order of magnitude, while dry mesas may take upward of thousands of years to attain a new steady-state water content profile when the infiltration rate changes.

4-C-8. Tritium Modeling Results

Tritium transport model results are presented to further demonstrate the validity of the model and to explore important processes occurring in the vadose zone. Figure 4-C-10 shows the three-dimensional model predictions of the tritium concentration of fluid reaching the water table in the year 1999. Significant, above-background concentrations are predicted along the canyon at locations downstream of where the Bandelier Tuff is not present in the canyon bottom. An important characteristic of the model is the preferential transport to the water table at locations downstream of the confluence of Los Alamos and DP canyons. The main reason for this result is that the thickness of Bandelier Tuff is much greater at upstream locations in the canyon, whereas in the vicinity of R-9, no Bandelier Tuff is present. Recall that the conceptual model for vadose zone flow consists of matrix flow and transport in the Bandelier Tuff, and preferential fracture flow and transport in the basalt units. Rapid transport to the water table at the downstream locations is due to fracture flow in the basalts and fairly rapid transport through the Puye Formation. Therefore, concentration levels in these locations in the canyon are predicted to be significantly greater than zero (in the thousands of pCi/l) in this portion of model domain.

The wells at which tritium concentrations in the regional aquifer can be compared are the water supply well O-4 and test well-3, both located near the confluence of Los Alamos and DP canyons, and characterization wells R-7 and R-9. Well O-4 results indicate that tritium is predicted to be mostly present in the vadose zone; however, a small but non-zero concentration is predicted to have reached the regional aquifer. Well R-7, located downstream of tritium contaminants but upstream of the Los Alamos-DP Canyon confluence, shows the slowest migration rate of tritium. By contrast, the most rapid transport to the water table is observed at R-9, where the peak concentrations of tritium are predicted to already have reached the water table. These model results are consistent with the available field data. Regional aquifer fluid collected in well R-7 has indetectable levels of tritium, whereas TW-3 and R-9 show that tritium has reached the regional aquifer. Determining more quantitatively the ability of the model to reproduce the field data is difficult because of mixing of the tritium percolating from the vadose zone with regional aquifer fluid and the subsequent mixing of contaminated and clean fluid in the wellbore itself. The latter difficulty is especially acute for the water supply wells, which may draw water from hundreds of feet of screened length.

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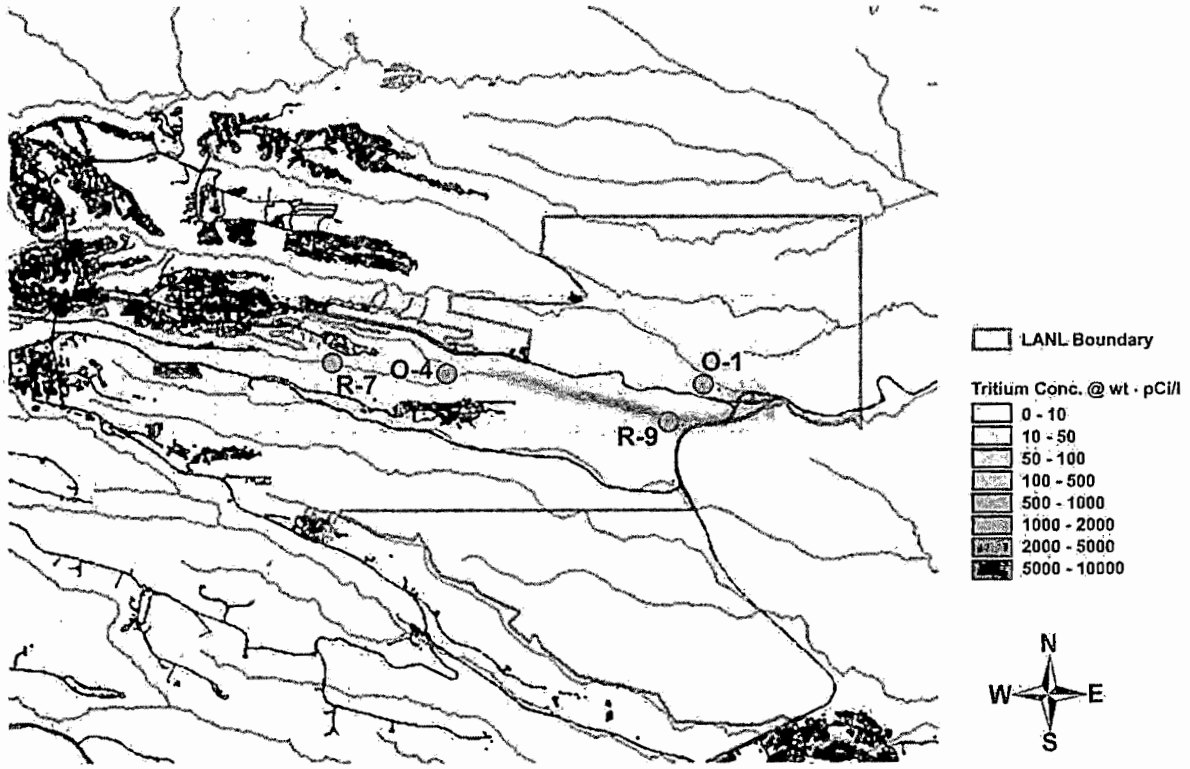

Figure 4-C-10. Three-dimensional model predictions of the tritium concentration of fluid reaching the water table in the year 1999. Significant, above background concentrations are predicted along the canyon at locations downstream of where the Bandelier Tuff is not present in the canyon bottom.

As a final comparison to the available data, we contrast the model results with regional aquifer water supply well O-1. However, because contaminant transport sources from Pueblo Canyon (north of Los Alamos Canyon) were not included in this model, the conclusions related to O-1 are more qualitative. For this comparison, monitoring information (LANL 2001) is used. Contaminants tritium, perchlorate, and nitrate are all thought to be nonsorbing in this system, and thus the combined results of all three contaminants are used in this interpretation. Well O-1 has been found to contain measurable levels of perchlorate at about a 5 ppb level, nitrate levels higher than at other regional aquifer wells in the area, and consistent, above-background levels of tritium in the 30-40 pCi/L range. All observations point to both Laboratory-derived contaminants and effluent discharges from Los Alamos County from past releases in Los Alamos and Pueblo Canyons having traversed the entire vadose zone. The present model explains these observations as a consequence of the hydrostratigraphy along the canyon, with rapid travel times at locations where the Bandelier Tuff is thin or non-existent.

Contrast these results with the transport model for MDA G presented in Appendix 4-B. Most important, travel times through the vadose zone are predicted to be orders of magnitude longer for this mesa site than for transport from the bottom of a wet canyon. The reason for this is straightforward. Infiltration rates, which directly impact transport velocities, are much larger in a canyon setting, in which all water in a catchment is channeled to the canyon bottom. A

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significant percentage of that water will escape evapotranspiration and percolate into the deep subsurface along the canyon. In contrast, a mesa top typically provides opportunity for water to drain as surface water, evaporate, or transpire. Therefore, percolation rates are much lower,

APPENDIX 4-D. REGIONAL AQUIFER MODEL DEVELOPMENT

4-D-1. Grid Information

Three-dimensional groundwater models have been developed using FEHM (Zyvoloski et al. 1997); computational grids were generated using LaGriT (Trease et al. 1996). The computational grids for both the basin- and site-scale models are shown in Figures 4-D-1 to 4-D-4; grid characteristics are summarized in Table 4-D-1. The structure of the two models are identical, except for the increased vertical resolution of the site-scale model and the smaller lateral extent.

A view of the upper surface of the basin model grid is shown in Figure 4-D-1. Constant head nodes are indicated by circles. Boundary conditions for the basin-scale model are shown in Figure 4-D-2. A view of the upper surface of the site-scale model is shown in Figure 4-D-3. Boundary conditions for the site-scale model are shown in Figure 4-D-4. Horizontal grid resolution varies from 250 m near the margins to 125 m beneath LANL. Vertical resolution varies from 12.5 m in the upper portion of the aquifer to 500 m at depth.

Each node in the computational mesh is assigned to a unit according to its location relative to the 3-D hydrostratigraphic structure defined by the geologic model. Interpolation from the hydrostratigraphic model to the grid nodes is done by defining closed volumes for each hydrostratigraphic unit. Each node of the mesh can be in one and only one of these volumes. The node properties are assigned based on which volume a node resides in. In this relatively simple approach, the location of contacts between hydrostratigraphic units can only be resolved to the degree of discretization in the finite element mesh. The resulting zonation for the basin and site-scale models are shown in Figures 4-D-5 and 4-D-6.

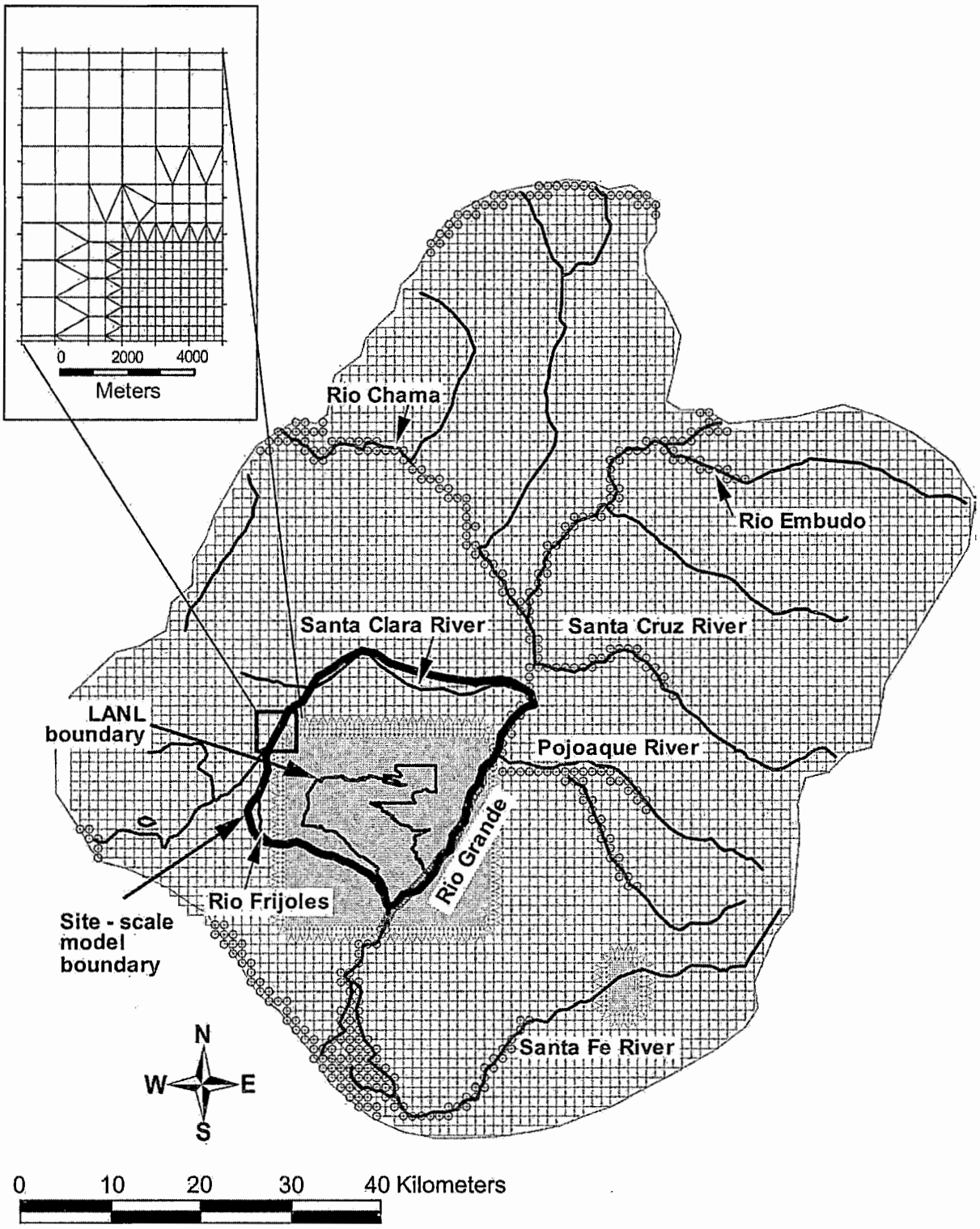

Figure 4-D-1. Top view of basin-scale model grid with side view (inset).

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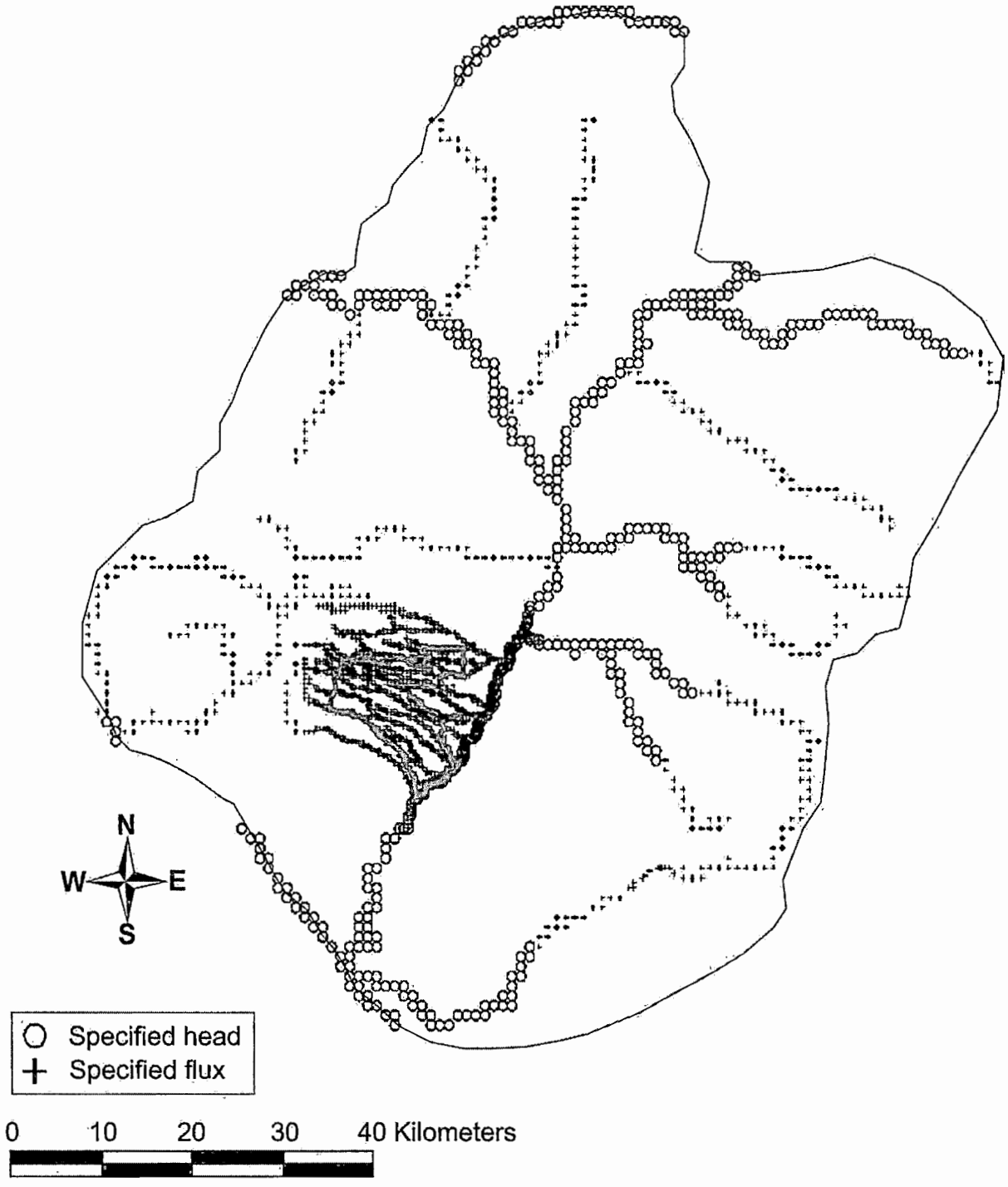

Figure 4-D-2. Boundary conditions along top surface of basin-scale model.

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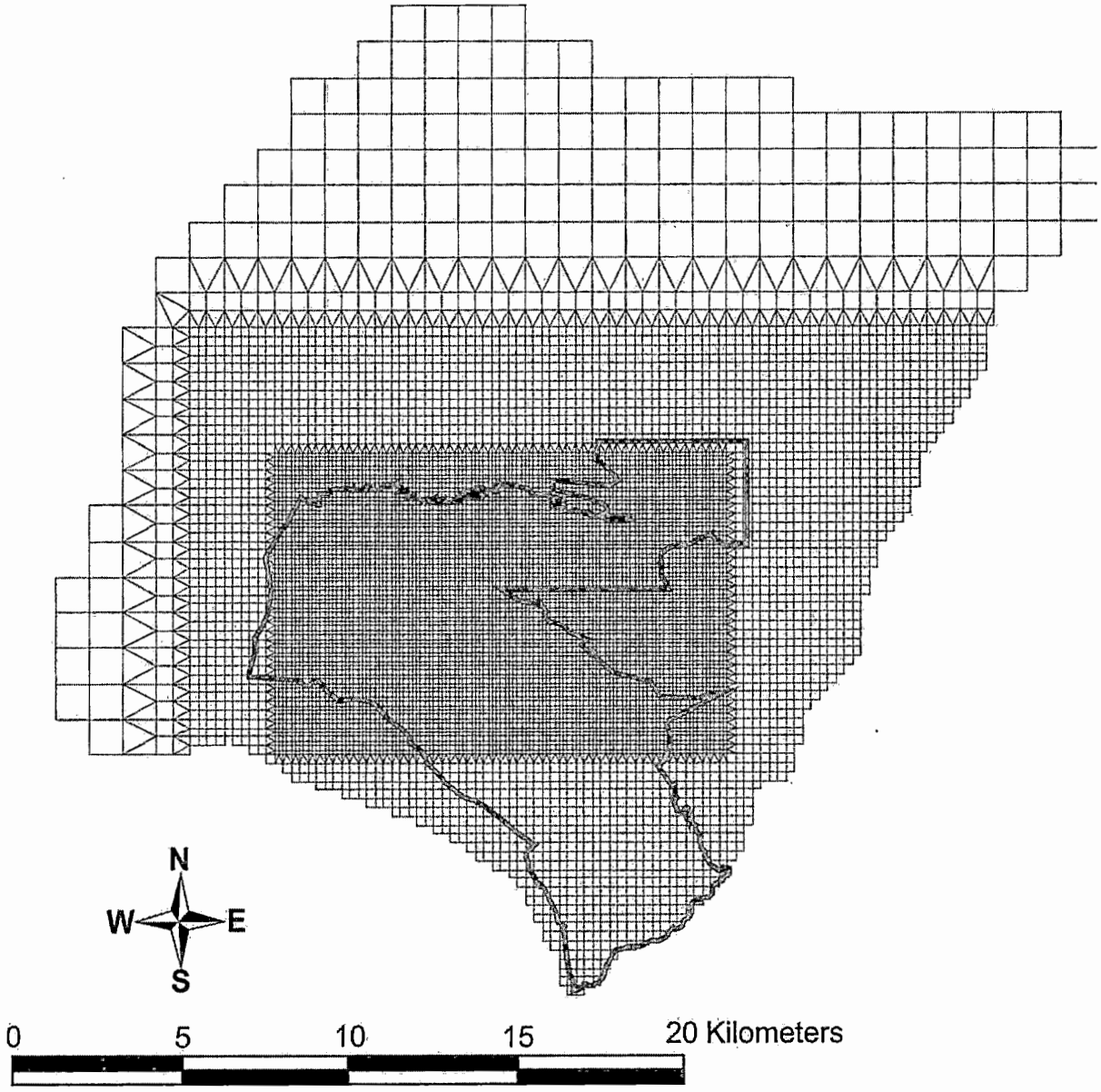

Figure 4-D-3. Plan view of the site-scale grid. LANL boundary shown for reference.

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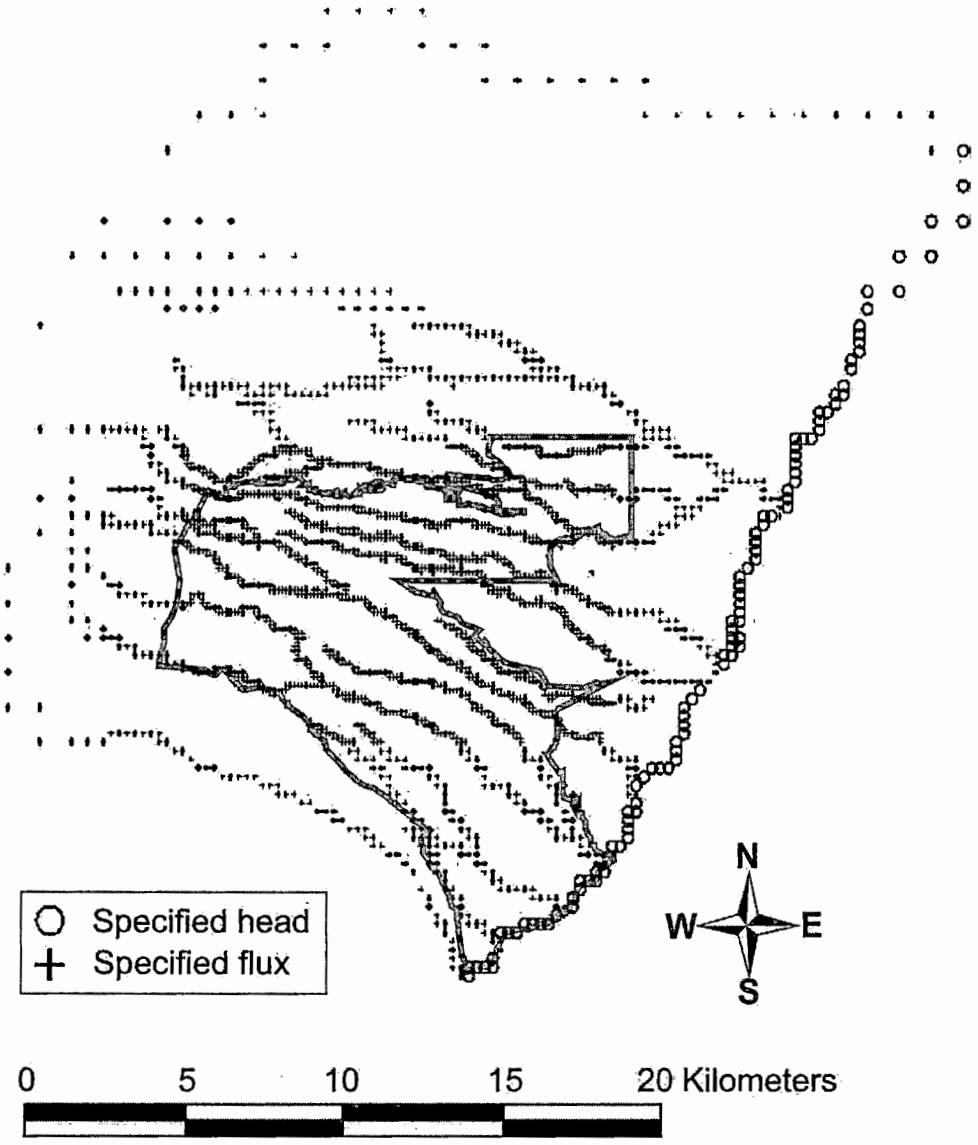

Figure 4-D-4. Boundary conditions along top surface of site-scale model.

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Table 4-D-1.
Hydrostratigraphic Units in Site-Scale Model

Unit	Sub-unit	Abbreviation	Volume (km³)	Fraction of Total
PreCambrian		p€	4.50	0.005
Paleozoic/Mesozoic		PM	273.53	0.292
Santa Fe Group	Deep	Tsf-deep	36.47	0.039
	fanglomerate	Tsf-fang	23.62	0.025
	sandy	Tsf-sandy	457.58	0.489
Keres Group	deep	Tk (deep)	12.59	0.013
	shallow	Tk (shallow)	1.15	0.001
Basalts		Tb1	6.19	0.007
		Tb2	5.61	0.006
		Tb4	2.20	0.002
Tschicoma		Tt	7.09	0.008
Puye Formation	Totavi Lentil	Tpt	2.02	0.002
	Pumiceous	Tpp	1.96	0.002
	fanglomerate	Tpf	5.45	0.006
Uncertain (1)		Tb2s	14.02	0.015
Uncertain (2)		Tb4f	0.45	0.000
Pajarito Fault zone			82.04	0.088
Total volume			936.51	1.000

4-D-2. Recharge Model

We define groundwater recharge R over the model domain as follows:

$$R(x,y) = \alpha\, \xi(x,y) \cdot P[Z(x,y)], \tag{1}$$

$$\xi(x,y) = \begin{cases} 1 & Z(x,y) > Z_{\max} \\ \frac{Z_{\max} - Z(x,y)}{Z_{\max} - Z_{\min}} & Z_{\min} < Z(x,y) < Z_{\max} \\ 0 & Z(x,y) < Z_{\min} \end{cases}, \tag{2}$$

where P is precipitation, Z is ground-surface elevation defined from the digital elevation model of the region, ξ is a dimensionless weight function which is characterized by parameters $Z_{\min}$ and $Z_{\max}$, α is the fraction of precipitation that becomes recharge above $Z_{\max}$. Note that $Z_{\min}$ defines the elevation below which no recharge occurs, and above elevation $Z_{\max}$ the recharge is equal to αP. The total recharge flux Q over the model domain Ω is defined as

$$Q = \iint_{\Omega} R\,dx\,dy = \alpha \iint_{\Omega} \xi P\,dx\,dy = \alpha P'(Z_{\min}, Z_{\max}), \tag{3}$$

where P' is a function of $Z_{\min}$ and $Z_{\max}$ only. We assume $P(Z)$ is a simple linear model with fixed regression parameters, which we derive using annual precipitation data for the region (Bowen, 1992; Spiegel and Baldwin 1963). Thus, there are four unknowns to be estimated (Q, α, $Z_{\min}$ and $Z_{\max}$) coupled through Equation 3. For example, to calculate Q we need to

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estimate α, Z_{min} and Z_{max}. For our inverse models, we found it to be more computationally efficient to include Q, Z_{min} and Z_{max} in the estimation process, and compute α as

$$\alpha = \frac{Q}{P'(Z_{min}, Z_{max})}. \quad (4)$$

Precipitation (P) is defined as a function of elevation (Z), according to a regression equation derived from regional data (Spiegel and Baldwin 1963) and Pajarito Plateau data (Rogers 1994). Figure 4-D-7 shows these data; the derived regression relationship is

$$P \text{ (in/yr)} = -16.4 + (.004542) * Z \text{ (feet)}, r^2 = 0.9$$

Using a USGS DEM model for the basin, we derive a map of annual precipitation from which the recharge fluxes are derived. We apply focused recharge along the upper reaches of perennial streams in the basin; the ratio of R_f (focused recharge along perennial streams) to Q is an unknown parameter that can be estimated in the inverse analysis. Finally, recharge along ephemeral streams on the Pajarito Plateau is applied in linear proportion to the indices developed by Birdsell (see Nylander 2002). The ratio of this type of recharge to Q is defined as κ.

Figure 4-D-8 shows an example of a recharge model derived using equations 1-4. Note that this particular example applies the highest rates of recharge in the basin to the streams flowing through LANL (>>35 mm/yr). This approach assures that the maximum possible fluxes of contaminants into the regional aquifer are captured in the models. The model parameters employed to generate this particular recharge map are

$$Q = 6400 \text{ kg/s}; Z_{min} = 2300 \text{ m}; \alpha = 12.5\%; \kappa = 0.03, \text{ and } R_f = 0.2.$$

In summary, the full set of recharge model parameters are Q, Z_{min}, Z_{max}, R_f/Q, and κ. These five parameters can be varied to provide a wide range of recharge conditions, all within the calibration constraints of head and baseflow discharge.

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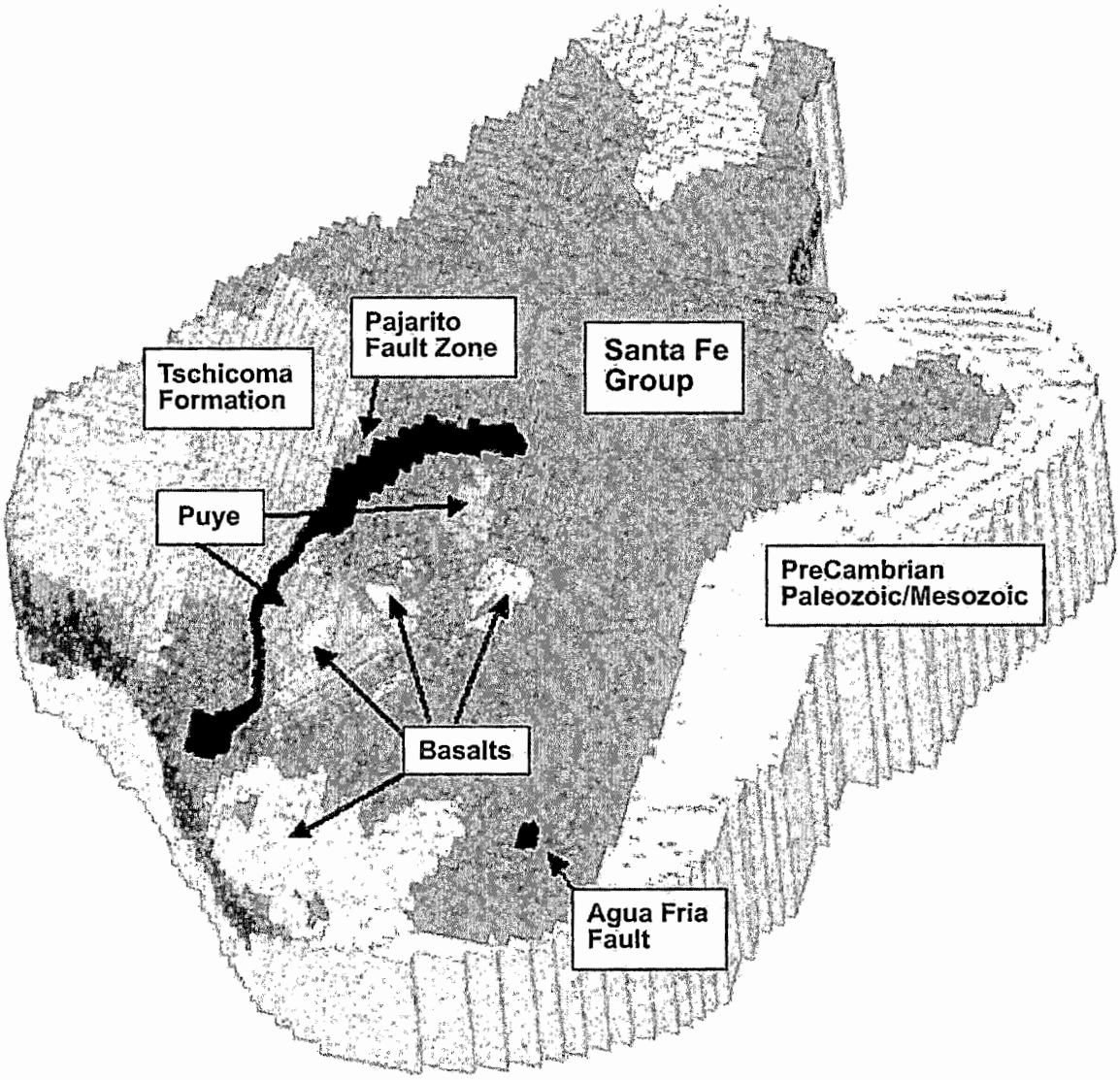

Figure 4-D-5. Three-dimensional representation of the major hydrostratigraphic units in the basin-scale model.

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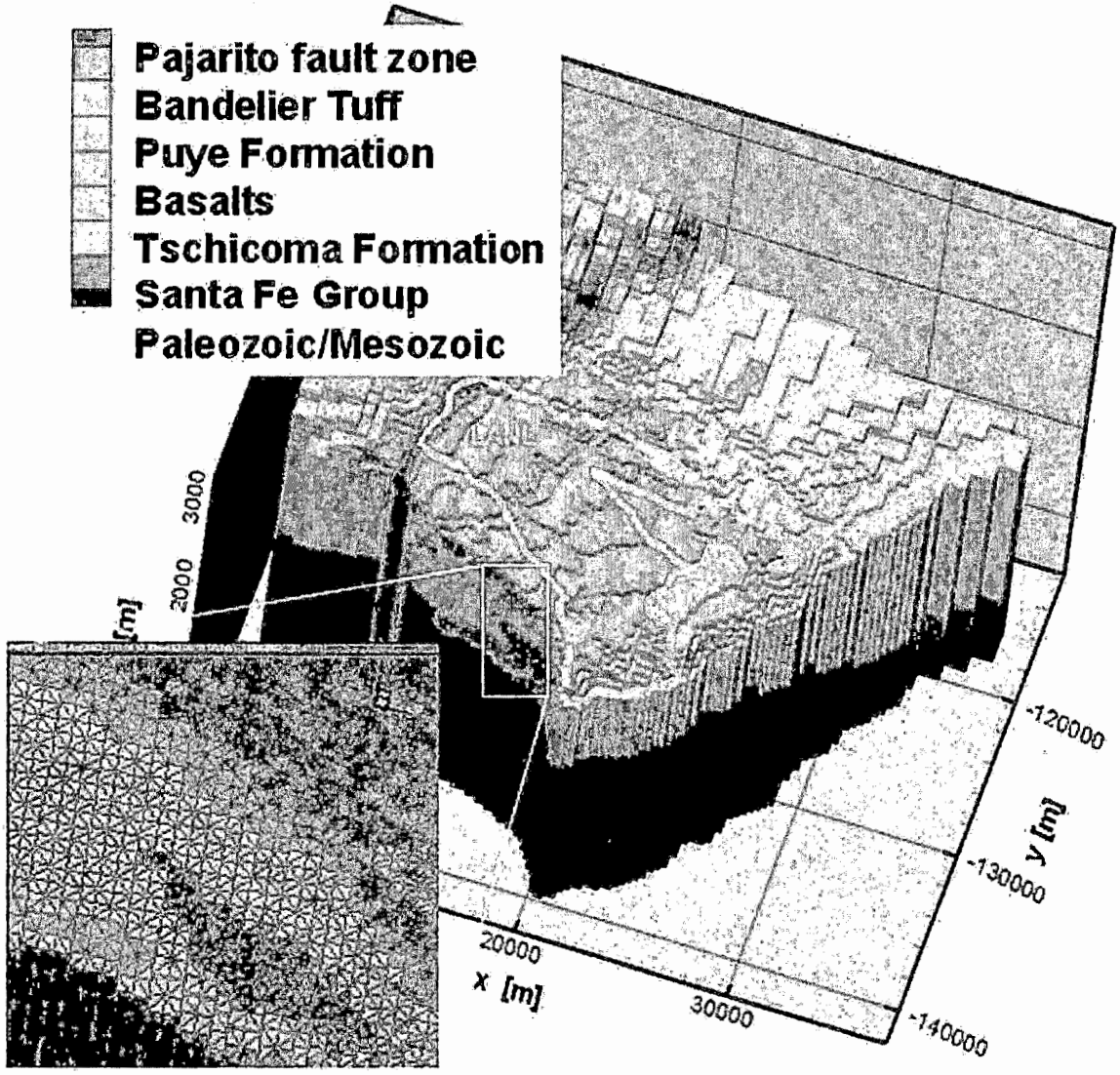

Figure 4-D-6. Site-scale model grid, colored according to major hydrostratigraphic units.

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4-D-3. Flux Estimates.

Table 4-D-2 compares flux estimates from previous models developed for the Española Basin.

Table 4-D-2.
Flux Estimates Derived from Previous Models, in AFY

		cfs/.0014	0.0014	
INFLOW		McAda	Frenzel	Hearne
	Total Area (km^2)			
	Areal Recharge (cfs)	7571	3429	0
Lateral Boundaries				
Inflow (cfs) rom:	east	21571	14929	2693
	west	7429	7214	8100
	north	1429	1357	971
	south	1571	500	
Rivers				
Inflow (cfs) rom:	SF River	5357	5357	5150
	Poj. River	0	929	1261
	RG	1357	0	0
	Cochiti	0	0	0
	Tesuque	3071	2714	1772
	Rio En Medio/Nambe	2857	3000	1714
	Arroyo Hondo	500	500	0
	Santa Cruz	0	0	2936
	Head dependent rivers	0	929	0
TOTAL INFLOW		52714	40857	24597
OUTFLOW				
Lateral Boundaries				
Outflow[1] (cfs) to:	east	0	0	0
	west	12429	8643	0
	north	2143	2714	243
	south	214	1643	0
Rivers		0	0	0
Outflow (cfs) to:	Santa Fe River	4643	0	3107
	Pojoaque River	5214		2766
	Rio Grande	28071	0	11293
	Cochiti	0	0	4464
	La Cienega	0	4643	0
	Tesuque	0	0	243
	Rio En Medio/Nambe	0	0	0
	Arroyo Hondo	0	0	0
	Santa Cruz	0	0	1071
	Head dependent rivers	0	23357	0
TOTAL OUTFLOW		52714	41000	23187

[1] Outflow to "west" is outflow to the Albuquerque Basin. For comparison, subsurface inflow to the Albuquerque Basin from the north (including the Española Basin and Jemez Mountains) was estimated to be 19,400 afy (Kernodle et al. 1995), 28,500 afy (McAda and Barroll, 2002), and 2772 afy (Sanford et al. 2004).

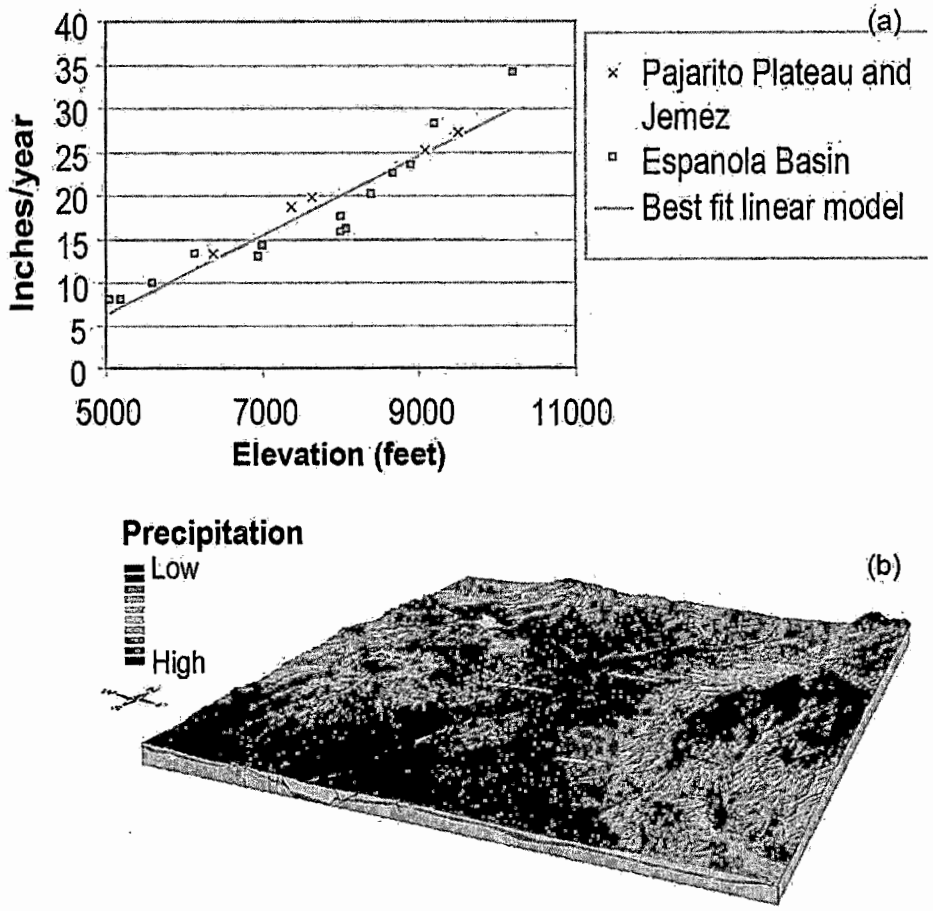

Figure 4-D-7. (a) Average annual precipitation in the vicinity of the Española Basin. (b) Regression equation for precipitation applied using USGS DEM.

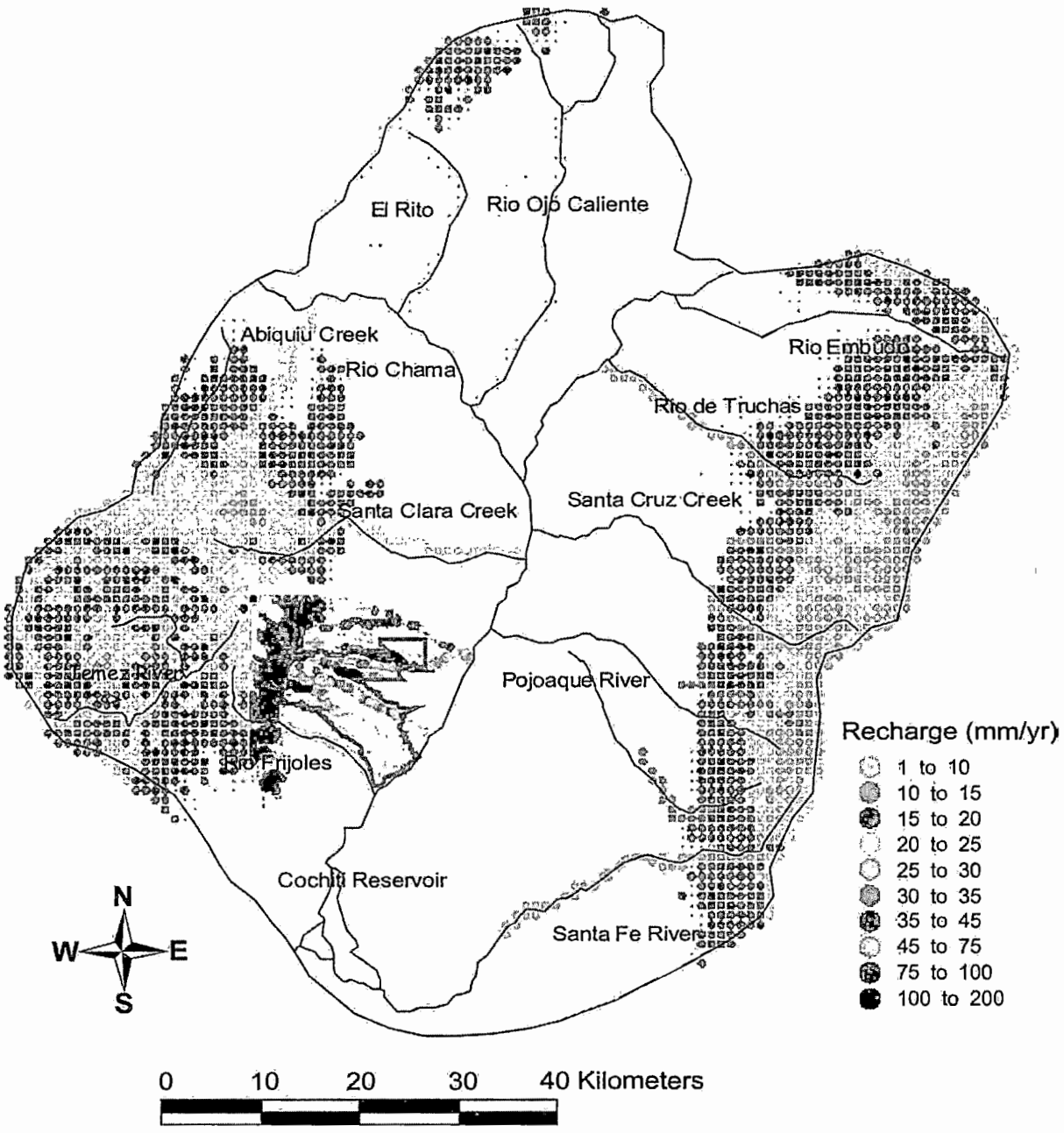

Figure 4-D-8. Average annual precipitation verses elevation derived from data of Spiegel and Baldwin (1963) and Rogers (1994).

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APPENDIX 4-E. ESTIMATING AQUIFER DISCHARGE USING STREAMFLOW DATA

The method we use for estimating base flow gain along the Rio Grande is a very simple one, also used by Spiegel and Baldwin (1963), the U.S. Department of Justice (1996), and others. The strategy is to difference measured surface water flow at two gages during January, when other causes of streamflow loss/gain such as evapotranspiration and irrigation withdrawals are likely to be minimal. Because the calculated baseflow gain is generally small compared to total flow in the Rio Grande, small measurement errors in flow at the gages could have large influence on these calculations. The approach applied here assumes that measurement errors are random; therefore, their impact can be minimized by repeating the calculations over a number of years and deriving a long-term mean. Uncertainty in the mean estimate will be an indication of measurement error. Unless the record is much longer than significant temporal trends, temporal trends cannot be ascertained with this method.

We apply this approach to two reaches of the Rio Grande: (1) San Juan Pueblo (828110) to Otowi (8313000) and (2) Otowi (8313000) to Cochiti (8314500). Collectively, these two reaches span the entire length of the Rio Grande that comprises the eastern extent of the Pajarito Plateau, from Santa Clara Creek to Rio Frijoles.

(1) San Juan Pueblo (828110) to Otowi (8313000). A major tributary to the Rio Grande, the Rio Chama, enters this reach just downstream from the gage 8290000 (Rio Chama at Chamita). There was a 23-year period during which all three of these gages were operational (1963 to 1985). By comparing this period of record to a much longer period of record at the Otowi gage (1890–2004), it can be seen that flows were normal during the 1963–1985 period, except two unusually high flow years (1973 and 1975). The January flow at Otowi was highly correlated to, and slightly more than, the sum of flows at San Juan Pueblo and Rio Chama at Chamita, suggesting a consistent base flow gain component along this reach. Three minor tributaries, the Santa Cruz River, the Pojoaque River, and the Santa Clara River, contribute to gain along this reach. Insufficient data during the 1963 to 1985 prevents using measured flows for these years; instead, we use a long-term average from other years, shown in Table 4-E-1.

For each of the 23 year period from 1963 to 1985, we calculated base flow gain during January by the following relationship:

Base flow gain = measured flow (RG Otowi – RG San Juan – Rio Chama, Chamita) – long-term average measured flow (Pojoaque + Santa Clara + Santa Cruz).

The 23-average base flow gain calculated using this approach is 41.2 cfs.(+/- 12.8 at the 95% confidence interval). There is a strong trend evident for gain to be higher in years of higher flow; it is unclear whether this trend is real or is related to sources of error such as small ungaged tributaries which may only be significant at high flow. The adequacy of the derived long-term estimate is shown in Figure 4-E-1a.

(2) Otowi (8313000) to Cochiti (8314500). These two gages have both been operational since 1926, well before pumping began at the Buckman wellfield below Otowi. January flow at the

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two stations is highly correlated (r^2=0.96). For most years the data suggest that the reach is gaining; for some years the data suggest a losing reach. One tributary enters the Rio along this reach, Rio Frijoles, which was gaged from 1983 to 1996. We estimate the average January flow at the Rio Frijoles to be 1.2 cfs. Accounting for the inflow from the Rio Frijoles, the gain between these reaches is 13.0 cfs +/- 8.8. The sum of the flow at Otowi and Rio Frijoles and this base flow estimate, compared to the flow at Cochiti, is shown as a yellow line in Figure 4-E-1b.

Table 4-E-1.
Comparison of Gain/Loss Calculations to Other Studies

Reach	Source	Method	Reach Length (km)	Total Gain (m^3/s)	Gain/mi ($m^3/s/km$)
Rio Grande (Otowi to Cochiti)	This report (Table 2-3)	Streamflow analysis	41.8	0.39	0.009
	U.S. Department of Justice (1996)	Streamflow analysis	41.8	0.40	0.009
	Hearne (1985)	Numerical model	38.6	0.46	0.012
	McAda (1988)	Numerical model	27.4	0.63	0.023
	Purtymun (1966)	Seepage runs	18.5	0.43	0.023
	Griggs (1964)	Seepage runs	18.5	0.37	0.020
	Spiegel & Baldwin (1963)[1]	Streamflow analysis	32.2	0.71	0.022
Rio Grande (Embudo to Otowi)	This report (Table 2-3)	Streamflow analysis	51.0	0.67	0.013
	U.S. Department of Justice (1996)	Streamflow analysis	51.0	1.50	0.029
Rio Grande (Española to Otowi)	Hearne (1985)	Numerical model	33.8	0.20	0.006
	McAda (1988)	Numerical model	17.7	0.43	0.024
	USGS seepage runs	Seepage runs	27.4	0.15	0.005
Rio Chama (Abiquiu to Chamita)	This report (Table 2-3)	Streamflow analysis	39.9	1.00	0.025
	This report (Table 2-2)	Area relation	39.9	1.19	0.030
	Hearne (1985)(lower reach only)	Numerical model		0.06	
Santa Cruz River	Hearne (1985)	Numerical model		0.04	
	This report (Table 2-2)	Area relation		0.33	
	This report (Table 2-3)	Streamflow analysis		0.14	
Pojoaque River	Reiland & Koopman (1975)	Streamflow analysis		0.40	
	McAda (1988)	Numerical model		0.21	
	This report (Table 2-2)	Area relation		0.27	
	Hearne (1985)	Numerical model		0.09	
Santa Clara River	This report (Table 2-3)	Streamflow analysis		0.09	
	This report (Table 2-2)	Area relation		0.05	
Santa Fe River	This report (Table 2-3)	Streamflow analysis		0.23	
	McAda (1988)	Numerical model		0.18	
	this report (Table 2-2)	Area relation		0.32	
	Hearne (1985)	Numerical model		0.12	
Rio Embudo	This report (Table 2-3)	Streamflow analysis		0.58	
	This report (Table 2-2)	Area relation		0.30	

[1] Their approach includes only those years when the reach was deemed "gaining." ("Losing" years were assumed to be caused by erroneous data and were deleted from the analysis.)

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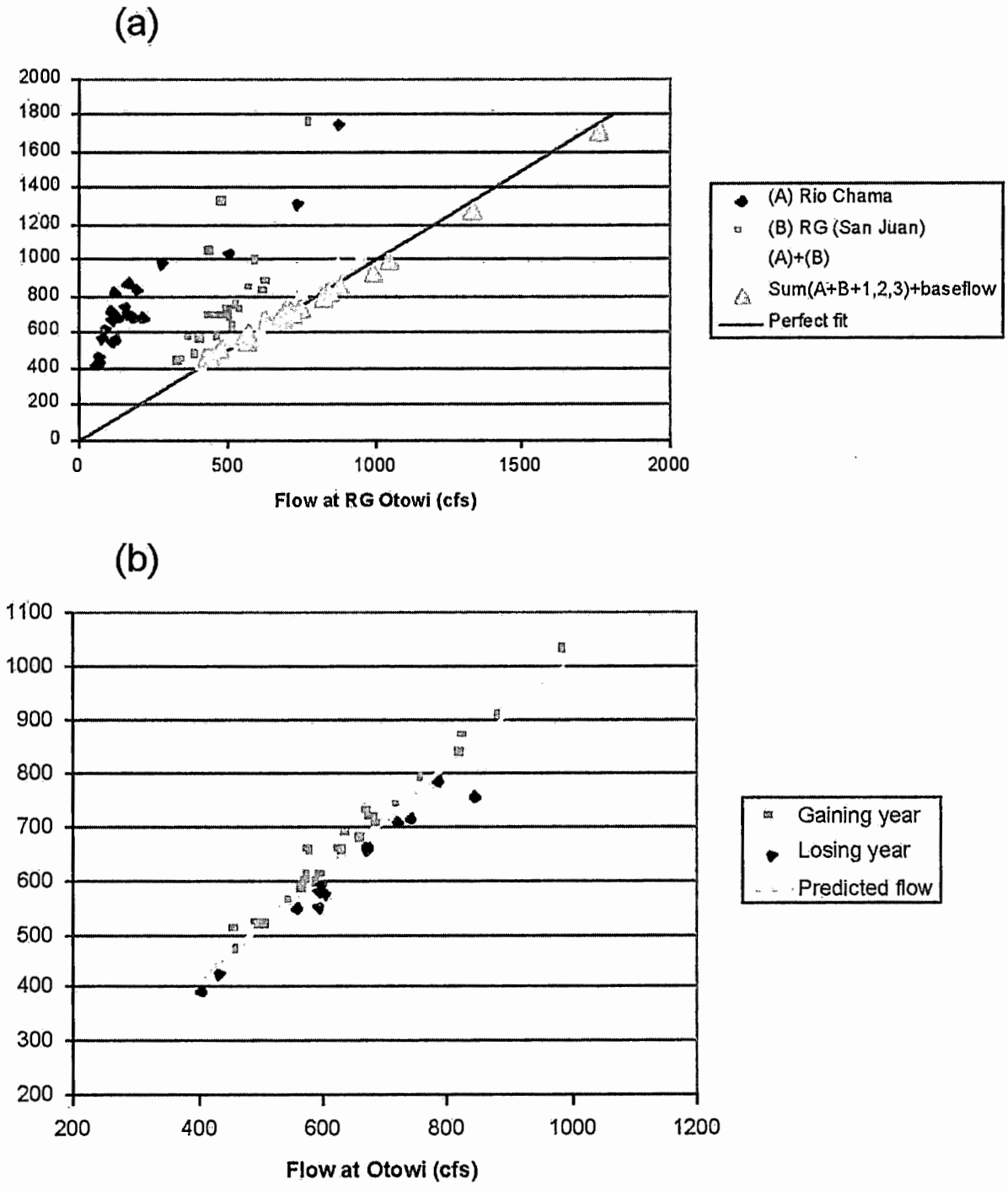

Figure 4-E-1. Measured January flow at the Otowi gage, compared to (a) contributing flow at Rio Chama, Rio Grande at San Juan, minor tributaries, and estimated base flow, and (b) measured January flow at the Cochiti gage.

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To extrapolate these estimates to a slightly different reach of the Rio Grande, from Santa Clara Creek to Rio Frijoles, we calculate the ratios of stream lengths within each of the estimated reaches above. Santa Clara to the Otowi Bridge gage is approximately 6/10 the distance of RG San Juan to Otowi Bridge; we estimate 24.7 +/- 7.7 cfs gain along this reach. Otowi to Rio Frijoles is approximately $^1/_2$ the distance of Otowi to the Cochiti gage; for this reach we estimate 6.5 cfs +/- 4.4. In total, our baseflow estimate for the Santa Clara to Rio Frijoles reach of the Rio Grande is 31.2 cfs +/- 12.1 or 884 kg/s +/- 343.

Errors. Sources of errors in the method include systematic errors in streamflow measurements which do not affect all of the streamflow gages used in the differencing equations and which are persistent for the entire period of overlapping record, systematic departures of tributary flows (Pojoaque + Santa Clara + Santa Cruz) from the long-term averages shown in Table 4-E-2 and and unmeasured surface water inflows/outflows. Water budget components are estimated for watersheds in the Española Basin and are shown in Table 4-E-3.

Table 4-E-2.
Estimates of Long-Term Average Flow at Small Tributaries

Gage			Data Source	# of Years of Record	Period	Mean January Flow (cfs)
1	Pojoaque River, at mouth	Site 6	Reiland and Koopman (1975)	38	1935–1972	4.9
2	Santa Clara Creek	8292000	USGS	17	1936–1994	3.3
3	Santa Cruz River	8291500	USGS	10	1941–1950	5.9
4	Rio Frijoles	8313350	USGS	14	1983–1996	1.2

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Table 4-E-3.
Water Budget Components Estimated for Watersheds within the Española Basin, Expressed as Fraction of Total Precipitation

	Watershed Area (square miles)	Area-Weighted Average Elevation[a] (feet)	Precipitation[b] (acre-ft/yr)	ET[c]	Runoff	Recharge	Sublimation	Recharge	Source
				Fraction of total precipitation				Inches/yr	
Santa Fe River	28.7	8989	36706	0.69	0.19	0.11	0.01	2.71	Wasiolek (1995)
Santa Fe River	26.95	8989	30060	0.71 0.73[d]	0.19	0.10 0.08[d]	---	2.02 1.61[d]	Anderholm (1994, Table 7)
Little Tesuque Creek	7.7	8786	9370	0.72	0.09	0.19	0.00	4.41	Wasiolek (1995)
Little Tesuque Creek	7.34	8786	8,573	0.88	0.05	0.07	---	1.61	Anderholm (1994, Table 7)
Rio Nambe	34.2	9325	48826	0.62	0.19	0.11	0.08	3.03	Wasiolek (1995)
Tesuque Creek	11.2	9197	15288	0.65	0.20	0.10	0.05	2.45	Wasiolek (1995)
Tesuque Creek	11.84	9197	13120	0.75	0.18	0.07	---	1.50	Anderholm (1994, Table 7)
Combined Little Tesuque and Tesuque Creeks	19.18	9030	21693	0.89 0.93[d]	0.04	0.07 0.03[d]	---	1.54 0.67[d]	Anderhom (1994, Table 7)
Rio en Medio	8.7	9242	11973	0.64	0.15	0.14	0.07	3.73	Wasiolek (1995)
Arroyo Hondo	8.38	?	8560	0.84	0.06	0.10	---	1.86	Anderholm (1994, Table 7)
LA Canyon '93	?	8428	13694	0.71	0.03	0.26	0.00	6.52	Gray (1997)
LA Canyon '94	?	8428	12409	0.83	0.00	0.17	0.00	4.01	Gray (1997)
LA Canyon '95	?	8428	15912	0.73	0.02	0.25	0.00	7.33	Gray (1997)

[a] Average basin elevation was calculated by the authors for drainage basins as defined by Wasiolek (1995). No adjustments were made to the average drainage basin elevations to account for the small differences in drainage basin areas between the Anderholm (1994) and Wasiolek (1995) studies.

[b] Precipitation volumes reported by Wasiolek (1995) for winter and spring had already been adjusted to reflect the effects of sublimation of snow. The precipitation volume estimated to exist before before sublimation was determined using information provided by Wasiolek (1995, p. 18). Calculated fractions for evapotranspiration, runoff, recharge, and sublimation reported here for the Wasiolek study are relative to this pre-sublimation precipitation value.

[c] The authors estimated the evapotranspiration (ET) for Anderholm's study based on Anderholm's estimates for precipition (P), runoff (RO), and recharge (R):
ET = P – RO - R

[d] These estimates used the chloride-based recharge estimate corrected for runoff from the basin.

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AGENDA
LANL – NMED Managers Meeting
Environmental and Water Protection Topics

November 13, 2017
1:00 PM
Harold Runnels Building

1. **Leadership/Personnel Changes**
   - NMED
   - DOE: *LANL M&O contract RFP has been released: https://nnsa.energy.gov/aboutus/ouroperations/apm/majcontrsolicitation/los-alamos-national-laboratory-management-and/lanlrfp*
   - LANS

2. **NNSA Focus Areas**

   Groundwater Permits
   - DP-1132 Radioactive Liquid Waste Facility*: Logistics*
   - DP-857: *GWQB has requested to inspect TA-33. Coordinating with HWB to conduct the inspections.*

   RCRA Permitting and Compliance
   - TA-16-399 Closure Plan process update: *Discussion*
   - FTWCs Update: *HWB planning site visit on November 16. ESS revision under review with EM-LA – If approved, will allow for resuming RCRA compliant inspections*

   Other
   - Ship to WIPP update

3. **EM Focus Areas**

   EM Work Activities and Status

   - Chromium Project: *Technical discussions continued on the use of CrIN-6; path forward on operational testing has been established; injection of chemical and biological amendments in pilot tests was completed successfully; Status of CrEX-4 drilling*
   - RDX Project: *Current status of RDX activities: R-68 sampling, R-69 preparations*
   - Other CO Topics: *Annual Work Planning process is ongoing – summary of progress and preparations for public meeting on FY2018 work scope and milestones.*
   - Remediated Nitrate Salts: *RNS campaign is complete; preparations for UNS processing are ongoing*

- Plans for shipping large waste containers from TA-55 to Area G

4. **Supplemental Environmental Projects**
   - Potable Water: *90% design review scheduled for late November (on schedule)*
   - Watershed Enhancement: *Designs continuing, most at or past 60%. First LID project has begun, second LID project completing design.*
   - Triennial *Review: Document sharing and review is continuing. Pre-visit completed. On target for late February, early March review.*
   - Roads: *USACE has begun work on road coring in support of design effort. 90% design discussion with NMDOT on November 13. Meeting with the Los Alamos County Transportation Committee on December 7 to inform them of the plans.*
   - Storm Water Monitoring – *IntellusNM upgrades are in place and in use. A good sampling season was completed this late summer, equipment is being readied for winter.*
   - General: *Preparing for mid-January meeting with NMED to discuss overall status, spending trends, priority lists, etc. to determine if any mid-project adjustments are appropriate.*

5. **Other Business/Communications**

6. **Decisions/Actions**

Attendees:
Butch Tongate, Secretary NMED
JC Borego - NMED
Bruce Yurdin – NMED
John Kieling - NMED
Neelam Dhawan - NMED
Michael Brandt - LANS
Raeanna Sharp-Geiger - LANS
John Bretzke - LANS
Randy Erickson - LANS
Bruce Robinson – LANS
Taunia Van Valkenburg – LANS
Steve Goodrum - NNSA
Doug Hintze – DOE-EM
Jody Pugh - NNSA
Karen Armijo - NNSA

2 of 7

Contents:
Hydrogeologic Studies LA-14263-MS.
Hydrogeologic Site Atlas. LAUR-09-3763.
Groundwater Level Status Rpt. LA-14437-PR.

Discharge Permit Application (DP-1132),
RLWTF and TA-52 ZLD
ENV-DO-12-0005;
LAUR-12-00672
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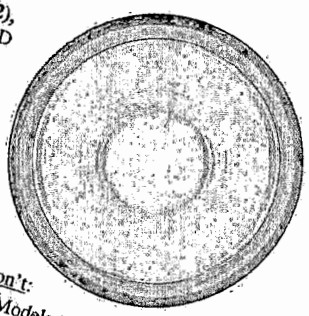

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Contents Con't:
Conceptual Models of Vadose Zone Vadose Zone Journal, Vol. 4, August 2005.
NRCS Soil Survey.
Mortandad Canyon Investigation Report, LA-UR-06-6752
Groundwater Monitoring Plan. LA-UR-11-6958.

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Environmental Programs
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National Nuclear Security Administration
Los Alamos Site Office, MS A316
Environmental Restoration Program
Los Alamos, New Mexico 87544
(505) 667-4255/FAX (505) 606-2132

Date: June 30, 2009
Refer To: EP2009-0191

James P. Bearzi, Bureau Chief
Hazardous Waste Bureau
New Mexico Environment Department
2905 Rodeo Park Drive East, Building 1
Santa Fe, NM 87505-6303

Subject: Submittal of the General Facility Information Component #9 - 2009 Hydrogeologic Site Atlas

References: (1) Letter, Messrs. Gregory and Graham to Bearzi, dated February 13, 2009
(2) Letter, Bearzi to Messrs. Gregory and McInroy, dated February 26, 2009

Dear Mr. Bearzi:

Enclosed please find two hard copies with electronic files of the 2009 Hydrogeologic Site Atlas (Atlas). This fulfills the submittal of component #9 of the 2009 General Facility Information Report according to the schedule in Reference 2. As stated in Reference 1, the Atlas map surfaces were prepared from the significantly updated 2009 Geologic Framework Model (GFM) which captures geologic contact data from wells logged as recently as early March 2009.

If you have any questions or if you and your staff would like a briefing on the 2009 GFM and Atlas, please contact Ardyth Simmons at (505) 665-3935 (asimmons@lanl.gov) or Hai Shen at (505) 665-5046 (hshen@doeal.gov).

Sincerely,

Michael J. Graham, Associate Director
Environmental Programs
Los Alamos National Laboratory

Sincerely,

David R. Gregory, Project Director
Environmental Operations
Los Alamos Site Office

MG/DG/PH/AS:sm

Enclosures: 1) Two hard copies with electronic files – 2009 Hydrogeologic Site Atlas (LA-UR-09-3763)

Cy: (w/enc.)
Neil Weber, San Ildefonso Pueblo
Ardyth Simmons, EP-LWSP, MS M992 (20 extra copies)
Greg Cole, EES-16, MS D462
Bob King, EP-LWSP, MS M992
Hai Shen, DOE-LASO, MS A316
RPF, MS M707 (with two CDs)
Public Reading Room, MS M992

Cy: (Letter and CD and/or DVD only)
Laurie King, EPA Region 6, Dallas, TX
Steve Yanicak, NMED-OB, White Rock, NM
Jeff Heikoop, EES-14, MS D462
Kristine Smeltz, EP-WES, MS M992
EP-LWSP File, MS M992

Cy: (w/o enc.)
Tom Skibitski, NMED-OB, Santa Fe, NM
Keyana DeAguero, DOE-LASO (date-stamped letter emailed)
Michael J. Graham, ADEP, MS M991
Alison M. Dorries, EP-WES, MS M992
Paul R. Huber, EP-LWSP, MS M992
IRM-RMMSO, MS A150 (date-stamped letter emailed)

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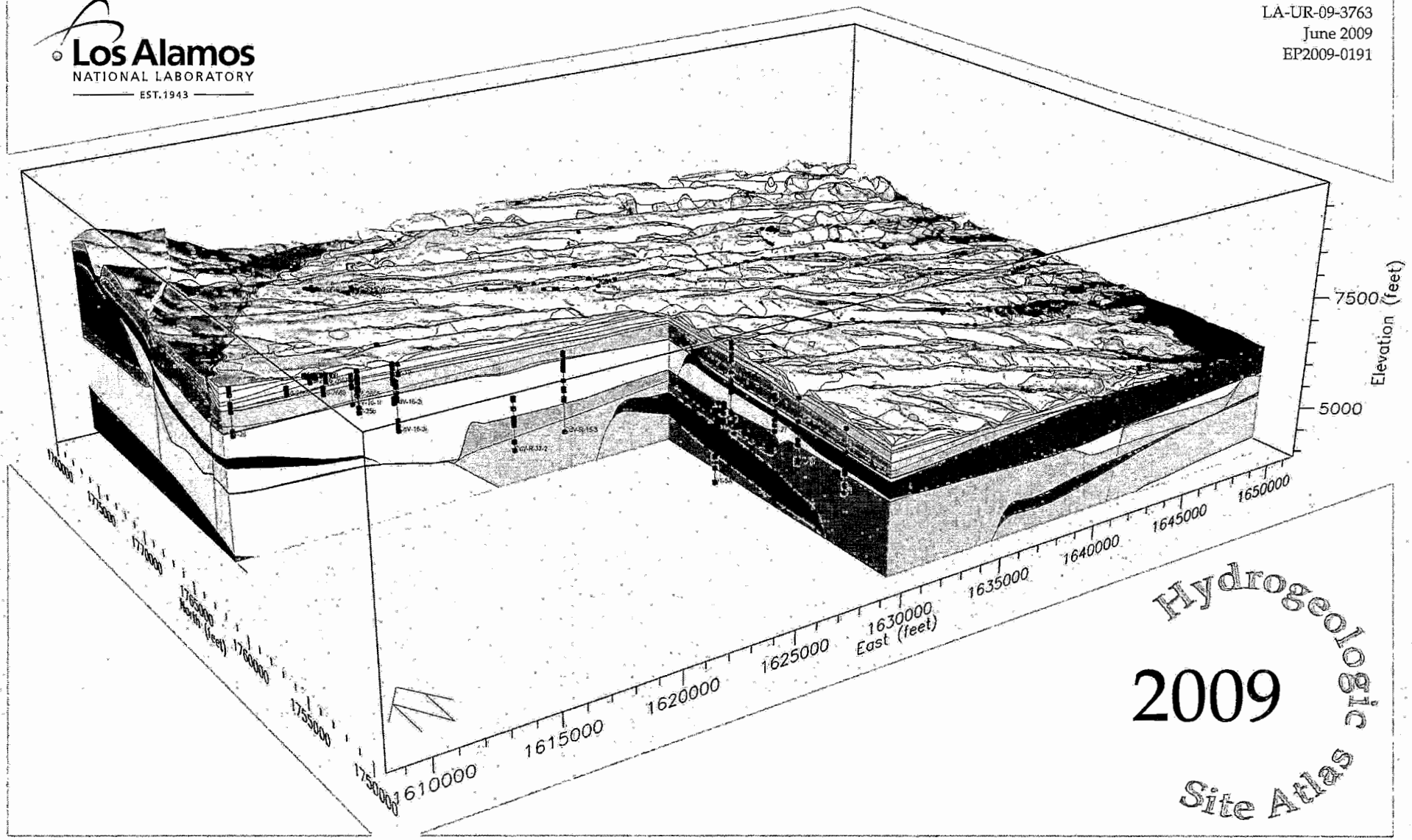

Hydrogeologic 2009 Site Atlas

The cover shows a three-dimensional geologic framework model of the region near Technical Area 03, depicting the geology down to a depth of 4000 feet above sea level. The stratigraphic units in the area wells are also shown. For illustrative purposes, a modified color palette was used for this model that differs from that used for illustrations in the rest of the atlas to highlight the large-scale character of the Quaternary tuffs (tan colors), older flows (blues), and the basalt flows (red).

Prepared by the Environmental Programs Directorate–LANL Water Stewardship Project

The primary author of the 2009 Hydrogeologic Site Atlas text and creator of the map plates was Greg Cole. David Broxton and Dan Koning provided figures and text describing the geologic units in Section 2, and Velimir (Monty) Vesselinov provided the text, tables, and water-table data for the plates of Section 3. David Coblentz used Earth Vision software to create the cross-section, three-dimensional views of the geologic framework model, and the atlas cover. Susan Rhyne provided editing support. Pamela Maestas provided graphics and editing support and created the cover using images generated by David Coblentz.

Greg Cole led the development of the 2009 geologic framework model. Other contributors included David Coblentz and Elaine Jacobs, who assisted in the model development; and Dan Koning, David Broxton, David Vaniman, and Fraser Goff, who provided structure contours and/or cross-sections for many of the model units.

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2009 Hydrogeologic Site Atlas

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ABSTRACT

The "2009 Hydrogeologic Site Atlas" describes those portions of the 2009 geologic framework model (GFM) that encompass Los Alamos National Laboratory (the Laboratory) and surrounding area. This atlas is extracted from the 2009 GFM, a major revision and expansion of the previous 2005 GFM, and incorporates a large amount of new subsurface data from an expanded drilling program. The 2009 GFM is a set of three models: the site model (SITE), the southern Española Basin (SEB) model and the Española Basin (EB) model, which provide computational grids for increasingly larger portions of the EB at decreasing resolutions. The 2009 GFM has also been extended to greater depths beneath the Pajarito Plateau through a projection of modeled EB geology to the east and southeast and utilization of new geologic map data from the Valles Caldera to the west and the Cochiti Pueblo region to the south. The atlas incorporates enhanced stratigraphic control to identify additional details of the deeper Santa Fe Group sediments beneath the Laboratory and provides new and/or updated geologic maps, structure contour and thickness maps, and water-table maps, as well as cross-sections and three-dimensional (3-D) visualizations of the geology.

1.0 INTRODUCTION

The Laboratory has produced a series of hydrologic site atlases that document updated models for the Laboratory site (Stone et al. 1999, 064039; Stone et al. 2001, 069830; Cole et al. 2006, 095079). This current document is the latest addition to the atlas series. This document satisfies component 9 as indicated in the 2009 General Facility Information (LANL 2009, 105632).

1.1 Background

The earliest 3-D geologic model for the Laboratory site was produced in the mid-1990s to support compliance with the Laboratory's Hazardous Waste Facility permit(s), required under the Resource Conservation and Recovery Act. The 1995 site geologic model (Vaniman et al. 1996, 106129) used early-version, ArcInfo software for building the model, and IBM DX-Explorer software for 3-D visualizations. The model consisted of 14 surfaces that were derived from the contouring of triangular integrated networks (TINs) created from limited sets of surface and drill hole control points. The model surfaces did not extend to the Laboratory boundaries and were limited to units/subunits of the Bandelier Tuff, portions of the Cerro Toledo and Puye and Totavi units, and a small piece of the Santa Fe Group. Figures 1-1a and b provide samples of the surfaces and visualizations from this early model of the 3-D geology and the Laboratory site.

Through the ensuing years, there has been an ongoing effort to accelerate the characterization and remediation of the hazardous (release) sites at the Laboratory. This effort has resulted in the installation of many new characterization and monitoring wells and additional surface geologic mapping. The effort has also resulted in the need to extend geologic-based groundwater flow and contaminant transport models past Laboratory boundaries into the surrounding communities. The Laboratory has continued to support the development of 3-D geologic models with updated models produced for 1997 (Cole et al. 1997, 106127), 1998 (Cole et al. 1998, 106128), 1999 (Carey et al. 1999, 066782), 2002 (no report produced), 2003 (partial model, including Area G and Mortandad and Sandia Canyons [Stauffer et al. 2005, 097432]), and 2006 (Cole et al. 2006, 095079). These newer models were developed mainly to support the numerical analysis of groundwater flow and transport.

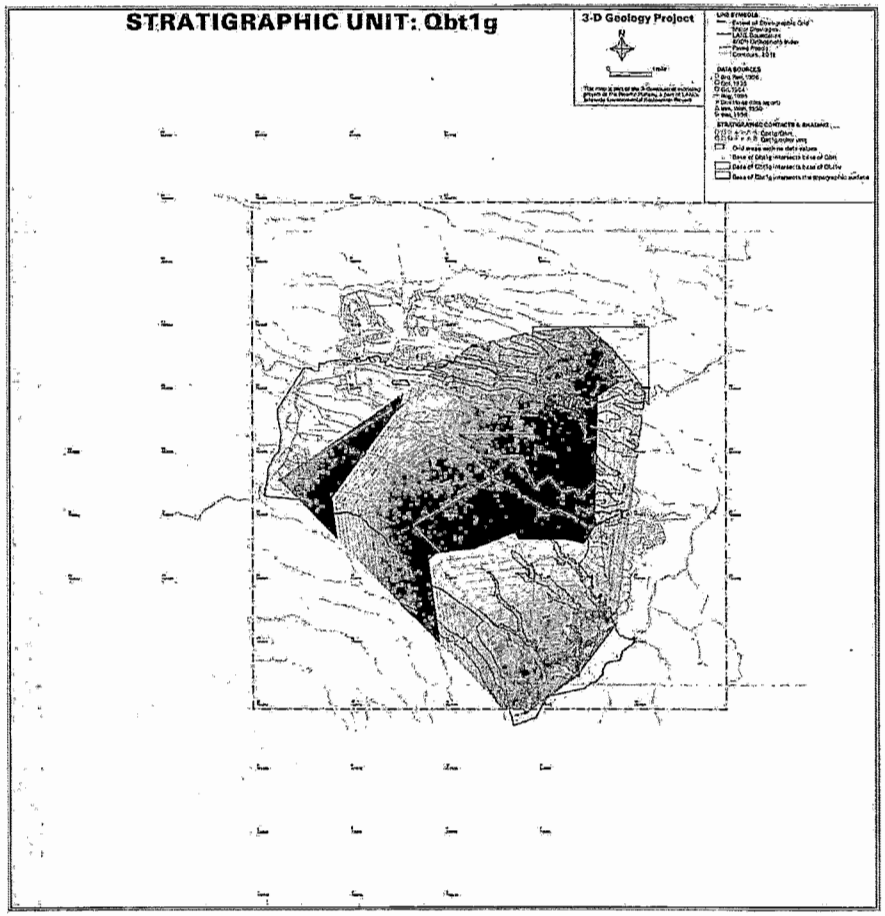
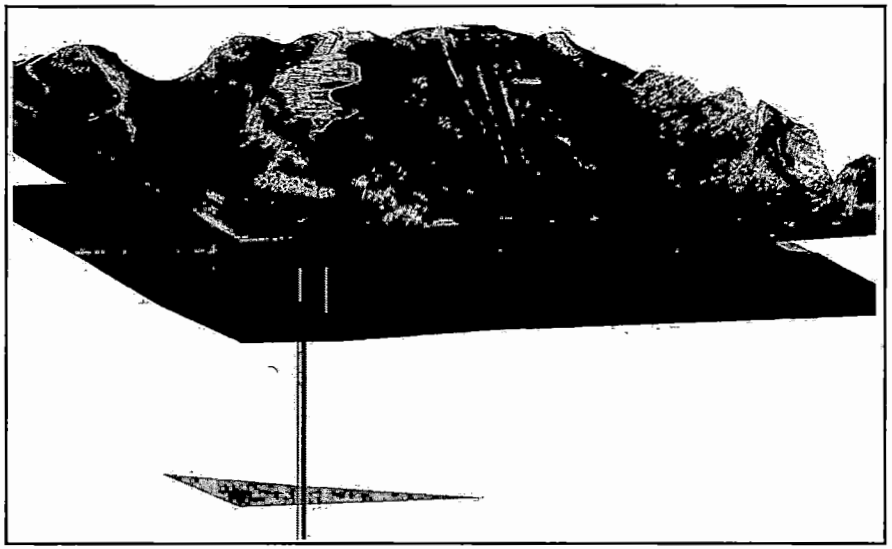


Figure 1-1a. Example of a geologic unit surface (Qbt1g) from the 1995 site geologic model



Source: Vaniman et al. 1996, 106129.

Figure 1-1b. Visualization at TA-21, utilizing the 1995 site geologic model

The earlier geologic models have been expanded in geographical extent to address issues of possible contaminant transport past Laboratory boundaries. The 2002 geologic model was expanded to include the full extent of all four 7.5-min quadrangle maps intersected by the Laboratory boundary. This model was called the "Pajarito Plateau" model in Cole et al. (2006, 095079). The model presented in this atlas includes the SITE model and a portion of the SEB model of the 2009 GFM. Table 1-1 provides a measure of the data support used to create each of the past and present GFMs. The fiscal year (FY) 2003 model provided only a partial coverage of the site and is therefore not included in the comparison.

Table 1-1.
Quantities of Contact Points Available for Past and Present GFMs

Model Year	FY96	FY97	FY98	FY99	FY02	FY06	FY09
Total Number of Data Points	34,989	40,991	43,369	31,624	76,638	121,284	>200,000
Number of Drill Hole Data Points	615	615	703	866	1042	1398	2228

Subsets of the total set of data points, augmented by outcrop maps, are used to develop structure contours. Final digital grids for the unit surfaces are created from the structure contours and "hard" data points reflecting the actual preerosional position of unit surfaces. Increased point counts at the FY02, FY06, and FY09 GFM dates reflect the combined increase in data density, as well as the increased geographical extent of these models.

1.2 Scope

In addition to the Laboratory, a number of government entities have been involved in the development of digital geologic data and geologic-based groundwater models for the region surrounding Los Alamos, including the New Mexico Bureau of Geology and Mineral Resources, the U.S. Geological Survey (USGS), and the City and County of Santa Fe. Development of the 2009 expanded Laboratory GFM incorporates the following:

- voluminous new subsurface (drill hole) data collected to support current characterization and remediation projects at the Laboratory
- new regional geologic information for development of accurate models of deeper, hydrologically significant units beneath the Laboratory (Grauch et. al. 2009, available at http://pubs.usgs.gov/pp/1761/)
- new models by other government agencies, reflecting a communal redefinition of many of the hydrogeologic units for the region (INTERA Incorporated 2006, 106106; Pantea et al. 2009 personal communication)
- revision of many of the geologic quadrangle maps within and along the boundaries of previous Laboratory GFMs
- revision of a large percentage of the geologic quadrangle maps within the EB that provide "boundary constraints" for the numerical flow and transport modeling at the Laboratory

The 2009 GFM was developed at three extents, with two resolutions (cell size) for each extent. The extents of the 2009 3-D geologic model(s) are shown in Figure 1-2. The areal extent of the EB model intersects more than 60 7.5-min quadrangle maps, that of the SEB model incorporates 12 quadrangle maps, and that of the site model consists of the four quadrangle maps encompassing the Laboratory site. The lower resolution for each model version is half the higher resolution and is limited to be no more than a million cells per grid surface. The SITE model has the highest resolution of the three model extents, with the model developed at 50-ft cell center spacing. Additional models of limited extent, including the model presented in this atlas, as well as a local model for Area G at the Laboratory site, represent extraction of data from these larger models and not a regeneration of model surfaces.

The map extent of this atlas encompasses the Laboratory and surrounding area. This region lies mainly within the SITE model but extends into the western portions of the Española and Horcado Ranch quadrangle maps, the northern edges of the Cochiti Dam, Montoso Peak quadrangle maps, and the northwest corner of the Agua Fria quadrangle map. Because the atlas surfaces extend past the SITE model boundary, surfaces were extracted from the lower-resolution (100-ft) SEB model.

The atlas presents a set of maps/plates that provide

1. land ownership and the location of wells that provide constraints for the 3-D geologic model,
2. mapped and modeled surface geology with mapped faults,
3. structure contours for the top of each unit and subunit of the model present within the atlas extent,
4. isochors (vertical thickness contours) for each unit and subunit of the model present within the atlas extent,
5. structure contours for the bottom of each unit of the model present within the atlas extent,
6. elevations of the regional water table produced for this atlas from the currently available data,
7. the geology at the water table,
8. cross-sections of the geology with the water-table position, and
9. locations of the cross-sections.

Basic information for the atlas, including land ownership, roads, and well locations with descriptions is provided in Plates 1-1, 1-2, and 1-3.

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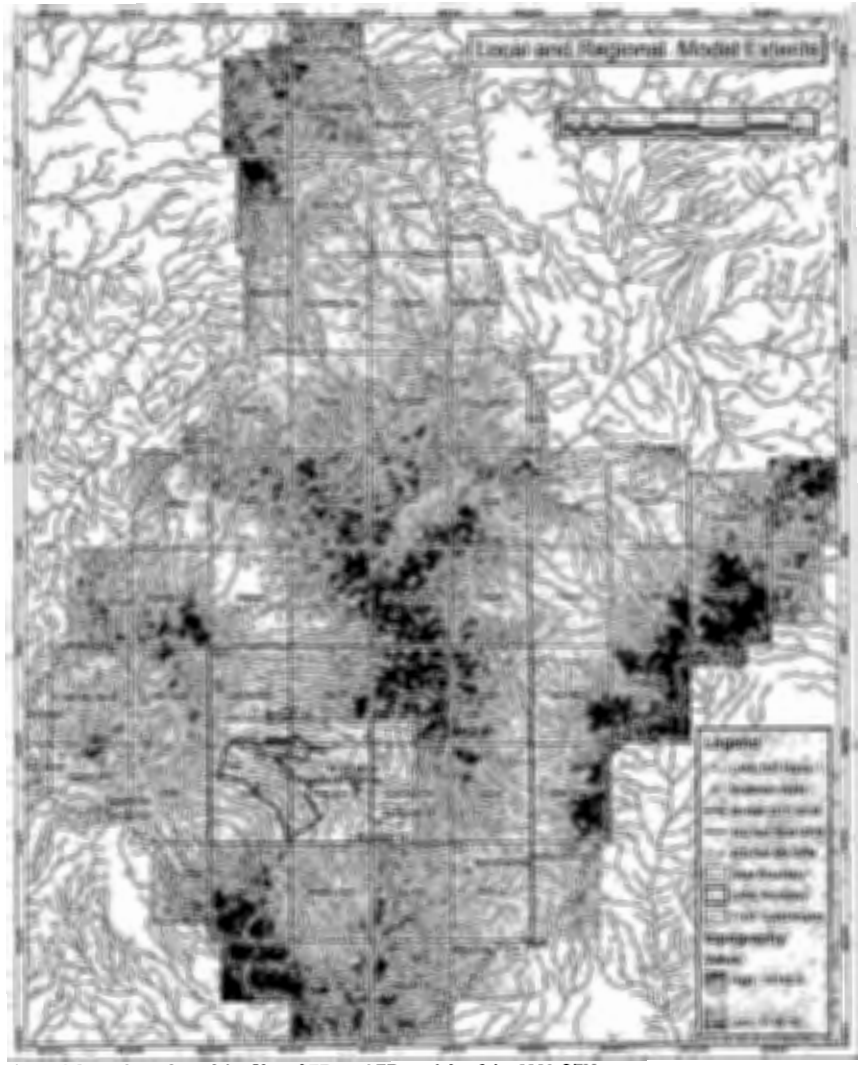

Figure 1-2. Location of the SITE, SEB, and EB models of the 2009 GFM

1.3 Data Sets

Data used to develop the SEB model that encompasses the atlas extent include the following:

- mapped surface geology and associated cross-sections for the following 7.5-min geologic quadrangle maps:
  - Guaje Mountain (Kempter et al. 2007, 106111)
  - Puye (Dethier 2003, 106113)
  - Española (Koning 2002, 105710)
  - Cundiyo (Koning 2002, 105710)
  - Frijoles (Goff et al. 2002, 088776)
  - White Rock (Dethier 1997, 049843)
- professional papers and open file reports for the following 7.5-min geologic quadrangle maps:
  - Horcado Ranch (Read et al. 2005, 105709)
  - Tesuque (Read et al. 2005, 105709)
  - Cochiti Dam (Sawyer et al. 2007, 106130)
  - Montoso Peak (Sawyer et al. 2007, 106130)
  - Agua Fria (Read et al. 2005, 105709)
  - Santa Fe (Read et al. 2005, 105709)
- mapping of subunits of the Bandelier Tuff by Laboratory scientists (Rogers 1995, 054419; Lewis et al. 2002, 073785; Lavine et al. 2003, 092527)
- subsurface geologic contacts from the current Laboratory database (Cole et al. 2006, 095079)

Source data were obtained from digital and analog (paper map) sources and converted to digital contact control points. All geologic unit data were preprocessed to convert (field) mapped units to the set of "regional" units of the model in the appropriate coordinate system. The preprocessed surface geologic map data for the 12-quadrangle map area of the SEB model are shown in "model" units as Figure 1-3.

The analog-to-digital conversion process includes

- scanning of contacts from cross-sections and geologic maps,
- extracting points at constant horizontal and/or vertical distances along the lines, and
- obtaining the "third" part of the spatial coordinate through a digital elevation model (for surface maps) or from geometric calculations (for cross-sections).

The conversion process was performed using the R2V digitizing software (Able Software), ArcInfo Geographical Information System (GIS) software and scripts, and utility FORTRAN programs.

2.0 THE 2009 GFM

The 2009 GFM is the latest of a series of 3-D geologic models that have been developed to support environmental cleanup and waste management programs at the Laboratory. This new GFM is unique in that it comprises multiple overlapping models of differing resolutions that allow the highest-resolution model centered on the Laboratory site to be seamlessly joined with lower resolution models at successive distances outside of the Laboratory boundary, with an ultimate model extent of the entire EB. Model resolution, defined by the distance between cell centers on a rectilinear grid, can range from 50 to 800 ft, with possible cell center increments of 50, 100, 200, 400, and 800 ft.

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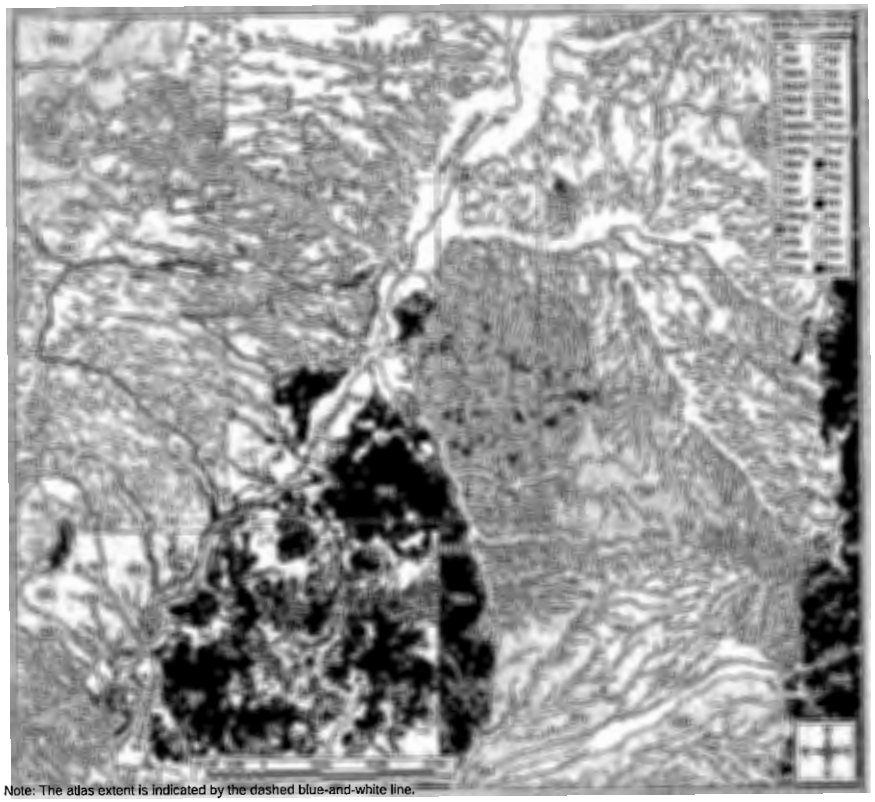


Note: The atlas extent is indicated by the dashed blue-and-white line.

Figure 1-3. Map of geologic unit polygons obtained from the surface geologic maps of the SEB region

The GFM reflects current ideas about the geologic evolution of the model area and depositional processes within the EB, embracing the voluminous amounts of new geologic mapping by the joint USGS and State mapping project, as well as the results of associated geological and geophysical studies. The GFM incorporates a large amount of new, subsurface data, including contact data from borehole logs of more than 100 new wells (through February 2009) that result in a 50% increase of subsurface contact control points. In addition, repositioning of well locations through global positioning system (GPS) techniques and reanalysis of existing geological and geophysical logs have resulted in many changes in the preexisting drill hole database. The locations of wells that provide new or updated contact control data are shown in Plate 1-1.

The 2009 GFM also provides a completely revised definition for the Santa Fe Group units that comprise most of the saturated zone stratigraphy. The GFM incorporates the breakout of geologic units used in the recent geologic remapping of most of the quadrangle maps within the model area.

Surfaces of the new GFM were developed with the ArcInfo software. Digital data sets were obtained from a variety of sources, including

- existing digital grids or digital line data from USGS and the New Mexico Bureau of Geology and Mineral Resources,
- published geologic maps and cross-sections (scanned and digitized),
- "open-source" topographic grids and digital line graphs of the USGS,
- structure contours for unit surfaces developed by the Laboratory, and
- well logs from the Laboratory database as well as off-site logs from other sources, where available.

Quality assurance was provided through comparison of the modeled and actual 3-D position of the input data with emphasis on the fit of subsurface data. USGS topographic data were used rather than the higher-quality, light detection and ranging (LIDAR) elevation data available at the Laboratory (Carey and Cole 2002, 073784). A single-source data set was desired for the GFM, and the LIDAR data do not extend into the SEB and EB portions of the model. Topographic maps (7.5 min) are usually the basis for placement of geologic contacts by field geologists and are the source of the digital line graph (DLG) contour data that are used as the elevation model for the GFM. The subsurface contacts at drill holes are normally positioned relative to high-resolution surface measurements obtained from LIDAR or GPS elevation data and not from the DLG data.

2.1 Geologic Overview

The Laboratory is located on the Pajarito Plateau within the eastern area of the Jemez volcanic field (JVF), along the east-southeastern slope of the Valles Caldera at the western edge of the EB (Figure 2-1).

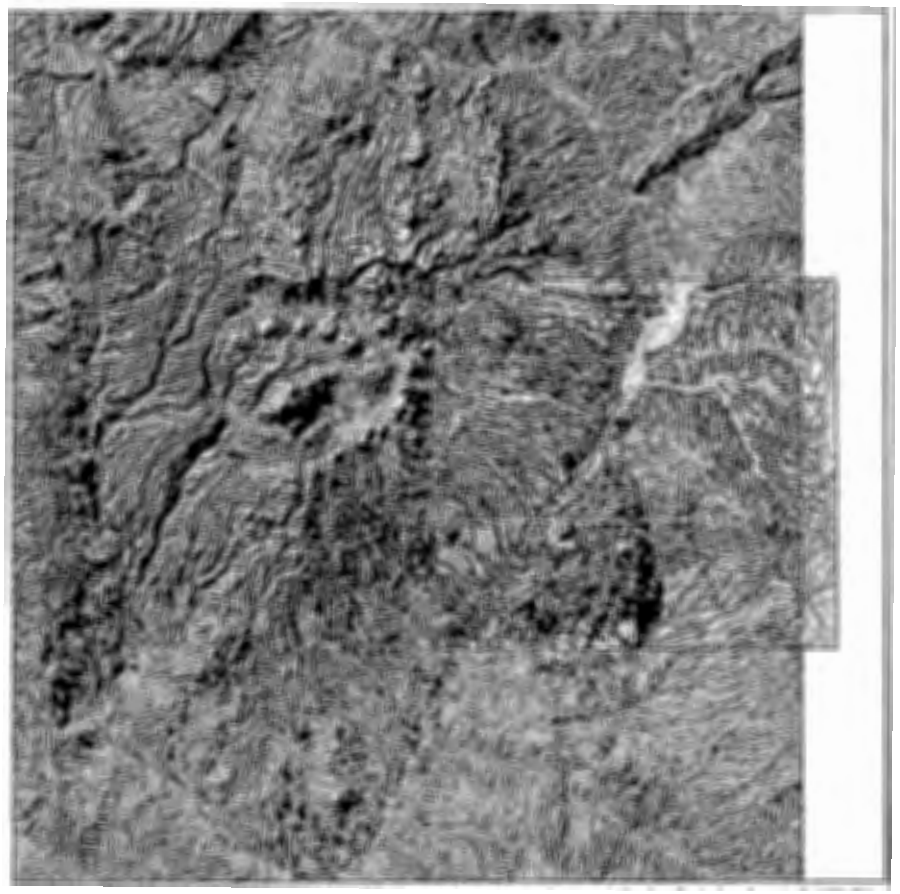
The stratigraphy of the modeled area reflects the interplay of tectonic and depositional processes within the developing EB, which at the model latitude, is hinged at its eastern edge with major, predominantly downward, displacements at its western margin. This geometry is schematically shown in Figure 2-2.

The tectonically active portion of the western edge of the EB is present within the far western portion of the GFM, at the Pajarito fault system, which exhibits both discrete offsets and distributed strain. Other, poorly defined, north-south faults with major offsets occur west of the model area, within the eastern portion of the Valles Caldera. The volcanic activity began approximately 14 million years ago (Ma) (Goff 2009, 106105), with the most recent major eruptive events creating the Pajarito Plateau. The origin of the upper (above water table) geologic units of the plateau is predominantly volcanic, and these geologic units include dacitic and rhyolitic flows, ash-flow tuffs, and their erosional derivatives. Basaltic flows from sources within and to the east and southeast of the Laboratory are intermixed with this Jemez volcanic material. The units generally tilt to the east and southeast, although downward displacements to the west may offset or reverse the original depositional dips of units, depending on their age.

The JVF material lies on top of EB sedimentary units and extends almost to the currently active position of the Rio Grande, with some intermixing with basin sediments to the east. The EB sedimentary units exposed further east, reflect the erosion of the uplifting Sangre de Cristo Mountains, which form the eastern boundary of the basin, as well as sediment sources farther to the north. The units tilt regionally to the west, reflecting both the depositional attitude as well as their increased downward displacement to the west, along poorly defined north-south trending faults within the basin. Older basin sedimentary units underlie the JVF volcanic material to the west. Figures 2-3 and 2-4 show relationships between the stratigraphic units in the east-west direction between the JVF volcanic and fanglomerate material and the river gravels and other sedimentary material in the EB.

Plates 2-1 and 2-2 show the mapped and modeled geology in greater detail within its extent identified in Figure 2-1. Plate 2-3 provides the observed and inferred geologic structure for this region. Plates 2-84 through 2-91 provide cross-section information for the GFM, which add some reality to the schematic views provided by Figures 2-3 and 2-4. Plates 2-93 and 2-94 provide 3-D views for cutouts of the atlas and SEB model.

: 06087



Notes: The Laboratory site is outlined in yellow. The purple boundary identifies the geologic extent of this atlas. Geologic units are colored for the extent of the SEB model. The flat, pale-green area running from the north-central to southwest corners of the SEB model identifies the alluvial units of the Rio Grande that approximate the eastern extent of volcanic material of the JVF.

Figure 2-1. The Laboratory setting along the eastern flank of the Valles Caldera

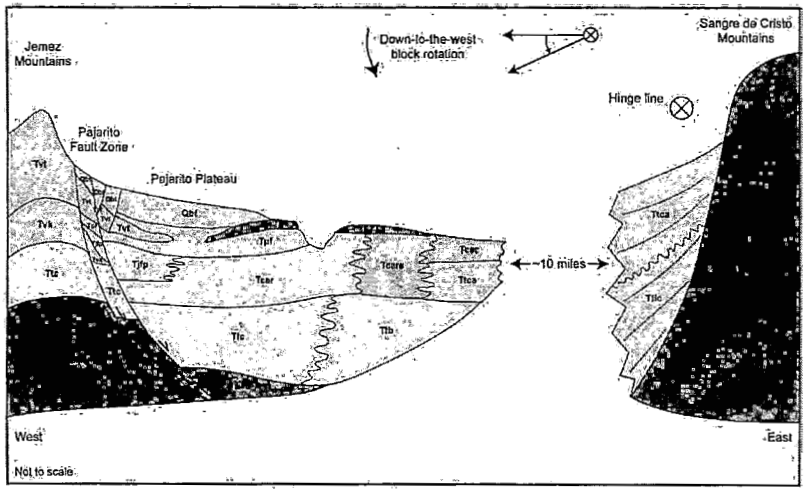
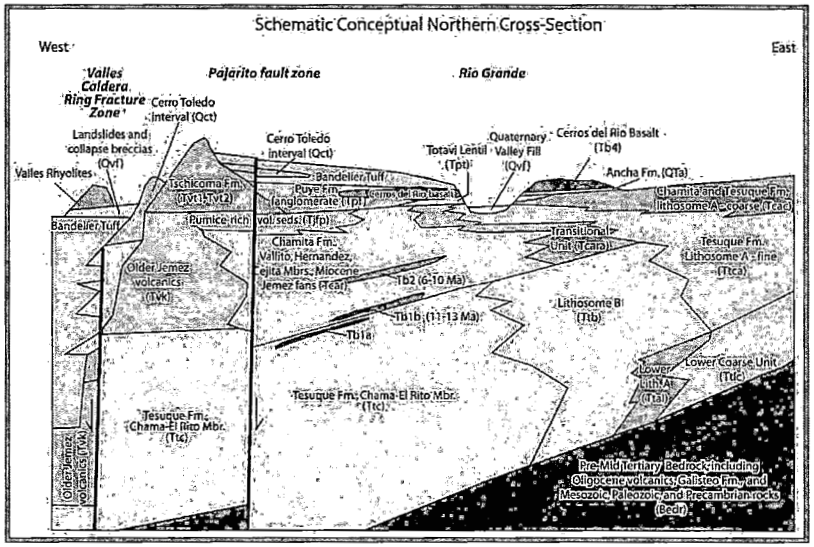
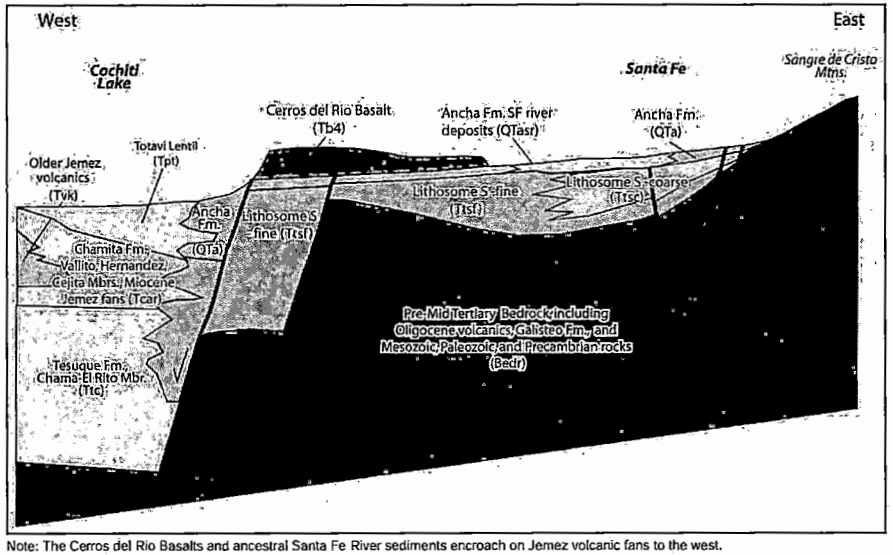


Figure 2-2. Schematic cross-section across the EB



Note: Volcanic material of the JVF dominates the upper portions of the section to the west.

Figure 2-3. Units of the northern portion of the SEB model



Note: The Cerros del Rio Basalts and ancestral Santa Fe River sediments encroach on Jemez volcanic fans to the west.

Figure 2-4. Units of the southern portion of the SEB model

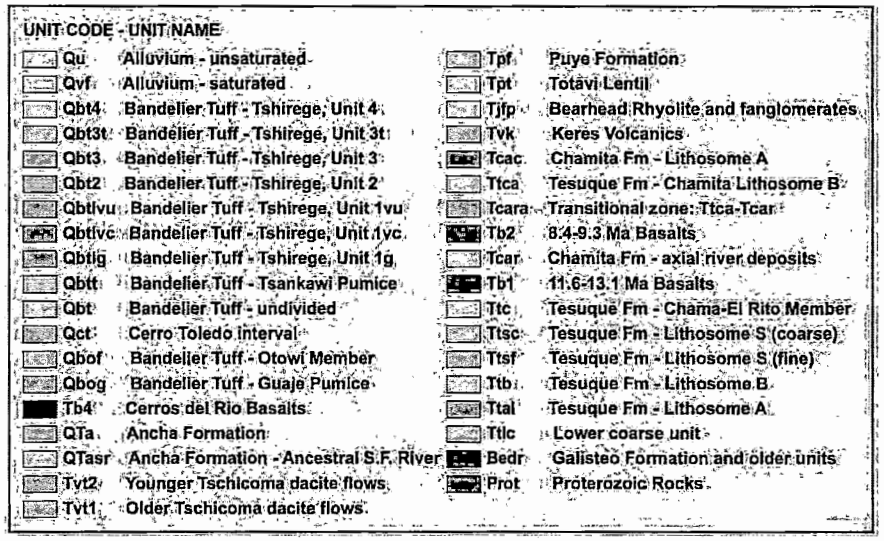


Figure 2-5. Codes and colors used for the GFM units

2.2 Stratigraphic/Geologic Units

The following section describes the modeled geologic units, which include both sedimentary and volcanic units. Figure 2-5 provides the colors and codes that are used in the GFM and on the plates provided in this atlas. Also included are descriptions (and colors) for several units within the SEB that do not extend into the reduced extent of the atlas. Plates showing the top structure and vertical thickness of each unit and the bottom structure of all units, except for the units/subunits of the Tshirege Member of the Bandelier Tuff, are provided as Plates 2-5 through 2-83. The alluvial units are not included in any of the models.

2.2.1 Tshirege Member, Bandelier Tuff (Qbt)

The Tshirege Member is the youngest member of the Bandelier Tuff, a multiple-flow ash-and-pumice unit that erupted from the Valles Caldera at approximately 1.22 Ma (Izett and Obradovich 1994, 048817; Spell et al. 1996, 055542). This is the most widely exposed bedrock unit of the Pajarito Plateau. The Tshirege Member tends to be more strongly welded than the Otowi Member, especially toward the western side of the plateau, closer to the Valles Caldera. Time breaks between the successive emplacements of ash-flow units caused the tuff to cool as several distinct cooling units, resulting in a complex internal stratigraphy that varies laterally as a function of distance from the caldera source. The stratigraphic nomenclature for the subunits of the Tshirege Member has evolved significantly through time (Broxton and Eller 1995, 058207; Broxton and Reneau 1995, 049726; Broxton and Vaniman 2005, 090038). The 2009 GFM follows the Tshirege subdivisions of the 2005 3-D GFM. The Tshirege Member is broken into a basal pumice layer and four overlying cooling units. Two of the cooling units are further subdivided, based on lithologic differences (Cole et al. 2006, 095079).

2.2.1.1 Unit 4 (Qbt4)

Unit 4 is a complex unit consisting of nonwelded to densely welded ash-flow tuffs that crop out in the western part of the Laboratory. Lewis et al. (2002, 073785) divide Qbt4 into local subunits and provide detailed descriptions of this heterogeneous unit. However, for the 3-D GFM, Qbt4 is not subdivided.

2.2.1.2 Unit 3t (Qbt3t)

Unit 3t is a moderately to densely welded ash-flow tuff that has petrographic and geochemical characteristics transitional between unit 3 and unit 4. Unit 3t is present in the western part of the Laboratory (Broxton and Vaniman 2005, 090038) and can impede the downward flow of surface water, creating seasonal springs along canyon walls.

2.2.1.3 Unit 3 (Qbt3)

Unit 3 is a nonwelded to partially welded tuff that forms the cap rock of mesas in the central part of the Pajarito Plateau. This unit and the overlying units Qbt3t and Qbt4 are absent from large areas in the eastern part of the Laboratory where they have been removed by erosion (Broxton and Eller 1995, 058207; Broxton and Reneau 1995, 049726; Broxton and Vaniman 2005, 090038).

2.2.1.4 Unit 2 (Qbt2)

Unit 2 is typically the most strongly welded tuff in the Tshirege Member and is characterized by lower porosity and higher density than the other units. It forms a distinctive medium-brown, vertical cliff that stands out in marked contrast

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to the slope-forming, lighter-colored tuffs above and below. Unit 2 contains numerous well-developed, near-vertical fractures (Broxton and Reneau 1995, 049726; Broxton et al. 1995, 058207; Broxton and Vaniman 2005, 090038).

2.2.1.5 Unit 1

Cooling unit 1 of the Tshirege Member is a thick succession of ash-flow tuffs that dips gently east-southeast. This unit is characterized by a lack of welding and has been subdivided into a glassy lower tuff and an upper devitrified, vapor-phase crystallized tuff. The vapor-phase tuff is further divided into a colonnade portion and an upper portion (Broxton and Reneau 1995, 049726; Broxton and Vaniman 2005, 090038).

2.2.1.5.1 Unit 1vu (Qbt1vu)

The upper part of the vapor-phase unit (Qbt1vu) forms a distinctive grayish-white band between the darker colored colonnade tuff (Qbt1vc) below and unit 2 above. The upper vapor-phase unit is generally nonwelded and slope-forming, but in some localities it forms weakly developed cliffs and benches due to slight variations in welding (Broxton and Reneau 1995, 049726; Broxton and Vaniman 2005, 090038).

2.2.1.5.2 Unit 1, Colonnade (Qbt1vc)

The base of this altered vapor-phase unit (Qbt1vc) is a thin, horizontal zone of preferential weathering that forms a marker horizon, often called the vapor-phase notch, which marks the transition from glassy tuffs below to vapor-phase crystallized tuffs above. In some places, the vapor-phase notch grades laterally into a prominent bench developed on top of the glassy tuff. This colonnade vapor-phase tuff has distinctive columnar cooling joints and is a resistant, cliff-forming unit that may be slightly welded (Broxton and Reneau 1995, 049726; Broxton and Vaniman 2005, 090038).

2.2.1.5.3 Unit 1, Glassy (Qbt1g)

The lower part of unit 1 (Qbt1g) is not vapor-phase altered, retaining primary glass in both pumice and ash. Vapor-phase alteration is absent in this and all lower units of the Bandelier Tuff.

2.2.1.5.4 Unit 1 Tsankawi Pumice (Qbtt)

The Tsankawi Pumice Bed is the basal pumice fall of the Tshirege Member. This unit is typically 20 to 100 cm thick. Pumices in the Tsankawi Pumice Bed are mostly of rhyolitic composition, but there is a small (<5%) amount of dacitic pumice as well (Broxton and Reneau 1995, 049726). This pumice fall is vitric and unaltered by vapor-phase processes.

2.2.2 Cerro Toledo Interval (Qct)

The Cerro Toledo interval comprises a stratified sequence of volcaniclastic sediments and tephra and occurs between the two tuff members of the Bandelier Tuff. It is not considered as an integral part of the Bandelier Tuff (Broxton and Eller 1995, 058207; Broxton and Reneau 1995, 049726; Goff 1995, 049682; Broxton and Vaniman 2005, 090038). Structure contours for the base of the Cerro Toledo indicate that this unit fills a broad southeast-draining valley fed by one or more canyons exiting the Sierra de los Valles. The rhyolitic tuffaceous sandstone and tephra within this interval represent the reworked equivalents of Cerro Toledo rhyolitic tephra erupted from the Cerro Toledo and Rabbit Mountain dome complexes located northeast and southeast of the Valles Caldera, respectively. Clast-supported gravel, cobble, and boulder deposits derived from the Tschicoma Formation are interbedded with the tuffaceous rocks. In the western part of the Plateau, the interval also contains tuffaceous sediments that represent reworked Otowi Member of the Bandelier Tuff (Broxton and Vaniman 2005, 090038).

2.2.3 Otowi Member (Qbo)

The Otowi Member includes both the ash-flow (Qbof) and the basal pumice (Qbog).

2.2.3.1 Otowi Member, Bandelier Tuff (Qbof)

The Otowi Member consists of moderately consolidated, porous, nonwelded ash-flow tuffs. The ash-flow tuffs are vitric and contain light gray-to-orange pumice supported in a white to tan ashy matrix of glass shards, broken pumice, crystals, and rock fragments (Broxton et al. 1995, 058207; Goff 1995, 049682). Structure contours indicate that the Otowi Member ash-flow tuffs filled a broad south-draining paleovalley west of the Cerros del Rio basaltic highland and east of the Sierra de los Valles (Broxton and Vaniman 2005, 090038).

2.2.3.2 Guaje Pumice Bed, Otowi Member, Bandelier Tuff (Qbog)

The Guaje Pumice Bed forms the base of the Otowi Member of the Bandelier Tuff, which erupted from the Toledo Caldera at approximately 1.61 Ma (Izett and Obradovich 1994, 048817, Spell et al. 1996, 055542). The Guaje Pumice Bed contains layers of sorted vitric pumice fragments whose mean size varies between 2 and 4 cm. It has an average thickness of ~9 m over much of the Plateau. Geophysical logs show that the Guaje Pumice Bed has a higher porosity than overlying Otowi Member ash-flow tuffs and the underlying Puye Formation (Broxton and Vaniman 2005, 090038).

2.2.4 Puye Formation

The Puye Formation is a large apron of overlapping alluvial and pyroclastic fans that were shed eastward from the JVF into the western EB (Griggs and Hem 1964, 092516; Bailey et al. 1969, 021498). This unit consists of highly stratified, poorly cemented gravels and conglomerates, consisting of subrounded dacitic and andesitic lava clasts in a poorly sorted, sandy to silty matrix. Debris flows, ash beds, pumiceous volcaniclastic sediments, and beds of fluvial sand and silt are interbedded with the gravels and conglomerates. Because its primary source area was volcanic domes in the Sierra de los Valles, the Puye Formation overlaps and postdates the Tschicoma Formation (Broxton and Vaniman 2005, 090038).

2.2.5 Tschicoma Formation

The Tschicoma Formation includes dacitic to low-silica rhyolitic flows.

2.2.5.1 Tschicoma Formation, Pajarito and Caballo Mountains, Cerro Grande (Tvt2)

The Tschicoma Formation of the Polvadera Group consists of thick dacitic to low-silica rhyolitic lava flows that make up the rugged Sierra de los Valles highlands west of Los Alamos. The flows erupted from large overlapping dome complexes. The upper portion of this unit (Tvt2) includes the Pajarito Mountain, Cerro Grande, and Caballo Mountain lobes of the Tschicoma Formation, as well as fine-grained dacites encountered in the subsurface of an unknown source. Lavas from the Pajarito Mountain, Cerro Grande, and Caballo Mountain centers are predominantly dacite, aged between 2.93 and 3.35 Ma (Broxton and Vaniman 2005, 090038).

2.2.5.2 Tschicoma Formation, Rendija Canyon Lobe (Tvt1)

The lower portion of the Tschicoma Formation (Tvt1) consists of the Rendija Canyon lobe and includes low-silica rhyolite erupted from a deeply eroded dome complex in the Rendija Canyon and Guaje Mountain area that has yielded ages between 4.98 and 5.36 Ma (Broxton et al. 2007, 106121).

2.2.6 Cerros del Rio Basalt (Tb4)

The Cerros del Rio volcanic field was active from approximately 4.5 to 2.0 Ma (WoldeGabriel et al. 2001, 092523). These rocks are mostly basalts and basaltic andesites, but subordinate dacite is also present. The Cerros del Rio Basalt is generally composed of thick sequences of stacked lava flows separated by interflow breccia, scoria, sediment, and ash. Outcrops of the Cerros del Rio Basalt cap the Tesuque Formation east of the Rio Grande and the Puye Formation in the vicinity of White Rock. These basalts are buried to increasing depths below the Plateau in the

central portions of the model and may lap onto or interfinger with the Tschicoma flows at isolated locations to the west (Cole et al. 2006, 095079).

2.2.7 Ancha Formation

The Ancha Formation was deposited on an alluvial slope in the Santa Fe area by west-flowing, ephemeral streams (Koning et al. 2002, 105711). It overlies older strata across an angular unconformity. The Ancha Formation contains a coarse-grained and a fine-grained part (Koning et al. 2002, 105711).

2.2.7.1 Ancha Formation (QTa)

Found near the base of the deposit and the mountain front to the east, the coarse-grained part is commonly reddish and consists of sandy pebbles to cobbles. The coarse-grained deposit laterally grades westward into a finer-grained deposit consisting of light yellowish brown to brownish yellow, silty-clayey sand (mostly very fine- to medium-grained). In many places, the Ancha Formation is not saturated. Where it is saturated, groundwater is found near the base of the deposit where the deposit is relatively thick (50–90 m thick). Most of the deposition occurred in the late Pliocene, with aggradation continuing near the mountain-front during the early Pleistocene (Koning et al. 2002, 105711).

2.2.7.2 Ancha Formation, Santa Fe River (QTasr)

An ancestral Santa Fe River was present during Ancha Formation deposition (primarily late Pliocene). The river deposited relatively coarse-grained sediment that interfingers southward and northward into alluvial slope deposits of unit QTa. The sediment of this unit contains sandy gravel (typically cobbles and pebbles) that interfinger with overbank facies of clayey-silty sand. Colors are generally reddish. Near Santa Fe, the unit is inset into lithosome S of the Tesuque Formation (Ttsc).

2.2.8 Totavi Lentil (Tpt)

This unit includes the Totavi Lentil as well as older river gravels. Based on new well data, it appears that the Totavi Lentil river gravels may form lenticular deposits of limited lateral extent and that ancient river deposits in the Pajarito Plateau area are coeval with a variety of stratigraphic units that span a longer time interval than previously recognized (Broxton and Vaniman 2005, 090038). The river gravels probably represent channel deposits of the ancestral Rio Chama/Rio Grande drainages and contain Precambrian and younger cobbles from northern source areas, indicating through-going, north-to-south fluvial systems dating to at least approximately 7.9 Ma (Broxton and Vaniman 2005, 090038; Broxton et al. 2006, 092520).

2.2.9 Bearhead Rhyolite and Fanglomerates (Tjfp)

This unit incorporates the pumiceous Bearhead Rhyolite, vitric pumiceous deposits related to the Peralta Tuff, and older fanglomerate material derived predominantly from erosion of the Keres Group volcanic highlands. These fanglomerates interfinger with Santa Fe Group sands within a north-south trending, troughlike structure in the central portion of the Plateau. This unit does not crop out; its existence and modeled geometry are based solely on well logs and cuttings and surrounding geologic controls. The geometry of this unit suggests deposition within a fault-controlled basin with associated episodic basaltic volcanism (Cole et al. 2006, 095079). This unit tends to be part of the most productive aquifer beneath the Pajarito Plateau (Purtymun 1995, 045344).

2.2.10 Keres Group Volcanics (Tvk)

The Keres Group includes basaltic and rhyolitic rocks that erupted as the JVF began to develop (Gardner et al. 1986, 059104; Goff and Gardner 2004, 092526). These rocks intrude and cover Santa Fe Group rocks along the western edge of the EB (Cole et al. 2006, 095079).

2.2.11 Chamita Formation

The Chamita Formation forms the upper part of the Santa Fe Group.

2.2.11.1 Chamita Formation, Lithosome A (Tcac)

Lithosome A of the Chamita Formation is used to designate strata containing arkosic sand and granite-bearing gravel that were deposited on an alluvial slope by streams draining the west flank of the Sangre de Cristo Mountains south of Truchas Peaks (Cavazza 1986, 105708). Technically, lithosome A extends into the Tesuque Formation east of the Rio Grande (Koning and Aby 2005, 106162).

Lithosome A that is younger than 13.2 Ma is relatively coarser grained (Koning 2002, 105710; Koning et al. 2002, 105711; Koning et al. 2005, 106120), and consists of slightly orange-tan, coarse channel-fill of sandy conglomerate and conglomeratic sandstone, interbedded with subordinate clayey-silty sandstone. Unit Tcac reflects this coarse-grained lithosome A, excluding relatively fine-grained, distal alluvial slope strata. These relatively coarse strata correlate with the Cuarteles Member of the Chamita and Tesuque Formations (Koning and Aby 2005, 106162; Koning et al. 2005, 106120). The Cuarteles Member is considered part of the Tesuque Formation east of the Rio Grande and part of the Chamita Formation west of the Rio Grande. This unit interfingers westward with unit Ttca and gradationally overlies unit Ttca.

2.2.11.2 Chamita and Tesuque Formations, Lithosome A (Ttca)

Unit Ttca includes relatively fine-grained, distal alluvial slope strata that postdates the 13.2 Ma coarsening of Tcac (Koning et al. 2007, 106122). The sediment is a slightly orange-tan to tan, clayey-silty sandstone intercalated with subordinate coarse channel-fills of sandy conglomerate and conglomeratic sandstone. Gravel includes granite with minor, yellowish Paleozoic limestone and siltstone. Minor quartzite clasts are also present. The unit correlates with the fine-grained, distal Cuarteles Member of the Chamita and Tesuque Formations (Koning and Aby 2005, 106162; Koning et al. 2005, 106120) and also correlates with lithosome A sediment of the Pojoaque, Skull Ridge, and Nambe Members of the Tesuque Formation (Cavazza 1986, 105708). This unit grades laterally westward into lithosome B (Ttb) and laterally southward into deposits of the ancestral Santa Fe River (units Ttsc and Ttsf).

2.2.11.3 Transition Zone between Ttca and Tcar (Tcara)

This unit reflects a zone of interfingering and mixing between coarse-grained lithosome A and the axial river deposits of the Chamita Formation. Lithosome A in this zone is typically a slightly orange-tan, silty-clayey sand, interbedded with minor pebbly channel-fills. The axial river deposits include floodplain deposits of claystone, siltstone, and very fine- to medium-grained sandstone that are subequal in proportion to coarse channel-fills of fine- to very coarse-grained sand, pebbly sand, and sandy pebbles-cobbles. Colors of the axial river deposits are generally tannish. This unit interfingers eastward with unit Ttca, and interfingers westward with unit Tcar. It gradationally overlies lithosome B of the Tesuque Formation (Ttb).

2.2.11.4 Chamita Formation, Axial River Deposits (Tcar)

Sediments deposited by the river system flowing south along the basin floor of the EB coarsened after ~13.2 Ma (Koning et al. 2005, 106120; Koning et al. 2007, 106122). This coarser sediment consists primarily of channel-fills of sandstone, gravelly sandstone, and sandy conglomerate. Floodplain deposits of claystone, siltstone, and very fine- to medium-grained sandstone are subequal in proportion to the coarse channel-fills. The gravel of the axial river deposits contains felsic to intermediate volcanic clasts, with lesser quartzite and Paleozoic sedimentary clasts. Tannish colors generally typify the unit. The unit correlates to the Vallito, Hernandez, and Cejita Members of the Chamita Formation (Koning and Aby 2005, 106162). The unit includes sandy channel-fills from a drainage that flowed southeastward in the region that is now the Jemez Mountains. This unit interfingers eastward with unit Tcara and overlies units Ttb and Ttc.

2.2.12 8.4–9.3 Ma Basalts (Tb2)

The Bayo Canyon Basalt is a rift basalt and consists of local, episodic, Miocene basalt to latitic flows that are 8.4 to 9.3 Ma (WoldeGabriel et al. 1996, 054427; WoldeGabriel et al. 2001, 092523) that are interbedded with basin sediments. The flows are intermixed with both Keres Group and Santa Fe Group sedimentary units in a zone that extends from the central plateau east to Bayo Canyon, and south to Ancho Canyon (Cole et al. 2006, 095079). Model boundaries for this unit extend from the bottom of the oldest flow to the top of the youngest flow. Thus, the volume of this unit includes any intercalated sediments.

2.2.13 11.6–13.1 Ma Basalts (Tb1)

The Guaje Canyon Basalt (Tb1) is a thick sequence of basalt flows contained within the Tesuque Formation in the vicinity of Guaje Canyon. The basalts range from 11.55 to 13.1 Ma (WoldeGabriel et al. 1996, 054427; WoldeGabriel et al. 2001, 092523). The Tb1 unit crosses the stratigraphic boundary between the Chamita Formation (Tcar) and the Chama–El Rito Member of the Tesuque Formation (Ttc). The portion of this flow unit within Ttc is designated as Tb1a. The portion of this flow unit within Tcar is designated as Tb1b.

2.2.14 Tesuque Formation

The Tesuque Formation forms the lower part of the Santa Fe Group.

2.2.14.1 Tesuque Formation, Chama–El Rito Member (Ttc)

In the study area, strata assigned to the Chama–El Rito Member are light orange-tan. Sediment consists primarily of very fine- to medium-grained sand, siltstone, and claystone. Pebble beds are very sparse. The unit was deposited on a southward-southeastward alluvial slope environment in the west part of the EB during the early to middle Miocene epoch. The unit includes quartz-rich sand from a southeast-flowing, tributary drainage. This unit gradationally underlies unit Tcar and interfingers eastward with lithosome B of the Tesuque Formation (Ttb).

2.2.14.2 Tesuque Formation, Lithosome S, Coarse-Grained Part (Ttsc)

An ancestral equivalent of the Santa Fe River deposited relatively coarse-grained sediment in the Santa Fe area during the early to middle Miocene epoch. This sediment was named lithosome S by Koning et al. (2004, 106104). Generally reddish, this sediment consists mostly of pebbly sand and sandy pebble channel-fills. Overbank deposits of clay, siltstone, and clayey very fine- to fine-grained sandstone are subordinate. Gravel includes granite with minor, yellowish Paleozoic limestone and siltstone. Minor quartzite clasts are also present. The unit grades northward into lithosomes A and B (units Ttca and Ttb) and westward into finer-grained lithosome S (Ttsf). The unit gradationally overlies the finer-grained part of lithosome S (Ttsf).

2.2.14.3 Tesuque Formation, Lithosome S, Fine-Grained Part (Ttsf)

This unit is also identified as a part of lithosome S by Koning et al. (2004, 106104). Although finer grained than the coarse-grained part of lithosome S (Ttsc), the finer-grained part of lithosome S is still, in an overall sense, coarser grained than lithosomes B and A to the north (units TTb and Ttca). This unit contains relatively abundant, reddish clay, silt, and very fine- to medium-grained sand deposits, which are intercalated with subordinate coarse-grained channel-fills of pebbly sand and sandy pebbles-cobbles. The finer-grained part of lithosome S grades northward into lithosomes A and B (units Ttca and Ttb) and westward into lithosome B (Ttb). The unit gradationally underlies the coarser-grained part of lithosome S (Ttsc).

2.2.14.4 Tesuque Formation, Lithosome B (Ttb)

Lithosome B was deposited on a wide basin floor between approximately 25 and 13 Ma by a drainage system flowing south southwest from the San Luis Basin and Peñasco embayment (Cavazza 1986, 105708; Koning et al. 2005, 106120). Relatively fine-grained, overbank deposits predominate in the SEB model area (Koning 2002, 105710; Koning and Maldonado 2003, 106112). These consist of light gray to light greenish gray clay, silt, and very fine- to medium-grained sand. Subordinate coarse-grained channels contain medium- to very coarse-grained sand, pebbly sand, and sandy pebbles. Gravel includes clasts of Paleozoic sedimentary rocks (limestone, sandstone, and siltstone), in addition to minor quartzite and felsic-intermediate volcanic clasts. This unit grades southward into ancestral Santa Fe River deposits (units Ttsc and Ttsf) and eastward into alluvial slope deposits of lithosome A (Ttca).

2.2.14.5 Tesuque Formation, Lower Lithosome A, Fine Grained (Ttal)

In the Santa Fe area, adjacent to the Sangre de Cristo Mountain front, lies tannish to pinkish sand, clayey sand, and pebbly-cobbly sand. Gravel contains primarily granite clasts, although locally, yellowish Paleozoic limestone-siltstone clasts are present. This unit is well-consolidated and underlies fine-grained lithosome S. It grades northward into the lower, coarse-grained unit (Ttlc).

2.2.14.6 Tesuque Formation, Lower Coarse Unit (Ttlc)

At the base of the Santa Fe Group in the eastern E, lies relatively coarse-grained, alluvial slope deposits. This sediment is tannish to pinkish and contains channel-fills of sandy pebbles-cobbles, pebbly sand, and very fine- to very coarse-grained sand. Overbank beds of clay, silt, and very fine- to fine-grained sand are minor. Gravel contains primarily granite clasts, although the proportion of Paleozoic limestone clasts increases to the south. Near the Rio Tesuque drainage, the proportion of Paleozoic limestone clasts increases down section. This unit grades laterally southward into unit Ttal and is gradationally overlain by unit Ttca. This unit grades laterally westward into lithosome B (unit Ttb).

2.2.15 Bedrock (Bedr)

Underlying the Santa Fe Group are various, typically well-cemented or indurated, formations that we have combined into one unit called "bedrock," or the Pre-Miocene-Tertiary bedrock. This surface represents the base of the Santa Fe Group, as defined by Grauch et al. (available at http://pubs.usgs.gov/pp/1761/). The combined formations of this unit are described from top to bottom (youngest to oldest). At the top of this unit are lava flows and intercalated, mafic volcaniclastic deposits of the Cieneguilla basanite; this unit is typically dark gray. The Espinaso Formation consists of alluvial fan deposits that were shed away from a volcanic edifice centered near the Cerrillos Hills–La Cienega area. The sediment is composed of latitic to andesitic detritus. There are minor latitic flows intercalated in the well-cemented, light gray to gray alluvial fan deposits. The Galisteo Formation includes red sandstone, pebbly sandstone, and mudstone deposited in a depression formed during the Laramide orogeny. Sand and clasts in the study area are primarily of arkosic and granitic composition, with minor Paleozoic limestone detritus. Mesozoic–Paleozoic strata in the study area mostly consist of interbedded limestone, shale, and sandstone.

The EB model includes an older/deeper unit of Proterozoic rocks that includes pink to red granite and gneiss to the southwest of the model (Goff 2009, 106105), and metasedimentary, metavolcanic, and granitic rocks to the east (Daniel 1995, 106123). This unit is not shown in the atlas because it will be added to the model at a later date when the full basin model is completed. Within the extent of the atlas, this unit is probably located at depths below sea level.

3.0 MAPPING OF THE REGIONAL WATER-TABLE ELEVATION

The regional aquifer beneath the Laboratory is a complex hydrogeological system. The top of the aquifer is predominantly under phreatic (water-table) conditions. However, there are also areas of local confinement that are caused by local hydrogeological conditions. In general, the top of the regional aquifer is defined by the elevation of the regional water table. In the areas of local confinement, there is a regional piezometric surface that represents the elevation of hydraulic heads in the confined zones. In general, the regional piezometric surface can be considered to represent a spatial continuation of the water table in the confined areas. Because the aquifer is predominantly under

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phreatic conditions, in the text below, the term "regional water table" is used even though in some areas of the aquifer the term "regional piezometric surface" is more appropriate.

The general shape of the regional water table is predominantly controlled by the areas of regional recharge to the west (flanks of Sierra de los Valles) and discharge to the east (the Rio Grande and the White Rock Canyon Springs). The structure of regional phreatic flow is also expected to be impacted by (1) local infiltration zones (e.g., beneath wet canyons), (2) aquifer properties heterogeneity, and (3) discharge zones (water supply wells and springs).

Information about the elevation of the regional water table is provided by existing data from monitoring wells (water levels) and selected springs (discharge elevations). Well data are predominantly applied to map the elevation of the regional water table; spring discharge elevations are used only in the vicinity of White Rock Canyon to provide additional constraints on the water-table elevation.

Water-table elevations vary in time due to transient effects that include pumping of the water supply wells, and large- and small-scale variability in aquifer recharge. Therefore, water-level maps represent specific periods of time. Based on analysis of 2008 water-level data (Koch and Schmeer 2009, 105181), it has been observed that water levels generally reached recent maxima in March 2008. The March 2008 data are likely to be the least affected by pumping and thus are potentially most representative of ambient flow conditions. Therefore, these data are used, in part, to construct the water-table map.

Monthly averaged water levels for March 2008 are computed for 36 regional aquifer wells and presented in Table 3-1. For the wells, R-7, R-14, R-33, and R-36, water-level data are not available for March 2008 (Table 3-1), and alternative periods of representative measurements have been selected. For five wells, H-19, TW-1, TW-2, TW-3 and TW-4 (Table 3-1), historic water-level data considered to be less certain but important for constraining the water-table map in the northern portion of the Laboratory site are used. New water-level data are also available from a series of recently drilled wells (R-38, R-39, R-40, R-41, R-42, R-43, R-44, R-45, and R-46), but the measurements are difficult to interpret because they are preliminary and for a different time period. Future analysis will address how these data will be incorporated in the water-table mapping. The available preliminary water-level measurements for these wells are listed in Table 3-1 but are not applied in the mapping process.

Inclusion of water-level data that do not represent the March 2008 time period is a source of uncertainty in the mapping process. Differences in the screen placements and local hydrogeologic conditions also complicate the interpretation of the water-level data for the following reasons.

1. Some screens are substantially below the top of regional saturation (more than 60 ft); as a result, the collected water-level data may not be representative of the actual water-table elevations (TW-1, R-10a, R-13, R-18, R-20, R-21, R-24, R-26, R-32, and R-34; 10 wells in total).
2. Some screens are long (more than 50 ft) and may represent composite water levels within the aquifer (DT-5A, DT-9, DT-10, R-8, R-13, and R-15; 6 wells in total).
3. Some screens are potentially under confined conditions and may represent piezometric surface elevations (R-4 and R-24; 2 wells).
4. R-25 is drilled in a complicated hydrogeological setting, and it is uncertain which of the R-25 screens (screen 4 or 5) provides information about the water-table elevation.
5. R-9 is screened in a zone (basalts within Santa Fe Group, Tb2) that is potentially disconnected from the regional aquifer. The regional aquifer screen R-12 is in a similar setting, but this screen has been plugged and abandoned. Water-table screens are located in various hydrostratigraphic units, including sedimentary and volcanic rocks with contrasting hydrogeologic properties (Table 3-1). The structure of the regional water table is probably impacted by groundwater flow within hydrostratigraphic units with contrasting properties. For example, low permeability lava flows may divert the phreatic groundwater flow. Lavas occur at or near the regional water table at R-5, R-9, and R-12 (Miocene basalts [Tb2], and at R-32, R-20, and R-22 [Cerros del Rio Basalts, Tb4]).

Related to issue 5 above, the regional water levels observed at R-9 and at the former R-12 regional screen are substantially lower than water levels observed at nearby wells. (Since December 2007, the regional screen at R-12, screen 3, is abandoned and not monitored; the regional screen of R-12 is replaced by R-36.) The regional screens in both wells are in Miocene basalt (Tb2). R-9 and R-12 monitoring wells are located near water supply wells PM-1 and O-1, and their low water levels might define cones of drawdown around the production wells. However, water levels at R-9 and R-12 do not respond to daily or seasonal changes in municipal water production, suggesting that their low heads are not caused by the water supply pumping. Alternatively, the regional screens at R-9 and R-12 may represent a deep compartmentalized zone within the Santa Fe Group basalt that is in poor hydraulic connection with the rest of the aquifer.

Because of the uncertainties described above, we evaluated a series of alternative conceptual-model assumptions pertaining to the regional groundwater flow and chose the model presented in Plate 3-1.

The process of water-table contouring is theoretically constrained by the following conformity rules (Freeze and Cherry 1979, 088742): (1) the contour lines should be perpendicular to the flow paths and (2) the length and the width of the flow net cells formed by the contour lines between two adjacent flow paths should have the same ratios. These rules are theoretically valid only for the case of a uniform isotropic aquifer with no recharge/discharge sources within flow net cells. Deviations from the conformity rules are caused by aquifer heterogeneity and anisotropy as well as recharge/discharge sources within flow net cells.

The regional water table is contoured by attempting to satisfy three goals simultaneously: (1) to match the water-level data at the monitoring wells, (2) to account for issues of data representativeness, and (3) to preserve flow net conformity. Plate 3-1 is a contour map of the regional water table that attempts to satisfy those three goals. The actual contouring is performed using a combination of manual and automated techniques. (The automated contouring is performed using the standard splining methods.) Table 3-1 lists the deviations between observed and predicted (based on the contoured water-table map) water levels.

The water-level data and the contoured map (Plate 3-1) suggest potential mounding of the regional water table near TW-1, R-8, and R-36 (the water level at R-36 is slightly higher than the water levels of R-28 and R-11). The mounding may result from local recharge of the regional aquifer along Los Alamos, Pueblo, and Sandia Canyons.

The water-level data represented by the contour map indicate that thick lavas near R-32 and R-22 may be the cause of the increased phreatic hydraulic gradients in this area. This may be the result of lower transmissive properties of lava flows compared with the more transmissive Puye Formation and Santa Fe Group sediments. The hydrogeologic properties associated with the lava flows may be also responsible for diverting the flow of phreatic groundwater to the north. The increased hydraulic gradients in the area of R-32 and R-22 may also be an indication of recharge in the lower Pajarito Canyon area that causes local mounding in the lavas, which are expected to be of low storativity when compared with the Puye Formation fanglomerates and Santa Fe Group sediments.

Table 3-1 also lists the differences between observed and contoured water-level elevations displayed in Plate 3-1. Most of the discrepancies are minor and within 3 ft. Substantial deviations are calculated for locations at which the water-level data are uncertain: TW-1, R-5, R-9, R-8, R-10a, and R-25. The table also compares the predicted water levels with recently collected water-level data not included in the mapping. Substantial differences are observed only at R-41 and R-46 where static water-level conditions may not have been achieved. Future analysis will incorporate the water-level data from recently installed monitoring wells.

Plate 3-2 identifies the modeled geologic units present at the regional water table model.

Table 3-1.
Summary of Well-Screen Positions, Water-Level Observations, and Differences between Observed and Contoured Water Levels

Well/Screen Name	Geologic Unit	Surface Elevation (ft)	Screen Top (ft bgs)	Screen Bottom (ft bgs)	Screen Length (ft)	Observed Water-Level Elevation (ft)	Representative Measurement Period	Top of the Screen from the Water Level (ft)	Comments	Differences between Observed and Contoured Water-Level Elevation (ft)
H-19	Tpf	7172	—	—	—	6228.00	Jan-51	—	Historic observation applied to constrain water-levels in the NW section of LANL site. The data are uncertain	1.47
TW-1	Tcar	6369.19	632.00	642.00	10.00	5855.50	Feb-06	118.31	Historic observation applied to constrain water-levels in the NE section of LANL site. The data are uncertain and potentially affected by well construction problems	35.53
TW-2	Tcar	6648.06	768.00	824.00	56.00	5845.70	Oct-00	-34.36	Historic observation applied to constrain water-levels in the N section of LANL site. The data are uncertain	0.09
TW-3	Tcar	6626.90	805.00	815.00	10.00	5840.10	Feb-06	18.20	Historic observation applied to constrain water-levels in the N section of LANL site. The data are uncertain	0.74
TW-4	Tvt1	7244.56	1195.00	1205.00	10.00	6071.50	Feb-06	21.94	Historic observation applied to constrain water-levels in the NW corner of LANL site. The data are uncertain	1.79
CdV-16-3i	Tvt2	7486.40	—	—	—	6136.75	Oct-05	—	Open borehole. The data are uncertain	2.17
CdV-R-15-3#4	Tpf	7258.90	1235.10	1278.90	43.80	6019.50	Mar-08	-4.30	No comment	-1.17
CdV-R-37-2#2	Tvt2	7330.60	1188.70	1213.80	25.10	6137.00	Mar-08	-4.90	No comment	0.62
DT-10	Tb4/Tpf/Tcar	7019.00	1080.00	1408.00	328.00	5918.70	Mar-08	-20.30	Long screen; Composite water-level expected	1.31
DT-5A	Tb4/Tpf/Tcar	7144.20	1172.00	1821.00	649.00	5958.08	Mar-08	-14.12	Long screen; Composite water-level expected	0.10
DT-9	Tb4/Tpf/Tcar	6936.00	1040.00	1501.00	461.00	5915.12	Mar-08	19.12	Long screen; Composite water-level expected	0.71
R-1	Tjfp	6881.21	1031.12	1057.42	26.30	5878.27	Mar-08	28.18	No comment	-0.44
R-2	Tcar	6770.38	906.45	929.57	23.12	5870.65	Mar-08	6.72	No comment	-0.46
R-4	Tcar	6577.49	792.90	816.00	23.10	5830.83	Mar-08	46.24	Hydrogeologic data suggest confined conditions	-0.84
R-5#3	Tcar	6472.60	676.90	720.30	43.40	5766.75	Mar-08	-28.95	No comment	-42.83
R-6	Tcar	6995.80	1205.00	1228.00	23.00	5838.44	Mar-08	47.64	Screen significantly below water table	-0.82
R-7#3	Tjfp	6779.20	895.50	937.40	41.90	5877.25	Apr-08	-6.45	Water-level data missing for Mar 2008	-0.91
R-8#1	Tcar	6544.74	705.31	755.70	50.39	5853.22	Mar-08	13.79	Long screen below water table	7.29
R-9	Tb2	6382.80	683.00	748.50	65.50	5691.52	Mar-08	-8.28	Water-level may be not representative of the regional water-table due to local aquifer heterogeneities	-108.48
R-10a	Tcar	6363.74	690.00	700.00	10.00	5740.49	Mar-08	66.75	Screen significantly below water table	-3.65
R-11	Tjfp	6673.72	855.00	877.90	22.90	5837.78	Mar-08	19.06	No comment	0.19
R-13	Tpf/Tjfp	6673.05	958.33	1018.72	60.39	5836.08	Mar-08	121.36	Long screen significantly below water table	0.18
R-14#1	Tpf/Tjfp	7062.08	1200.60	1233.20	32.60	5880.19	Feb-08	18.71	Water-level data missing for Mar 2008	0.00
R-15	Tpf/Tjfp	6820.00	958.60	1020.30	61.70	5850.65	Mar-08	-10.75	Long screen; Compsite water-level expected	-0.41
R-16r	Tpt	6256.97	600.00	617.60	17.60	5692.58	Mar-08	35.61	No comment	-0.08
R-17#1	Tpf	6921.51	1057	1080	23.00	5884.77	Mar-08	20.26	No comment	-0.05
R-18	Tpf	7404.83	1358.00	1381.00	23.00	6117.11	Mar-08	70.28	Screen significantly below water table	-0.93
R-19#3	Tpf	7066.30	1171.40	1215.40	44.00	5887.40	Mar-08	-7.50	No comment	-0.73
R-20#1	Tb4	6694.35	904.60	912.20	7.60	5864.60	Mar-08	74.85	Screen significantly below water table	1.26
R-21	Tpf	6656.24	888.80	906.80	18.00	5854.53	Mar-08	87.09	Screen significantly below water table	0.19
R-22#1	Tb4	6650.50	872.30	914.20	41.90	5755.00	Mar-08	-23.20	No comment	0.28

Table 3-1. (continued)

Well/Screen Name	Geologic Unit	Surface Elevation (ft)	Screen Top (ft bgs)	Screen Bottom (ft bgs)	Screen Length (ft)	Observed Water-Level Elevation (ft)	Representative Measurement Period	Top of the Screen from the Water Level (ft)	Comments	Differences between Observed and Contoured Water-Level Elevation (ft)
R-23	Tcar	6527.75	816.00	873.20	57.20	5697.41	Mar-08	-14.34	No comment	0.09
R-24	Tcar	6547.38	825.00	848.00	23.00	5830.04	Mar-08	107.66	Hydrogeologic data suggest confined conditions	-1.17
R-25#5	Tpf	7516.10	1294.70	1304.70	10.00	6234.27	Mar-08	12.87	Uncertain which of the R-25 screens characterizes water-table elevation (4 or 5)	-4.15
R-26#2	Tpf	7641.69	1422.00	1445.00	23.00	6538.00	Mar-08	318.31	Screen significantly below water table	-2.20
R-27	Tpf	6713.72	852	875	23.00	5898.21	Mar-08	36.49	No comment	-0.79
R-28	Tpf/Tjfp	6728.61	934.30	958.10	23.80	5838.31	Mar-08	44.00	Screen significantly below water table	1.13
R-31#2	Tb4	6362.50	515.00	545.70	30.70	5827.44	Mar-08	-20.06	No comment	0.29
R-32#1	Tb4/Tpt	6637.63	867.50	875.20	7.70	5852.74	Mar-08	82.61	Hydrogeologic data suggest confined conditions	0.19
R-33#1	Tjfp	6853.33	995.50	1018.50	23.00	5871.20	Jun-08	13.37	Water-level data missing for Mar 2008	-0.34
R-34	Tcar	6629.99	883.70	906.60	22.90	5834.47	Mar-08	88.18	Screen significantly below water table	0.51
R-35b	Tpf	6625.21	825.40	848.50	23.10	5837.00	Mar-08	37.19	No comment	-0.66
R-36	Tcar	6591.37	766.90	789.90	23.00	5839.47	Apr-08	15.00	Water-level data not available for Mar 2008	1.49
R-38	Tpf	6668.58	821.20	831.20	10.00	5858.73	Jan-09	11.35	Recently installed well. Insufficient water-level record; Hydrogeologic data suggest confined conditions	1.43
R-39	Tb4/Tpf	6580.86	859.00	869.00	10.00	5754.16	Jan-09	32.30	Recently installed well. Insufficient water-level record; Hydrogeologic data suggest confined conditions	-2.85
R-40 # 2	Tpf	6718.00	849.30	870.00	20.70	5864.10	Oct-08	-4.60	Recently installed well. Insufficient water-level record	-2.78
R-41	Tpt	6650.50	965.00	975.00	10.00	5690.37	Mar-09	4.87	Recently installed well. Insufficient water-level record	-72.26
R-42	Tjfp	6759.02	931.80	952.90	21.10	5839.22	Nov-08	12.00	Recently installed well. Insufficient water-level record	0.49
R-43#1	Tcar	6732.65	903.90	924.60	20.70	5839.65	Jan-09	10.90	Recently installed well. Insufficient water-level record	-1.88
R-44#1	Tpf	6714.91	895.00	905.00	10.00	5835.91	Jan-09	16.00	Recently installed well. Insufficient water-level record	-1.25
R-45#1	Tpf	6704.02	880.00	890.00	10.00	5836.12	Jan-09	12.10	Recently installed well. Insufficient water-level record	0.45
R-46	Tpf	7213.33	1340.00	1360.00	20.00	5885.33	Jan-09	12.00	Recently installed well. Insufficient water-level record	-12.17

*— = No data.

4.0 MAP SPECIFICATIONS

All maps are presented in 11- × 17-in. format at a scale of 1:80,000. All map plates include the boundary of the Laboratory and major roads for reference. Unit codes and colors, as defined in Figure 2-5, are consistent for all plates, cross-sections, and 3-D views. The map indices for wells are consistent throughout the set of plates.

Plates mapping the unit surfaces provide well locations only for those wells that contribute exact data to the surface that is mapped. "Exact" is used to mean "hard" data that provide an elevation value. Other wells contain "soft" data that provide "greater than," "less than," or "absent" constraints. While this "soft" information is used in the development of the surfaces, well locations for these data are not shown. In some cases, the density of the data prevents identification of all wells with "hard" constraints.

The principal component of an atlas is the set of maps or plates. The maps of this atlas provide the identification and/or definition of surface and subsurface features for the region encompassing the Laboratory and the town of Los Alamos (including White Rock), extending west past the Pajarito Fault zone into the Sierra de los Valles, and east approximately 8 mi past the eastern extent of the Laboratory boundary. The maps are presented using New Mexico state plane (NAD 83) coordinates (in feet). The mapped area, and the reference grid with labels outside of the map area, are extended to the full page size. Placement of map labels, legends, scale, north arrow, and descriptive text are therefore restricted to within the map area, resulting in the masking of some of the map data.

The Laboratory site and most of the volcanic, geologic units are located within the western portion of the map area. For this reason, the sets of tabular data are normally placed within the upper-right (eastern) portions of the map plates. The caption is always located at the lower-right corner, the legend and data credits are normally placed in the lower-left corner, and the map scale and north arrow are usually at the upper-left corner of the plate. Many of the older units are defined only within the eastern portions of the map area.

4.1 Base Map

The base map (Plate 1-1) shows the extent of the Hydrogeologic Site Atlas as well as the locations of R-wells, water supply wells, and other wells or boreholes important in constraining the GFM. The base map also shows the location of the major roads and outlines of Laboratory properties. This map also depicts the surrounding land ownership. Plates 1-2 and 1-3 identify all wells that provide data to the geologic models of the Laboratory. Plate 1-2 identifies the vintage of the well data, highlighting the large amounts of new data that were used in this current GFM.

Plate 1-3 provides a table that lists all wells that contributed to the 2009 GFM, including wells outside of the atlas extent but within the SEB. Where wells on a plate are completely within the extent of Laboratory SITE model, the wells are identified in the legend as Laboratory wells. If the set of wells for a plate consists only of wells outside of the Laboratory boundaries and within the SEB model, they are identified in the legend as SEB wells. The Buckman wells are within the Laboratory SITE model but provide minimal "exact" geologic contact information. These wells are displayed separately as the Buckman wells on selected sets of unit maps where they may be of interest.

4.2 Geology

The geology of the atlas region is presented in a series of plates. Plates 2-1 and 2-2 provide a comparison of the mapped geologic quadrangles, and the surface geology predicted by the modeled geologic unit surfaces. Plate 2-3 provides a compilation of mapped fault trace data within the atlas extent, much of which is inferred. Plates 2-4 through 2-83 provide structure contour maps of the unit surface elevations and isochors (vertical thickness). And finally, Plates 2-93 and 2-94 present a 3-D view for the atlas and that of the encompassing SEB model.

4.2.1 Surface Geology

There are two plates that provide maps of the surface geology. Plate 2-1 provides the merged geologic quadrangle maps identified and referenced in Section 1.3. The unit names have been adjusted to reflect the mapping of source unit names to model unit names. Plate 2-2 provides the surface geologic map defined by the GFM and includes a breakout of the subunits of the Tshirege and Otowi members of the Bandelier Tuff not provided in the geologic quadrangle maps. Plate 2-3 provides fault trace data for the atlas area. The structural block model of the 2005 GFM is shown in the western portion of this plate. The faults to the west (in red) were mapped by the seismic hazards team at the Laboratory. Many of the other fault traces are inferred and/or poorly constrained. The inferred faults are older and do not intersect the Bandelier Tuff. Many of these are inferred based on apparent stratigraphic discontinuities in widely spaced well data. Some of these discontinuities may actually represent paleotopography.

The fault traces can be extruded vertically or with a given dip to provide 3-D structural controls for flow models.

4.2.2 Geologic Unit Morphology

The 3-D morphology and geometry of the geologic units are presented in a series of plates: Plate 2-3 through Plate 2-83. Structure contours of the unit surfaces provide a 3-D definition of the units. Such maps are commonly defined as 2.5-D maps. Maps for the tops, isochors, and bottoms of all units are presented in top-to-bottom order through the set of units. Maps for the top and isochors of the Tshirege subunits are also provided.

Each of these plates also identifies the position of all wells that contributed to the definition of the mapped surface. The number at the well position on the map provides an index to the included map table which shows the well name and the elevation or thickness of the unit at the well. The well numbers also correlate to those of Plates 1-2 and 1-3. For Plate 2-4, there were too many wells to place in a map table, so the user must refer to Plate 1-3 for top elevation values at the wells.

The geologic outcrops can provide critical elevation control points for the surfaces. The geologic contacts are often exposed best in the canyons or regions of rugged topography, while wells intersecting these exposed units are usually located some distance within the Pajarito Plateau. The locations of unit outcrops are therefore identified on all plates, using the modeled color of the units. As these outcrops are often of limited geographical extent, e.g., when on the canyon walls, the structure contours for the top of the unit are clipped at the outcrop/topography so that the outcrop is visible to the map reader. For the Cerros del Rio Basalt, which outcrops over a broad surface area in the south-central portion, these top contours have been reinserted into the plate.

4.3 Cross-Sections

Geologic cross-sections of the GFM are provided for the atlas extent at 10,000-ft intervals in both the north-south and east-west directions. These sections identify both the geologic units and the water table. with a 1.75x vertical exaggeration. The modeled water table is not defined throughout the atlas extent, so the water table may be absent from some lines and represented for only parts of other cross-section lines. The locations of the cross-section lines are shown in Plate 2-84. Plate 2-84 also provides the location of "source" geologic cross-sections that were used in the development of the GFM.

4.4 3-D Views of the GFM

The 3-D views of the GFM, with the southeast quadrant removed, are provided for the atlas extent as Plate 2-93 and for the SEB as Plate 2-94.

4.5 Water-Table Elevation and Geology

Plate 3-1 shows the elevations of the regional water table, highlighting the 100-ft contour interval. Fainter contours at 10- or 20-ft intervals are provided for finer resolution, especially in the central portion of the laboratory. The location of springs and major drainages are also indicated. Topographic contours are provided to allow visual determination of the depth to the water table. Plate 3-2 shows the modeled geology at the water-table surface.

5.0 REFERENCES

The following list includes all documents cited in this report. Parenthetical information following each reference provides the author(s), publication date, and ER ID. This information is also included in text citations. ER IDs are assigned by the Environmental Programs Directorate's Records Processing Facility (RPF) and are used to locate the document at the RPF and, where applicable, in the master reference set.

Copies of the master reference set are maintained at the NMED Hazardous Waste Bureau and the Directorate. The set was developed to ensure that the administrative authority has all material needed to review this document, and it is updated with every document submitted to the administrative authority. Documents previously submitted to the administrative authority are not included.

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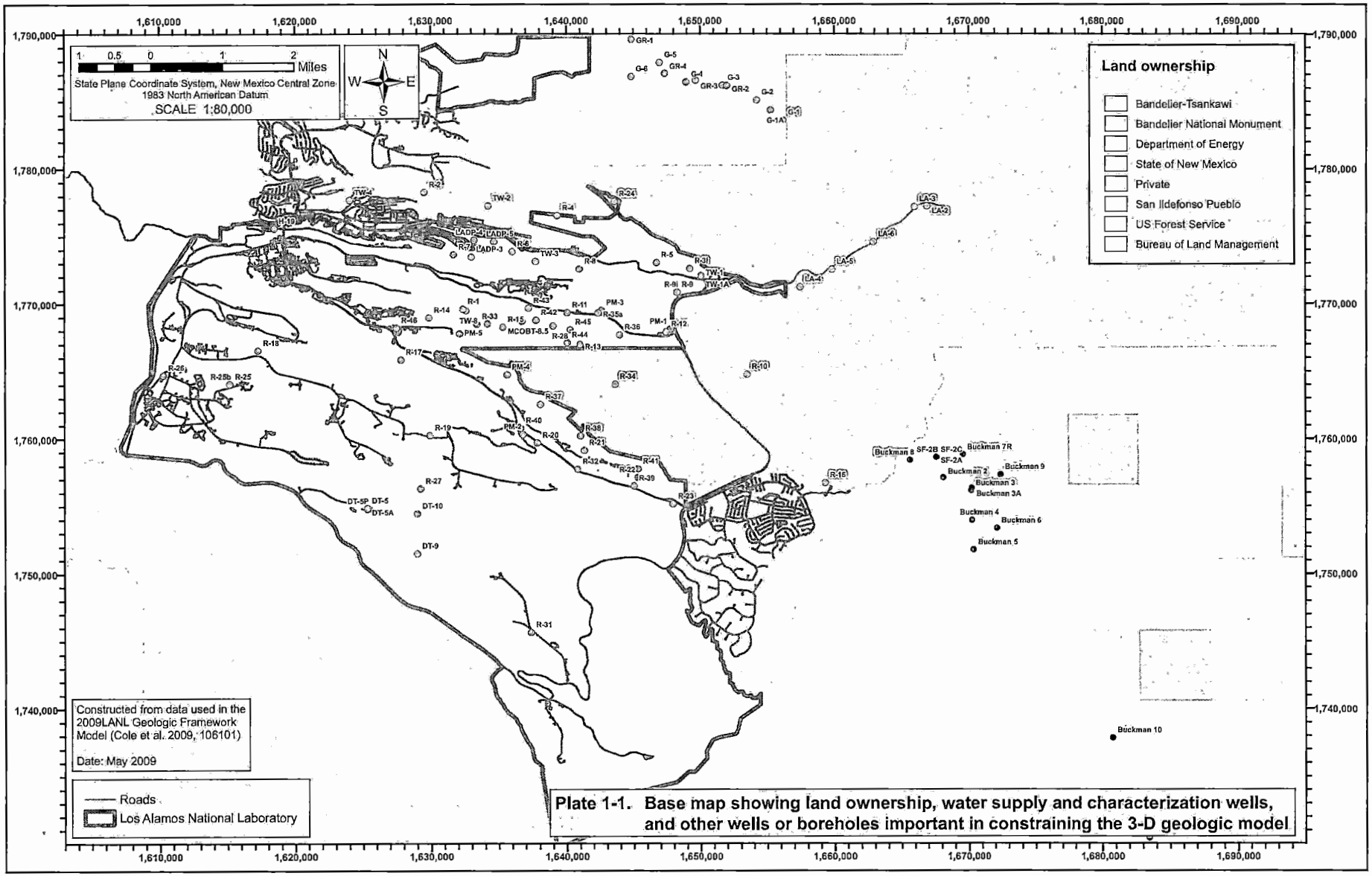

Plate 1-1. Base map showing land ownership, water supply and characterization wells, and other wells or boreholes important in constraining the 3-D geologic model

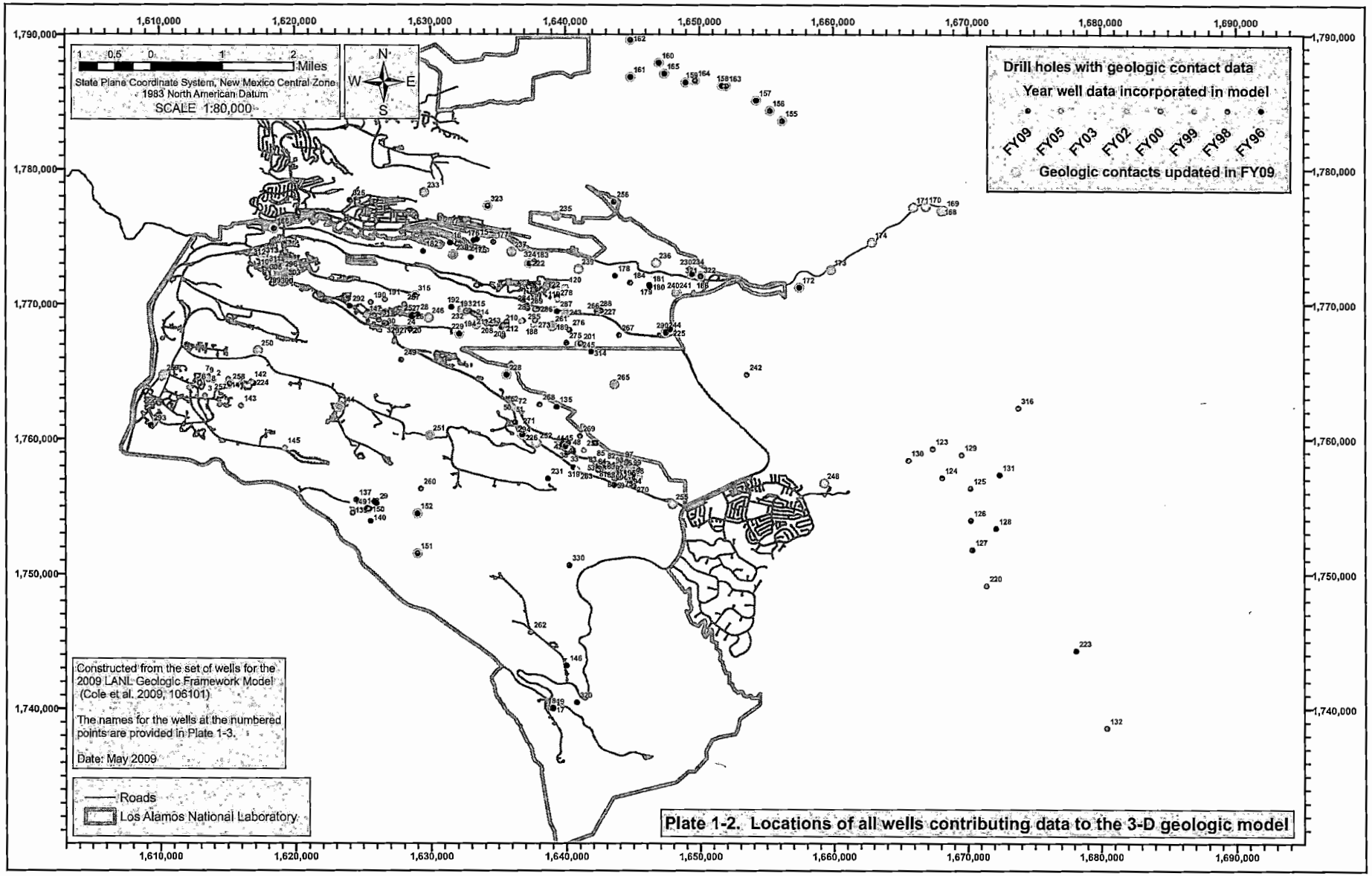

Plate 1-2. Locations of all wells contributing data to the 3-D geologic model

ID	Well name	Top elev.	Bot elev.
1	16-2665	7517.4	7392.4
2	16-2667	7532.0	7325.0
3	16-2668	7556.0	7368.5
4	16-2669	7584.3	7419.3
5	16-2701	7547.0	7462.0
6	16-2702	7535.0	7466.0
7	16-2703	7549.6	7480.0
8	16-2704	7538.9	7469.0
9	16-2706	7530.0	7440.0
10	16-2708	7543.9	7429.5
11	16-2709	7519.8	7486.0
12	16-2711	7521.0	7453.0
13	16-2712	7522.4	7422.0
14	16-2735	7536.5	7446.0
15	21-1811	7032.5	6772.5
16	21-2523	7159.0	6839.0
17	33-1230	6514.0	6284.0
18	33-1231	6516.0	6201.0
19	33-1232	6517.0	6271.0
20	35-2004	7180.2	7080.2
21	35-2005	7170.7	7070.7
22	35-2006	7179.9	7079.9
23	35-2007	7175.5	7082.5
24	35-2008	7172.0	7072.0
25	35-2009	7165.3	7065.3
26	35-2011	7166.8	7066.8
27	35-2013	7171.1	7071.1
28	35-2028	7103.4	6803.4
29	49-2-700-1	7133.9	6433.9
30	50-24769	7240.7	6540.7
31	50-24818	7239.7	6619.7
32	54-1001	6781.7	6499.8
33	54-1002	6789.3	6499.9
34	54-1003	6791.7	6492.7
35	54-1004	6788.2	6448.2
36	54-1005	6778.5	6506.8
37	54-1006	6790.3	6500.3
38	54-1007	6790.3	6640.3
39	54-1008	6796.6	6646.6
40	54-1009	6792.0	6642.0
41	54-1010	6790.6	6748.2
42	54-1011	6792.2	6751.2
43	54-1012	6793.1	6752.1
44	54-1013	6793.6	6752.6
45	54-1014	6793.8	6752.8
46	54-1015	6706.2	6242.4
47	54-1016	6700.4	6177.4
48	54-1018	6787.7	6459.7
49	54-1023	6884.0	6624.3
50	54-1024	6885.0	6795.0
51	54-1025	6889.5	6799.5
52	54-1026	6889.6	6799.6
53	54-1102	6720.6	6656.2
54	54-1105	6710.5	6662.4
55	54-1106	6700.4	6648.4
56	54-1107	6718.1	6588.1
57	54-1108	6701.1	6649.1
58	54-1110(G-3)	6691.2	6588.2
59	54-1111(G-4)	6674.6	6521.6
60	54-1112	6693.2	6632.7
61	54-1114	6667.2	6625.5
62	54-1115	6672.0	6600.5
63	54-1116	6683.0	6593.5
64	54-1117	6679.7	6587.2
65	54-1120	6688.3	6638.8
66	54-1121	6673.5	6525.5
67	54-1123	6665.3	6565.3
68	54-1124	6636.1	6597.6
69	54-1125	6669.4	6605.9
70	54-1126	6655.8	6604.8

ID	Well name	Top elev.	Bot elev.
71	54-1128	6853.2	6612.0
72	54-15462	6880.0	6580.0
73	54-24360	6670.6	6470.6
74	54-24361/27436	6695.1	6503.6
75	54-24362	6681.6	6492.6
76	54-24363	6692.0	6442.0
77	54-24364	6704.7	6504.7
78	54-24366	6680.7	6430.7
79	54-24367	6692.1	6492.1
80	54-24368	6715.6	6430.6
81	54-24369	6725.0	6475.0
82	54-24370	6726.4	6476.9
83	54-12371	6728.4	6526.4
84	54-24372	6748.5	6498.5
85	54-24373	6746.0	6496.0
86	54-24374	6677.2	6477.2
87	54-243751	6708.9	6703.9
88	54-24375	6638.9	6507.9
89	54-24376	6693.5	6493.5
90	54-24377	6684.0	6484.0
91	54-24378	6684.8	6502.3
92	54-24379	6675.6	6475.6
93	54-24380	6697.6	6501.6
94	54-24381	6660.1	6460.1
95	54-24382	6672.4	6525.4
96	54-24383	6653.7	6506.2
97	54-24384	6605.5	6537.5
98	54-24385	6677.4	6500.4
99	54-24386	6676.8	6475.8
100	54-24387	6616.0	6535.0
101	54-24388	6684.8	6503.8
102	54-24389	6698.2	6498.2
103	54-24390	6704.0	6518.0
104	54-24391	6711.0	6511.0
105	54-24392	6686.4	6466.4
106	54-24393	6717.8	6511.8
107	54-24394	6726.1	6419.6
108	54-24395	6729.3	6529.3
109	54-24396	6684.0	6484.0
110	54-24397	6671.9	6427.6
111	54-24399	6793.0	6133.0
112	54-25105	6709.0	6007.7
113	54-G-2	6694.1	6592.1
114	54-G-5	6699.1	6586.1
115	Archery	7185.0	6032.0
116	BH1	6915.8	6865.8
117	BH2	6914.4	6866.4
118	BH3	6896.4	6846.4
119	BH4	6929.2	6729.2
120	BH5	6913.8	6713.8
121	BH6	6911.9	6711.9
122	BH7	6910.0	6611.0
123	Buckman_1	5510.0	4406.0
124	Buckman_2	5539.0	4066.0
125	Buckman_3A	5619.0	4169.0
126	Buckman_4	5646.0	4211.0
127	Buckman_5	5690.0	4255.0
128	Buckman_6	5718.0	4330.0
129	Buckman_7R	5606.0	4143.0
130	Buckman_8	5514.0	4582.0
131	Buckman_9	5738.0	4303.0
132	Buckman_10	6045.0	4035.0
133	Buckman_11	6155.0	4152.0
134	Buckman_12	6250.0	4318.0
135	CDBM-1	6721.6	6532.6
136	CDBM-2	6634.1	6535.1
137	CH-1	7170.6	6869.6
138	CH-2	7141.3	6634.3
139	CH-3	7169.9	6869.9
140	CH-4	7118.2	6815.2

ID	Well name	Top elev.	Bot elev.
141	CdV-16-1i	7382.2	6699.2
142	CdV-16-2i	7457.1	6394.1
143	CdV-16-3i	7486.8	6081.8
144	CdV-R-15-3	7258.9	5536.9
145	CdV-R-37-2	7330.6	5666.6
146	DMB-1	6276.1	6152.1
147	DSC-2	7285.0	6880.0
148	DT-5	7144.5	6182.5
149	DT-5A	7144.2	5323.2
150	DT-5P	7136.8	6651.9
151	DT-9	6936.0	5435.0
152	DT-10	7019.0	5610.0
153	EB-35	6930.0	5120.0
154	EB-47	7140.0	5580.0
155	G-1	5978.9	3958.9
156	G-1A	6015.9	3944.9
157	G-2	6057.8	4051.8
158	G-3	6138.8	4142.8
159	G-4	6235.0	4233.0
160	G-5	6309.6	4312.5
161	G-6	6424.4	4419.4
162	GR-1	6416.2	4386.2
163	GR-2	6140.2	4096.2
164	GR-3	6212.2	4202.2
165	GR-4	6299.2	4371.2
166	H-19	7172.0	5172.0
167	Kelly_Fed	6035.0	3332.0
168	LA-1	5624.0	4623.0
169	LA-1B	5622.0	3366.0
170	LA-2	5651.0	4769.0
171	LA-3	5672.0	4762.0
172	LA-4	5970.9	3951.9
173	LA-5	5840.0	3816.0
174	LA-6	5770.0	3740.0
175	LADP-3	6755.6	6406.6
176	LADP-4	7049.7	6249.7
177	LADP-5	7018.1	6298.1
178	LAO-4.5	6479.8	6417.9
179	LAO-5	6427.1	6400.1
180	LAO-6	6423.5	6397.6
181	LAO-6A	6423.8	6408.8
182	LAOI(A)-1.1	6833.2	6510.2
183	LAOI-3.2a	6624.4	6357.5
184	LAOI-7	6458.4	6076.1
185	Las_Campanas	6400.0	4395.0
186	LAWS-01	6304.8	6023.3
187	MC1	6764.6	6580.0
188	MC2	6751.9	6580.0
189	MC3	6726.6	6582.5
190	MCB-1	7150.2	7045.2
191	MCB-2	7076.4	6971.9
192	MCB-5	6895.3	6791.3
193	MCB-6	6875.5	6786.5
194	MCB-7	6852.4	6751.4
195	MCB-8	6824.4	6719.9
196	MCB-9	6824.1	6721.1
197	MCB-10	6805.7	6701.7
198	MCB-11	6805.4	6701.4
199	MCB-12	6805.2	6700.7
200	MCB-14	6827.1	6543.1
201	MCB-16	6670.7	6570.7
202	MCC-8.2	6775.2	6591.2
203	MCM-5.1	6870.8	6759.3
204	MCM-5.9A	6850.2	6656.2
205	MCOBT-4.4	6836.2	6069.2
206	MCOBT-8.5	6780.5	6040.5
207	MCOI-1	7106.2	6263.9
208	MCOI-4	6837.2	6297.2
209	MCOI-5	6819.7	6102.7
210	MCOI-6	6811.1	6091.1

ID	Well name	Top elev.	Bot elev.
211	MCOI-8	6859.2	6114.2
212	MCOI-10	7034.5	5984.5
213	MCRES-2	6838.2	6638.0
214	MCRES-3	6862.6	6662.6
215	MCRES-4	6870.6	6645.6
216	NAD-84	6635.0	5635.0
217	NAD-83	6415.0	5455.0
218	NAD-60	6225.0	5205.0
219	Northwest	7100.0	5100.0
220	Nuc_Dynamics_34	5683.0	5120.0
221	O-1	6400.9	3791.9
222	O-4	6639.0	3833.0
223	OSE_Devils_Throne	5985.0	3485.0
224	P-12	7451.6	7251.6
225	PM-1	6513.2	4012.2
226	PM-2	6712.0	4112.0
227	PM-3	6610.9	4058.9
228	PM-4	6920.0	4000.0
229	PM-5	7094.0	3974.0
230	POI-4	6372.3	6191.3
231	POTO-4A	6622.0	6448.0
232	R-1	6881.2	5716.2
233	R-2	6770.4	5827.4
234	R-3I	6390.1	6121.9
235	R-4	6577.5	5732.5
236	R-5	6472.6	5570.6
237	R-6	6995.8	5692.8
238	R-7	6779.2	5682.2
239	R-8	6542.9	5520.9
240	R-9	6382.8	5611.8
241	R-9I	6382.8	6060.8
242	R-10	6362.3	5197.3
243	R-11	6672.4	5745.4
244	R-12	6499.6	5613.6
245	R-13	6873.1	5540.1
246	R-14	7062.1	5735.1
247	R-15	6820.0	5713.0
248	R-16	6256.9	4969.9
249	R-17	6921.5	5754.5
250	R-18	7404.8	5974.8
251	R-19	7066.3	5163.8
252	R-20	6594.3	5329.3
253	R-21	6656.2	5661.2
254	R-22	6650.5	5161.5
255	R-23	6527.8	5601.8
256	R-24	6547.4	5666.4
257	R-25	7516.1	5574.1
258	R-25b	7516.0	6376.0
259	R-26	7641.6	6151.1
260	R-27	6713.7	5726.7
261	R-28	6728.5	5723.5
262	R-31	6362.5	5259.5
263	R-32	6637.6	5629.6
264	R-33	6853.3	5723.3
265	R-34	6830.0	5565.0
266	R-35a	6623.1	5481.1
267	R-36	6593.0	5728.0
268	R-37	6860.0	5780.0
269	R-38	6670.0	5760.0
270	R-39	6580.0	5684.0
271	R-40	6718.0	5905.0
272	R-41	6650.0	6650.0
273	R-42	6759.1	5731.1
274	R-43	6730.0	5795.0
275	R-44	6718.0	5624.0
276	R-45	6699.0	5642.0
277	R-46	7212.0	5797.0
278	SC1	6691.5	6578.5
279	SC2	6722.8	6580.0
280	SC3	6701.7	6578.5

ID	Well name	Top elev.	Bot elev.
281	SC4	6682.1	6578.5
282	SC5	6661.8	6580.0
283	SCC-1	6738.3	6338.3
284	SCC-2	6723.7	6335.1
285	SCC-3	6713.0	6369.0
286	SCC-4	6709.2	6386.2
287	SCC-5	6683.6	6393.6
288	SCC-6	6619.3	6359.8
289	SCI-2	6730.0	5840.0
290	SCOI-3	6499.0	6367.0
291	SF_River	6365.0	4365.0
292	SHB-1	7315.9	6615.9
293	SHB-3	7607.7	6747.7
294	SHB-4	6798.7	6547.7
295	SHB-CMR-1	7402.2	7334.7
296	SHB-CMR-10	7398.4	7338.4
297	SHB-CMR-2	7399.8	7337.3
298	SHB-CMR-3	7398.6	7343.6
299	SHB-CMR-4	7398.4	7346.0
300	SHB-CMR-5	7397.5	7345.0
301	SHB-CMR-6	7392.2	7334.7
302	SHB-CMR-7	7394.9	7337.4
303	SHB-CMR-8	7392.7	7340.2
304	SHB-NISC-1	7439.2	7358.7
305	SHB-NISC-2	7428.1	7345.6
306	SHB-NISC-3	7427.8	7352.8
307	SHB-NISC-4	7439.3	7356.8
308	SHB-NISC-5	7432.5	7347.5
309	SHB-SCC-1	7440.2	7342.7
310	SHB-SCC-2	7430.5	7345.5
311	SHB-SCC-3	7428.1	7343.1
312	SHB-SCC-4	7441.9	7351.9
313	SHB-SCC-5	7435.7	7353.2
314	SIMO	6655.4	6551.4
315	Sigma_Mesa	7209.5	4917.5
316	Skillet	5850.0	3946.0
317	St_Michael	6870.0	4850.0
318	TH-5	6590.7	6327.8
319	TH-6	6642.4	6342.5
320	TH-7	6223.5	6168.5
321	TW-1	6369.9	5727.9
322	TW-1A	6389.8	6144.8
323	TW-2	6646.4	5812.4
324	TW-3	6626.9	5811.9
325	TW-4	7242.7	6037.7
326	TW-8	6875.1	5810.1
327	TestHole6-53	6921.2	6771.2
328	TestHole7-53	6701.0	6621.0
329	USGS-TH	7227.4	7017.4
330	WCO-3	6433.9	6420.0
331	Yates_2	6605.0	2634.0

Constructed from the 2009 LANL Geologic Framework Model (Cole et al. 2009, 106101) Date: May 2009

Plate 1-3. Identification of all wells contributing data to the 3-D geologic model

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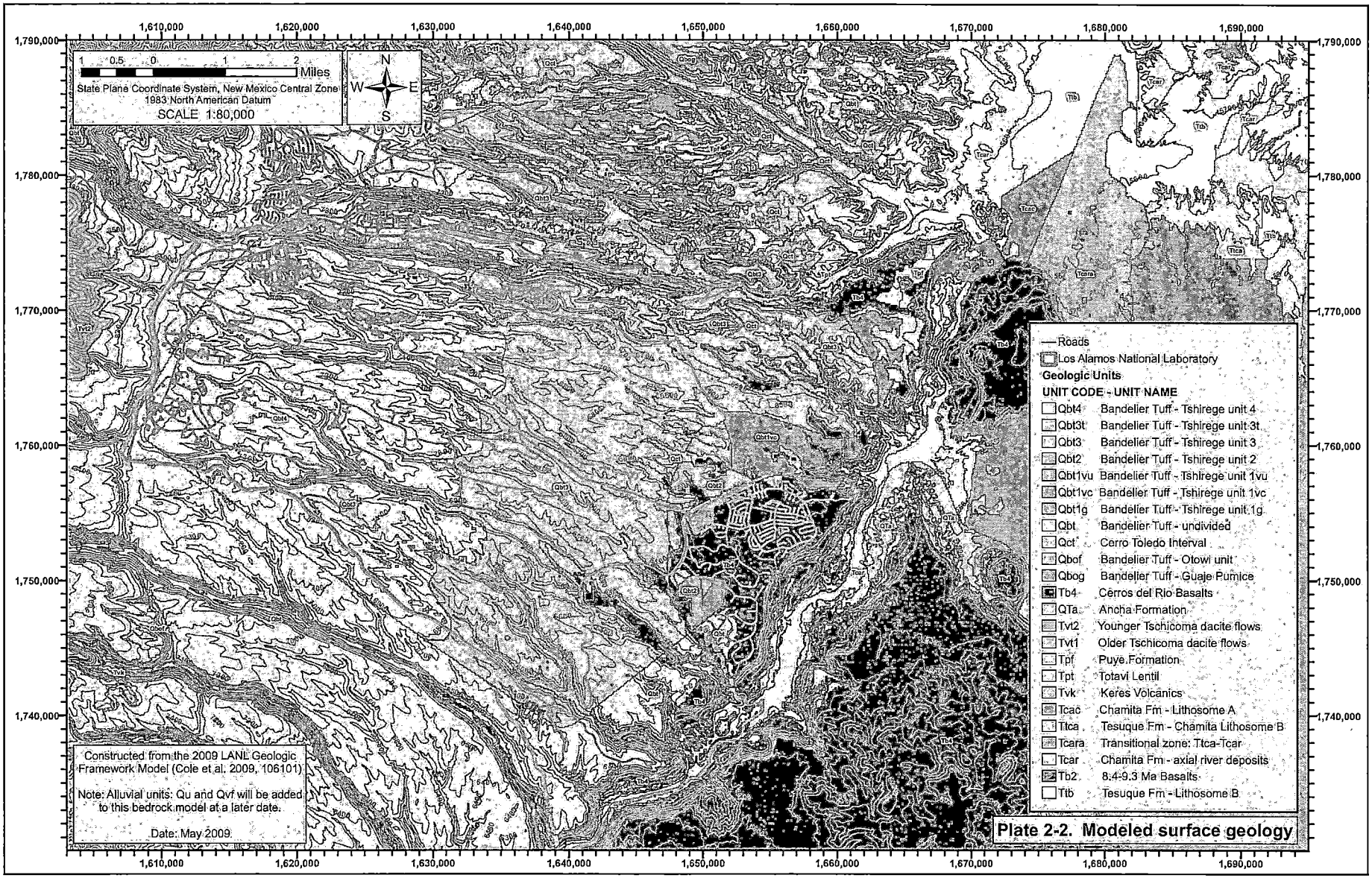
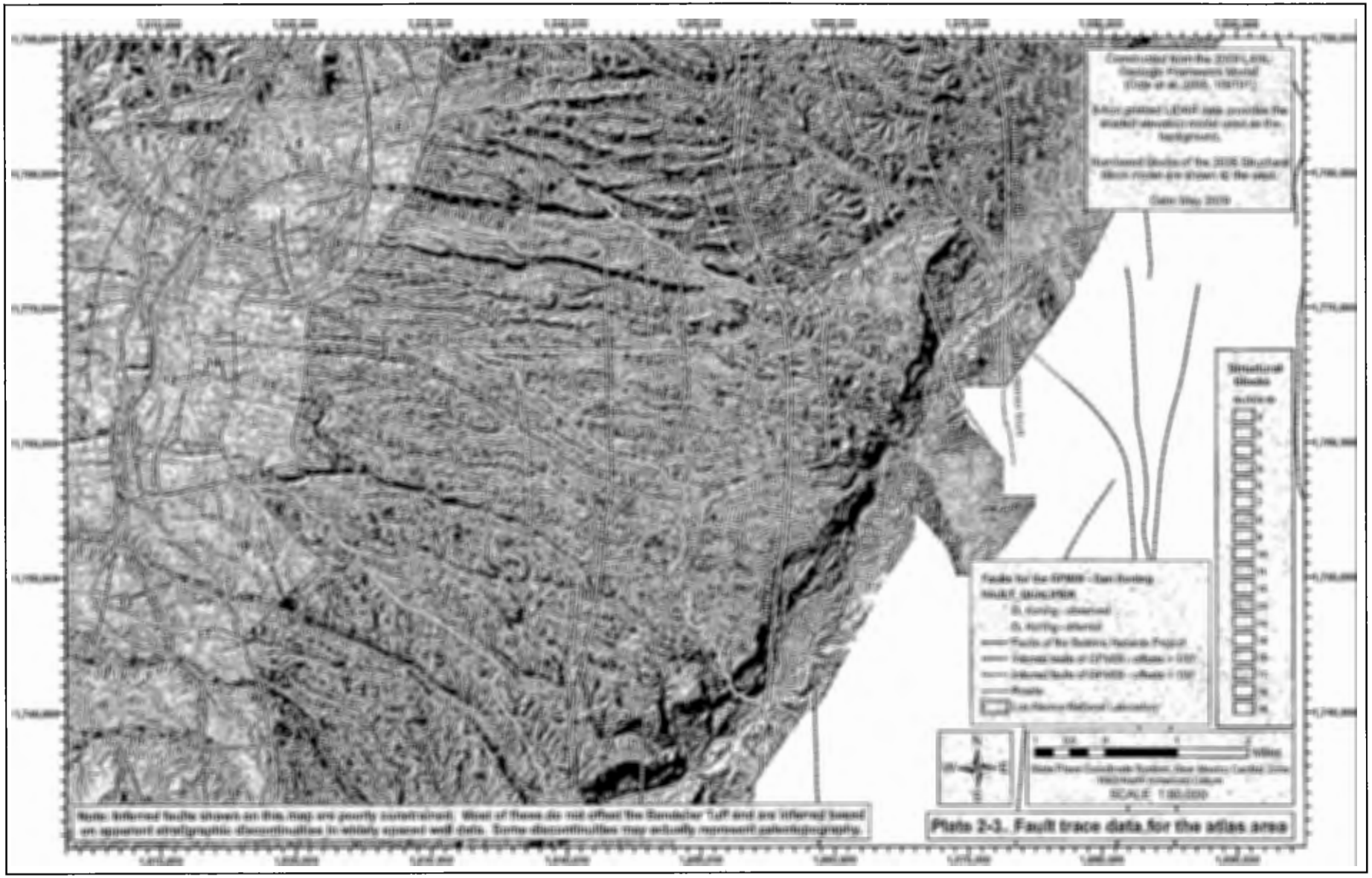


Plate 2-2. Modeled surface geology



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State Plane Coordinate System, New Mexico Central Zone
1983 North American Datum
SCALE: 1:80,000
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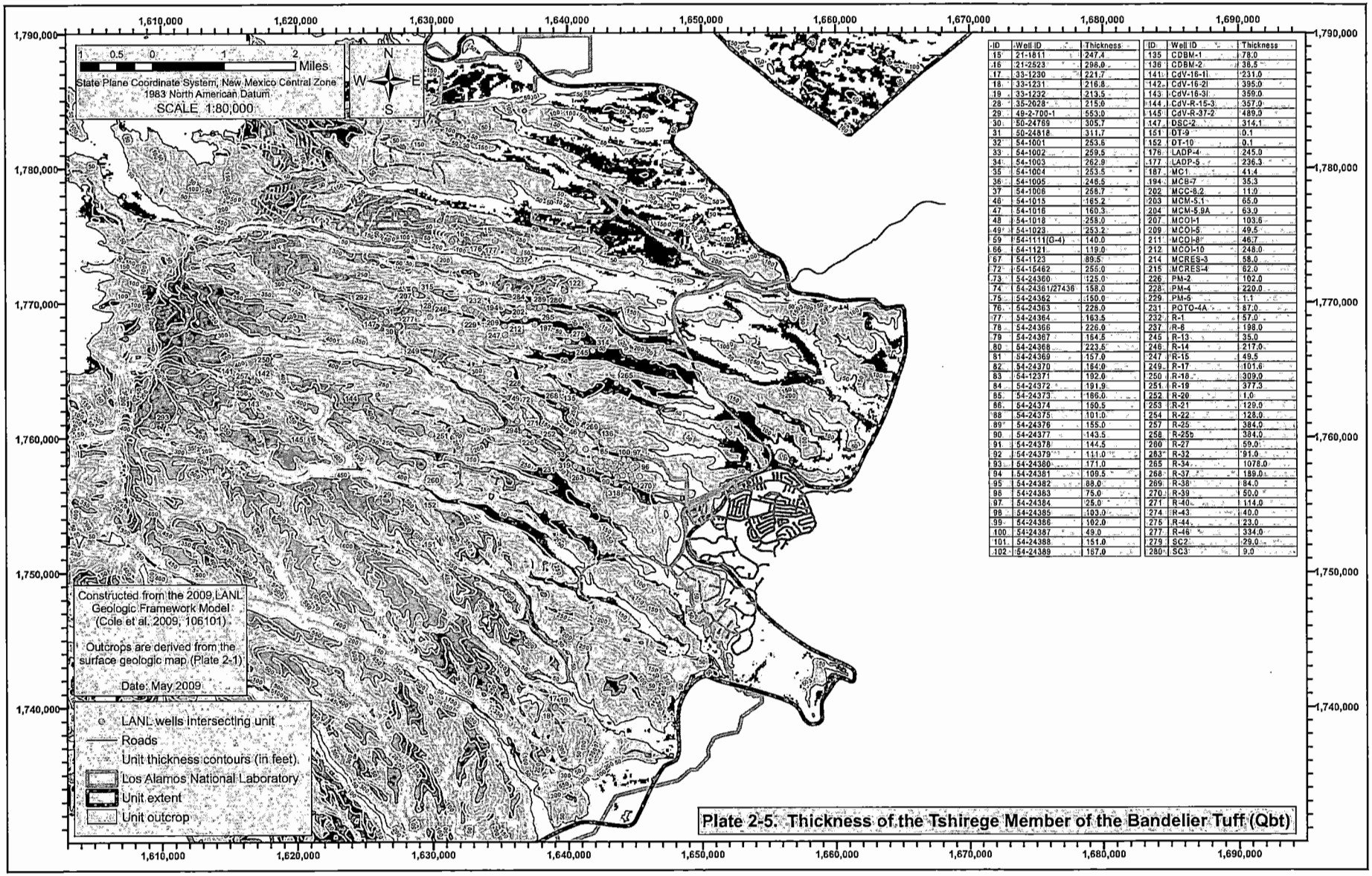
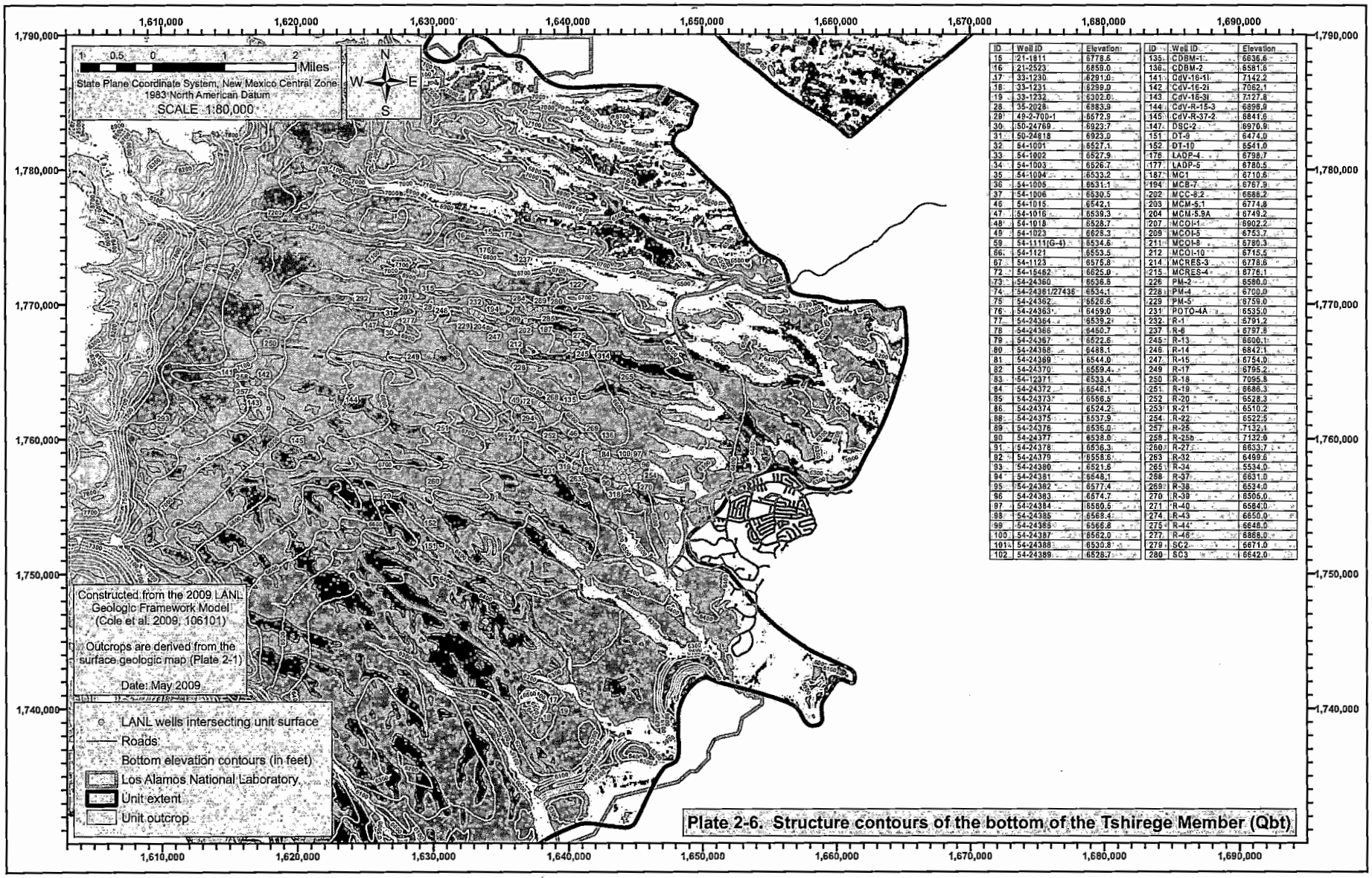
IDs, well names and top elevations are provided in Plate 1-3.
Constructed from the 2009 LANL Geologic Framework Model (Cole et al. 2009, 106101)
Outcrops are derived from the surface geologic map (Plate 2-1)
Date: May 2009
LANL wells sited within unit
Roads
Top elevation contours (in feet)
Los Alamos National Laboratory
Unit extent
Unit outcrop
Plate 2-4. Structure contours of the top of the Tshirege Member (Qbt)



ID	Well ID	Thickness
16	21-1611	247.4
16	21-2523	296.0
17	33-1230	221.7
18	33-1231	216.8
19	33-1232	213.5
28	35-2028	215.0
29	49-2-700-1	553.0
30	50-24769	305.7
31	50-24818	311.7
32	54-1001	253.6
33	54-1002	259.5
34	54-1003	262.9
35	54-1004	253.5
36	54-1005	248.5
37	54-1006	258.7
46	54-1015	165.2
47	54-1016	160.3
48	54-1018	258.0
49	54-1023	253.2
59	54-1111(G-4)	140.0
66	54-1121	119.0
67	54-1123	89.5
72	54-15462	255.0
73	54-24360	125.0
74	54-24361/27436	158.0
75	54-24362	150.0
76	54-24363	228.0
77	54-24364	163.5
78	54-24366	226.0
79	54-24367	164.5
80	54-24368	223.5
81	54-24369	157.0
82	54-24370	164.0
83	54-12371	192.0
84	54-24372	191.9
85	54-24373	186.0
86	54-24374	150.5
88	54-24375	101.0
89	54-24376	155.0
90	54-24377	143.5
91	54-24378	144.5
92	54-24379	111.0
93	54-24380	171.0
94	54-24381	109.5
95	54-24382	88.0
96	54-24383	75.0
97	54-24384	25.0
98	54-24385	103.0
99	54-24386	102.0
100	54-24387	49.0
101	54-24388	151.0
102	54-24389	167.0

ID	Well ID	Thickness
135	CDBM-1	78.0
136	CDBM-2	36.5
141	CdV-16-1i	231.0
142	CdV-16-2i	395.0
143	CdV-16-3i	359.0
144	CdV-R-15-3	357.0
145	CdV-R-37-2	489.0
147	DSC-2	314.1
151	DT-9	0.1
152	DT-10	0.1
176	LADP-4	245.0
177	LADP-5	236.3
187	MC1	41.4
194	MCB-7	35.3
202	MCC-8.2	11.0
203	MCM-5.1	65.0
204	MCM-5.9A	69.0
207	MCOI-1	103.6
209	MCOI-5	49.5
211	MCOI-8	46.7
212	MCOI-10	248.0
214	MCRES-3	58.0
215	MCRES-4	62.0
226	PM-2	102.0
228	PM-4	220.0
229	PM-5	1.1
231	POTO-4A	87.0
232	R-1	57.0
237	R-6	198.0
245	R-13	35.0
246	R-14	217.0
247	R-15	49.5
249	R-17	101.6
250	R-18	309.0
251	R-19	377.5
252	R-20	1.0
253	R-21	129.0
254	R-22	128.0
257	R-25	384.0
258	R-25b	384.0
260	R-27	59.0
263	R-32	91.0
265	R-34	1078.0
268	R-37	189.0
269	R-38	84.0
270	R-39	50.0
271	R-40	114.0
274	R-43	40.0
275	R-44	23.0
277	R-46	334.0
279	SC2	29.0
280	SC3	9.0

Plate 2-5. Thickness of the Tshirege Member of the Bandelier Tuff (Qbt)



ID	Well ID	Elevation
15	21-1811	6778.6
16	21-2523	6859.0
17	33-1230	6291.0
18	33-1231	6299.0
19	33-1232	6302.0
28	35-2028	6983.9
29	49-2-700-1	6672.9
30	50-24769	6923.7
31	50-24818	6923.0
32	54-1001	6527.1
33	54-1002	6527.9
34	54-1003	6526.7
35	54-1004	6533.2
36	54-1005	6531.1
37	54-1006	6530.5
46	54-1015	6542.1
47	54-1016	6539.3
48	54-1018	6528.7
49	54-1023	6628.3
59	54-1111(G-4)	6534.6
66	54-1121	6553.5
67	54-1123	6575.8
72	54-15462	6625.0
73	54-24360	6536.8
74	54-24361/27436	6534.1
75	54-24362	6526.6
76	54-24363	6459.0
77	54-24364	6539.2
78	54-24366	6450.7
79	54-24367	6522.8
80	54-24368	6488.1
81	54-24369	6544.0
82	54-24370	6559.4
83	54-12371	6533.4
84	54-24372	6546.1
85	54-24373	6556.5
86	54-24374	6524.2
88	54-24375	6537.9
89	54-24376	6536.0
90	54-24377	6538.0
91	54-24378	6536.3
92	54-24379	6558.6
93	54-24380	6521.6
94	54-24381	6548.1
95	54-24382	6577.4
96	54-24383	6574.7
97	54-24384	6569.5
98	54-24385	6568.4
99	54-24386	6566.8
100	54-24387	6562.0
101	54-24388	6530.8
102	54-24389	6528.7

ID	Well ID	Elevation
135	CDBM-1	6636.6
136	CDBM-2	6581.6
141	CdV-16-1i	7142.2
142	CdV-16-2i	7062.1
143	CdV-16-3i	7127.8
144	CdV-R-15-3	6896.9
145	CdV-R-37-2	6841.6
147	DSC-2	6970.9
151	DT-9	6474.0
152	DT-10	6541.0
176	LADP-4	6798.7
177	LADP-5	6780.5
187	MC1	6710.6
194	MCB-7	6767.9
202	MCC-8-2	6668.2
203	MCM-5.1	6774.8
204	MCM-5.9A	6749.2
207	MCOI-1	6902.2
209	MCOI-5	6753.7
211	MCOI-8	6780.3
212	MCOI-10	6715.5
214	MCRES-3	6778.6
215	MCRES-4	6776.1
226	PM-2	6580.0
228	PM-4	6700.0
229	PM-5	6759.0
231	POTO-4A	6535.0
232	R-1	6791.2
237	R-8	6797.8
245	R-13	6600.1
246	R-14	6842.1
247	R-15	6754.0
249	R-17	6795.2
250	R-18	7095.8
251	R-19	6688.3
252	R-20	6528.3
253	R-21	6510.2
254	R-22	6522.5
257	R-25	7132.1
258	R-25b	7132.6
260	R-27	6833.7
263	R-32	6499.6
265	R-34	6534.0
268	R-37	6631.0
269	R-38	6534.0
270	R-39	6506.0
271	R-40	6584.0
274	R-43	6650.0
275	R-44	6648.0
277	R-46	6888.0
279	SC2	6671.0
280	SC3	6642.0

Plate 2-6. Structure contours of the bottom of the Tshirege Member (Qbt)

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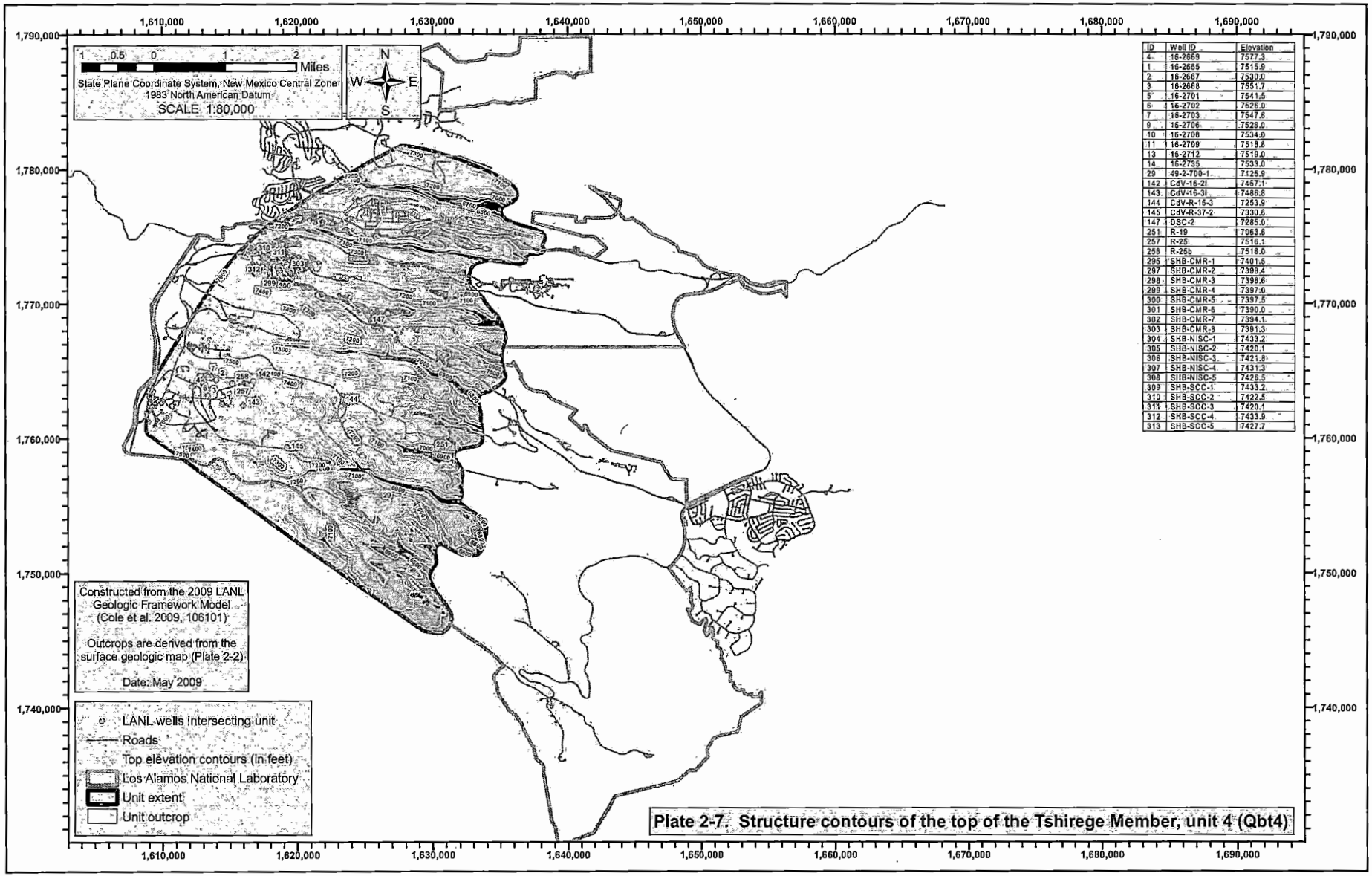
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State Plane Coordinate System, New Mexico Central Zone
1983 North American Datum
SCALE 1:80,000
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ID | Well ID | Elevation
4 | 16-2669 | 7577.3
1 | 16-2665 | 7515.9
2 | 16-2667 | 7530.0
3 | 16-2668 | 7551.7
5 | 16-2701 | 7541.5
6 | 16-2702 | 7526.0
7 | 16-2703 | 7547.6
8 | 16-2706 | 7528.0
10 | 16-2708 | 7534.0
11 | 16-2709 | 7518.8
13 | 16-2712 | 7519.0
14 | 16-2735 | 7533.0
29 | 49-2-709-1 | 7125.9
142 | CdV-16-2i | 7457.1
143 | CdV-16-3i | 7486.8
144 | CdV-R-15-3 | 7253.9
145 | CdV-R-37-2 | 7330.6
147 | DSC-2 | 7285.0
251 | R-19 | 7063.8
257 | R-25 | 7516.1
258 | R-25b | 7516.0
295 | SHB-CMR-1 | 7401.5
297 | SHB-CMR-2 | 7398.4
298 | SHB-CMR-3 | 7398.6
299 | SHB-CMR-4 | 7397.0
300 | SHB-CMR-5 | 7397.5
301 | SHB-CMR-6 | 7390.0
302 | SHB-CMR-7 | 7394.1
303 | SHB-CMR-8 | 7391.3
304 | SHB-NISC-1 | 7433.2
305 | SHB-NISC-2 | 7420.1
306 | SHB-NISC-3 | 7421.8
307 | SHB-NISC-4 | 7431.3
308 | SHB-NISC-5 | 7426.5
309 | SHB-SCC-1 | 7433.2
310 | SHB-SCC-2 | 7422.5
311 | SHB-SCC-3 | 7420.1
312 | SHB-SCC-4 | 7433.9
313 | SHB-SCC-5 | 7427.7
Constructed from the 2009 LANL Geologic Framework Model (Cole et al. 2009, 106101)
Outcrops are derived from the surface geologic map (Plate 2-2)
Date: May 2009
LANL wells intersecting unit
Roads
Top elevation contours (in feet)
Los Alamos National Laboratory
Unit extent
Unit outcrop
Plate 2-7. Structure contours of the top of the Tshirege Member, unit 4 (Qbt4)

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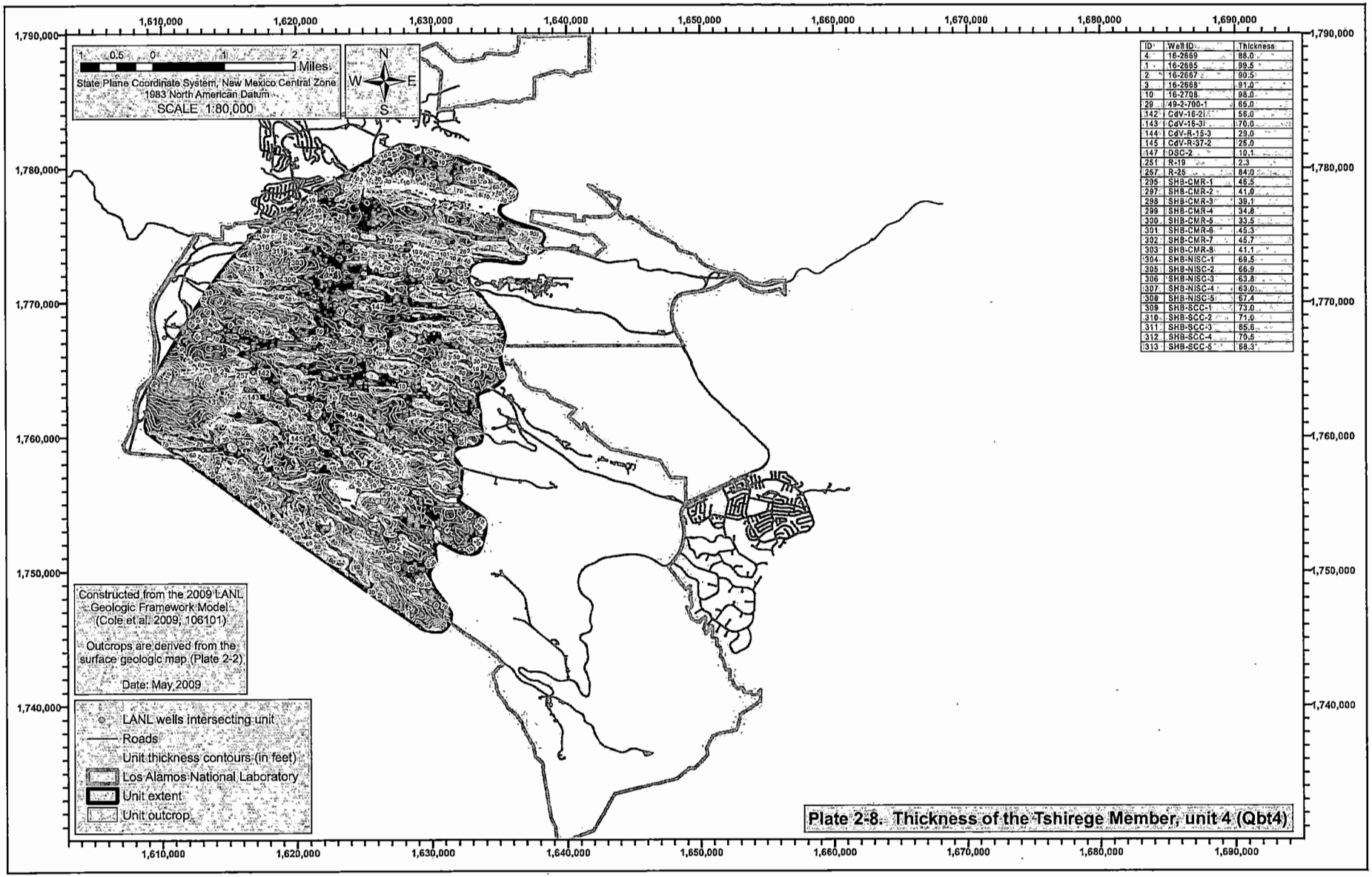


ID	Well ID	Thickness
4	16-2669	88.0
1	16-2665	99.5
2	16-2667	90.5
3	16-2668	91.0
10	16-2708	98.0
29	49-2-700-1	65.0
142	CdV-16-2i	56.0
143	CdV-16-3i	70.0
144	CdV-R-15-3	29.0
145	CdV-R-37-2	25.0
147	DSC-2	10.1
251	R-19	2.3
257	R-25	84.0
295	SHB-CMR-1	46.5
297	SHB-CMR-2	41.0
298	SHB-CMR-3	39.1
299	SHB-CMR-4	34.8
300	SHB-CMR-5	33.5
301	SHB-CMR-6	45.3
302	SHB-CMR-7	45.7
303	SHB-CMR-8	41.1
304	SHB-NISC-1	69.5
305	SHB-NISC-2	66.9
306	SHB-NISC-3	63.8
307	SHB-NISC-4	63.0
308	SHB-NISC-5	67.4
309	SHB-SCC-1	73.0
310	SHB-SCC-2	71.0
311	SHB-SCC-3	65.6
312	SHB-SCC-4	70.5
313	SHB-SCC-5	68.3

Plate 2-8. Thickness of the Tshirege Member, unit 4 (Qbt4)

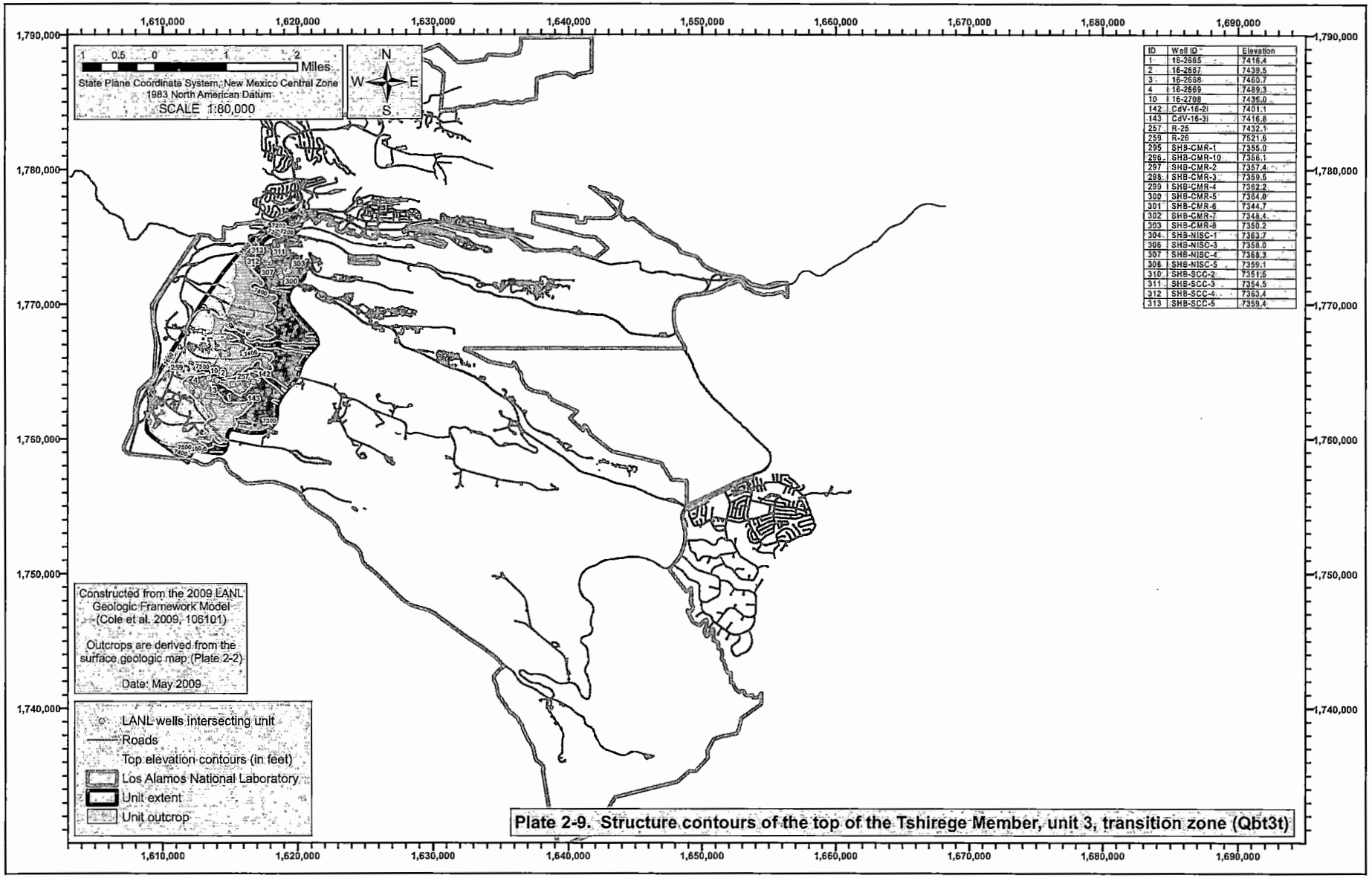
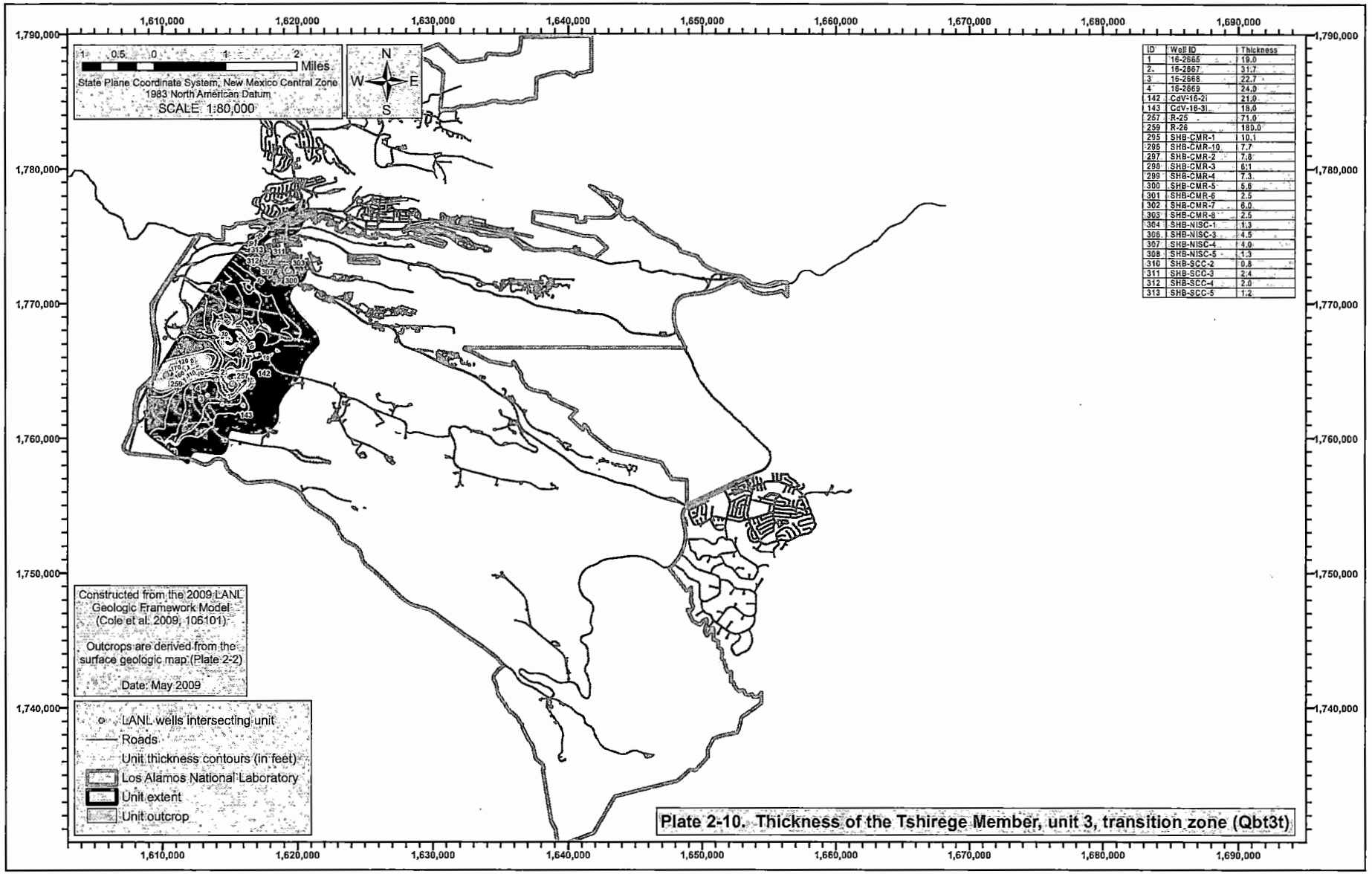


Plate 2-9. Structure contours of the top of the Tshirege Member, unit 3, transition zone (Qbt3t)

: 96112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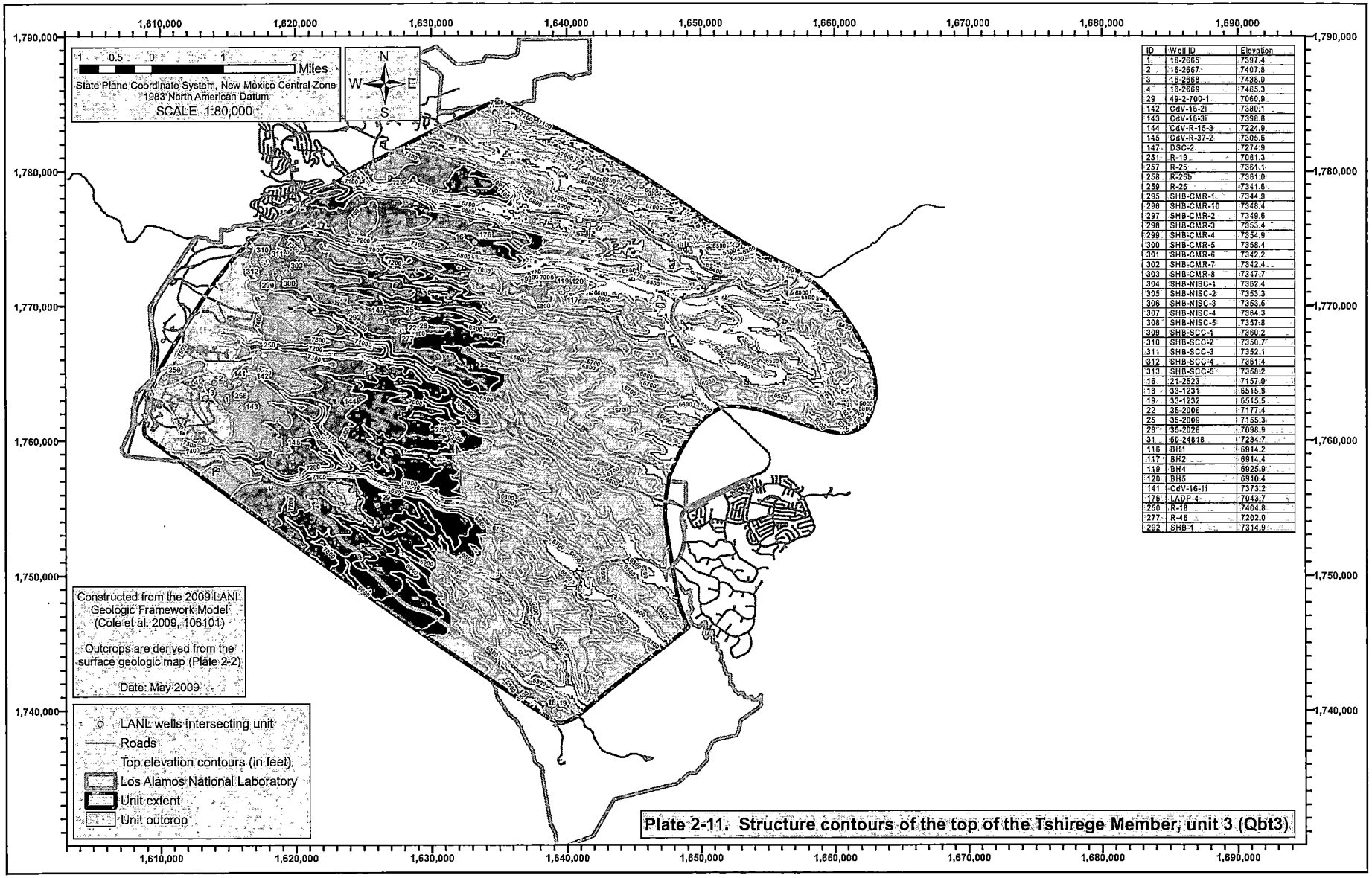
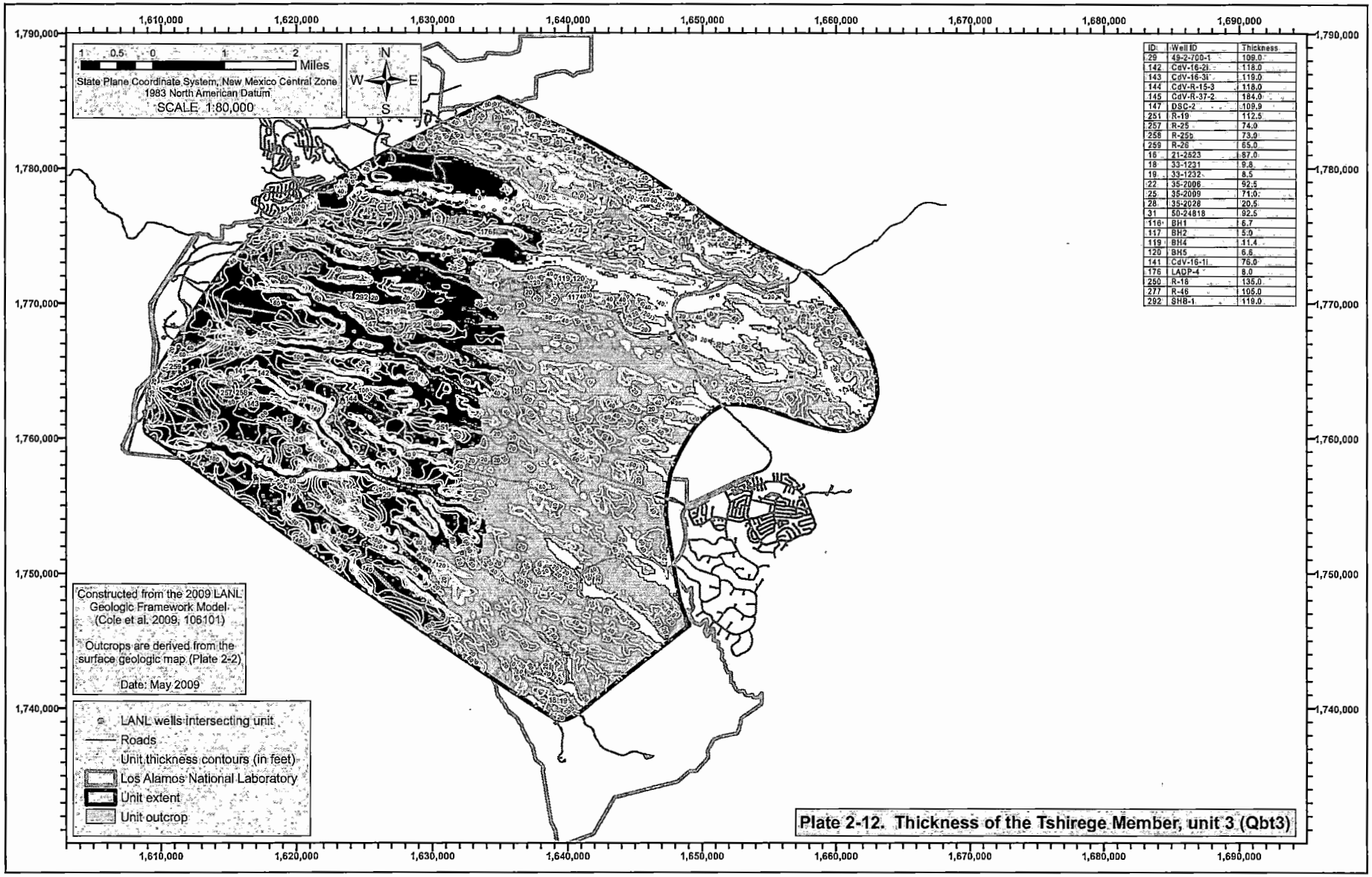
1,740,000
1 0.5 0 1 2 Miles
State Plane Coordinate System, New Mexico Central Zone
1983 North American Datum
SCALE 1:80,000
N
W E
S
ID Well ID Thickness
1 16-2665 19.0
2 16-2667 31.7
3 16-2668 22.7
4 16-2669 24.0
142 CdV-16-2i 21.0
143 CdV-16-3i 18.0
257 R-25 71.0
259 R-26 180.0
295 SHB-CMR-1 10.1
296 SHB-CMR-10 7.7
297 SHB-CMR-2 7.6
298 SHB-CMR-3 6.1
299 SHB-CMR-4 7.3
300 SHB-CMR-5 5.6
301 SHB-CMR-6 2.5
302 SHB-CMR-7 6.0
303 SHB-CMR-8 2.5
304 SHB-NISC-1 1.3
306 SHB-NISC-3 4.5
307 SHB-NISC-4 4.0
308 SHB-NISC-5 1.3
310 SHB-SCC-2 0.8
311 SHB-SCC-3 2.4
312 SHB-SCC-4 2.0
313 SHB-SCC-5 1.2
Constructed from the 2009 LANL Geologic Framework Model (Cole et al. 2009, 106101)
Outcrops are derived from the surface geologic map (Plate 2-2)
Date: May 2009
LANL wells intersecting unit
Roads
Unit thickness contours (in feet)
Los Alamos National Laboratory
Unit extent
Unit outcrop
Plate 2-10. Thickness of the Tshirege Member, unit 3, transition zone (Qbt3t)

09152



ID	Well ID	Elevation
1	16-2665	7307.4
2	16-2667	7407.8
3	16-2668	7438.0
4	16-2669	7465.3
29	49-2-700-1	7060.9
142	CdV-16-2i	7380.1
143	CdV-16-3i	7398.8
144	CdV-R-15-3	7224.9
145	CdV-R-37-2	7305.6
147	DSC-2	7274.9
251	R-19	7061.3
257	R-25	7361.1
258	R-25b	7361.0
259	R-26	7341.6
295	SHB-CMR-1	7344.9
296	SHB-CMR-10	7348.4
297	SHB-CMR-2	7349.6
298	SHB-CMR-3	7353.4
299	SHB-CMR-4	7354.9
300	SHB-CMR-5	7358.4
301	SHB-CMR-6	7342.2
302	SHB-CMR-7	7342.4
303	SHB-CMR-8	7347.7
304	SHB-NISC-1	7362.4
305	SHB-NISC-2	7353.3
306	SHB-NISC-3	7353.5
307	SHB-NISC-4	7364.3
308	SHB-NISC-5	7357.8
309	SHB-SCC-1	7360.2
310	SHB-SCC-2	7350.7
311	SHB-SCC-3	7352.1
312	SHB-SCC-4	7361.4
313	SHB-SCC-5	7358.2
16	21-2523	7157.0
18	33-1231	6515.9
19	33-1232	6515.5
22	35-2006	7177.4
25	35-2009	7165.3
28	35-2028	7098.9
31	50-24618	7234.7
116	BH1	6914.2
117	BH2	6914.4
119	BH4	6925.9
120	BH5	6910.4
141	CdV-16-1i	7373.2
176	LADP-4	7043.7
250	R-18	7404.8
277	R-46	7202.0
292	SHB-1	7314.9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1,630,000
1,640,000
1,650,000
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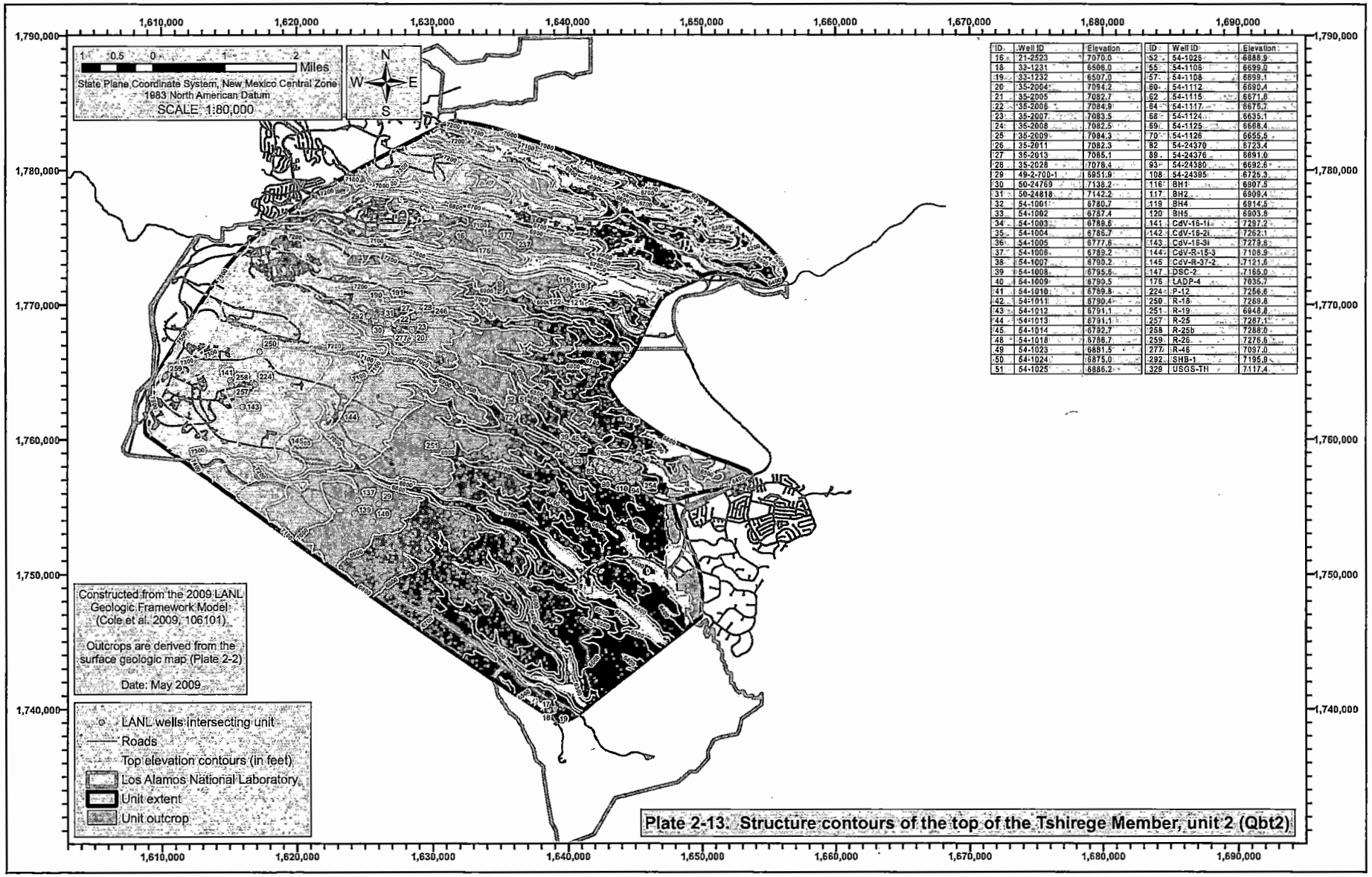
1,670,000
1,680,000
1,690,000
1,790,000
1,780,000
1,770,000
1,760,000
1,750,000
1,740,000
1 0.5 0 1 2 Miles
State Plane Coordinate System, New Mexico Central Zone
1983 North American Datum
SCALE 1:80,000
N
W E
S
ID: Well ID Thickness
29 49-2-700-1 109.0
142 CdV-16-2i 118.0
143 CdV-16-3i 119.0
144 CdV-R-15-3 118.0
145 CdV-R-37-2 184.0
147 DSC-2 109.9
251 R-19 112.5
257 R-25 74.0
258 R-25b 73.0
259 R-26 65.0
16 21-2523 87.0
18 33-1231 9.8
19 33-1232 8.5
22 35-2006 92.5
25 35-2009 71.0
28 35-2028 20.5
31 50-24818 92.5
116 BH1 6.7
117 BH2 5.9
119 BH4 11.4
120 BH5 6.6
141 CdV-16-1i 76.0
176 LADP-4 6.0
250 R-18 135.0
277 R-45 105.0
292 SHB-1 119.0
Constructed from the 2009 LANL Geologic Framework Model (Cole et al. 2009, 106101)
Outcrops are derived from the surface geologic map (Plate 2-2)
Date: May 2009
LANL wells intersecting unit
Roads
Unit thickness contours (in feet)
Los Alamos National Laboratory
Unit extent
Unit outcrop
Plate 2-12. Thickness of the Tshirege Member, unit 3 (Qbt3)

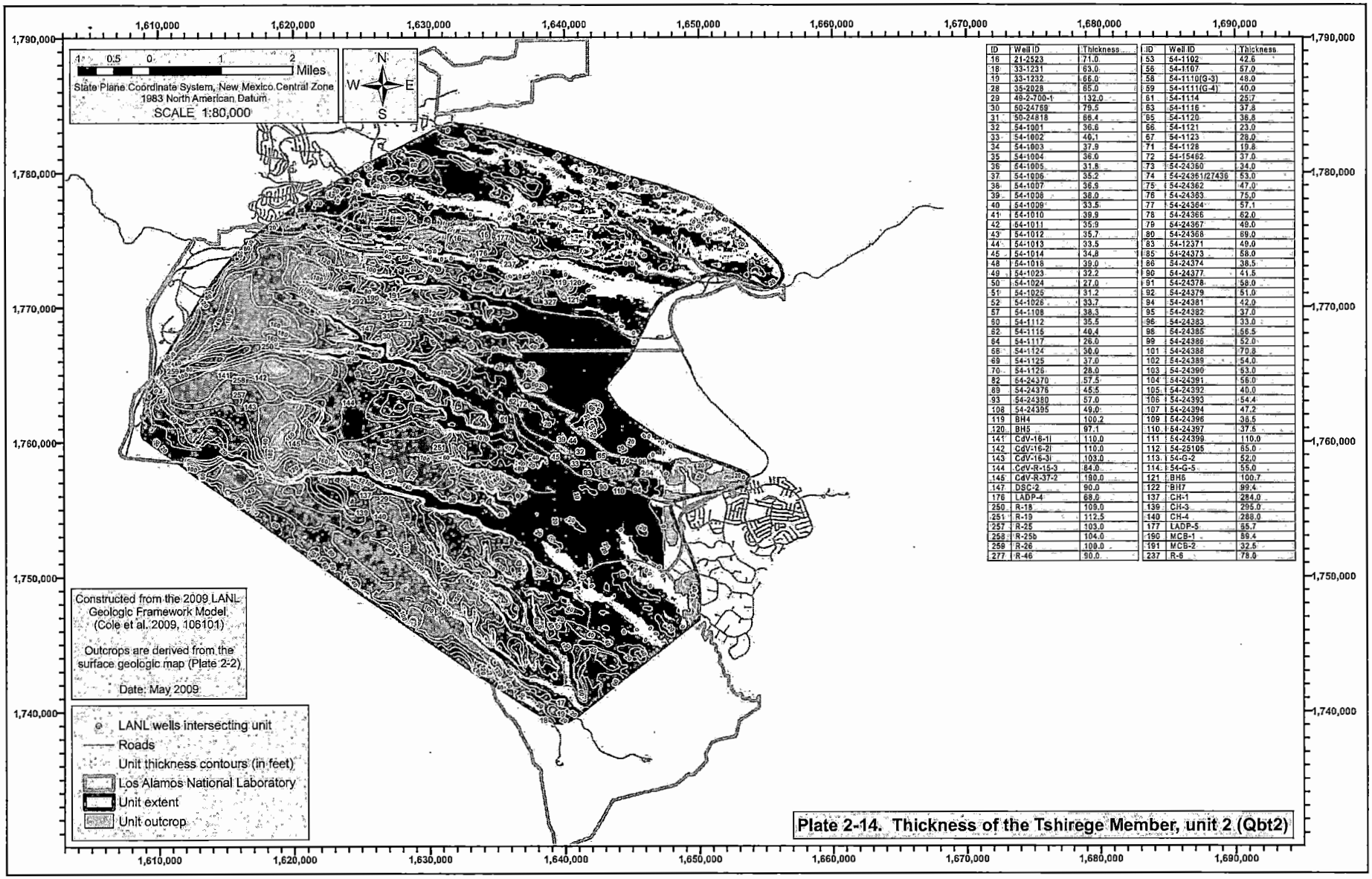


ID	Well ID	Elevation
16	21-2523	7070.0
18	33-1231	6506.0
19	33-1232	6507.0
20	35-2004	7094.2
21	35-2005	7082.7
22	35-2006	7084.9
23	35-2007	7083.5
24	35-2008	7082.5
25	35-2009	7084.3
26	35-2011	7082.3
27	35-2013	7085.1
28	35-2028	7078.4
29	49-2-700-1	6851.9
30	50-24769	7138.2
31	50-24818	7142.2
32	54-1001	6780.7
33	54-1002	6787.4
34	54-1003	6788.6
35	54-1004	6786.7
36	54-1005	6777.6
37	54-1006	6789.2
38	54-1007	6780.2
39	54-1008	6795.6
40	54-1009	6790.5
41	54-1010	6789.8
42	54-1011	6790.4
43	54-1012	6791.1
44	54-1013	6791.1
45	54-1014	6792.7
48	54-1018	6786.7
49	54-1023	6881.5
50	54-1024	6875.0
51	54-1025	6886.2

ID	Well ID	Elevation
52	54-1026	6886.9
55	54-1106	6699.0
57	54-1108	6699.1
60	54-1112	6690.4
62	54-1115	6671.6
64	54-1117	6675.7
68	54-1124	6635.1
69	54-1125	6668.4
70	54-1126	6655.5
82	54-24370	6723.4
89	54-24376	6691.0
93	54-24380	6692.6
108	54-24385	6725.3
116	BH1	6907.5
117	BH2	6909.4
119	BH4	6914.2
120	BH5	6903.8
141	CdV-16-1i	7297.2
142	CdV-16-2i	7262.1
143	CdV-16-3i	7279.8
144	CdV-R-15-3	7108.9
145	CdV-R-37-2	7121.8
147	DSC-2	7165.0
176	LADP-4	7035.7
224	P-12	7256.6
250	R-18	7269.8
251	R-19	6948.8
257	R-25	7287.1
258	R-25b	7268.0
259	R-26	7276.6
277	R-46	7097.0
292	SHB-1	7195.9
329	USGS-TH	7117.4

Plate 2-13. Structure contours of the top of the Tshirege Member, unit 2 (Qbt2)

ER2009-0115

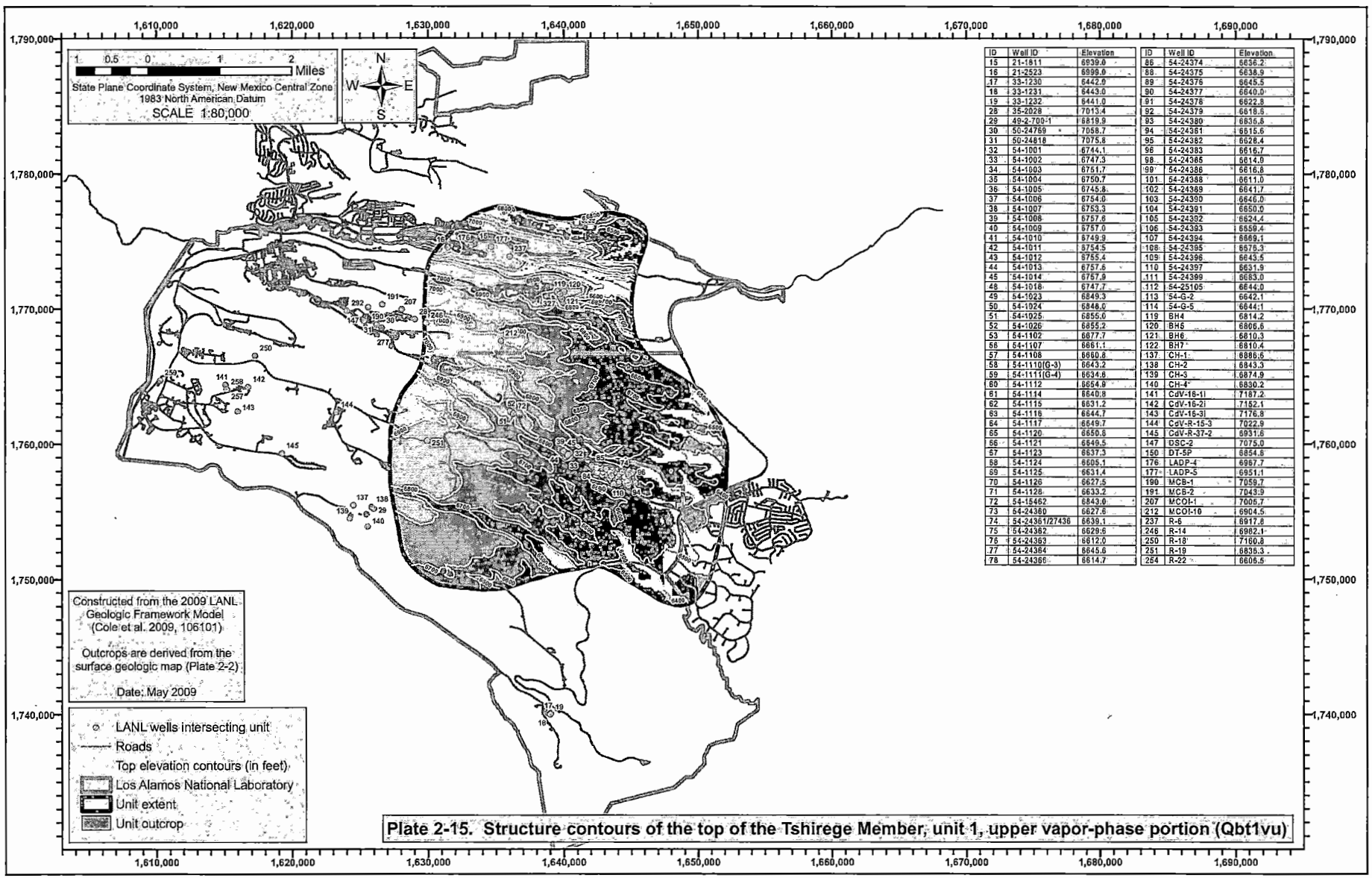


ID	Well ID	Thickness
16	21-2523	71.0
18	33-1231	63.0
19	33-1232	66.0
28	35-2028	65.0
29	49-2-700-1	132.0
30	50-24759	79.5
31	50-24818	66.4
32	54-1001	36.6
33	54-1002	40.1
34	54-1003	37.9
35	54-1004	36.0
36	54-1005	31.8
37	54-1006	35.2
38	54-1007	36.9
39	54-1008	38.0
40	54-1009	33.5
41	54-1010	39.9
42	54-1011	35.9
43	54-1012	35.7
44	54-1013	33.5
45	54-1014	34.8
48	54-1018	39.0
49	54-1023	32.2
50	54-1024	27.0
51	54-1025	31.2
52	54-1026	33.7
57	54-1108	38.3
60	54-1112	35.5
62	54-1116	40.4
64	54-1117	26.0
68	54-1124	30.0
69	54-1125	37.0
70	54-1126	28.0
82	54-24370	57.5
89	54-24376	45.5
93	54-24380	57.0
108	54-24395	49.0
119	BH4	100.2
120	BH5	97.1
141	CdV-16-1i	110.0
142	CdV-16-2i	110.0
143	CdV-16-3i	103.0
144	CdV-R-15-3	84.0
146	CdV-R-37-2	100.0
147	DSC-2	90.0
176	LADP-4	68.0
250	R-18	109.0
251	R-19	112.5
257	R-25	103.0
258	R-25b	104.0
259	R-26	100.0
277	R-46	90.0

ID	Well ID	Thickness
53	54-1102	42.6
56	54-1107	57.0
58	54-1110(G-3)	48.0
59	54-1111(G-4)	40.0
61	54-1114	25.7
63	54-1115	37.8
65	54-1120	36.8
66	54-1121	23.0
67	54-1123	28.0
71	54-1128	19.8
72	54-15462	37.0
73	54-24360	34.0
74	54-24361/27436	53.0
75	54-24362	47.0
76	54-24363	75.0
77	54-24364	57.1
78	54-24366	62.0
79	54-24367	49.0
80	54-24368	69.0
83	54-12371	49.0
85	54-24373	58.0
86	54-24374	38.5
90	54-24377	41.5
91	54-24378	58.0
92	54-24379	51.0
94	54-24381	42.0
95	54-24382	37.0
96	54-24383	33.0
98	54-24385	58.5
99	54-24386	52.0
101	54-24388	70.8
102	54-24389	54.0
103	54-24390	63.0
104	54-24391	56.0
105	54-24392	40.0
106	54-24393	54.4
107	54-24394	47.2
109	54-24396	38.5
110	54-24397	37.5
111	54-24399	110.0
112	54-25105	65.0
113	54-G-2	52.0
114	54-G-5	55.0
121	BH6	100.7
122	BH7	89.4
137	CH-1	284.0
139	CH-3	295.0
140	CH-4	288.0
177	LADP-5	65.7
190	MCB-1	89.4
191	MCB-2	32.5
237	R-6	78.0

Plate 2-14. Thickness of the Tshirege Member, unit 2 (Qbt2)

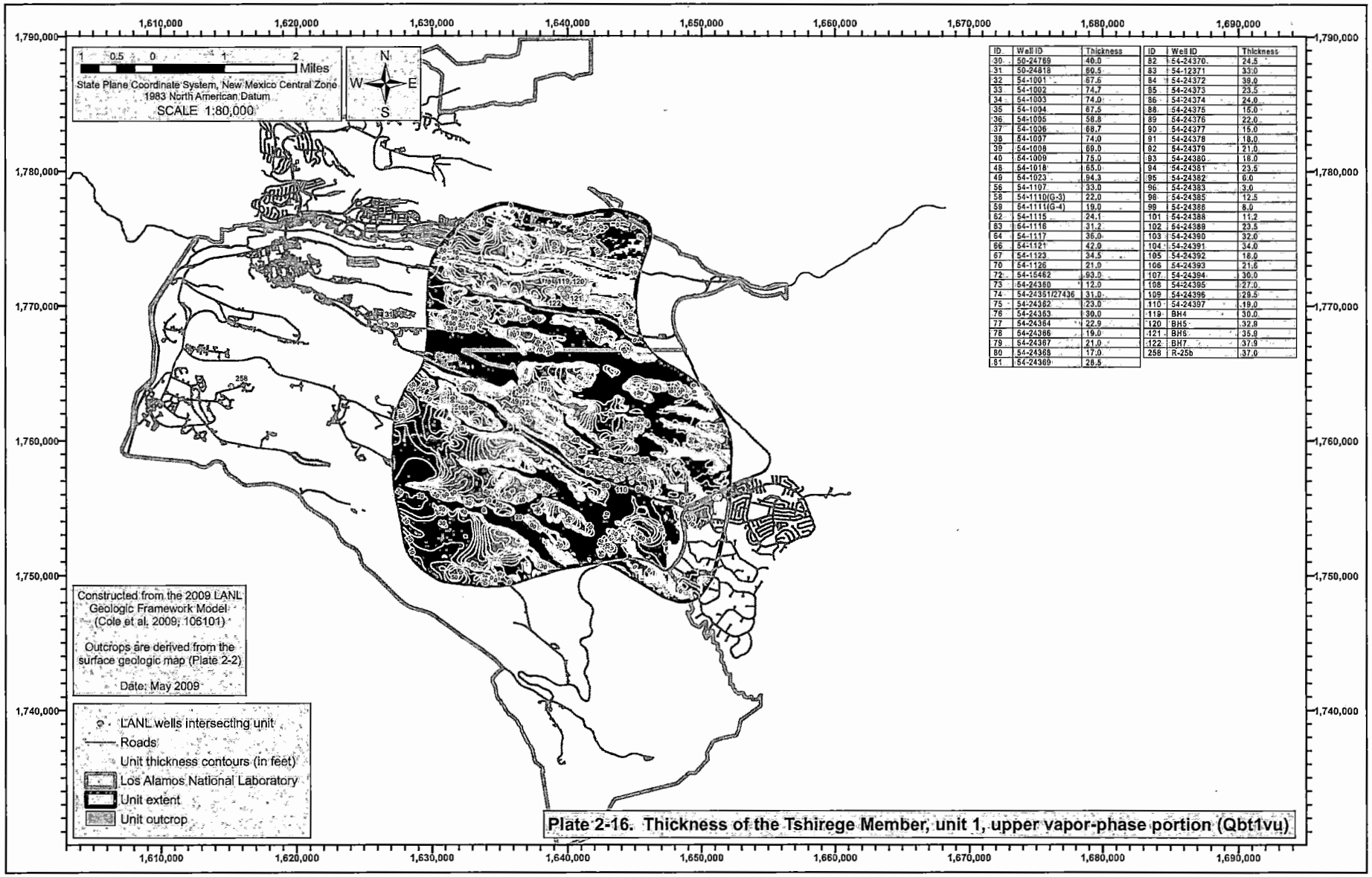
SG115



ID	Well ID	Elevation
15	21-1811	6939.0
16	21-2523	6998.0
17	33-1230	6442.9
18	33-1231	6443.0
19	33-1232	6441.0
28	35-2028	7013.4
29	49-2-7001	6819.9
30	50-24769	7058.7
31	50-24818	7075.8
32	54-1001	6744.1
33	54-1002	6747.3
34	54-1003	6751.7
35	54-1004	6750.7
36	54-1005	6745.8
37	54-1006	6754.0
38	54-1007	6753.3
39	54-1008	6757.6
40	54-1009	6757.0
41	54-1010	6749.9
42	54-1011	6754.5
43	54-1012	6755.4
44	54-1013	6757.6
45	54-1014	6757.9
48	54-1018	6747.7
49	54-1023	6849.3
50	54-1024	6848.0
51	54-1025	6855.0
52	54-1026	6855.2
53	54-1102	6677.7
56	54-1107	6661.1
57	54-1108	6660.8
58	54-1110(G-3)	6643.2
59	54-1111(G-4)	6634.6
60	54-1112	6654.9
61	54-1114	6640.8
62	54-1115	6631.2
63	54-1116	6644.7
64	54-1117	6649.7
65	54-1120	6650.6
66	54-1121	6649.5
67	54-1123	6637.3
68	54-1124	6605.1
69	54-1125	6631.4
70	54-1126	6627.5
71	54-1128	6633.2
72	54-15462	6843.0
73	54-24360	6627.6
74	54-24361/27436	6639.1
75	54-24362	6629.6
76	54-24363	6612.0
77	54-24364	6645.6
78	54-24366	6614.7

ID	Well ID	Elevation
86	54-24374	6636.2
88	54-24375	6638.9
89	54-24376	6645.5
90	54-24377	6640.0
91	54-24378	6622.8
92	54-24379	6618.6
93	54-24380	6636.8
94	54-24381	6615.6
95	54-24382	6628.4
96	54-24383	6616.7
98	54-24385	6614.0
99	54-24386	6616.8
101	54-24388	6611.0
102	54-24389	6641.7
103	54-24390	6646.0
104	54-24391	6650.0
105	54-24392	6624.4
106	54-24393	6659.4
107	54-24394	6669.1
108	54-24395	6675.3
109	54-24396	6643.5
110	54-24397	6631.9
111	54-24399	6683.0
112	54-25105	6644.0
113	54-G-2	6642.1
114	54-G-5	6644.1
119	BH4	6814.2
120	BH5	6806.6
121	BH6	6810.3
122	BH7	6810.4
137	CH-1	6886.6
138	CH-2	6843.3
139	CH-3	6874.9
140	CH-4	6830.2
141	CdV-16-1i	7187.2
142	CdV-16-2i	7152.1
143	CdV-16-3i	7176.8
144	CdV-R-15-3	7022.9
145	CdV-R-37-2	6931.6
147	DSC-2	7075.0
150	DT-5P	6854.8
176	LADP-4	6967.7
177	LADP-5	6951.1
190	MCB-1	7059.7
191	MCB-2	7043.9
207	MCOI-1	7005.7
212	MCOI-10	6904.5
237	R-6	6917.8
246	R-14	6982.1
250	R-18	7160.8
251	R-19	6838.3
264	R-22	6805.5

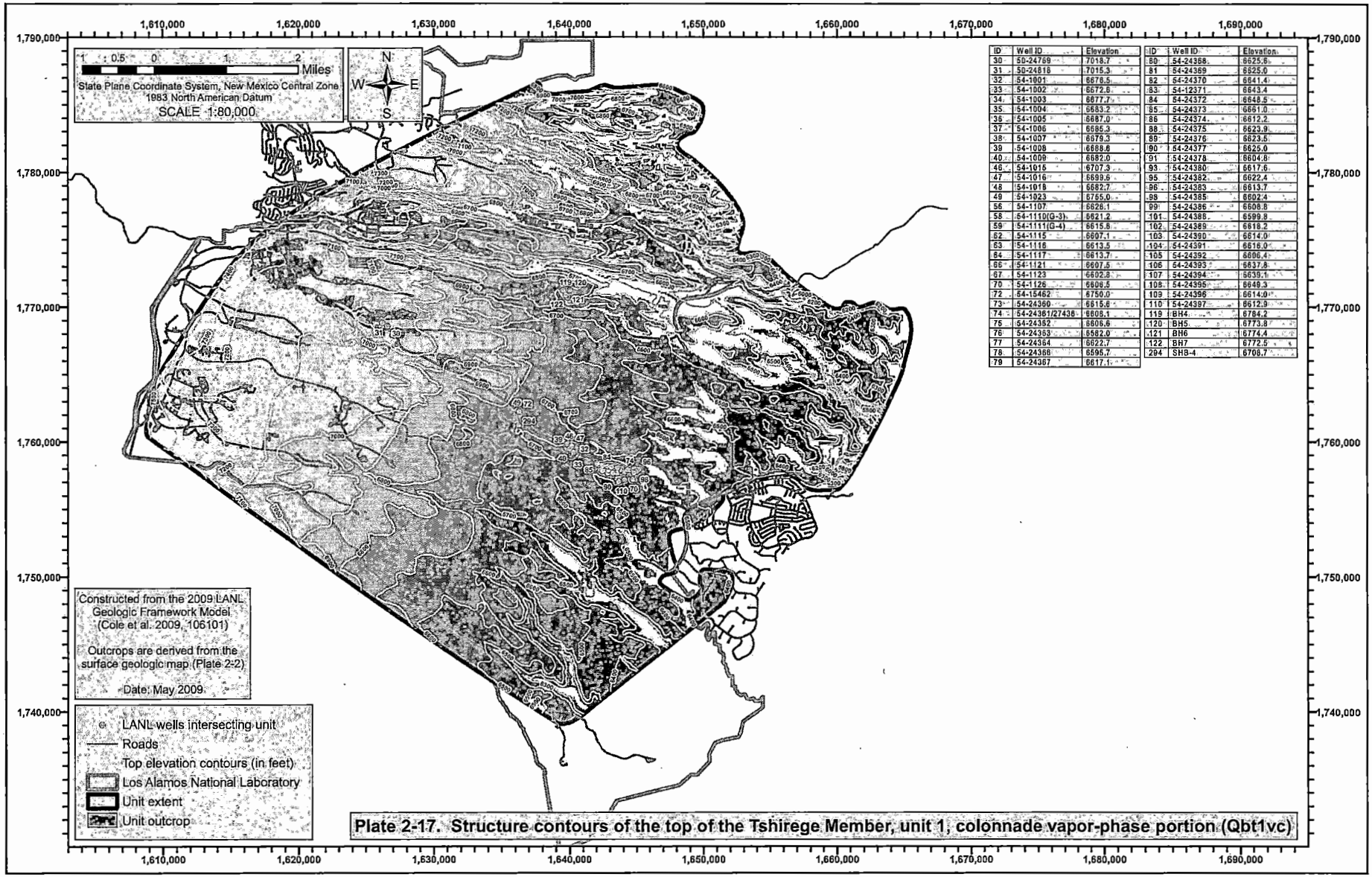
Plate 2-15. Structure contours of the top of the Tshirege Member, unit 1, upper vapor-phase portion (Qbt1vu)



ID	Well ID	Thickness
30	50-24769	40.0
31	50-24818	60.5
32	54-1001	67.6
33	54-1002	74.7
34	54-1003	74.0
35	54-1004	67.5
36	54-1005	58.8
37	54-1006	68.7
38	54-1007	74.0
39	54-1008	69.0
40	54-1009	75.0
48	54-1018	65.0
49	54-1023	94.3
56	54-1107	33.0
58	54-1110(G-3)	22.0
59	54-1111(G-4)	19.0
62	54-1115	24.1
63	54-1116	31.2
64	54-1117	36.0
66	54-1121	42.0
67	54-1123	34.5
70	54-1126	21.0
72	54-15462	93.0
73	54-24360	12.0
74	54-24361/27436	31.0
75	54-24362	23.0
76	54-24363	30.0
77	54-24364	22.9
78	54-24366	19.0
79	54-24367	21.0
80	54-24368	17.0
81	54-24369	28.5

ID	Well ID	Thickness
82	54-24370	24.5
83	54-12371	33.0
84	54-24372	39.0
85	54-24373	23.5
86	54-24374	24.0
88	54-24376	15.0
89	54-24376	22.0
90	54-24377	15.0
91	54-24378	18.0
92	54-24379	21.0
93	54-24380	18.0
94	54-24381	23.5
95	54-24382	6.0
96	54-24383	3.0
98	54-24385	12.5
99	54-24386	8.0
101	54-24388	11.2
102	54-24389	23.5
103	54-24390	32.0
104	54-24391	34.0
105	54-24392	18.0
106	54-24393	21.6
107	54-24394	30.0
108	54-24395	27.0
109	54-24396	29.5
110	54-24397	19.0
119	BH4	30.0
120	BH5	32.9
121	BH6	35.9
122	BH7	37.9
258	R-25b	37.0

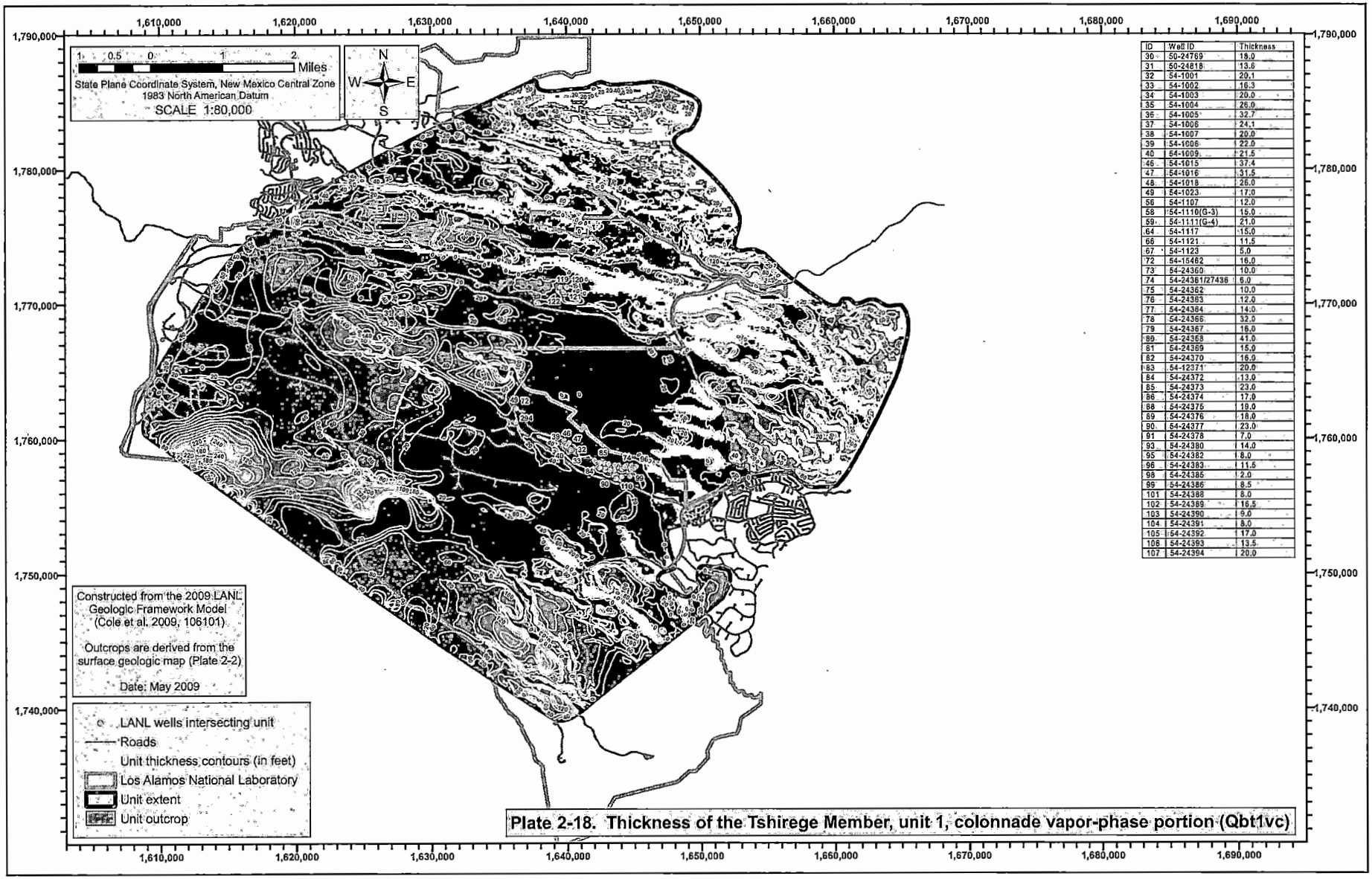
Plate 2-16. Thickness of the Tshirege Member, unit 1, upper vapor-phase portion (Qbt1vu)



ID	Well ID	Elevation
30	50-24759	7018.7
31	50-24818	7015.3
32	54-1001	6676.5
33	54-1002	6672.6
34	54-1003	6677.7
35	54-1004	6683.2
36	54-1005	6687.0
37	54-1006	6686.3
38	54-1007	6679.3
39	54-1008	6688.8
40	54-1009	6682.0
46	54-1015	6707.3
47	54-1016	6699.6
48	54-1018	6682.7
49	54-1023	6755.0
56	54-1107	6628.1
58	54-1110(G-3)	6621.2
59	54-1111(G-4)	6615.8
62	54-1115	6607.1
63	54-1116	6613.5
64	54-1117	6613.7
66	54-1121	6607.5
67	54-1123	6602.8
70	54-1126	6606.5
72	54-15462	6750.0
73	54-24360	6615.6
74	54-24361/27438	6608.1
75	54-24362	6606.6
76	54-24363	6582.0
77	54-24364	6622.7
78	54-24366	6595.7
79	54-24367	6617.1

ID	Well ID	Elevation
80	54-24368	6625.6
81	54-24369	6625.0
82	54-24370	6641.4
83	54-12371	6643.4
84	54-24372	6648.5
85	54-24373	6661.0
86	54-24374	6612.2
88	54-24375	6623.9
89	54-24376	6623.5
90	54-24377	6625.0
91	54-24378	6604.8
93	54-24380	6617.6
95	54-24382	6622.4
96	54-24383	6613.7
98	54-24385	6602.4
99	54-24386	6608.8
101	54-24388	6599.8
102	54-24389	6618.2
103	54-24390	6614.0
104	54-24391	6618.0
105	54-24392	6606.4
106	54-24393	6637.8
107	54-24394	6639.1
108	54-24395	6649.3
109	54-24396	6614.0
110	54-24397	6612.9
119	BH4	6784.2
120	BH5	6773.8
121	BH6	6774.4
122	BH7	6772.5
294	SHB-4	6706.7

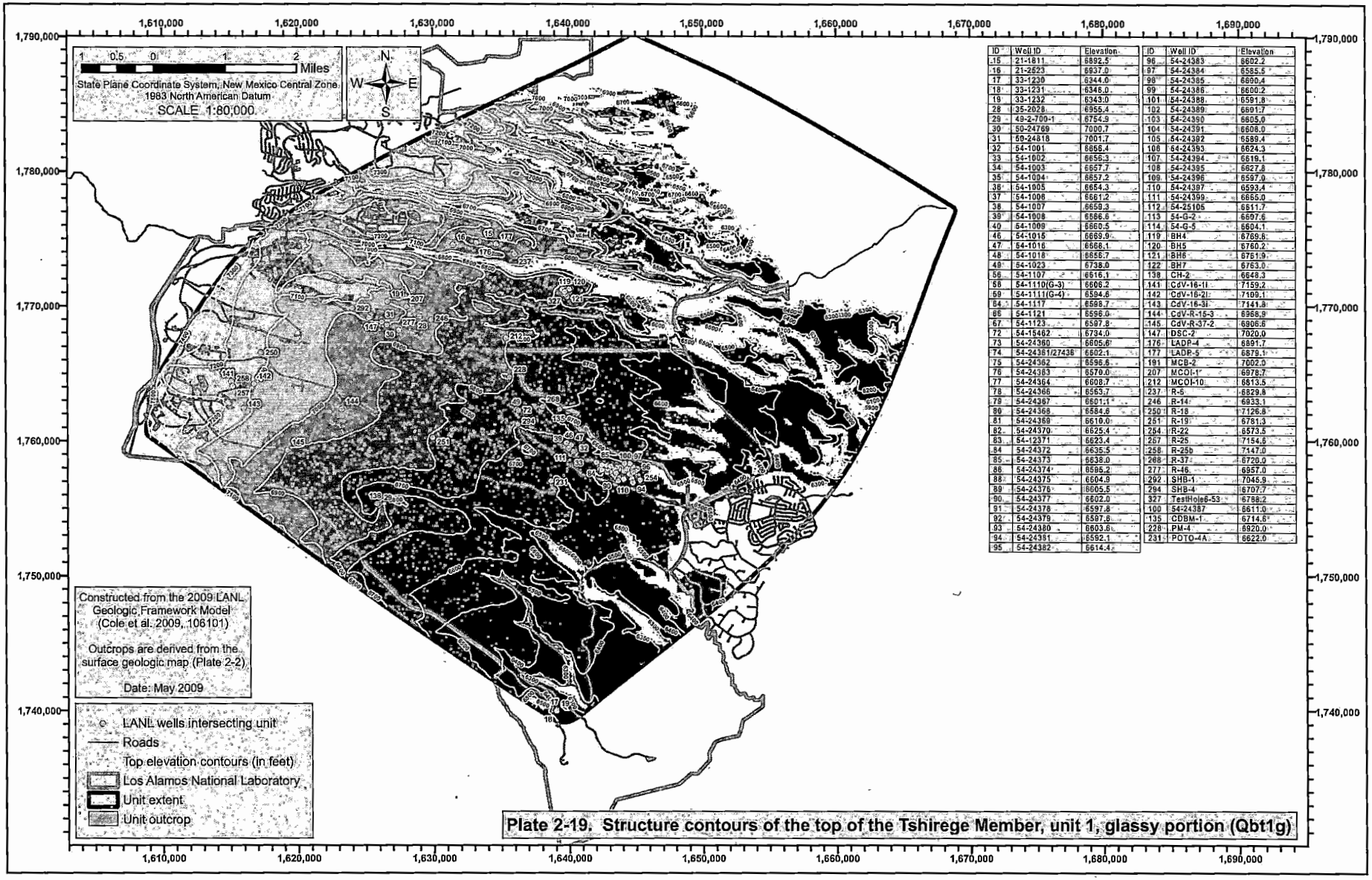
Plate 2-17. Structure contours of the top of the Tshirege Member, unit 1, colonnade vapor-phase portion (Qbt1vc)



ID	Well ID	Thickness
30	50-24769	18.0
31	50-24818	13.6
32	54-1001	20.1
33	54-1002	16.3
34	54-1003	20.0
35	54-1004	26.0
36	54-1005	32.7
37	54-1006	24.1
38	54-1007	20.0
39	54-1008	22.0
40	54-1009	21.5
46	54-1015	37.4
47	54-1016	31.5
48	54-1018	26.0
49	54-1023	17.0
56	54-1107	12.0
58	54-1110(G-3)	15.0
59	54-1111(G-4)	21.0
64	54-1117	15.0
66	54-1121	11.5
67	54-1123	5.0
72	54-15462	16.0
73	54-24360	10.0
74	54-24361/27436	6.0
75	54-24362	10.0
76	54-24363	12.0
77	54-24364	14.0
78	54-24366	32.0
79	54-24367	16.0
80	54-24368	41.0
81	54-24369	15.0
82	54-24370	16.0
83	54-12371	20.0
84	54-24372	13.0
85	54-24373	23.0
86	54-24374	17.0
88	54-24375	19.0
89	54-24376	18.0
90	54-24377	23.0
91	54-24378	7.0
93	54-24380	14.0
95	54-24382	8.0
96	54-24383	11.5
98	54-24385	2.0
99	54-24386	8.5
101	54-24388	8.0
102	54-24389	16.5
103	54-24390	9.0
104	54-24391	8.0
105	54-24392	17.0
106	54-24393	13.5
107	54-24394	20.0

Plate 2-18. Thickness of the Tshirege Member, unit 1, colonnade vapor-phase portion (Qbt1vc)

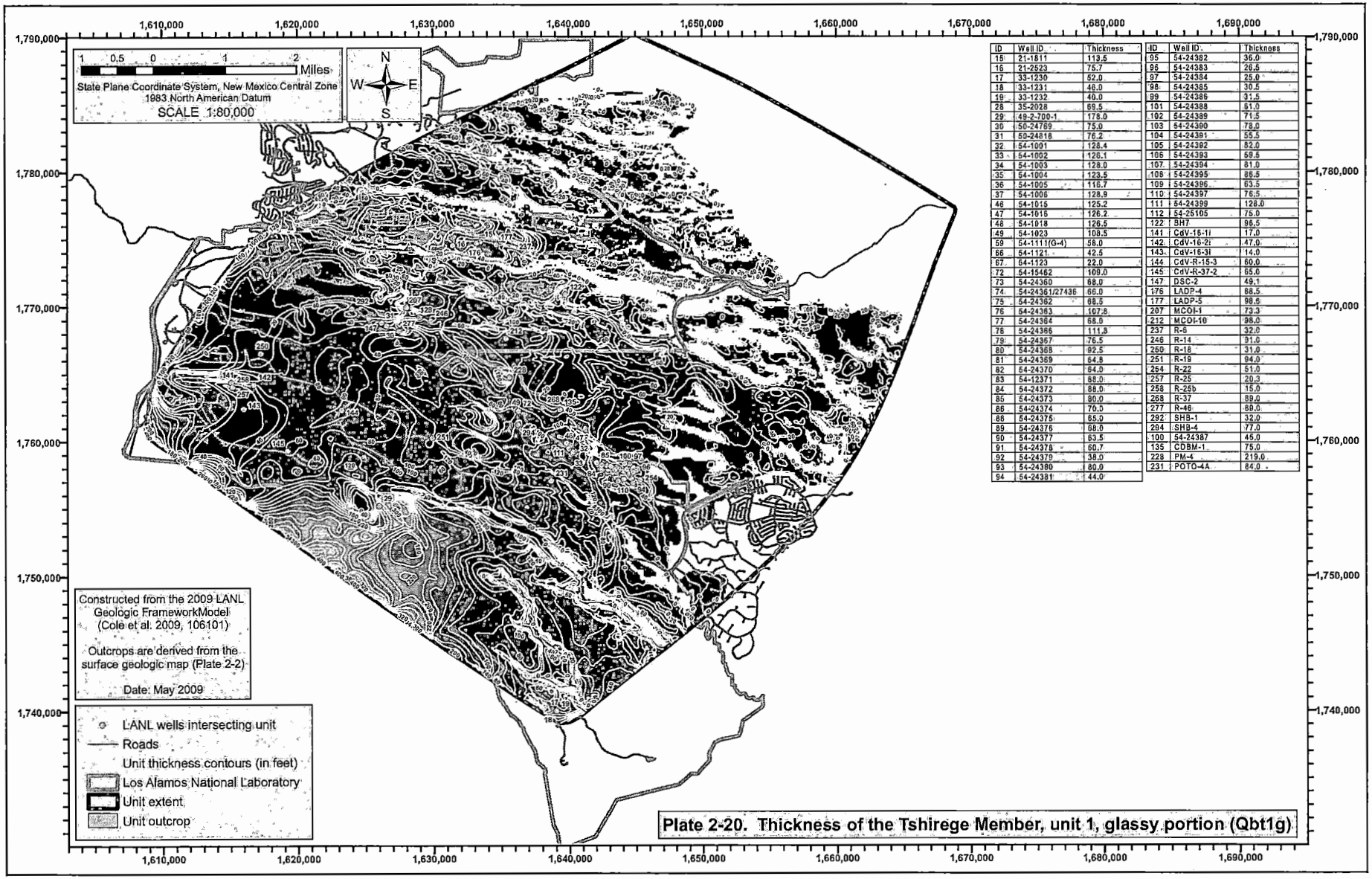
09120



ID	Well ID	Elevation
15	21-1811	6892.5
16	21-2623	6937.0
17	33-1230	6344.0
18	33-1231	6346.0
19	33-1232	6343.0
28	35-2028	6955.4
29	49-2-700-1	6754.9
30	50-24769	7000.7
31	50-24818	7001.7
32	54-1001	6658.4
33	54-1002	6656.3
34	54-1003	6657.7
35	54-1004	6657.2
36	54-1005	6654.3
37	54-1006	6661.2
38	54-1007	6659.3
39	54-1008	6666.6
40	54-1009	6660.5
46	54-1015	6669.9
47	54-1016	6668.1
48	54-1018	6656.7
49	54-1023	6738.0
56	54-1107	6616.1
58	54-1110(G-3)	6606.2
59	54-1111(G-4)	6594.6
64	54-1117	6599.7
66	54-1121	6596.0
67	54-1123	6597.8
72	54-15462	6734.0
73	54-24360	6605.6
74	54-24361/27436	6602.1
75	54-24362	6596.6
76	54-24363	6570.0
77	54-24364	6608.7
78	54-24366	6563.7
79	54-24367	6601.1
80	54-24368	6584.6
81	54-24369	6610.0
82	54-24370	6625.4
83	54-12371	6623.4
84	54-24372	6635.5
85	54-24373	6638.0
86	54-24374	6595.2
88	54-24375	6604.8
89	54-24376	6605.5
90	54-24377	6602.0
91	54-24378	6597.8
92	54-24379	6597.8
93	54-24380	6603.6
94	54-24381	6592.1
95	54-24382	6614.4

ID	Well ID	Elevation
96	54-24383	6602.2
97	54-24384	6585.5
98	54-24385	6600.4
99	54-24386	6600.2
101	54-24388	6591.8
102	54-24389	6601.7
103	54-24390	6605.0
104	54-24391	6608.0
105	54-24392	6589.4
106	54-24393	6624.3
107	54-24394	6619.1
108	54-24395	6627.8
109	54-24396	6597.9
110	54-24397	6593.4
111	54-24399	6665.0
112	54-25105	6611.7
113	54-G-2	6597.6
114	54-G-5	6604.1
119	BH4	6769.8
120	BH5	6760.2
121	BH6	6781.9
122	BH7	6783.0
139	CH-2	6648.3
141	CdV-16-1i	7159.2
142	CdV-16-2i	7109.1
143	CdV-16-3i	7141.8
144	CdV-R-15-3	6966.9
145	CdV-R-37-2	6906.6
147	DSC-2	7020.0
176	LADP-4	6891.7
177	LADP-5	6879.1
191	MCB-2	7002.0
207	MCOI-1	6978.7
212	MCOI-10	6813.5
237	R-5	6829.8
246	R-14	6933.1
250	R-18	7126.8
251	R-19	6781.3
254	R-22	6573.5
257	R-25	7154.6
258	R-25b	7147.0
268	R-37	6720.0
277	R-46	6957.0
292	SHB-1	7045.9
294	SHB-4	6707.7
327	TestHole6-53	6788.2
100	54-24387	6611.0
135	CDBM-1	6714.6
228	PM-4	6920.0
231	POTO-4A	6622.0

Plate 2-19. Structure contours of the top of the Tshirege Member, unit 1, glassy portion (Qbt1g)

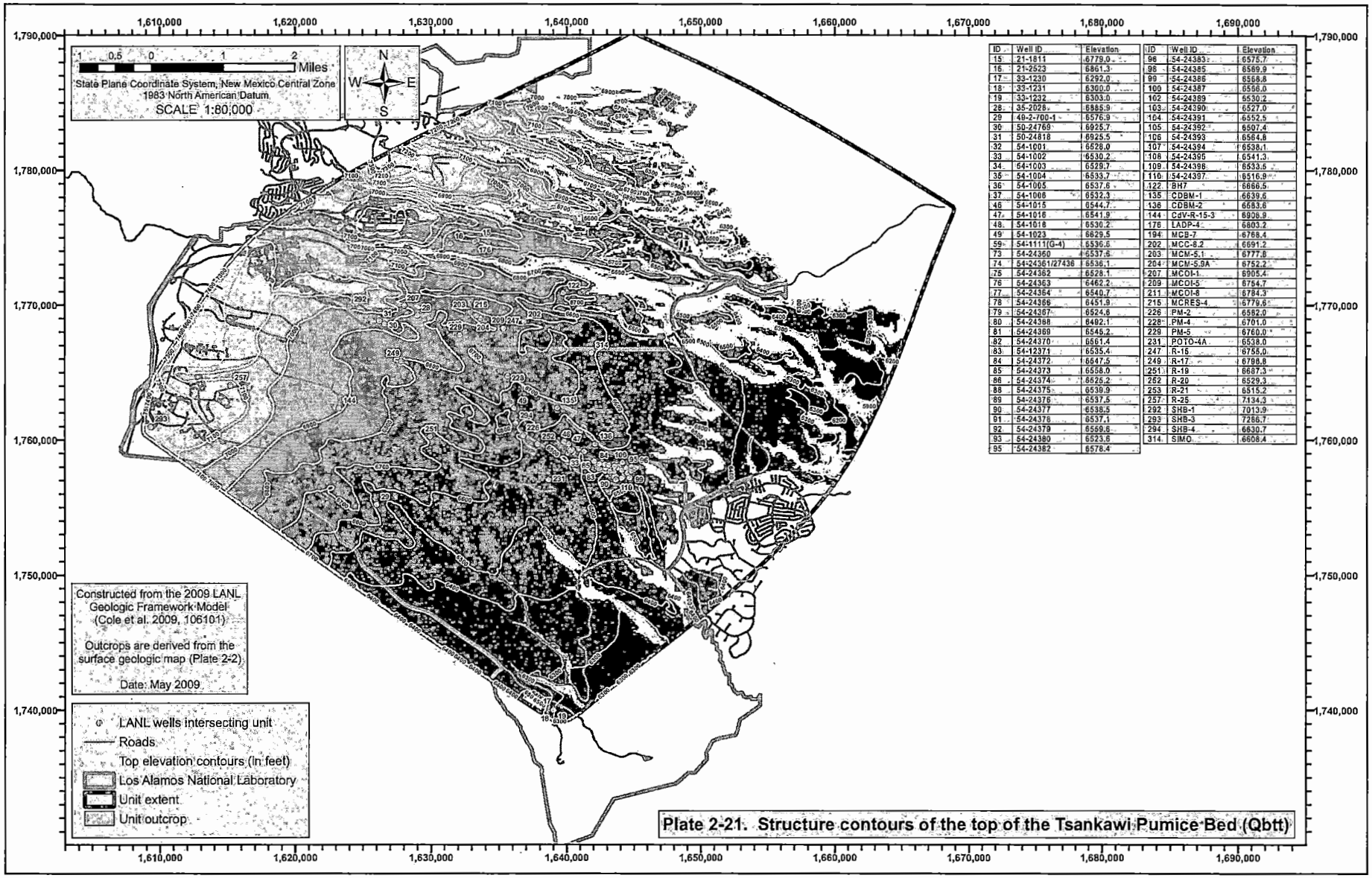


ID	Well ID	Thickness
15	21-1811	113.5
16	21-2523	75.7
17	33-1230	52.0
18	33-1231	46.0
19	33-1232	40.0
28	35-2028	69.5
29	49-2-700-1	178.0
30	50-24769	75.0
31	50-24818	76.2
32	54-1001	128.4
33	54-1002	126.1
34	54-1003	128.0
35	54-1004	123.5
36	54-1005	116.7
37	54-1006	128.9
46	54-1015	125.2
47	54-1016	126.2
48	54-1018	126.5
49	54-1023	108.5
59	54-1111(G-4)	58.0
66	54-1121	42.5
67	54-1123	22.0
72	54-15462	109.0
73	54-24360	68.0
74	54-24361/27436	66.0
75	54-24362	68.5
76	54-24363	107.8
77	54-24364	68.0
78	54-24366	111.5
79	54-24367	76.5
80	54-24368	92.5
81	54-24369	64.8
82	54-24370	64.0
83	54-12371	88.0
84	54-24372	68.0
85	54-24373	80.0
86	54-24374	70.0
88	54-24375	65.0
89	54-24376	68.0
90	54-24377	63.5
91	54-24378	60.7
92	54-24379	38.0
93	54-24380	80.0
94	54-24381	44.0

ID	Well ID	Thickness
95	54-24382	36.0
96	54-24383	26.5
97	54-24384	25.0
98	54-24385	30.5
99	54-24386	31.5
101	54-24388	61.0
102	54-24389	71.5
103	54-24390	78.0
104	54-24391	55.5
105	54-24392	82.0
106	54-24393	59.5
107	54-24394	81.0
108	54-24395	86.5
109	54-24396	63.5
110	54-24397	76.5
111	54-24399	128.0
112	54-25105	75.0
122	BH7	96.5
141	CdV-16-1i	17.0
142	CdV-16-2i	47.0
143	CdV-16-3i	14.0
144	CdV-R-15-3	60.0
145	CdV-R-37-2	65.0
147	DSC-2	49.1
176	LADP-4	88.5
177	LADP-5	98.5
207	MCOI-1	73.3
212	MCOI-10	98.0
237	R-6	32.0
246	R-14	91.0
250	R-16	31.0
251	R-19	94.0
254	R-22	51.0
257	R-25	20.3
258	R-25b	15.0
268	R-37	89.0
277	R-46	80.0
292	SHB-1	32.0
294	SHB-4	77.0
100	54-24387	45.0
135	CDBM-1	75.0
228	PM-4	219.0
231	POTO-4A	84.0

Plate 2-20. Thickness of the Tshirege Member, unit 1, glassy portion (Qbt1g)

09122

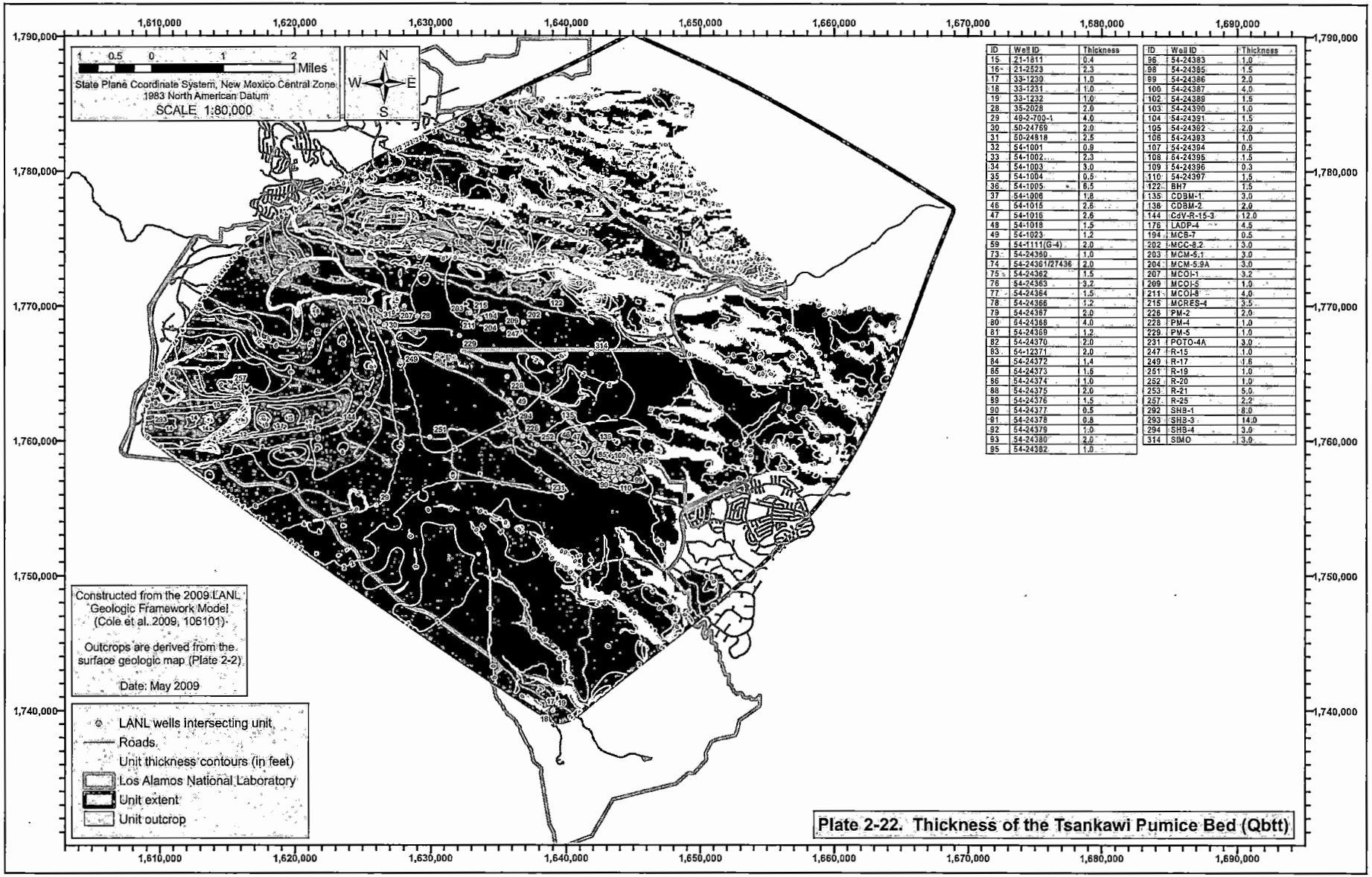


ID	Well ID	Elevation
15	21-1811	6779.0
16	21-2523	6861.3
17	33-1230	6292.0
18	33-1231	6300.0
19	33-1232	6303.0
28	35-2026	6885.9
29	49-2-700-1	6576.9
30	50-24769	6925.7
31	50-24818	6925.5
32	54-1001	6528.0
33	54-1002	6530.2
34	54-1003	6529.7
35	54-1004	6533.7
36	54-1005	6537.6
37	54-1006	6532.3
46	54-1015	6544.7
47	54-1016	6541.9
48	54-1018	6530.2
49	54-1023	6629.5
59	54-11111(G-4)	6536.6
73	54-24360	6537.5
74	54-24361/27436	6536.1
75	54-24362	6528.1
76	54-24363	6462.2
77	54-24364	6540.7
78	54-24366	6451.9
79	54-24367	6524.6
80	54-24368	6492.1
81	54-24369	6545.2
82	54-24370	6561.4
83	54-12371	6535.4
84	54-24372	6547.5
85	54-24373	6558.0
86	54-24374	6626.2
88	54-24375	6539.9
89	54-24376	6537.5
90	54-24377	6538.5
91	54-24378	6537.1
92	54-24379	6559.6
93	54-24380	6523.6
95	54-24382	6578.4

ID	Well ID	Elevation
96	54-24383	6575.7
98	54-24385	6589.9
99	54-24386	6568.6
100	54-24387	6556.0
102	54-24389	6530.2
103	54-24390	6527.0
104	54-24391	6552.5
105	54-24392	6507.4
106	54-24393	6564.8
107	54-24394	6538.1
108	54-24395	6541.3
109	54-24396	6533.5
110	54-24397	6516.9
122	BH7	6666.5
135	CDBM-1	6639.6
136	CDBM-2	6583.6
144	CdV-R-15-3	6908.9
176	LADP-4	6803.2
194	MCB-7	6768.4
202	MCC-8.2	6691.2
203	MCM-5.1	6777.8
204	MCM-5.9A	6752.2
207	MCOI-1	6905.4
209	MCOI-5	6754.7
211	MCOI-8	6784.3
215	MCRES-4	6779.6
226	PM-2	6582.0
228	PM-4	6701.0
229	PM-5	6760.0
231	POTO-4A	6538.0
247	R-15	6755.0
249	R-17	6798.8
251	R-19	6687.3
252	R-20	6529.3
253	R-21	6515.2
257	R-25	7134.3
292	SHB-1	7013.9
293	SHB-3	7286.7
294	SHB-4	6630.7
314	SIMO	6608.4

Plate 2-21. Structure contours of the top of the Tsankawi Pumice Bed (Qbtt)

96123

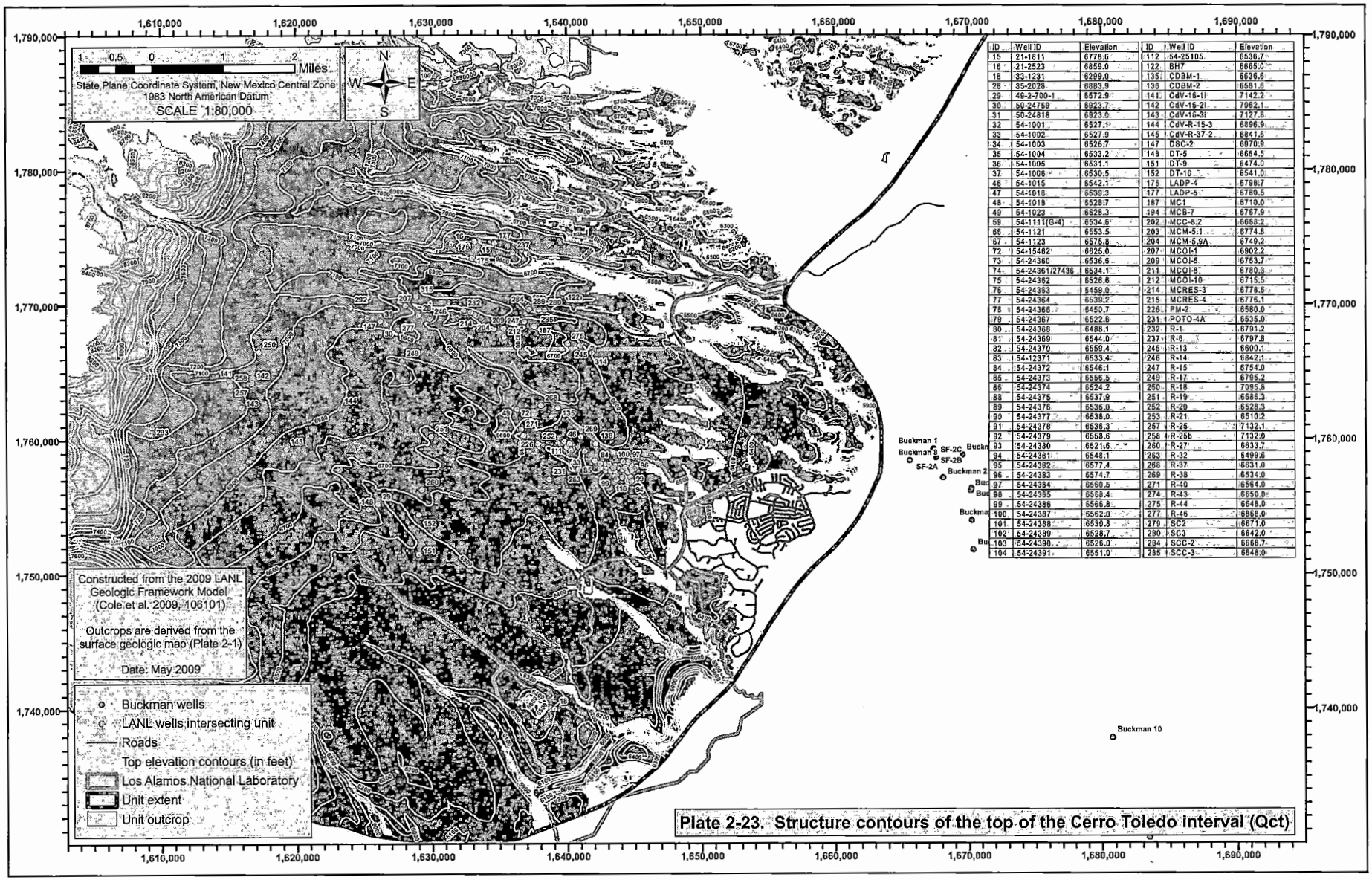


ID	Well ID	Thickness
15	21-1811	0.4
16	21-2523	2.5
17	33-1230	1.0
18	33-1231	1.0
19	33-1232	1.0
28	35-2028	2.0
29	49-2-700-1	4.0
30	50-24769	2.0
31	50-24818	2.5
32	54-1001	0.9
33	54-1002	2.3
34	54-1003	3.0
35	54-1004	0.5
36	54-1005	6.5
37	54-1006	1.8
46	54-1015	2.6
47	54-1016	2.6
48	54-1018	1.5
49	54-1023	1.2
59	54-1111(G-4)	2.0
73	54-24360	1.0
74	54-24361/27436	2.0
75	54-24362	1.5
76	54-24363	3.2
77	54-24364	1.5
78	54-24366	1.2
79	54-24367	2.0
80	54-24368	4.0
81	54-24369	1.2
82	54-24370	2.0
83	54-12371	2.0
84	54-24372	1.4
85	54-24373	1.5
86	54-24374	1.0
88	54-24375	2.0
89	54-24376	1.5
90	54-24377	0.5
91	54-24378	0.8
92	54-24379	1.0
93	54-24380	2.0
95	54-24382	1.0

ID	Well ID	Thickness
96	54-24383	1.0
98	54-24385	1.5
99	54-24386	2.0
100	54-24387	4.0
102	54-24389	1.5
103	54-24390	1.0
104	54-24391	1.5
105	54-24392	2.0
106	54-24393	1.0
107	54-24394	0.5
108	54-24395	1.5
109	54-24396	0.3
110	54-24397	1.5
122	BH7	1.5
135	CDBM-1	3.0
136	CDBM-2	2.0
144	CdV-R-15-3	12.0
176	LADP-4	4.5
194	MCB-7	0.5
202	MCC-8.2	3.0
203	MCM-5.1	3.0
204	MCM-5.9A	3.0
207	MCOI-1	3.2
209	MCOI-5	1.0
211	MCOI-8	4.0
215	MCRES-4	3.5
226	PM-2	2.0
228	PM-4	1.0
229	PM-5	1.0
231	POTO-4A	3.0
247	R-15	1.0
249	R-17	1.6
251	R-19	1.0
252	R-20	1.0
253	R-21	5.0
257	R-25	2.2
292	SHB-1	8.0
293	SHB-3	14.0
294	SHB-4	3.0
314	SIMO	3.0

Plate 2-22. Thickness of the Tsankawi Pumice Bed (Qbtt)

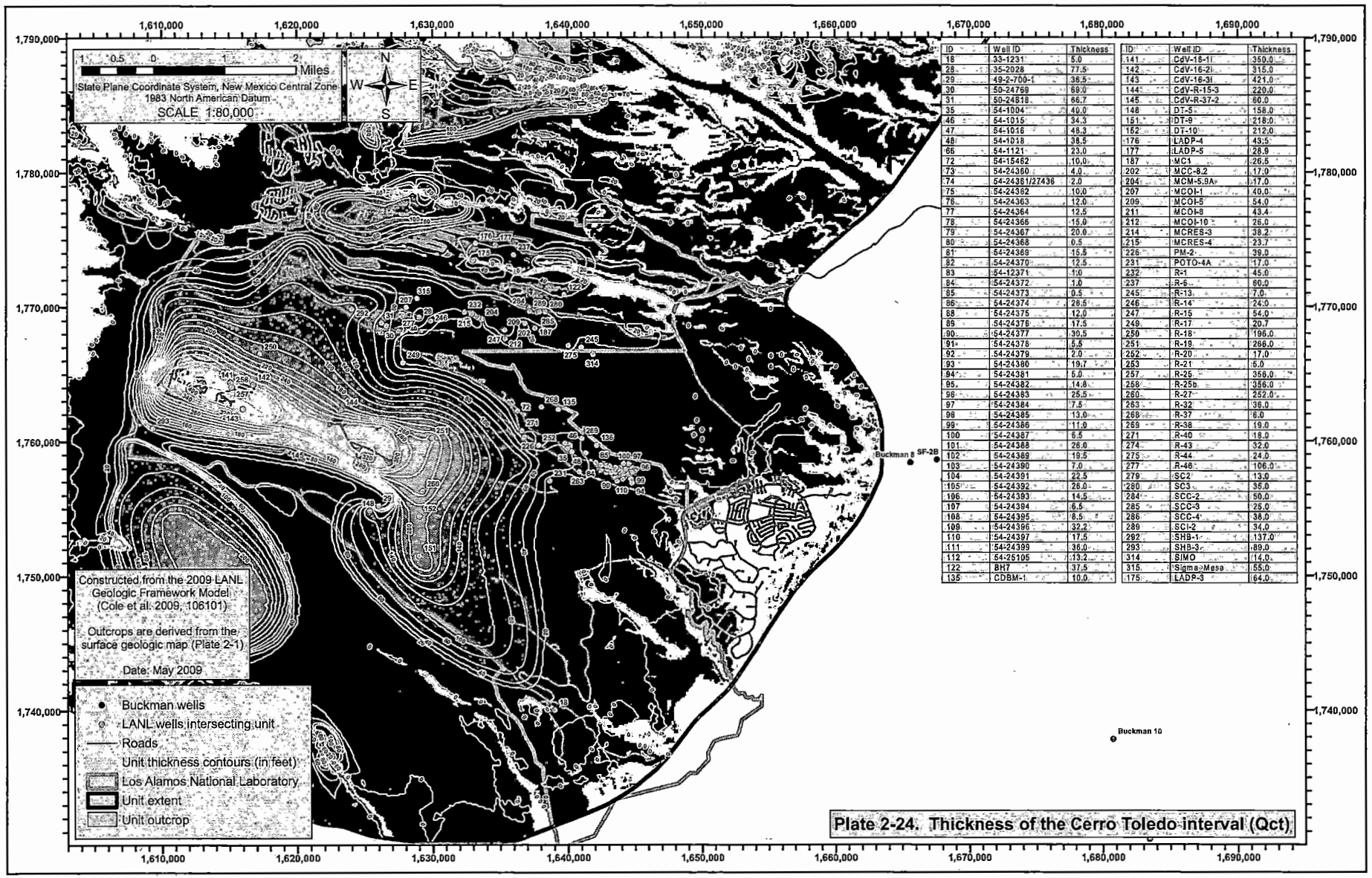
09-12-15



ID	Well ID	Elevation	ID	Well ID	Elevation
15	21-1811	6778.6	112	54-25105	6536.7
16	21-2523	6859.0	122	BH7	6665.0
18	33-1231	6299.0	135	CDBM-1	6636.6
28	35-2028	6883.9	136	CDBM-2	6581.6
29	46-2-700-1	6572.9	141	CdV-16-1i	7142.2
30	50-24769	6923.7	142	CdV-16-2i	7062.1
31	50-24818	6923.0	143	CdV-16-3i	7127.8
32	54-1001	6527.1	144	CdV-R-15-3	6896.9
33	54-1002	6527.9	145	CdV-R-37-2	6841.6
34	54-1003	6526.7	147	DSC-2	6970.9
35	54-1004	6533.2	148	DT-5	6684.5
36	54-1005	6531.1	151	DT-9	6474.0
37	54-1006	6530.5	152	DT-10	6541.0
46	54-1015	6542.1	176	LADP-4	6798.7
47	54-1016	6539.3	177	LADP-5	6789.5
48	54-1019	6529.7	187	MC1	6719.0
49	54-1023	6628.3	194	MCB-7	6767.9
58	54-11111(G-4)	6534.5	202	MCC-8.2	6688.2
66	54-1121	6553.5	203	MCM-5.1	6774.8
67	54-1123	6575.8	204	MCM-5.9A	6749.2
72	54-15462	6626.0	207	MCOI-1	6902.2
73	54-24360	6536.6	209	MCOI-5	6763.7
74	54-24361/27436	6534.1	211	MCOI-8	6780.3
75	54-24362	6526.6	212	MCOI-10	6715.5
76	54-24363	6459.0	214	MCRES-3	6778.6
77	54-24364	6539.2	215	MCRES-4	6776.1
78	54-24366	6450.7	226	PM-2	6580.0
79	54-24367	6522.6	231	POTO-4A	6535.0
80	54-24368	6488.1	232	R-1	6791.2
81	54-24369	6544.0	237	R-6	6797.8
82	54-24370	6559.4	245	R-13	6690.1
83	54-12371	6533.4	246	R-14	6842.1
84	54-24372	6546.1	247	R-15	6754.0
85	54-24373	6556.5	249	R-17	6795.2
86	54-24374	6524.2	250	R-18	7095.8
88	54-24375	6537.9	251	R-19	6686.3
89	54-24376	6536.0	252	R-20	6528.3
90	54-24377	6538.0	253	R-21	6510.2
91	54-24378	6536.3	257	R-25	7132.1
92	54-24379	6558.6	258	R-25b	7132.0
93	54-24380	6521.6	260	R-27	6833.7
94	54-24381	6548.1	263	R-32	6499.6
95	54-24382	6577.4	268	R-37	6631.0
96	54-24383	6574.7	269	R-38	6534.0
97	54-24384	6560.5	271	R-40	6564.0
98	54-24385	6558.4	274	R-43	6650.0
99	54-24386	6566.8	275	R-44	6648.0
100	54-24387	6562.0	277	R-46	6868.0
101	54-24388	6530.8	279	SC2	6671.0
102	54-24389	6528.7	280	SC3	6642.0
103	54-24390	6526.0	284	SCC-2	6668.7
104	54-24391	6551.0	285	SCC-3	6648.0

Plate 2-23. Structure contours of the top of the Cerro Toledo interval (Qct)

09125

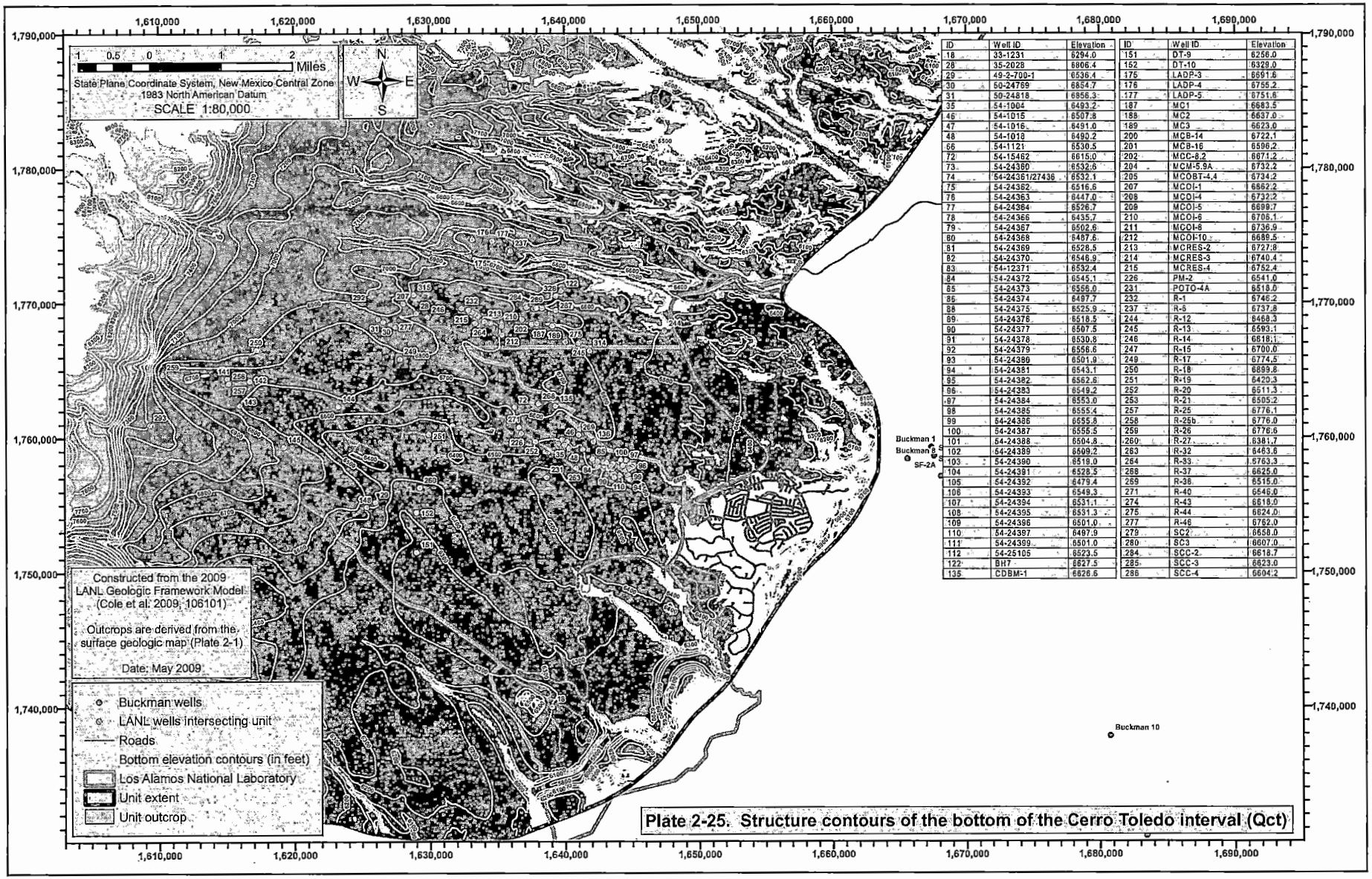


ID	Well ID	Thickness
18	33-1231	5.0
28	35-2028	77.5
29	49-2-700-1	36.5
30	50-24769	69.0
31	50-24818	66.7
35	54-1004	40.0
46	54-1015	34.3
47	54-1016	48.3
48	54-1018	38.5
66	54-1121	23.0
72	54-15462	10.0
73	54-24360	4.0
74	54-24361/27436	2.0
75	54-24362	10.0
76	54-24363	12.0
77	54-24364	12.5
78	54-24366	15.0
79	54-24367	20.0
80	54-24368	0.5
81	54-24369	15.5
82	54-24370	12.5
83	54-12371	1.0
84	54-24372	1.0
85	54-24373	0.5
86	54-24374	28.5
88	54-24375	12.0
89	54-24376	17.5
90	54-24377	30.5
91	54-24378	5.5
92	54-24379	2.0
93	54-24380	19.7
94	54-24381	5.0
95	54-24382	14.8
96	54-24383	25.5
97	54-24384	7.5
98	54-24385	13.0
99	54-24386	11.0
100	54-24387	6.5
101	54-24388	26.0
102	54-24389	19.5
103	54-24390	7.0
104	54-24391	22.5
105	54-24392	26.0
106	54-24393	14.5
107	54-24394	6.5
108	54-24395	8.5
109	54-24396	32.2
110	54-24397	17.5
111	54-24399	36.0
112	54-25105	13.2
122	BH7	37.5
135	CDBM-1	10.0

ID	Well ID	Thickness
141	CdV-16-1i	350.0
142	CdV-16-2i	315.0
143	CdV-16-3i	421.0
144	CdV-R-15-3	220.0
145	CdV-R-37-2	60.0
148	DT-5	158.0
151	DT-9	218.0
152	DT-10	212.0
176	LADP-4	43.5
177	LADP-5	28.9
187	MC1	26.5
202	MCC-8.2	17.0
204	MCM-5.9A	17.0
207	MCOI-1	40.0
209	MCOI-5	54.0
211	MCOI-8	43.4
212	MCOI-10	26.0
214	MCRES-3	38.2
215	MCRES-4	23.7
226	PM-2	39.0
231	POTO-4A	17.0
232	R-1	45.0
237	R-6	60.0
245	R-13	7.0
246	R-14	24.0
247	R-15	54.0
249	R-17	20.7
250	R-18	196.0
251	R-19	266.0
252	R-20	17.0
253	R-21	6.0
257	R-25	356.0
258	R-25b	356.0
260	R-27	252.0
263	R-32	36.0
268	R-37	6.0
269	R-38	19.0
271	R-40	18.0
274	R-43	32.0
275	R-44	24.0
277	R-46	106.0
279	SC2	13.0
280	SC3	36.0
284	SCC-2	50.0
285	SCC-3	25.0
286	SCC-4	38.0
289	SCI-2	34.0
292	SHB-1	137.0
293	SHB-3	89.0
314	SIMO	14.0
315	Sigma Mesa	55.0
175	LADP-3	64.0

Plate 2-24. Thickness of the Cerro Toledo interval (Qct)

09126

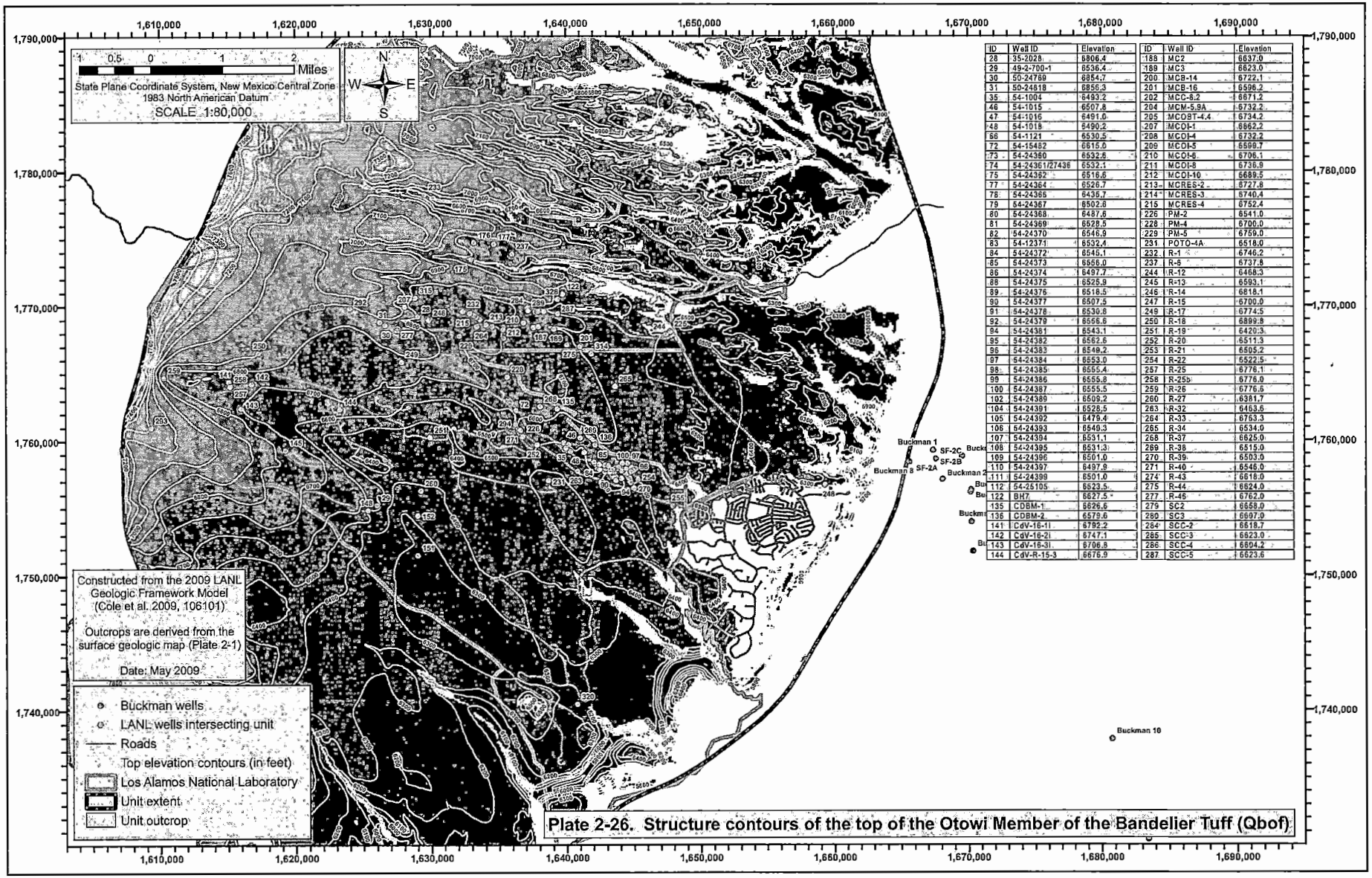


ID	Well ID	Elevation
18	33-1231	6294.0
28	35-2028	6806.4
29	49-2-700-1	6536.4
30	50-24769	6854.7
31	50-24818	6856.3
35	54-1004	6493.2
46	54-1015	6507.8
47	54-1016	6491.0
48	54-1018	6490.2
66	54-1121	6530.5
72	54-15462	6615.0
73	54-24360	6532.6
74	54-24361/27436	6532.1
75	54-24362	6516.6
76	54-24363	6447.0
77	54-24364	6526.7
78	54-24366	6435.7
79	54-24367	6502.6
80	54-24368	6487.6
81	54-24369	6528.5
82	54-24370	6546.9
83	54-12371	6532.4
84	54-24372	6545.1
85	54-24373	6556.0
86	54-24374	6497.7
88	54-24375	6525.9
89	54-24376	6518.5
90	54-24377	6507.5
91	54-24378	6530.8
92	54-24379	6556.6
93	54-24380	6501.9
94	54-24381	6543.1
95	54-24382	6562.6
96	54-24383	6549.2
97	54-24384	6553.0
98	54-24385	6555.4
99	54-24386	6555.8
100	54-24387	6556.5
101	54-24388	6504.8
102	54-24389	6509.2
103	54-24390	6519.0
104	54-24391	6528.5
105	54-24392	6479.4
106	54-24393	6549.3
107	54-24394	6531.1
108	54-24395	6531.3
109	54-24396	6501.0
110	54-24397	6497.9
111	54-24399	6501.0
112	54-25105	6523.5
122	BH7	6627.5
135	CDBM-1	6626.6

ID	Well ID	Elevation
151	DT-9	6256.0
152	DT-10	6329.0
175	LADP-3	6691.6
176	LADP-4	6755.2
177	LADP-5	6751.6
187	MC1	6683.5
188	MC2	6637.0
189	MC3	6623.0
200	MCB-14	6722.1
201	MCB-16	6596.2
202	MCC-8.2	6671.2
204	MCM-5.9A	6732.2
205	MCOBT-4.4	6734.2
207	MCOI-1	6662.2
208	MCOI-4	6732.2
209	MCOI-5	6699.7
210	MCOI-6	6706.1
211	MCOI-8	6736.9
212	MCOI-10	6689.5
213	MCRES-2	6727.8
214	MCRES-3	6740.4
215	MCRES-4	6752.4
226	PM-2	6541.0
231	POTO-4A	6518.0
232	R-1	6746.2
237	R-5	6737.8
244	R-12	6468.3
245	R-13	6593.1
246	R-14	6818.1
247	R-15	6700.0
249	R-17	6774.5
250	R-18	6899.8
251	R-19	6420.3
252	R-20	6511.3
253	R-21	6505.2
257	R-25	6776.1
258	R-25b	6776.0
259	R-26	6776.6
260	R-27	6381.7
263	R-32	6463.8
264	R-33	6763.3
268	R-37	6625.0
269	R-38	6515.0
271	R-40	6546.0
274	R-43	6618.0
275	R-44	6624.0
277	R-46	6762.0
279	SC2	6658.0
280	SC3	6607.0
284	SCC-2	6618.7
285	SCC-3	6623.0
286	SCC-4	6604.2

Plate 2-25. Structure contours of the bottom of the Cerro Toledo interval (Qct)

LA-UR-09-6127

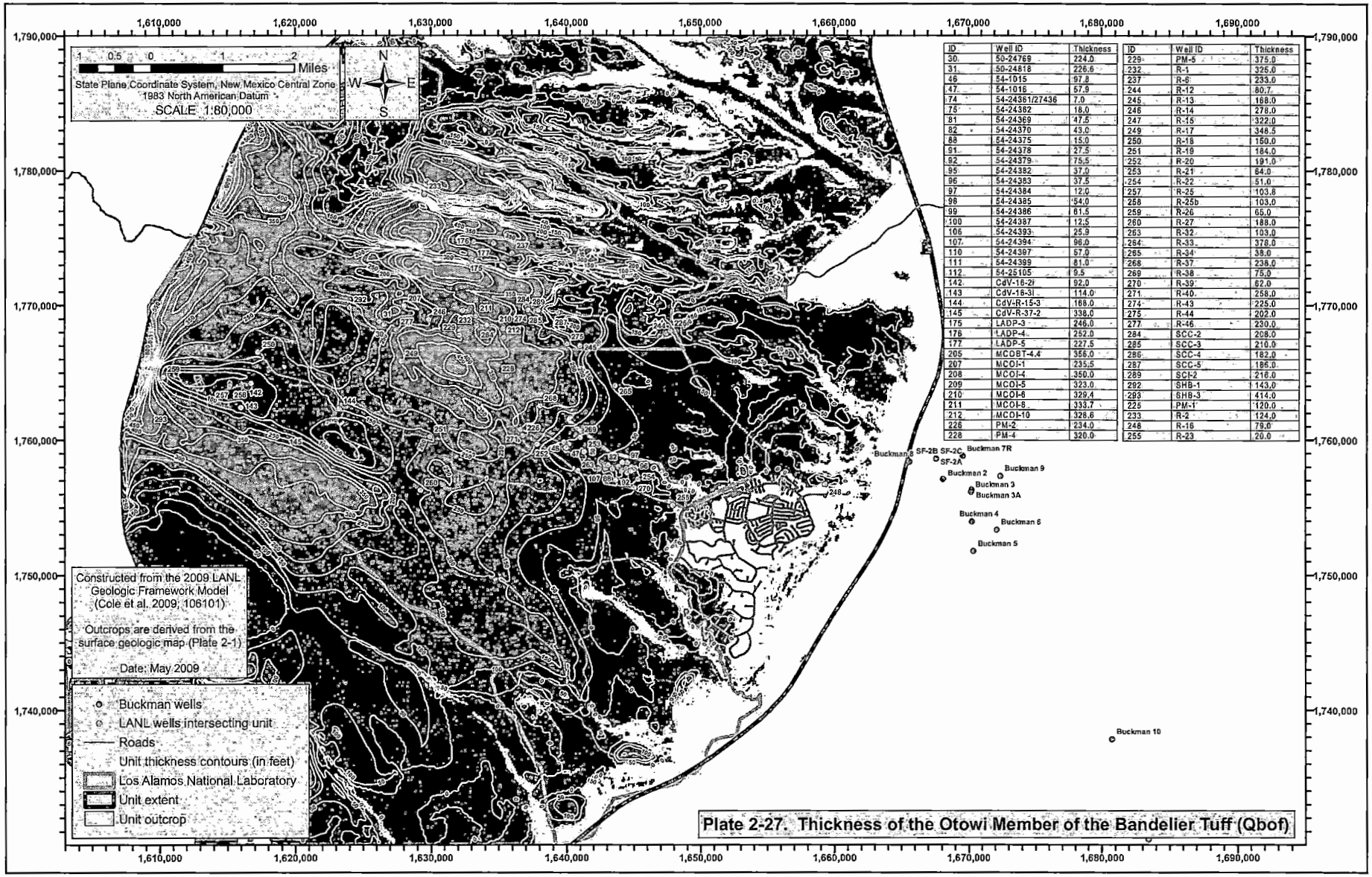


ID	Well ID	Elevation
28	35-2026	6806.4
29	49-2-700-1	6536.4
30	50-24769	6854.7
31	50-24618	6856.3
35	54-1004	6493.2
46	54-1015	6507.8
47	54-1016	6491.0
48	54-1018	6490.2
66	54-1121	6530.5
72	54-15482	6615.0
73	54-24360	6532.6
74	54-24361/27436	6532.1
75	54-24362	6516.6
77	54-24364	6526.7
78	54-24365	6435.7
79	54-24367	6502.8
80	54-24368	6487.6
81	54-24369	6528.5
82	54-24370	6546.9
83	54-12371	6532.4
84	54-24372	6546.1
85	54-24373	6556.0
86	54-24374	6497.7
88	54-24375	6525.9
89	54-24376	6518.5
90	54-24377	6507.5
91	54-24378	6530.8
92	54-24379	6556.6
94	54-24381	6543.1
95	54-24382	6562.6
96	54-24383	6549.2
97	54-24384	6553.0
98	54-24385	6555.4
99	54-24386	6555.8
100	54-24387	6555.5
102	54-24389	6509.2
104	54-24391	6528.5
105	54-24392	6479.4
106	54-24393	6549.3
107	54-24394	6531.1
108	54-24395	6531.3
109	54-24396	6501.0
110	54-24397	6497.9
111	54-24399	6501.0
112	54-25105	6523.5
122	BH7	6627.5
135	CDBM-1	6626.6
136	CDBM-2	6579.6
141	CdV-16-1i	6792.2
142	CdV-16-2i	6747.1
143	CdV-16-3i	6706.8
144	CdV-R-15-3	6676.9

ID	Well ID	Elevation
188	MC2	6637.0
189	MC3	6623.0
200	MCB-14	6722.1
201	MCB-16	6596.2
202	MCC-8.2	6671.2
204	MCM-5.9A	6732.2
205	MCOBT-4.4	6734.2
207	MCOI-1	6862.2
208	MCOI-4	6732.2
209	MCOI-5	6598.7
210	MCOI-6	6706.1
211	MCOI-8	6736.9
212	MCOI-10	6689.5
213	MCRES-2	6727.8
214	MCRES-3	6740.4
215	MCRES-4	6752.4
226	PM-2	6541.0
228	PM-4	6700.0
229	PM-5	6759.0
231	POTO-4A	6518.0
232	R-1	6746.2
237	R-6	6737.8
244	R-12	6468.3
245	R-13	6593.1
246	R-14	6818.1
247	R-15	6700.0
249	R-17	6774.5
250	R-18	6899.8
251	R-19	6420.3
252	R-20	6511.3
253	R-21	6505.2
254	R-22	6522.5
257	R-25	6776.1
258	R-25b	6776.0
259	R-26	6776.6
260	R-27	6381.7
263	R-32	6463.6
264	R-33	6753.3
265	R-34	6534.0
268	R-37	6625.0
269	R-38	6515.0
270	R-39	6503.0
271	R-40	6546.0
274	R-43	6618.0
275	R-44	6624.0
277	R-45	6762.0
279	SC2	6558.0
280	SC3	6697.0
284	SCC-2	6618.7
285	SCC-3	6623.0
286	SCC-4	6604.2
287	SCC-5	6623.6

Plate 2-26. Structure contours of the top of the Otowi Member of the Bandelier Tuff (Qbof)

06128

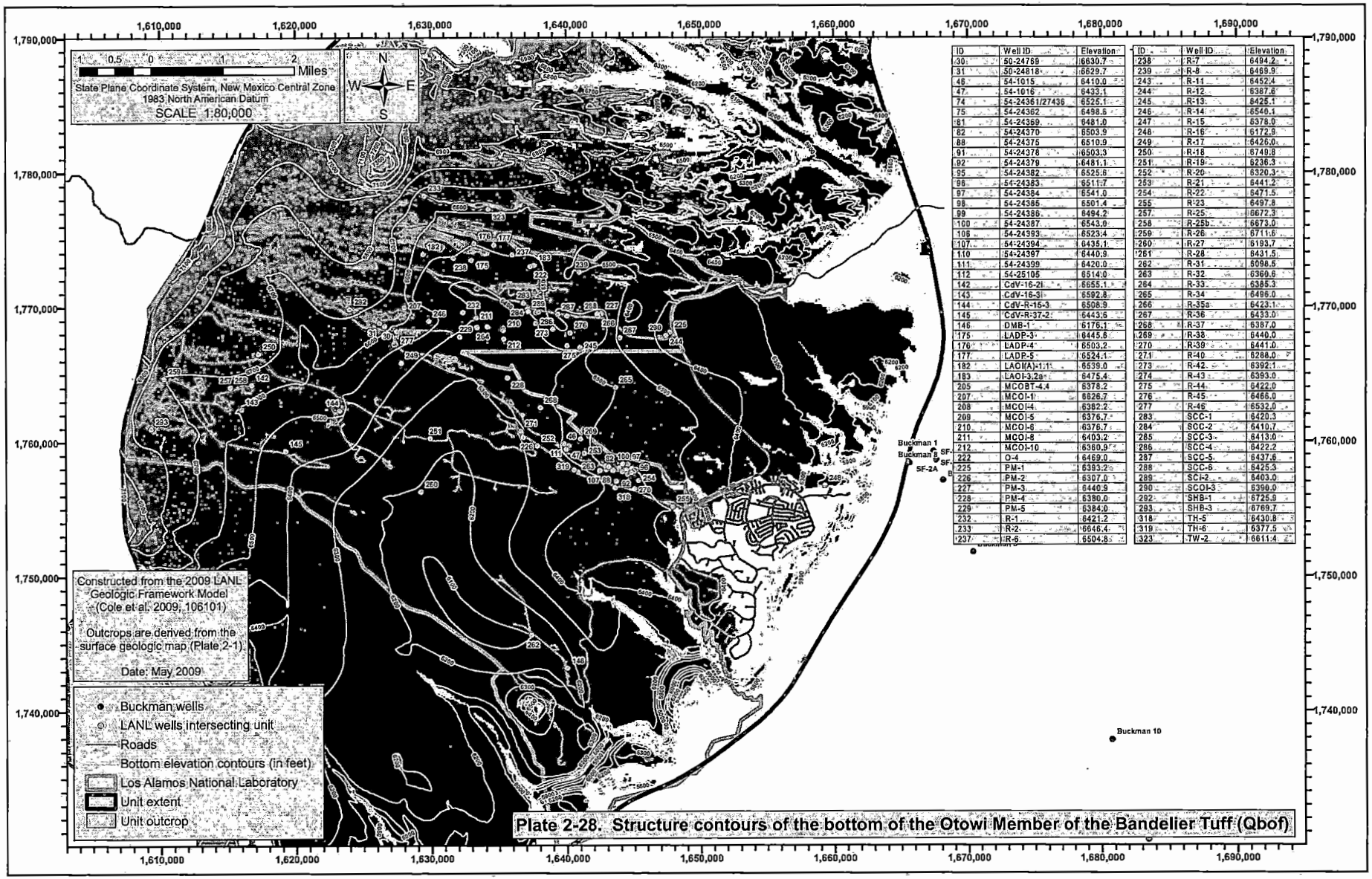


ID	Well ID	Thickness
30	50-24769	224.0
31	50-24818	226.6
46	54-1015	97.8
47	54-1016	57.9
74	54-24361/27436	7.0
75	54-24362	18.0
81	54-24369	47.5
82	54-24370	43.0
88	54-24375	15.0
91	54-24378	27.5
92	54-24379	75.5
95	54-24382	37.0
96	54-24383	37.5
97	54-24384	12.0
98	54-24385	54.0
99	54-24386	61.5
100	54-24387	12.5
106	54-24393	25.9
107	54-24394	96.0
110	54-24397	57.0
111	54-24399	61.0
112	54-25105	9.5
142	CdV-16-2i	92.0
143	CdV-16-3i	114.0
144	CdV-R-15-3	168.0
145	CdV-R-37-2	338.0
175	LADP-3	246.0
176	LADP-4	252.0
177	LADP-5	227.5
205	MCOBT-4.4	356.0
207	MCOI-1	235.5
208	MCOI-4	350.0
209	MCOI-5	323.0
210	MCOI-6	329.4
211	MCOI-8	333.7
212	MCOI-10	328.6
226	PM-2	234.0
228	PM-4	320.0

ID	Well ID	Thickness
229	PM-5	375.0
232	R-1	326.0
237	R-6	233.0
244	R-12	80.7
245	R-13	168.0
246	R-14	278.0
247	R-15	322.0
249	R-17	348.5
250	R-18	150.0
251	R-19	184.0
252	R-20	191.0
253	R-21	64.0
254	R-22	51.0
257	R-25	103.8
258	R-25b	103.0
259	R-26	65.0
260	R-27	188.0
263	R-32	103.0
264	R-33	378.0
265	R-34	38.0
268	R-37	238.0
269	R-38	75.0
270	R-39	62.0
271	R-40	258.0
274	R-43	225.0
275	R-44	202.0
277	R-46	230.0
284	SCC-2	208.0
285	SCC-3	210.0
286	SCC-4	182.0
287	SCC-5	186.0
289	SCI-2	216.0
292	SHB-1	143.0
293	SHB-3	414.0
225	PM-1	120.0
233	R-2	124.0
248	R-16	79.0
255	R-23	20.0

Plate 2-27 Thickness of the Otowi Member of the Bandelier Tuff (Qbof)

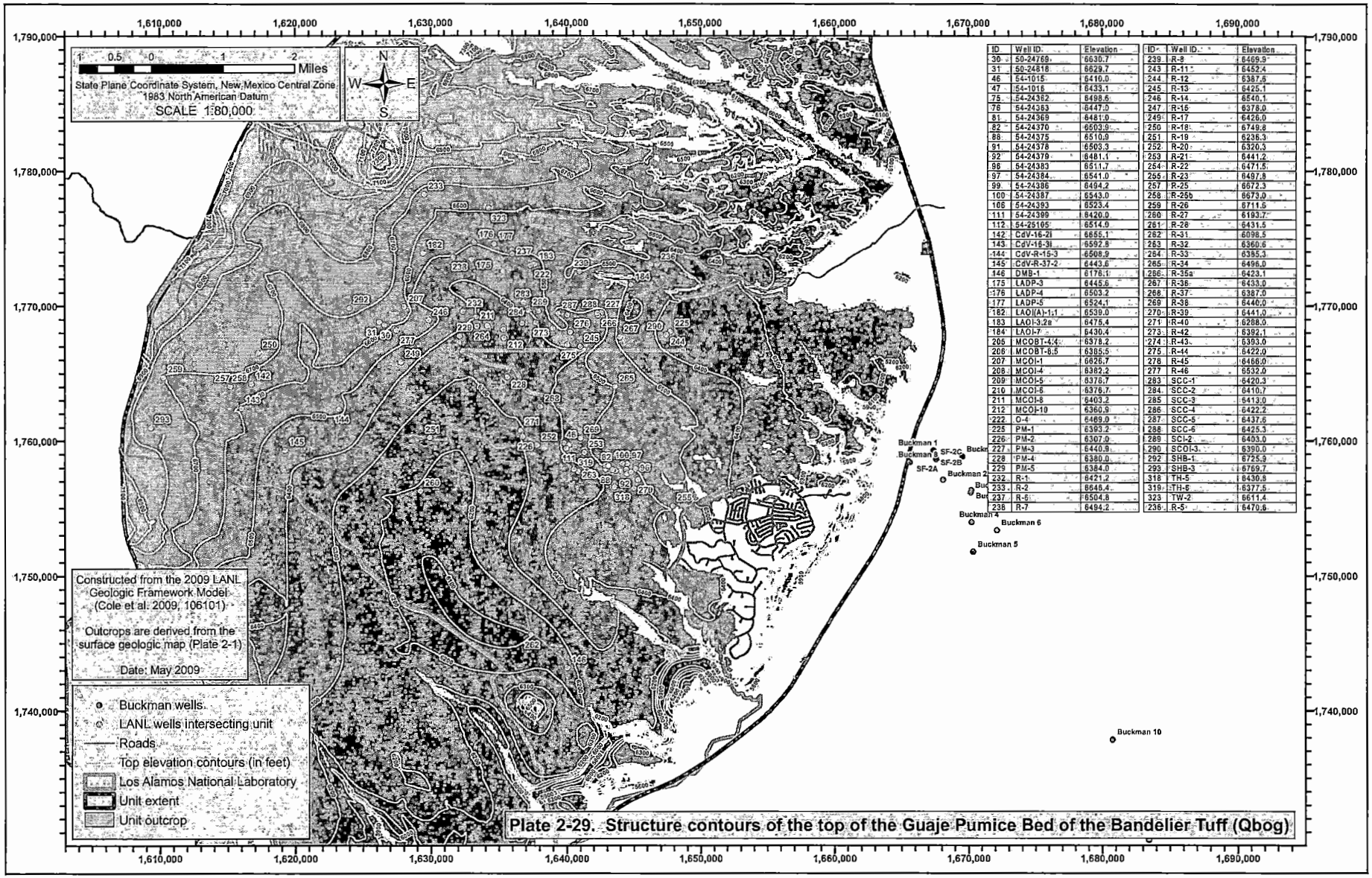
96129



ID	Well ID	Elevation
30	50-24769	6630.7
31	50-24818	6629.7
46	54-1015	6410.0
47	54-1016	6433.1
74	54-24361/27436	6525.1
75	54-24362	6498.5
81	54-24369	6481.0
82	54-24370	6503.9
88	54-24375	6510.9
91	54-24378	6503.3
92	54-24379	6481.1
95	54-24382	6525.6
96	54-24383	6511.7
97	54-24384	6541.0
98	54-24385	6501.4
99	54-24386	6494.2
100	54-24387	6543.0
106	54-24393	6523.4
107	54-24394	6435.1
110	54-24397	6440.9
111	54-24399	6420.0
112	54-25105	6514.0
142	CdV-16-2i	6655.1
143	CdV-16-3i	6592.8
144	CdV-R-15-3	6508.9
145	CdV-R-37-2	6443.6
146	DMB-1	6178.1
175	LADP-3	6445.8
176	LADP-4	6503.2
177	LADP-5	6524.1
182	LAOI(A)-1.11	6539.0
183	LAOI-3.2a	6475.4
205	MCOBT-4.4	6378.2
207	MCOI-1	6626.7
208	MCOI-4	6382.2
209	MCOI-5	6376.7
210	MCOI-6	6376.7
211	MCOI-8	6403.2
212	MCOI-10	6360.9
222	O-4	6469.0
225	PM-1	6393.2
226	PM-2	6307.0
227	PM-3	6440.9
228	PM-4	6380.0
229	PM-5	6384.0
232	R-1	6421.2
233	R-2	6646.4
237	R-6	6504.8

ID	Well ID	Elevation
238	R-7	6494.2
239	R-8	6469.9
243	R-11	6452.4
244	R-12	6387.6
245	R-13	6425.1
246	R-14	6540.1
247	R-15	6378.0
248	R-16	6172.9
249	R-17	6426.0
250	R-18	6749.8
251	R-19	6236.3
252	R-20	6320.3
253	R-21	6441.2
254	R-22	6471.5
255	R-23	6497.8
257	R-25	6672.3
258	R-25b	6673.0
259	R-26	6711.6
260	R-27	6193.7
261	R-28	6431.5
262	R-31	6098.5
263	R-32	6369.8
264	R-33	6385.3
265	R-34	6496.0
266	R-35a	6423.1
267	R-36	6433.0
268	R-37	6387.0
269	R-38	6440.0
270	R-39	6441.0
271	R-40	6288.0
273	R-42	6392.1
274	R-43	6393.0
275	R-44	6422.0
276	R-45	6466.0
277	R-46	6532.0
283	SCC-1	6420.3
284	SCC-2	6410.7
285	SCC-3	6413.0
286	SCC-4	6422.2
287	SCC-5	6437.6
288	SCC-6	6425.3
289	SCI-2	6403.0
290	SCOI-3	6390.0
292	SHB-1	6725.8
293	SHB-3	6769.7
318	TH-5	6430.8
319	TH-6	6377.5
323	TW-2	6611.4

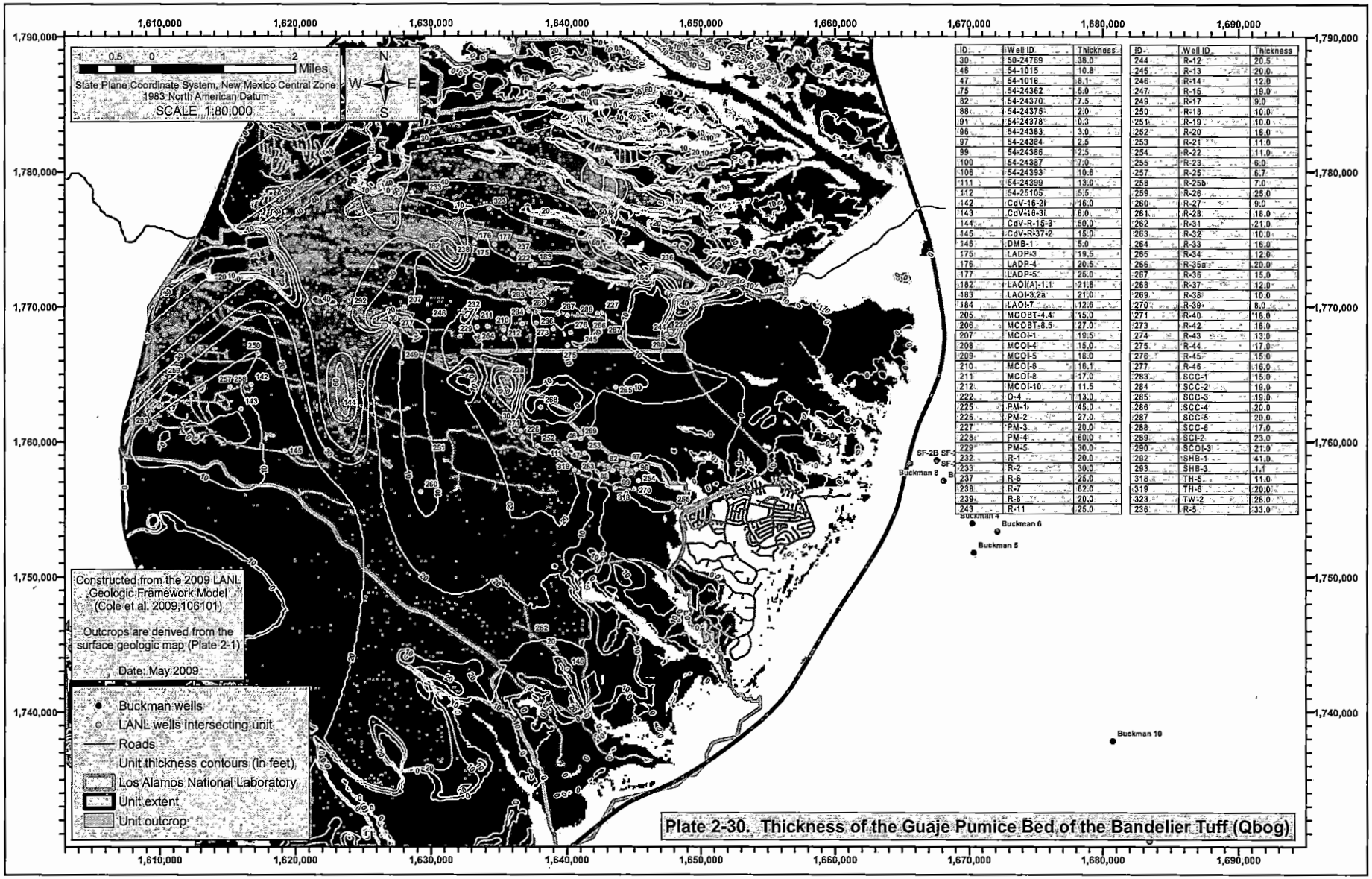
Plate 2-28. Structure contours of the bottom of the Otowi Member of the Bandelier Tuff (Qbof)



ID	Well ID	Elevation
30	50-24769	6630.7
31	50-24818	6629.7
46	54-1015	6410.0
47	54-1016	6433.1
75	54-24362	6498.6
76	54-24363	6447.0
81	54-24369	6461.0
82	54-24370	6503.9
86	54-24375	6510.9
91	54-24378	6503.3
92	54-24379	6481.1
96	54-24383	6511.7
97	54-24384	6541.0
99	54-24386	6494.2
100	54-24387	6543.0
106	54-24393	6523.4
111	54-24399	6420.0
112	54-25105	6514.9
142	CdV-16-2i	6655.1
143	CdV-16-3i	6592.8
144	CdV-R-15-3	6508.9
145	CdV-R-37-2	6443.6
146	DMB-1	6178.1
175	LADP-3	6445.6
176	LADP-4	6503.2
177	LADP-5	6524.1
182	LAOI(A)-1.1	6539.0
183	LAOI-3.2a	6475.4
184	LAOI-7	6430.4
205	MCOBT-4.4	6378.2
206	MCOBT-8.5	6385.5
207	MCOI-1	6626.7
208	MCOI-4	6382.2
209	MCOI-5	6376.7
210	MCOI-6	6376.7
211	MCOI-8	6403.2
212	MCOI-10	6360.9
222	O-4	6469.9
225	PM-1	6393.2
226	PM-2	6307.0
227	PM-3	6440.9
228	PM-4	6380.0
229	PM-5	6384.0
232	R-1	6421.2
233	R-2	6646.4
237	R-6	6504.8
238	R-7	6494.2

ID	Well ID	Elevation
239	R-8	6469.9
243	R-11	6452.4
244	R-12	6387.6
245	R-13	6425.1
246	R-14	6540.1
247	R-16	6378.0
249	R-17	6426.0
250	R-18	6749.8
251	R-19	6236.3
252	R-20	6320.3
253	R-21	6441.2
254	R-22	6471.5
255	R-23	6497.8
257	R-25	6672.3
258	R-25b	6673.0
259	R-26	6711.6
260	R-27	6193.7
261	R-28	6431.5
262	R-31	6098.5
263	R-32	6360.6
264	R-33	6395.3
265	R-34	6496.0
266	R-35a	6423.1
267	R-36	6433.0
268	R-37	6387.0
269	R-38	6440.0
270	R-39	6441.0
271	R-40	6288.0
273	R-42	6392.1
274	R-43	6393.0
275	R-44	6422.0
276	R-45	6466.0
277	R-46	6532.0
283	SCC-1	6420.3
284	SCC-2	6410.7
285	SCC-3	6413.0
286	SCC-4	6422.2
287	SCC-5	6437.6
288	SCC-6	6425.3
289	SCI-2	6403.0
290	SCOI-3	6390.0
292	SHB-1	6725.9
293	SHB-3	6769.7
318	TH-5	6430.8
319	TH-6	6377.5
323	TW-2	6611.4
236	R-5	6470.6

Plate 2-29. Structure contours of the top of the Guaje Pumice Bed of the Bandelier Tuff (Qbog)

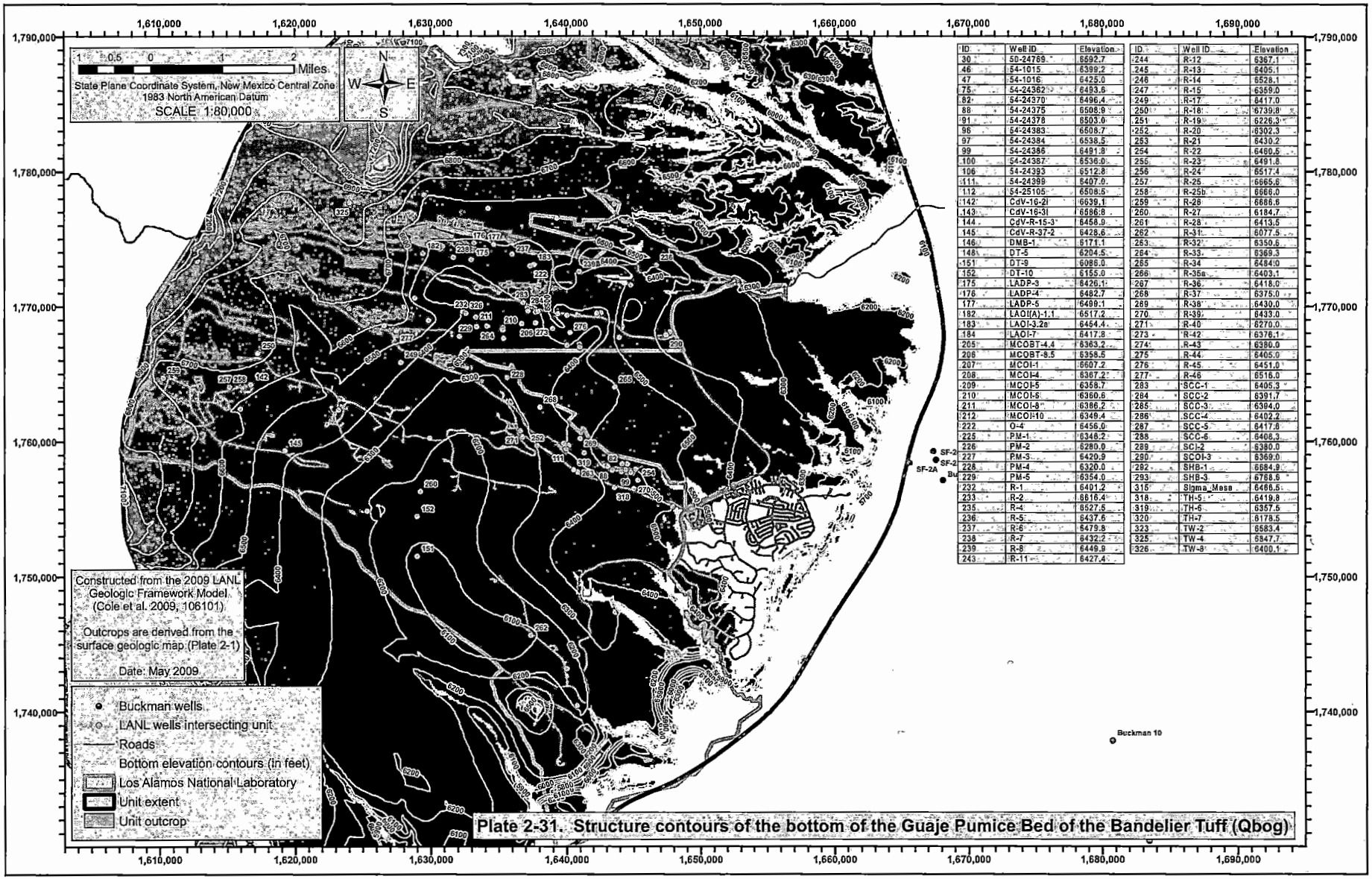


ID	Well ID	Thickness
30	50-24769	38.0
46	54-1015	10.8
47	54-1016	8.1
75	54-24362	6.0
82	54-24370	7.5
88	54-24375	2.0
91	54-24378	0.3
96	54-24383	3.0
97	54-24384	2.5
99	54-24386	2.5
100	54-24387	7.0
106	54-24393	10.6
111	54-24399	13.0
112	54-25105	5.5
142	CdV-16-2i	16.0
143	CdV-16-3i	6.0
144	CdV-R-15-3	50.0
145	CdV-R-37-2	15.0
146	DMB-1	5.0
175	LADP-3	19.5
176	LADP-4	20.5
177	LADP-5	25.0
182	LAOI(A)-1.1	21.8
183	LAOI-3.2a	21.0
184	LAOI-7	12.6
205	MCOBT-4.4	15.0
206	MCOBT-8.5	27.0
207	MCOI-1	19.5
208	MCOI-4	15.0
209	MCOI-5	18.0
210	MCOI-6	16.1
211	MCOI-8	17.0
212	MCOI-10	11.5
222	O-4	13.0
225	PM-1	45.0
226	PM-2	27.0
227	PM-3	20.0
228	PM-4	60.0
229	PM-5	30.0
232	R-1	20.0
233	R-2	30.0
237	R-6	25.0
238	R-7	62.0
239	R-8	20.0
243	R-11	25.0

ID	Well ID	Thickness
244	R-12	20.5
245	R-13	20.0
246	R-14	12.0
247	R-15	19.0
249	R-17	9.0
250	R-18	10.0
251	R-19	10.0
252	R-20	18.0
253	R-21	11.0
254	R-22	11.0
255	R-23	6.0
257	R-25	6.7
258	R-25b	7.0
259	R-26	25.0
260	R-27	8.0
261	R-28	18.0
262	R-31	21.0
263	R-32	10.0
264	R-33	16.0
265	R-34	12.0
266	R-35a	20.0
267	R-36	15.0
268	R-37	12.0
269	R-38	10.0
270	R-39	8.0
271	R-40	18.0
273	R-42	16.0
274	R-43	13.0
275	R-44	17.0
276	R-45	15.0
277	R-46	16.0
283	SCC-1	15.0
284	SCC-2	19.0
285	SCC-3	19.0
286	SCC-4	20.0
287	SCC-5	20.0
288	SCC-6	17.0
289	SCI-2	23.0
290	SCOI-3	21.0
292	SHB-1	41.0
293	SHB-3	1.1
318	TH-5	11.0
319	TH-6	20.0
323	TW-2	28.0
236	R-5	33.0

Plate 2-30. Thickness of the Guaje Pumice Bed of the Bandelier Tuff (Qbog)

09 32

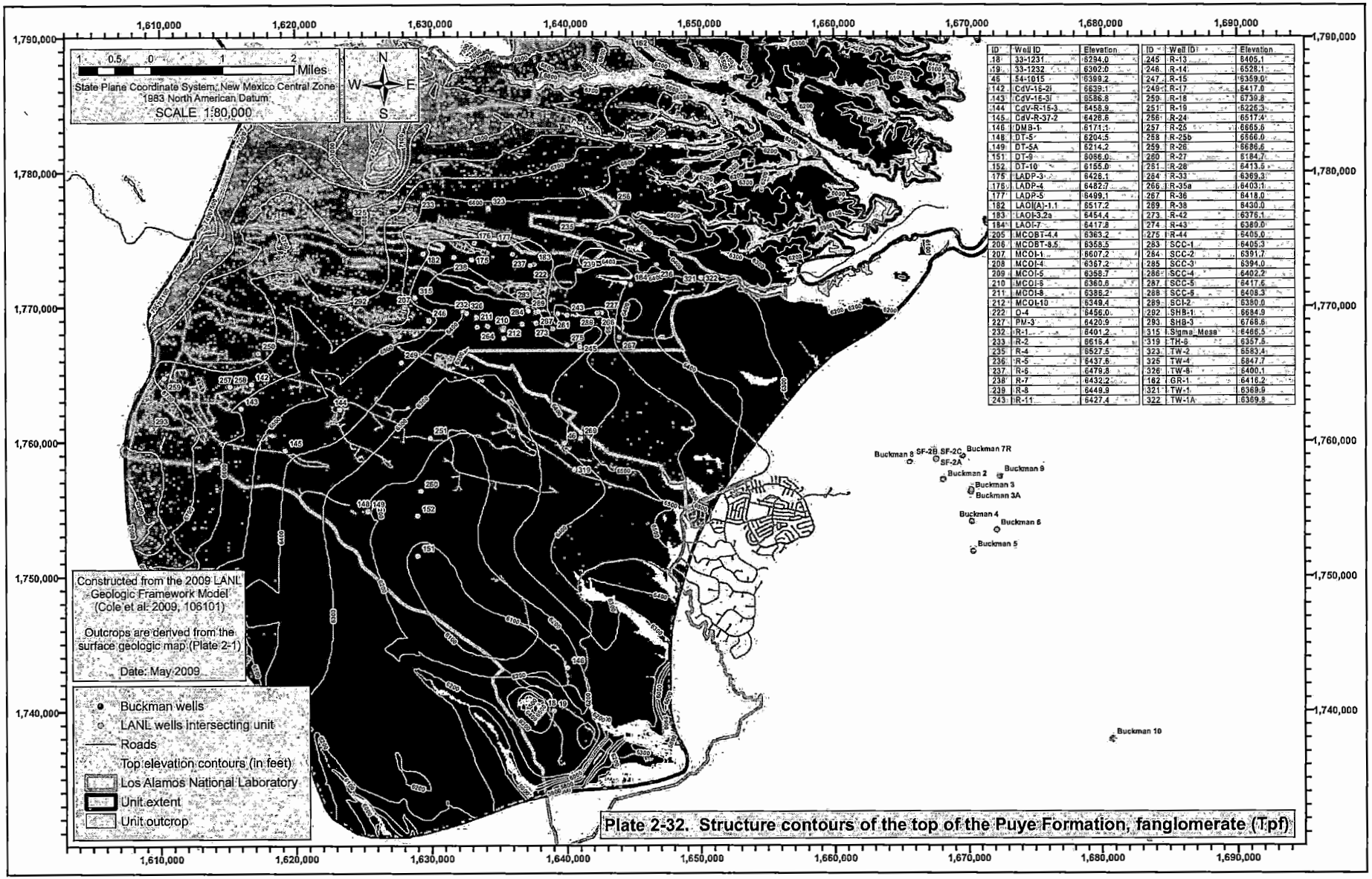


ID	Well ID	Elevation
30	50-24769	6592.7
46	54-1015	6399.2
47	54-1016	6425.0
75	54-24362	6493.6
82	54-24370	6496.4
88	54-24375	6508.9
91	54-24378	6503.0
96	54-24383	6508.7
97	54-24384	6538.5
99	54-24386	6491.8
100	54-24387	6536.0
106	54-24393	6512.8
111	54-24399	6407.0
112	54-25105	6508.5
142	CdV-16-2i	6639.1
143	CdV-16-3i	6586.8
144	CdV-R-15-3	6458.0
145	CdV-R-37-2	6428.6
146	DMB-1	6171.1
148	DT-5	6204.5
151	DT-9	6086.0
152	DT-10	6155.0
175	LADP-3	6426.1
176	LADP-4	6482.7
177	LADP-5	6499.1
182	LAOI(A)-1.1	6517.2
183	LAOI-3.2a	6454.4
184	LAOI-7	6417.8
205	MCOBT-4.4	6363.2
206	MCOBT-8.5	6358.5
207	MCOI-1	6607.2
208	MCOI-4	6367.2
209	MCOI-5	6358.7
210	MCOI-6	6360.6
211	MCOI-8	6386.2
212	MCOI-10	6349.4
222	O-4	6456.0
225	PM-1	6346.2
226	PM-2	6280.0
227	PM-3	6420.9
228	PM-4	6320.0
229	PM-5	6354.0
232	R-1	6401.2
233	R-2	6616.4
235	R-4	6527.5
236	R-5	6437.6
237	R-6	6479.8
238	R-7	6432.2
239	R-8	6449.9
243	R-11	6427.4

ID	Well ID	Elevation
244	R-12	6367.1
245	R-13	6405.1
246	R-14	6528.1
247	R-15	6359.0
249	R-17	6417.0
250	R-18	6739.8
251	R-19	6226.3
252	R-20	6302.3
253	R-21	6430.2
254	R-22	6460.5
255	R-23	6491.8
256	R-24	6517.4
257	R-25	6665.6
258	R-25b	6666.0
259	R-26	6686.8
260	R-27	6184.7
261	R-28	6413.5
262	R-31	6077.5
263	R-32	6350.6
264	R-33	6369.3
265	R-34	6484.0
266	R-35a	6403.1
267	R-36	6418.0
268	R-37	6375.0
269	R-38	6430.0
270	R-39	6433.0
271	R-40	6270.0
273	R-42	6376.1
274	R-43	6380.0
275	R-44	6405.0
276	R-45	6451.0
277	R-46	6516.0
283	SCC-1	6405.3
284	SCC-2	6391.7
285	SCC-3	6394.0
286	SCC-4	6402.2
287	SCC-5	6417.6
288	SCC-6	6408.3
289	SCI-2	6380.0
290	SCOI-3	6369.0
292	SHB-1	6684.9
293	SHB-3	6758.6
315	Sigma_Mesa	6466.5
318	TH-5	6419.8
319	TH-6	6357.5
320	TH-7	6178.5
323	TW-2	6583.4
325	TW-4	6847.7
326	TW-8	6400.1

Plate 2-31. Structure contours of the bottom of the Guaje Pumice Bed of the Bandelier Tuff (Qbog)

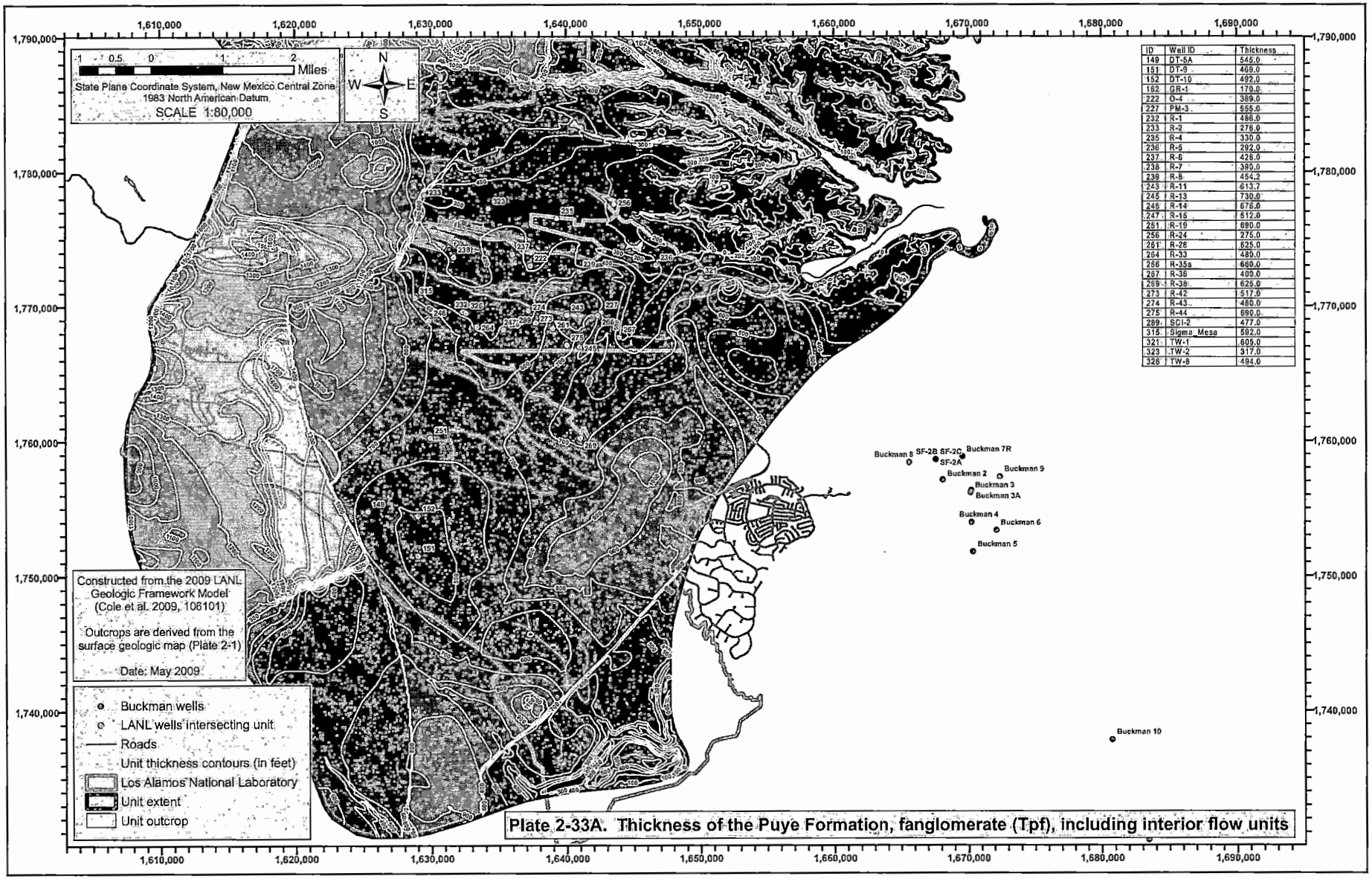
053133



ID	Well ID	Elevation	ID	Well ID	Elevation
18	33-1231	6294.0	245	R-13	6405.1
19	33-1232	6302.0	246	R-14	6528.1
46	54-1015	6399.2	247	R-15	6359.0
142	CdV-16-2i	6639.1	249	R-17	6417.0
143	CdV-16-3i	6586.8	250	R-18	6739.8
144	CdV-R-15-3	6458.9	251	R-19	6226.3
145	CdV-R-37-2	6428.6	256	R-24	6517.4
146	DMB-1	6171.1	257	R-25	6665.6
148	DT-5	6204.5	258	R-25b	6666.0
149	DT-5A	6214.2	259	R-26	6686.6
151	DT-9	6066.0	260	R-27	6184.7
152	DT-10	6155.0	261	R-28	6413.5
175	LADP-3	6426.1	264	R-33	6369.3
176	LADP-4	6482.7	266	R-35a	6403.1
177	LADP-5	6499.1	267	R-36	6418.0
182	LAOI(A)-1.1	6517.2	269	R-38	6430.0
183	LAOI-3.2a	6454.4	273	R-42	6376.1
184	LAOI-7	6417.8	274	R-43	6380.0
205	MCOBT-4.4	6363.2	275	R-44	6405.0
206	MCOBT-8.5	6358.5	283	SCC-1	6405.3
207	MCOI-1	6607.2	284	SCC-2	6391.7
208	MCOI-4	6367.2	285	SCC-3	6394.0
209	MCOI-5	6358.7	286	SCC-4	6402.2
210	MCOI-6	6360.6	287	SCC-5	6417.6
211	MCOI-8	6386.2	288	SCC-6	6408.3
212	MCOI-10	6349.4	289	SCI-2	6380.0
222	O-4	6456.0	292	SHB-1	6684.9
227	PM-3	6420.9	293	SHB-3	6768.6
232	R-1	6401.2	315	Sigma_Mesa	6466.5
233	R-2	6616.4	319	TH-6	6357.5
235	R-4	6527.5	323	TW-2	6583.4
236	R-5	6437.6	325	TW-4	6847.7
237	R-6	6479.8	326	TW-8	6400.1
238	R-7	6432.2	162	GR-1	6416.2
239	R-8	6449.9	321	TW-1	6369.9
243	R-11	6427.4	322	TW-1A	6369.8

Plate 2-32. Structure contours of the top of the Puye Formation, fanglomerate (Tpf)

06134



ID	Well ID	Thickness
149	DT-5A	545.0
151	DT-9	469.0
152	DT-10	492.0
162	GR-1	170.0
222	O-4	389.0
227	PM-3	555.0
232	R-1	486.0
233	R-2	276.0
235	R-4	330.0
236	R-5	292.0
237	R-6	428.0
238	R-7	390.0
239	R-8	454.2
243	R-11	613.7
245	R-13	730.0
246	R-14	676.0
247	R-15	512.0
251	R-19	690.0
256	R-24	275.0
261	R-28	625.0
264	R-33	480.0
266	R-35a	660.0
267	R-36	400.0
269	R-38	625.0
273	R-42	517.0
274	R-43	480.0
275	R-44	690.0
289	SCI-2	477.0
315	Sigma_Mesa	592.0
321	TW-1	605.0
323	TW-2	317.0
326	TW-8	494.0

Plate 2-33A. Thickness of the Puye Formation, fanglomerate (Tpf), including interior flow units

: 06135

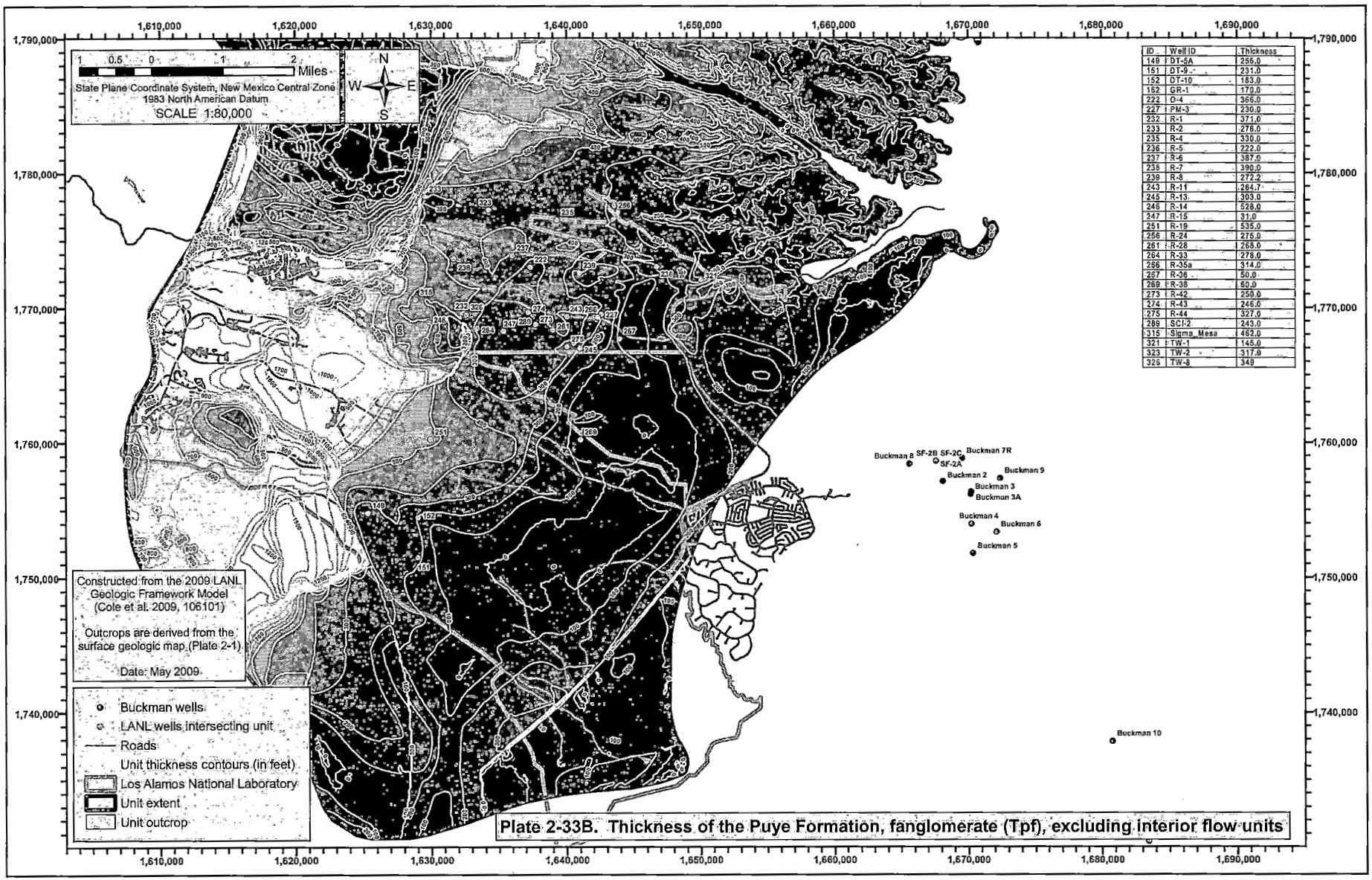
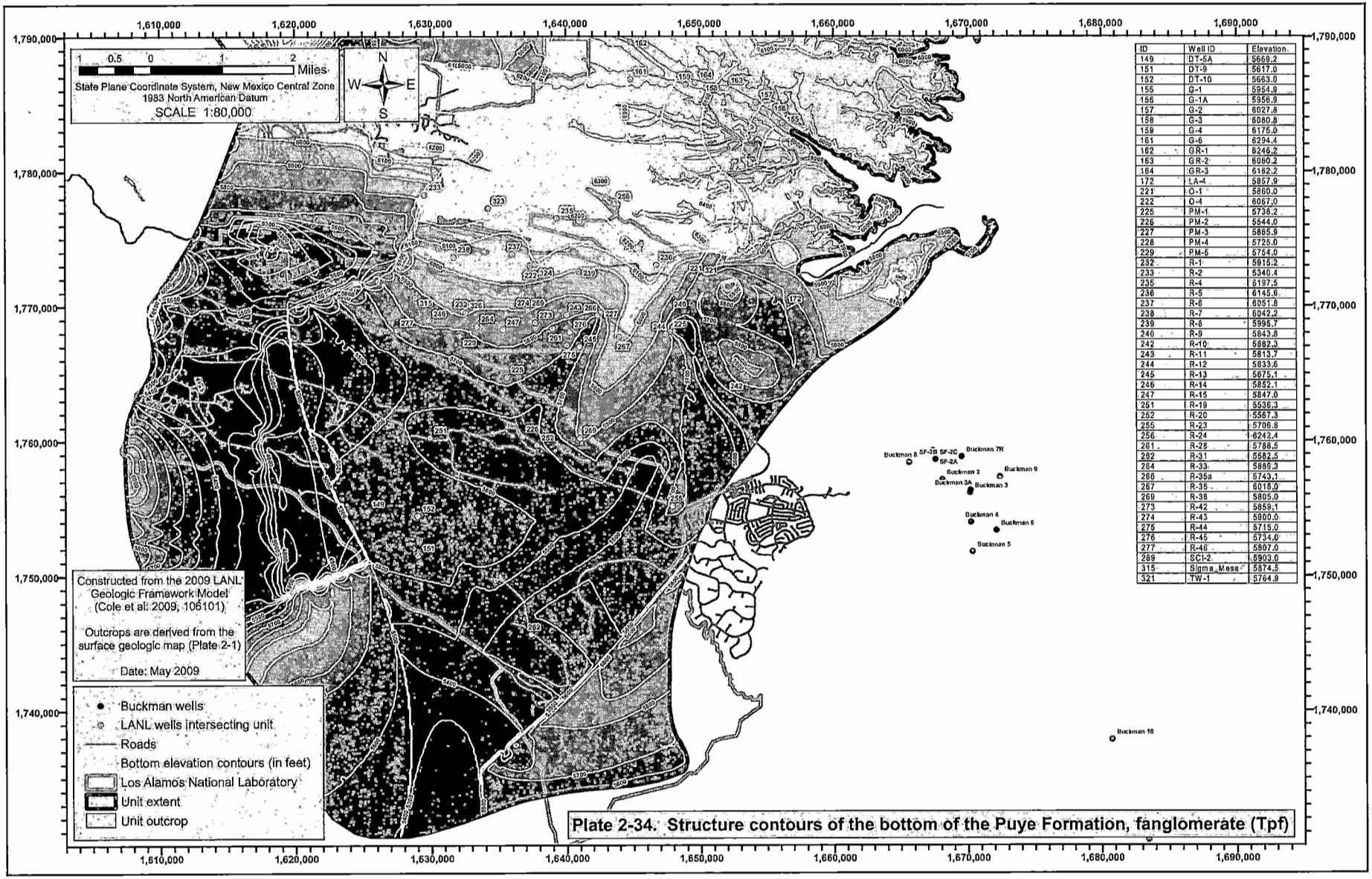


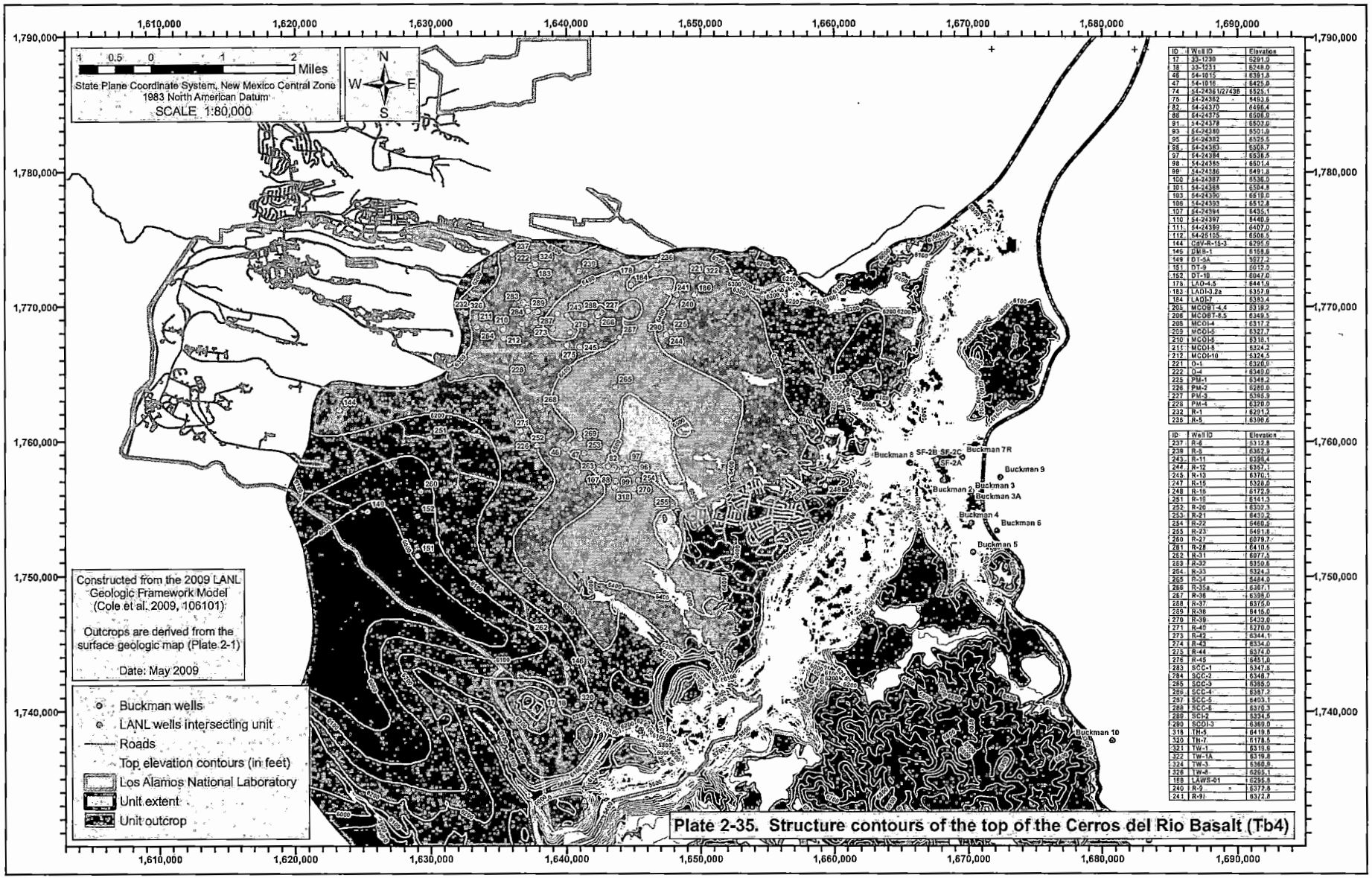
Plate 2-33B. Thickness of the Puye Formation, fanglomerate (Tpf), excluding interior flow units

96135



ID	Well ID	Elevation
149	DT-5A	5669.2
151	DT-9	5617.0
152	DT-10	5663.0
155	G-1	5954.9
156	G-1A	5956.9
157	G-2	6027.8
158	G-3	6080.8
159	G-4	6175.0
161	G-6	6294.4
162	GR-1	6246.2
163	GR-2	6080.2
164	GR-3	6162.2
172	LA-4	5857.9
221	O-1	5860.0
222	O-4	6067.0
225	PM-1	5738.2
226	PM-2	5544.0
227	PM-3	5865.9
228	PM-4	5725.0
229	PM-5	5754.0
232	R-1	5915.2
233	R-2	6340.4
235	R-4	6197.5
236	R-5	6145.6
237	R-6	6051.8
238	R-7	6042.2
239	R-8	5995.7
240	R-9	5843.8
242	R-10	5882.3
243	R-11	5813.7
244	R-12	5833.6
245	R-13	5675.1
246	R-14	5852.1
247	R-15	5847.0
251	R-19	5536.3
252	R-20	5567.3
255	R-23	5706.8
256	R-24	6242.4
261	R-28	5788.5
262	R-31	5582.5
264	R-33	5889.3
266	R-35a	5743.1
267	R-36	6018.0
269	R-38	5805.0
273	R-42	5859.1
274	R-43	5900.0
275	R-44	5715.0
276	R-45	5734.0
277	R-46	5807.0
289	SCI-2	5903.0
315	Sigma Mesa	5874.5
321	TW-1	5764.9

Plate 2-34. Structure contours of the bottom of the Puye Formation, fanglomerate (Tpf)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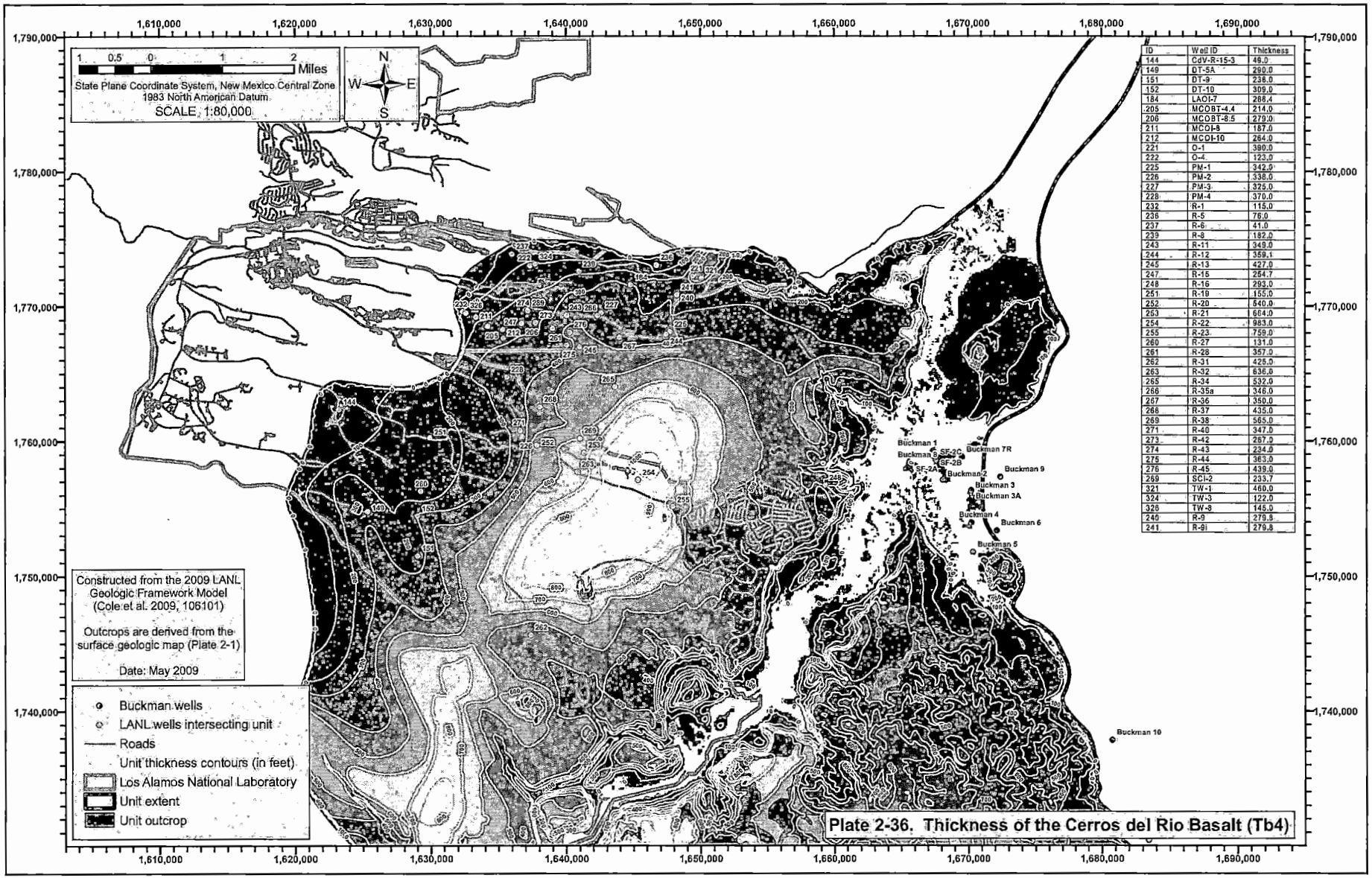
State Plane Coordinate System, New Mexico Central Zone
1983 North American Datum
SCALE 1:80,000
N
W E
S
Constructed from the 2009 LANL Geologic Framework Model (Cole et al. 2009, 106101)
Outcrops are derived from the surface geologic map (Plate 2-1)
Date: May 2009
Buckman wells
LANL wells intersecting unit
Roads
Top elevation contours (in feet)
Los Alamos National Laboratory
Unit extent
Unit outcrop
Buckman 8
SF-2B
SF-2C
Buckman 7R
SF-2A
Buckman 9
Buckman 2
Buckman 3
Buckman 3A
Buckman 4
Buckman 6
Buckman 5
Buckman 10
ID Well ID Elevation
17 33-1238 6291.0
18 33-1331 6248.0
46 54-1015 6391.8
47 54-1016 6425.0
74 54-24361/27438 6525.1
75 54-24362 6493.6
82 54-24370 6486.4
88 54-24375 6508.0
91 54-24378 6503.0
93 54-24380 6501.9
95 54-24382 6525.5
96 54-24383 6508.7
97 54-24384 6536.5
98 54-24385 6501.4
99 54-24386 6491.8
100 54-24387 6536.0
101 54-24388 6504.8
103 54-24390 6519.0
106 54-24393 6512.8
107 54-24394 6435.1
110 54-24397 6440.9
111 54-24399 6407.0
112 54-25105 6508.5
144 CdV-R-15-3 6295.6
146 DM-1 6159.6
149 DT-5A 5977.2
151 DT-9 6012.0
152 DT-10 6047.0
178 LAO-4.5 6441.0
183 LAOI-3.2a 6357.9
184 LAOI-7 6383.4
205 MCOBT-4.4 6319.2
206 MCOBT-8.5 6349.5
208 MCOI-4 6317.2
209 MCOI-5 6327.7
210 MCOI-6 6318.1
211 MCOI-9 6324.2
212 MCOI-10 6324.5
221 O-1 6320.0
222 O-4 6340.0
225 PM-1 6349.2
226 PM-2 6260.0
227 PM-3 6366.9
228 PM-4 6370.0
232 R-1 6291.2
235 R-5 6390.6
ID Well ID Elevation
237 R-6 6312.8
238 R-8 6362.9
243 R-11 6398.4
244 R-12 6357.1
245 R-13 6370.1
247 R-15 6328.0
248 R-16 6172.9
251 R-19 6141.3
252 R-20 6502.3
253 R-21 6410.2
254 R-22 6460.2
255 R-23 6491.8
260 R-27 6079.7
261 R-28 6410.5
262 R-31 6077.5
263 R-32 6350.6
264 R-33 6324.3
265 R-34 6484.0
266 R-35a 6387.1
267 R-36 6398.0
268 R-37 6375.0
269 R-38 6415.0
270 R-39 6433.0
271 R-40 6270.0
273 R-42 6344.1
274 R-43 6334.0
275 R-44 6374.0
276 R-45 6451.0
283 SCC-1 6347.8
284 SCC-2 6348.7
285 SCC-3 6385.0
286 SCC-4 6387.2
287 SCC-5 6403.1
288 SCC-6 6370.3
289 SCI-2 6334.5
290 SCDI-3 6369.0
318 TH-5 6419.0
320 TH-7 6178.5
321 TW-1 6319.6
322 TW-1A 6319.8
324 TW-3 6368.8
326 TW-8 6265.1
188 LAWS-01 6295.6
240 R-9 6372.8
241 R-9i 6372.8
Plate 2-35. Structure contours of the top of the Cerros del Rio Basalt (Tb4)

09139



ID	Well ID	Thickness
144	CdV-R-15-3	46.0
149	DT-5A	290.0
151	DT-9	236.0
152	DT-10	309.0
184	LAOI-7	288.4
205	MCOBT-4.4	214.0
206	MCOBT-8.5	279.0
211	MCOI-8	187.0
212	MCOI-10	264.0
221	O-1	390.0
222	O-4	123.0
225	PM-1	342.0
226	PM-2	336.0
227	PM-3	325.0
228	PM-4	370.0
232	R-1	115.0
236	R-5	76.0
237	R-6	41.0
239	R-8	182.0
243	R-11	349.0
244	R-12	359.1
245	R-13	427.0
247	R-15	254.7
248	R-16	293.0
251	R-19	155.0
252	R-20	540.0
253	R-21	664.0
254	R-22	983.0
255	R-23	759.0
260	R-27	131.0
261	R-28	357.0
262	R-31	425.0
263	R-32	636.0
265	R-34	532.0
266	R-35a	346.0
267	R-36	350.0
268	R-37	435.0
269	R-38	565.0
271	R-40	347.0
273	R-42	267.0
274	R-43	234.0
275	R-44	363.0
276	R-45	439.0
289	SCI-2	233.7
321	TW-1	460.0
324	TW-3	122.0
326	TW-8	145.0
240	R-9	279.8
241	R-9i	279.8

Plate 2-36. Thickness of the Cerros del Rio Basalt (Tb4)

ER2009-0529

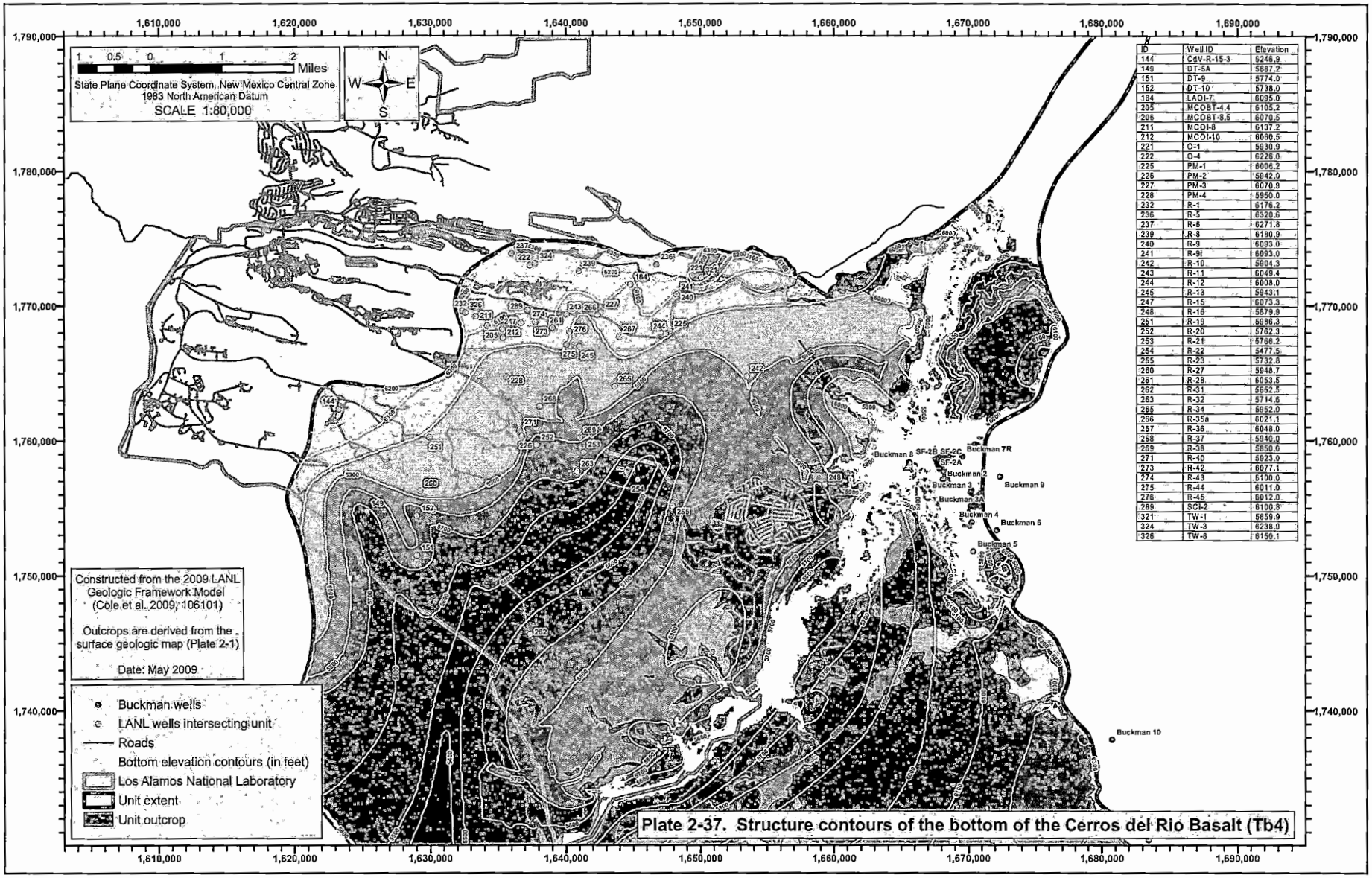


Plate 2-37. Structure contours of the bottom of the Cerros del Rio Basalt (Tb4)

09-1159

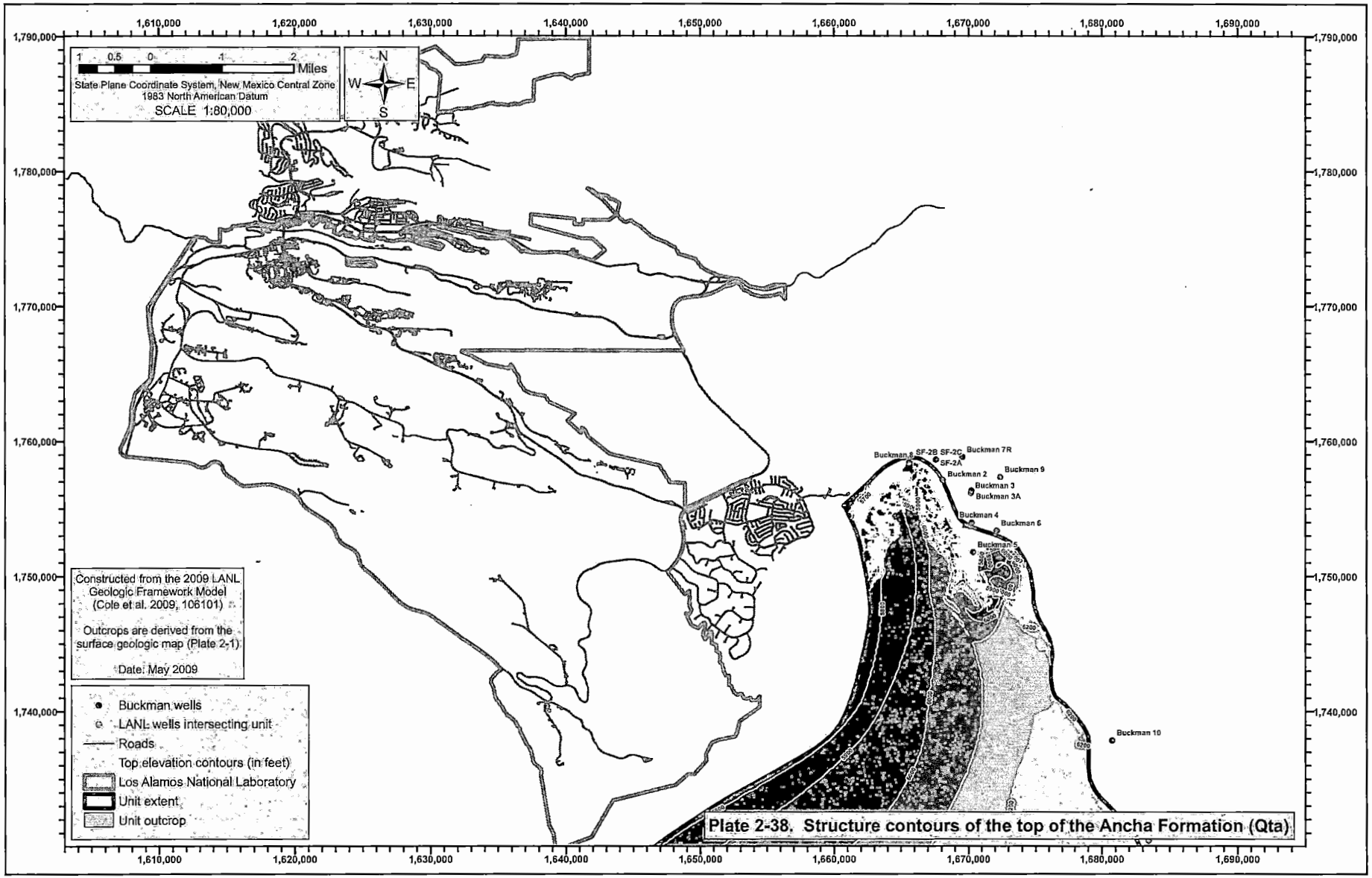
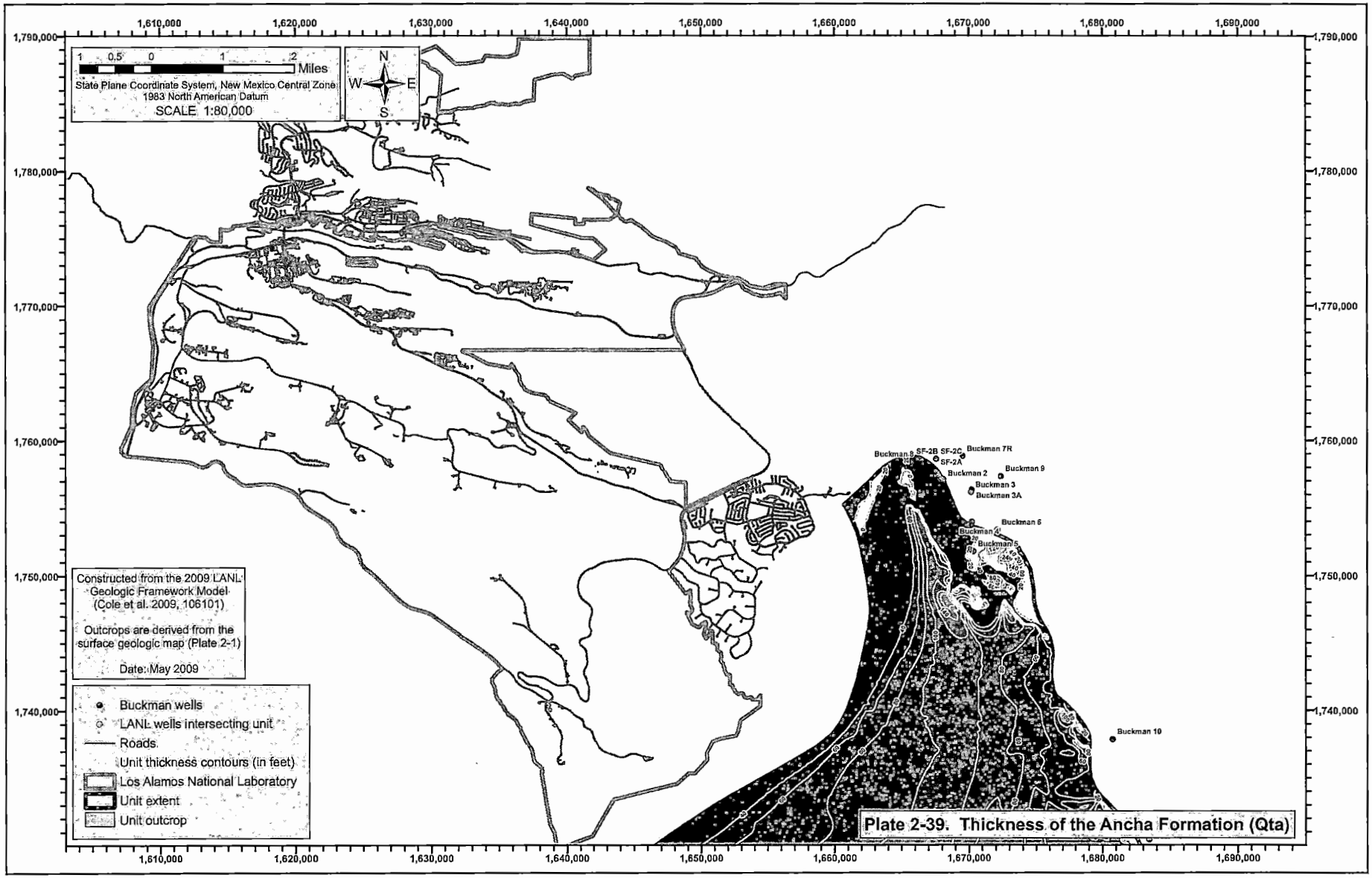


Plate 2-38. Structure contours of the top of the Ancha Formation (Qta)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State Plane Coordinate System, New Mexico Central Zone
1983 North American Datum
SCALE 1:80,000
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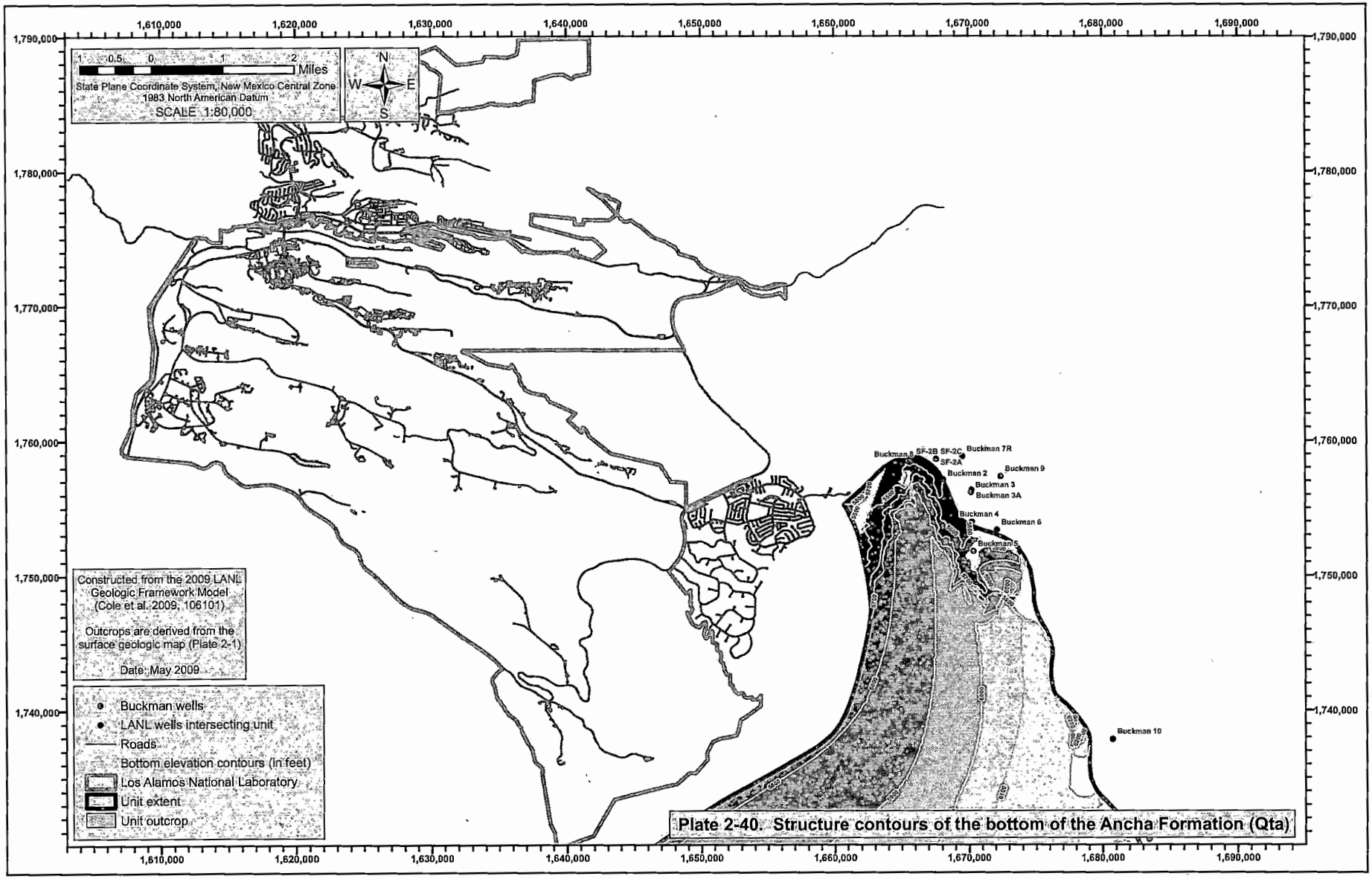
SF-2C
Buckman 7R
SF-2A
Buckman 2
Buckman 9
Buckman 3
Buckman 3A
Buckman 6
Buckman 4
Buckman 5
Buckman 10
Constructed from the 2009 LANL Geologic Framework Model (Cole et al. 2009, 106101)
Outcrops are derived from the surface geologic map (Plate 2-1)
Date: May 2009
Buckman wells
LANL wells intersecting unit
Roads
Unit thickness contours (in feet)
Los Alamos National Laboratory
Unit extent
Unit outcrop
Plate 2-39. Thickness of the Ancha Formation (Qta)

09152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1983 North American Datum
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SF-2C
SF-2A
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Buckman 2
Buckman 9
Buckman 3
Buckman 3A
Buckman 4
Buckman 6
Buckman 5
Buckman 10
Constructed from the 2009 LANL Geologic Framework Model (Cole et al. 2009, 106101)
Outcrops are derived from the surface geologic map (Plate 2-1)
Date: May 2009
Buckman wells
LANL wells intersecting unit
Roads
Bottom elevation contours (in feet)
Los Alamos National Laboratory
Unit extent
Unit outcrop
Plate 2-40. Structure contours of the bottom of the Ancha Formation (Qta)

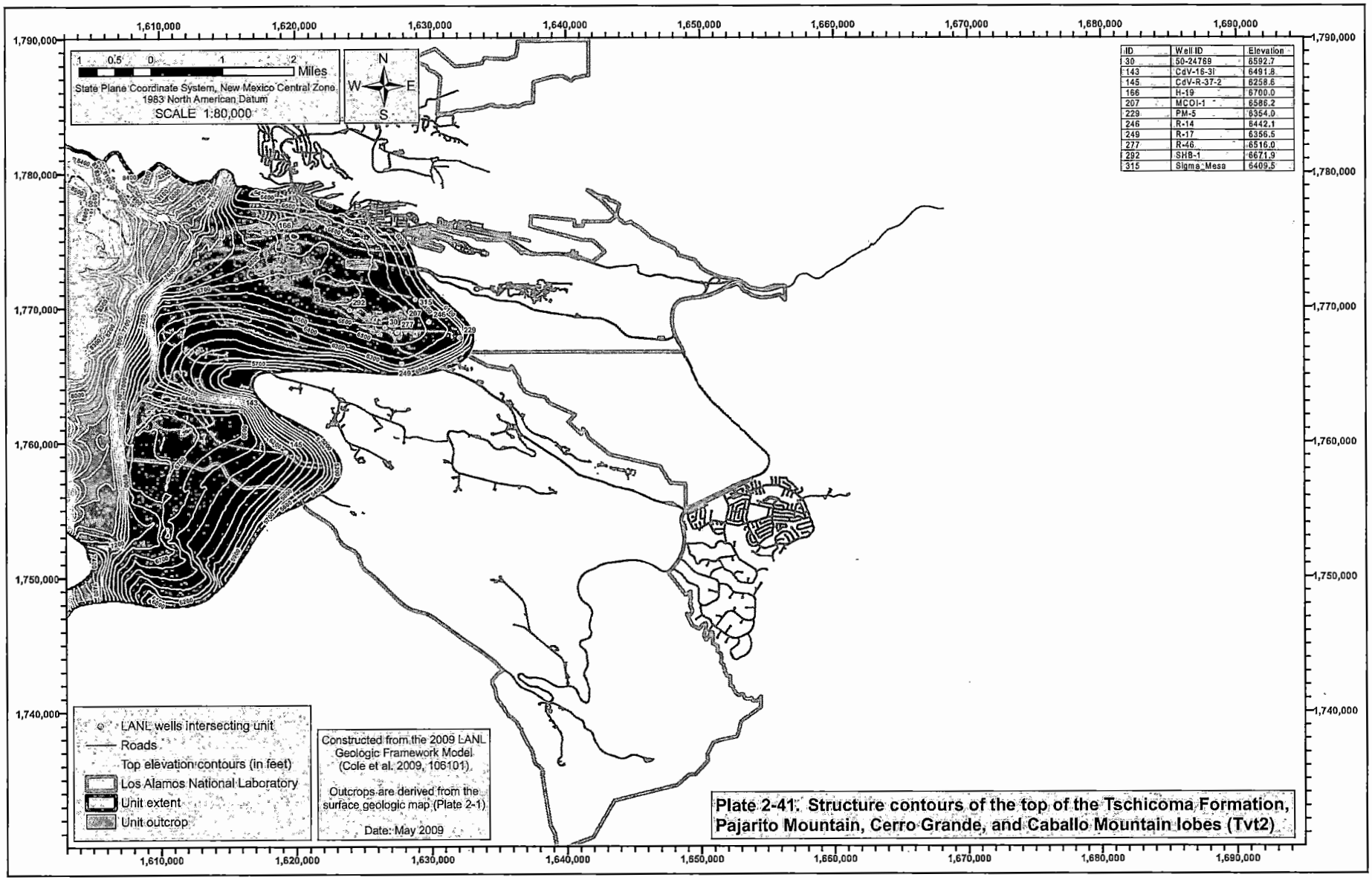
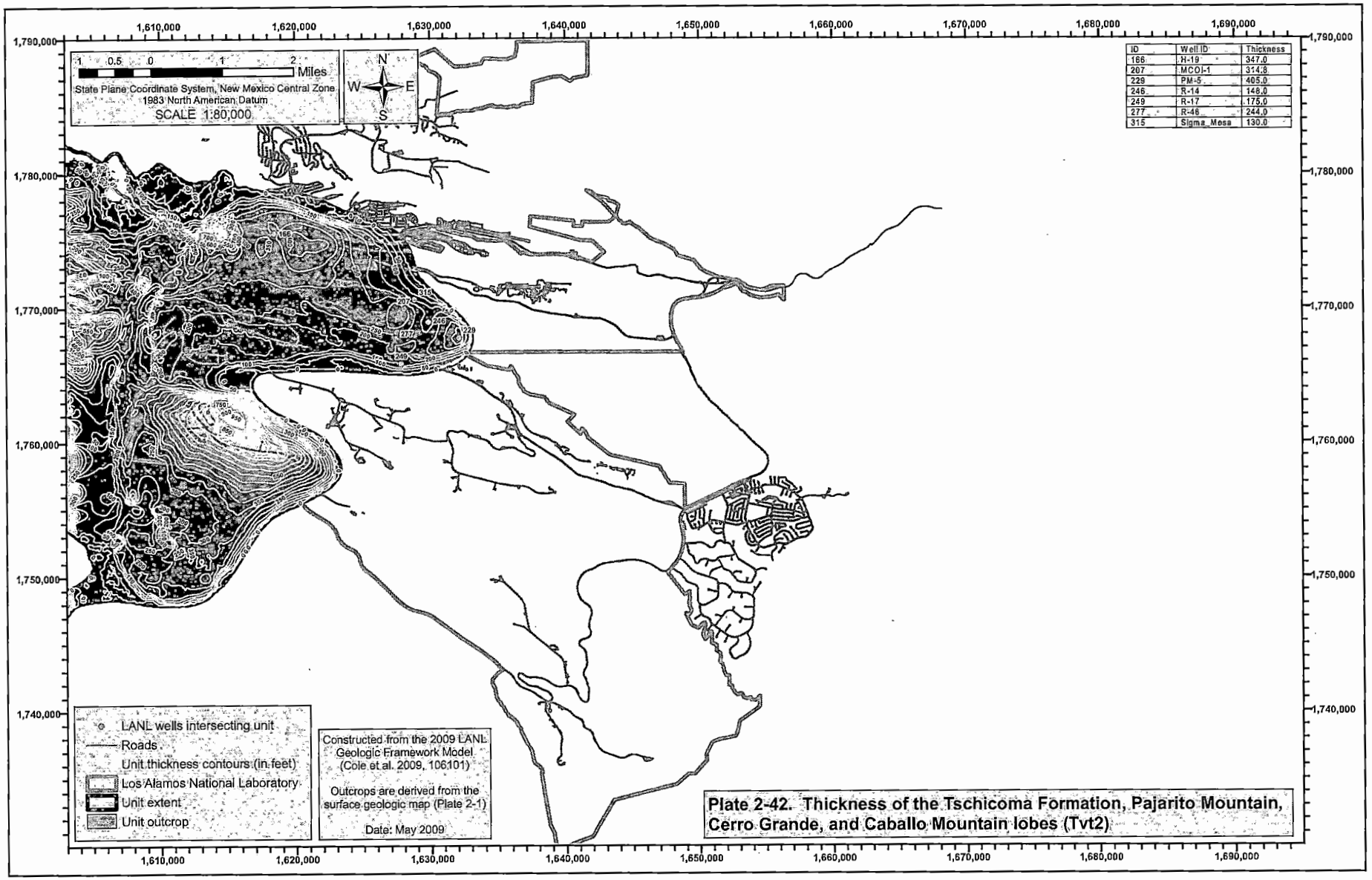


Plate 2-41. Structure contours of the top of the Tschicoma Formation, Pajarito Mountain, Cerro Grande, and Caballo Mountain lobes (Tvt2)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1 0.5 0 1 2 Miles
State Plane Coordinate System, New Mexico Central Zone
1983 North American Datum
SCALE 1:80,000
N
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ID | Well ID | Thickness
166 | H-19 | 347.0
207 | MCOI-1 | 314.8
229 | PM-5 | 405.0
246 | R-14 | 148.0
249 | R-17 | 175.0
277 | R-46 | 244.0
315 | Sigma_Mesa | 130.0
LANL wells intersecting unit
Roads
Unit thickness contours (in feet)
Los Alamos National Laboratory
Unit extent
Unit outcrop
Constructed from the 2009 LANL Geologic Framework Model (Cole et al. 2009, 106101)
Outcrops are derived from the surface geologic map (Plate 2-1)
Date: May 2009
Plate 2-42. Thickness of the Tschicoma Formation, Pajarito Mountain, Cerro Grande, and Caballo Mountain lobes (Tvt2)

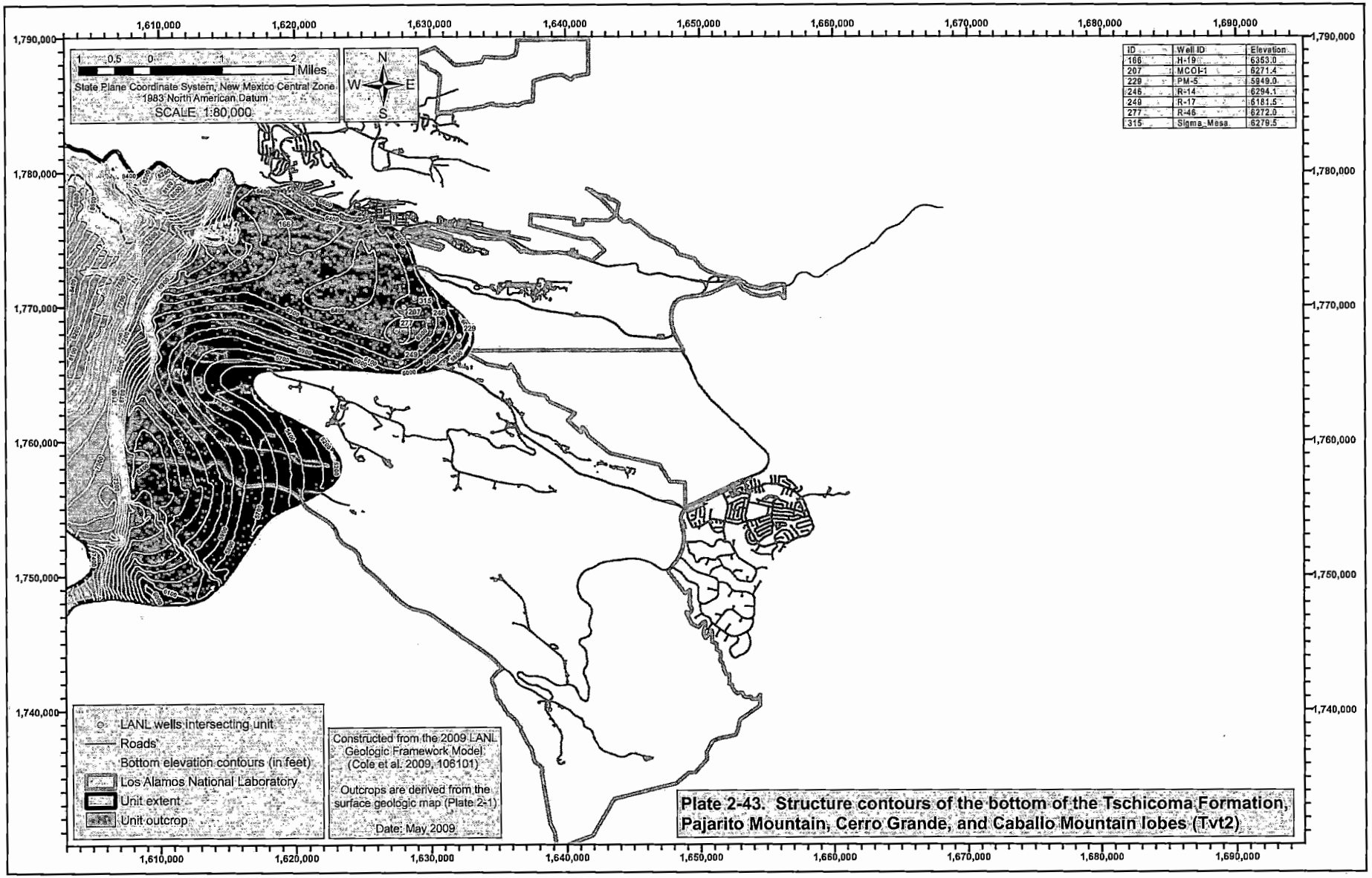


Plate 2-43. Structure contours of the bottom of the Tschicoma Formation, Pajarito Mountain, Cerro Grande, and Caballo Mountain lobes (Tvt2)

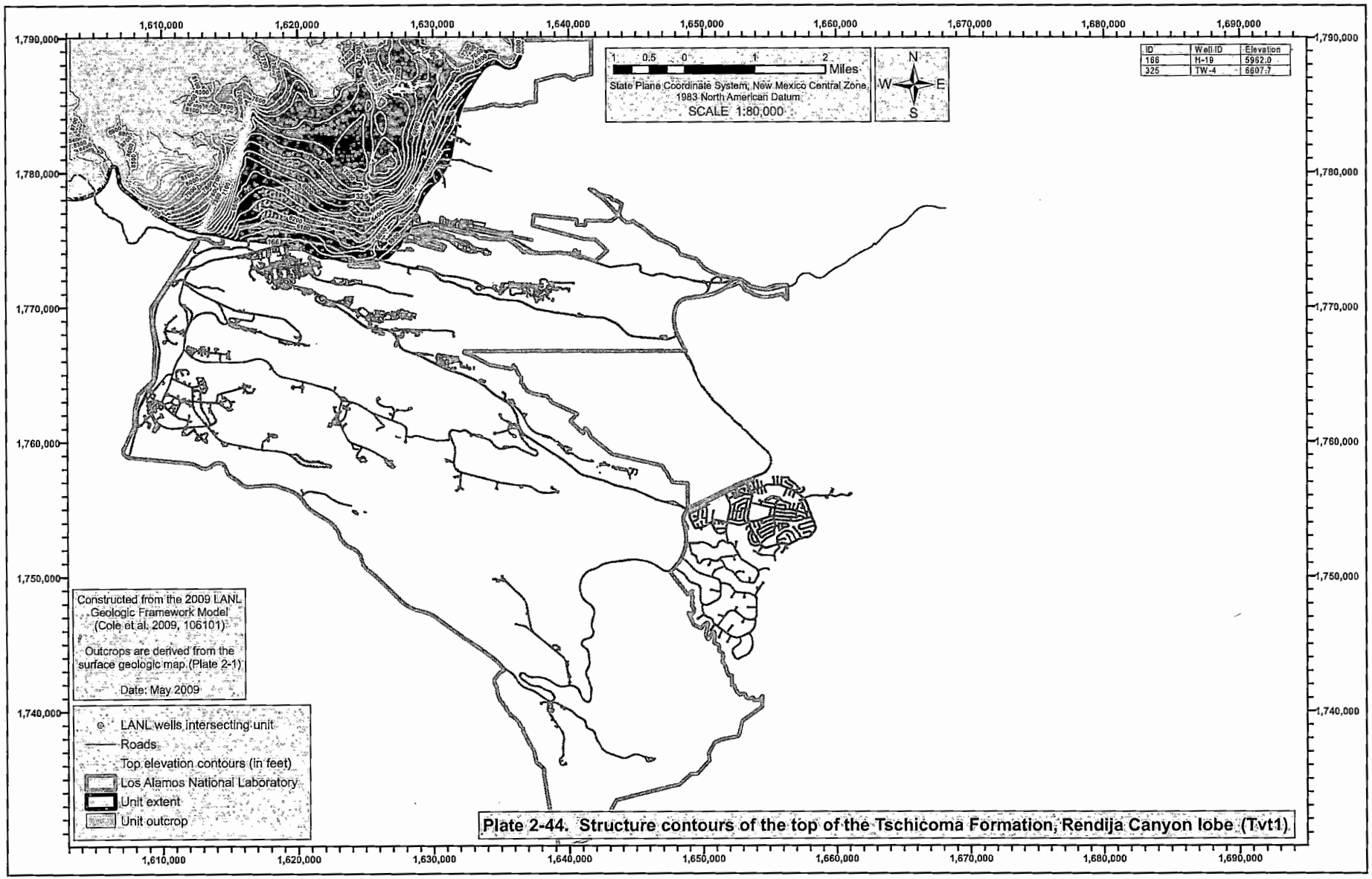
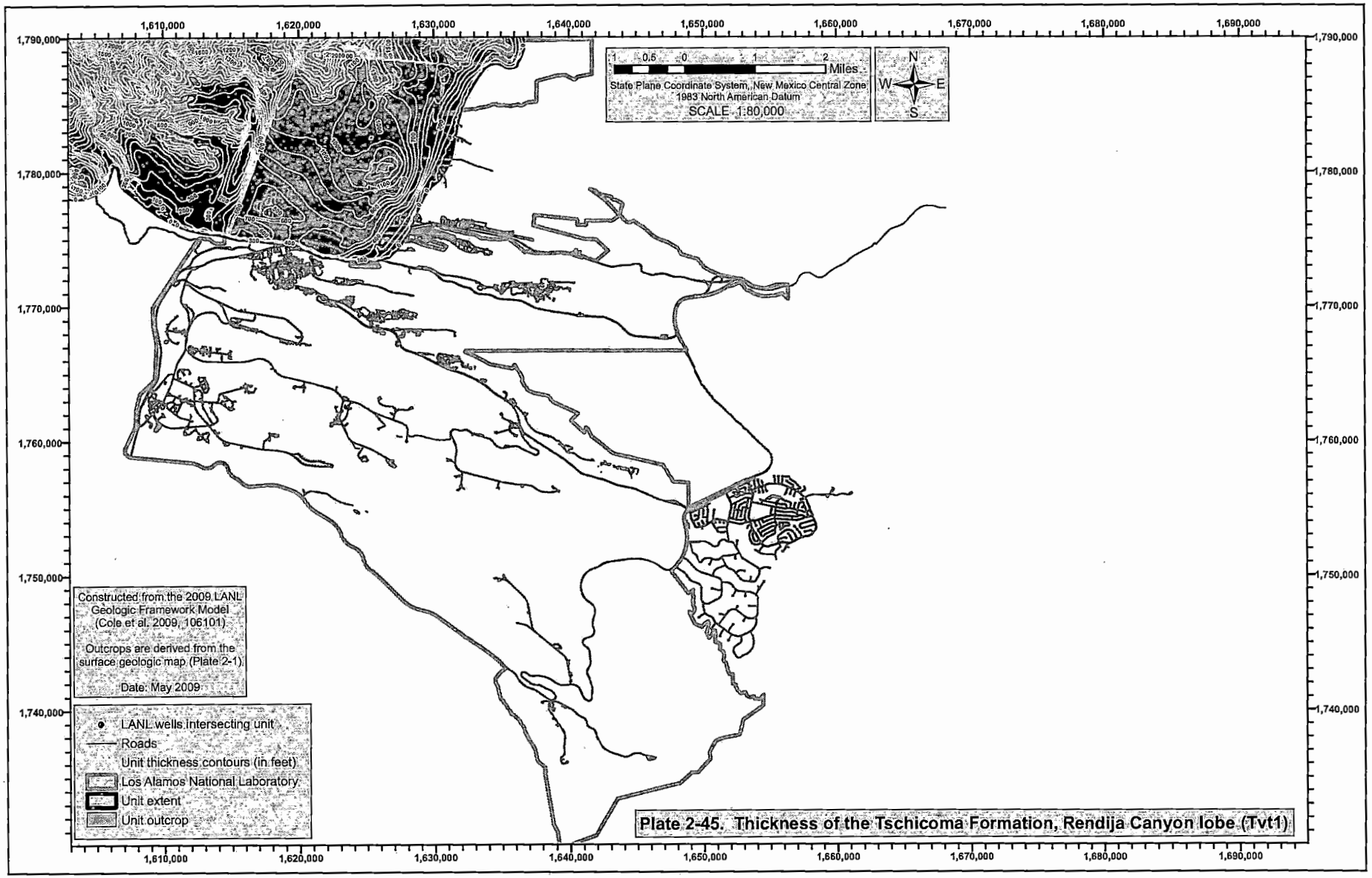


Plate 2-44. Structure contours of the top of the Tschicoma Formation, Rendija Canyon lobe (Tvt1)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1 0.5 0 1 2 Miles
State Plane Coordinate System, New Mexico Central Zone
1983 North American Datum
SCALE 1:80,000
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Constructed from the 2009 LANL Geologic Framework Model (Cole et al. 2009, 106101)
Outcrops are derived from the surface geologic map (Plate 2-1)
Date: May 2009
LANL wells intersecting unit
Roads
Unit thickness contours (in feet)
Los Alamos National Laboratory
Unit extent
Unit outcrop
Plate 2-45. Thickness of the Tschicoma Formation, Rendija Canyon lobe (Tvt1)

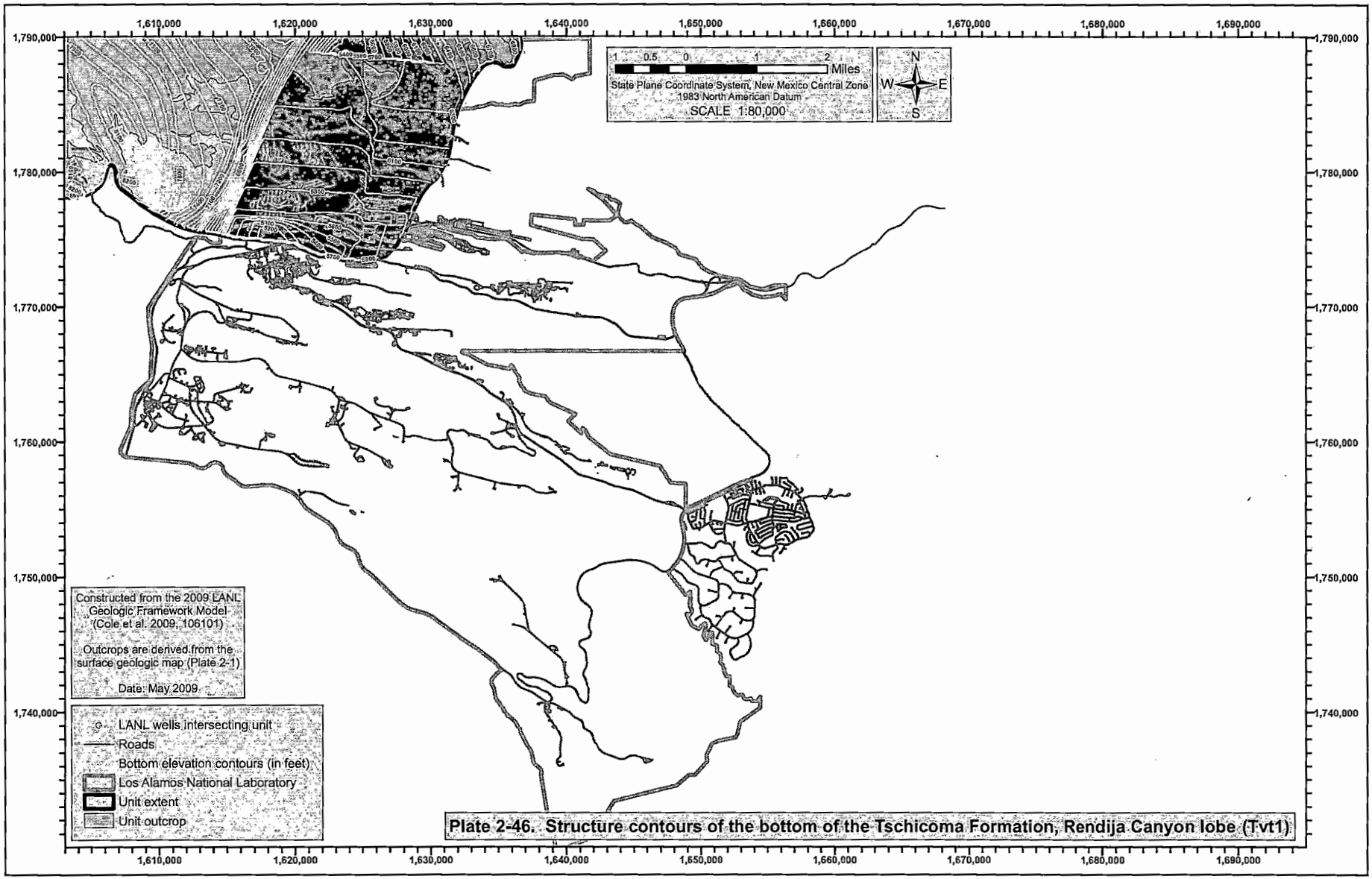


Plate 2-46. Structure contours of the bottom of the Tschicoma Formation, Rendija Canyon lobe (Tvt1)

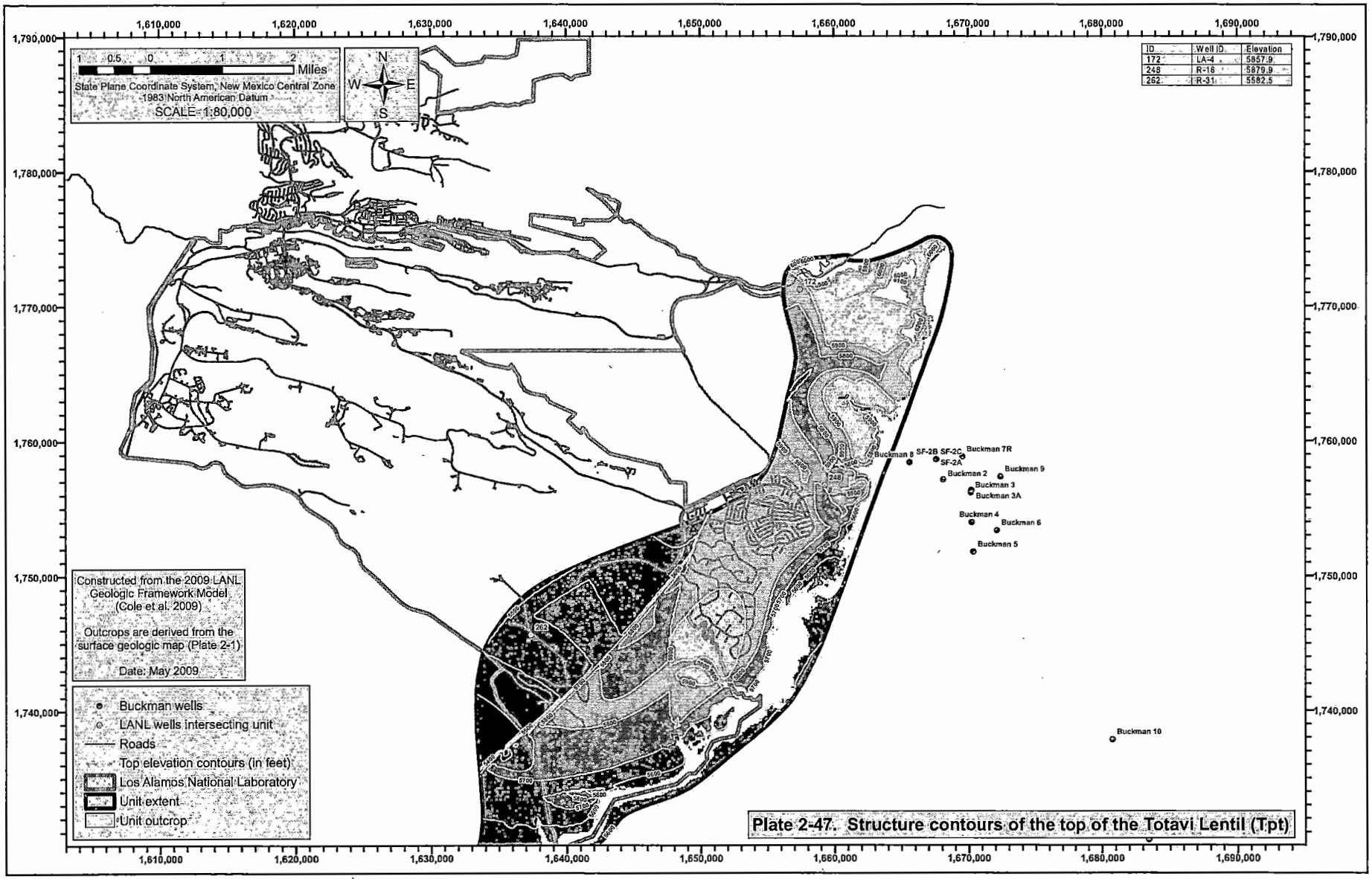
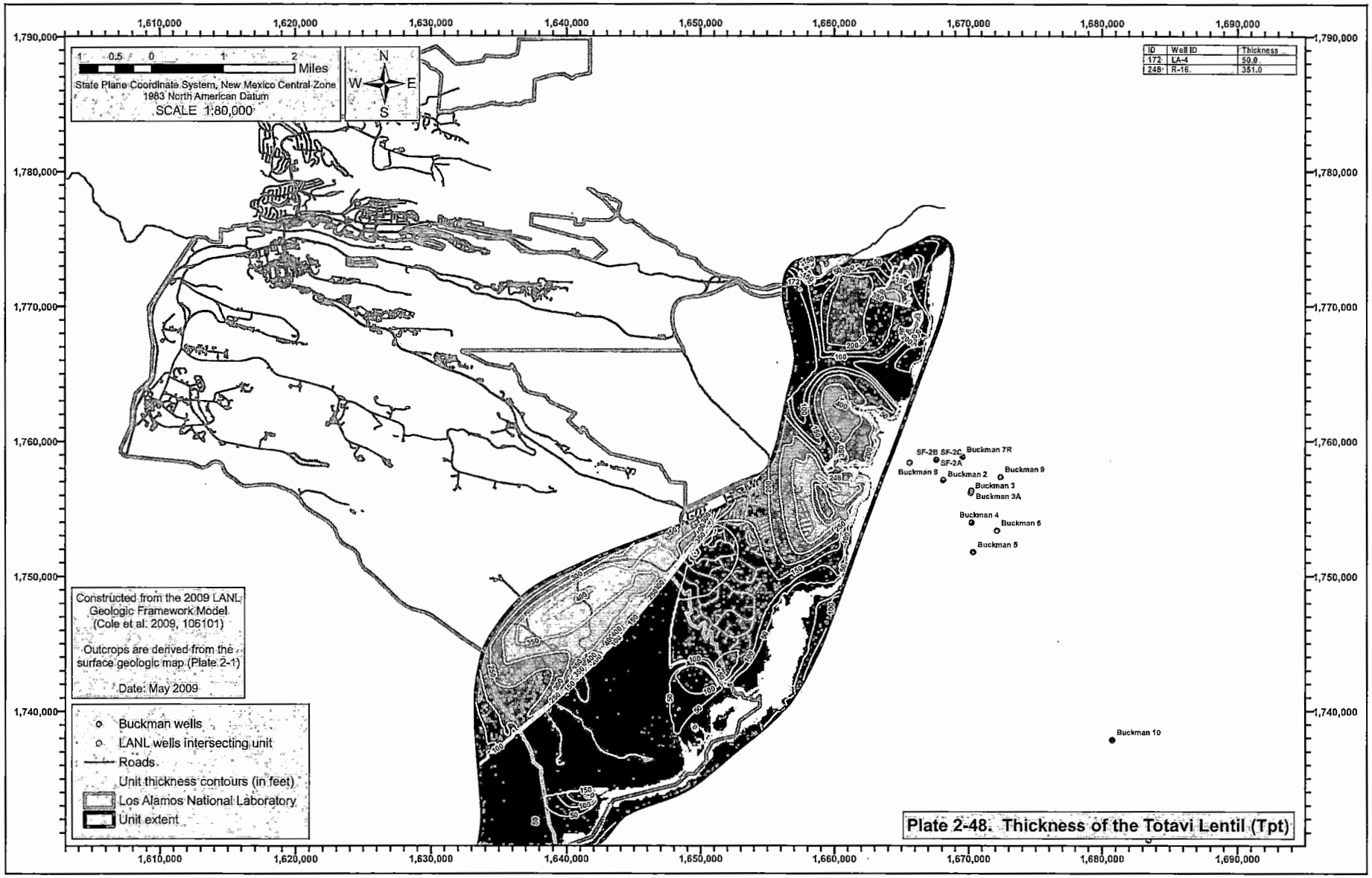


Plate 2-47. Structure contours of the top of the Totavi Lentil (Tpt)

69159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1 0.5 0 1 2 Miles
State Plane Coordinate System, New Mexico Central Zone
1983 North American Datum
SCALE 1:80,000
N
W E
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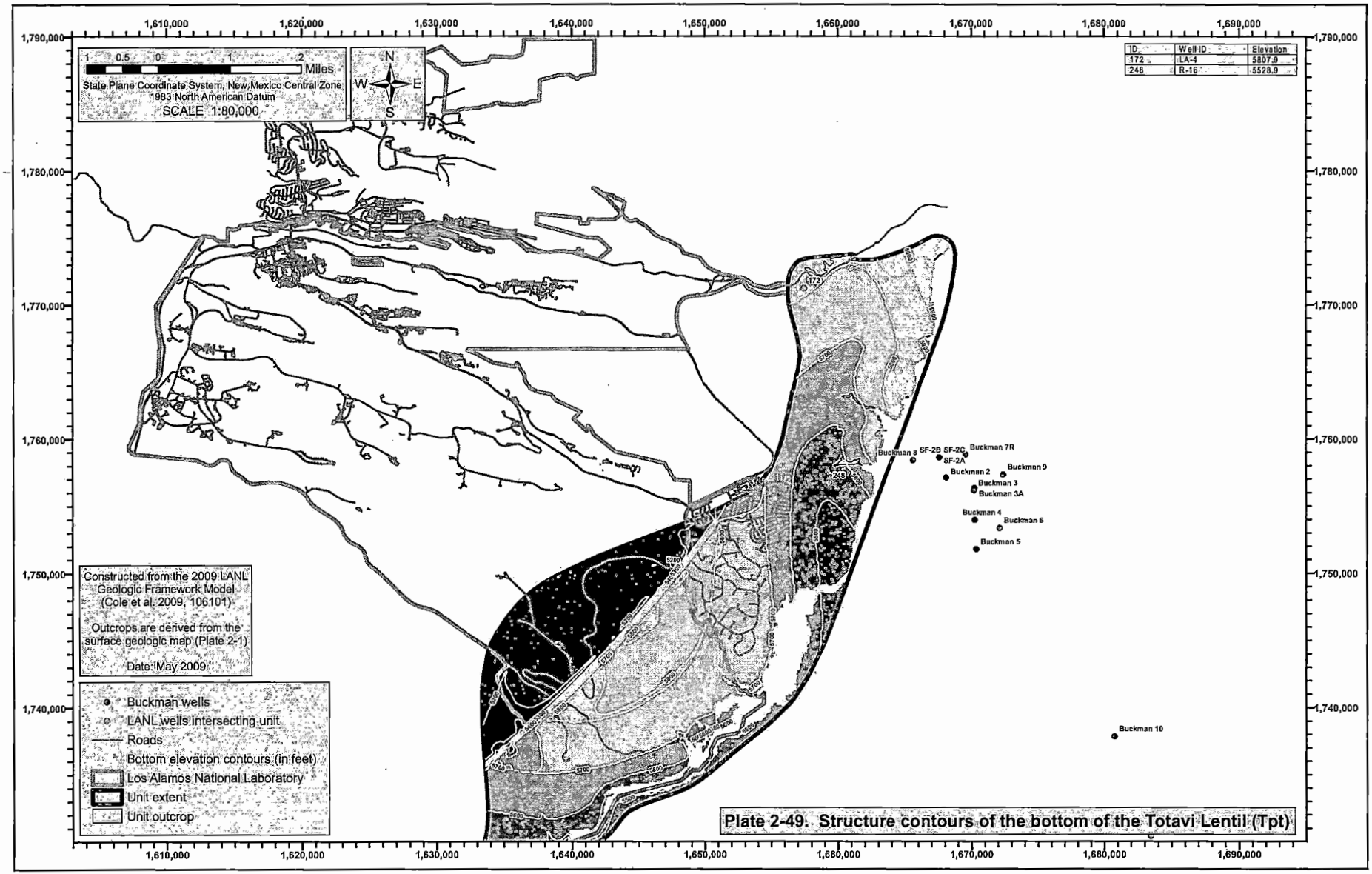
ID Well ID Thickness
172 LA-4 50.0
248 R-16 351.0
SF-2B SF-2C Buckman 7R
SF-2A
Buckman 8
Buckman 2
Buckman 9
Buckman 3
Buckman 3A
Buckman 4
Buckman 6
Buckman 5
Buckman 10
Constructed from the 2009 LANL Geologic Framework Model (Cole et al. 2009, 106101)
Outcrops are derived from the surface geologic map (Plate 2-1)
Date: May 2009
Buckman wells
LANL wells intersecting unit
Roads
Unit thickness contours (in feet)
Los Alamos National Laboratory
Unit extent
Plate 2-48. Thickness of the Totavi Lentil (Tpt)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1,750,000
1,740,000
1 0.5 0 1 2 Miles
State Plane Coordinate System, New Mexico Central Zone
1983 North American Datum
SCALE 1:80,000
N
W
E
S
ID | Well ID | Elevation
172 | LA-4 | 5807.9
248 | R-16 | 5528.9
Buckman 8
SF-2B
SF-2C
Buckman 7R
SF-2A
Buckman 2
Buckman 9
Buckman 3
Buckman 3A
Buckman 4
Buckman 6
Buckman 5
Buckman 10
Constructed from the 2009 LANL Geologic Framework Model (Cole et al. 2009, 106101)
Outcrops are derived from the surface geologic map (Plate 2-1)
Date: May 2009
Buckman wells
LANL wells intersecting unit
Roads
Bottom elevation contours (in feet)
Los Alamos National Laboratory
Unit extent
Unit outcrop
Plate 2-49. Structure contours of the bottom of the Totavi Lentil (Tpt)

09152

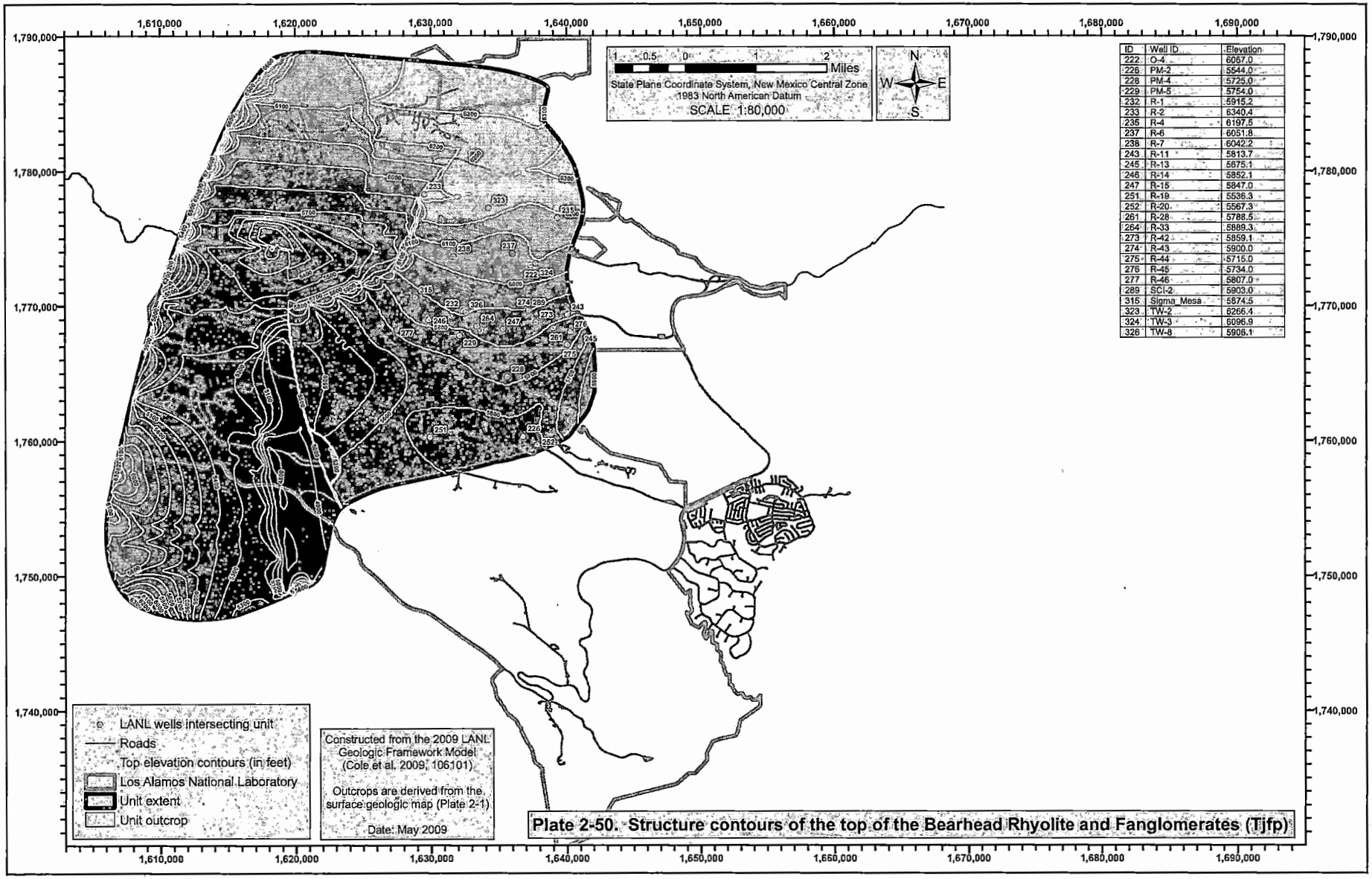


Plate 2-50. Structure contours of the top of the Bearhead Rhyolite and Fanglomerates (Tifp)

ER2009-0153

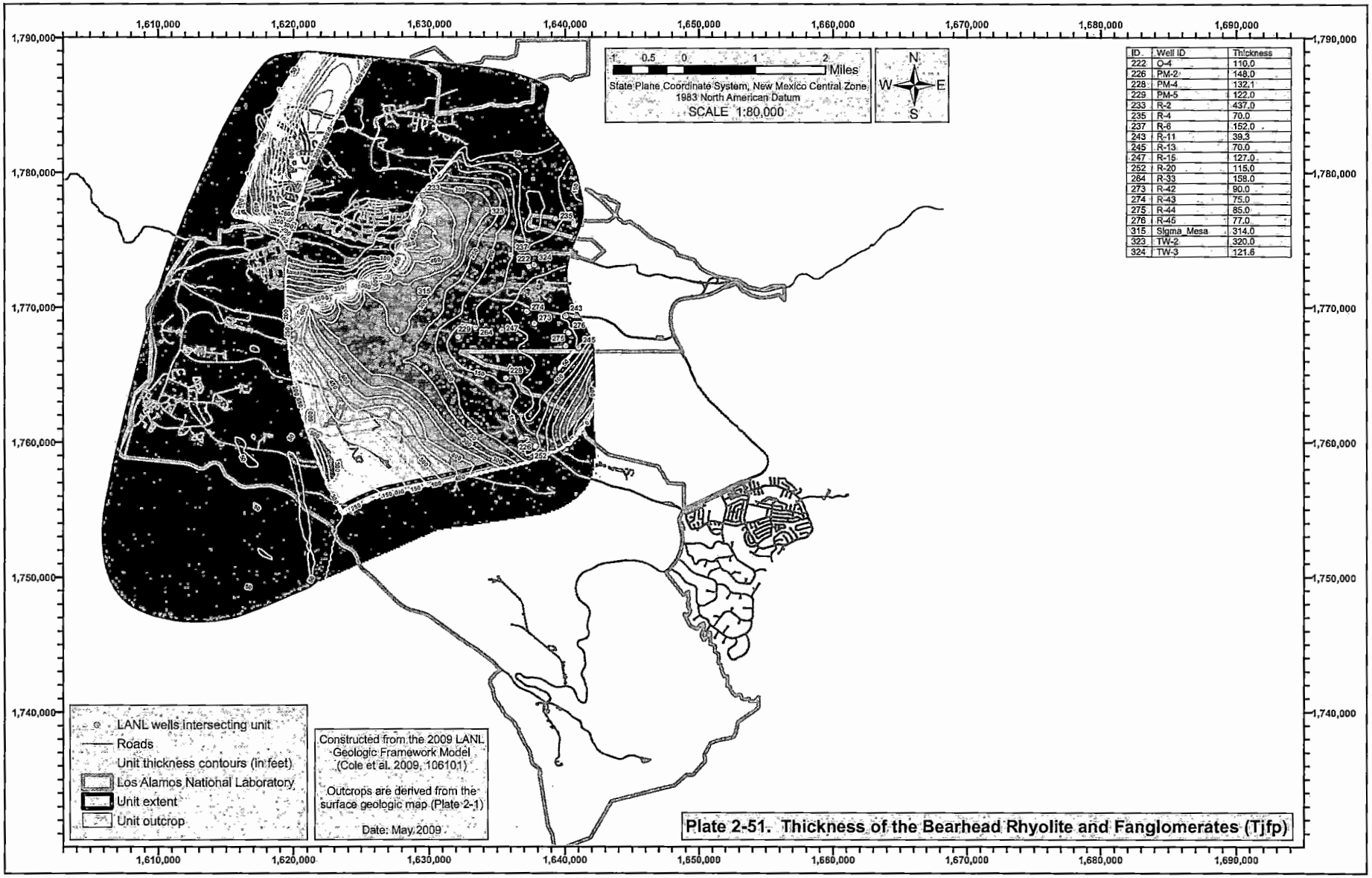


Plate 2-51. Thickness of the Bearhead Rhyolite and Fanglomerates (Tjfp)

Plate 2-51

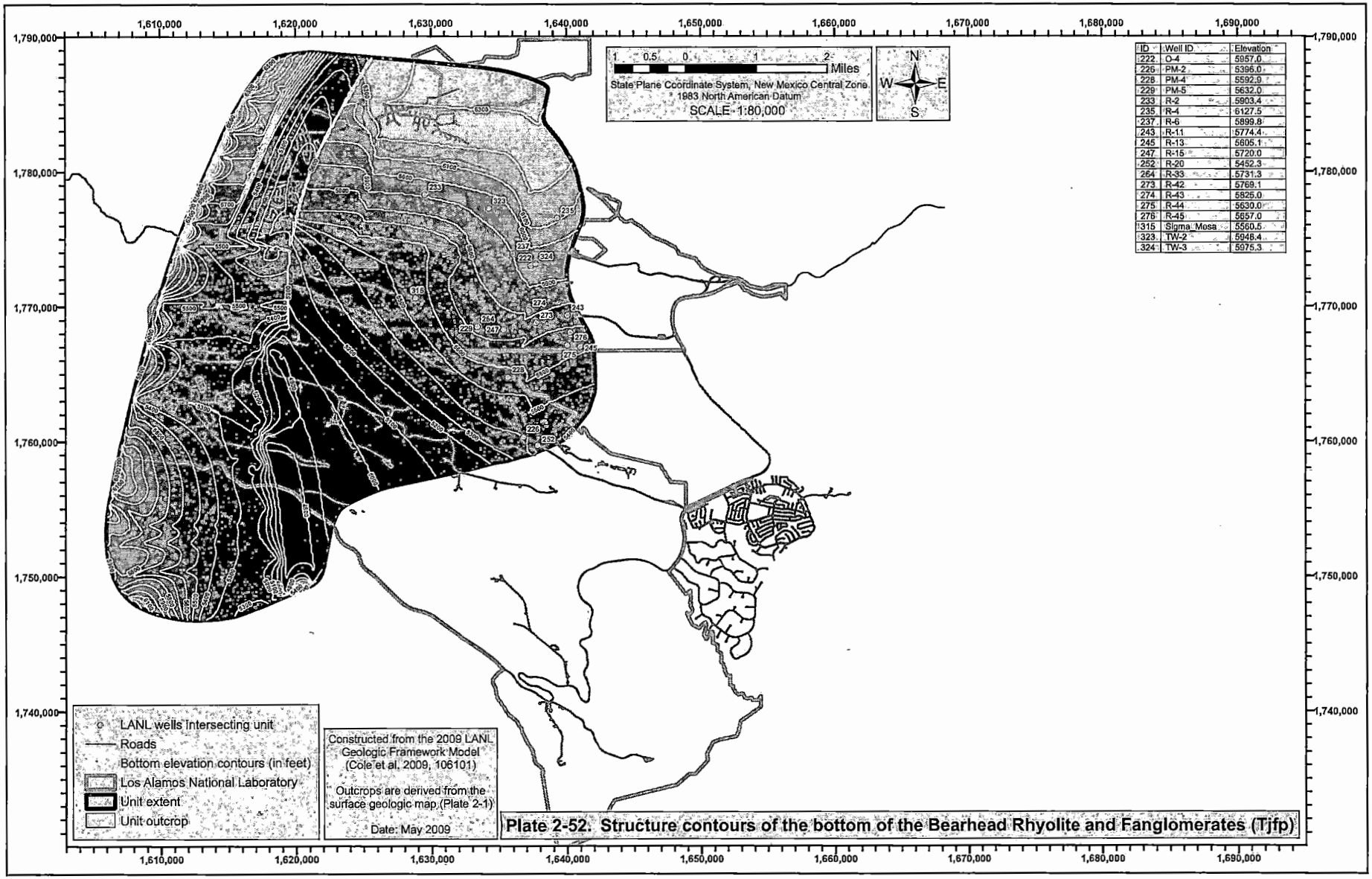


Plate 2-52. Structure contours of the bottom of the Bearhead Rhyolite and Fanglomerates (Tjfp)

09455

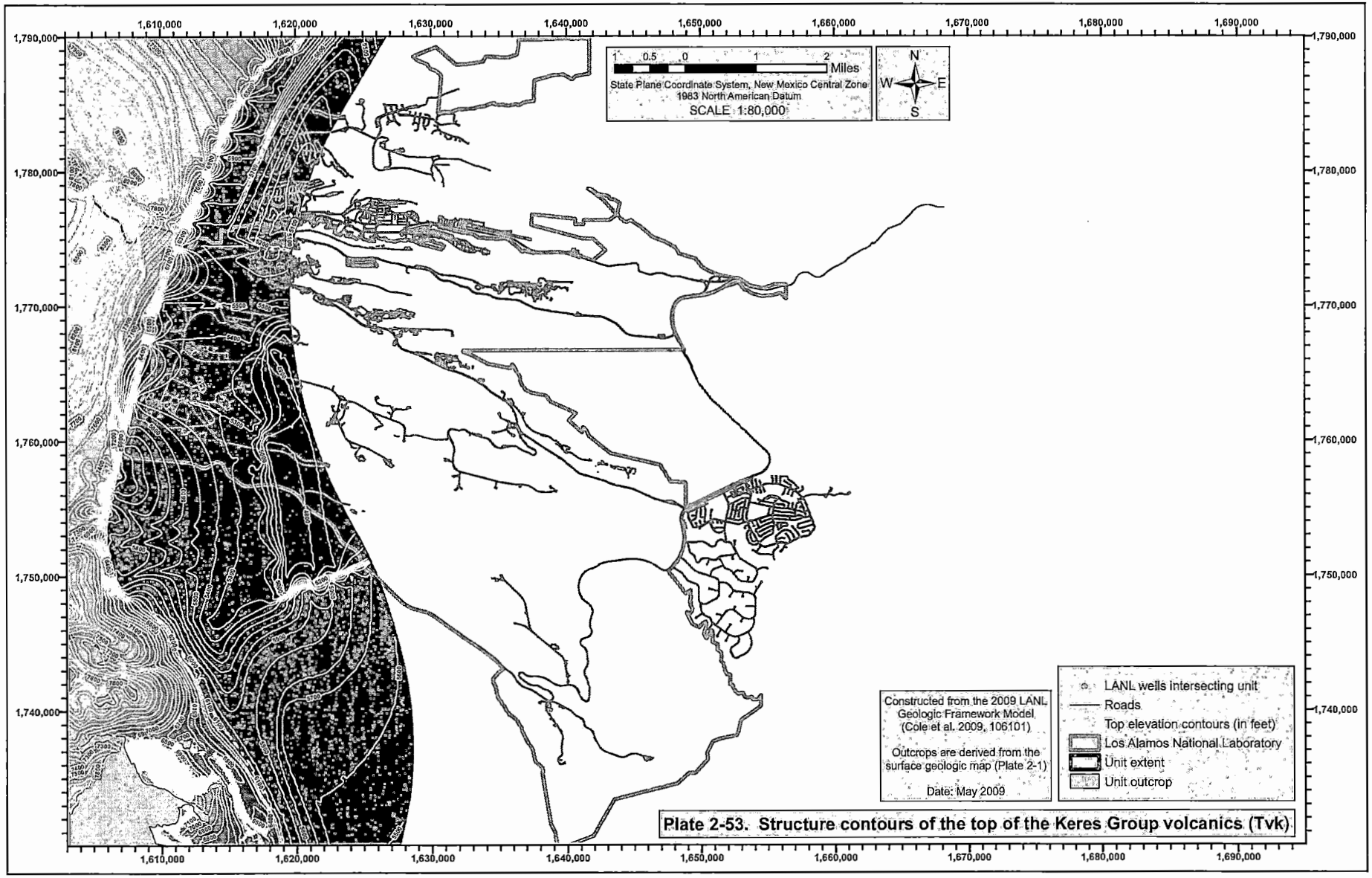
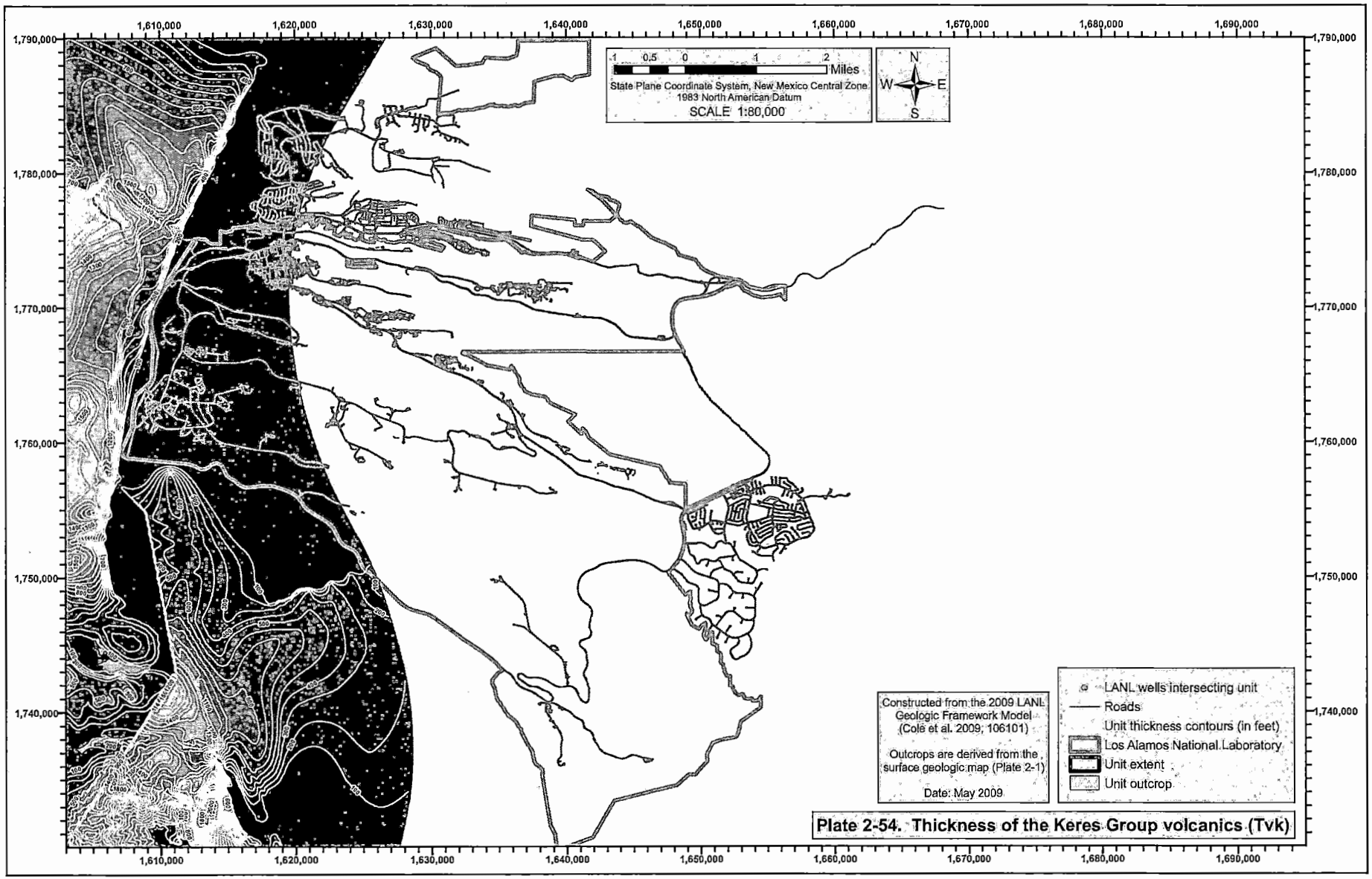


Plate 2-53. Structure contours of the top of the Keres Group volcanics (Tvk)

09156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1,750,000
1,740,000
1 0.5 0 1 2 Miles
State Plane Coordinate System, New Mexico Central Zone
1983 North American Datum
SCALE 1:80,000
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E
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Constructed from the 2009 LANL Geologic Framework Model (Cole et al. 2009, 106101)
Outcrops are derived from the surface geologic map (Plate 2-1)
Date: May 2009
LANL wells intersecting unit
Roads
Unit thickness contours (in feet)
Los Alamos National Laboratory
Unit extent
Unit outcrop
Plate 2-54. Thickness of the Keres Group volcanics (Tvk)

ER99157

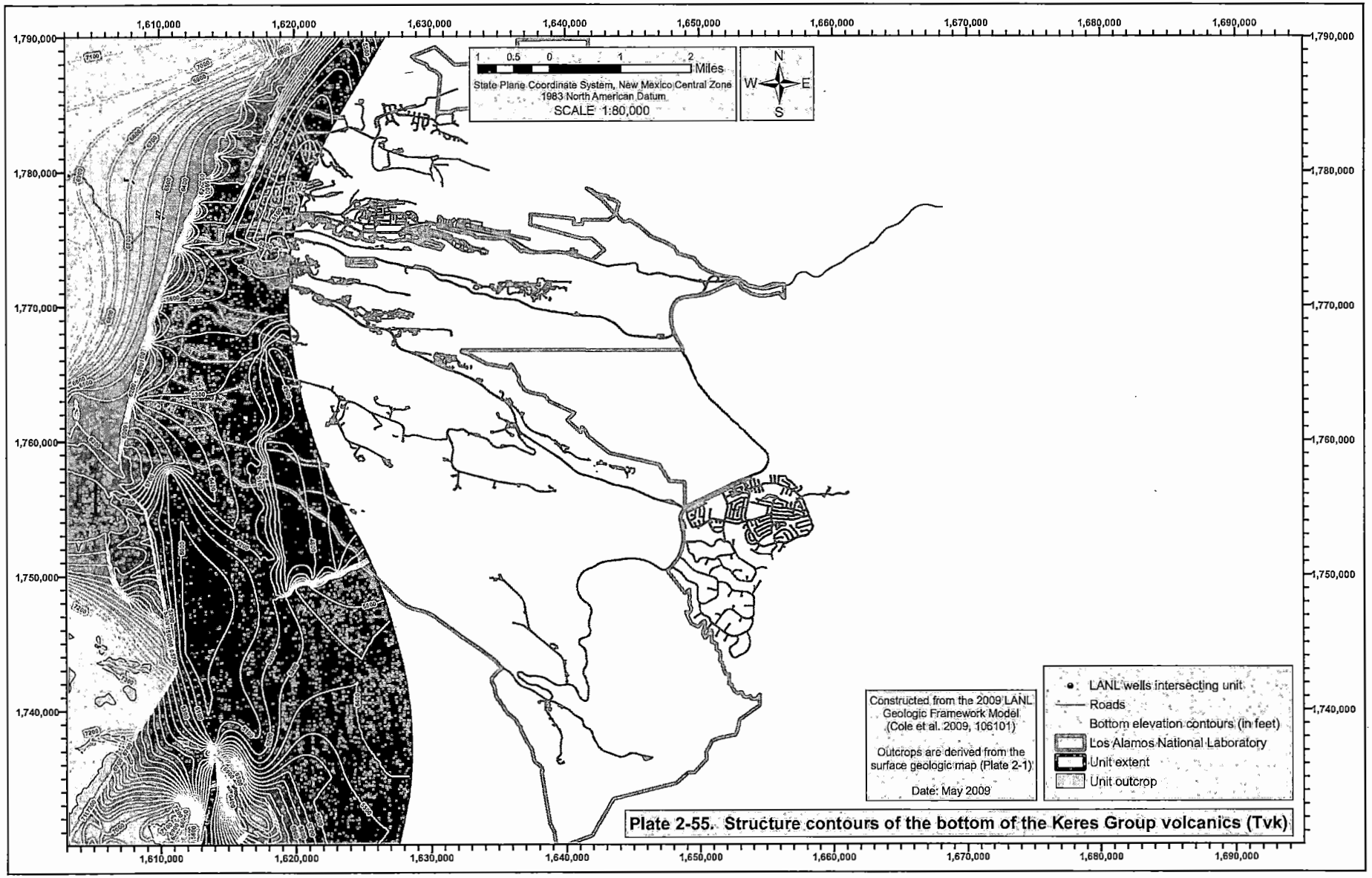


Plate 2-55. Structure contours of the bottom of the Keres Group volcanics (Tvk)

6519

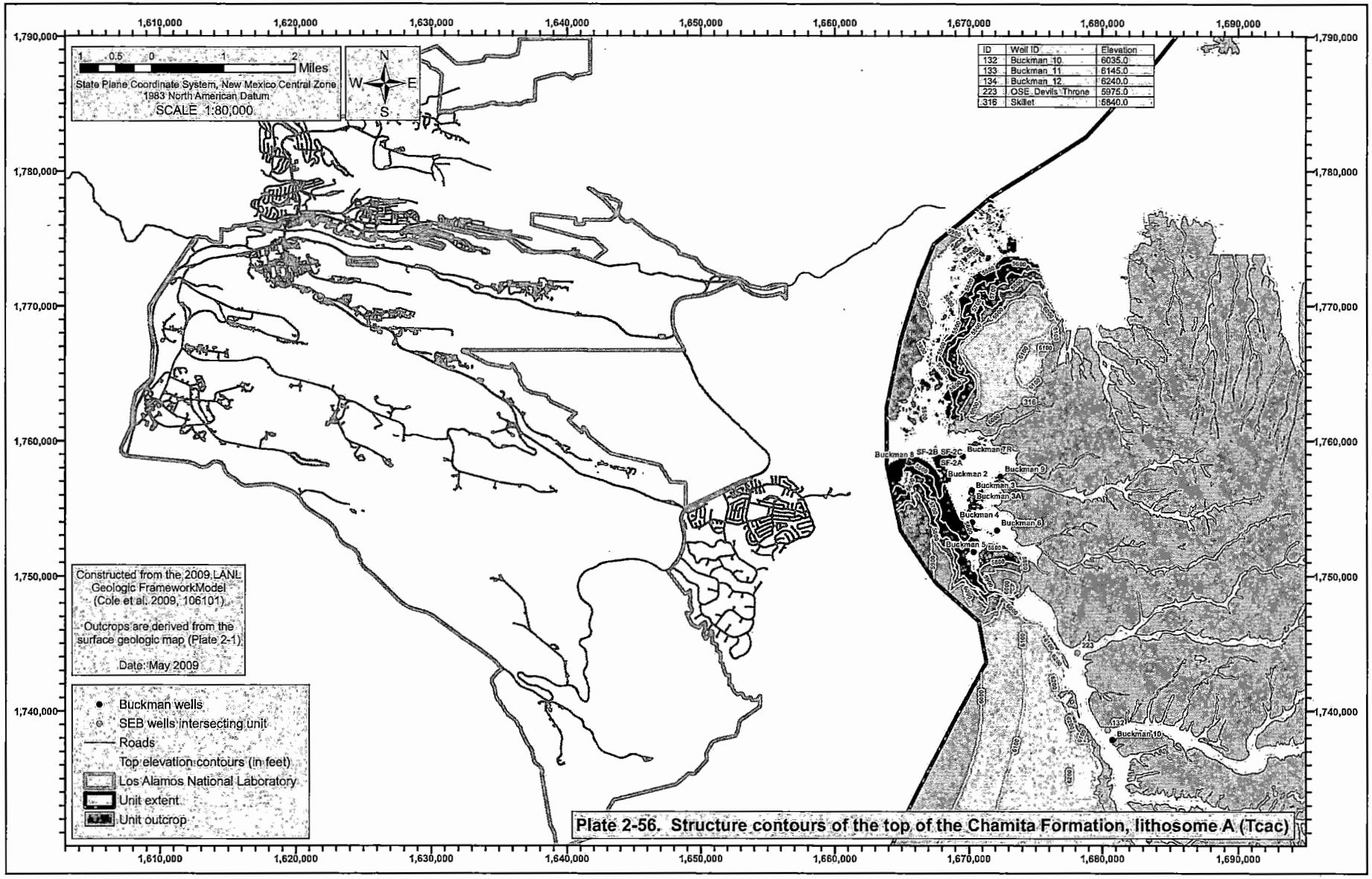
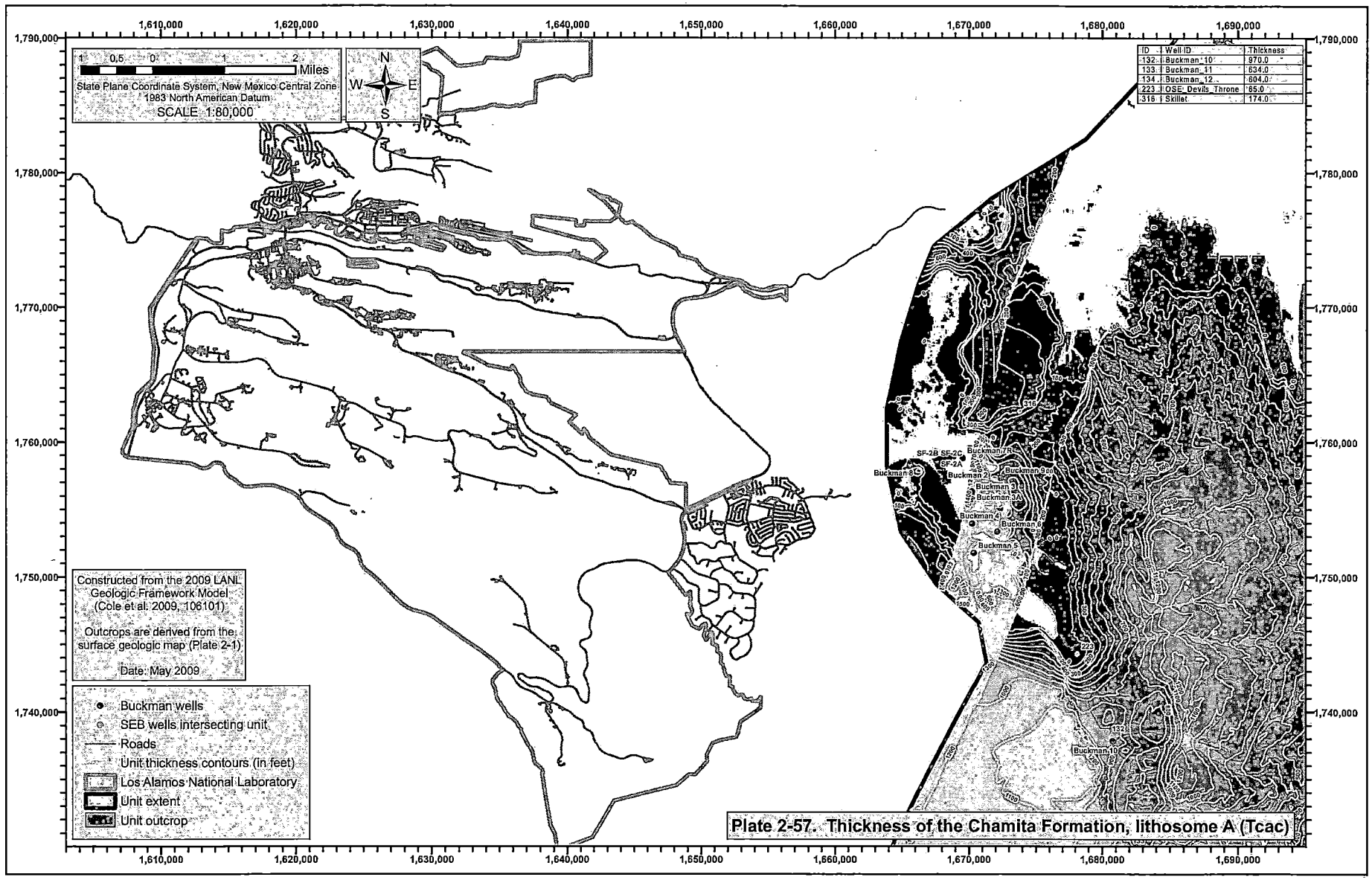


Plate 2-56. Structure contours of the top of the Chamita Formation, lithosome A (Tcac)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1,770,000
1,760,000
1,750,000
1,740,000
1 0.5 0 1 2 Miles
State Plane Coordinate System, New Mexico Central Zone
1983 North American Datum
SCALE 1:80,000
N
W
E
S
ID | Well ID | Thickness
132 | Buckman_10 | 970.0
133 | Buckman_11 | 634.0
134 | Buckman_12 | 604.0
223 | OSE_Devils_Throne | 65.0
316 | Skillet | 174.0
Constructed from the 2009 LANL Geologic Framework Model (Cole et al. 2009, 106101)
Outcrops are derived from the surface geologic map (Plate 2-1)
Date: May 2009
Buckman wells
SEB wells intersecting unit
Roads
Unit thickness contours (in feet)
Los Alamos National Laboratory
Unit extent
Unit outcrop
SF-2B
SF-2C
SF-2A
Buckman 8
Buckman 2
Buckman 9
Buckman 3
Buckman 3A
Buckman 4
Buckman 6
Buckman 5
Buckman 10
Plate 2-57. Thickness of the Chamita Formation, lithosome A (Tcac)

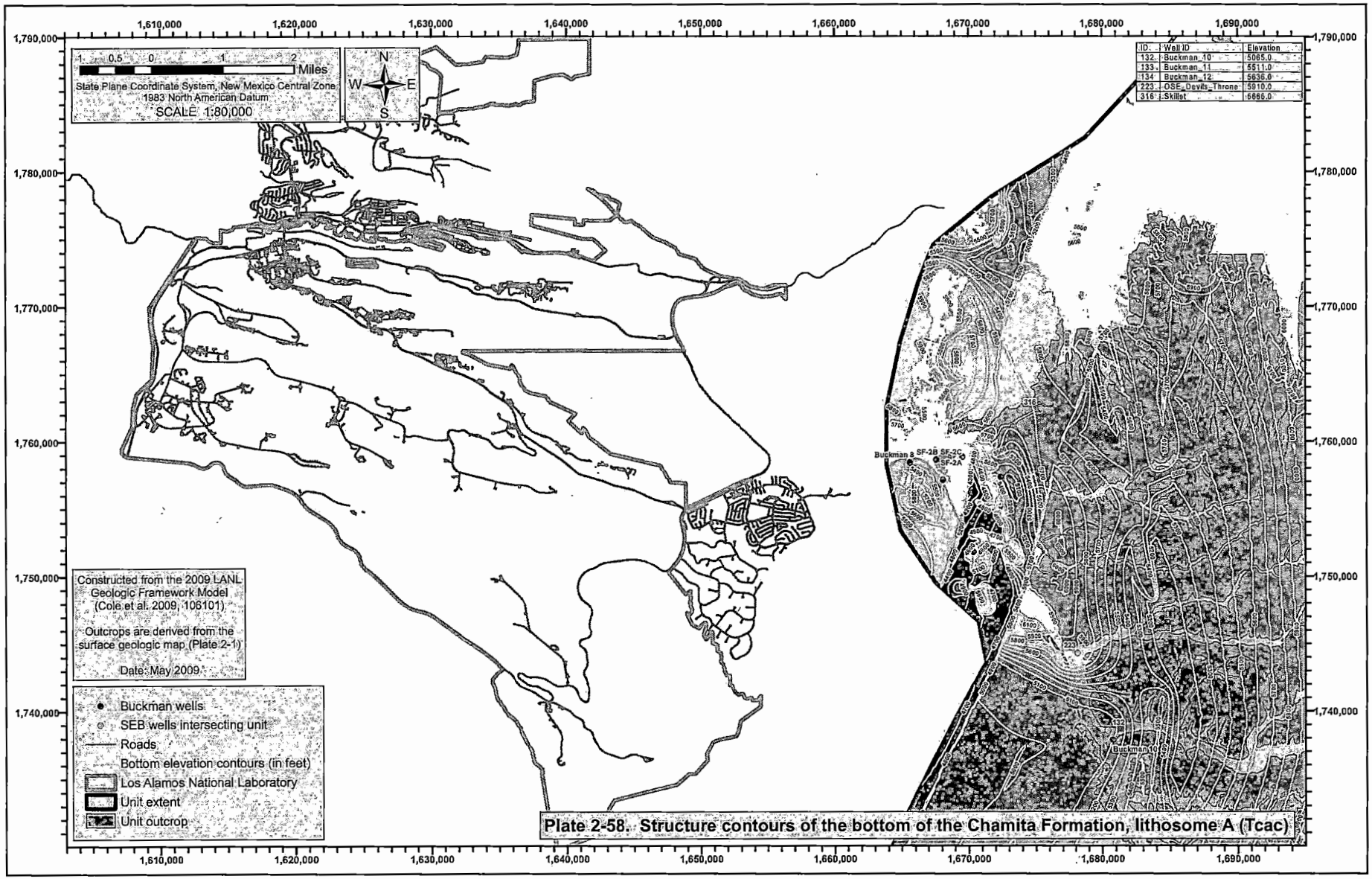


Plate 2-58. Structure contours of the bottom of the Chamita Formation, lithosome A (Tcac)

Plate 2-59. Structure contours of the top of the Tesuque Formation, Chamita lithosome B (Ttca)

96162

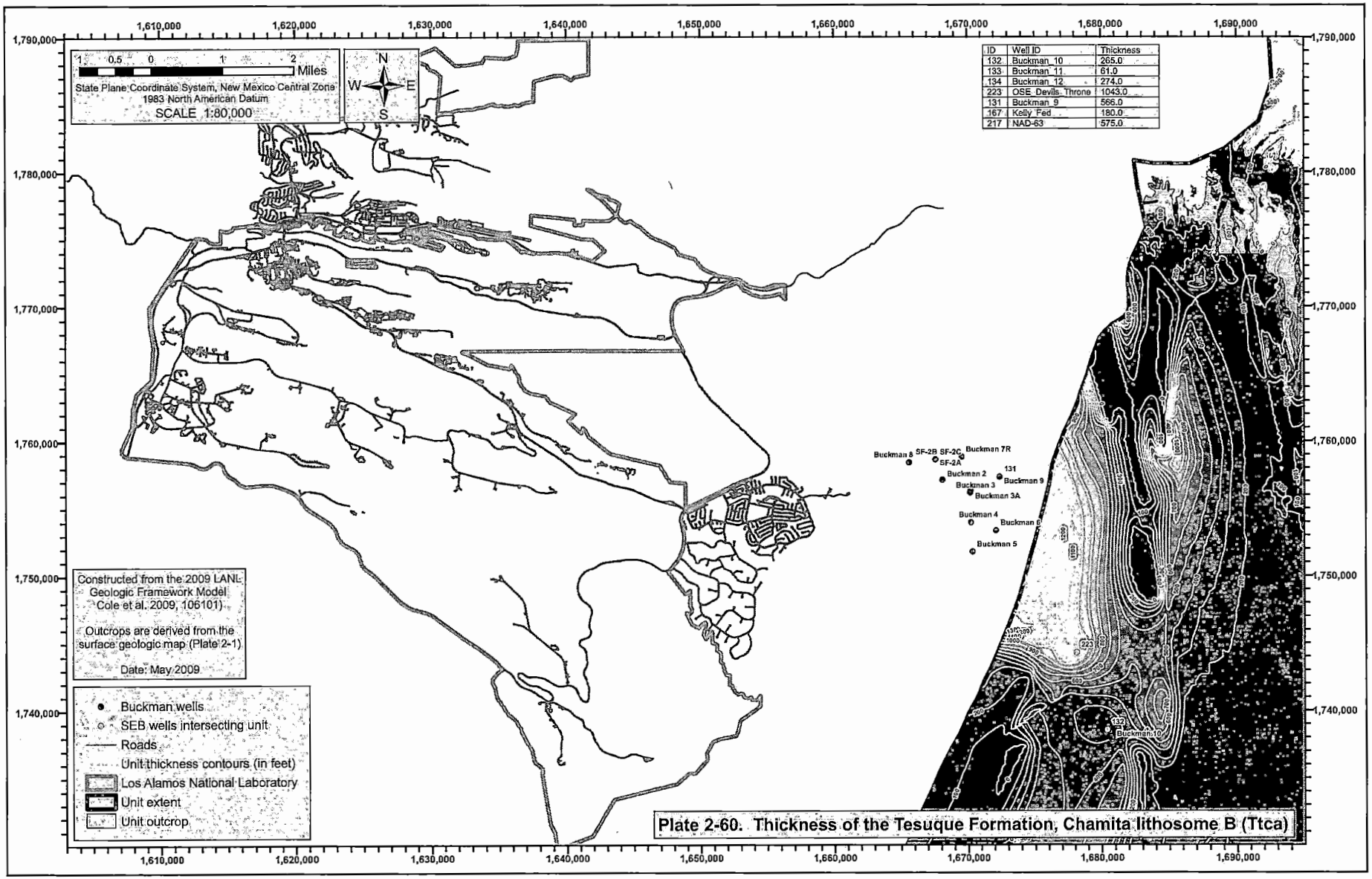


Plate 2-60. Thickness of the Tesuque Formation, Chamita lithosome B (Ttca)

ER2009-0153

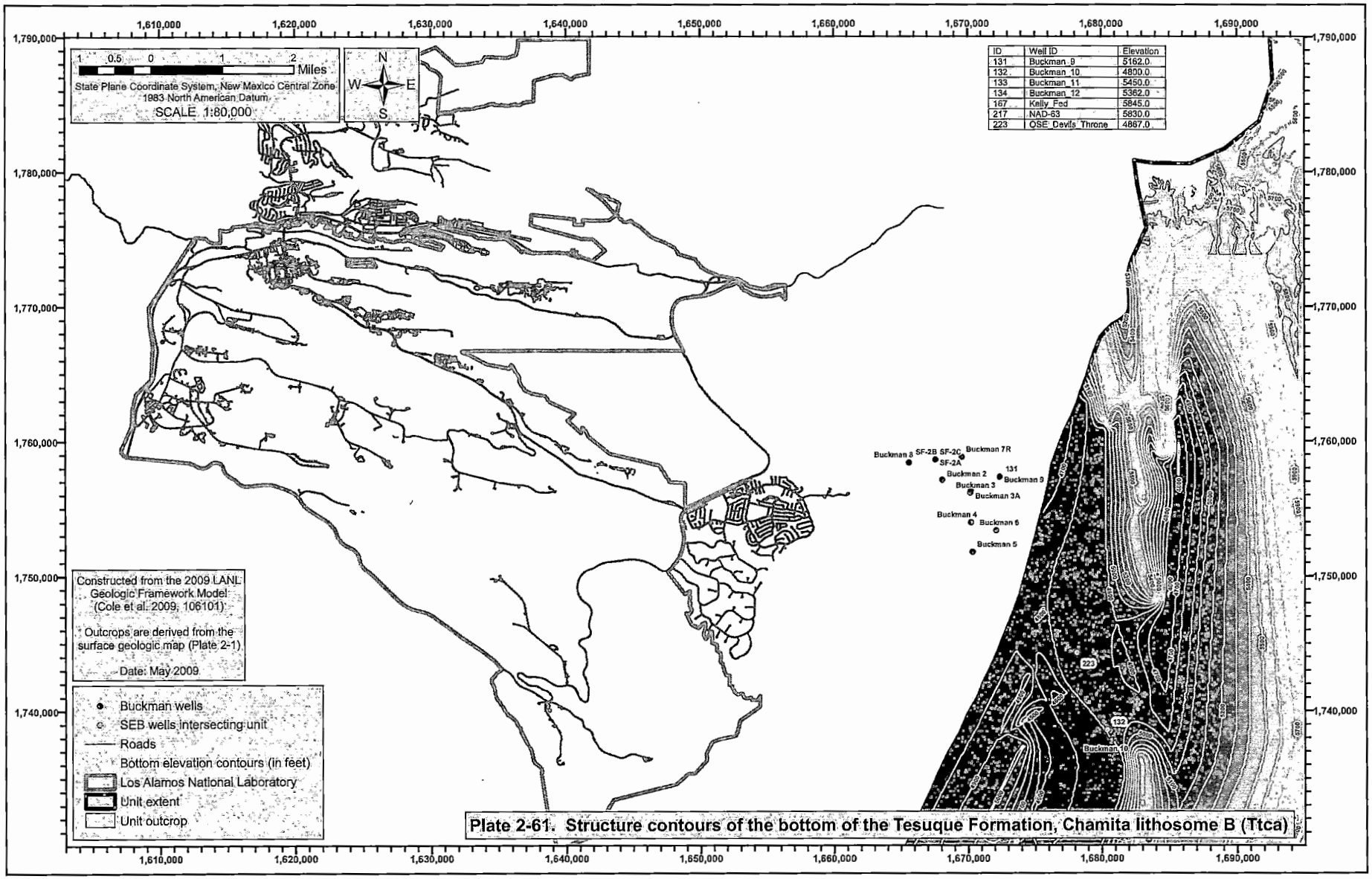


Plate 2-61. Structure contours of the bottom of the Tesuque Formation, Chamita lithosome B (Ttca)

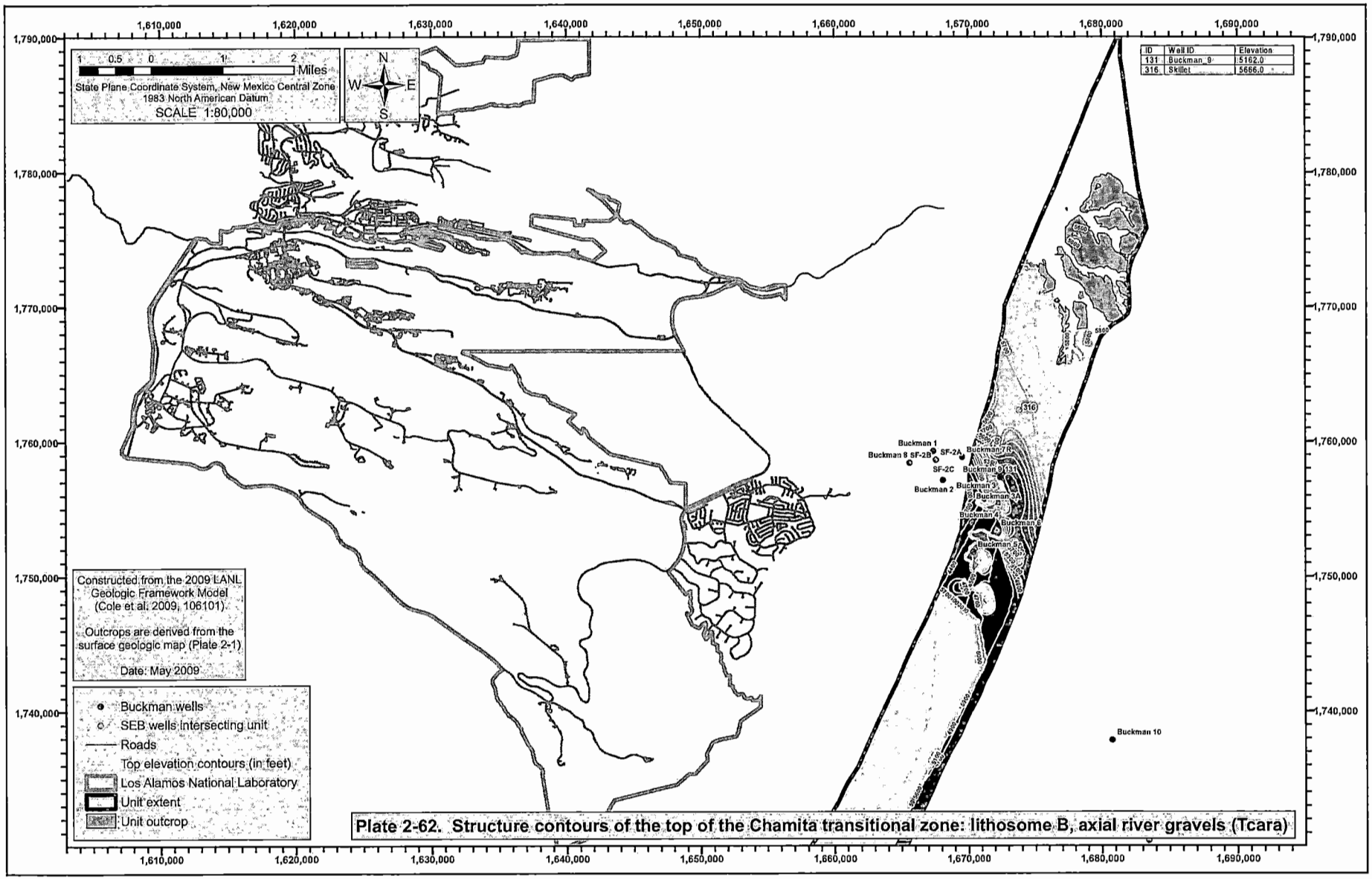


Plate 2-62. Structure contours of the top of the Chamita transitional zone: lithosome B, axial river gravels (Tcara)

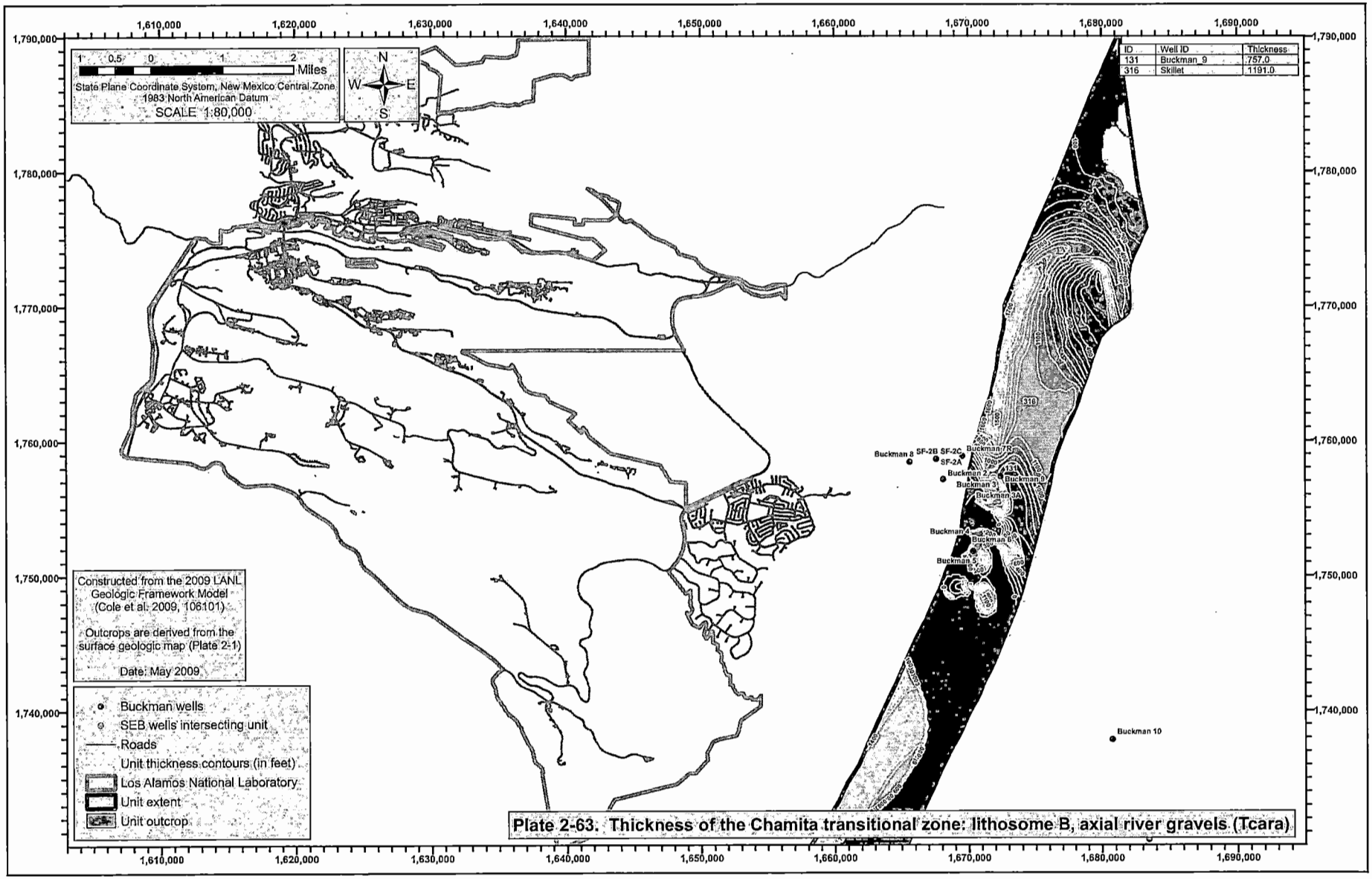


Plate 2-63. Thickness of the Chamita transitional zone: lithosome B, axial river gravels (Tcara)

96166

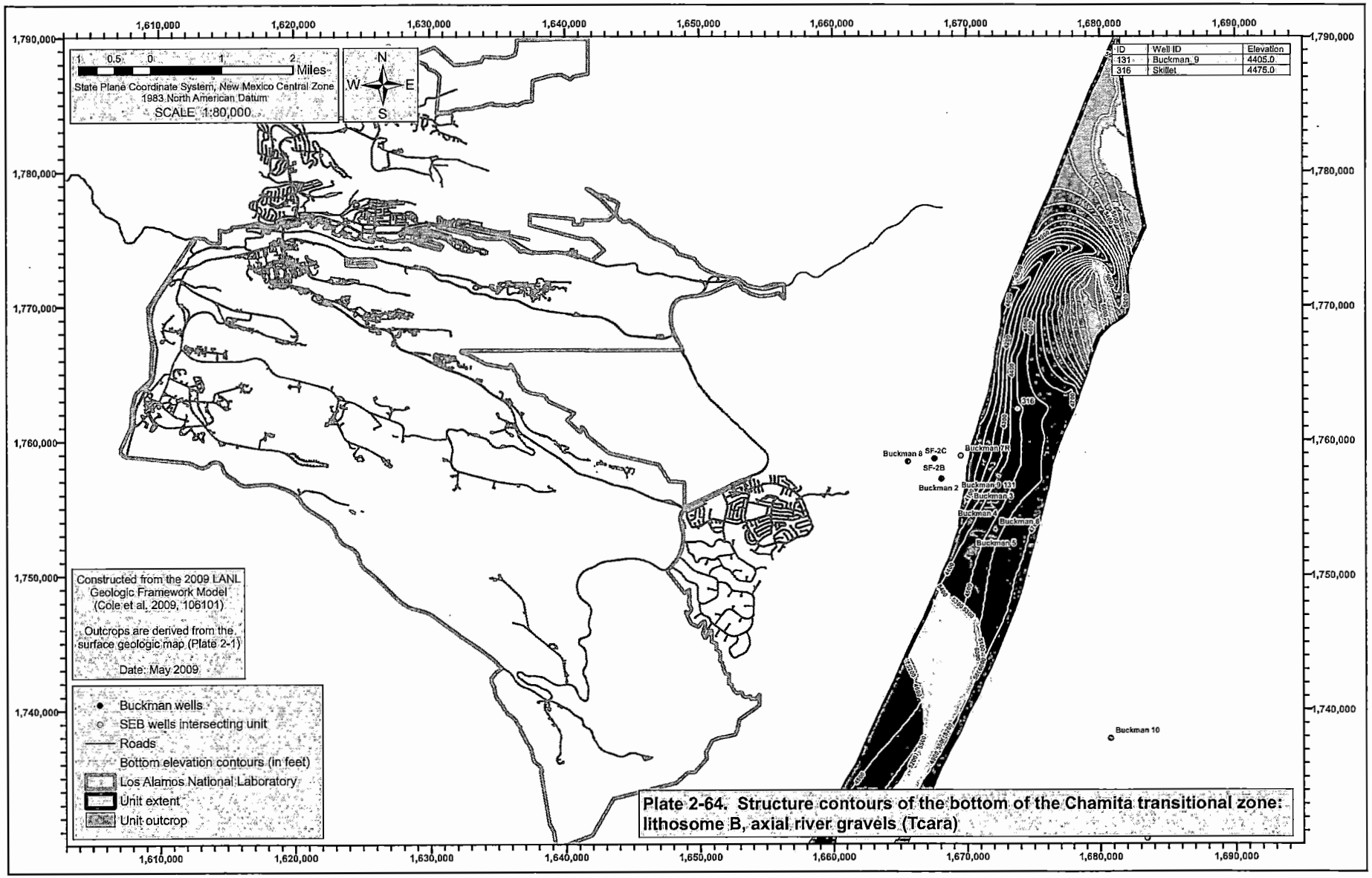


Plate 2-64. Structure contours of the bottom of the Chamita transitional zone: lithosome B, axial river gravels (Tcara)

: 06167

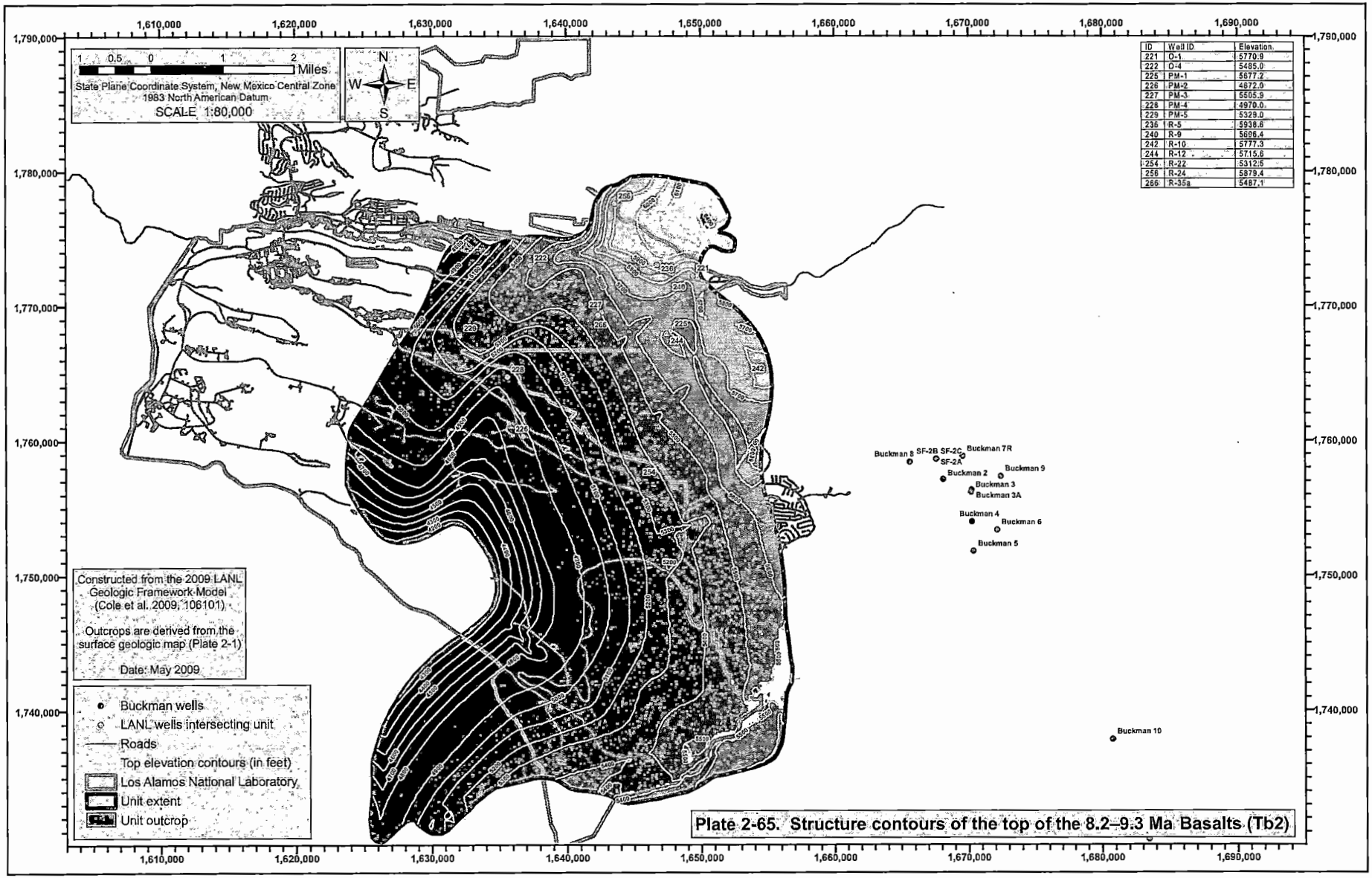
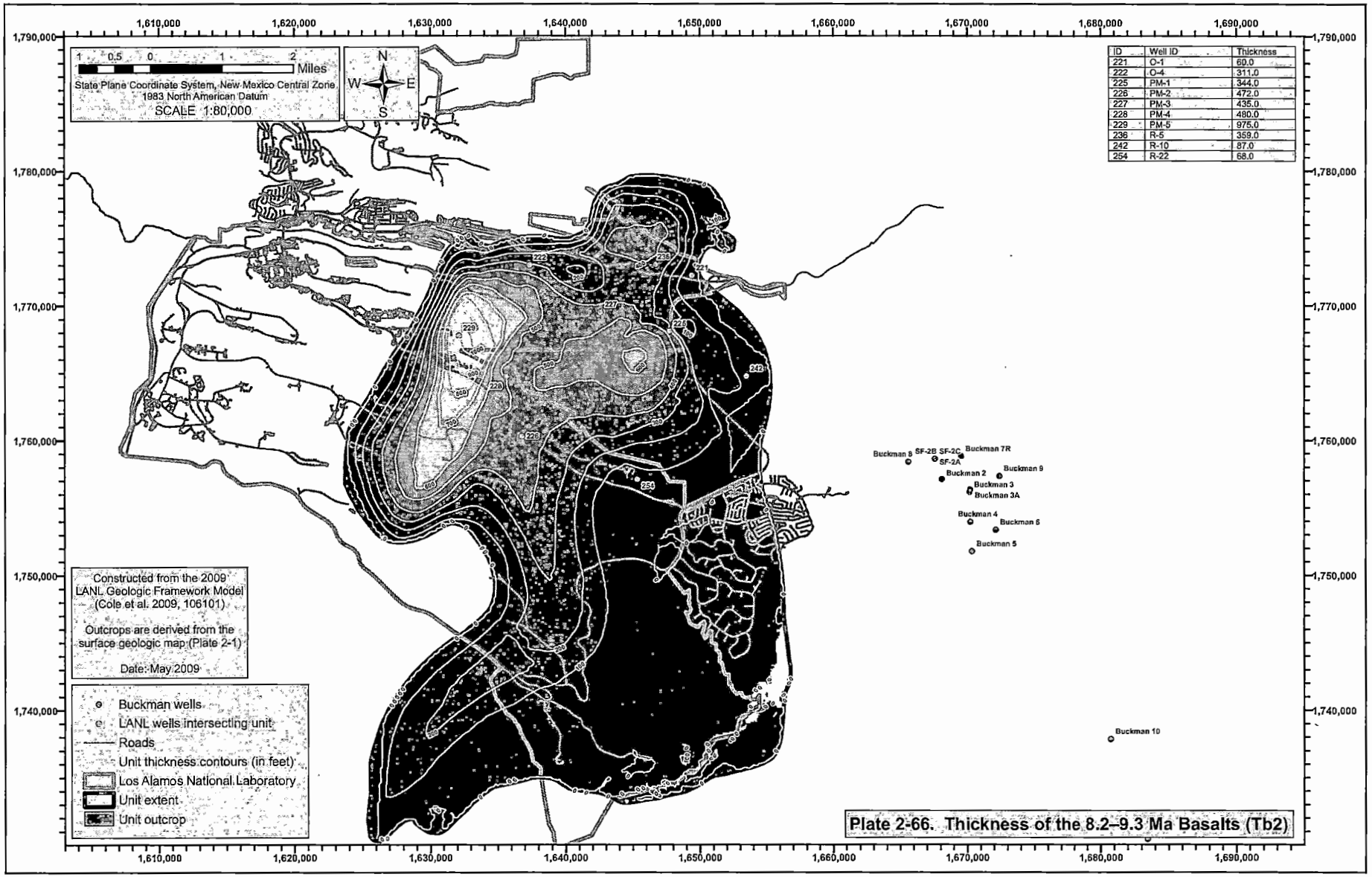


Plate 2-65. Structure contours of the top of the 8.2–9.3 Ma Basalts (Tb2)

5568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1,760,000
1,750,000
1,740,000
1 0.5 0 1 2 Miles
State Plane Coordinate System, New Mexico Central Zone
1983 North American Datum
SCALE 1:80,000
N
W E
S
ID | Well ID | Thickness
221 | O-1 | 60.0
222 | O-4 | 311.0
225 | PM-1 | 344.0
226 | PM-2 | 472.0
227 | PM-3 | 435.0
228 | PM-4 | 480.0
229 | PM-5 | 975.0
236 | R-5 | 359.0
242 | R-10 | 87.0
254 | R-22 | 68.0
Buckman 8
SF-2B
SF-2C
Buckman 7R
SF-2A
Buckman 9
Buckman 2
Buckman 3
Buckman 3A
Buckman 4
Buckman 6
Buckman 5
Buckman 10
Constructed from the 2009 LANL Geologic Framework Model (Cole et al. 2009, 106101)
Outcrops are derived from the surface geologic map (Plate 2-1)
Date: May 2009
Buckman wells
LANL wells intersecting unit
Roads
Unit thickness contours (in feet)
Los Alamos National Laboratory
Unit extent
Unit outcrop
Plate 2-66. Thickness of the 8.2–9.3 Ma Basalts (Tb2)

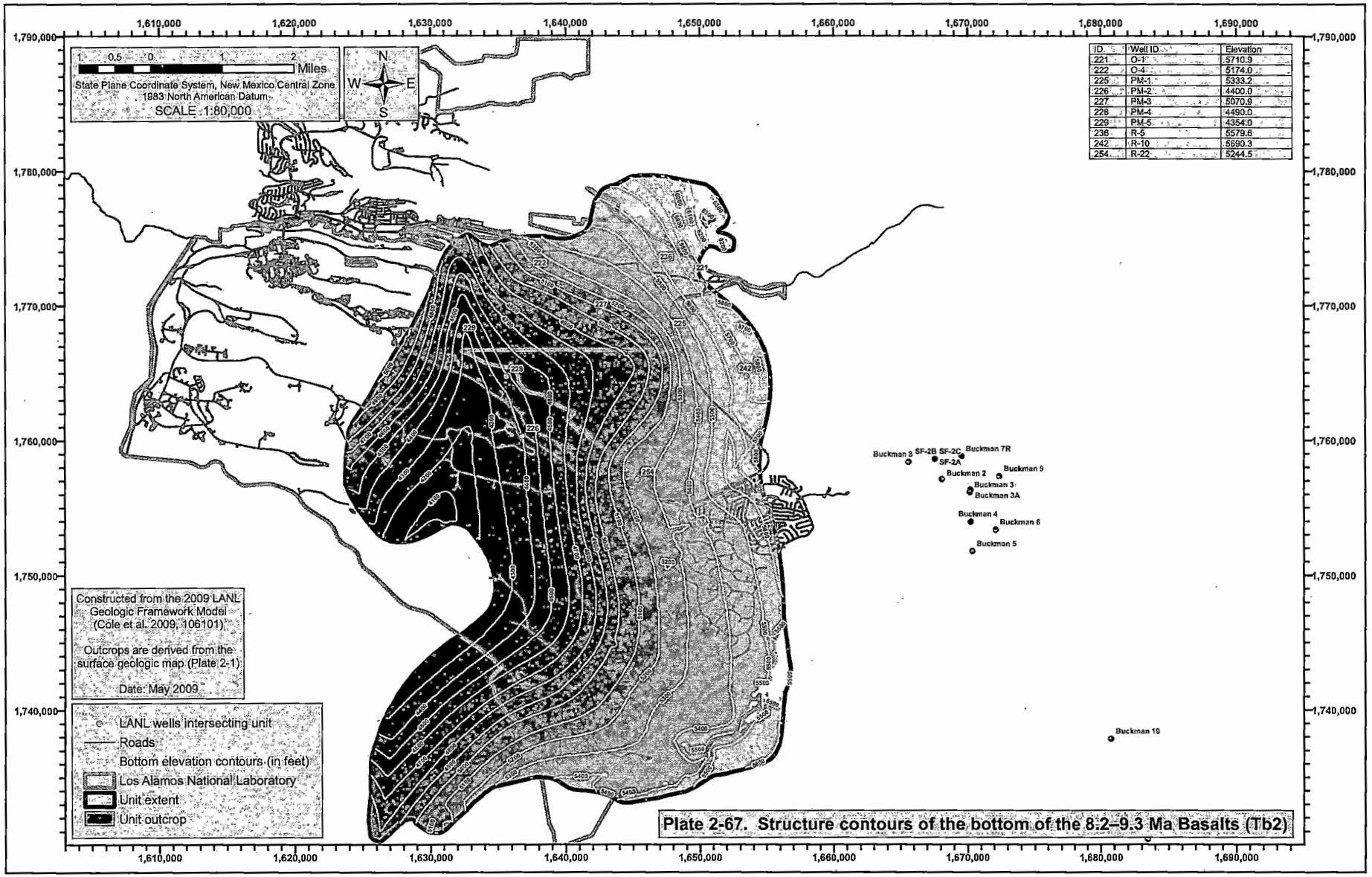


Plate 2-67. Structure contours of the bottom of the 8.2–9.3 Ma Basalts (Tb2)

: 06170

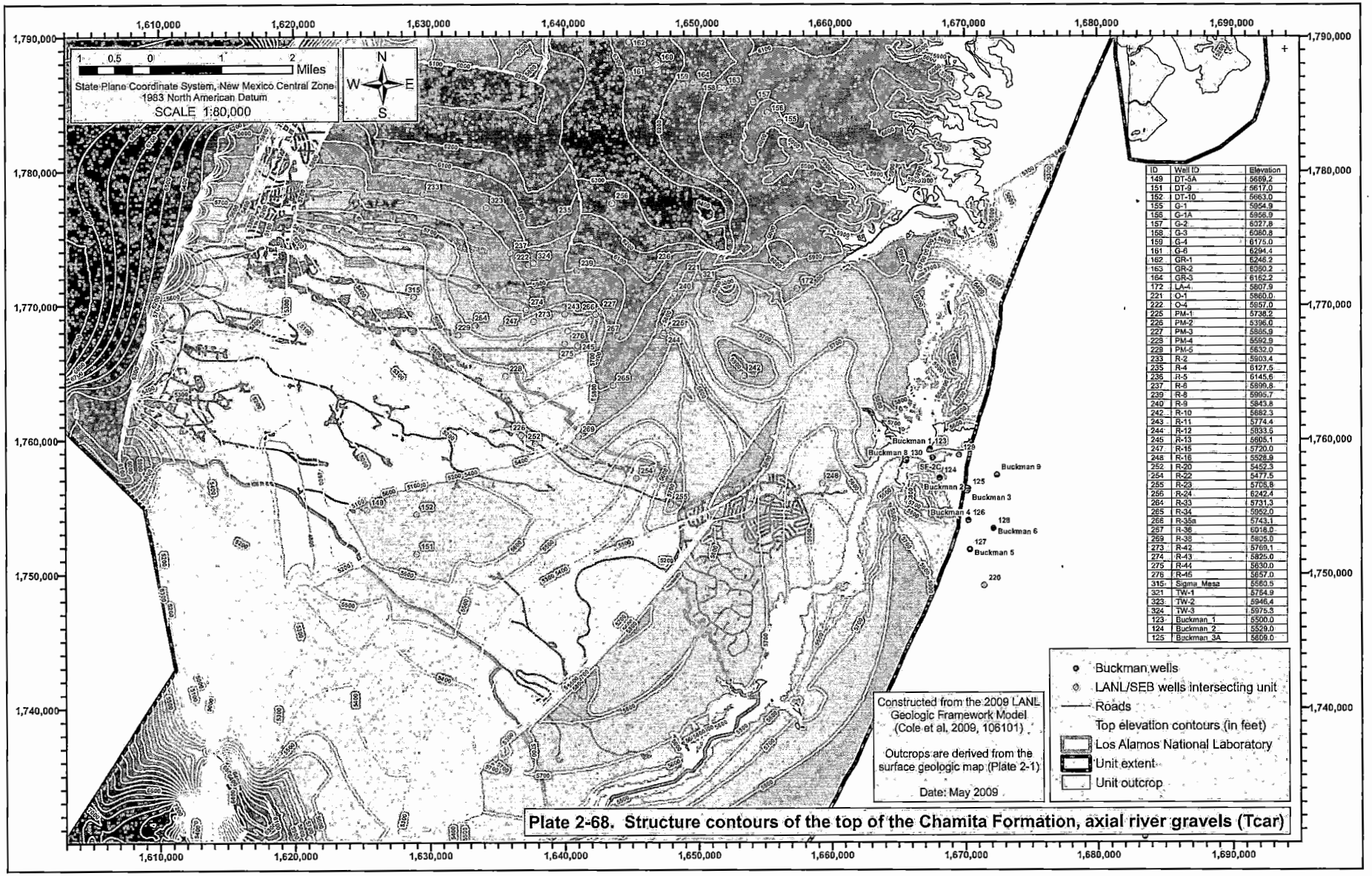


Plate 2-68. Structure contours of the top of the Chamita Formation, axial river gravels (Tcar)

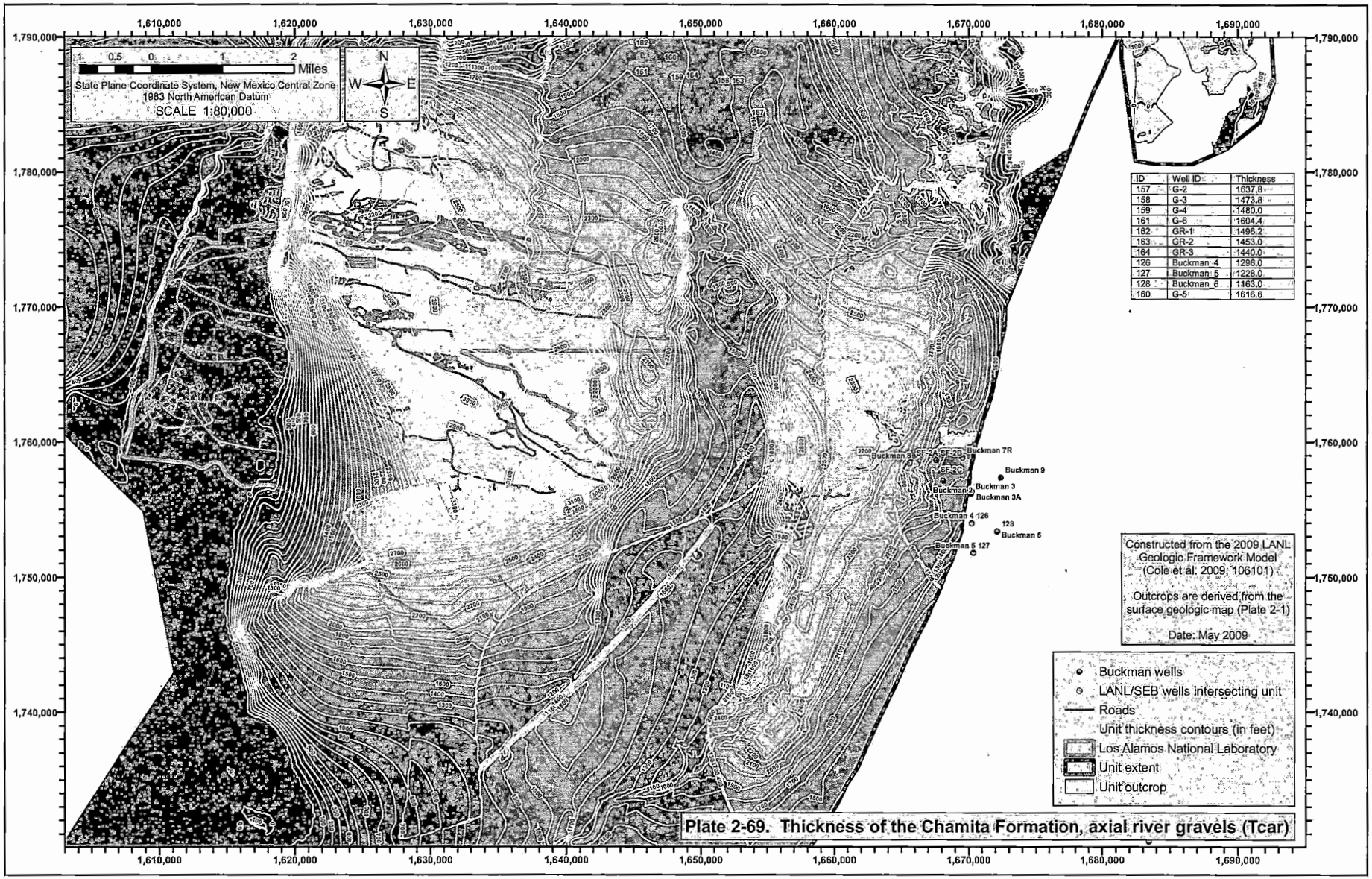


Plate 2-69. Thickness of the Chamita Formation, axial river gravels (Tcar)

09172

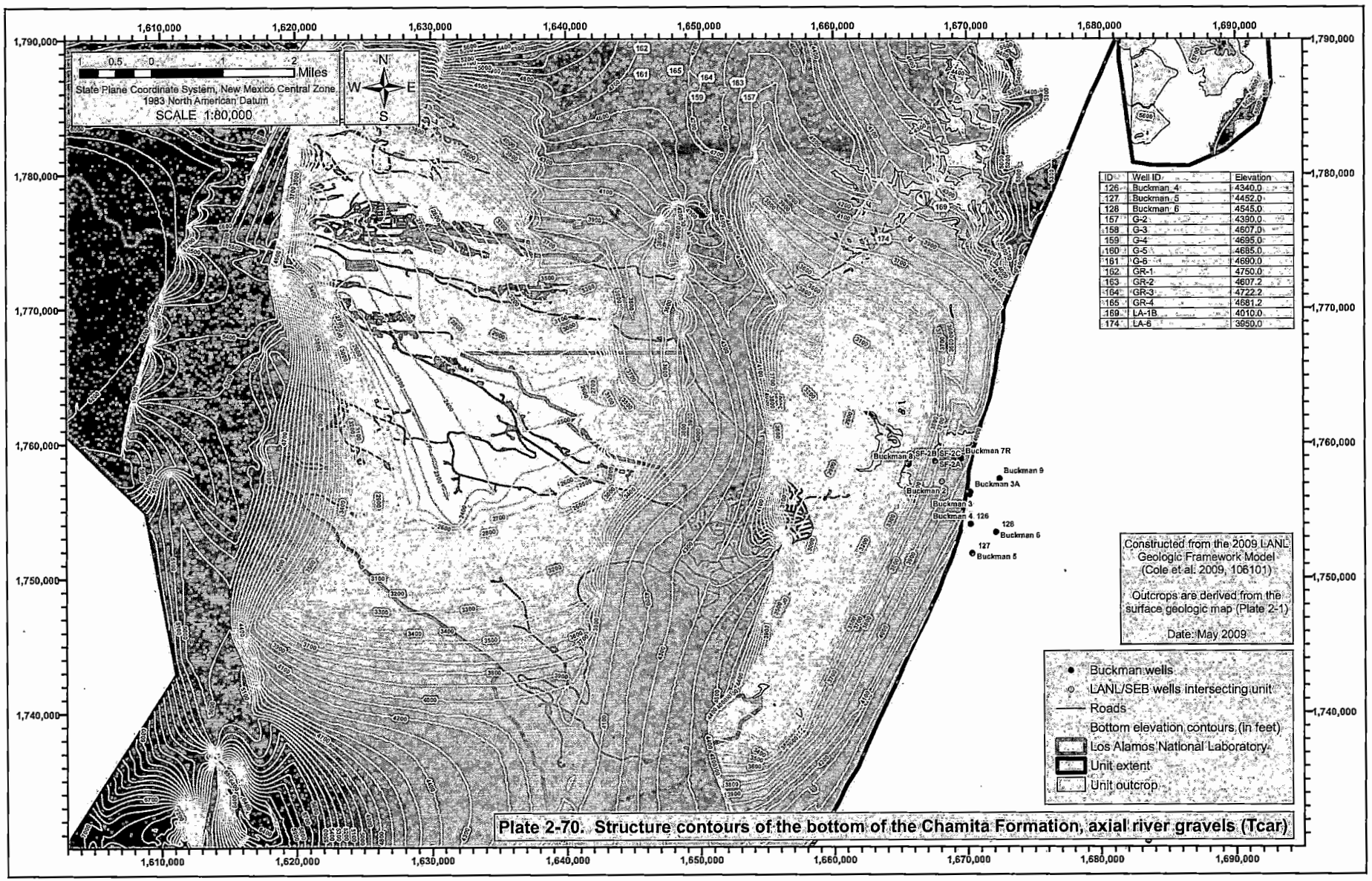


Plate 2-70. Structure contours of the bottom of the Chamita Formation, axial river gravels (Tcar)

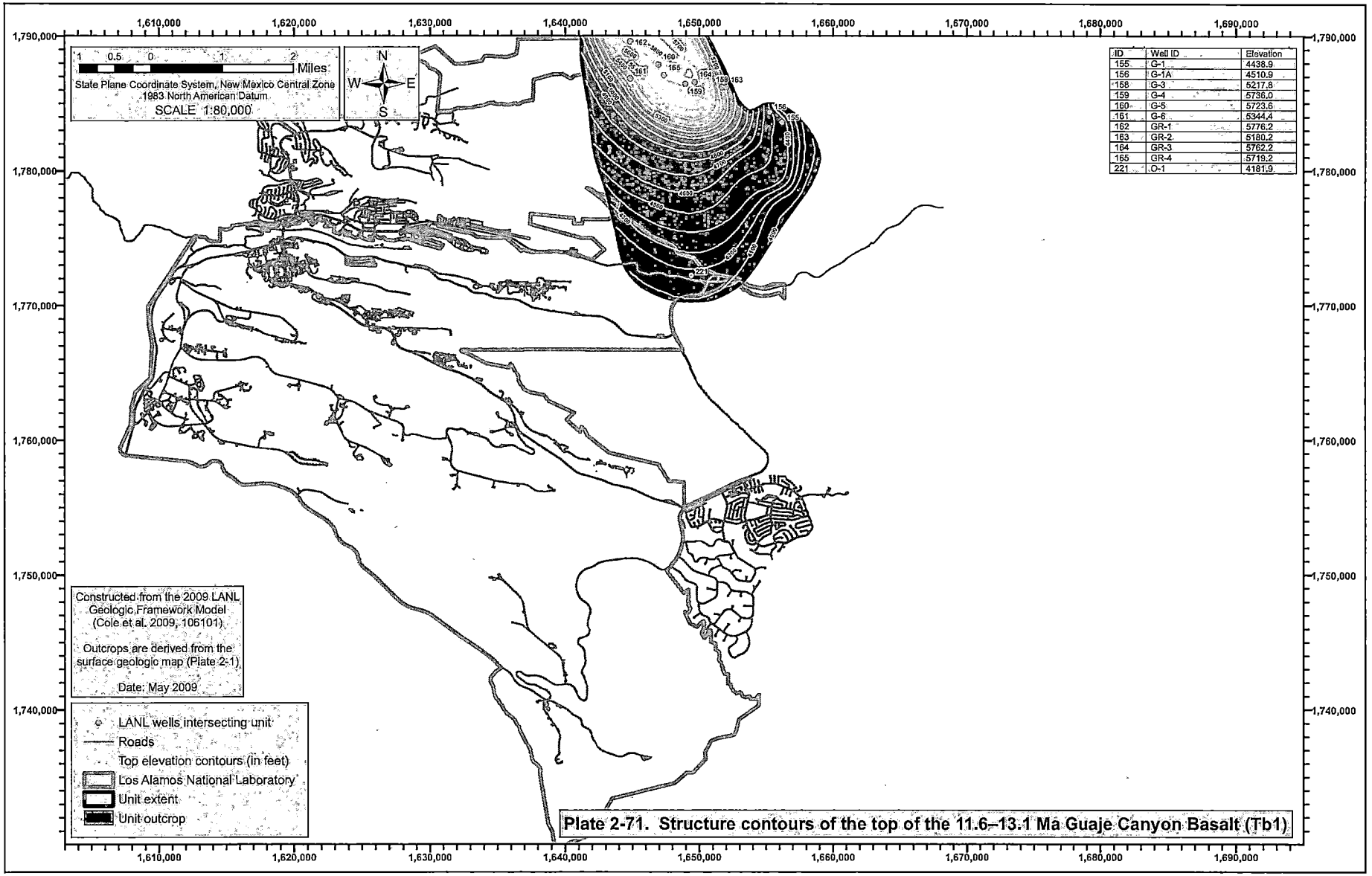
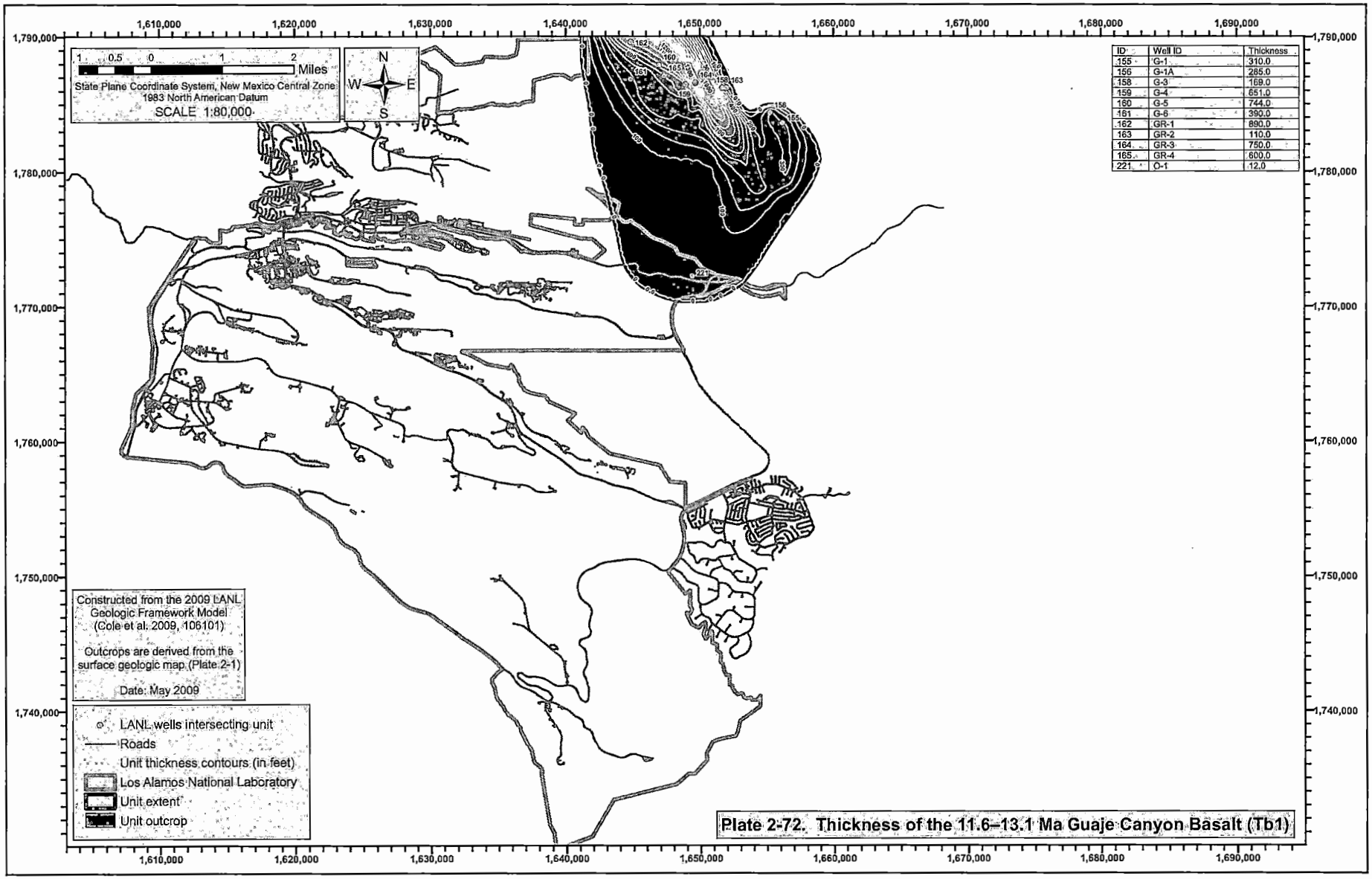


Plate 2-71. Structure contours of the top of the 11.6–13.1 Ma Guaje Canyon Basalt (Tb1)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1,760,000
1,750,000
1,740,000
1 0.5 0 1 2
Miles
State Plane Coordinate System, New Mexico Central Zone
1983 North American Datum
SCALE 1:80,000
N
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ID Well ID Thickness
155 G-1 310.0
156 G-1A 285.0
158 G-3 169.0
159 G-4 651.0
160 G-5 744.0
161 G-6 390.0
162 GR-1 890.0
163 GR-2 110.0
164 GR-3 750.0
165 GR-4 600.0
221 O-1 12.0
Constructed from the 2009 LANL Geologic Framework Model (Cole et al. 2009, 106101)
Outcrops are derived from the surface geologic map (Plate 2-1)
Date: May 2009
LANL wells intersecting unit
Roads
Unit thickness contours (in feet)
Los Alamos National Laboratory
Unit extent
Unit outcrop
Plate 2-72. Thickness of the 11.6–13.1 Ma Guaje Canyon Basalt (Tb1)

052575

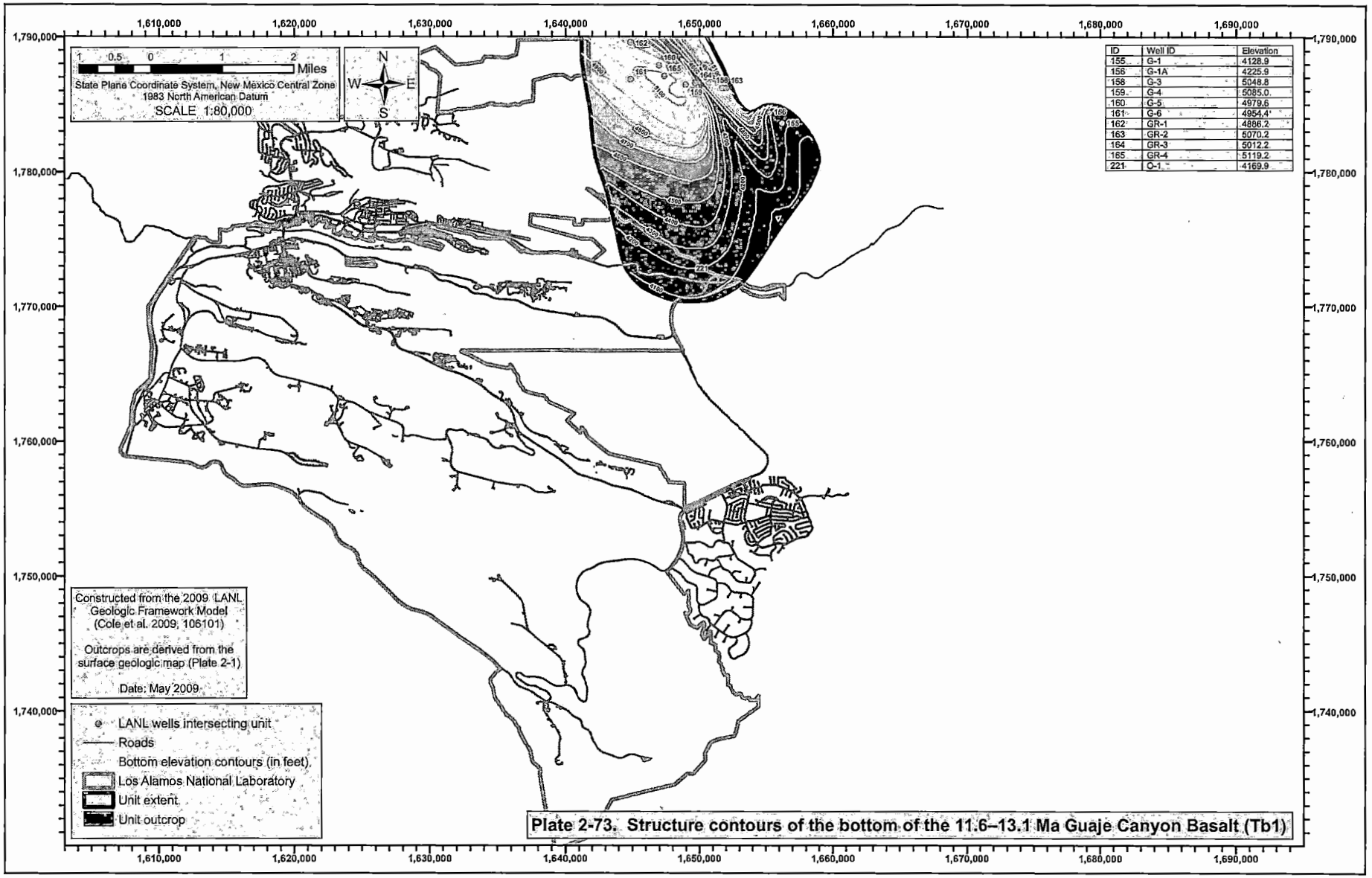


Plate 2-73. Structure contours of the bottom of the 11.6–13.1 Ma Guaje Canyon Basalt (Tb1)

96175

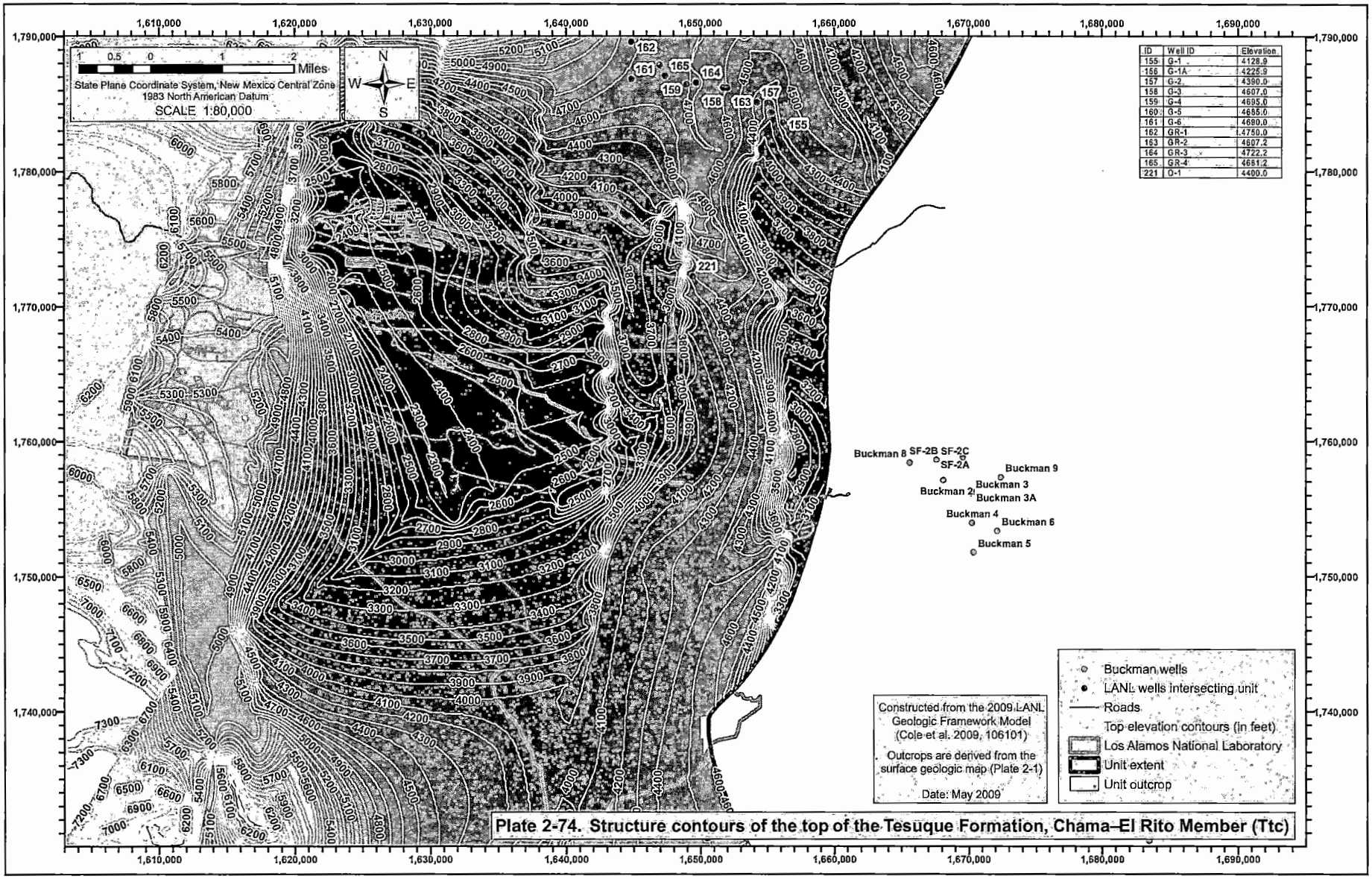


Plate 2-74. Structure contours of the top of the Tesuque Formation, Chama–El Rito Member (Ttc)

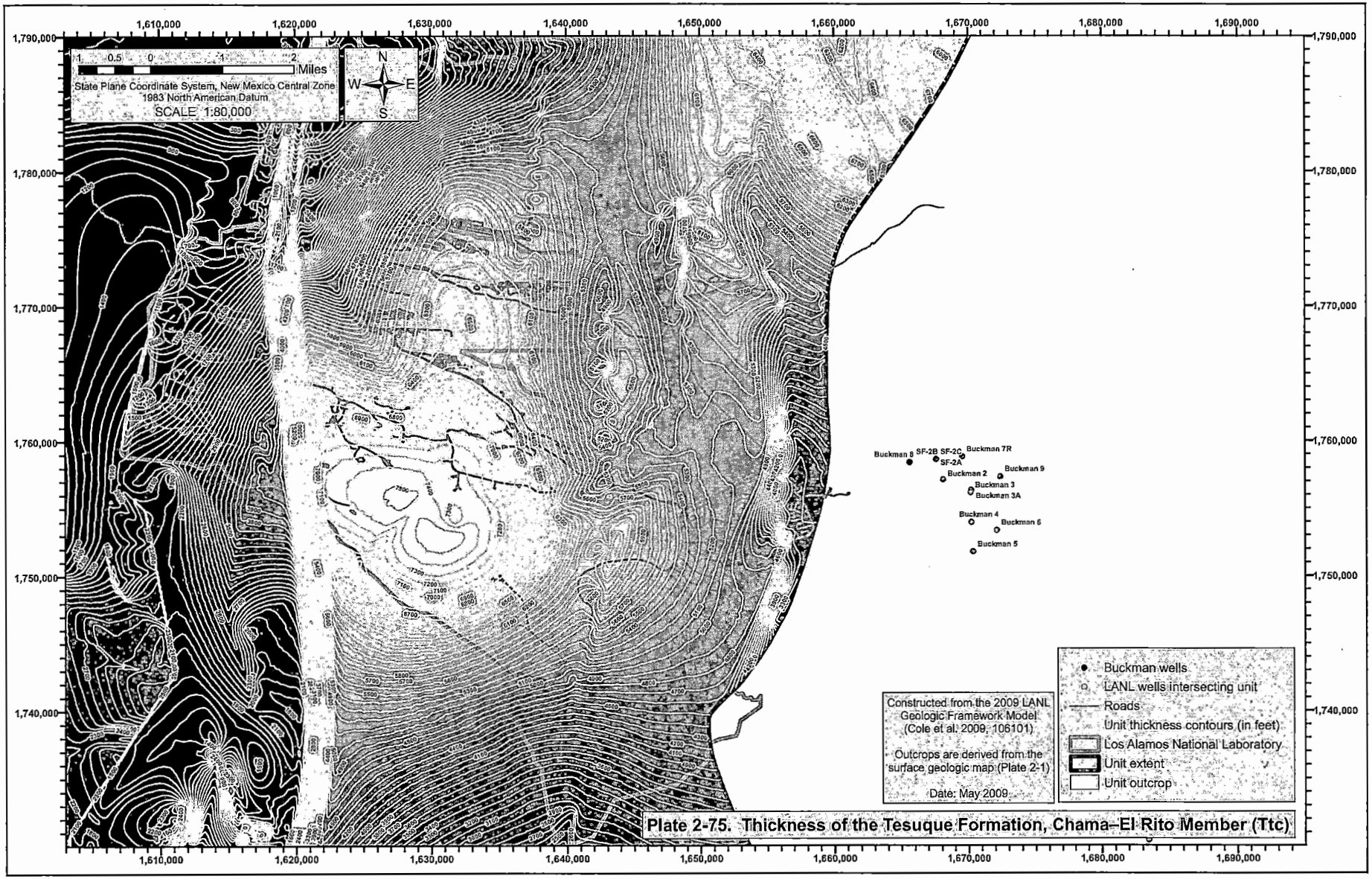


Plate 2-75. Thickness of the Tesuque Formation, Chama–El Rito Member (Ttc)

09179

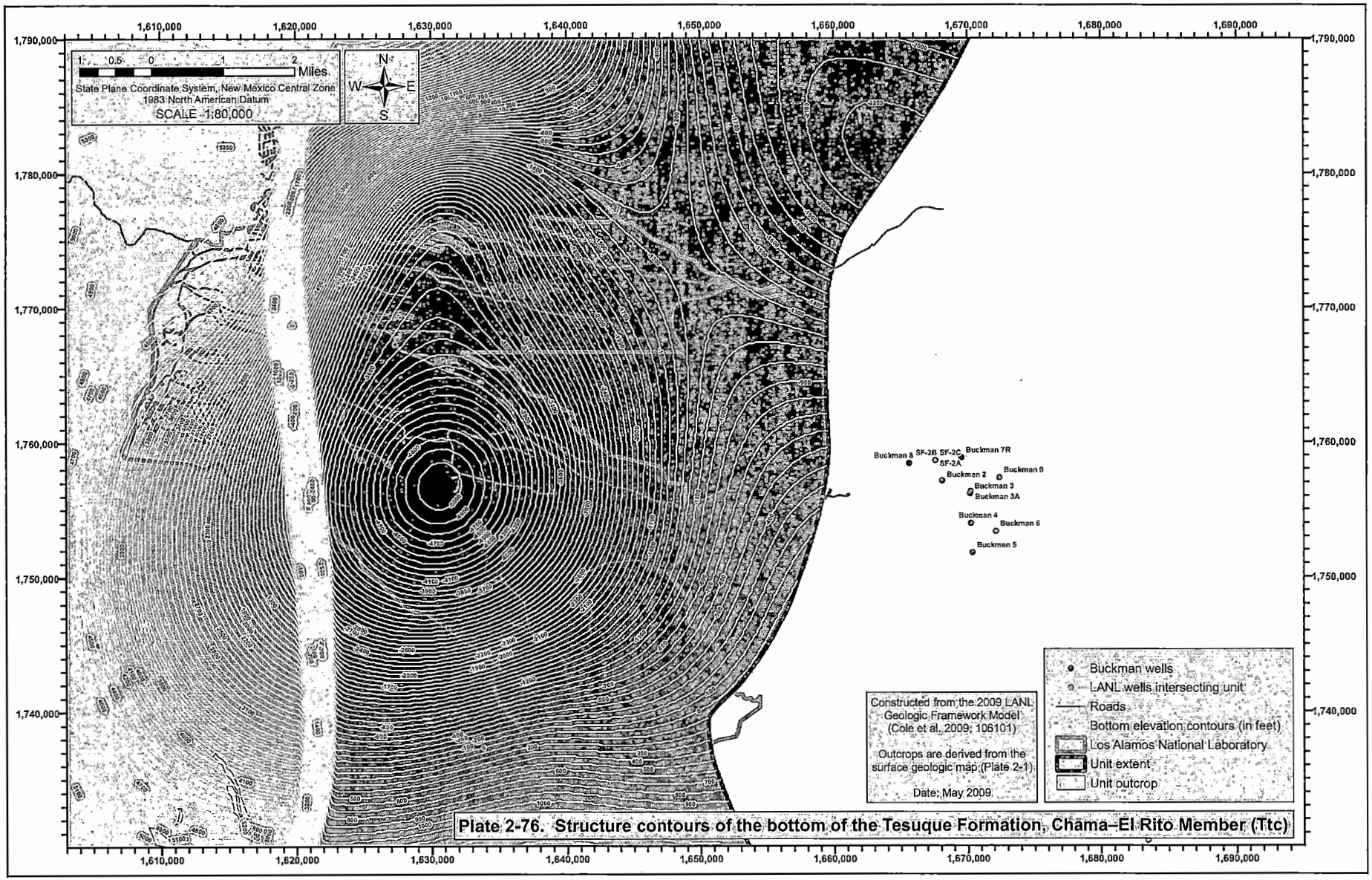


Plate 2-76. Structure contours of the bottom of the Tesuque Formation, Chama–El Rito Member (Ttc)

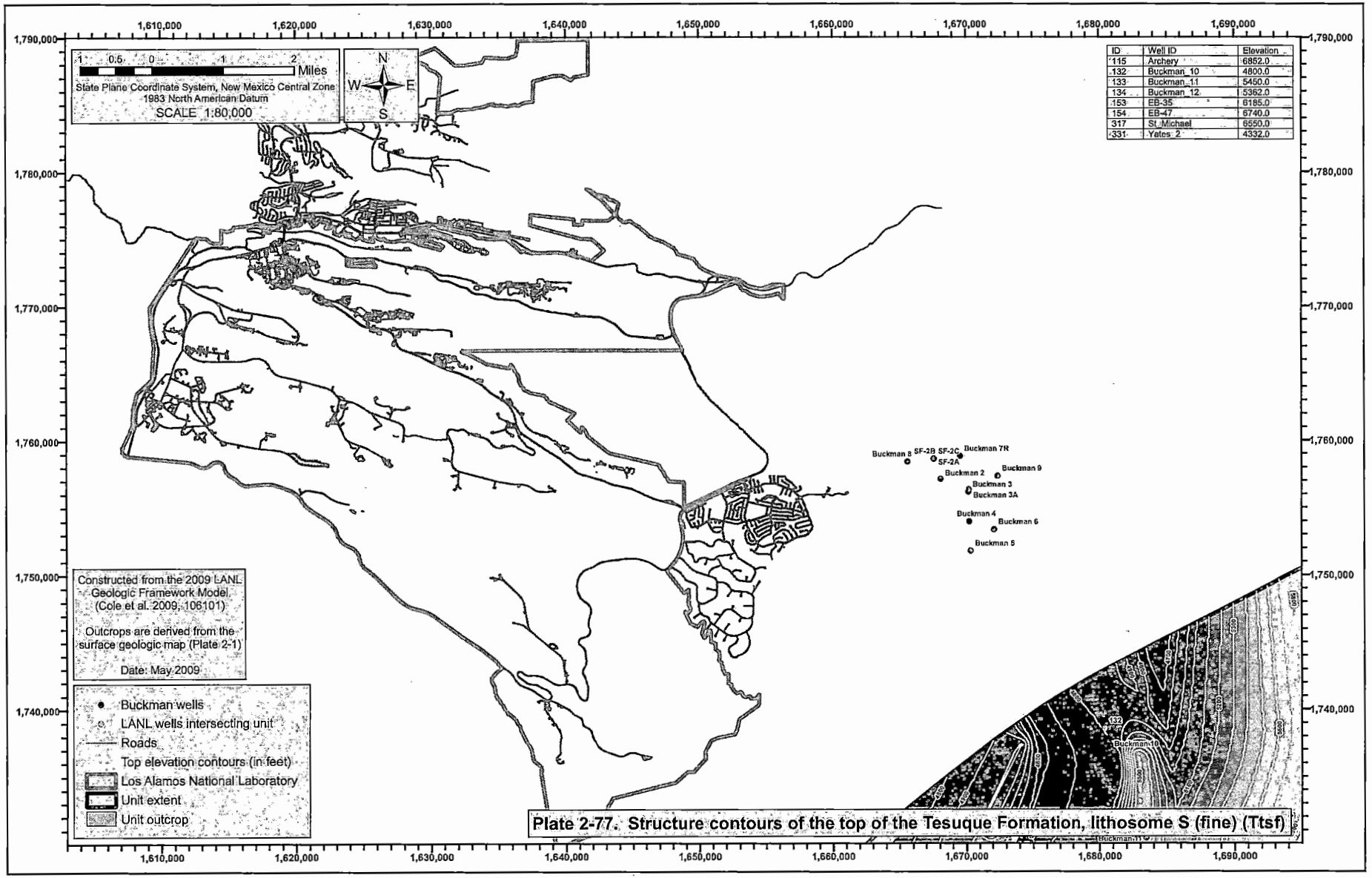


Plate 2-77. Structure contours of the top of the Tesuque Formation, lithosome S (fine) (Ttsf)

091169

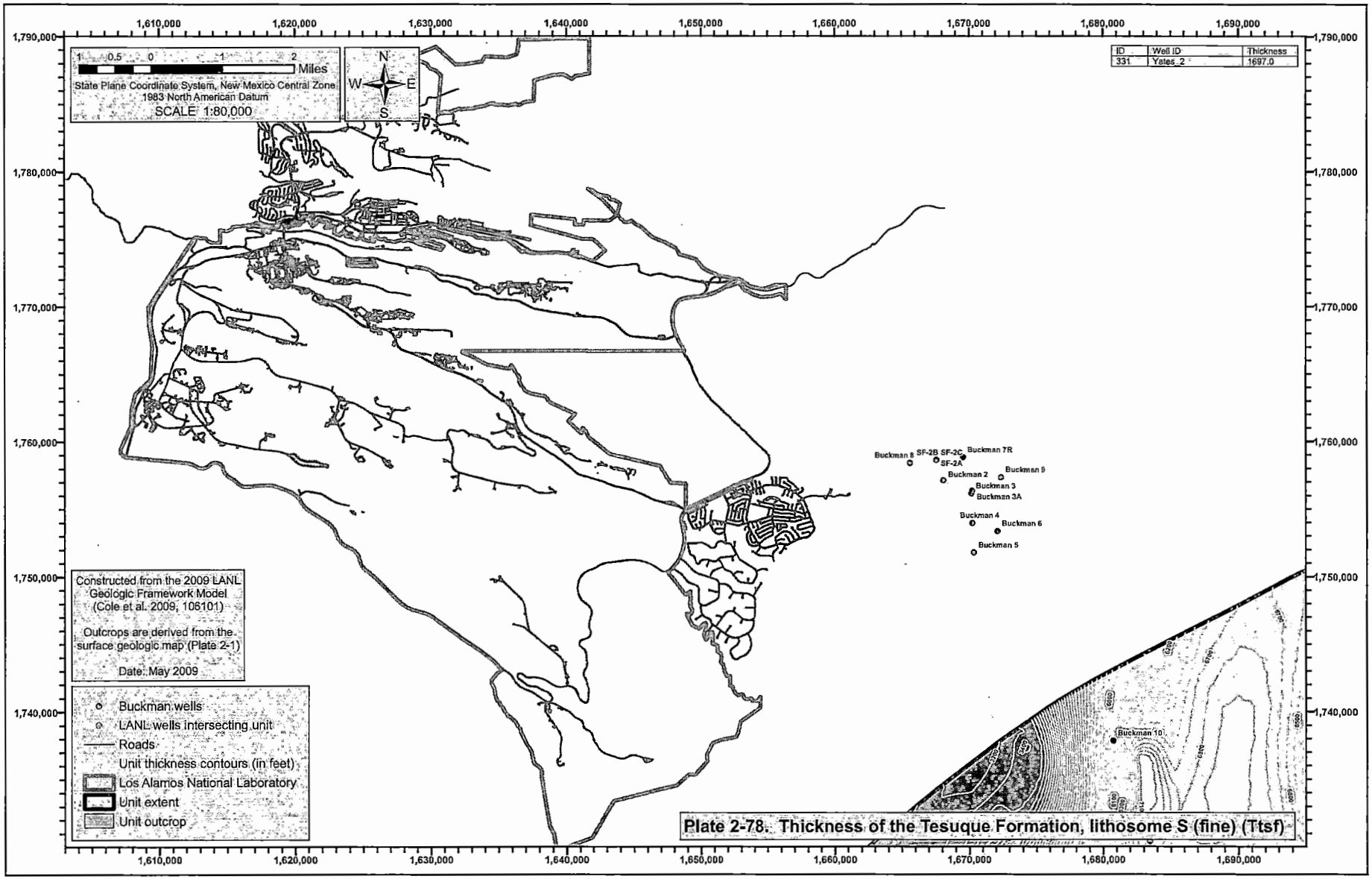


Plate 2-78. Thickness of the Tesuque Formation, lithosome S (fine) (Ttsf)

09194

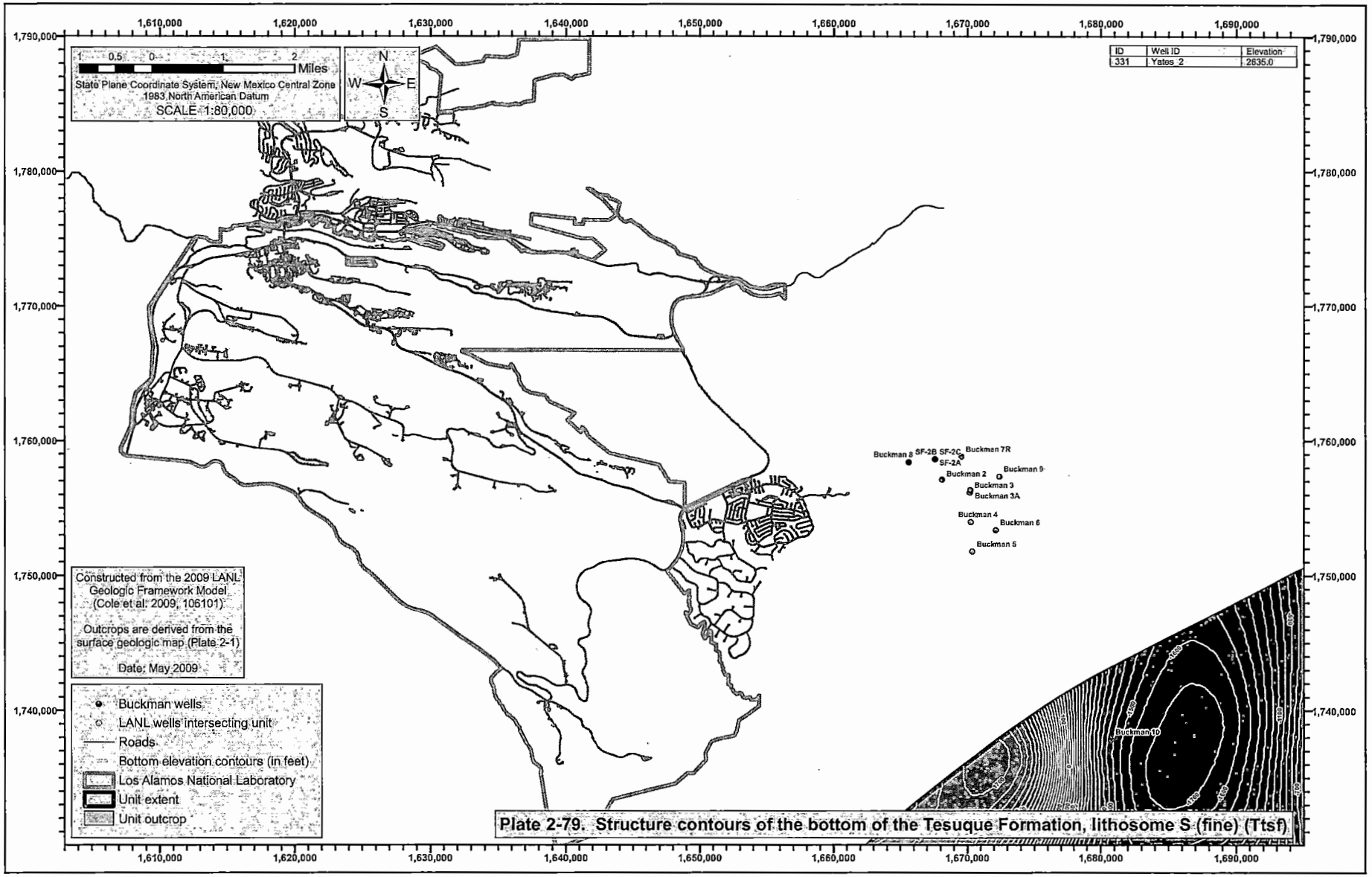


Plate 2-79. Structure contours of the bottom of the Tesuque Formation, lithosome S (fine) (Ttsf)

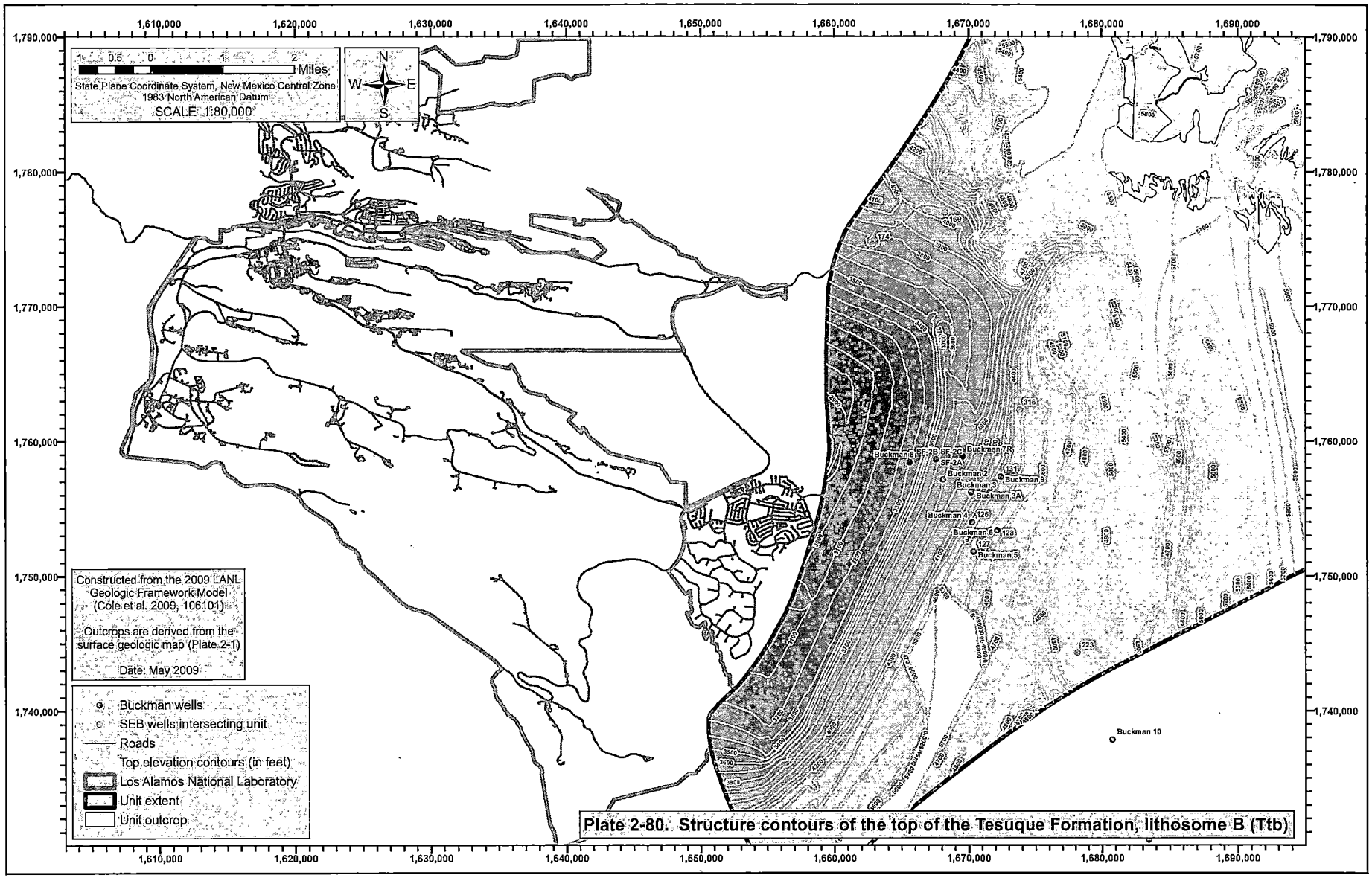


Plate 2-80. Structure contours of the top of the Tesuque Formation, lithosome B (Ttb)

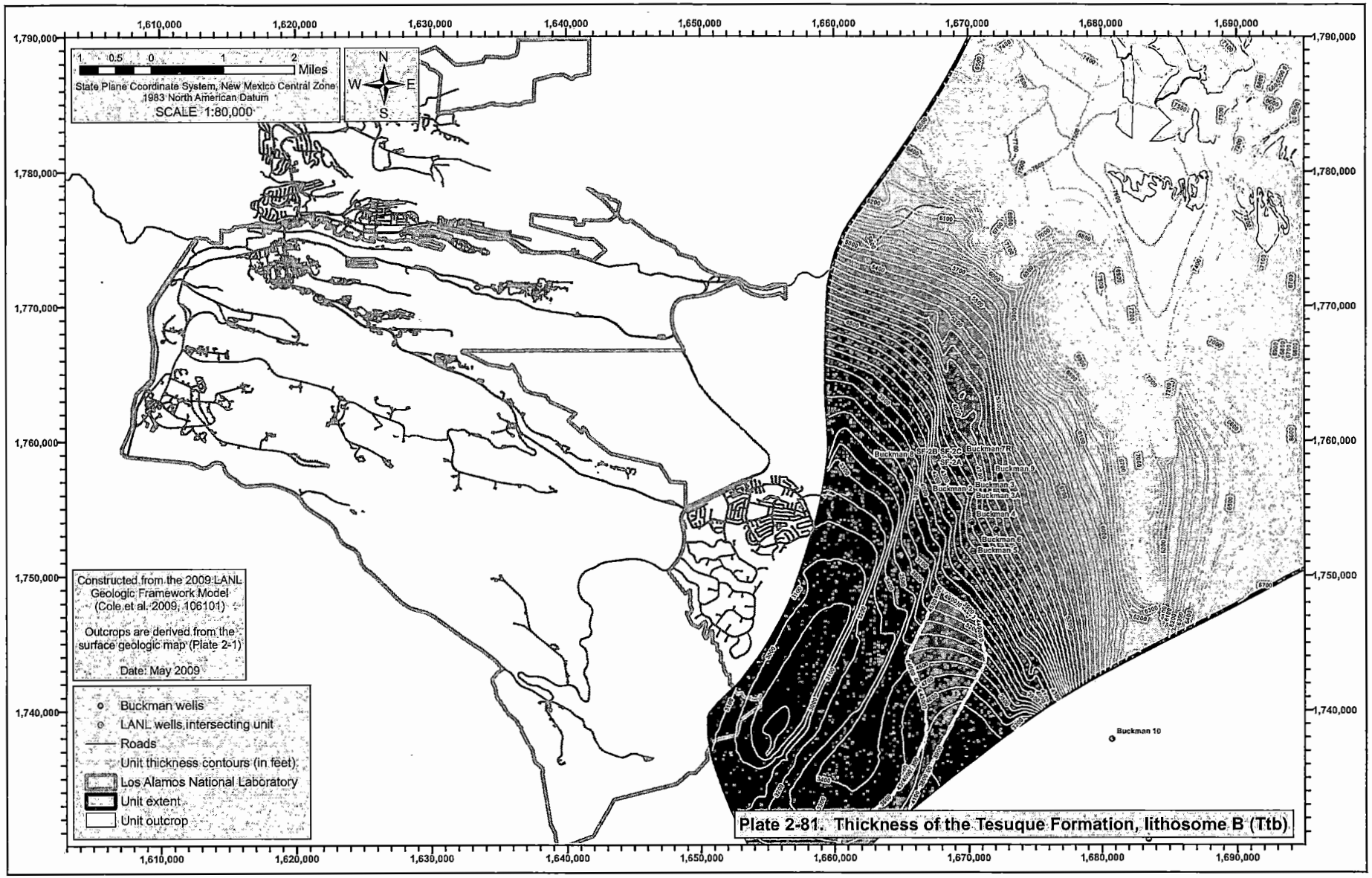
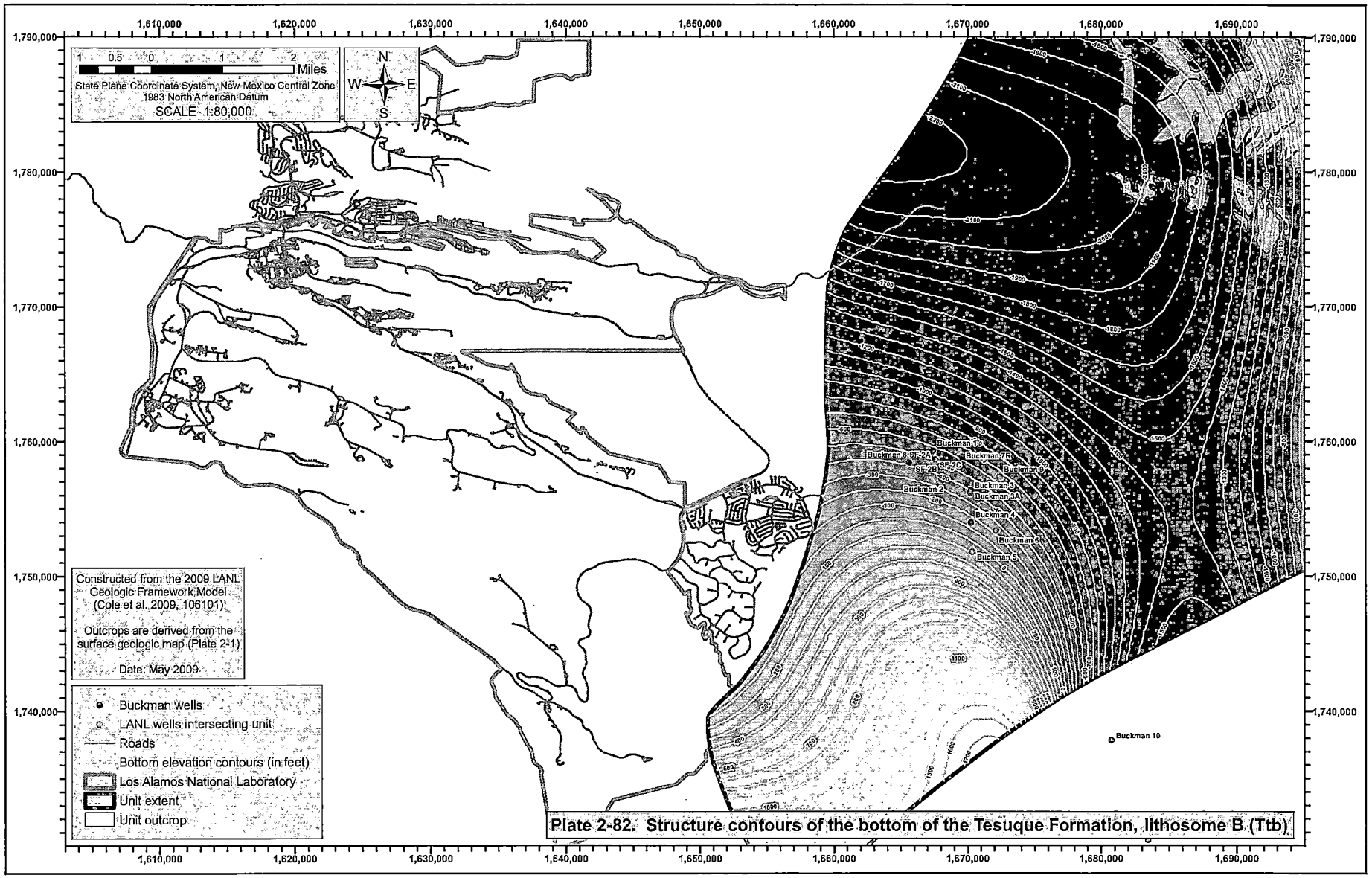


Plate 2-81. Thickness of the Tesuque Formation, lithosome B (Ttb)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1983 North American Datum
SCALE 1:80,000
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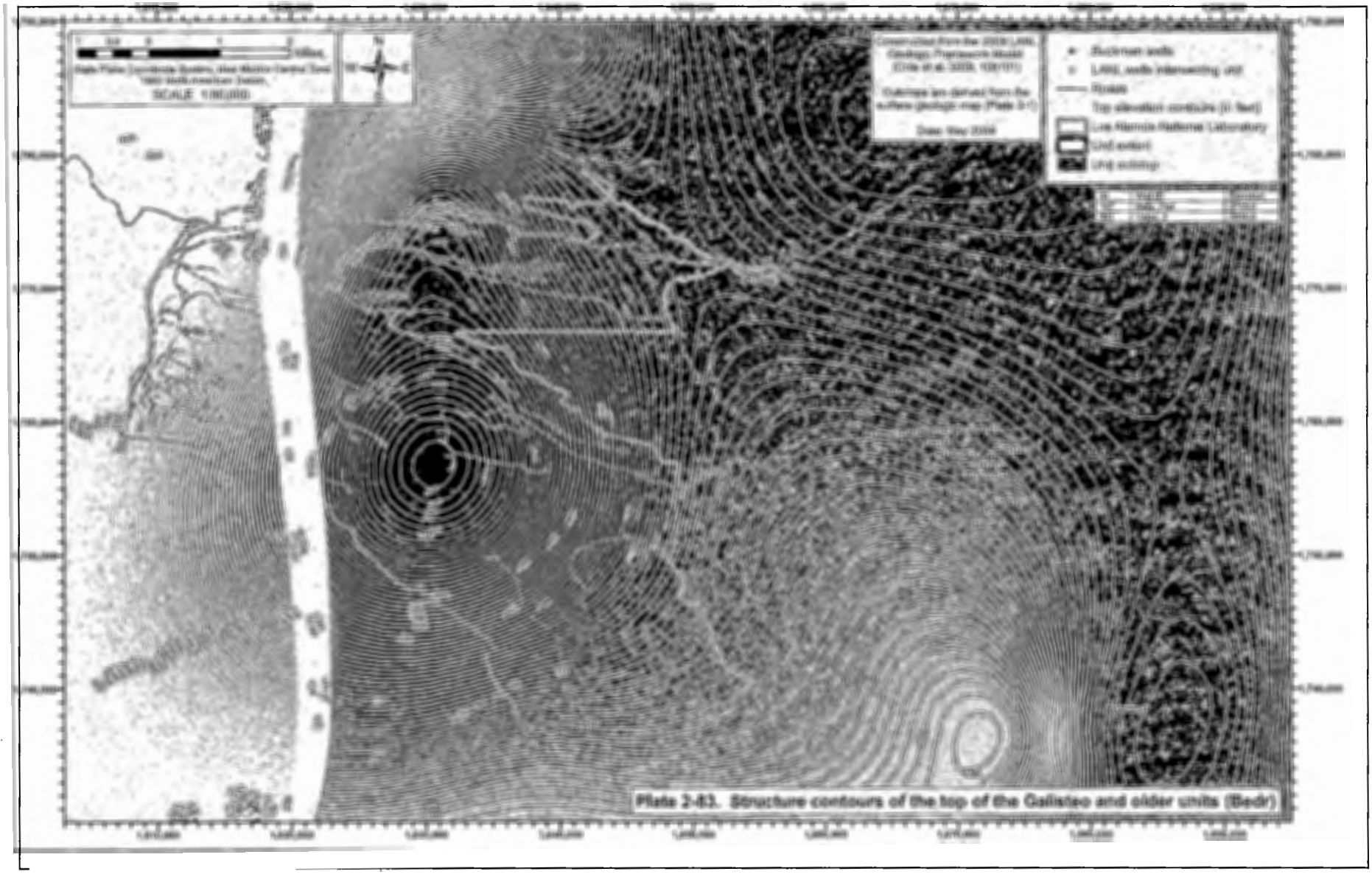
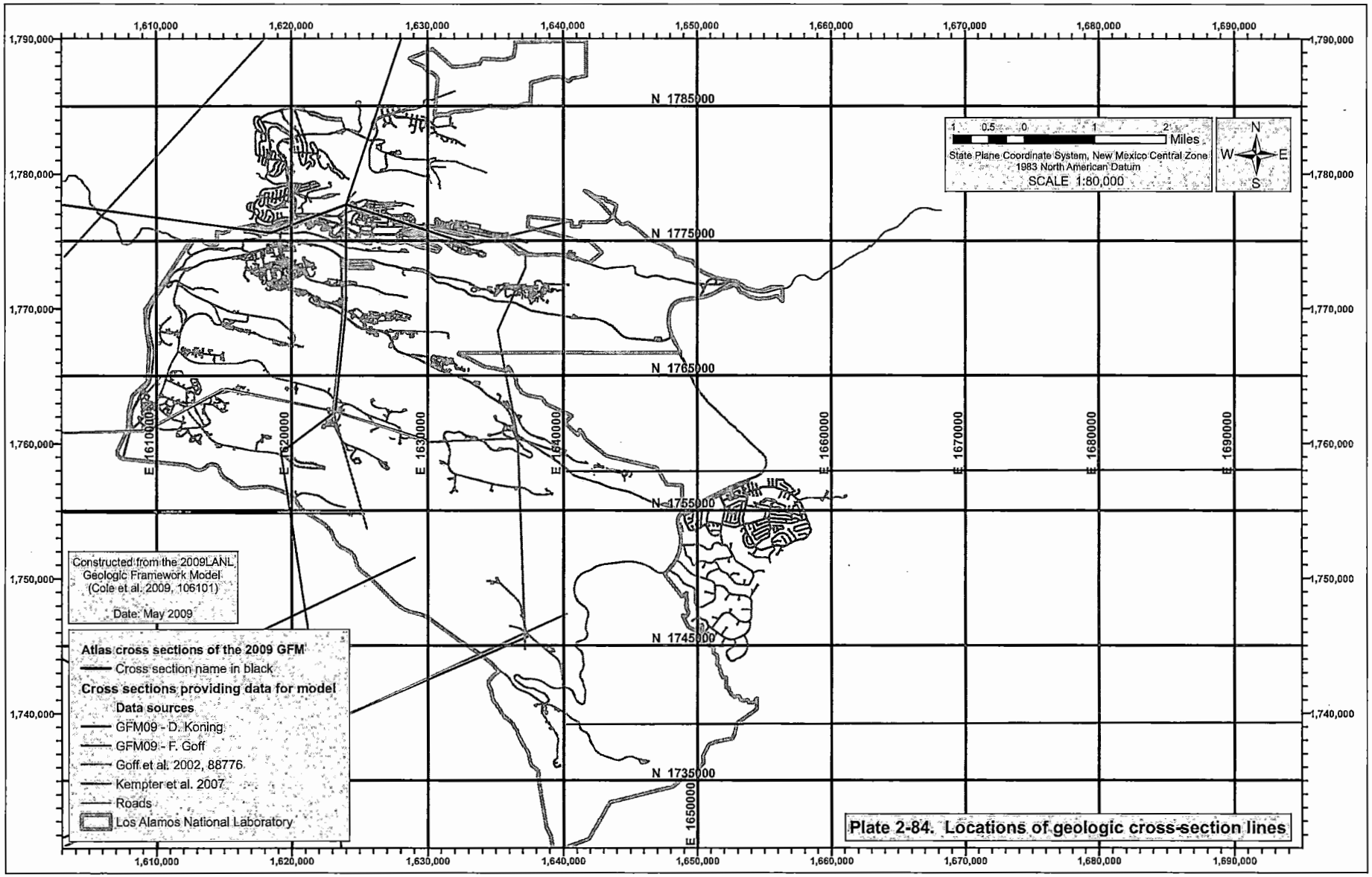
Constructed from the 2009 LANL Geologic Framework Model (Cole et al. 2009, 106101)
Outcrops are derived from the surface geologic map (Plate 2-1)
Date: May 2009
Buckman wells
LANL wells intersecting unit
Roads
Bottom elevation contours (in feet)
Los Alamos National Laboratory
Unit extent
Unit outcrop
Buckman 10
Plate 2-82. Structure contours of the bottom of the Tesuque Formation, lithosome B (Ttb)


SCALE 1:80,000
Plate 2-83. Structure contours of the top of the Galisteo and older units (Bedr)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State Plane Coordinate System, New Mexico Central Zone
1983 North American Datum
SCALE 1:80,000
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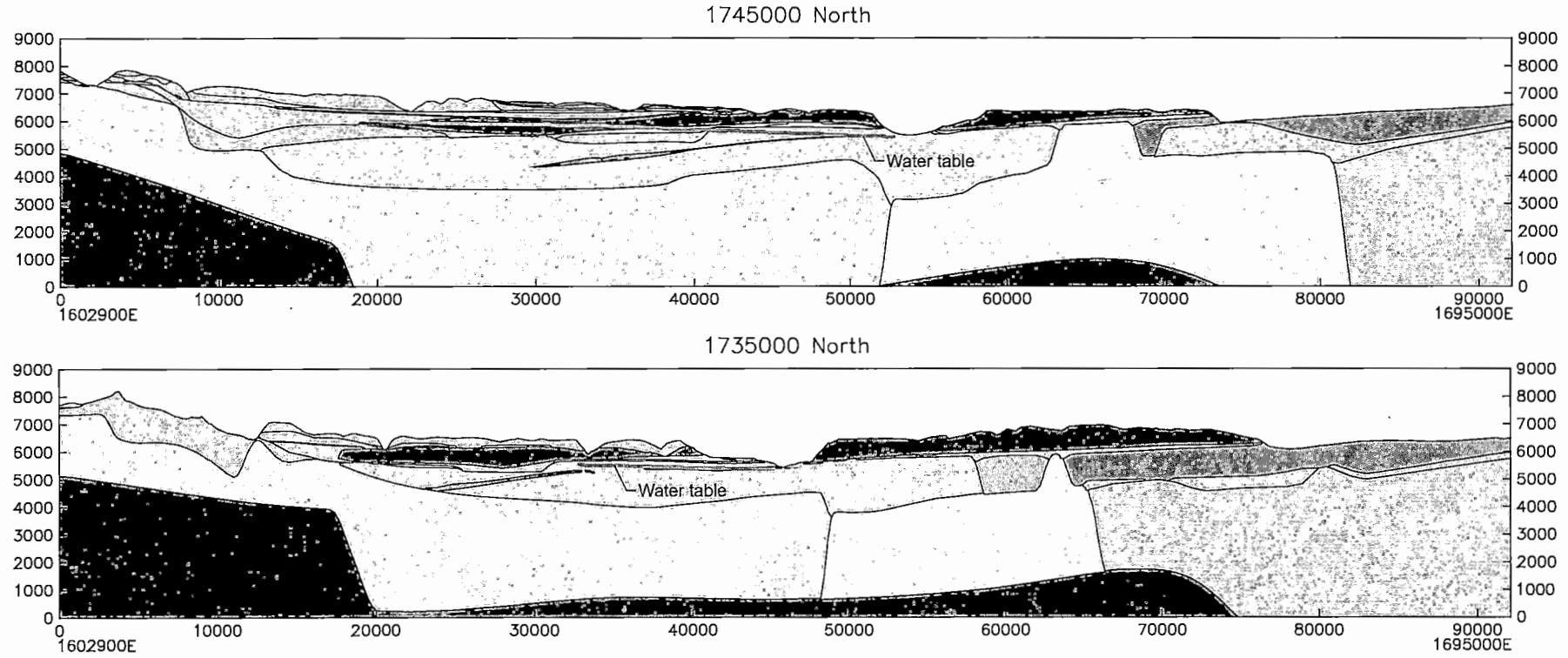
Constructed from the 2009LANL Geologic Framework Model (Cole et al. 2009, 106101)
Date: May 2009
Atlas cross sections of the 2009 GFM
Cross section name in black
Cross sections providing data for model
Data sources
GFM09 - D. Koning
GFM09 - F. Goff
Goff et al. 2002, 88776
Kempter et al. 2007
Roads
Los Alamos National Laboratory
Plate 2-84. Locations of geologic cross-section lines

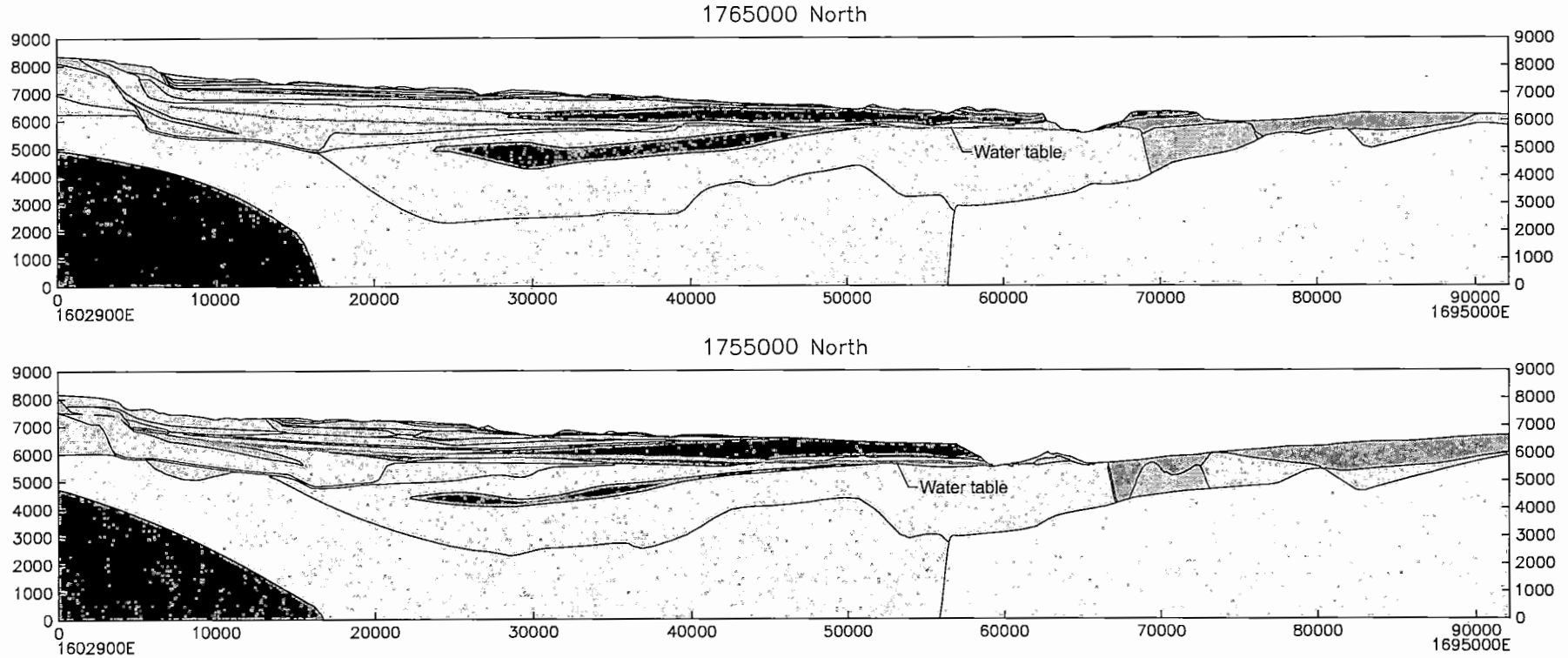


Note: Vertical exaggeration = 1.75x.

Constructed from the 2009 LANL Geologic Framework Model (Cole et al. 2009, 106101) Date: May 2009

Plate 2-85. Southern east-west cross-sections (N_1735000, N_1745000)

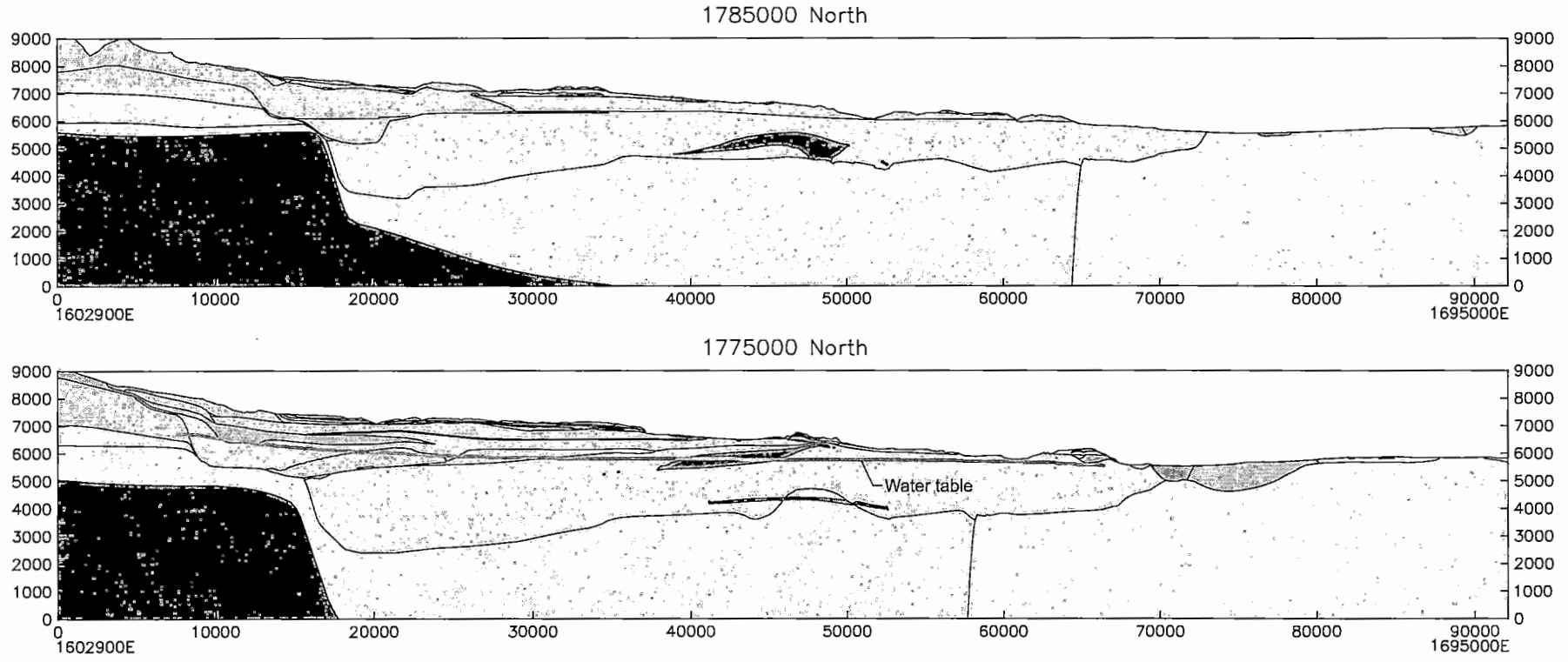
09-0188



Note: Vertical exaggeration = 1.75x.

Constructed from the 2009 LANL Geologic Framework Model (Cole et al., 2009, 106101). Date: May 2009

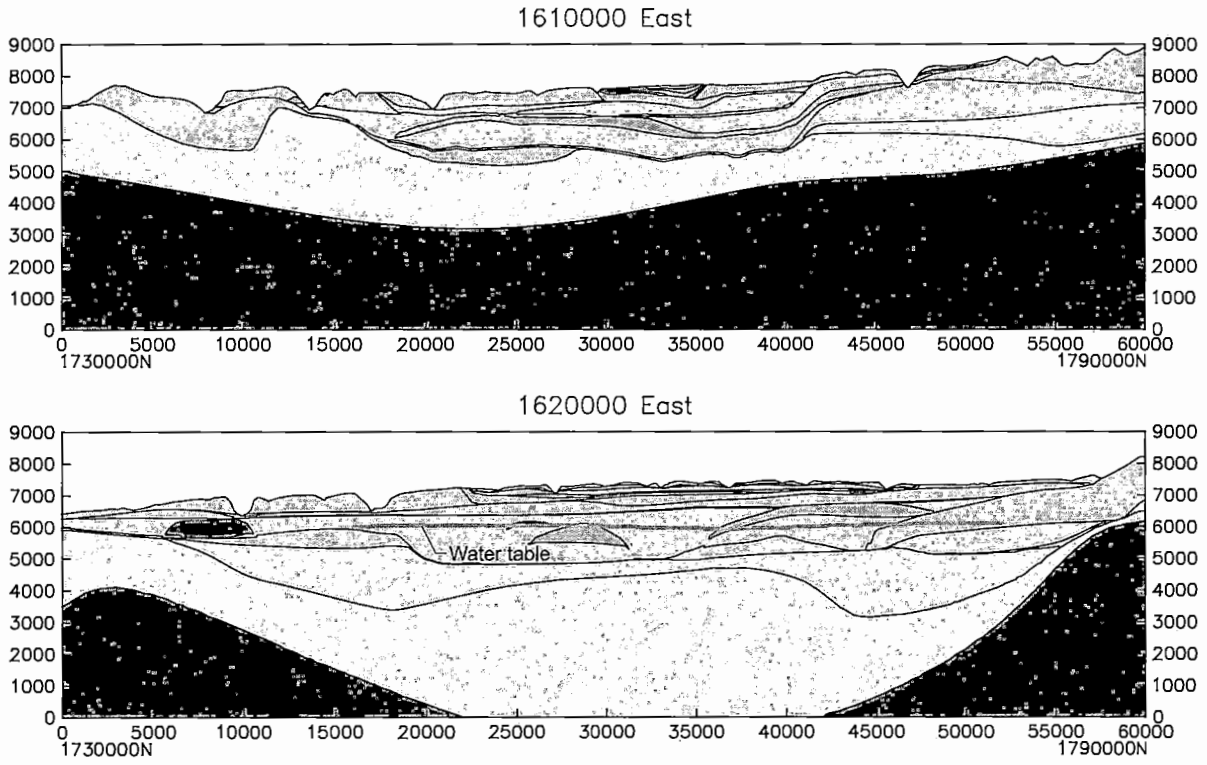
Plate 2-86. Central east-west cross-sections (N_1755000, N_1765000)



Note: Vertical exaggeration = 1.75x.

Constructed from the 2009 LANL Geologic Framework Model (Cole et al. 2009, 106101). Date: May 2009

Plate 2-87. Northern east-west cross-sections (N_1775000, N_1785000)

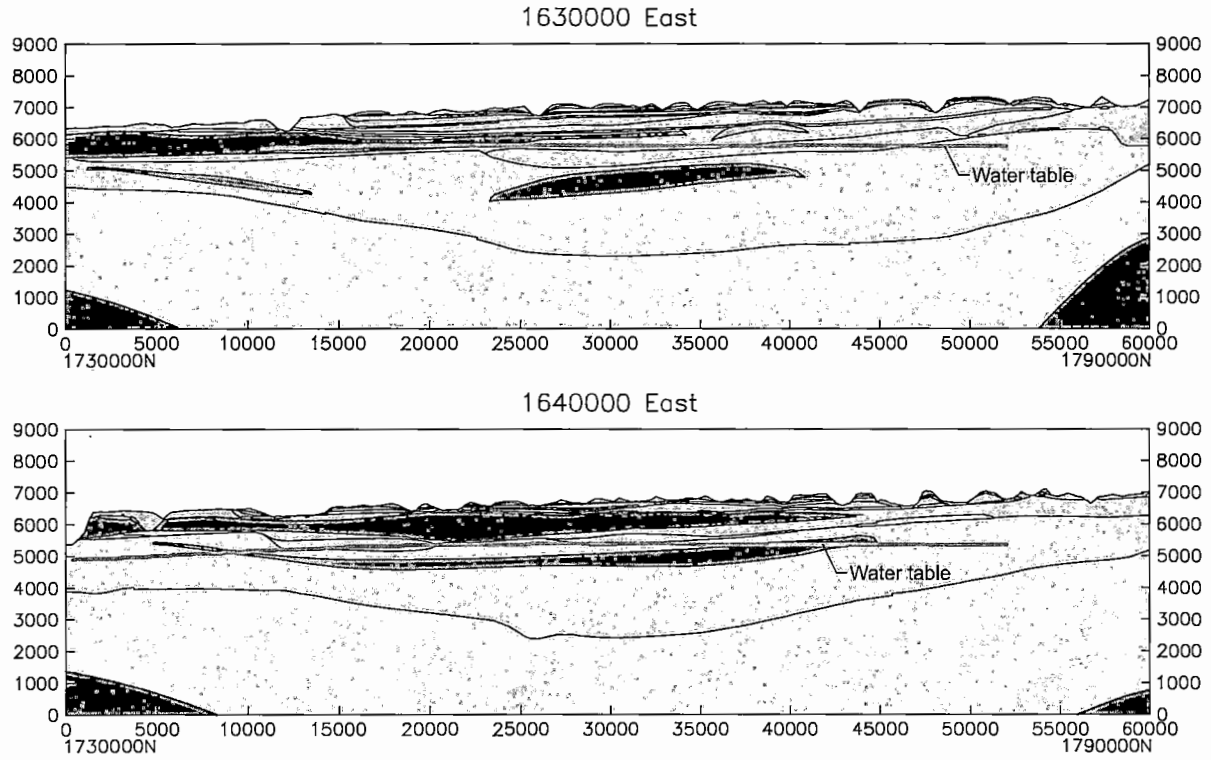


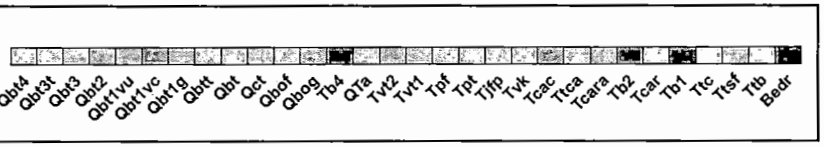
Note: Vertical exaggeration = 1.75x.

Constructed from the 2009 LANL Geologic Framework Model (Cole et al. 2009, 106101) Date: May 2009

Plate 2-88. Western north-south cross-sections (E_1610000, E_1620000)

06131



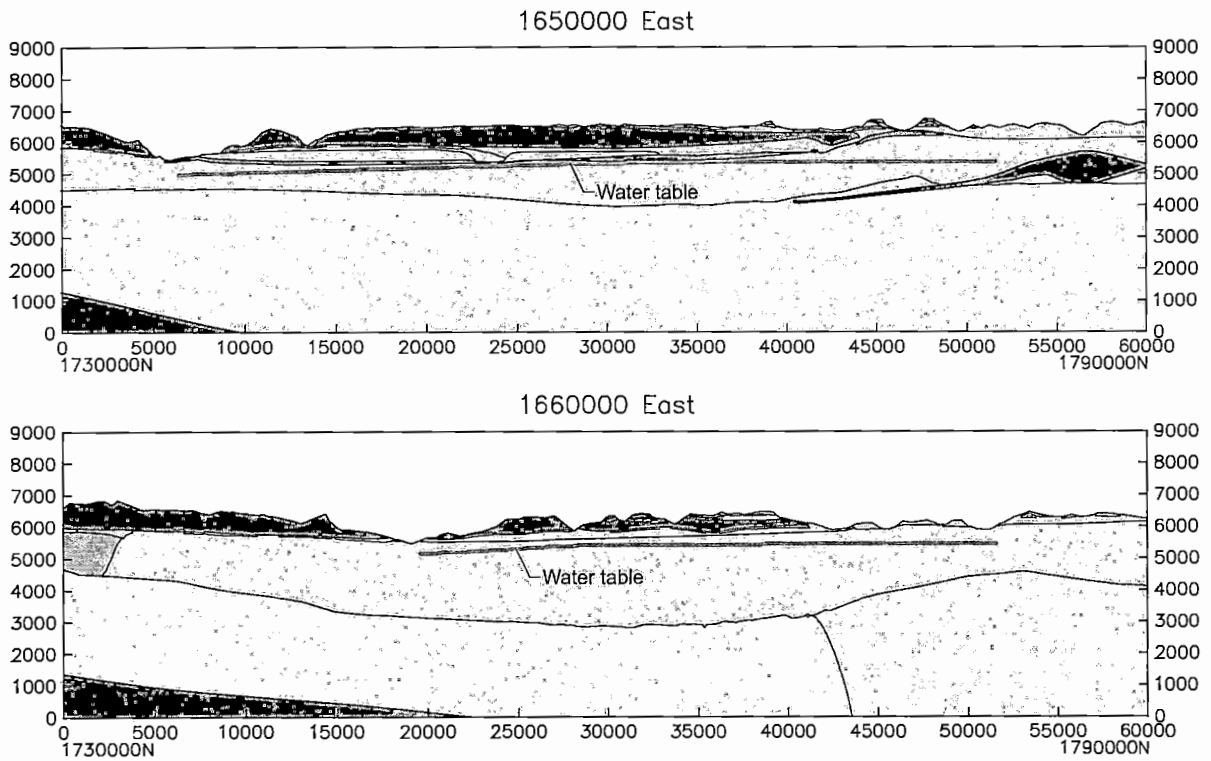


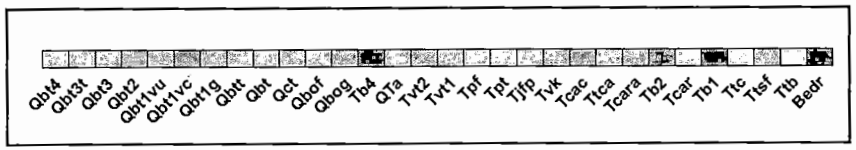
Note: Vertical exaggeration = 1.75x.

Constructed from the 2009 LANL Geologic Framework Model (Cole et al. 2009, 106101) Date: May 2009

Plate 2-89. West central north-south cross-sections (E_1630000, E_1640000)

96192

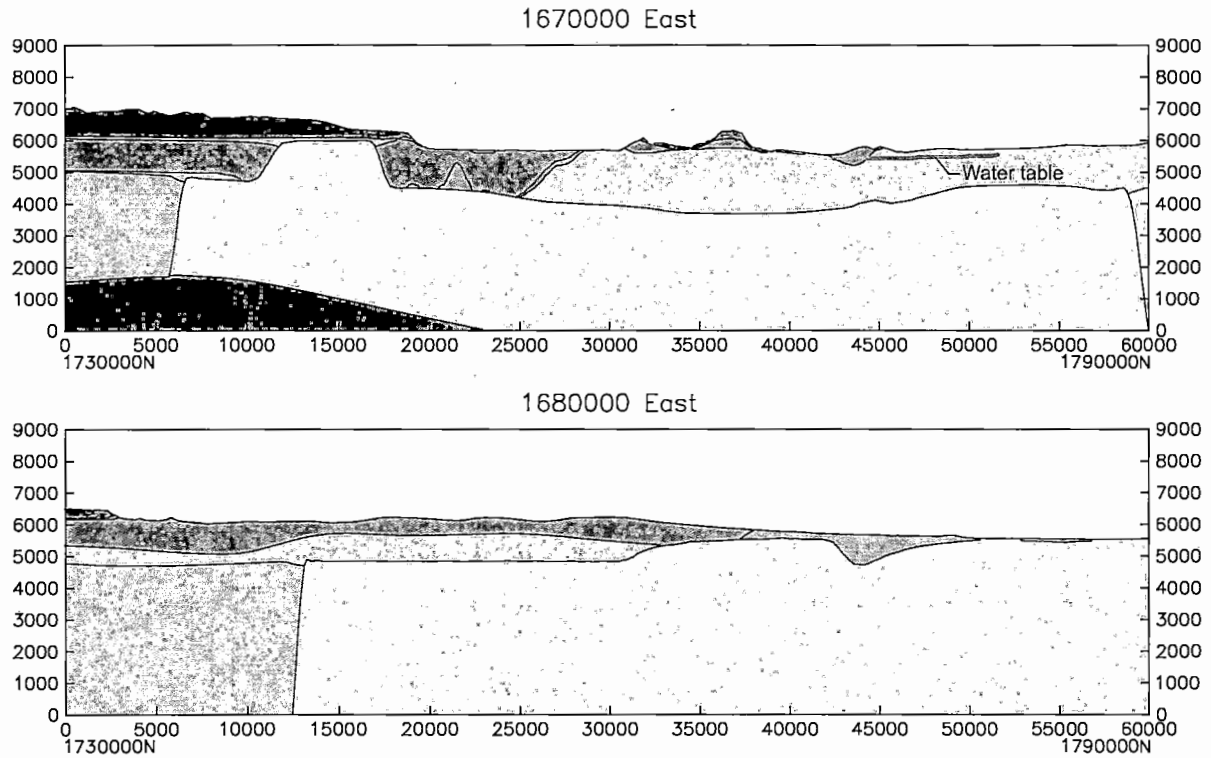


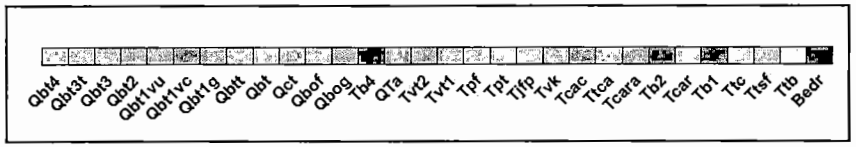


Note: Vertical exaggeration = 1.75x.

Constructed from the 2009 LANL Geologic Framework Model (Cole et al. 2009, 106101). Date: May 2009

Plate 2-90. Central north-south cross-sections (E_1650000, E_1660000)



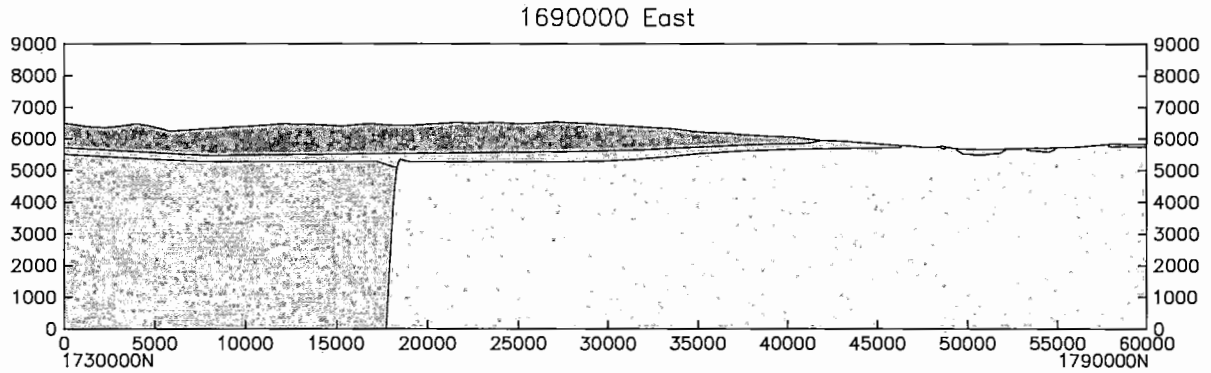


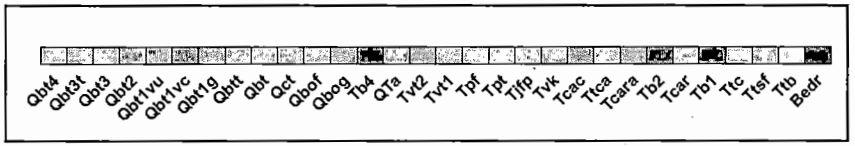
Note: Vertical exaggeration = 1.75x.

Constructed from the 2009 LANL Geologic Framework Model (Cole et al. 2009, 106101) Date: May 2009

Plate 2-91. East central north-south cross-sections (E_1670000, E_1680000)

LA-UR-09-05191

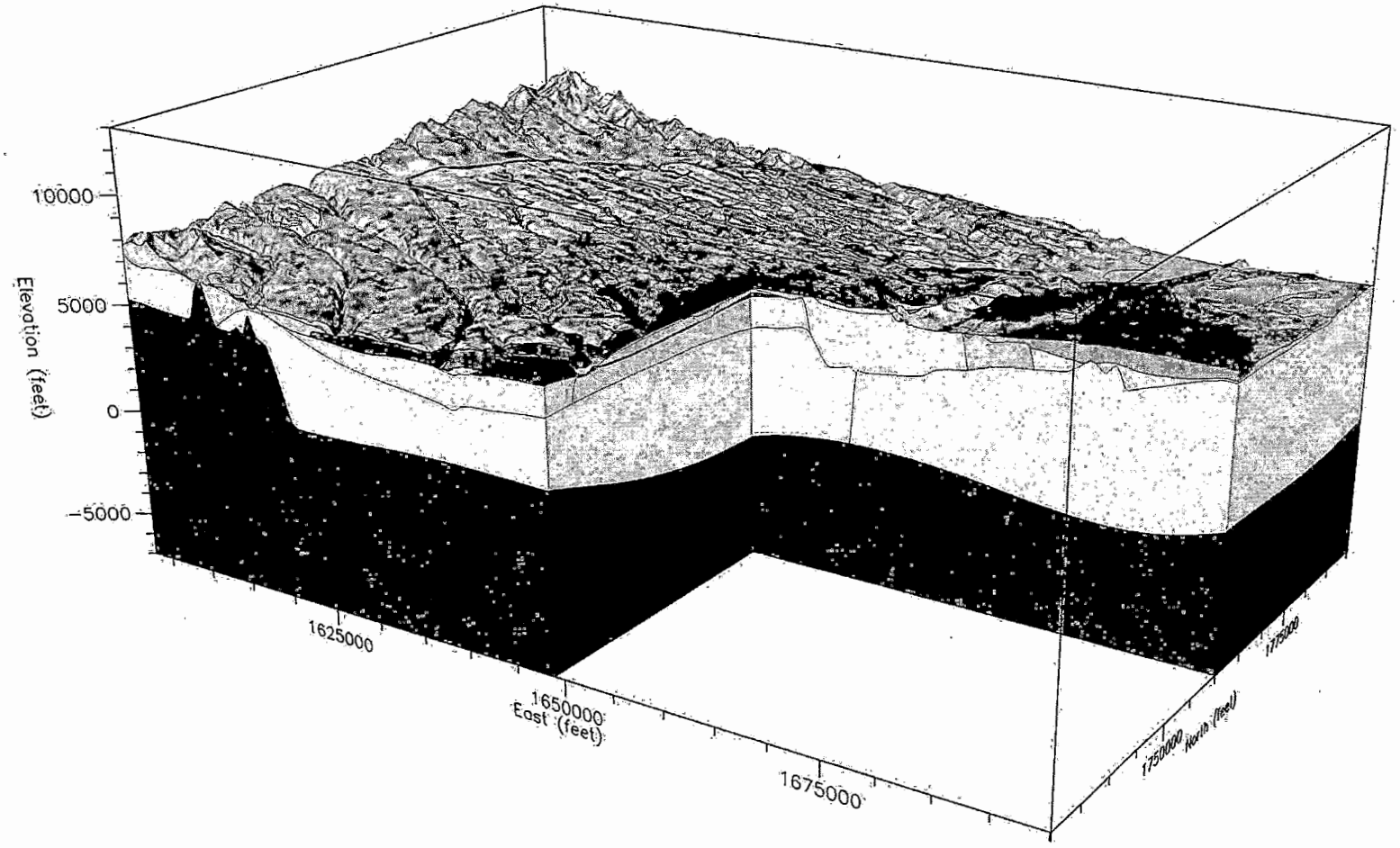




Note: Vertical exaggeration = 1.75x.

Constructed from the 2009 LANL Geologic Framework Model (Cole et al. 2009, 106101) Date: May 2009

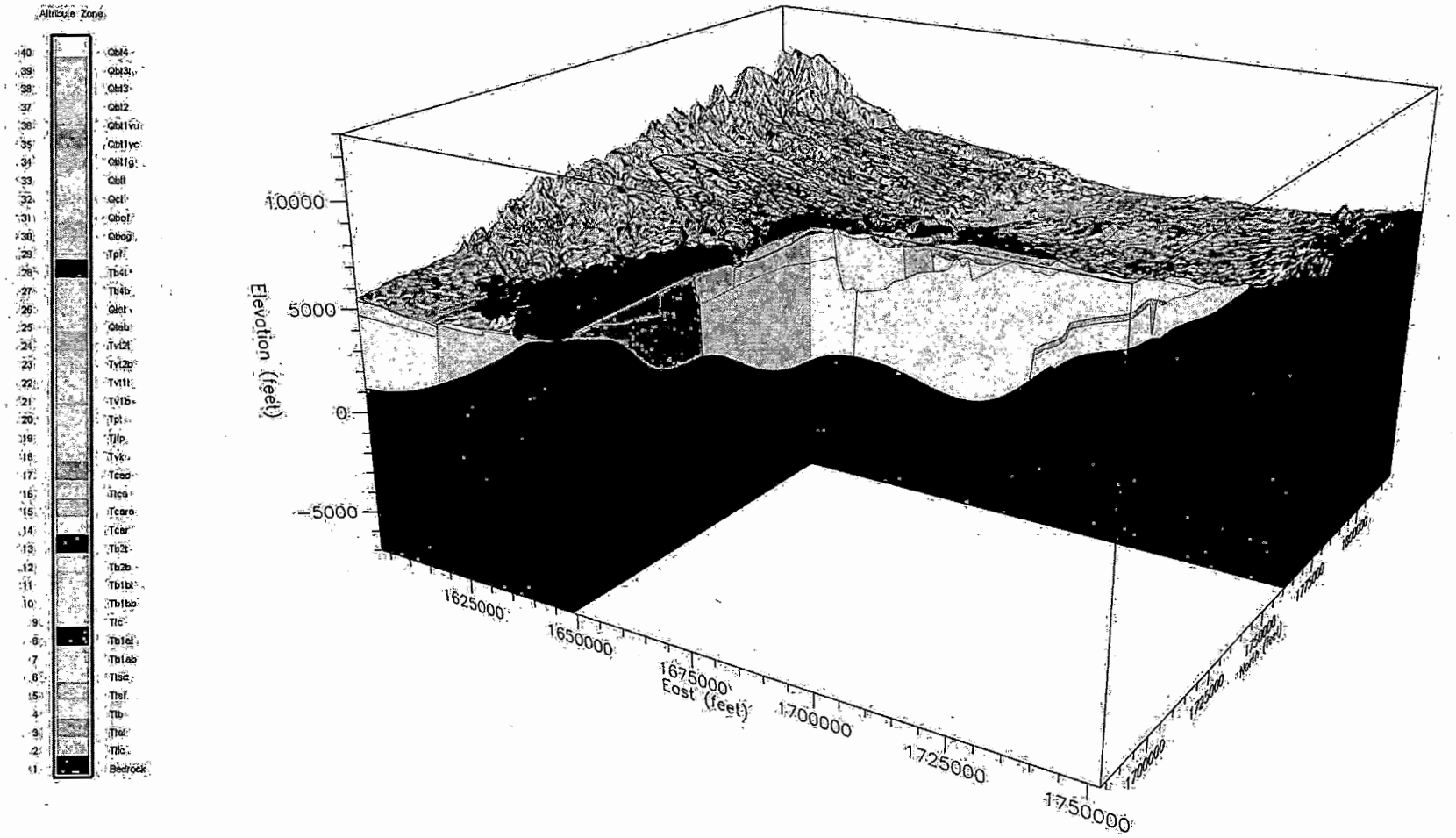
Plate 2-92. Eastern north-south cross-section (E_1690000)



Constructed from the 2009 LANL Geologic Framework Model (Cole et al. 2009, 106101)
Date: May 2009

Plate 2-93. The atlas portion of the southern Española Basin model—view from the southeast

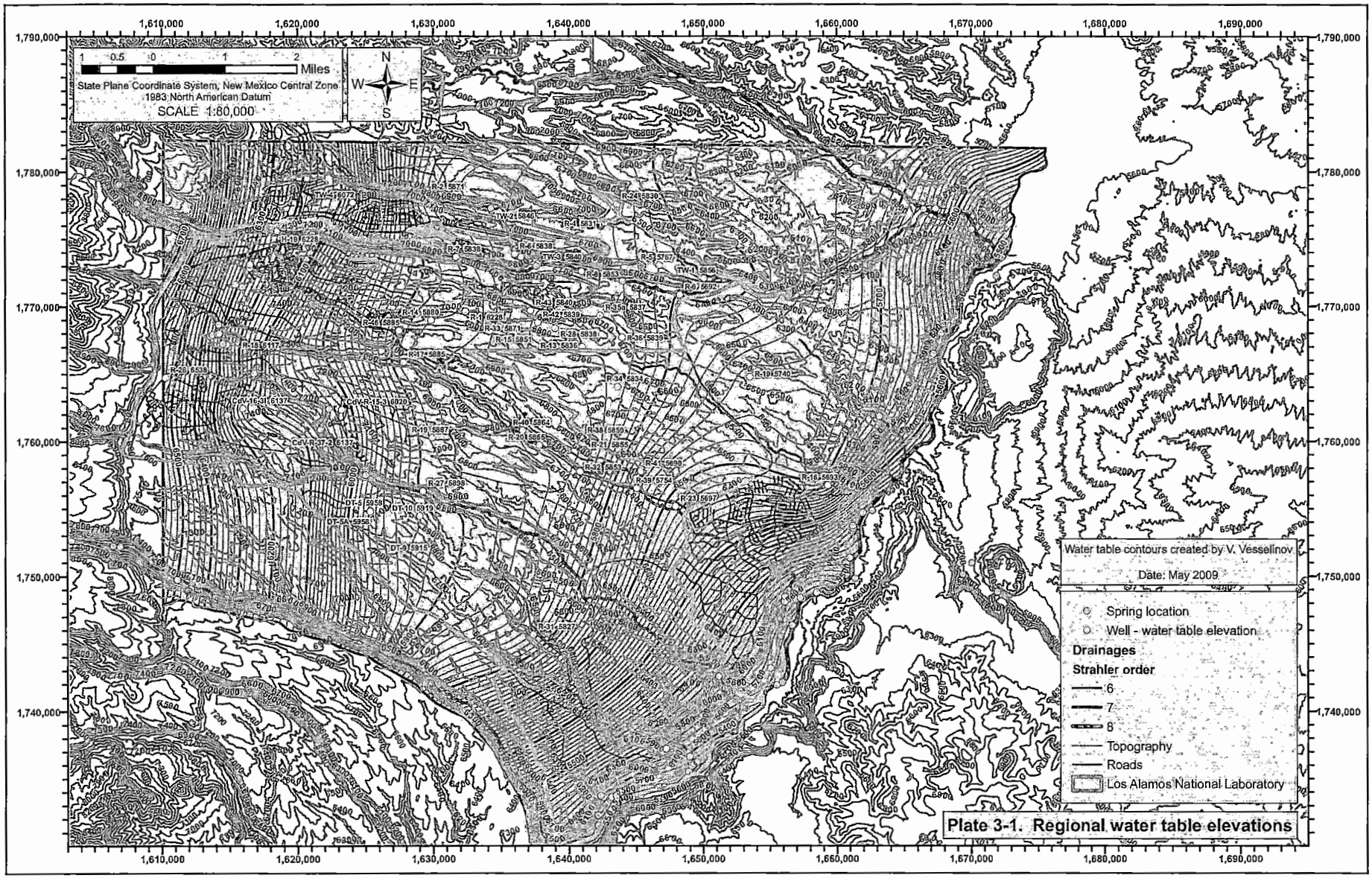
09156



Constructed from the 2009 LANL Geologic Framework Model (Cole et al. 2009, 106101)
Date: May 2009

Plate 2-94. The southern Española Basin model—view from the southeast

ER197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State Plane Coordinate System, New Mexico Central Zone
1983 North American Datum
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Water table contours created by V. Vesselinov
Date: May 2009
Spring location
Well - water table elevation
Drainages
Strahler order
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7
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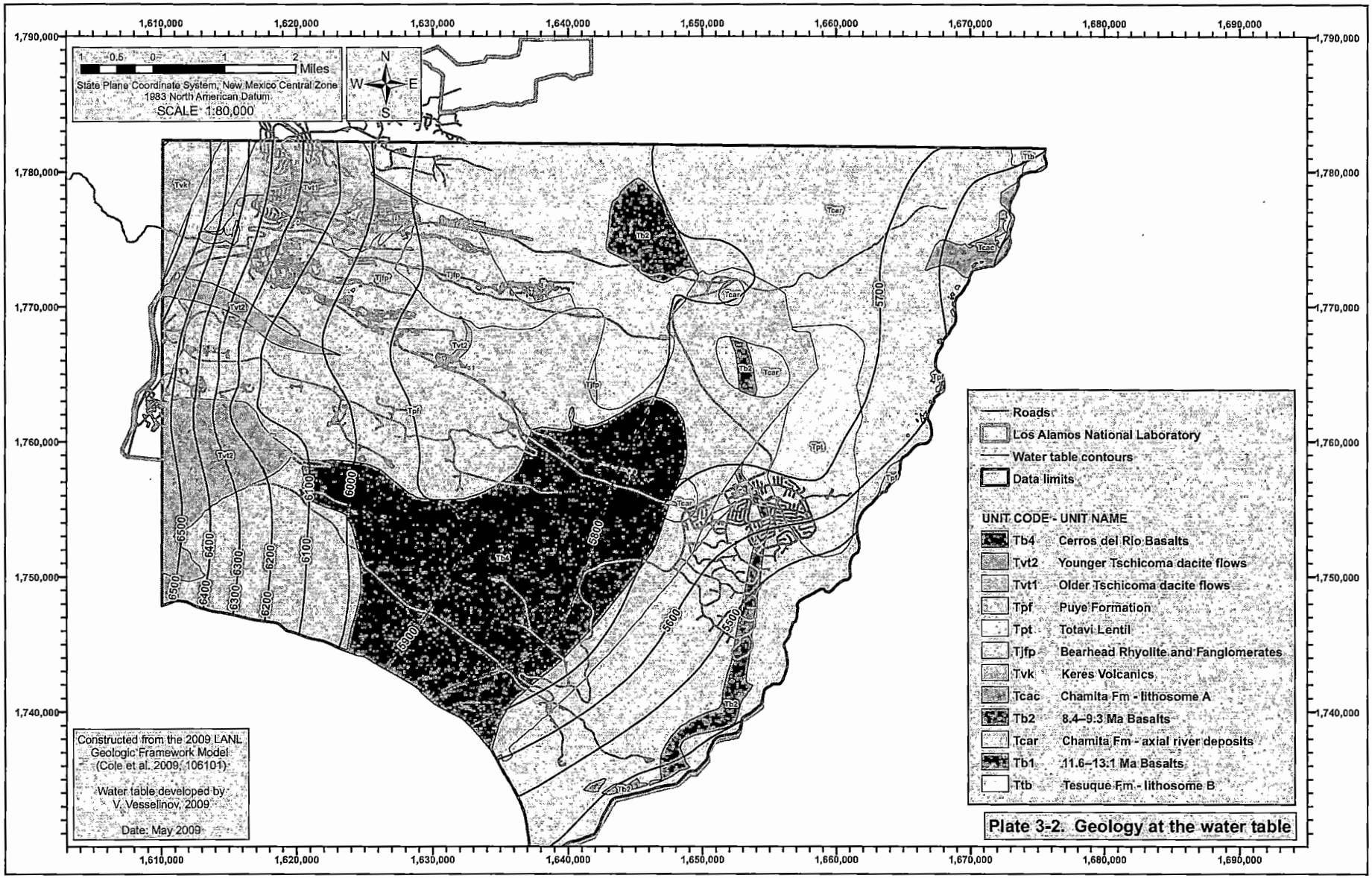
Topography
Roads
Los Alamos National Laboratory
Plate 3-1. Regional water table elevations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State Plane Coordinate System, New Mexico Central Zone
1983 North American Datum
SCALE 1:80,000
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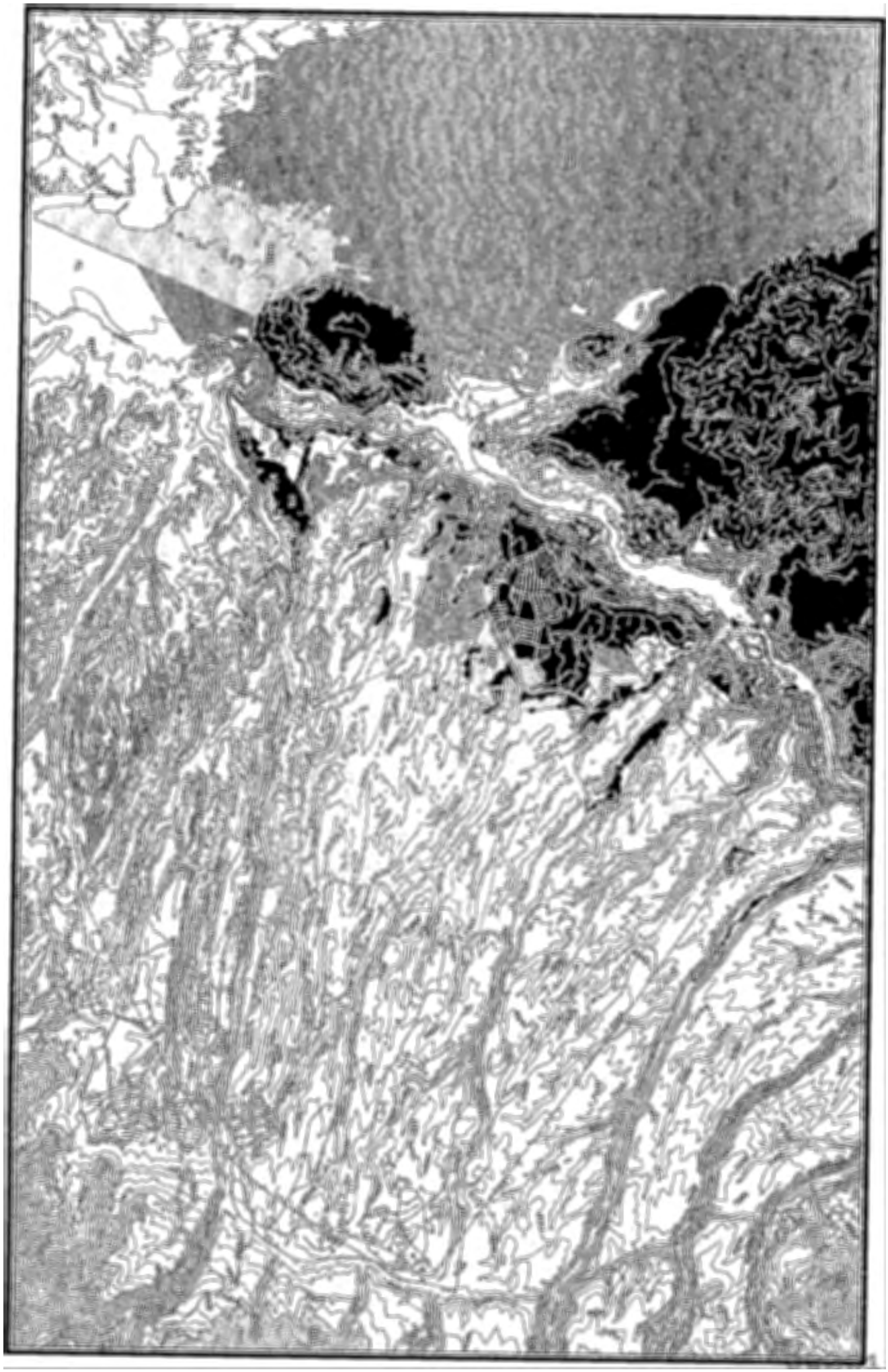
Roads
Los Alamos National Laboratory
Water table contours
Data limits
UNIT CODE- UNIT NAME
Tb4 Cerros del Rio Basalts
Tvt2 Younger Tschicoma dacite flows
Tvt1 Older Tschicoma dacite flows
Tpf Puye Formation
Tpt Totavi Lentil
Tjfp Bearhead Rhyolite and Fanglomerates
Tvk Keres Volcanics
Tcac Chamita Fm - lithosome A
Tb2 8.4–9.3 Ma Basalts
Tcar Chamita Fm - axial river deposits
Tb1 11.6–13.1 Ma Basalts
Ttb Tesuque Fm - lithosome B
Constructed from the 2009 LANL Geologic Framework Model (Cole et al. 2009, 106101)
Water table developed by V. Vesselinov, 2009
Date: May 2009
Plate 3-2. Geology at the water table

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