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RCRA PERMITS PROGRAM

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Date: February 3, 1998
Refer to: EM/ER:98-027

Dr. Robert S. Dinwiddie
NMED-HRMB
P.O. Box 26110
Santa Fe, NM 87502

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SUBJECT: RESPONSE TO REQUEST FOR SUPPLEMENTAL INFORMATION FOR IWP FOR ER PROGRAM, REVISION 6, DECEMBER 1996

Dear Dr. Dinwiddie:

Enclosed is the Los Alamos National Laboratory Environmental Restoration Project's response to your Request for Supplemental Information (RSI) on our Installation Work Plan (IWP).

Included with this response is a revised Chapter 2. This chapter was in revision prior to receipt of the RSI and has been updated to reflect changes as requested in the RSI. The work schedule/schedule of compliance will be provided to the New Mexico Environment Department with sufficient time allowed for review in anticipation of approval by March 31, 1998. Most of the remaining comments in the RSI necessitate a revision to our Quality Assurance Project Plan (QAPP), as well as Standard Operating Procedures (SOPs) and Quality Procedures (QPs). As discussed with members of your staff, the QAPP will be revised as indicated in our responses. Submittal dates for these revisions are yet to be determined. The SOPs and QPs will be revised and can be transmitted to you for information upon request.

Our staff will continue to work closely with your staff to proceed with any other comments on our response to the RSI and future submittals of the IWP.

Should you have any questions, please contact Dave McInroy at (505) 667-0819.

Sincerely,

Julie A. Canepa, Program Manager
LANL/ER Project

Sincerely,

Theodore J. Taylor, Program Manager
DOE/LAAO

TG/JC/TT/ss

15680

Enclosure: Response to Request for Supplemental Information for IWP for ER Program, Revision 6, December 1996

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EM/ER File, MS M992

Los Alamos National Laboratory
Response to
NMED Request for Supplemental Information on the Hydrogeologic Workplan

General Comment 1

"HRMB recommends that quarterly "progress" meetings occur in addition to the meeting scheduled for March. This will provide a regular forum for communication between LANL and HRMB to discuss issues such as the DQO process outputs, new data, etc.. HRMB also recommends communication between NMED and DOE/LANL regarding updates, changes, decisions, etc. in the form of phone calls, E-Mail, and faxes."

General Comment 1 Response

LANL and DOE agree with HRMB on the need to establish and maintain open communication lines to facilitate decision-making when groundwater characterization data are collected. Quarterly meetings would be an excellent forum for maintaining the flow of communication. The Groundwater Integrating Team (GIT) is the DOE/LANL organization that will compile all groundwater characterization data collected, integrate the data, and make refinements to the conceptual model. As it is refined, the conceptual model will be the basis of decisions regarding the location and types of data collected from subsequent wells. The GIT will meet with HRMB on a quarterly basis to discuss refinements to the conceptual model. Communication outside of quarterly meetings will be in a form appropriate to the informational content and regulatory requirements.

General Comment 1(A)

"LANL should submit to HRMB in January all available documents regarding the proposed Workplan negotiation meeting for March. This will enable HRMB to adequately review documents prior to the negotiation meeting."

General Comment 1(A) Response

DOE/LANL concur with the need for HRMB to have adequate review time prior to the March negotiation meeting. This first year the documents will not be ready until March. However, in future years the Annual Report and associated documents will be submitted to HRMB in January. In years when the documents are submitted in January, DOE/LANL would like to encourage HRMB to provide comments and concerns on the Annual Report and associated documents prior to the March meeting to facilitate discussion and decision-making during the negotiation meeting.

General Comment 1(B)

"HRMB reminds LANL that the HSWA Module currently requires that within thirty (30) days of the completion of each well a report is due to HRMB."

General Comment 1(B) Response

LANL acknowledges the requirement for submittal of a well report within 30 days of completion of a well.

General Comment 1(C)

"Describe how the data gathered from the progression of this Workplan, RFI Reports, etc. will be condensed and presented to the HRMB prior to the proposed March meetings. Document if the excluded data will be readily available on FIMAD or another data base by this time."

General Comment 1(C) Response

DOE/LANL intend to evaluate all of the valid data collected during the preceding fiscal year that could be used to refine the conceptual model. The data will be from any program at LANL that collects environmental data – Environmental Restoration Project, Environmental Surveillance, Waste Management, NEPA, facilities, etc. These data and the resulting refinements to the conceptual model will be summarized in the Annual Report, which will be submitted to NMED prior to the March meetings. All valid data will be available from the Facility for Information Management, Analysis, and Display (FIMAD). The conceptual model is will be refined by incorporating all of the available valid data; therefore, no valid data will be excluded.

General Comment 2

"The Hydrogeologic Workplan should be coordinated and consistent with the Watershed Management Project Plan, the Canyons Investigation Core Document and subsequent canyon and site-specific workplans and reports. The Workplan should also coordinate OB/OD/other permitting activities (e.g., TA-14, -15, -36, -39 OB/OD permit)"

General Comment 2 Response

DOE/LANL concur with the need for consistency between Laboratory programs and have taken positive steps to ensure that consistency and coordination. One step is that the Hydrogeologic Workplan Planning Team and the Watershed Management Planning Team consisted of representatives of several LANL programs areas to ensure coordination of efforts. A second step is the establishment of the GIT which consists of representatives of various LANL programs areas, also to ensure coordination. A third step is the coordination of well drilling, construction, and sampling techniques between the Environmental Restoration Program and the Defense Program-funded program, as documented in a Memorandum of Understanding and a December 17 memo from the Laboratory Director, John Browne which assigns roles and responsibilities for completing the work described in the Hydrogeologic Workplan. DOE/LANL do not believe it is appropriate to revise previously submitted documents <u>solely</u> for the purpose of making them consistent with the Hydrogeologic Workplan.

Other permitting activities will be coordinated within the aggregates as part of the comprehensive approach to characterization described in the workplan.

General Comment 2(A)

"Please state clearly how investigations and characterization efforts from the Core Document for Canyons Investigations, Watershed Management, etc. will be integrated by the Workplan."

General Comment 2(A) Response

As described in the response to General Comment 1(C), all of the valid data that could be used to refine the conceptual model collected during the preceding fiscal year will be described in the Annual Report. The Annual Report will be submitted to NMED in January (after 1998) each year. The GIT will be the integrating entity, responsible for summarizing the data and making refinements to the conceptual model. The GIT is composed of representatives from several program areas at LANL to ensure that all of the valid data available is incorporated into the conceptual model so that decisions about subsequent characterization activities can be made.

General Comment 3

"If modifications, as outlined in the Corrective Action Flow Process, to the Canyons Investigation Core Document, any subsequent canyon-specific workplans and reports, and the Watershed Management Project Plan affect this document, please provide an addendum to this workplan."

General Comment 3 Response

DOE/LANL concur with the need to maintain consistency and coordination between programs. Modification of the Hydrogeologic Workplan are expected and intended to occur as a result of refinements to the conceptual model as more characterization data are collected. These changes to the Hydrogeologic Workplan will be discussed and agreed to during negotiation meetings with the NMED. The discussions and agreements made during the negotiation meeting will be summarized in an annual addenda that will be distributed as an appendix to the workplan. In this way, complete revision of the Hydrogeologic Workplan each year will not be necessary.

Programs conducted pursuant to regulatory requirements other than RCRA, like the Watershed Management project, are intended to ensure a comprehensive approach to groundwater protection and are not enforceable through the Hydrogeologic Workplan.

General Comment 4

"It would be useful if LANL provided a glossary containing pertinent definitions."

General Comment 4 Response

DOE/LANL agrees to provide a glossary containing pertinent definitions in the final Workplan submitted to HRMB.

General Comment 5

"Please provide a figure or figures (plates in Appendix 6?) illustrating the proposed alluvial, intermediate, and regional well locations relative to the existing alluvial, intermediate, and regional wells (please label existing wells). Also, be sure to revise text and reference the appropriate figure that illustrates the location of the referenced well(s)."

General Comment 5 Response
DOE/LANL agrees to provide a map showing both proposed and existing wells and to change the references in the text in the final Workplan submitted to HRMB.

General Comment 6
"LANL should provide a table and figure indicating the sampling locations (spring, surface, and groundwater) that have had at any time detected radioactive or hazardous constituents equal to or above an acceptable regulatory standard or "background" (include analyte, detected concentrations, dates observed, currently above background/MCL, filtered/unfiltered)."

General Comment 6 Response
DOE/LANL concur with the need to identify all areas where contaminants have been detected equal to or above an acceptable regulatory standard or "background". Tasks described in the Hydrogeologic Workplan are intended to accomplish this. The tasks are listed on Table 3-1. One task that is critical to completing this compilation is the in-progress background study to establish what the expected background distributions. When they are complete, the data will be submitted under separate cover and will be summarized in the Annual Report.

Please note that the data on radioactive contaminants will be submitted voluntarily, but radioactive substances are not under the authority of RCRA.

General Comment 7
"HRMB recommends that the tasks identified in Tables 3-1 and 3-2 and other tasks such as compilation of spring and well data, be prioritized and tentative schedules be developed by HRMB and LANL. This could be accomplished in a meeting pursuant of the approval of this workplan."

General Comment 7 Response
DOE/LANL agrees that the tasks listed in Tables 3-1 and 3-2 are critical to characterizing the groundwater regime beneath the Laboratory. Much of the data are currently available in the annual environmental surveillance reports and the ER Project reports. Progress made on these tasks will be described in the Annual Report. Criteria for prioritizing these tasks can be discussed at the meeting in March.

General Comment 8

"The Workplan indicates that the one time sampling of the intermediate systems (sampled as regional aquifer wells are installed) will occur. One time sampling is not likely to provide enough information to "characterize" the intermediate groundwater systems. HRMB recommends that quarterly meetings occur to discuss installation and prioritization of wells.

General Comment 8 Response

DOE/LANL chose to characterize the hydrogeologic setting of LANL by drilling, logging, installing and sampling wells to the regional aquifer without installing separate intermediate depth wells because this approach provides the greatest amount of characterization data. This approach was discussed with NMED representatives at a meeting on August 7, 1996 and consensus with the approach is documented in a letter sent to NMED on September 11, 1996 (addressed to Dr. Ed Kelley, subject: The proposed Los Alamos National Laboratory (Laboratory) Groundwater Protection Strategy and Related Data Quality Objectives and Decision Flow Process) The following reasons are rationale for this approach:

- The presence of intermediate zone(s) is controlled by geologic structure and the geology across the Lab 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 was 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. Wells that may be needed to monitor the intermediate zone(s) will be considered as part of the monitoring system design.

Sampling and testing the intermediate zone within the borehole is expected to provide adequate characterization data to make decisions regarding the need to continue monitoring the intermediate zone. This is supported by data presented at an August 7, 1996 meeting with NMED (documented in a letter sent to Dr. Ed Kelley on September 11, 1996, Subject: The Proposed Los Alamos National Laboratory (Laboratory) Groundwater Protection Strategy and Related data Quality Objectives and Decision Flow Processes). The data consists of analytical results from four wells (PO-4, POI-4, LADP-3, and LAOI-1.1) that were sampled from the borehole before the well was installed and on a quarterly basis from completed wells. The major ion chemistry and tritium analyses were in good agreement for all of the wells. Data from a fifth well, LAO-B, was

presented to show the variation that can be expected in quarterly sampling from completed wells. Based on these data, adequate characterization of the intermediate zones will be accomplished by sampling and comprehensive analyses of groundwater within the borehole and pore water from the core.

The information gathered during the characterization will be used to design a detection monitoring network that almost certainly include monitoring wells in the intermediate zone. However, until the characterization effort described in the workplan is complete, the number and location of intermediate zones wells can not be determined.

General Comment 9
"As the Canyons team (from Field Unit 4) are already mobilized, producing results, and currently drilling R-9, HRMB suggests expanding the role of the Canyons team to encompass the investigations outlined in this workplan."

General Comment 9 Response
DOE/LANL agree with the need to have knowledgeable and experienced teams drilling and installing the wells and collecting data. DOE/LANL retain the responsibility of identifying, selecting, and acquiring resources to complete these activities. To maintain efficiency and consistency and to promote economies of scale, the Laboratory announced on December 17 that the ER Program will be the construction manager for all of the wells described in the Hydrogeologic Workplan.

General Comment 10
"Please check the Table of Contents. Section 3.3.2 is incorrectly identified"

General Comment 10 Response
DOE/LANL agrees to correct the Table of Content in the final Hydrogeologic Workplan.

Specific Comments: Section 1.2, Comment 1
Figure 1-1, ID#48 (page1-5), indicates the first "Annual NMED Negotiation Meeting for Fiscal Year 1998" is scheduled for the second quarter of 1999. Please clarify if the meeting is scheduled for 1999 or the second quarter of FY98 as indicated in the text."

Specific Comments: Section 1.2, Comment 1 Response
DOE/LANL intends to hold the first Annual NMED Negotiation Meeting on March 31, 1998 (second quarter of FY98). Figure 1-1 will be corrected to reflect this date in the final Hydrogeologic Workplan.

Specific Comments: Section 1.5, Comment 1

"Clarify the Canyon Scenario (1-4) that addresses releases to ground and surface water via contaminated soils and sediments in the DQO process is not clear"

Specific Comments: Section 1.5, Comment 1 Response
DOE/LANL agree that the Canyon scenario description should be clarified to reflect all of the contaminant transport pathways that were used in developing the DQO outputs shown in Appendix 4. In the DQO outputs for each canyon, decision 4 is: "Are the alluvial sediments and uppermost subsurface water (USSW) from various present and legacy sources at contaminant concentrations greater than a regulatory limit or risk level?" The questions that were considered to resolve this decision included: "What are the concentrations of these contaminants in sediments and USSW?" When data are used to answer this question and resolve the decision, then releases to groundwater and surface water via contaminated soils and sediments has been addressed.

Specific Comments: Section 1.5, Comment 2
"Please clarify whether there are eight or nine aggregates. There are only eight(8) aggregates described, not nine as mentioned on page 1-17 and in section 4.2."

Specific Comments: Section 1.5, Comment 2 Response
DOE/LANL agree to make the final Workplan internally consistent with respect to the number of aggregates. There are nine aggregates. Eight of the aggregates are specific areas containing one or more canyons and adjacent mesas. The ninth aggregates is the region of the Pajarito Plateau beneath LANL. The decisions that must be resolved for the regional aggregate are large scale, e.g. recharge areas, water supply.

Specific Comments: Section 1.5, Comment 3
"The decisions developed from scenarios (Canyon and Mesa) delineated from the Data Quality Objective (DQO) process overlook some HRMB concerns. Below is a partial list of concerns:"

Specific Comments: Section 1.5, Comment 3 Response
DOE/LANL believe that it is important to address all of HRMB concerns as soon as possible in the planning process. DOE/LANL hope to discuss the full list of HRMB concerns prior to implementing the work described in this Workplan.

Specific Comments: Section 1.5, Comment 3(A)
Although the contaminants in various ground water occurrences may not currently exceed regulatory limit or risk level what provisions are there in the DQO process for future impacts to ground water. LANL should document how this is incorporated into the DQO for the Workplan."

Specific Comments: Section 1.5, Comment 3(A) Response

DOE/LANL concur with the need to address potential future impacts from releases. The DQO process presented in the Workplan explicitly addresses present and potential future impacts by collecting data to determine if pathways exist that would allow migration of contaminants to groundwater. Figure 1-4 is the decision flow diagram for groundwater protection. One the left side of the diagram are a series of decision diamonds that are used to determine whether groundwater currently exceeds standards. On the right side of the diagram are decision diamonds that establish whether pathways exist that may allow contamination to occur in the future. If source terms and pathways exist, then remedial actions may be necessary. The pathways decision shown in Figure 1-4 are incorporated in the DQO process as a decision and associated questions that must be answered to resolve the decision in each aggregate. Existing and newly-collected data are used to characterize sources and pathways to address this issue. As shown in Appendix 4, Aggregate 1, pages 6-7, the decision and questions are:

Decision:

> "what are the pathways for exposure to contaminants from alluvial sediments and uppermost subsurface water?"

Questions:

- "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?
- Groundwater movement from intermediate perched zones to Regional Aquifer?
- Are fractures and faults important contaminant transport pathways for liquids in canyons?"

When existing and newly collected data are utilized to answer these questions and resolve the decision, the potential for future impacts to groundwater has been addressed.

Specific Comments: Section 1.5, Comment 3(B)

"As surface water is part of the hydrogeological cycle, LANL should incorporate surface water decisions/concerns into the Canyon and Mesa scenarios."

Specific Comments: Section 1.5, Comment 3(B) Response

DOE/LANL agree that surface water impacts groundwater as it infiltrates and the groundwater impacts surface water when it discharges in springs and other surface water bodies. However, requirements of the Clean Water Act are not enforceable under this document. The final Workplan will contain revised scenario descriptions to clarify the inclusion of surface water in the decision-making process. The impact of surface water has been addressed in the DQO outputs. For the canyons, under decision 1, question 1 the effect of stormwater and NPDES outfalls is listed (for example, Appendix 4, Aggregate 1, p. 1). Also, the recharge of alluvial water from surface water is addressed in Decision 6, question 1 (for example, Appendix 4, Aggregate 1, p. 6). For the mesas, the impact of surface water is addressed under Decision 1, question 4 (for example, Appendix 4,

Aggregate 1, p. 8). The impact of springs discharging to surface water is evaluated under the mesa scenarios (for example Appendix 4, Aggregate 1, p. 12).

Specific Comments: Section 1.5, Comment 4
"Although determination of the cumulative impacts of spatially related technical areas (TAs) is useful, HRMB questions the use of aggregates as outlined in this workplan. HRMB is concerned that impacts to the hydrogeologic system by other Potential Release Sites (PRSs) not included within an aggregate will be overlooked."

Specific Comments: Section 1.5, Comment 4 Response
To ensure that the potential impacts from PRSs not included in an aggregate are not overlooked, the entire length of each canyon and mesa have been evaluated using the DQO process.

Specific Comments: Section 1.5, Comment 4(A)
"Please clarify the applicability/usefulness of aggregates as this approach is unclear to HRMB"

Specific Comments: Section 1.5, Comment 4(A) Response
DOE/LANL agree to clarify the description of the aggregate approach in the final Workplan. The utility of the aggregates is two-fold. First, aggregates facilitate assessing the cumulative impact of multiple sources on the groundwater. This avoids the pitfall of finding no groundwater impacts on a PRS-by-PRS basis, where as the cumulative impact of the PRSs together may warrant remedial action. Second, the aggregate approach prioritizes areas where impacts are most likely to occur, so that resources are not spent on areas likely to have no problems. The aggregates are grouping of PRSs in close proximity to each other. Assessing the cumulative impact of a group of PRSs is a more effective use of resources than to attempt to assess each PRS individually, and has the same outcome – the remediation of groundwater contamination and sources of potential groundwater contamination. Further, focusing finite resources on areas that are likely to have problems is another effective use of resources. The aggregate approach also has a regulatory precedent in the waste management area in 40 CFR 264.95b2, where a line circumscribing a number of related waste units can be used to define a waste management area.

Specific Comments: Section 1.5, Comment 4(B)
"Describe the criteria for how each of the aggregates was defined."

Specific Comments: Section 1.5, Comment 4(B) Response
DOE/LANL agree to clarify how the aggregates were designated in Section 1 of the final Workplan. In general, the aggregate boundaries were drawn to encompass groups of PRSs within canyons and on adjacent mesa tops. The boundaries are proximal to

geographic groupings of PRSs and/or similar operational functions. This is indicated in the individual aggregate descriptions in Section 4 (for example, see Section 4.3.1.1).

Specific Comments: Section 1.5, Comment 5

"Many issues discussed in a letter, Subject: Concerns Regarding the Proposed Los Alamos National Laboratory Groundwater Protection Strategy, The Data Quality Objectives and the Decision Flow Process dated July 24, 1996, were not addressed in the Hydrogeologic Workplan. Please address the issues discussed in the letter (e.g. the inappropriate use of • 50 gallons/day yield used to define ground water and regulator input to the DQO process)."

Specific Comments: Section 1.5, Comment 5 Response

DOE/LANL valued NMED's input throughout the planning process that resulted in the Hydrogeologic Workplan. The referenced letter contains 7 issues, all of which were discussed with HRMB at a meeting on August 7, 1996 and documented in a letter sent to NMED on September 11, 1996(addressed to Dr. Ed Kelley, subject: The Proposed Los Alamos National Laboratory (Laboratory) Groundwater Protection Strategy and Related Data Quality Objectives and Decision Flow Process). The resolution of these issues were incorporated as appropriate in the draft workplan submitted in December, 1997. Those issues and their resolutions are as follows:

1. Issue: Use definitions consistent with regulatory definitions. Resolution: Appendix 3 contains the August 15 version of the "Los Alamos National Laboratory Groundwater Protection Strategy". This version of the Strategy incorporates definitions from the New Mexico Water Quality Control Commission and the Environmental Protection Agency.
2. Issue: Use of 50 gallons/day to define groundwater. Resolution: The yield of a water-bearing zone is not being used to determine <u>if</u> the water should be protected, but to decide which standards apply. As described in the strategy, standards for constituents in listed RCRA (40 CFR 264.94) will be applied to water encountered. If an Alternate Concentration Level (ACL) must be proposed, then the yield would be used to determine which WQCC standards are applicable. For water-bearing zones that yield less than 50 gallons per day, the abatement standards (20 NMAC 6.2, Subpart IV) apply. For water-bearing zones that yield greater than 50 gallons per day, the groundwater standards (20 NMAC 4.1) are applied.
3. Issue: Replacing intermediate wells with Regional Aquifer wells. Resolution: This approach to hydrogeological characterization was discussed with NMED during a meeting on August 7, 1996 (documented in a letter sent to Dr. Ed Kelley on September 11, 1996, Subject: The Proposed Los Alamos National Laboratory (Laboratory) Groundwater Protection Strategy and Related data Quality Objectives and Decision Flow Processes). The rationale for this approach is described in greater detail in the response to General Comment 8. There was consensus with this approach by the HRMB staff present at the meeting.
4. Issue: Regulatory input within the DQO process and the decision flow. Resolution: There were four meetings in spring/summer of 1996 to obtain regulatory input on the

Addenda to Page 10:

All references to "20 NMAC 4.1" are meant to be interpreted as "20 NMAC 6.2, III."

DQO process and the decision flow. The draft Hydrogeologic Workplan submitted in December 1996 reflects the input received during those meetings.

5. Issue: Quantification of sources of sufficient magnitude. Resolution: In the DQO outputs in the Hydrogeologic Workplan only the aggregate containing Guaje, Rendija, and Barrancas Canyons was considered to have sources of insufficient magnitude to impact groundwater. This determination is based on current knowledge and historical data. If, as the ER Project progresses, this determination appears to be questionable, the GIT in consultation with NMED will establish new data collection for the aggregate and will document it in the Annual Report.
6. Issue: HSWA permit conditions listed at each step of DQO process and decision flow. Resolution: The DQO process and the decision flow are intended to characterize the hydrogeologic setting of the Laboratory to a sufficient degree such that an adequate detection monitoring system can be developed. As such, the entire process addresses the requirements of the HSWA permit. The process was intended to be a comprehensive response to regulatory requirements, so no one step or decision corresponds to a particular HSWA permit conditions.
7. Issue: Historical pulse release of contaminants. Resolution: The decision flow begins with an evaluation of existing data. One purpose of the evaluation is to determine where pulses might be expected. It shows an evaluation of current groundwater problems and potential future problems through pathway analysis. Long-term monitoring will be used to detect pulses of contamination.

Specific Comments: Section 1.5, Comment 6
"HRMB reminds LANL that in 50 years, contaminants are already found in the intermediate groundwater systems and the regional aquifer. Therefore some of the DQO process decisions may not be appropriate."

Specific Comments: Section 1.5, Comment 6 Response
DOE/LANL acknowledge the presence of anthropogenic substances in the groundwater at some locations beneath the Laboratory. The Groundwater Protection Management Plan and the Hydrogeologic Workplan demonstrate the Laboratory's commitment to protecting groundwater quality and quantity by pollution prevention and remedial activities. The DQO process was used because it is action-oriented. The decisions are statements of what observations will cause DOE/LANL to take an action. The observation that anthropogenic substances are present in groundwater above a specified concentration will lead to an appropriate remedial response.

Specific Comments: Appendix 4, Comment 1
"Page 2, Decision Rule for New Data: If there is saturation in the alluvium, then determine which standards apply". Clarify which standards need to be determined."

Specific Comments: Appendix 4, Comment 1 Response

DOE/LANL have included collecting data on the yield of alluvium in order to determine which standards apply. As described in the strategy, standards for constituents in listed RCRA (40 CFR 264.94) will be applied to water encountered. If an Alternate Concentration Level (ACL) must be proposed, then the yield would be used to determine which WQCC standards are applicable. For water-bearing zones that yield less than 50 gallons per day, the abatement standards (20 NMAC 6.2, Subpart IV) apply. For water-bearing zones that yield greater than 50 gallons per day, the groundwater standards (20 NMAC 4.1) are applied.

Specific Comments: Appendix 4, Comment 2

"Pages 3 and 4, Decision Rule for New Data: utilizing an average yield (• 50 gallons/day) to determine if WQCC and 20 NMAC 4.1 groundwater standards apply. See comment 5 previous section."

Specific Comments: Appendix 4, Comment 2 Response

DOE/LANL have proposed 50 gallons/day as a numerical value of yield to determine whether saturation can be defined as "groundwater" under 20 NMAC 4.1. If the yield is sufficient to classify the water as "groundwater" under the definition in 20 NMAC 4.1 then the standards applicable to groundwater will be applied. If the yield is not sufficient to be "groundwater", then the water is considered uppermost subsurface water and the abatement standards (20 NMAC 6.2, Subpart IV) will be applied.

Specific Comments: Appendix 4, Comment 3

"Provide rationale for the decisions based on "....various present and legacy sources at contaminant concentrations greater than some regulatory limit or risk level?". HRMB is concerned these decisions may miss some contamination that is possible in the future due to migrating contaminant plumes and sediments."

Specific Comments: Appendix 4, Comment 3 Response

DOE/LANL concurs with the concern regarding future contamination. The DQO process was used to ensure these concerns are addressed. The cited decision is only the first in a series of decisions that will be resolved for each aggregate. The complete set of decisions is illustrated in the Decision Flow Diagram (Figure 1-4). As shown on this figure, the first decisions are focused on present day contamination by evaluating the water quality as it exists now. Other decisions (see for example the right side of Figure 4-1 and Appendix 4, pages 6-7) are focused on potential future contamination by determining whether sources and pathways exist that may allow contaminant migration.

Specific Comments: Appendix 4, Comment 4

"HRMB recommends action be taken prior to contaminant detection in the regional aquifer. The DQO process, for example page 3 of Aggregate 5 (Cañon de Valle), implies

if COPCs are detected in the Regional Aquifer only then will remedial options be evaluated. Contamination detected in the intermediate ground water systems, for example, may trigger the evaluation of remedial options."

Specific Comments: Appendix 4, Comment 4 Response
DOE/LANL share the concern that contaminants detected in an upper water-bearing zone may warrant remedial options. As illustrated on Figure 4-1, the detection of contaminants in any water bearing zone leads to both an evaluation of remedial options and the decisions regarding pathways. If there are pathways that would allow contaminants to migrate to other water-bearing zones, then remedial options will be evaluated.

Specific Comments: Appendix 4, Comment 5
"The potential for vapor-phase migration of contaminants should be addressed where tritium, organics, etc. are of concern (e.g., TA-33-Ancho Canyon-Chaquehui Canyon, Los Alamos Canyon, DP Canyon, etc.)"

Specific Comments: Appendix 4, Comment 5 Response
DOE/LANL agree that vapor-phase migration should be addressed and have included data collection for contaminants amenable to vapor phase transport (see for example Aggregate 1, pages 11-12). Vapor transport occurs in any scenario, but is driven mostly by the presence and concentration of contaminant sources.

Specific Comments: 2.1.2.1 Bedrock Stratigraphy, Comment 1
"As the geology is important to the hydrogeology, LANL should provide a geologic map. In addition, generalized stratigraphic cross-sections of LANL should be included to better illustrate the heterogenic distribution of geologic units observed on the Pajarito Plateau."

Specific Comments: 2.1.2.1 Bedrock Stratigraphy, Comment 1 Response
DOE/LANL agree with the need to include a geologic map. A geologic map will be included in the final Hydrogeologic Workplan. There are seven generalized stratigraphic cross-sections included in the document which are judged to be sufficient for illustrating the heterogeneity across the Laboratory. These cross sections will also be referenced in this background section in the final Hydrogeologic Workplan.

Specific Comments: 2.1.2.1 Bedrock Stratigraphy, Comment 1A
"LANL should include on the geologic map(s), the Pajarito Fault Zone, Rendija and Guaje Mountain Faults, fracture swarms, slump blocks and other features."

Specific Comments: 2.1.2.1 Bedrock Stratigraphy, Comment 1A Response
DOE/LANL concur with the need to show features of significance to the hydrogeologic setting. The geologic map included in the final Hydrogeologic Workplan will include

existing data on geologic features necessary to interpret the hydrogeologic setting and to assess pathways for contaminant migration.

Specific Comments: 2.1.2.1 Bedrock Stratigraphy, Comment 2
"Clarify, if known, what bounds the eastern boundary of the "Chaquehui Formation" (e.g. fault?)."

Specific Comments: 2.1.2.1 Bedrock Stratigraphy, Comment 2 Response
The nature of the eastern boundary of the "Chaquehui Formation" is unknown. A statement regarding the uncertain nature of the eastern boundary will be added to the text in the final Hydrogeologic Workplan.

Specific Comments: 2.1.2.1 Bedrock Stratigraphy, Comment 3
"Although potentially a significant hydrogeologic feature, the "Chaquehui Formation" of Purtymun (1995), has not been recognized, HRMB recommends not using "Chaquehui Formation" instead, refer to the upper coarse-grained facies of the Santa Fe Group or state that the "Chaquehui Formation" is not formally recognized and use quotes around the name (Core Document for Canyons Investigations, 4/97)."

Specific Comments: 2.1.2.1 Bedrock Stratigraphy, Comment 3 Response
The final Hydrogeologic Workplan will follow the stratigraphic usage in the Core Document for Canyons Investigations, 4/97.

Specific Comments: 2.1.2.1 Bedrock Stratigraphy, Comment 4
"LANL should provide descriptions of the basic characteristics of the various soil types identified at LANL. This may be accomplished by adding a table with basic descriptions of the Carjo, Frijoles, etc."

Specific Comments: 2.1.2.1 Bedrock Stratigraphy, Comment 4 Response
A table with basic descriptions of the soil types at LANL will be included in the final Hydrogeologic Workplan.

Specific Comments: 2.1.3.1 Surface Water, Comment 1
"LANL should provide locations and extent of the identified perennial reaches and surface water. HRMB suggests this information be incorporated into Figure 2-6."

Specific Comments: 2.1.3.1 Surface Water, Comment 1 Response
The perennial surface water reaches will be added to Figure 2-6 in the final Hydrogeologic Workplan. They are included to ensure a comprehensive approach to groundwater

protection, but requirements of the Clean Water Act are not enforceable through this document.

Specific Comments: 2.1.3.1 Surface Water, Comment 1A
"The Department of Energy-Oversight Bureau (DOE-OB) has indicated to HRMB that there are six canyons that contain perennial reaches within laboratory boundaries, not the four indicated in the text. DOE-OB includes Pajarito, Ancho, Chaquehui, Twomile, Threemile Canyons and Cañon de Valle. Currently, perennial surface-water flow in Water Canyon does not extend onto the western boundary of LANL (see comment 2 this section). The perennial flow in Twomile and Threemile Canyons is supported by Anderson and TA-18 Springs respectively."

Specific Comments: 2.1.3.1 Surface Water, Comment 1A Response
The four perennial surface water reaches within the Laboratory boundary include: Ancho, Water, Pajarito, and Chaquehui Canyons. A spring on DOE property within the western Laboratory boundary occurs in Pajarito Canyon, i.e. perennial flow has been noted in Pajarito Canyon associated with Homestead Spring. Springs near the Rio Grande in Water, Ancho, and Chaquehui Canyons are within the eastern Laboratory boundary. The additional springs that have been located by the NMED Oversight Bureau, will investigated under the tasks described in the Workplan. These springs and any new springs that are identified their flow characteristics will be evaluated, and they will be added to the inventory of springs and the Workplan text regarding perennial reaches of surface water will be amendedd, as appropriate.

Specific Comments: 2.1.3.1 Surface Water, Comment 1B
"The DOE-OB has also noted to HRMB that perennial flow from Starmer Gulch and Arroyo de Ladelfe should be included in the discussion of perennial reaches in Pajarito Canyon."

Specific Comments: 2.1.3.1 Surface Water, Comment 1B Response
Same as 2.1.3.1 Comment 1A above.

Specific Comments: 2.1.3.1 Surface Water, Comment 2
"Please provide a table listing all known springs. Include range of observed flow rates, contaminants detected, concentrations, dates of sampling, and unit. Illustrate the location of each spring on Figure 2-8."

Specific Comments: 2.1.3.1 Surface Water, Comment 2 Response
DOE/LANL concur with the need to identify the locations and characteristics of all springs at the Laboratory. As agreed with NMED during discussions on the Core Document for Canyons Investigations, spring data will be included with each canyon-specific workplan.

Specific Comments: 2.1.3.1 Surface Water, Comment 3
"Provide the locations of all surface water gauging stations at LANL."

Specific Comments: 2.1.3.1 Surface Water, Comment 3 Response
The location of all surface water gaging stations will be included on Figure ___ in the final Hydrogeologic Workplan.

Specific Comments: 2.1.3.2 Groundwater, Comment 1
"Figure 2-8 incorrectly identifies the north branch of Ancho Canyon as Indio Canyon."

Specific Comments: 2.1.3.2 Groundwater, Comment 1 Response
The mis-identification of Indio Canyon will be corrected in the final Hydrogeologic Workplan.

Specific Comments: 2.1.3.2 Groundwater, Comment 2
"Please include the Technical Areas on Figures 2-7 and 2-8."

Specific Comments: 2.1.3.2 Groundwater, Comment 2 Response
The Technical Areas will be included on Figures 2-7 and 2-8 in the final Hydrogeologic Workplan.

Specific Comments: 2.1.3.2 Groundwater, Comment 3
"Please clarify where the results of an extensive monitoring study of alluvial ground water are presented. The paragraph is unclear whether the "study" is found in Abrahams et al. (1961) and the six references following Abrahams et al. (1961) or the Purtymun reviews."

Specific Comments: 2.1.3.2 Groundwater, Comment 3 Response
The referenced paragraph is incorrectly worded. It should say "The results of extensive monitoring studies of the alluvial groundwater in Mortandad Canyon.....". The final Hydrogeologic Workplan will include this correction.

Specific Comments: 2.1.3.2 Groundwater, Comment 4
"Please indicate if LANL recognizes a separate perched groundwater occurrence within the Tschicoma Formation and Tshirege member of the Bandelier Tuff (located on the western portion of the Pajarito Plateau). Since this ground water system has provided a minimum of 23 to 96 million gallons annually (page 2-18, Hydrogeologic Workplan), it is an important aspect of the hydrogeologic system. Provide rationale of agreement or non-agreement of this fourth groundwater occurrence."

Specific Comments: 2.1.3.2 Groundwater, Comment 4 Response
LANL includes the occurrences of perched groundwater in the Tschicoma Formation and Bandelier Tuff along the western margin of the Pajarito Plateau and on the eastern flanks of the Sierra de Los Valles in the general category of intermediate perched zone groundwater. For simplicity of description, these groundwater bodies are included with all other perched systems that generally lie between alluvial groundwater and the regional aquifer, Although the discharge points (springs) for some intermediate-depth perched zones occur above the local stream channel (e.g.Water Canyon Gallery), the main body of these perched zones follows groundwater pathways within bedrock geologic units rather than alluvium in canyon floors. This is the distinction we made when categorizing alluvial and intermediate zone groundwaters. We see no advantage in further subdividing intermediate perched zone groundwater to distinguish groundwater in the Tschicoma Formation and Bandelier Tuff as a separate category. We recognize that each occurrence of intermediate perched groundwater across the Plateau has its own unique hydrogeologic setting, recharge pathway, bedrock and structural controls, flowpaths, connections to the surface or other groundwater bodies, and geochemistry. Further subdivision of the intermediate perched zone groundwaters would not fundamentally change our recognition of the unique characteristics of each of these perched systems.

Specific Comments: 2.1.3.2 Groundwater, Comment 5
Please provide a figure illustrating where intermediate perched zones have been identified or are speculated to exist. Differentiate between the various hydrostratigraphic zones and between speculated and known occurrences."

Specific Comments: 2.1.3.2 Groundwater, Comment 5 Response
The general locations of intermediate perched zones will be provided as data are collected within each canyon.

Specific Comments: 2.1.3.2 Groundwater, Comment 6
"Considering the 23 to 96 million gallons produced annually by the Water Canyon gallery (page 2-18,Hydrogeologic Workplan) clarify whether the statement "The regional aquifer of the Los Alamos area is the only aquifer capable of large-scale municipal water supply." is appropriate."

Specific Comments: 2.1.3.2 Groundwater, Comment 6 Response
Use of the Water Canyon Gallery for public water supply was discontinued in 1989 due to a heavy and variable sediment load which resulted in undesirable water quality. During 1988 the Water Canyon Gallery produced only about 2% of the municipal and industrial water supply. The gallery was a part of the original Manhattan Project water supply system along with the Los Alamos and Guaje Canyon reservoirs. This system was notoriously inadequate and unreliable, and development of a reliable, high-capacity water supply system was one of the Atomic Energy Commission's highest priorities for Los Alamos following the end of World War II.

In a large-scale municipality, Albuquerque, the average per capita water use (includes residential and industrial users) was 225 gallons/person/day. With conservation efforts, the per capita water use dropped to 185 gallons/person/day in 1997. Based on the latest per capita water use, the Water Canyon gallery could supply water for approximately 340 to 1,420 people. Additionally, the average water use does not take into account peak water use, which could be as high as double the average. If the Water Canyon Gallery were to be used as the sole supply of water, it would support approximately 170 to 710 people. Water canyon gallery could provide a water supply for a very small community, but could not support "large-scale municipal water supply".

Specific Comments: 2.1.3.2 Groundwater, Comment 7
"LANL should clarify within the conceptual model, the confined or unconfined nature of the regional aquifer. The data presented are not clear: the recharge source for the regional aquifer is the Sangre de Cristo Mountains and the regional aquifer responds to barometric and tidal forces?"

Specific Comments: 2.1.3.2 Groundwater, Comment 7 Response
First, a general comment on the conceptual model. The first paragraph of section 2 in the workplan states that "there is considerable uncertainty in the conceptual model as a whole". All elements of the conceptual model are presented in light of this view point. Further, LANL has indicated that the conceptual model will be updated in the annual report, and that much of the purpose of proposed drilling is to gather information needed to clarify these uncertainties.

LANL agrees that the data regarding the confined or unconfined nature of the regional aquifer are indeed not clear. The sources of recharge for the regional aquifer and the confined versus unconfined nature of the aquifer are not completely understood, as NMED has pointed out in several letters to LANL. These questions will be addressed further by the proposed workplan.

As stated in the workplan, the above-ground water levels in some of the former Los Alamos well field (water supply wells with the designation LA-) indicate that the regional aquifer in that locality is confined. Data from wells in the central portion of the Laboratory suggest that the regional aquifer there may not be confined.

As stated in the workplan, isotope and other data suggest that water found in the Los Alamos well field (water supply wells with the designation LA-) may originate from the Sangre de Cristo Mountains. Water produced in the Pajarito Mesa field has a different chemical composition and may originate from another source. LANL's studies of the Pajarito Plateau indicate that possible infiltration through the Plateau surface is insufficient to account for the relatively large quantity of water supply pumping.

LANL will modify the workplan to indicate that recharge from the Jemez Mountains and the Pajarito Plateau appears to be insufficient to account for the relatively large quantity of water supply pumping. This is the basis for statements indicating that the hydrologic connection between the plateau surface and the regional aquifer is not strong, and that recharge from the plateau is small.

Specific Comments: 2.1.3.2 Groundwater, Comment 8
"HRMB interprets the discussion of LANL's conceptual model as accepted by LANL and not subject to much debate. LANL should discuss any uncertainties with recharge of the Regional Aquifer beneath the Pajarito Plateau from the Sangre De Cristo Mountains to the east. For example, questions arise from the presence of relatively major faults and the Cerros del Rio volcanic field along the eastern margin of the Espanola Basin.

Specific Comments: 2.1.3.2 Groundwater, Comment 8 Response
LANL agrees that there are many uncertainties regarding the understanding of the hydrogeology of the Pajarito Plateau. LANL's discussion of recharge sources for the regional aquifer begins with the statement "the exact source of recharge to the regional aquifer is unknown".

Regarding HRMB's interpretation that the conceptual model is not subject to debate, the first paragraph of section 2 in the workplan states that "there is considerable uncertainty in the conceptual model as a whole". All elements of the conceptual model are presented in light of this view point. Further, LANL has indicated that the conceptual model will be updated in the annual report, and that much of the purpose of proposed drilling is to gather information needed to clarify uncertainties.

Specific Comments: 2.1.3.2 Groundwater, Comment 9
"The Rodgers (1996b) study collected composite samples (600 to 3,100 ft screened interval) for the radiocarbon analyses. Please discuss any uncertainties that may arise from the collection of composite samples. HRMB believes that caution should be used when considering these age determinations due to uncertainty associated with composite sampling and that the radiometric carbon age determinations do not preclude significant recharge from the Jemez Mountains/Pajarito Plateau."

Specific Comments: 2.1.3.2 Groundwater, Comment 9 Response
The correct citation is Rogers (1996b). The uncertainties present in this sort of age estimate were described in the original article, and given as a caveat for accepting the radiocarbon data on their face. Among the uncertainties are the fact that a water sample may be formed by mixing of several water masses; possible mixing of carbon by dissolution of carbonate minerals; and the fact that the samples are drawn from wells with large screened intervals.

Contrary to HRMB's assumption, LANL does not believe that the radiocarbon age determinations preclude recharge from the Jemez Mountains and Pajarito Plateau. However, these results along with results from a number of independent lines of evidence including age dating, isotopic composition (tritium and stable isotopes), chemical composition, moisture profiles, and measurements of recharge rates, suggest that current recharge through the Pajarito Plateau is only a tiny fraction of the water that is withdrawn from the aquifer for public water supply.

Regarding the phrases "preclude significant recharge from the Jemez Mountains" and "considerable source for recharge to the regional aquifer" (from comment 3 on 2.2), there are two ways to view "significant". In terms of overall volume (as stated above) there are numerous lines of evidence that suggest that recharge through the plateau may be small in relative terms (compared to water supply pumping for example). On the other hand, infiltration of a small volume of contaminated water could have a significant negative impact on the aquifer. LANL agrees that sources of recharge and their relative magnitudes are insufficiently understood, and intends to improve this understanding through activities under the workplan.

There is ample chemical, isotopic, and hydrologic data to support a hypothesis that the water tapped by the Pajarito Well Field and by the Los Alamos Well Field come from very different water masses. This suggests that the regional aquifer has a somewhat complex structure. The clarification of these issues awaits further modeling studies and data collection, as indicated by the workplan.

Specific Comments: 2.2 Preliminary Conceptual Model for the Pajarito Plateau, Comment 1

"The bullet on Figure 2-11, "~~Vapor phase contaminant movement possible~~" should be omitted. It should be replaced by "Vapor phase contaminant movement likely" or similar terminology as evidenced by tritium and organic vapor plumes beneath TA-54 MDA L and MDA G."

Specific Comments: 2.2 Preliminary Conceptual Model for the Pajarito Plateau, Comment 1 Response

LANL agrees that vapor phase contaminant movement is likely, as investigations have shown. The bullet on Figure 2-11 will be changed to read "Vapor phase contaminant movement likely" in the final Hydrogeologic Workplan. Vapor phase contaminant movement has been established at Material Disposal Area L. However, sources of vapor phase contaminants are only present at a few locations, therefore vapor phase contaminant movement is only possible and a concern at some locations.

Specific Comments: 2.2 Preliminary Conceptual Model for the Pajarito Plateau, Comment 2

"Figure 2-12 ignores the significant contribution of alluvial ground water to the hydrogeologic system and contaminant transport. Please provide rationale for the omission."

Specific Comments: 2.2 Preliminary Conceptual Model for the Pajarito Plateau, Comment 2 Response

LANL feels that Figure 2-12 does not ignore the significant contribution of alluvial groundwater to the hydrologic system and contaminant transports. Please provide a rationale for the viewpoint that there is an omission.

Figure 2-12 describes alluvial groundwater as potentially a significant source of recharge to both the intermediate perched zones and to the regional aquifer. This is further emphasized in section 2.2.2. The remainder of the workplan constantly draws attention to the significance of the alluvial groundwater as a source of both contaminants and of recharge.

Specific Comments: 2.2 Preliminary Conceptual Model for the Pajarito Plateau, Comment 3

Figure 2-12 also indicates that intermediate ground water may be "....laterally extensive near the Jemez Mountains". This suggests that the Jemez Mountains may indeed be a considerable source for recharge to the regional aquifer. The Workplan generally indicates that recharge from the Jemez Mountains and Pajarito Plateau is not significant."

Specific Comments: 2.2 Preliminary Conceptual Model for the Pajarito Plateau, Comment 3 Response

LANL agrees that there is considerable uncertainty regarding recharge along the Jemez Mountains, however no drilling to date has discovered extensive perched groundwater in the western portion of the Laboratory, except possibly SHB-3. The uncertainties regarding possible recharge and the hydrogeologic regime along the Jemez Mountains are the reason that well R-25, near MDA-P, is the highest ranked well on the basis of its timing score. The phrase regarding "significance" of recharge reflects a comparison of relative volumes of such recharge to the amount of public water supply pumping from the regional aquifer. This phrase is not intended to minimize the possible importance of this groundwater as a possible contaminant source and pathway. LANL will clarify this in the text indicated.

Specific Comments: 2.2.2 Alluvial Groundwater, Comment 1

"The text implies that the alluvial groundwater is only interconnected to the perched intermediate groundwater. LANL should clarify if interconnectedness of the alluvial systems to the regional aquifer is precluded (Lower Los Alamos Canyon?)."

Specific Comments: 2.2.2 Alluvial Groundwater, Comment 1 Response

The text does not imply that alluvial groundwater is only connected to the perched intermediate groundwater. Figure 2-12 shows a direct connection between canyon bottom recharge and the regional aquifer. Section 2.2.4 explicitly states that "alluvial groundwater may be a minor source of recharge to the regional aquifer". In this context, "minor" refers to relative volumes of such recharge when compared to public water supply withdrawals. This is not intended to indicate that this is not a potential significant pathway for contamination. LANL will modify the text to clarify this point.

Specific Comments: 2.2.2 Alluvial Groundwater, Comment 2
"LANL should include fractures, joints, surge beds and permeable geologic units (e.g., Guaje Pumice and Puye Formation) as probable pathways for downward movement in the following sentence: "...faults, fractures, joints, surge beds and permeable geologic units (e.g. Guaje Pumice, Cerro Toledo, and Puye Formation) that underlie alluvial saturated zones or intermediate perched zones could provide pathways for downward water movement."'

Specific Comments: 2.2.2 Alluvial Groundwater, Comment 2 Response
The suggested revision will be made in the final Hydrogeologic Workplan.

Specific Comments: 2.2.4 Regional Aquifer, Comment 3
"LANL should omit the statement "~~The hydraulic connection between the regional aquifer and the land surface is not strong~~" as it is misleading. The interconnectedness of the hydrogeologic system is not adequately understood to make this statement at this time.

Specific Comments: 2.2.2 Alluvial Groundwater, Comment 3 Response
As explained above, phrases such as "is not strong" indicate that the relative volume of such recharge is small compared to the overall volume of the aquifer and to the annual volume of public water supply withdrawals. This is not intended to indicate that no connection exists or that it is not a potential contaminant pathway. LANL will clarify this text.

Specific Comments: 4.0 Hydrogeologic Characterization, Comment 1
HRMB points out that the LANL ranking system may not concur with the requirements of RCRA compliance, for example, Future Water Supply seems inappropriate as a criteria."

Specific Comments: 4.0 Hydrogeologic Characterization, Comment 1 Response
The Hydrogeologic Workplan is intended to ensure a comprehensive, well integrated approach to addressing all applicable regulatory programs. The ranking system was developed to meet, as a minimum, the requirements of RCRA compliance. However, other regulatory programs and best management practices are also embedded within the

ranking system. Additionally, the impact of future pumping of water supply wells must be considered in estimating contaminant migration.

Specific Comments: 4.0 Hydrogeologic Characterization, Comment 2
"To avoid confusion and remain consistent with other documentation (e.g., the Core Document for Canyons Investigations) the boreholes/wells should have one designation".

Specific Comments: 4.0 Hydrogeologic Characterization, Comment 2 Response
The boreholes/wells described in the Hydrogeologic Workplan will retain the designations when they are referenced in other documents. The Core Document for Canyons Investigations uses well designations consistent with the Hydrogeologic Workplan.

Specific Comments: 4.0 Hydrogeologic Characterization, Comment 3
"It is unclear to HRMB why alluvial and regional wells were proposed, but only one intermediate well was proposed. Please clearly explain the rationale for proposing only one intermediate well and indicate where the installation of intermediate wells are to be addressed."

Specific Comments: 4.0 Hydrogeologic Characterization, Comment 3 Response
The rationale supporting the approach to hydrogeologic characterization using alluvial wells and regional wells was not sufficiently described in the text of the Hydrogeologic Workplan. This approach was discussed with NMED representatives at a meeting on August 7, 1996 and consensus with the approach is documented in a letter sent to NMED on September 11, 1996 (addressed to Dr. Ed Kelley, subject: The proposed Los Alamos National Laboratory (Laboratory) Groundwater Protection Strategy and RelatedData Quality Objectives and Decision Flow Process). The rationale is:

- The presence of intermediate zone(s) is controlled by geologic structure and the geology across the Lab 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 was 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. Wells that may be needed to monitor the intermediate zone(s) will be considered as part of the monitoring system design.

The information gathered during the characterization will be used to design a detection monitoring network that almost certainly include monitoring wells in the intermediate zone. However, until the characterization effort described in the workplan is complete, the number and location of intermediate zones wells can not be determined.

One intermediate well was proposed because this well was completed prior to the completion of the Hydrogeologic Workplan. The final Hydrogeologic Workplan will include the rationale for the proposed characterization approach.

Specific Comments: 4.0 Hydrogeologic Characterization, Comment 4
"Please revise Table 4-1 and 4-2 to reflect current drilling activities (installation of R-9) and include driver for altering the schedule."

Specific Comments: 4.0 Hydrogeologic Characterization, Comment 4 Response
Revised Tables 4-1 and 4-2 will be included in the final Hydrogeologic Workplan. The change in schedule for R-9 was made to meet ER Project needs to accelerate groundwater investigations in Los Alamos Canyon. This canyon is currently the focus of surface and groundwater investigations by the Canyons technical team, and it was felt that data from R-9 could influence the deep groundwater characterization strategy for the rest of the canyon.

Specific Comments: 4.0 Hydrogeologic Characterization, Comment 5A
"HRMB recommends that the proposed location for R-5 is moved closer to TW-1 as it is proposed to replace TW-1 and may provide additional information on a ground water mound present in the TW-1 area."

Specific Comments: 4.0 Hydrogeologic Characterization, Comment 5A Response
The location of R-5 further delimits the western extent of the groundwater mound near TW-1. The apparent groundwater mound may have begun to appear in TW-1 after the LA County sewage treatment plant began to discharge effluent to Pueblo Canyon in 1963. The proposed site for R-5 is located between the sewage treatment plant and TW-1. Therefore, the proposed location of R-5 will help determine how far the mound extends up canyon of its already determined occurrence at TW-1. The current location of R-5 will also delimit the western extent of perched groundwater that was encountered in basalts of boreholes TW-1A and POI-4. This perched groundwater is also recharged by effluent from the LA County sewage treatment plant. Adjustments to the siting of R-5 can be made at the quarterly and annual meetings between NMED and DOE/LANL.

Specific Comments: 4.0 Hydrogeologic Characterization, Comment 5B
"R-27 is located in an area where contamination is present. This well is proposed to gather background water chemistry data. If contamination is expected (HE, Ba, etc. in springs) this proposed location may be inappropriate."

Specific Comments: 4.0 Hydrogeologic Characterization, Comment 5B Response
R-27 may be in an area where contaminants are present in the regional aquifer. This well serves the dual purpose of determining if contaminants are present from upgradient sources in Aggregate 5 and providing information about the baseline geochemistry of regional groundwater entering Aggregate 3. The term background water chemistry may not be accurate if R-27 contains contaminants from upgradient sources. The term *baseline* will be substituted for *background* in the final Hydrogeologic Workplan.

Specific Comments: 4.0 Hydrogeologic Characterization, Comment 5C
"The proposed location of R-8 in Los Alamos Canyon is above the confluence with DP Canyon. Provide rationale if this location will be useful for detecting contamination originating in DP Canyon."

Specific Comments: 4.0 Hydrogeologic Characterization, Comment 5C Response
The location of R-8 is problematic because of the narrow, confined nature of the canyon floor in the vicinity of the Los Alamos Canyon and DP Canyon confluence. As sited now, R-8 is located just west of water supply well Otowi 4, on the narrow strip of canyon floor separating Los Alamos and DP Canyons. As sited, R-8 is about 150 ft northwest of Otowi 4. This location places R-8 downgradient of numerous contaminant sources in aggregate 1, but provides relatively little early warning time if contaminants are present in the regional aquifer and are moving towards Otowi 4. We would like to discuss the location of R-8 at the upcoming annual meeting between NMED and DOE/LANL.

Specific Comments: 4.0 Hydrogeologic Characterization, Comment 5D
"The location of R-10 appears to head in the northern extension of the pre-Bandelier paleodrainage and not the southern extension as indicated in the text."

Specific Comments: 4.0 Hydrogeologic Characterization, Comment 5D Response
The text is poorly worded and will be modified to say *"...investigate the southward extension of this perched system from the Los Alamos Canyon area."* in the final Hydrogeologic Workplan.

Specific Comments: 4.0 Hydrogeologic Characterization, Comment 5E
"Due to vapor-phase plumes present beneath MDA L and MDA G, HRMB recommends re-evaluating proposed (FY2001) regional aquifer well R-20."

Specific Comments: 4.0 Hydrogeologic Characterization, Comment 5E Response
Data from two deep boreholes (54-0015 and 54-0016) located in Canada del Buey and inclined beneath MDA L suggest there is no immediate threat to the regional aquifer in this area. Acceleration of the schedule R-20 will result in a delayed start at another well

location. Re-prioritization of wells can be made at the quarterly and annual meetings between NMED and DOE/LANL.

Specific Comments: 4.0 Hydrogeologic Characterization, Comment 5F
"Depending on the capture zone of PM-5 and the source of contamination (presumably Mortandad Canyon), the proposed location of R-14 (mesa top and to the west) may be inadequate to provide "protection" for PM-5."

Specific Comments: 4.0 Hydrogeologic Characterization, Comment 5F Response
The location of R-14 will be optimized to detect contamination approaching PM-5 from sources in Mortandad Canyon. The Mortandad Canyon Workplan proposes a location for R-14 that is 800 ft west of the location shown in the Hydrogeologic Workplan. This places R-14 in a more intermediate position between contaminant sources in Mortandad Canyon and water supply well PM-5. The optimum location for R-14 can be discussed at the quarterly and annual discussions between NMED and DOE/LANL. In the meantime, the R-14 location shown in the Mortandad Canyon Workplan will be shown in the final Hydrogeologic Workplan.

Specific Comments: 4.0 Hydrogeologic Characterization, Comment 6
"If funding is available, HRMB recommends the acquisition of continuous core on R-26 and R-24. The locations are proximal to the Pajarito Fault Zone and may provide information concerning brecciated zones, fault splays, etc. As discussed within the Workplan, only 10% will be cored and overlook some pertinent information."

Specific Comments: 4.0 Hydrogeologic Characterization, Comment 6 Response
We agree that 10% core may not be sufficient to adequately characterize potential groundwater pathways in faults and breccia zones associated with the Pajarito Fault System. The figure of 10% core is an approximate target for Type 2 wells in general and should be adjusted upwards or downwards on a well by well basis to ensure that objectives for each of the wells are achieved. More core should probably be collected in R-24 and R-26, and the additional amount of core needed will be determined when the detailed drilling plans for these holes are developed. Given our current experience with coring operations in R-9, we find that coring goals identified in the planning stage will often be revised during drilling to account for unanticipated or unpredictable geologic and hydrologic conditions.

Specific Comments: 4.1 Hydrogeologic Characterization, Introduction and Procedures, Comment 1
The screened interval in wells advanced to the regional aquifer should be determined on a site-by-site basis. Where LANL can document significant drawdown of the regional aquifer, the screened interval shall not exceed 60 feet. In areas of the Laboratory where little or no drawdown is documented, the screened interval shall be 20 feet according to

the Groundwater Technical Enforcement Guidance Document (TEGD, 1986) and the draft Groundwater Monitoring (1992) guidance. Please revise the text as necessary."

Specific Comments: 4.1 Hydrogeologic Characterization, Introduction and Procedures, Comment 1 Response

The screened interval in wells advanced to the regional aquifer will be determined on a site-by-site basis. The text in this section of the Workplan will be revised to indicate this, and to acknowledge the screen length limitations indicated in the NMED comments.

Specific Comments: 4.1.1.1 Type 1 Wells, Comment 1

"The slot size/screen/filter pack should be based on sieve analysis of materials."

Specific Comments: 4.1.1.1 Type 1 Wells, Comment 1 Response

LANL has significant experience installing wells in the alluvium of the canyons. The selected slot size for the screened interval is based on this experience. If the alluvium encountered during the drilling of any Type 1 well is observably different, then a sieve analysis will be performed to determine the appropriate slot size. A statement regarding screen size selection will be added to the text of the final Hydrogeologic Workplan.

Specific Comments: 4.1.1.2 Type 2 Wells, Comment 1

"Clarify what geologic contacts will be cored. Will it include soil horizons/perching units, individual surge/pumice fall deposits, etc. or is it more broad based, for instance Bandelier Tuff, Cerro Toledo interval, etc."

Specific Comments: 4.1.1.2 Type 2 Wells, Comment 1 Response

Core will be collected at stratigraphic contacts and in intermediate zone perched groundwater zones as they are encountered. Core will also be collected at other zones of hydrologic significance such as buried soil horizons and at the top of the regional aquifer.

Specific Comments: 4.1.1.4 Type 4 Wells, Comment 1

HRMB has concerns with using a "multi-port Westbay-type casing" and casing string due to potential problems with isolating individual units of saturation. Provide rationale or list advantages and disadvantages for utilizing this type of casing.

Specific Comments: 4.1.1.4 Type 4 Wells, Comment 1 Response

There are many advantages from using a multi-port casing. These are 1) ability to conduct repeatable sampling and testing of discrete zones within the same well; 2) measurements of vertical gradients; 3) intervals will have dedicated sampling equipment to minimize the potential for cross contamination; 4) provides the most information for least cost. The disadvantages of these wells are: 1) they must be carefully installed to ensure isolation of zones and 2) specialized equipment is required to install and sample the wells.

Specific Comments: 4.1.1.4 Type 4 Wells, Comment 2
"RPMP does not recommend the use of multi-port Westbay-type casing."

Specific Comments: 4.1.1.4 Type 4 Wells, Comment 2 Response
Westbay wells have been installed in at least two locations in New Mexico with NMED approval. One location is the South Valley Superfund Site. Four Westbay wells were installed in 1993-1994. The depths range from 700 to 1100 feet. The number of ports is up to seven. The wells have been sampled on a quarterly basis for a period of 4 years. NMED representatives for this project were Baird Swanson and Susan Morris. The EPA RPM is Bert Gorrod. Several Westbay wells with depths greater 1500 feet have been installed at White Sands Missile Range for NASA. These have also functioned as designed. LANL encourages RPMP to discuss the performance of Westbay wells with personnel in the Groundwater Protection and Remediation Bureau.

Specific Comments: 4.1.1.5 Type 5 Wells, Comment 1
"Schedule 40 PVC may not be appropriate for all intermediate well situations. Please refer to ASTM guidance."

Specific Comments: 4.1.1.5 Type 5 Wells, Comment 1 Response
The specific well design is described in the Drilling Plan developed for each well. The ASTM standards will be applied as appropriate. Reference to the development of detailed well-specific drilling plans will be included in the final Hydrogeologic Workplan.

Specific Comments: 4.1.2 HSWA Module VIII Requirements, Comment 1
"Please modify the language stating ~~"Any boring drilled to a depth of 300 feet or deeper~~ shall grout in a surface casing to prevent downward migration of surface contamination along the well bore." With language stating <u>any saturated condition encountered will require</u> *grout in a surface casing to prevent any downward migration of surface contamination along the well bore".*

Specific Comments: 4.1.2 HSWA Module VIII Requirements, Comment 1 Response
Language related to the grouting of surface casings will be amended in the Workplan to address NMED's concerns regarding "saturated conditions encountered" as well as downward migration of surface contamination along the well bore.

Specific Comments: 4.1.3 Borehole Sampling, Comment 1
"Please list the hydraulic properties to be determined (bullet f)."

Specific Comments: 4.1.3 Borehole Sampling, Comment 1 Response
The measured hydraulic properties may vary depending upon the geologic unit and site-specific conditions. A "typical" list of hydraulic properties to be determined on most core samples includes the following: in-situ water content, porosity, particle density, bulk

density, saturated hydraulic conductivity, and water retention characteristics from 0 to 15300 cm suctions.

Specific Comments: 4.1.4 Groundwater Sampling, Comment 1
"LANL should include language that indicates the borehole will be developed and groundwater sampling accomplished according to LANL standard operating procedures, TEGD, and other appropriate RCRA guidance through the use of indicator parameters, etc."

Specific Comments: 4.1.4 Groundwater Sampling, Comment 1 Response
The suggested language will be included in the Hydrogeologic Workplan.

Specific Comments: 4.1.4 Groundwater Sampling, Comment 2
"Please clarify whether ground water samples will be filtered or unfiltered. This section is contradictory as it indicates that filtered and unfiltered samples will be collected in bullet "a" and filtered only in bullet "d"."

Specific Comments: 4.1.4 Groundwater Sampling, Comment 2 Response
Groundwater samples will be both filtered and non filtered prior to inorganic analyses. Organic analyses for volatile and semi volatile anthropogenic organic compounds shall be performed on non-filtered water samples. General inorganic analytes include radionuclides, major cations, major anions, trace metals, and trace non metals. The language will be changed in Section 4.1.4 Groundwater sampling to eliminate ambiguity. The sentence on page 4-27 (third line down from the top of the page) will be changed to "Filtered and non filtered samples will be used for laboratory analyses."

Specific Comments: 4.2 Site-Wide Hydrogeological Characterization, Comment 1
"Aggregate 9 is not defined in Section 1.3"

Specific Comments: 4.2 Site-Wide Hydrogeological Characterization, Comment 1 Response
As described in Section 4.2, Aggregate 9 consists of the regional studies that are not specific to an aggregate. A description of Aggregate 9 will be included in the final Hydrogeologic Workplan.

Specific Comments: 4.2.2.4 Water Supply Issues, Comment 1
"Replace "...~~naturally occurring contaminants~~" with "...naturally occurring constituents" *(last paragraph, 4-33)."*

Specific Comments: 4.2.2.4 Water Supply Issues, Comment 1 Response
The suggested wording change will be included in the final Hydrogeologic Workplan.

Specific Comments: 4.3 Descriptions of Aggregates, Comment 1
"Reference Figure 1-3 in discussions of the individual aggregates. Include locations, in another diagram(?) of former Technical Areas (e.g. TA-1, TA-45, etc.) where appropriate."

Specific Comments: 4.3 Description of Aggregates, Comment 1 Response
References to Figure 1-3 will be included in this section in the final Hydrogeologic Workplan. The locations of former Technical Areas will be shown on the block diagrams for each aggregate in the final Hydrogeologic Workplan.

Specific Comments: 4.3.1.2 Pueblo Canyon, Comment 1
"Intermediate Perched Zone and Regional Aquifer Groundwater Investigations
Figure 2-9 does not indicate the "potential recharge mound" referenced in the Workplan. Please provide a revised groundwater contour map indicating this and any other potential recharge mounds that are speculated to exist."

Specific Comments: 4.3.1.2 Pueblo Canyon, Comment 1 Response
Existence of a recharge mound is speculative, based on water level measurements from a single well (TW-1). Insufficient data exist to map such a hypothetical mound in a meaningful fashion. Investigations under the workplan are designed to address this question.

Specific Comments: 4.3.1.4 Sandia Canyon, Comment 1
"Surface Water
Clarify if the effluent discharge in Sandia Canyon is considered a "perennial reach".

Specific Comments: 4.3.1.4 Sandia Canyon, Comment 1 Response
The effluent discharge in Sandia Canyon is not considered a "perennial reach", but is rather considered an effluent-supported reach or artificial stream reach.

Specific Comments: 4.3.1.4 Sandia Canyon, Comment 2
"Alluvial Groundwater Investigations
Since the piezometer transect (A-26, A-27, and A-28) is located near the eastern limit of alluvium saturation , clarify if the transect will be moved to a point where saturation occurs if no saturation is encountered."

Specific Comments: 4.3.1.4 Sandia Canyon, Comment 2 Response
The purpose of the transect is to determine the presence, extent, and quality of alluvial water in Sandia Canyon (see Appendix 4, Aggregate 1, pp. 1-2). The transect will be located to encounter alluvial water.

Specific Comments: 4.3.1.4 Sandia Canyon, Comment 3
"Intermediate Perched Zones and Regional Aquifer Groundwater Investigations Please clarify what chemical data will be used to determine if the perched zones are interconnected (R-12 relative to POI-4 and TW1A). If the data are inconclusive, provide alternatives to be used in the determination of interconnectedness."

Specific Comments: 4.3.1.4 Sandia Canyon, Comment 3 Response
The following physical data will be measured or collected to determine if two saturated zones are hydrologically and chemically connected: temperature and hydraulic gradient information. The following chemical data will also be measured or collected from the saturated zones: radionuclides (tritium, Sr-90, Cs-137, Am-241, plutonium isotopes, uranium isotopes, gamma spectrometry, and gross alpha, beta, and gamma), pH, specific conductance, alkalinity, stable isotopes (hydrogen, oxygen, and in special cases nitrogen), major ions (cations and anions), trace metals, and trace elements. Mobile species such as tritium, chloride (Cl^-), nitrate (NO_3^-), and boron ($B(OH)_3^0$) have been very useful in determining if two or more saturated zones are interconnected within Los Alamos and Pueblo Canyons, especially at future R-12 relative to POI-4 and TW-1A. Tracer tests will be considered under special conditions to determine if a hydraulic connection occurs between two or more saturated zones. Potentiometric maps shall be constructed to determine flow directions and hydraulic gradients.

Use of chemical data for determining groundwater flow paths and contaminant chemistry require that background concentrations are well established for the different saturated zones found in the alluvium, Tschicoma Formation, Bandelier Tuff, basalts, Puye Formation, and Santa Fe Group beneath Los Alamos and Pueblo Canyons. Geochemical modeling consisting of mixing reactions based on chloride (or some other tracer) and reaction path modeling are useful in determining if two or more saturated zones are connected. Time-chemical species plots will be used to establish short- and long-term trends between two or more saturated zones. Hydrologic flow and solute transport modeling shall be used to quantify the degree of connection between different saturated zones.

Specific Comments: 4.3.2.3 Cañada del Buey, Comment 1
"Alluvial Groundwater
The first sentence of this section states there is not; however, CDBO-6 and CDBO-7 have encountered water perched in the alluvium and may result from discharges from PM-4. Because of the discrepancy please clarify if alluvial groundwater is present in Cañada del Buey."

Specific Comments: 4.3.2.3 Cañada del Buey, Comment 1 Response
Alluvial groundwater is present in the canyon along an approximately one-half mile long reach near wells CDBO-6 and CDBO-7; this reach is immediately below the PM-4

discharge point. Saturation has not been observed in other wells in the canyon. The final Hydrogeologic Workplan will be revised to clarify this issue.

Specific Comments: 4.3.2.3 Cañada del Buey, Comment 1A
"Provide the date of start-up for PM-4. In addition, clarify if discharges from PM-4 still occur, list the range of documented water levels at CDBO-6 and 7, and what time of year the wells are sampled."

Specific Comments: 4.3.2.3 Cañada del Buey, Comment 1A Response
Well PM-4 began to produce water in 1982. Discharges from PM-4 still occur (under NPDES permit) but infrequently. The most recent discharge occurred on November 10, 1997. The discharge was for 20 minutes at approximately 1350 gallons per minute. Water levels in CDBO-6 since 1992 have ranged from 0 (dry) to 12 feet of saturation. Water levels in CDBO-7 since 1992 have ranged from 0 (dry) to 7 feet of saturation. CDBO-6 and –7 are sampled quarterly for nitrogen species and in the 3rd or 4th quarter for metals and radioactivity.

Specific Comments: 4.3.2.3 Cañada del Buey, Comment 2
"Intermediate Perched Zone and Regional Aquifer
Please clarify "No intermediate perched zones occur in this area". Intermediate perched ground water was encountered at 334 feet in PM-2 and tentatively identified in SHB-4 between 125-145 feet."

Specific Comments: 4.3.2.3 Cañada del Buey, Comment 2 Response
There is no current evidence of intermediate perched zones beneath Cañada del Buey. The cited wells are located in Pajarito Canyon.

Specific Comments: 4.3.2.4 Pajarito Canyon, Comment 1
"Please check the Purtymun and Kennedy, (1971) reference to determine if it is appropriately cited concerning "....springs issue from hillslopes in the Tshirege Member of the Bandelier Tuff...".."

Specific Comments: 4.3.2.4 Pajarito Canyon, Comment 1 Response
This is not an appropriate reference for this information, and will be deleted in the final Hydrogeologic Workplan.

Specific Comments: 4.3.2.4 Pajarito Canyon, Comment 2
"Intermediate Perched Zone and Regional Aquifer Groundwater Investigations
The proposed location of R-20 is 0.25 miles east of PM-2. Clarify if this well is proposed to be early detection from up-gradient sources or if it is providing early detection for potential capture of the tritium and organic plumes at TA-54."

Specific Comments: 4.3.2.4 Pajarito Canyon, Comment 2 Response
R-20 is located between PM-2 and tritium and organic plumes at TA-54. It is designed to provide early detection of contamination moving towards PM-2.

Specific Comments: 4.3.3.1 Area Description and History, Comment 1
"Intermediate Perched Zones and Regional Aquifer
LANL should provide the locations of Areas 1, 2, 2A, 2B, 3 and 4"

Specific Comments: 4.3.3.1 Area Description and History, Comment 1 Response
The locations of these areas will be included in the final Hydrogeologic Workplan.

Specific Comments: 4.3.3.1 Area Description and History, Comment 2
"Please provide any explanations as to the source of water in CH-2.

Specific Comments: 4.3.3.1 Area Description and History, Comment 2 Response
The Laboratory's 1992 RFI Workplan for TA-49 (Sections 7.3.6.3 – 7.3.6.5) considered various hypotheses of possible sources of water in CH-2. That review did not identify a conclusive source of the water. RFI characterization activities are ongoing to allow a determination of the source(s) of the water.

Specific Comments: 4.3.3.1 Area Description and History, Comment 2A
"Document what unit the groundwater is found (e.g. Guaje Pumice Bed). If known, document the groundwater "occupance" relative to pre-Bandelier geologic surfaces"

Specific Comments: 4.3.3.1 Area Description and History, Comment 2A Response
The comment implies that saturated conditions have been found at TA-49 within the Bandelier Tuff. None of the many boreholes drilled at TA-49 have encountered groundwater in the tuff during drilling. A natural perched zone that either was not detected during site characterization or is episodic in nature could hypothetically explain the infrequent shows of water in CH-2. This hypothesis seems unlikely, however, given the relatively extensive site characterization performed to date and the fact that this recharge pathway apparently developed more than a decade after the hole was completed. The 20-ft slotted interval of CH-2 straddles the Unit 1v/Unit 1g contact.

Specific Comments: 4.3.3.1 Area Description and History, Comment 3
"Describe, if known, what unit the water loss occurred during the drilling of DT-5A and CH-2."

Specific Comments: 4.3.3.1 Area Description and History, Comment 3 Response

In the drilling of deep test well DT-5A, air circulation was lost at about 285 feet near the Unit 1v/Unit 2 contact. In the unsuccessful attempt regain circulation, an estimated 2.5 to 10 million gallons of drilling fluid was expended in this hole. According to Weir and Purtymun (1962) circulation was very poor in the upper 520 feet of the hole, within the Tshirege Member of the Bandelier Tuff. Twelve-inch casing was installed and cemented at this depth. Below 520 feet, drilling mud circulation was maintained to the total depth of 1821 feet. There was no water loss during the drilling of CH-2; the hole was drilled with air. After the drilling was completed, water was added to CH-2 to facilitate borehole geophysical logging. In the logging of CH-2, a significant amount of fluid was lost below a depth of about 300 feet, indicating the presence of a relatively permeable formation in stratigraphic Unit 1v and/or Unit 1g.

Specific Comments: 4.3.3.1 Area Description and History, Comment 4
"Intermediate Perched zones and Regional Aquifer Groundwater Investigations Clarify if the location of proposed regional well R-30 is in a position to monitor the east to southeast component of potential groundwater flow in this area of LANL. Given the volumes and nature of the materials used at TA-49 and those found in groundwater samples, justify the number of wells proposed and the location of each well associated with this aggregate."

Specific Comments: 4.3.3.1 Area Description and History, Comment 4 Response
R-30 is located east (downgradient in the regional aquifer) of the major source term at TA-49. This well will deepen existing borehole 49-2-700-1 which is already drilled to a depth of 700 ft, providing a significant cost savings to the drilling program. The need for additional wells in this area can be determined after characterization data becomes available from the planned wells.

Specific Comments: 4.3.4.2 Ancho Canyon, Comment 1
"Alluvial Groundwater
Please clarify the 4 ft to 9 ft of saturation encountered in ASC-15, -16, and -18."

Specific Comments: 4.3.4.2 Ancho Canyon, Comment 1 Response
The thickness of saturated alluvium encountered ranged from a minimum of 4 feet in one boring to a maximum of 9 feet in another boring. The thickness of saturated alluvium in the third boring was between 4 and 9 feet.

Specific Comments: 4.3.4.2 Ancho Canyon, Comment 2
"Figure 4-16 indicates MDA Y is located below the confluence of Ancho and the north fork of Ancho canyons. HRMB believes that it is incorrectly located on Figure 4-18 as MDA Y is located at TA-39 above the confluence. Please correct the figure if appropriate."

Specific Comments: 4.3.4.2 Ancho Canyon, Comment 2 Response

The location of MDA Y is in error in Figure 4-18 and will be corrected in the final Hydrogeologic Workplan.

Specific Comments: 4.3.4.2 Ancho Canyon, Comment 3
"Please justify the statement that "...the alluvium is quite permeable in contrast to the underlying Bandelier Tuff and underlying basalts." Due to the highly fractured and jointed nature of both the Bandelier Tuff and underlying basalts this statement is not entirely accurate."

Specific Comments: 4.3.4.2 Ancho Canyon, Comment 3 Response
If the alluvium were not "quite permeable" in contrast to the underlying rock, water would not be perched in the alluvium overlying the tuff. The exact nature of the perching interface requires more investigation in several areas. In some places the perching horizon appears to be weathered tuff.

In any case, the tuff beneath the alluvium is unsaturated. It is well established among hydrologists that in the case of unsaturated water flow, fractures and joints are a barrier to aqueous flow. Fractures and joints can only contain and transport water if the entire rock is saturated. If the rock is unsaturated water will be drawn into the surrounding rock matrix.

Specific Comments: 4.3.4.2 Ancho Canyon, Comment 4
"Intermediate Perched Zone and Regional Aquifer
The RFI Report for Operable Unit 1132 (March 1997) indicates that the regional aquifer is estimated to be between 300 to 600 feet below the canyon bottom (page 2-3). The Workplan indicates an estimate of 600 feet. Please clarify the discrepancy (be sure to include references)."

Specific Comments: 4.3.4.2 Ancho Canyon, Comment 4 Response
These depths are given as generalities. The exact depth of the regional aquifer in this area is unknown as there are no wells nearby. The elevation of the floor of Ancho Canyon in this area is about 6000 ft; the Rio Grande (which is believed to be contiguous with the regional aquifer surface) is approximately 600 ft lower, at an elevation of about 5400 ft. References for these observations include topographic maps.

Specific Comments: 4.3.4.3 Chaquehui Canyon, Comment 1
"Intermediate Perched Zones and Regional Aquifer
Ancho Spring is indicated to be 300 feet above the Rio Grande in Section 4.3.4.2, Intermediate Perched Zones and Regional Aquifer. In this section it is indicated to be 130-200 feet above the Rio Grande. Please clarify the discrepancy and provide references."

Specific Comments: 4.3.4.3 Chaquehui Canyon, Comment 1 Response
The correct elevation difference is 300 feet. Available GPS survey data (LANL FIMAD database) indicates that Ancho Spring issues at an altitude of approximately 5700 feet; the altitude of Ancho Canyon at the Rio Grande is approximately 5400 feet. The text will be corrected in the final Hydrogeologic Workplan.

Specific Comments: 4.3.4.3 Chaquehui Canyon, Comment 2
"Intermediate Perched Zones and Regional Aquifer Ground Water Investigations Considering the presence of a tritium source/other contamination at TA-33, provide rationale for not proposing characterization/monitoring wells in this area of LANL."

Specific Comments: 4.3.4.3 Chaquehui Canyon, Comment 2 Response
The mesa-top setting of the tritium source suggests that the need for characterization well(s) will be based on results of on-going RFI investigations. The largest canyon near TA-33, Chaquehui Canyon, is generally dry, and it is inaccessible because of deep incision. However, the need for characterization/monitoring wells in this area can be discussed at the quarterly and annual meetings between NMED and DOE/LANL.

Specific Comments: 4.3.5 Aggregate 5, Comment 1
"Table 4-7 lists proposed alluvial and regional wells for aggregate 5 not aggregate 4 as indicated in the text."

Specific Comments: 4.3.5 Aggregate 5, Comment 1 Response
The reference to aggregate 4 was an error. The correct reference to aggregate 5 will be included in the final Hydrogeologic Workplan.

Specific Comments: 4.3.5.2 Cañon de Valle, Comment 1
"Surface Water
The text refers to Cañon del Valle, replace with Cañon de Valle."

Specific Comments: 4.3.5.2 Cañon de Valle, Comment 1 Response
The name of Cañon de Valle will be corrected in the final Hydrogeologic Workplan.

Specific Comments: 4.3.5.2 Cañon de Valle, Comment 2
"Alluvial Groundwater
Figure 4-20 mis-labels/identifies the Tschicoma Formation in the key."

Specific Comments: 4.3.5.2 Cañon de Valle, Comment 2 Response
The labeling of the Tschicoma Formation in the key of Figure 4-20 was an error. The correct identification will be included in the final Hydrogeologic Workplan.

Specific Comments: 4.3.5.2 Cañon de Valle, Comment 3
"The text refers to Cañon del Valle, replace with Cañon de Valle."

Specific Comments: 4.3.5.2 Cañon de Valle, Comment 3 Response
The name of Cañon de Valle will be corrected in the final Hydrogeologic Workplan.

Specific Comments: 4.3.6 Aggregate 6, Comment 1
"Table 4-8 lists proposed alluvial and regional wells for aggregate 6 not aggregate 4 as indicated in the text."

Specific Comments: 4.3.6 Aggregate 6, Comment 1 Response
The reference to aggregate 4 was an error. The correct reference to aggregate 6 will be included in the final Hydrogeologic Workplan.

Specific Comments: 4.3.6.1 Area Description and History, Comment 1
"TA-39 is included in Aggregate 4, Figure 4-22 indicates it is part of Aggregate 6. TA-36 appears to be mis-identified on Figure 4-22."

Specific Comments: 4.3.6.1 Area Description and History, Comment 1 Response
The identification of TA-39 on Figure 4-22 was an error. Figure 4-22 will show TA-36 in the final Hydrogeologic Workplan.

Specific Comments: 4.3.6.2 Potrillo Canyon, Comment 1
"Surface Water
The reference for Becker (1991) is not listed in the references in Section Six (6)."

Specific Comments: 4.3.6.2 Potrillo Canyon, Comment 1 Response
The omission of the Becker (1991) in the reference list was an error. The complete citation to Naomi Becker's doctoral dissertation will be included in the final Hydrogeologic Workplan.

Specific Comments: 4.3.6.2 Potrillo Canyon, Comment 2
"Provide the location of the discharge sink on Figure 4-22."

Specific Comments: 4.3.6.2 Potrillo Canyon, Comment 2 Response
The location of the discharge sink will be included on Figure 4-22 in the final Hydrogeologic Workplan.

Specific Comments: 4.3.6.2 Potrillo Canyon, Comment 3

"The number and location of wells should reflect the significance of the discharge sink to groundwater recharge and the overall groundwater protection strategy at the lab. Since the discharge sink is collecting uranium contaminated surface water and sediments, groundwater monitoring of any alluvial, intermediate groundwater systems and the regional aquifer should be included in the design of the well type, placement and number in order to adequately delineate the effect of the discharge sink on potential contaminant (e.g., U) transport offsite."

Specific Comments: 4.3.6.2 Potrillo Canyon, Comment 3 Response

Potrillo Canyon has been the focus of some of the most detailed near-surface characterization activities at the Laboratory. A partial list of subsurface instrumentation already installed within or adjacent to the discharge sink includes 3 neutron moisture access tube clusters and 2 multi-level observation wells. These stations monitor the vertical moisture movement and the occurrence of saturation within the discharge sink (the observation wells have remained dry since their installation in 1991). Monitoring results from these holes and data from additional surface water and sediment monitoring activities will be evaluated to guide the design, placement, and number of additional wells needed to characterize this site.

Specific Comments: 4.3.6.2 Potrillo Canyon, Comment 3A

"Document, if known, what controls the discharge sink (e.g., structurally controlled?)."

Specific Comments: 4.3.6.2 Potrillo Canyon, Comment 3A Response

The probable feature that creates the discharge sink is an underlying fault, below the alluvium at the upstream end of the discharge sink, according to Becker (1991). The discharge sink will be investigated during site characterization activities.

Specific Comments: 4.3.7 Aggregate 7, Comment 1

"Table 4-9 lists proposed alluvial and regional wells for aggregate 7 not aggregate 4 as indicated in the text."

Specific Comments: 4.3.7 Aggregate 7, Comment 1 Response

The reference to aggregate 4 was an error. The correct reference to aggregate 7 will be included in the final Hydrogeologic Workplan.

Specific Comments: 4.3.7.2 Mortandad Canyon, Comment 1

"Alluvial Groundwater
If available, provide the estimated volumes of water lost to seepage into the tuff from the Purtymun (1977) and Koenig (1993) water balance studies:"

Specific Comments: 4.3.7.2 Mortandad Canyon, Comment 1 Response

Purtymun et al (1977) report that from 1963 through 1974, the estimated losses to the tuff ranged from 64,000 to 150,000 m^3 of water per year. These should be viewed as estimates with possible large sources of error.

For the two year period July 1963 to June 1965, Koenig (1993) estimated a total inflow to the tuff of 177,000 m^3. These figures cannot be directly compared to Purtymun's (1977) values as he gives figures on an annual basis. Assuming that Purtymun's values can be divided in half for 1963 and 1965 to represent the latter and first halves of these years, a rough approximation of 244,500 m^3 comes from his values for this time period.

Specific Comments: 4.3.7.2 Mortandad Canyon, Comment 1A
"Please clarify the last paragraph of this section as it is unclear. 20% of water entering the canyon is stored in the alluvium. 80% of the water entering the canyon is lost. 15% of the 80% water lost is due to evapo-transpiration. The remaining 65% of the 80% is lost to seepage into the tuff?"

Specific Comments: 4.3.7.2 Mortandad Canyon, Comment 1A Response
The previous paragraph incorrectly cited Purtymun's (1977) findings. Purtymun states that the average annual losses are "about the same volume that entered the canyon each year". Regarding the mechanism of loss, he says that "The losses attributed to evapotranspiration were estimated at about 15%..." (of the total loss) "with infiltration accounting for the remainder". The amount in storage does not directly bear on either the amount entering or the amount lost.

Specific Comments: 4.3.7.2 Mortandad Canyon, Comment 1B
"The reference for Koenig (1993) is missing in Section 6."

Specific Comments: 4.3.7.2 Mortandad Canyon, Comment 1B Response
The omission of Koenig (1993) from the reference list in Section 6 was an error. The correct reference will be included in the final Hydrogeologic Workplan.

Specific Comments: 4.3.8 Aggregate 8, Comment 1
"Table 4-10 lists proposed alluvial and regional wells for aggregate 8 not aggregate 4 as indicated in the text."

Specific Comments: 4.3.8 Aggregate 8, Comment 1 Response
The reference to aggregate 4 was an error. The correct reference to aggregate 8 will be included in the final Hydrogeologic Workplan.

Specific Comments: 4.3.8.1 Area Description and History, Comment 1
"Cabra Canyon is not identified on the figures. Please indicate on a figure and reference."

Specific Comments: 4.3.8.1 Area Description and History, Comment 1 Response

A block diagram showing the boundaries of Aggregate 8, including Cabra Canyon, will be included in the final Hydrogeologic Workplan.

Specific Comments: 4.3.8.1 Guaje Canyon, Comment 1
"Surface Water
The Guaje Canyon and Area Description and History sections share the same 4.3.8.1 section number."

Specific Comments: 4.3.8.1 Guaje Canyon, Comment 1 Response
The mis-numbering in this section was an error. The section numbering will be corrected in the final Hydrogeologic Workplan.

Specific Comments: Appendix 5, Criteria for Scheduling Well Installation, Comment 1
"See Comment 1, Section 4.0."

Specific Comments: Appendix 5, Criteria for Scheduling Well Installation, Comment 1 Response
The Hydrogeologic Workplan is intended to ensure a comprehensive, well integrated approach to addressing all applicable regulatory programs. The ranking system was developed to meet, as a minimum, the requirements of RCRA compliance. However, other regulatory programs and best management practices are also embedded within the ranking system.

Specific Comments: Appendix 6, Maps, Comment 1
"See Comment 1, Section 2.1.2.1."

Specific Comments: Appendix 6, Maps, Comment 1 Response
DOE/LANL agree with the need to include a geologic map. A geologic map will be included in the final Hydrogeologic Workplan. There are seven generalized stratigraphic cross-sections included in the document which are judged to be sufficient for illustrating the heterogeneity across the Laboratory. These cross sections will also be referenced in this background section in the final Hydrogeologic Workplan.

Preliminary Response to
Request for Supplemental Information
Installation Work Plan for Environmental Restoration Program
Revision 6, December 1996

INTRODUCTION

To facilitate review of this response, the New Mexico Environmental Department's (NMED's) comments are included verbatim. The comments are divided into general and specific categories as presented in the letter. Los Alamos National Laboratory's (LANL's) responses follow each NMED comment.

GENERAL COMMENTS

NMED Comment

1. *LANL should revise the hydrogeology and geology information presented in Chapter 2.0 to assure consistency with information presented in the Hydrogeologic Work Plan dated December 6, 1996.*

LANL Response

1. LANL has revised all of Chapter 2.0 in order to update current information as well as to ensure consistency with the December 6, 1996, Hydrogeologic Work Plan. See Revision 6.1 of Chapter 2.0, included as an attachment.

NMED Comment

2. *LANL should provide explanation for the "reason codes" to the qualifiers and discuss the expected impact on the true result value of each and all qualified data*

LANL Response

2. Explanations for the reason codes and data qualifier flags are given in the *LANL ER Checklist and Criteria for Verification and Baseline Validation* (LANL 1995, 52241), as cited in the QAPP, Section D1, *Data Review: Verification and Baseline Validation*. The ER Project verification and baseline data validation process is based on Environmental Protection Agency (EPA) guidelines for inorganic data review (EPA 1994, 48639) and organic data review (EPA 1994, 48640). LANL will incorporate the current baseline data validation requirements that have been in use since October 1995 into an SOP. The scheduled completion date for the baseline validation SOP is August 28, 1998. The baseline validation SOP will contain the explanations for the reason codes and data qualifier flags.

   The reason codes are a concise way of conveying to the data user the reason for qualifying data (i.e., applying a data qualifier flag). Reason codes are always associated with a corresponding data qualifier flag. The reason codes and data qualifier flags alert the data user to a potential problem associated with qualified results. LANL will prepare a quality procedure (QP) that will address how the reason codes and associated qualifier flags may be used to evaluate the potential impact of the data qualifications on the true result with respect to the direction and magnitude of this impact. Ultimately, however, the impact of the data qualifications on decision-making is site-specific and depends on the best professional

judgment of the technical team. LANL requires that the usability of qualified data be explained in any documents where such data are used for decision-making.

NMED Comment

3. *LANL should identify and describe mechanisms inherent in the streamlined verification/baseline validation process that assure adequate data quality for the Environmental Restoration (ER) Project.*

LANL Response

3. The ER Project verification and baseline data validation process is based on Environmental Protection Agency (EPA) guidelines for inorganic data review (EPA 1994, 48639) and organic data review (EPA 1994, 48640). The validation process requires that data generated by the routine analytical services are evaluated against a minimum set of EPA quality acceptance criteria. (Appendix III of the QAPP contains a description of the routine analytical services currently employed by the ER Project.) LANL will incorporate the current baseline data validation requirements that have been in use since October 1995 into an SOP. The scheduled completion date for the baseline validation SOP is August 28, 1998. (See comment response no. 2.)

   The baseline data validation process alone does not ensure adequate data quality for the ER Project. The validation process is part of an overall system designed to ensure that data of adequate quality are generated and used in environmental decision-making. The basis of the baseline validation process is discussed in the QAPP, Section D1, *Data Review: Verification and Baseline Validation*, in which data verification, baseline data validation, data quality assessment, and focused validation are addressed. These activities are also depicted in Figure D-2 relative to the entire environmental planning, implementation, and assessment process. The relationship of baseline validation to the overall data collection process is also described in the last paragraph of Section D1.

NMED Comment

4. *LANL should not obtain composite samples without prior RCRA Permits Management Program (RPMP) approval. The appropriate method of sample collection for the purposes of site characterization is to obtain discrete samples by depth intervals. Compositing is one of the sampling methodologies which may be appropriate for evaluating average waste characteristic properties for disposal purposes. Composite sampling should* ***not*** *be used as the only input to risk assessment; discrete soil depth intervals are needed to characterize site contaminants to determine or predict exposure.*

LANL Response

4. As agreed upon in the LANL/NMED workshop on October 15, 1997, LANL will not use composite sampling without prior Administrative Authority approval.

NMED Comment

5. *LANL should review and revise the analytical/radiochemical methods and detection limits used to assure that the detection limits are below the levels of human and ecological health concern for all environmental media samples.*

LANL Response

5. LANL's approach to the appropriate choice of analytical chemistry methods for the purposes of site screening decisions is outlined in Chapter 3 of the IWP, *Technical Approach*, and in *Risk-Based Corrective Action Process* (Dorries 1996, 55575), as cited in Chapter 3 of the IWP. LANL's technical approach requires the use of EPA SW-846 methods unless other methods are justified. LANL's current statement of work (SOW) for analytical services is consistent with this technical approach. A new SOW for analytical services to the ER Project has been developed and will be used to obtain subcontract analytical laboratory services in 1998. This new SOW also requires the use of EPA SW-846 methods for the analysis of inorganic and organic chemicals in environmental media. The detection limit requirements were determined by taking into consideration the environmental levels of concern as well as the capabilities of modern analytical instrumentation. LANL will revise Appendix III of the QAPP to reflect changes in the requirements for routine analytical services when the new SOW becomes effective.

   In preparing a SAP, the QAPP requires that the technical team select EPA methods that will meet the data quality objectives of the investigation. If comparison with concentration levels that are protective of human and ecological health is required, analytical methods with appropriate detection limits should be selected. The current routine analytical methods presented in Appendix III of the QAPP were chosen because they are frequently used EPA methods that allow a large number of analytes to be measured in a single analysis. However, as presented in Appendix III, there are many other acceptable EPA or consensus standard methods available to the ER Project as nonroutine analyses. If a particular site investigation requires the measurement of analyte concentrations that are less than the lowest concentrations measured by the routine analytical methods, the technical team has the option to select any appropriate analytical method that will provide the lower detection limits.

   LANL will revise the text in Section B4, page B-5, of the QAPP to emphasize that the detection limit of the analytical method must be considered with respect to levels of human or ecological health concern. The role of the Sample Management Office ensuring that adequate analytical methods and detection limits are provided by the subcontract laboratories will also be explained.

NMED Comment

6. *The use of Analytical results based on the Toxicity Characteristic Leachate Procedure (TCLP) is inappropriate for the purpose of site characterization. TCLP should* ***not*** *be used for the following activities:*

   (a) site characterization in determining the nature, rate, and extent of contamination, screening action levels (SALs), standards, etc.);

   (b) release determination;

   (c) risk assessment;

   (d) soil screening action levels; or

   (e) confirmation sampling.

LANL Response

6. As agreed upon in the LANL/NMED workshop on October 15, 1997, LANL will not use TCLP except when appropriate. The following examples were discussed in the workshop as to when TCLP may be appropriate and when LANL may need to use TCLP:

    - characterizing waste for determining if a solid waste exhibits the characteristic of toxicity and is, therefore, a characteristic hazardous waste (40 CFR 261.24); and

    - determining disposal options—solid waste versus hazardous waste.

NMED Comment

7. *LANL should discuss its Contract Laboratory Program (CLP) assessment procedures (including performance assessment, analytical requirements, etc.) to meet ER Program objectives and identify if and how these data are readily available to the Administrative Authority (AA) and public*

LANL Response

7. The performance assessment of LANL's subcontract laboratories is addressed in the QAPP, Section C1.2, *Oversight of Analytical Laboratories*. The QAPP requires that the performance of LANL's analytical laboratories be assessed prior to their acceptance for use. In 1997, LANL used on-site audits conducted by the Department of Energy Albuquerque Operations Office to assess laboratory performance.

    A new SOW for analytical services to the ER Project has been developed and will be used to obtain subcontract analytical laboratory services in 1998. Section C1.2 of the QAPP will be revised to reflect the quality assessment procedures included in the new SOW when it becomes effective. The new SOW contains comprehensive quality assurance requirements for the analytical laboratories, including the laboratory quality assurance plan, annual LANL systems audits, quarterly progress reports to LANL, and mandatory participation in interlaboratory comparison studies administered by the Environmental Protection Agency and the Department of Energy. The quality assurance information collected under the new SOW is intended for use by LANL to evaluate the subcontract laboratory's ability to meet the contractual requirements of the SOW.

NMED Comment

8. *In accordance with the Hazardous and Solid Waste Amendments (HSWA) Module VIII, the LANL Installation Work Plan (IWP) should contain the potential release sites (by task), prioritization of sites/tasks, and a work schedule.*

LANL Response

8. Members of our staffs have agreed on the format and content for a table that is intended to meet the HSWA module requirements. The table will contain the PRSs in the HSWA module, identified by number; site type; anticipated waste types and volumes; and potential contaminants. It will also contain the potential remedial action for each site; site status; site ranking score; ranking score for LANL-ER-AP 4.5 investigations, *Evaluation of Potential*

Surface Water Concerns at Environmental Restoration Sites; work schedule; and anticipated start date for field work. If a report will be generated as a result of the field work, the anticipated delivery date for that report will be included. LANL will continue to work with your staff to ensure that NMED is receiving the appropriate level of detail.

The table, containing information on key deliverables for FY98, will be provided to NMED with sufficient time allowed for NMED review and approval by March 31, 1998.

SPECIFIC COMMENTS

NMED Comment

9. *Chapter 2.0, Installation Description, Section 2.3.2.3, Wetlands refers to 2 figures found on pages 2-7 and 2-8. These figures depict only a portion of the LANL property boundary for location reference. The figures should identify major roads and canyons. Also, the figures should delineate between palustrine and riverine wetlands and include legends which define all symbols used.*

LANL Response

9. The wetlands figures found on pages 2-7 and 2-8 of the 1996 Installation Work Plan have been combined into one figure (Figure 2-4 on page 2-7 of Chapter 2 of the 1996 Installation Work Plan, Revision 6.1). The new figure shows the entire LANL property boundary, major roads, and canyons and distinguishes between palustrine and riverine wetlands. The legend defines all symbols used. (See attachment.)

NMED Comment

10. *Chapter 4, Section 1.0, Document Purpose and Context, page i should indicate if the Generic Quality Assurance Project Plan LANL 1991, 2360 has been approved by the AA.*

LANL Response

10. LANL will revise the text in Section 1.0 to indicate that on July 12, 1991, the US Environmental Protection Agency Region VI approved the LANL Generic Quality Assurance Project Plan.

NMED Comment

11. *Chapter 4, Section A1, Title and Approval Sheet, page A-1. LANL should revise Section A1 to include names, titles, and signatures of DOE ER Program Manager, LANL ER Project Manager, ER Quality Assurance Officer, and New Mexico Environment Department, Water and Waste Management Division Director and approval dates. Submission of at least two original approval pages is recommended.*

LANL Response

11. LANL will make the requested revisions, and after signatures are obtained, LANL will work with NMED regarding appropriate distribution.

NMED Comment

12. *Chapter 4, Table of Contents, page A-7 should be referred to as Section A2 per the U.S. EPA's Region 6 "Interim Draft Requirements for Quality Assurance Project Plans" (EPA QA/R-5, 1994).*

LANL Response

12. LANL will make the requested revision.

NMED Comment

13. *Chapter 4, Section A3, Distribution List, page A-9. Please add: "and Organization" to the third column heading and revise the section accordingly.*

LANL Response

13. LANL will make the requested revision.

NMED Comment

14. *Chapter 4, Section A4, Project/Task Organization, page A-10. Figure 1-1 and relevant text in Appendix I should include other data users who are outside of the organization generating the data, but for whom the data are intended (e.g., modelers, risk assessors).*

LANL Response

14. The ER Project organizational structure is being revised and will be detailed at a later date in a separate document. Appendix I will be removed from the QAPP, and an appropriate reference will be added to Section A4. With reference to Figure I-1, ER Project data users are participants in the data-generating process (e.g., risk assessors, statisticians, decision support) and are thus an integral part of the data-generating organization.

NMED Comment

15. *Chapter 4, Project/Task Description, Section A6, page A-12 should include a synopsis of applicable technical, regulatory, or program-specific quality standards, criteria, or objectives to be incorporated in the Sampling and Analysis Plan (SAP).*

LANL Response

15. LANL will add the following text to the bulleted list in Section A6.

    - applicable technical, regulatory, or program-specific quality standards, criteria, or objectives;

NMED Comment

16. *Chapter 4, Quality Objectives and Criteria for Measurement Data, Section A7, page A-12 should include the geographical area for which the conclusions and decisions will apply.*

LANL Response

16. LANL will replace the bulleted item referring to subpopulations in the second bulleted list in Section A7 with the following text.

    - geographical area for which the conclusions and decisions will apply;

NMED Comment

17. Chapter 4, Quality Objective and Criteria for Measurement Data, Section A7, page A-12 should include a statement of the project quality objectives and state these objectives in quantitative terms. If there is no basis for these objectives, it should be explained as such.

LANL Response

17. LANL will add the following text to the last paragraph in Section A7.

    Based on this analysis of consequences, include a statement of the quality objectives in quantitative terms (such as specific limits on decision errors), or explain why there is no basis for establishing quantitative criteria and specify qualitatively what the investigation is trying to achieve.

NMED Comment

18. Chapter 4, Quality Objective and Criteria for Measurement Data, Section A7, page A-12 should include the sensitivity, precision, bias, and completeness criteria for each measurement planned for each sample matrix. These criteria are expected to assure adequate selection of analytical methods to meet the measurement goals.

LANL Response

18. LANL will add the following text to the last paragraph in Section A7.

    In developing a statistical design, certain assumptions are made about the relative contribution of variability and error that are factored in to maximize the probability that the data collected will be adequate to support the decision to be made. Based on the historical performance of the measurement systems and criteria set forth in the analytical laboratory contracts, the SAP should specify the required sensitivity, precision, and bias for each measurement in each matrix that will be sampled. In addition, criteria for completeness should be specified and factored into the design.

NMED Comment

19. Chapter 4, Quality Objectives and Criteria for Measurement Data, Section A7, page A-12, first bullet. LANL should revise the first bullet in the second grouping of bullets to read "... (e.g., analyses, concentrations/radioactivities, physicochemical parameters, exposure model parameters)" (delete the word "risk").

LANL Response

19. LANL will make the requested revision.

NMED Comment

20. Chapter 4, Quality Objectives and Criteria for Measurement Data, Section A7, page A-12, last bullet. LANL should revise the last bullet in the second grouping of bullets to read "... e.g., screening action levels (SALs) and basis for deriving them ..." (substitute the word "or" for "and").

LANL Response

20. LANL will make the requested revision.

NMED Comment

21. Chapter 4, Quality Objectives and Criteria for Measurement Data, Section A7, page A-13, second bullet. LANL should define "risk-based exposure units" and clarify how they will be established and used.

LANL Response

21. The term "risk-based exposure unit" will be deleted because a discussion of risk assessment methodologies is not appropriate to the QAPP. LANL's technical approach to risk assessment is addressed in Chapter 3 of the IWP, *Technical Approach*, and in *Risk-Based Corrective Action Process* (Dorries 1996, 55575), as cited in Chapter 3 of the IWP.

NMED Comment

22. Chapter 4, Quality Objectives and Criteria for Measurement Data, Section A7, page A-13, fifth bullet. LANL should explain the difference between SALs and preliminary remediation goals (PRGs) and clarify how SALs and PRGs will be used to make corrective action decisions.

LANL Response

22. The use of SALs and PRGs to make corrective action decisions is addressed in Chapter 3 of the IWP, *Technical Approach*, and in *Risk-Based Corrective Action Process* (Dorries 1996, 55575), as cited in Chapter 3 of the IWP. The QAPP requires that a SAP specify how data will be used to support the decision. Comparisons with criteria such as PRGs and SALs are provided in the QAPP only as examples. LANL will remove the term "PRG" from the QAPP to avoid confusion regarding its meaning.

NMED Comment

23. Chapter 4, Documentation and Records, Section A10, page A-14. LANL should specify which sections in the IWP describe the reporting format for data which will be included in all corrective action documents.

LANL Response

23. LANL specifications for the data-reporting formats in corrective action documents are contained in the following two documents:

- *Resource Conservation and Recovery Act Facility Investigation (RFI) Report Framework Policy* (LANL 1996, 56386); and
- *Accelerated Cleanup Plans and Reports* (LANL 1996, 56454).

LANL is preparing a comprehensive Information Management Plan that will integrate, standardize, and document all data-handling operations that the ER Project performs. This plan will integrate information that currently resides in such documents as the two cited above. Upon completion, a description of the Information Management Plan will be added to the QAPP.

NMED Comment

24. *Chapter 4, Documentation and Records, Section A10, page A-14. LANL should specify record retention time and physical location.*

LANL Response

24. Record retention time and physical location are components of Chapter 5 of the IWP, *Records Management Plan*, as cited in Section A10 of the QAPP. The Records Management Plan applies to all the types of technical data that are discussed in Section A10. LANL-ER-AP-02.1, R1, *Procedure for LANL ER Records Management*, which is cited in the Records Management Plan, specifies that a schedule for records retention consistent with all regulatory requirements will be developed and, until such time, all records are considered permanent. A statement that references the LANL ER procedure for records management indicating that it specifies records retention times and physical location will be added to Section A10.

NMED Comment

25. *Chapter 4, Documentation and Records, Section A10, page A-14. LANL should:*

    (a) specify whether or not the Facility for Information Management, Analysis, and Display (FIMAD) data base is available for routine access to potential external users, and if not, what plans are in progress to provide said access and when it is anticipated;

    (b) refer to plans, if any, to develop features or mechanisms supporting user-friendly access (e.g., query and information retrieval) to the FIMAD data base;

    (c) describe the procedure, including point of contact or organization to be contacted, for obtaining an on-line or other access to the FIMAD data base; and

    (d) specify the process and typical time frame of data acquisition to validation and finally, their availability through FIMAD to the external data users such as regulators and the public.

LANL Response

25. LANL is developing a comprehensive Information Management Plan that will integrate, standardize, and document all data-handling operations that the ER Project performs. The Information Management Plan will address the components of the data management system referred to by this comment and identify requirements for detailed data management procedures. LANL will revise Section A10 of the QAPP to indicate that the Information

Management Plan is under development. Upon completion, a description of the Information Management Plan will be added to the QAPP, including statements similar to the first two sentences above.

In order to gain access to the FIMAD database, an account must be obtained by contacting Nancy Marusak, EES-5, (505/667-5698).

NMED Comment

26. *Chapter 4, Documentation and Records, Section A10, Figure A-1, Project Data Flow for the Environmental Restoration Project, page A-15. LANL should identify the principal users of the data.*

LANL Response

26. LANL will revise Figure A-1 to include the principal users of the data.

NMED Comment

27. *Chapter 4, Environmental Sampling Plan Design, Section B1.1, page B-1 through B-3. LANL should include a discussion of the following activities: 1) field decontamination procedures and materials needed, 2) sampling equipment, 3) how sampling locations are determined, 4) strategies and criteria for sample type selection, and 5) criteria for well installation design (see the Hydrogeologic Workplan, Section 4.1.1, Well Types).*

LANL Response

27. LANL has addressed the activities included in this comment in Sections B1 and B2 of the QAPP, as outlined below.

    1. Field decontamination procedures and materials needed are addressed in the seventh bulleted item in Section B2, page B-2, which refers to LANL-ER-SOP-01.08, R0, *Field Decontamination of Drilling and Sampling Equipment.*

    2. Sampling methods and equipment are addressed in the sixth bullet in Section B2, page B-2, and discussed in detail in Appendix II, as stated in Section B2, page B-3, paragraph 3.

    3. The requirement to discuss how sampling locations are determined is addressed in the second, third, and fourth bullets in Section B1.1, page B-1.

    4. The requirement to present strategies and criteria for sample type selection is addressed in the first bullet in Section B1.1, page B-1, and in the first, second, and third bullets in Section B2, page B-2.

    5. The requirement to discuss the design for well installation is addressed in the tenth bullet in Section B1.1. The following sentence will be added to the last bullet on page B-1.

       The criteria for well installation design should be explained with reference to the well types and installation criteria described in Section 4.1.1 of the *Hydrogeologic Work Plan* (LANL 1996, 55430).

NMED Comment

28. Chapter 4, Environmental Sampling Plan Design, Section B1. 1, page B-1. LANL should include the classification of measurements as critical (required to achieve project objectives) or non-critical (information purposes only).

LANL Response

28. LANL will add the following bulleted item to Section B1.1.

- classification of all measurements as critical (i.e., required to achieve SAP objectives) or noncritical (informational purposes only);

NMED Comment

29. Chapter 4, Sampling Methods Requirements, Section B2, Sampling Methods Requirements, page B-2 and Section B4, Analytical Methods Requirements, page B-5. LANL should include a definition of a failure in the sampling or measurement system and the analytical system and discuss what will be done if there is a failure. This definition should also be included in Appendix V Glossary.

LANL Response

29. LANL will modify the last paragraph in Section B2 as follows.

> The SAP should address what to do if the sampling or measurement system is not performing as expected and required (i.e., a failure in the system is detected) and who is responsible for corrective action. Performance criteria will be established during SAP development based on historical performance data and the requirements of the decision. The applicable SOPs for field measurement methods should include performance criteria and the corrective action to be taken if performance criteria are not met. Ultimate authority and responsibility for field operations lies with the responsible focus area leader. However, responsibility for corrective actions in the field that address field work-related contingencies usually rests with the cognizant field team leaders who report to the focus area leader. For example, if the SAP specifies a sampling method that cannot be properly implemented due to site conditions at the time of sampling, the field team leader may choose an alternate sampling method. When possible, corrective actions should be anticipated and delineated in the SAP.

The following text will be added to the last paragraph in Section B4.

> If EPA or equivalent methods are chosen for laboratory analyses, corrective actions for failures in analytical systems are contained in the individual methods. The analytical laboratory is responsible for implementing the corrective action specified by the method. Corrective action requirements for on-site measurements, as well as assignment of responsibility for corrective action, should be included in the SAP or applicable SOP.

A universal definition of failure cannot be provided because LANL defines failure in the context of a particular study, method, or procedure.

NMED Comment

30. *Chapter 4, Sample Handling and Custody Requirements, Section B3, page B-3. LANL should include examples of sample documentation forms, such as sample labels, custody seals, and chain-of-custody forms.*

LANL Response

30. LANL-ER-SOP-01.04, R3, *Sample Control and Field Documentation*, contains examples of the following sample documentation forms: sample labels, sample collection log, master collection log, chain of custody/request for analysis, custody seal, daily report form, and daily activity log. LANL-ER-SOP-01.04 is cited in Section B3, page B-3, paragraphs 2 and 3. A statement will be inserted in Section B3 to let ER personnel know that they should use these forms as provided in the SOP.

NMED Comment

31. *Chapter 4, Quality Control Requirements, Section B5, page B-6 lacks information concerning acceptance criteria for analytical results and general requirements for precision, bias, and detection limits.*

LANL Response

31. Section B5.2, *Analyses/Measurements*, states that the default set of quality control (QC) procedures and criteria are specified in the analytical laboratory SOW (LANL 1995, 49738). A new SOW for analytical services to the ER Project has been developed and will be used to obtain subcontract analytical laboratory services in 1998. LANL will revise Section B5.2 and Appendix III of the QAPP to reflect changes in the QC requirements for routine analytical services when the new SOW becomes effective.

NMED Comment

32. *Chapter 4, Section B5, Quality Control Requirements, page B-7, second paragraph. This paragraph describes the procedure for replicate sampling yet fails to address air and source material quality control samples, as well as, background quality control sampling frequencies. Therefore, LANL should:*

    (a) revise LANL-ER-SOP-1.05, Rev. 0 (Field Quality Control Samples) such that it complies with the current EPA guidelines for recommended frequencies of quality control samples for field sampling programs;

    (b) define field duplicate (replicate) samples (see LANL-ER-SOP-1.05, Rev. 0 Field Quality Control Samples, page 2 of 7) to reflect the difference between collocated and replicated samples;

    (c) revise the title for Attachments A and B to LANL-ER-SOP-1.05, Rev. 0, to read: "Quality Control Sample Summary for Radiological Samples" and "Quality Control Sample Summary for Nonradiological Samples", respectively;

    (d) explain the QC procedure applicable to air and source material sample collection activities.

LANL Response

32. LANL will revise LANL-ER-SOP-1.05 such that it complies with current EPA guidelines. Revision of the SOP is expected to be completed by August 28, 1998.

NMED Comment

33. Chapter 4, Instrument/Equipment Testing, Inspection, and Maintenance Requirements, Section B6, page B-8. LANL should provide the following information:

(a) discussion of how inspections and acceptance testing, including the use of QC standards and reference materials, or environmental sampling and measurement systems and their components must be performed and documented to assure their intended use as specified by the design;

(b) identification and discussion of how acceptance shall be performed by independent personnel (e.g., personnel other than those performing the work);

(c) a discussion on how deficiencies are to be resolved when acceptance criteria are not met and how re-inspection will be performed as necessary;

(d) identification of the equipment requiring routine maintenance and its maintenance/inspection schedule. Please include the routine schedule in a table format (see Comment number 34); and

(e) a discussion on how the availability of critical spare parts will be assured and maintained.

LANL Response

33. The information follows.

(a) Inspections and acceptance testing of instruments and equipment will be addressed in LANL-ER-QP-5.2, *Control of Measuring and Test Equipment*. This procedure is scheduled to be complete by August 28, 1998.

(b) This requirement will be addressed in LANL-ER-QP-5.2 (see response to Comment No. 33[a]).

(c) LANL-ER-QP-01.3, *Deficiency Reporting*, details how deficiencies are resolved when acceptance criteria are not met. A reference to this QP will be added to the QAPP. LANL ER procedures can be obtained by contacting Daleen Hendrickson in the ER Records-Processing Facility (505/665-1402).

(d) Requirements for measuring and testing equipment will be detailed in a procedure scheduled to be completed by August 28, 1998.

(e) The availability of spare parts has not been an issue for the LANL ER Project. The following text will be incorporated into section B8.

All heavy earth-moving equipment and drill rigs are rented. Maintenance and repair of this equipment is supplied by the vendor. Historically, spare and duplicate field equipment has been available for backup use, and other spare parts needed for the ER Project have been plentiful at the Laboratory. The ER Project has never experienced shortages that would lead to increased costs or schedule delays.

NMED Comment

34. *Chapter 4, Instrument Calibration and Frequency, Section B7, page B-8. LANL should provide the following information in a table format:*

    (a) identify all tools, gauges, instruments, and other sampling, measuring, and test equipment used for data collection. This list should include frequency of calibration;

    (b) identify the certified equipment and/or standards used for calibration;

    (c) ensure that calibration of instruments using certified equipment and/or standards with known valid relationships to nationally recognized standards is documented in the IWP. If no nationally recognized standard exists for an instrument, then LANL should document the basis for the calibration; and

    (d) ensure that instrument manufacturer directions for calibration are physically attached to the applicable SOP/SAP (rather than cited only).

LANL Response

34. Requirements for instrument calibration and frequency will be detailed in a procedure scheduled to be completed by August 28, 1998. Copyright laws prevent LANL from copying manufacturer directions and attaching them to each copy of an SOP because the SOPs receive wide distribution. LANL will ensure that the correct manufacturer directions are cited and used to calibrate the equipment by requiring that the SOPs be reviewed against manufacturer requirements during the review and approval process. LANL will also ensure that ER Project document control procedures direct ER Project personnel to use the correct documents to perform calibrations, that the personnel receive adequate training in these procedures, and that controls are in place to ensure that the correct documents are available for personnel use.

NMED Comment

35. *Chapter 4, Data Management, Section B10, p. B-10. LANL should include examples of forms or checklists used for data management.*

LANL Response

35. LANL is developing a comprehensive Information Management Plan that will integrate, standardize, and document all data-handling operations that the ER project performs. The Information Management Plan will address the components of the data management system referred to by this comment and identify requirements for detailed data management procedures. Upon completion, a description of the Information Management Plan will be added to the QAPP.

NMED Comment

36. Chapter 4, Data Management, Section B10, page B-10. LANL should include the following:

(a) criteria and procedures for the review of data entered into FIMAD;

(b) identify and discuss the control mechanisms for detecting and correcting potential data entry errors in the electronic data base; and

(c) provide examples of checklists to be used for data and records management.

LANL Response

36. LANL is developing a comprehensive Information Management Plan that will integrate, standardize, and document all data-handling operations that the ER project performs. The Information Management Plan will address the components of the data management system referred to by this comment, and identify requirements for detailed data management procedures. Upon completion, a description of the Information Management Plan will be added to the QAPP.

NMED Comment

37. Chapter 4, Assessments and Response Actions, Section C1, pages C-1 through C-3. LANL should include the following:

(a) identify the number and frequency of each type of assessment activities needed for the project;

(b) identify the organization and person(s) that will perform the independent assessments;

(c) discuss how and to whom the results of the assessments will be reported;

(d) define explicitly the unsatisfactory conditions under which the assessors are authorized to act; and

(e) discuss how response actions to "non-conforming" conditions will be addressed and by whom.

LANL Response

37. LANL will address the assessment activities itemized in (a) through (d) above in the ER Quality Management Plan, Sections 9.0 and 10.0, and in a procedure, LANL-ER-AP-9.1, *Procedure for Conduct of Management Assessments*. The procedure is scheduled to be completed by August 28, 1998. Disposition of nonconforming conditions is addressed in LANL-ER-QP-01.3, *Deficiency Reporting*. LANL ER Project procedures can be obtained by contacting Daleen Hendrickson in the ER Records-Processing Facility (505/665-1402).

NMED Comment

38. Chapter 4, Reports to Management, Section C2, page C-3. LANL should identify the frequency, content, and distribution of quality assurance reports; the responsible organization(s) that will prepare the reports; and specify the recipients of the reports.

LANL Response

38. The requirements for quality assurance reports to management will be detailed in a procedure to be completed by August 28, 1998.

NMED Comment

39. Chapter 4, Quality Assurance Reports, Section C2.2, page *C-3. LANL should define the criteria established to determine "significant quality problems".*

LANL Response

39. The criteria for determining "significant quality problems" will be detailed in a procedure scheduled to be completed by August 28, 1998.

NMED Comment

40. Chapter 4, Data Review: Verification and Baseline Validation, Section D1, page D-1. LANL should include further information:

(a) describing how the FIMAD data base will be used for data quality assessment;

(b) stating the criteria used to review and validate (i.e., accept, reject, or qualify) data in an objective and consistent manner; and

(c) providing examples of forms or checklists used to review/verify and validate the data.

LANL Response

40. Further information follows.

(a) The FIMAD database is an electronic repository for LANL ER environmental data. Data quality assessment (DQA) is a process for ensuring that data are of the right type, quality, and quantity for their intended use. The DQA process exists outside of the FIMAD database and, other than being a source of technical data, the database is not actually used for DQA. LANL will revise Section D1 of the QAPP to indicate that the validation report is available in hard copy form (not in FIMAD) to ER Project personnel performing the DQA process.

(b) In preparing this QAPP, LANL has taken the approach that detailed information such as requested by this comment is relegated to quality procedures or SOPs. LANL ER Project will incorporate the current baseline data validation requirements that have been in use since October 1995 into an SOP. The scheduled completion date for the baseline validation SOP is August 28, 1998.

(c) The LANL ER baseline validation SOP that is in preparation (see response 40[b] above) will provide examples of the forms and checklists used to verify and validate the analytical data. The scheduled completion date for the baseline validation SOP is August 28, 1998.

NMED Comment

41. Chapter 4, Data Review: Verification and Baseline Validation, Section D1, page D-4. LANL should clarify how the streamlined verification/baseline validation process will assure adequate data quality for the ER Project.

LANL Response

41. Please see the response to General Comment No. 3.

NMED Comment

42. Chapter 4, Focused Data Validation, Section D2, page D-4. LANL should include the data chain-of-custody procedures throughout the project, as well as, how analytical results are conveyed to users.

LANL Response

42. In preparing the QAPP, LANL has taken the approach that detailed information such as requested by this comment is relegated to quality procedures or SOPs. LANL will incorporate the current data verification process into an SOP that will also incorporate checks on the data chain-of-custody documentation. The scheduled completion date for the verification SOP is August 28, 1998.

    LANL is also developing a formal Information Management Plan for the ER Project that will address the communication of analytical results to the data users.

NMED Comment

43. Chapter 4, Focused Data Validation, Section D2, page D-4. LANL should state the focused data validation criteria to determine "unusual, excessive, or potentially fatal deficiencies" and describe the mechanism developed to trigger focused data validation and provide relevant examples.

LANL Response

43. LANL is unable to generate definitions of the terms "unusual," "excessive," or "potentially fatal," that are specific enough to allow the reader to use them unambiguously. Therefore, LANL will delete the sentence containing these terms and insert the following text.

    > If the significance of deficiencies identified during baseline data validation are judged by the technical team to warrant further investigation, the qualifier flags provide a convenient point of departure for the additional scrutiny.

    Considerations that might trigger focused validation are presented in the last paragraph of Section D2. As shown in Figure D-3, focused validation is triggered by the exploratory data analysis performed as part of the data quality assessment process.

NMED Comment

44. *Chapter 4, Focused Data Validation, Section D2, page D-4. The first sentence of the second paragraph states: "Figure D-3 depicts where focused validation usually occurs in the DQA process." LANL should identify possible exceptions to the data quality assessment process shown in Figure D-3.*

LANL Response

44. LANL will incorporate into the QAPP examples of those instances for which focused data validation is triggered by other than exploratory data analysis.

NMED Comment

45. *Appendix II, Introduction, Section 1.0, page II-1, first paragraph. LANL should clarify criteria for determining the true contaminant distribution at the site and how this determination will impact "Decisions concerning the possibility of taking NFA or of having to remediate a site ...".*

LANL Response

45. In accord with US EPA *Guidance for the Data Quality Objectives Process* (EPA 1994, 44324), it is recognized that environmental samples can only represent contaminant distributions at a site and that "true" contaminant distributions are unknowable. The SAP is designed to provide estimates of "truth" through the collection of samples that are judged by the technical team to be representative of site contaminant distributions.

    A discussion of LANL's technical approach to corrective action decision-making is not appropriate to the QAPP. LANL's technical approach is addressed in Chapter 3 of the IWP, *Technical Approach*, and in *Risk-Based Corrective Action Process* (Dorries 1996, 55575), as cited in Chapter 3 of the IWP.

NMED Comment

46. *Appendix II, Introduction, Section 1.0, page II-1, second paragraph. LANL should describe how contaminants of potential concern (COPCs) are identified prior to identifying sampling locations and depths and the criteria and methodologies for selecting sampling locations, types, and depths for various environmental and waste media.*

LANL Response

46. The criteria and methodologies for identifying COPCs and selecting sampling locations, types, and depths for various media are not appropriate to Appendix II. LANL's corrective action technical approach is addressed in Chapter 3 of the IWP, *Technical Approach*, and in *Risk-Based Corrective Action Process* (Dorries 1996, 55575), as cited in Chapter 3 of the IWP. These two documents contain the assumptions made for data collection and evaluation by the LANL ER Project. Sections A5, *Problem Definition*, and B1, *Sampling Process Design*, of the QAPP require that the SAP address such criteria in the context of the site-specific conceptual model and the site-specific decisions to be made. Because such considerations are site-specific and rely upon the best professional judgment of the technical team, the QAPP cannot specify particular sampling strategies. As discussed in Appendix II,

identification of the list of target analytes is required before sampling and analysis methods can be selected for determining their concentrations at a site. If the target analytes are not identified early in the planning process, it is possible that appropriate sample collection and analysis methods will not be applied to the site and contaminants that pose unacceptable risk to human health or the environment will go undetected.

LANL will revise the paragraph in question as follows.

> The list of target analytes must be identified, and the sampling locations and depths must be identified, prior to selecting the devices or methods for collecting the samples.

NMED Comment

47. Appendix II, Factors Affecting Sampling Tool Selection and Sample Handling, Section 2.0, item 2, page II-1, last paragraph and page II-2, first paragraph. LANL should revise these two paragraphs to be consistent with comment number 4.

LANL Response

47. LANL will make the requested revision.

NMED Comment

48. Appendix II, Section 2.0 Factors Affecting Sampling Tool Selection and Sample Handling, item 4, page II-2. The Sampling Point Coordinates discussion should not only include sampling time but also sampling date.

LANL Response

48. LANL will revise the sentence as follows.

> Each sample collected must be linked to four coordinates: the three spatial coordinates (x, y, and z) and the date and time of collection.

NMED Comment

49. Appendix II, Section 2.0 Factors Affecting Sampling Tool Selection and Sample Handling, item 8, page II-3. This item should mandate that samples be analyzed before holding times are exceeded and delineate chain-of-custody procedures.

LANL Response

49. LANL will add text to indicate that the holding times that are specified in LANL-ER-SOP-01.02 must be satisfied. LANL-ER-SOP-01.02, R0, *Sample Containers and Preservation*, is scheduled to be reviewed and revised by August 28, 1998. LANL chain-of-custody procedures are delineated in LANL-ER-SOP-01.04, R3, *Sample Control and Field Documentation*, as cited in Section B3.

NMED Comment

50. *Appendix II, Factors Affecting Sampling Tool Selection and Sample Handling, Section 2.0, item 8, page II-3, third paragraph, last sentence. LANL should verify that using sodium bisulfate or hydrochloric acid is the appropriate method to preserve water samples for volatile organic contaminant/compound (VOC) analyses and reference the appropriate guidance document.*

LANL Response

50. The use of sodium bisulfate or hydrochloric acid for preservation of water samples with no residual chlorine present for volatile organic analysis is described in Chapter 4 of *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods* (SW-846) (EPA 1986, 31733) in Update III, dated December 1996. LANL-ER-SOP-1.02, R0, *Sample Containers and Preservation*, is scheduled to be reviewed and revised by August 28, 1998; the revision will reflect current EPA requirements for sample preservation, including the option to use sodium bisulfate as a preservative.

NMED Comment

51. *Appendix II, Factors Affecting Sampling Tool Selection and Sample Handling, Section 2.0, item 8, page II-3, fourth paragraph, last sentence. LANL should rewrite the sentence to read: "If an insufficient amount of preservative is added, the preservative might be consumed before the sample is analyzed".*

LANL Response

51. LANL will make the requested revision.

NMED Comment

52. *Appendix II, Factors Affecting Sampling Tool Selection and Sample Handling, Section 2.0, page II-3. LANL should 1) address potential failures in the sampling or measurement system and the party responsible for correcting the action and 2) the preparation and decontamination of sampling equipment.*

LANL Response

52. Section 2.0 of Appendix II is intended to prompt readers to consider the various factors that influence the selection of appropriate sample collection tools and the proper handling of samples. It is not designed to address corrective actions such as failures in the sampling or measurement systems. Corrective actions are addressed in the QAPP in Section B2, *Sampling Methods Requirements*, and Section B4, *Analytical Methods Requirements*. (See the LANL response to Specific Comment No. 29.)

    Section 2.0 of Appendix II is not intended to discuss preparation or decontamination of sampling equipment. This subject is addressed in Section B2, *Sampling Methods Requirements*.

NMED Comment

53. *Appendix II, The Sample Collection Method Selection Process, Section 3.0, item 1, Soil and Sediment Sampling, page II-4. LANL should discuss soil and sediment sampling depth selection strategies and criteria under various source-term conditions (e.g., leach field, surface impoundment, waste pile, firing site, etc.). Sediment sampling techniques and procedures should also be described.*

LANL Response

53. Appendix II is designed to provide general information and guidance to the reader such that considerations for appropriate sampling tool selection and proper sample handling are not overlooked. The discussion of depth selection strategies and criteria under various source-term conditions is not appropriate to this appendix. LANL's corrective action technical approach is addressed in Chapter 3 of the IWP, *Technical Approach*, and in *Risk-Based Corrective Action Process* (Dorries 1996, 55575), as cited in Chapter 3 of the IWP. These two documents contain the assumptions made for data collection and evaluation by the LANL ER Project. Sections A5, *Problem Definition*, and B1, *Sampling Process Design*, of the QAPP require that the SAP address such strategies and criteria in the context of the site-specific conceptual model and the site-specific decisions to be made. Because such considerations are site-specific and rely upon the best professional judgment of the technical team, the QAPP cannot specify particular sampling strategies.

    LANL will revise Sections A7 and B2 of the QAPP to indicate that the source term type and conceptual model of contaminant transport must be considered in selection of the subpopulation of interest and appropriate sampling methods. Appendix II will also be revised as appropriate.

    Specific guidance on the appropriate choice of sampling tools is provided in Appendix II for various environmental media including sediment sampling techniques. Section 3.1, *Soil and Sediment Sampling*, cites LANL-ER-SOPs that are applicable to both soil and sediment sampling.

NMED Comment

54. *Appendix II, The Sample Collection Method Selection Process, Section 3.0, item 1, Soil and Sediment Sampling, page II-5, Table II-2. The table should be entitled: "Sediment Sampling Tools Useful for Sampling in Flowing Water".*

LANL Response

54. LANL will make the requested revision.

NMED Comment

55. *Appendix II, The Sample Collection Method Selection Process, Section 3.0, item 1, Soil and Sediment Sampling, page II-6, Table II-3. The table should be entitled: "Sediment Sampling Tools Useful for Sampling in Standing Water".*

LANL Response

55. LANL will make the requested revision.

NMED Comment

56. Appendix II, Section 2.0, The Sample Collection Method Process, item 2, Water Sampling, page II-6. LANL should discuss rinsing sample containers with the surface water to be sampled prior to collecting the sample and should discuss disturbing the sediments and potential impact of this disturbance on analytical results.

LANL Response

56. LANL-ER-SOP-06.13, R0, *Surface Water Sampling*, is undergoing review and is scheduled to be revised by August 28, 1998. The revision will address prerinsing of sample containers, disturbance of sediments during sampling, and the potential impact of this disturbance on analytical results.

NMED Comment

57. Appendix II, Section 3.0, Table II-6, page II-8. The table should be entitled: "Tools Useful for Sampling Groundwater, Soil and Water".

LANL Response

57. The title of Table II-6 is consistent with LANL-ER-SOP-06.05, *Soil Water Samples*, that is cited in the table. As shown in Table II-6, LANL-ER-SOP-06.05 is applicable to the use of lysimeters to collect soil water (moisture) samples in the vadose zone. This table does not apply to any soil sampling methods.

NMED Comment

58. Appendix III, Section 1.0, Introduction, p.III-1. LANL should:

(a) define "the estimated detection limit (EDL)" concept;

(b) discuss the EDL relation to commonly used practical quantitation limits (PQLs), detection limits (DLs), estimated quantitation limits (EQLs), method detection limits (MDLs), and "Contract Required Detection Limits" (CRDLs); and

(c) address the nature and level of uncertainty associated with each of these measures.

LANL Response

58. LANL is in the process of eliminating the confusion that results from using many terms related to detection limits and quantitation limits by focusing on those limits that are truly useful. A new statement of work (SOW) for analytical services to the ER Project has been developed and will be used to obtain subcontract analytical laboratory services in 1998. LANL will use the following analytical limits in defining requirements for analytical measurements: instrument detection limit (IDL), method detection limit (MDL), and estimated quantitation limit (EQL). The use of these terms is consistent with the US EPA Contract Laboratory Program and SW-846 methods. LANL will revise Appendix III to reflect changes in the requirements for routine

analytical services when the new SOW becomes effective. The revision to Appendix III will address the use of the terms IDL, MDL, and EQL, as well as the nature and level of uncertainty associated with each of these measures.

NMED Comment

59. *Appendix III, Section 1.0, Introduction, page III-1, second paragraph. LANL should revise this paragraph and avoid the current reporting practice (i.e., EQLs and data for soil/sediment are reported based on dry and wet sample weight, respectively) by using common reporting basis (i.e., dry or wet sample weight).*

LANL Response

59. LANL data reporting practices are consistent with standard EPA methods. There is an error in the last sentence of the cited paragraph that will be corrected by changing the second-to-last word of this sentence from "dry" to "wet".

NMED Comment

60. *Appendix III, Section 2.0, Routine Analytical Services, page III-1. LANL should review the analytical methods selected for metal analyses and update them where appropriate according to SW-846 EPA Test Methods for Evaluating Solid Waste; Volume IA: Laboratory Manual Physical/Chemical Methods.*

LANL Response

60. Please see the response to General Comment No. 5.

NMED Comment

61. *Appendix III, Section 2.0, Routine Analytical Services. LANL should review the analytical/radiochemical methods and detection limits used to ensure that the detection limits are below the levels of human and ecological health concern for all environmental media samples. For instance, Table III-1 on page III-2 indicates that the EDL for cadmium in water is 5 μg/L which exceeds the ecological health-based threshold of 1 μg/L (for hardness of 100 mg/L as calcium carbonate).*

LANL Response

61. Please see the response to General Comment No. 5.

NMED Comment

62. *Appendix III, Section 2.0, Routine Analytical Services. The use of Analytical results based on the TCLP is inappropriate for the purpose of site characterization. (See Comment number 6).*

LANL Response

62. LANL will add the following text to Appendix III.

The use of analytical results based on SW-846 method 1311, Toxicity Characteristic Leaching Procedure (TCLP), is inappropriate for the purpose of site characterization. The TCLP should not be used for the following activities:

- site characterization;
- release determination;
- risk assessment;
- comparison to soil screening action levels; or
- confirmatory sampling following site cleanup.

NMED Comment

63. Appendix IV, Section 2.0, Consideration in Selecting Analytical Methods and QC, Sample Holding Times, page IV-3. . Because it is a regulatory requirement, holding times should not be exceeded regardless of the "scientific basis". Therefore, LANL should strike the last paragraph from the text on page IV-3.

LANL Response

63. LANL will make the requested revision.

NMED Comment

64. Chapter 6.0, Health and Safety Plan. It is LANL's responsibility to maintain working conditions that ensure worker health and safety pursuant to 29 Code of Federal Regulation (CFR), Section 1910.120. Therefore, liability for operations relating to worker health and safety remains with the facility. [No response is required].

LANL Response

64. Comment noted.

NMED Comment

65. Chapter 7.0, Public Involvement Plan. In this Section, LANL should detail how the public will be notified about Community Meetings, tours of ER Sites, etc. For example, the paragraph concerning public involvement in the budget process should include information about how the public will obtain copies of the budget.

LANL Response

65. LANL will add the following text to Section 7.2, *The ER Project's Public Involvement Plan.*

> The ER Project maintains communication with the public in several ways. The Project notifies the public of community meetings, tours, and related programs through mailings from the Laboratory's facility mailing list, public service announcements on local radio stations, and publications in local newspapers (*Journal North, Santa Fe New Mexican,*

Rio Grande Sun, Taos News, and Los Alamos Monitor). Dialogue with members of the public is provided through meetings of the Northern New Mexico Citizens' Advisory Board and meetings with various civic nonprofit organizations, such as the Kiwanis and Rotary clubs, senior citizen organizations, etc.

LANL will add the following text to Section 7.2.7, *Public Involvement in the Budget Process*.

DOE provides budget information to the public through the Focus 2006 Plan, which contains projections of proposed budgets through the completion of the ER Project. The Focus 2006 Plan generally is released in the winter and summer of each year. The next release will occur in March 1998. The Focus 2006 Plan will be available to the public at the Laboratory's Outreach Center and Reading Room, the outreach centers in Espanola and Taos, and the local libraries.

Attachment

Chapter 2.0 of the 1996 ER Installation Work Plan

Revision 6.1

INSTALLATION DESCRIPTION

2.0 INSTALLATION DESCRIPTION

2.1 Geographic Setting

Los Alamos National Laboratory (the Laboratory) and the neighboring residential areas of Los Alamos and White Rock are located predominantly in Los Alamos County, north-central New Mexico, approximately 60 mi north-northeast of Albuquerque and 25 mi northwest of Santa Fe (Figure 2-1). The 43-mi^2 Laboratory site and the communities adjacent to it are situated on the Pajarito Plateau, which consists of a series of fingerlike mesas separated by deep canyons containing ephemeral and intermittent streams that run from west to east. Mesa tops range in elevation from approximately 7,800 ft on the flank of the Jemez Mountains to about 6,200 ft at their eastern termination above the Rio Grande valley. The eastern margin of the plateau stands 300 to 900 ft above the Rio Grande (DOE 1979, 8610). The Department of Energy (DOE) controls the area within the Laboratory's boundaries and determines restrictions on access.

2.2 History of Los Alamos National Laboratory

In 1942, the US Army Manhattan Engineer District was established to develop the atomic bomb. The research quickly progressed to a point that necessitated a remote site for experimental work, and the Army selected the Los Alamos Ranch School for Boys as an appropriate location. The Undersecretary of War directed acquisition of the school site, which consisted of a group of some 50 log buildings on a 790-acre site northwest of Santa Fe. The project ultimately acquired an additional 3,120 privately owned acres and 45,666 acres of public land managed by the US Forest Service. In 1943, this land became known as the Los Alamos Site, later Los Alamos Scientific Laboratory.

Since its inception, the Laboratory has been operated by University of California (UC) for the federal government. Research activities were established in wooden buildings south of the original Ranch School buildings in what is now downtown Los Alamos. Additional Laboratory buildings were constructed; army-style barracks, temporary and prefabricated, provided housing.

With the end of World War II and the growth of international competition, a national policy of maintaining superiority in the field of atomic energy was established. Congress chose to sustain the Los Alamos site; the Atomic Energy Commission (AEC) received control of the Laboratory from the Army and renewed the operating contract with UC. Thereafter, a major construction program was started south of Los Alamos Canyon. During subsequent years, the Laboratory continued to expand at a steady rate, first under the AEC and later under the Energy Research and Development Administration. Since 1978, the Laboratory has operated under the control of the DOE and is currently officially known as Los Alamos National Laboratory. A map showing active technical areas at the Laboratory is shown in Figure 2-2.

2.3 Environmental Setting

2.3.1 Land Use Patterns

Most Laboratory and community developments are confined to mesa tops. Large tracts of land north, west, and south of the Laboratory site are managed by the Santa Fe National Forest, Bureau of Land Management, Bandelier National Monument, General Services Administration, and Los Alamos County (Figure 2-3). The San Ildefonso Pueblo borders Los Alamos County and the Laboratory to the east.

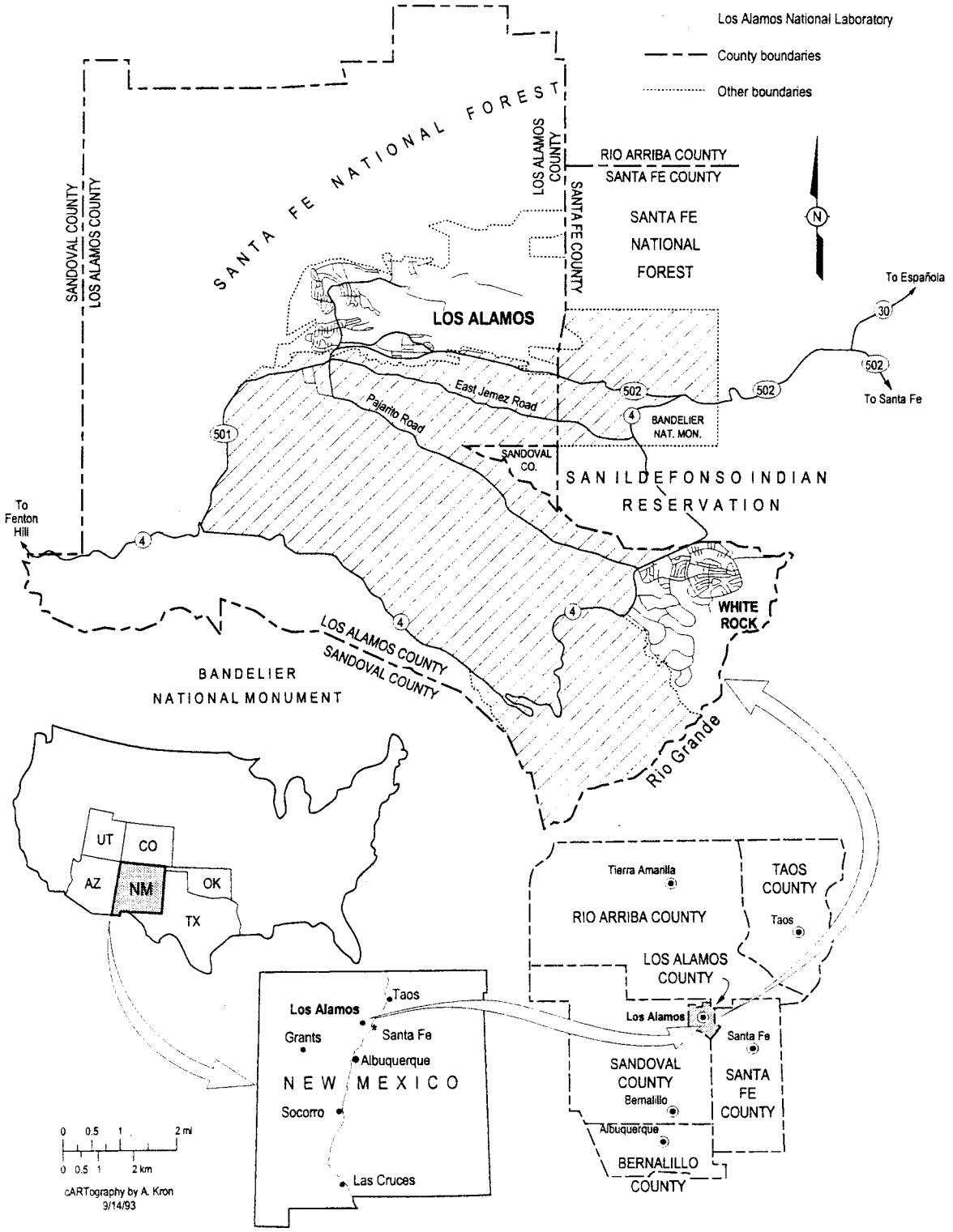


Figure 2-1. Location map of Los Alamos National Laboratory.

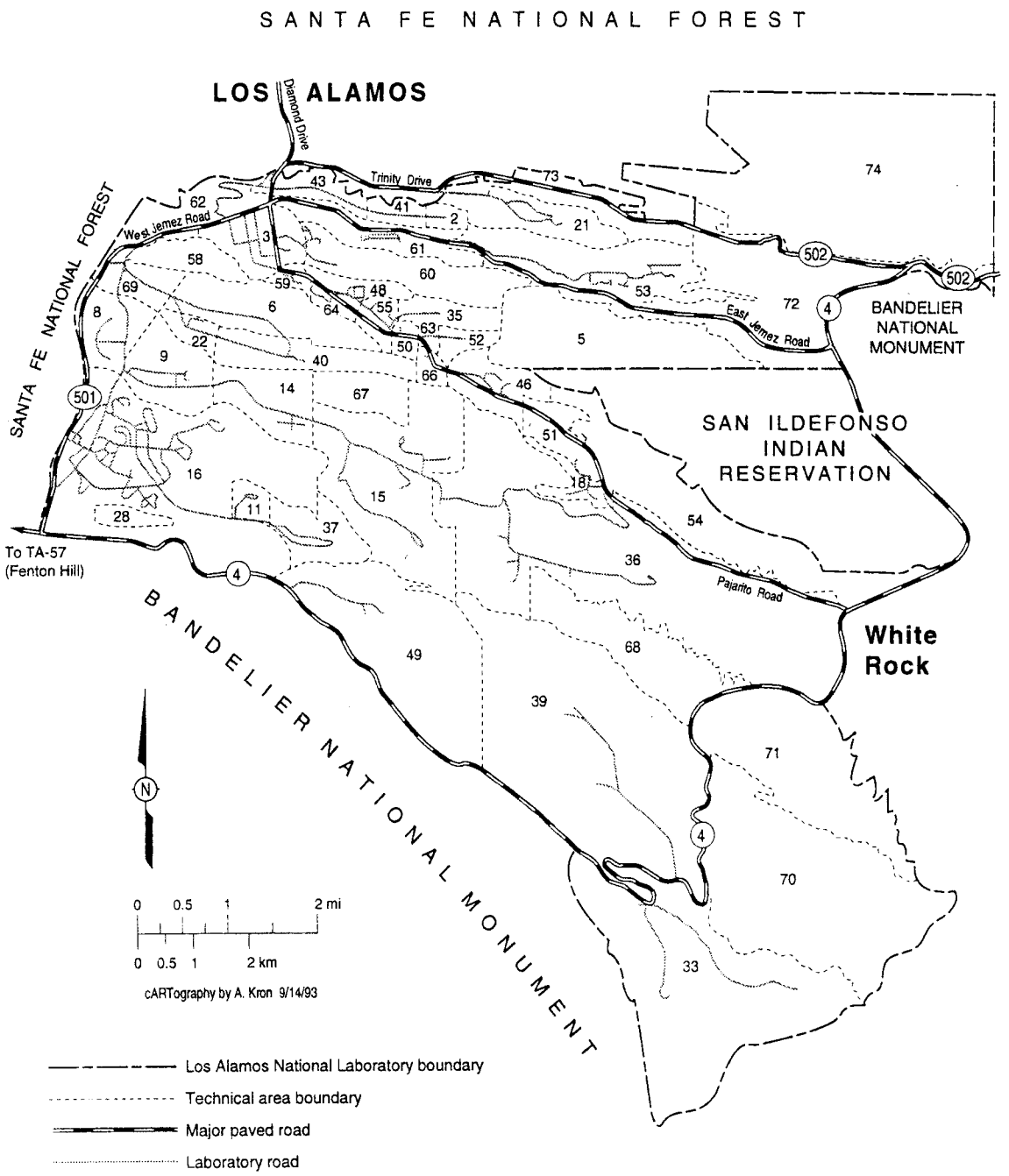


Figure 2-2. Technical areas at Los Alamos National Laboratory.

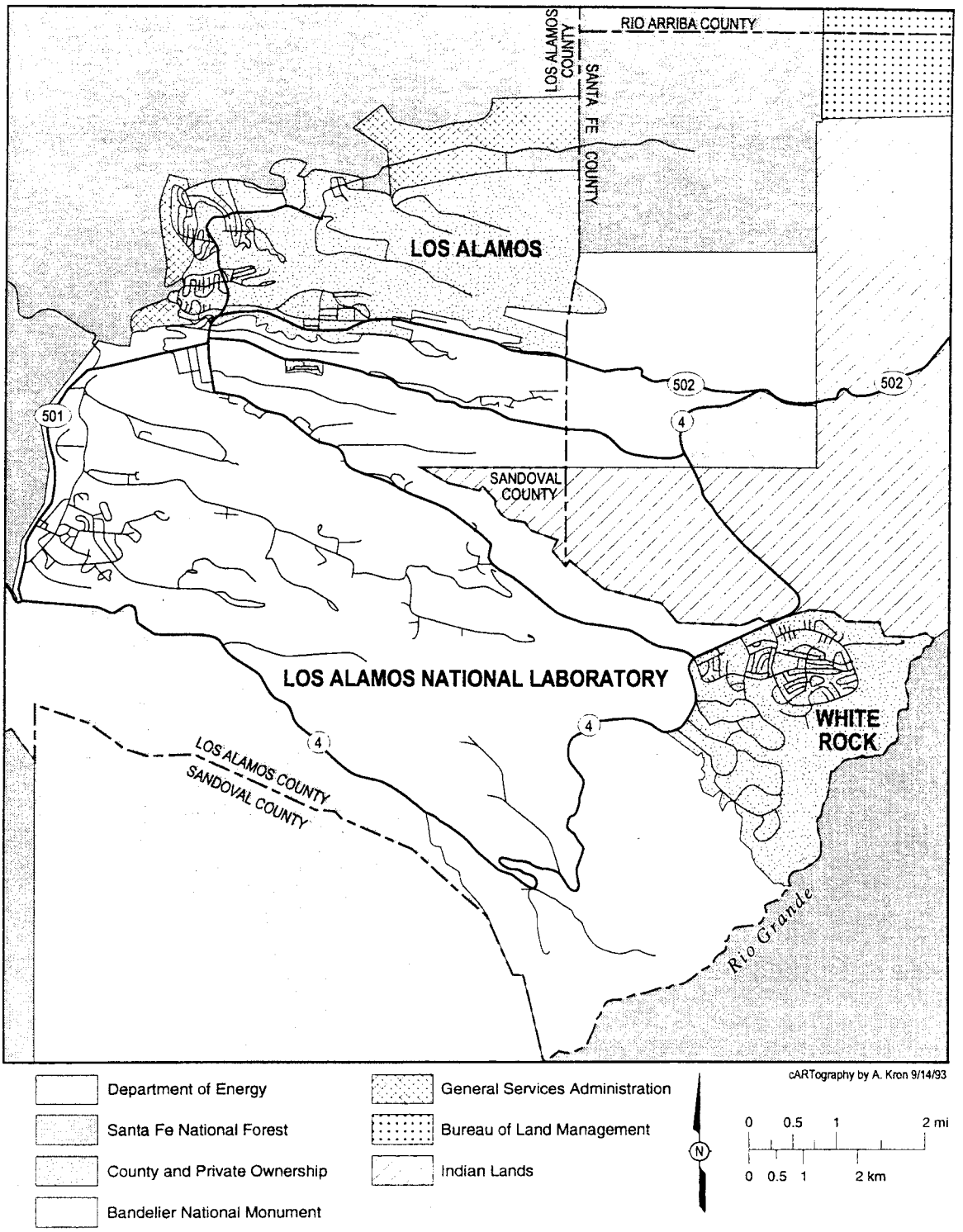


Figure 2-3. Land use map for the Laboratory and adjacent lands.

Laboratory land is used for building sites, experimental areas, waste disposal locations, roads, and utility rights-of-way. However, these uses account for only a small part of the land. Most of the land controlled by the Laboratory serves as a buffer zone for Laboratory facilities, providing security and safety to the public, and as a reserve for future construction. The Laboratory's long-range site development plan (LANL 1995, 52976) addresses the best possible future uses of available Laboratory lands.

The public is allowed limited access to certain areas of the Laboratory site. An area north of Ancho Canyon between the Rio Grande and State Road 4 is open to hikers, but woodcutting and vehicles are prohibited. Portions of Mortandad and Pueblo Canyons are also open to the public. An archaeological site (the Otowi tract), northwest of State Road 502 near the White Rock Y, is open to the public, subject to restrictions imposed by regulations to protect cultural resources.

2.3.2 Ecology

The Pajarito Plateau is a biologically diverse area. This diversity is due partly to the dramatic 5,000-ft elevation gradient from the Rio Grande to the east and the Jemez Mountains 12 mi to the west and partly to the many steep canyons that dissect the area. The pronounced east-west canyon and mesa orientations, with concomitant differences in soils, moisture, and solar radiation, produce an interlocking finger effect among ecological life zones, resulting in many transitional overlaps of plant and animal communities within small areas.

2.3.2.1 Flora

Five major vegetative cover types are found in Los Alamos County: juniper-savannah, piñon-juniper, ponderosa pine, mixed conifer, and spruce-fir. The juniper-savannah community is found along the Rio Grande on the eastern border of the plateau and extends upward on the south-facing sides of canyons, at elevations between 5,600 to 6,200 ft. The piñon-juniper cover type, generally in the 6,200- to 6,900-ft elevation range, covers large portions of the mesa tops and north-facing slopes at the lower elevations. Ponderosa pines are found in the western portion of the plateau in the 6,900- to 7,500-ft elevation range. The juniper-savannah, piñon-juniper, and ponderosa pine cover types predominate, each occupying roughly one-third of the Laboratory site. The mixed conifer cover type, at an elevation of 7,500 to 9,500 ft, overlaps the ponderosa pine community in the deeper canyons and on north slopes and extends from the higher mesas onto the slopes of the Jemez Mountains. The subalpine grassland is at higher elevations of 9,500 to 10,500 ft. Twenty-seven wetlands and several riparian areas enrich the diversity of plant and animals found on Laboratory lands.

2.3.2.2 Fauna

Before the Laboratory was established, Native Americans and European settlers farmed the mesas, disturbing areas that are now in various stages of succession. These areas afford suitable feeding locations for herbivores, especially mule deer and Rocky Mountain elk. Adjacent timbered canyon slopes provide protective cover for these species. Large mammals such as black bear, coyote, gray fox, mountain lion, and bobcat range in large areas of the Laboratory through numerous habitat types. Sheer canyon walls at all elevations serve as important nesting and foraging habitats for birds of prey. Generally, smaller mammals, songbirds, reptiles, and invertebrates are most sensitive to variations in habitat and are confined to smaller ranges.

Past Laboratory-wide information on the fauna within the Laboratory complex was largely qualitative; however, much quantitative information has been gathered in recent years in support of the biological assessment process. Biological assessments have been written for a great many projects and sampling activities throughout the Laboratory, but the assessments do not provide a comprehensive quantitative coverage of the entire Laboratory. Species lists have been compiled from observational

data, biological research, and published data. Special studies are currently under way to provide a more comprehensive list of vertebrate fauna.

Based on ongoing surveys, at least four federally protected animal species, the American peregrine falcon (endangered), the bald eagle (endangered), the Mexican spotted owl (threatened), and the southwestern willow flycatcher (endangered) have been recorded on Laboratory and Los Alamos County lands.

The American peregrine falcon establishes breeding territories near cliffs in areas of mixed-conifer, ponderosa pine, and piñon pine. A historical aerie exists in the county, and American peregrine falcons are known to forage on Laboratory lands.

The bald eagle winters along the Rio Grande and has been observed over Laboratory lands. The entire Laboratory is considered suitable foraging habitat for the bald eagle.

Mexican spotted owls have been documented nesting on Laboratory lands, Bandelier National Monument, and US Forest Service lands in Los Alamos County. Nesting Mexican spotted owls inhabit canyons characterized as mixed conifer and ponderosa pine-Gamble oak forests and forage on mesa tops surrounding the canyons. Suitable habitat for this species exists throughout the Laboratory.

The southwestern willow flycatcher has been recorded during surveys in the wetlands in lower Pajarito Canyon and along the Rio Grande. To date, the southwestern willow flycatcher has been detected only during its migration and has not nested on Laboratory lands; however, suitable nesting habitat does exist at the Laboratory. Southwestern willow flycatchers inhabit areas near water with 13- to 23-ft-high thickets of willow, buttonbush, seepwillow, and tamarisk (Sogge et al. 1997, 57040).

Three other federally protected species may inhabit the Laboratory and the county and must be considered when evaluating a proposed project: the whooping crane (endangered), black-footed ferret (endangered), and Arctic peregrine (threatened). Of these three species, the Arctic peregrine and the whooping crane have been recorded in New Mexico in recent history. The black-footed ferret is extremely unlikely to be found in the state.

Several federal species of concern (formal federal candidate species) and state protected faunal species have been documented in Los Alamos County. They include the Northern Goshawk, Goat Peak pika, Jemez Mountain salamander, spotted bat, and several Myotis bat species. Other species that may occur in the area, but their presence has not been confirmed, include the New Mexico jumping mouse, loggerhead shrike, and gray vireo. (Hinojosa and Nguyen 1996, 57042).

2.3.2.3 Wetlands

Under the Resource Conservation and Recovery Act (RCRA) and the Hazardous and Solid Waste Amendments (HWSA) Module of the Laboratory's operating permit, the Environmental Protection Agency (EPA) required a determination of all wetlands located in areas that either lie within Laboratory boundaries or that drain Laboratory land (Figure 2-4).

US Fish and Wildlife personnel mapped the wetlands around Los Alamos, using US Geological Survey (USGS) quadrangle maps as base maps and infrared high-altitude aerial maps. To cover all of the watersheds that drain the Laboratory site, five quadrangles were mapped (Frijoles, White Rock, Guaje, Valle Toledo, and Puye). In addition to the watershed of the Laboratory proper, the Seven Springs quadrangle, which gives the location of the Laboratory's geothermal site at Fenton Hill, was mapped. Personnel in the Ecology group (ESH-20) have delineated and characterized individual wetlands by conducting a detailed on-the-ground and historical analysis of single sites containing wetland vegetation.

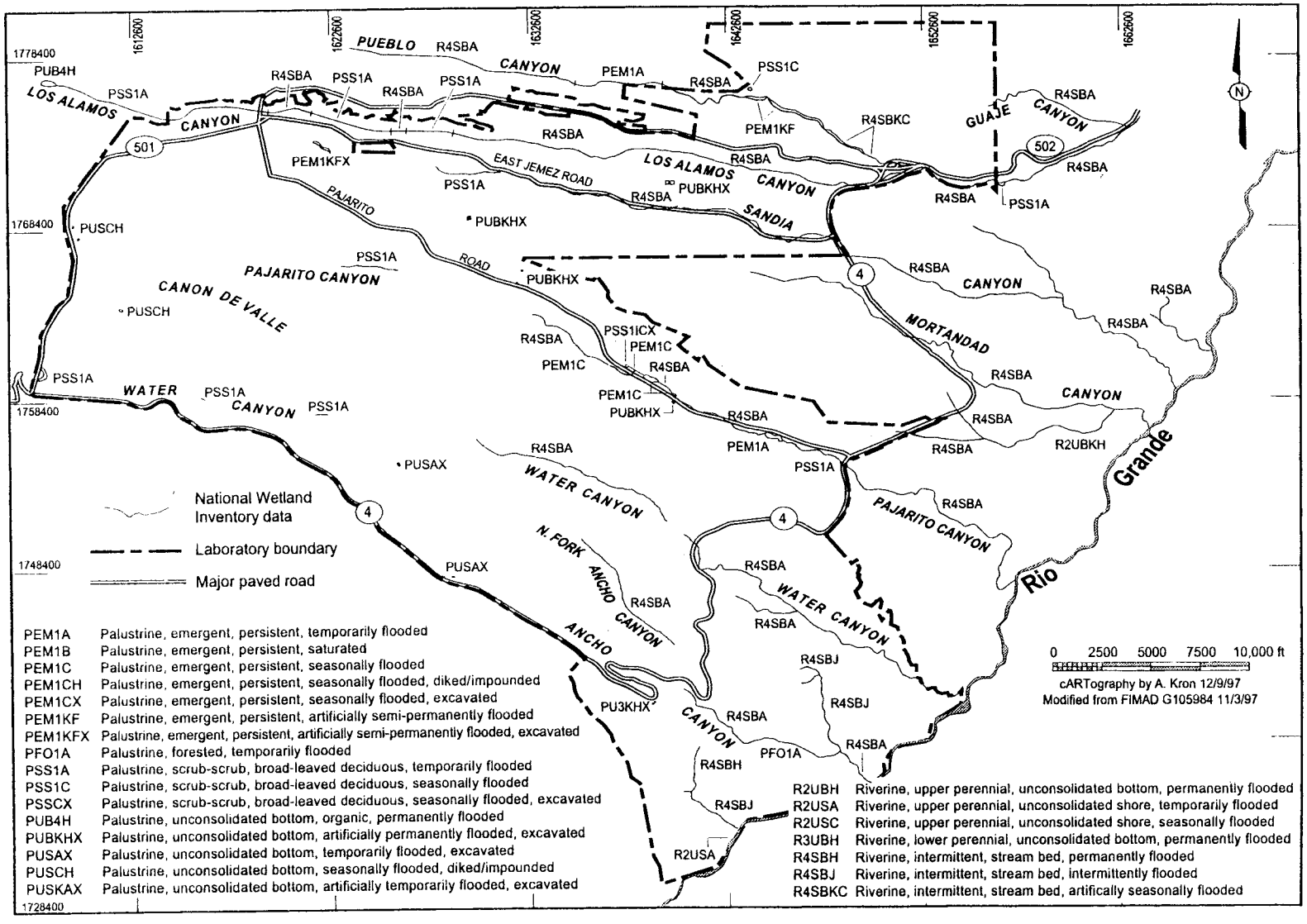


Figure 2-4. Map of wetlands.

Wetlands within Laboratory boundaries fall primarily into two classifications: palustrine and riverine. Palustrine wetlands (ponds and marshes) have been identified in Sandia, Pajarito, and Pueblo canyons, and smaller ones have been identified in other parts of the Laboratory. Wetlands in Sandia and Pueblo canyons are primarily maintained by effluent releases. Beds of ephemeral and intermittent streams that traverse the Laboratory have been classified as temporarily flooded riverine wetlands. In addition, the Laboratory has several small wetlands associated with outfalls that have existed long enough to have wetland vegetation associated with them.

2.3.3 Climate

Bowen (1990, 6899) has compiled and interpreted climatological data for the Los Alamos area, and this information is summarized below.

Los Alamos has a semiarid, temperate mountain climate. Forty percent of the 18-in. annual precipitation normally occurs from thundershowers during July and August. Winter precipitation falls primarily as snow, with accumulations of about 51 in. annually.

Summers are generally sunny, with moderate, warm days and cool nights. Maximum daily temperatures are usually below 90°F. Brief afternoon and evening thundershowers are common, especially in July and August. High altitude, light winds, clear skies, and dry atmosphere allow night temperatures to drop to the 50s (°F) after even the warmest day. Winter temperatures typically range from about 15°F to 25°F during the night and from 30°F to 50°F during the day. Occasionally, temperatures drop to 0°F or below. Many winter days are clear with light winds, allowing strong sunshine to make conditions comfortable even when air temperatures are cold. Snowstorms with accumulations exceeding 4 in. are common in Los Alamos, and some of these storms are associated with strong winds, frigid air, and dangerous wind chills, especially in the mountains. The climate from 1961 through 1988 had slightly cooler temperatures and higher precipitation than those recorded from 1911 through 1988 (entire record). The only significant difference between the period from 1961 through 1988 and the entire record period is the large amount of snowfall.

Because of complex terrain, surface winds in Los Alamos often vary greatly with time of day and location. With light winds and clear skies, a distinct daily wind cycle often exists: a light southeasterly to southerly upslope wind during the day and a light westerly to northwesterly drainage wind during the night (Figure 2-5, from Environmental Protection Group 1990, 6995). However, several miles to the east toward the edge of Pajarito Plateau near the Rio Grande valley, a different daily wind cycle is common: a moderate southwesterly up-valley wind during the day and either a light northwesterly to northerly drainage wind or moderate southwesterly wind at night. The predominant winds are southerly to northwesterly over western Los Alamos County and southwesterly and northeasterly toward the Rio Grande valley. Historically, no tornadoes have been reported to have touched down in Los Alamos County. Strong dust devils can produce winds up to 75 mph at isolated spots in the county, especially at lower elevations. Strong winds with gusts exceeding 60 mph are common during the spring.

Lightning is common over the Pajarito Plateau. Fifty-eight thunderstorm days occur during an average year, mostly during the summer. Lightning protection is an important design factor for most facilities at the Laboratory. Hail damage can also occur. Hailstones with diameters up to 0.25 in. are common; 0.5-in.-diameter hailstones are infrequent.

The irregular terrain at Los Alamos affects atmospheric turbulence and dispersion, sometimes favorably and sometimes unfavorably. Enhanced dispersion promotes greater dilution of contaminants released into the atmosphere. The complex terrain and forests create an aerodynamically rough surface, forcing increased horizontal and vertical dispersion. Dispersion generally decreases at lower elevations, where the terrain becomes smoother and less vegetated. The frequent clear skies and light, large-scale winds cause good vertical daytime dispersion, especially during the warm

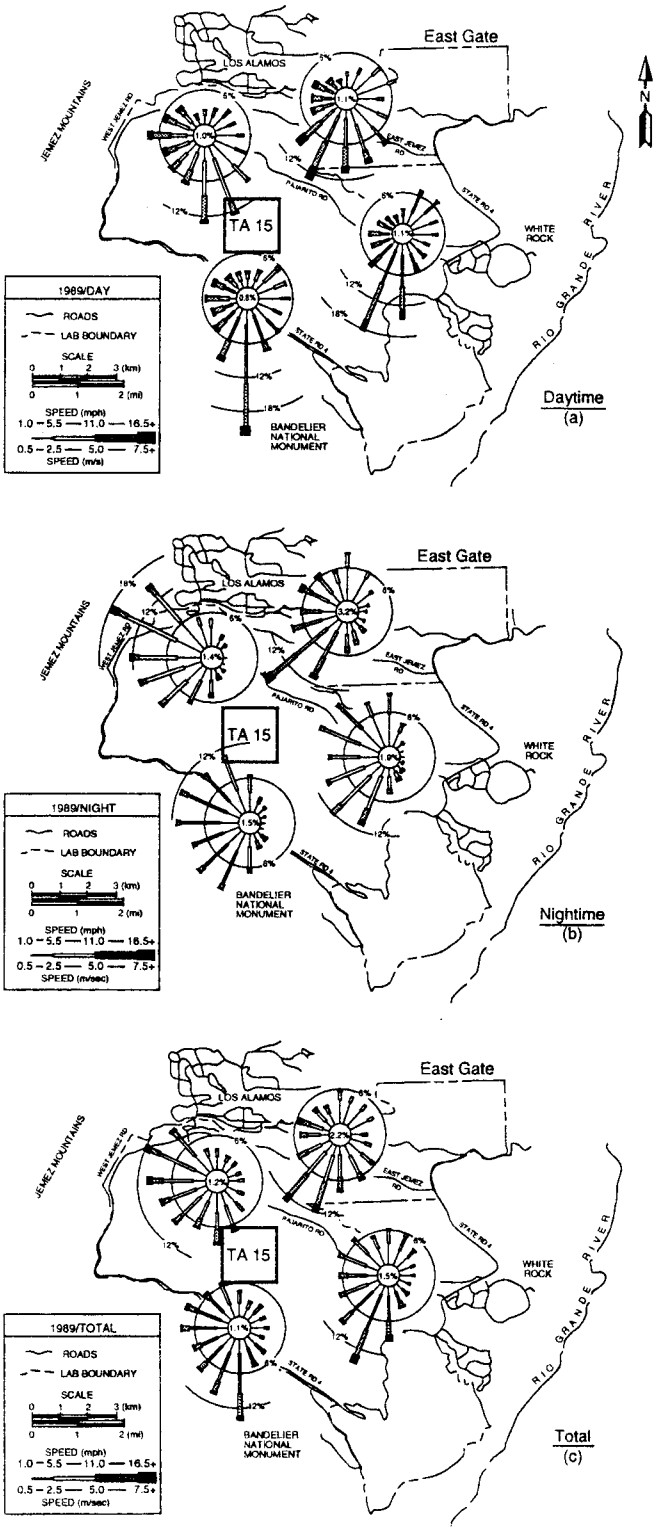


Figure 2-5. Wind roses at Laboratory stations during 1989.

season. Strong daytime heating during the summer can force vertical mixing up to 3,000 to 6,000 ft above ground level, but the effectiveness of the generally light winds in diluting contaminants horizontally is limited.

Clear skies and light winds have a negative effect on nighttime dispersion, causing strong, shallow surface inversions to form. These inversions can severely restrict near-surface vertical and horizontal dispersion. Inversions are especially strong during the winter. Drainage winds can fill lower areas with cold air, thereby creating deeper inversions, which are common toward the Rio Grande valley on clear nights with light winds. Canyons can also limit dispersion by channeling air flow. Strong, large-scale inversions during the winter can limit vertical mixing to under 3,000 ft above ground level.

Dispersion is generally greatest during the spring, when winds are strongest. However, deep vertical mixing is greatest during the summer. Dispersion is generally low during summer and autumn, when winds are light. Even though low-level winter dispersion is generally greater, intense surface inversions can cause least-dispersive conditions during the night and early morning.

During the winter, the frequencies of atmospheric dispersive capability sampled at Technical Area (TA) 59 are 52% unstable (Stability Classes A through C), 21% neutral (Class D), and 27% stable (Classes E and F). The frequencies are 44%, 22%, and 34%, respectively, during the summer. These stability category frequencies are based on measured vertical wind variations. Stability generally increases (the winds become less dispersive) toward the valley.

2.3.4 Population Distribution

Los Alamos County had an estimated 1992 population of approximately 18,200, based on the 1990 census adjusted to 1992 (Environmental Protection Group 1994, 35363). Two residential areas (Los Alamos and White Rock) and their related commercial areas exist in the county (Figure 2-1). The Los Alamos townsite (the original area of development that now includes the residential areas known as Eastern Area, Western Area, North Community, Barranca Mesa, and North Mesa) has an estimated population of 11,400. The White Rock area (including the residential areas of White Rock, La Senda, and Pajarito Acres) has about 6,800 residents. About 40% of the people employed in Los Alamos commute from other counties. Population data from 1990, adjusted to 1992, place about 224,000 persons within a 50-mi radius of Los Alamos (Table 2-1) (Environmental Protection Group 1994, 35363).

2.4 Geology

This summary of the hydrogeologic environment at the Laboratory and in the northern New Mexico region is intended to describe the major geologic, hydrologic, and hydrogeologic features and their conceptual interrelationships. It addresses the regional and installation-wide geologic setting and the hydrologic characteristics that affect surface water and groundwater occurrence and movement and their interactions as they relate to the potential for contaminant transport. The sources cited here and additional literature on the hydrology and geology of the Los Alamos region may be found in an annotated bibliography of geologic, hydrogeologic, and environmental studies related to solid waste management units at the Laboratory (LANL 1990, 47588). This bibliography was submitted to EPA in September 1990. The bibliography and the literature it describes are available for review in the Laboratory's public reading room located at 1350 Central Avenue, Suite 101, in Los Alamos.

TABLE 2-1

1992 POPULATION WITHIN 80 KM OF LOS ALAMOS

	Distance from TA-53 (km)								
Direction	1–2	2–4	4–8	8-15	15–20	20–30	30–40	40–60	60–80
N	1	0	0	0	0	0	1,169	0	378
NNE	0	0	0	582	0	558	1,781	1,850	227
NE	1	0	0	0	326	15,860	1,039	1,170	3,965
ENE	0	0	0	2,031	1,609	2,843	2,827	1,222	2,267
E	0	0	87	26	582	1,199	728	0	1,422
ESE	0	0	0	0	0	306	24,239	1,091	1,511
SE	0	0	6,796	0	0	0	56,036	2,558	8
SSE	0	0	0	0	0	0	446	4,551	99
S	0	0	0	50	0	347	670	7,363	0
SSW	0	0	0	20	0	891	219	8,981	36,507
SW	0	0	0	0	0	0	343	4,532	0
WSW	0	0	0	0	0	343	341	2,775	225
W	0	0	0	0	0	0	0	179	144
WNW	0	1,443	6,572	0	0	0	0	0	3,359
NW	0	526	1,731	0	0	0	0	1,481	0
NNW	0	581	582	0	0	0	0	65	64
1992 Population Distribution	2	2,550	15,768	2,709	2,517	22,347	89,838	37,818	50,176

Note: Total population within 80 km of Los Alamos is 223,725.

2.4.1 Geologic Overview

The Laboratory is sited on the Pajarito Plateau, an east-sloping, dissected tableland bounded on the west by the eastern Jemez Mountains (Sierra de los Valles) and on the east by White Rock Canyon of the Rio Grande (Figure 2-6). The geology of the Pajarito Plateau reflects the interplay of volcanism in the Jemez Mountains and surrounding areas with the development of the Rio Grande rift, a series of north-south trending fault troughs extending from southern Colorado to southern New Mexico (Figure 2-6). Volcanism over the last 13 Ma (million years) has built up the highlands area of the Jemez Mountains, while the contemporaneous tectonic rifting has resulted in subsidence of the area extending from the eastern margin of the Jemez Mountains to the western margin of the Sangre de Cristo Mountains. This area of subsidence, locally termed the Española basin of the Rio Grande rift, is a graben between two larger basins—the Albuquerque basin to the south and San Luis basin to the north (Kelley 1978, 11659). During this interplay of volcanism and rifting, erosion has removed materials from the highlands areas to the west and deposited them downslope to the east into the rifted lowlands, which were contemporaneously receiving sediments from other sources. The Pajarito Plateau has developed in and now occupies the western part of the Española basin (Figure 2-6).

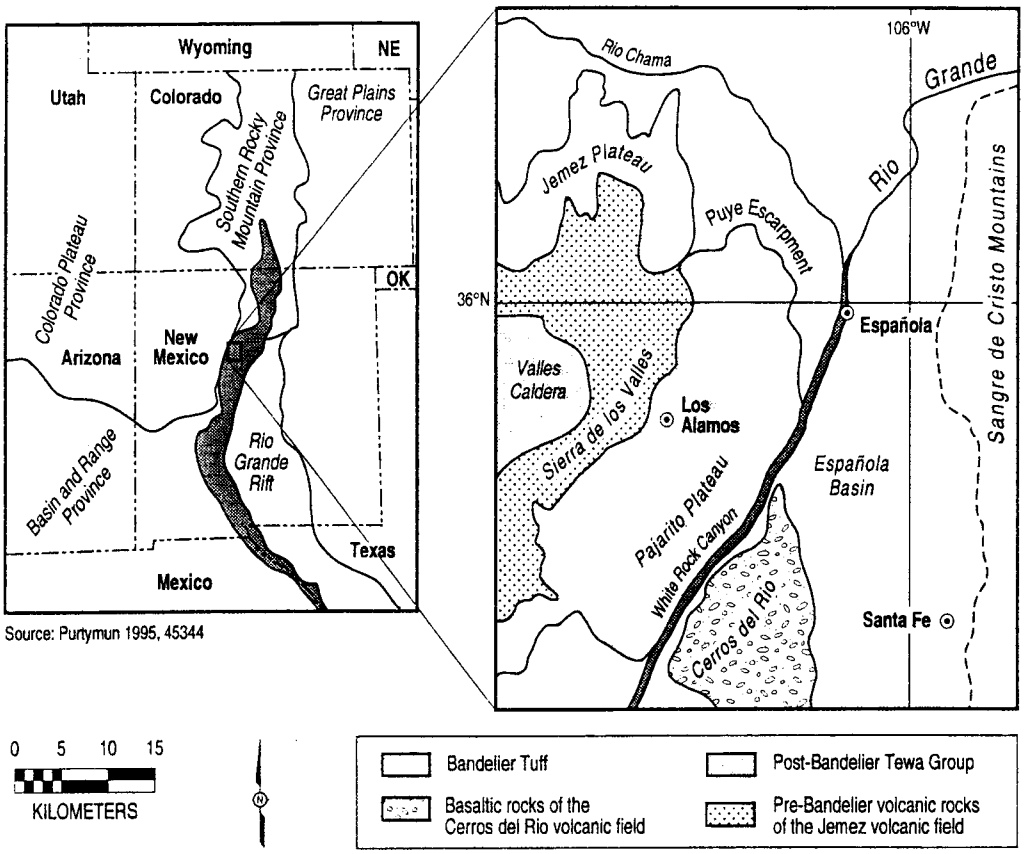
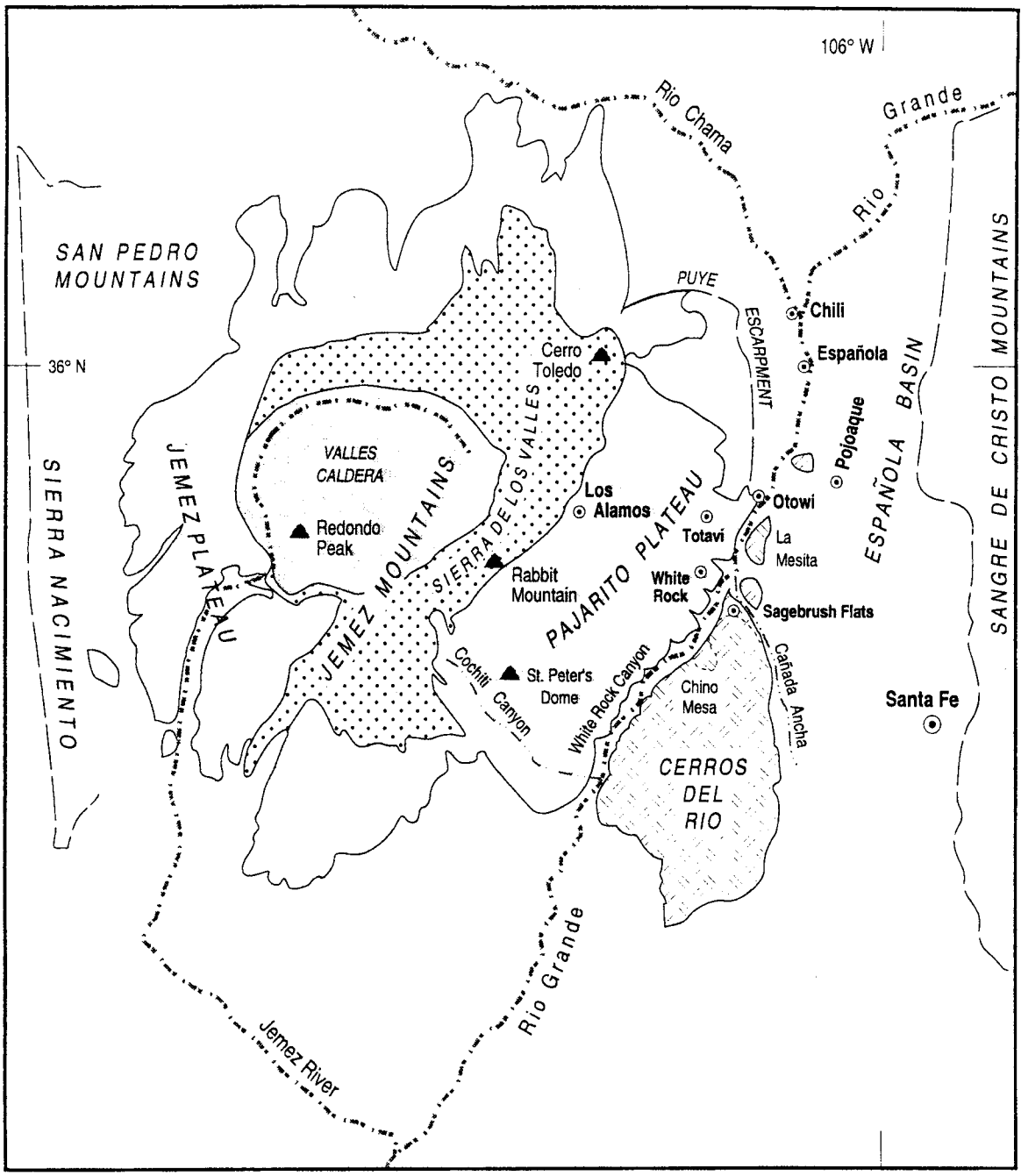


Figure 2-6. Physiographic features of the Pajarito Plateau.

Figure 2-7 is a general geologic map highlighting the dominantly volcanic rock types of the area. The gently east-sloping Bandelier Tuff covers the Pajarito Plateau (Figure 2-8). Deep canyons are incised into the Bandelier Tuff and expose it to depths of up to several hundred feet below the general level of the plateau. From west to east, these canyons cut progressively deeper into the Bandelier Tuff and, near the Rio Grande, some of the deeper canyons expose older lavas and sedimentary rocks. Figure 2-9 and Figure 2-10 schematically portray the complex interfingering of volcanic rocks and sediments that occurs below the Bandelier Tuff. Volcanic rocks of the Tschicoma Formation and their derivative sediments (fanglomerate facies of the Puye Formation) extend eastward under the plateau where they interfinger with Santa Fe Group rocks and basaltic rocks of the Cerros del Rio volcanic field (also called "basaltic rocks of Chino Mesa").

2.4.2 Stratigraphy

The following descriptions cover the rock units relevant to the ER investigations, starting with the oldest (deepest) and proceeding to the youngest (topmost). Fossil evidence, stratigraphic



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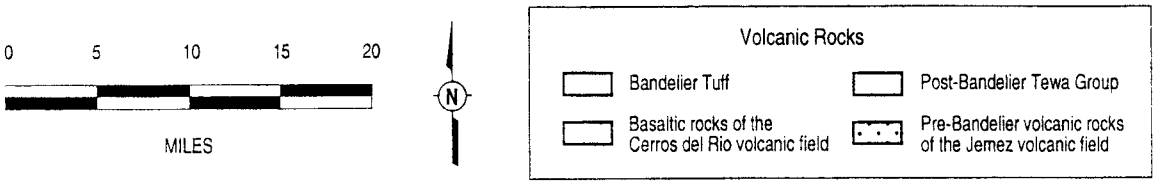
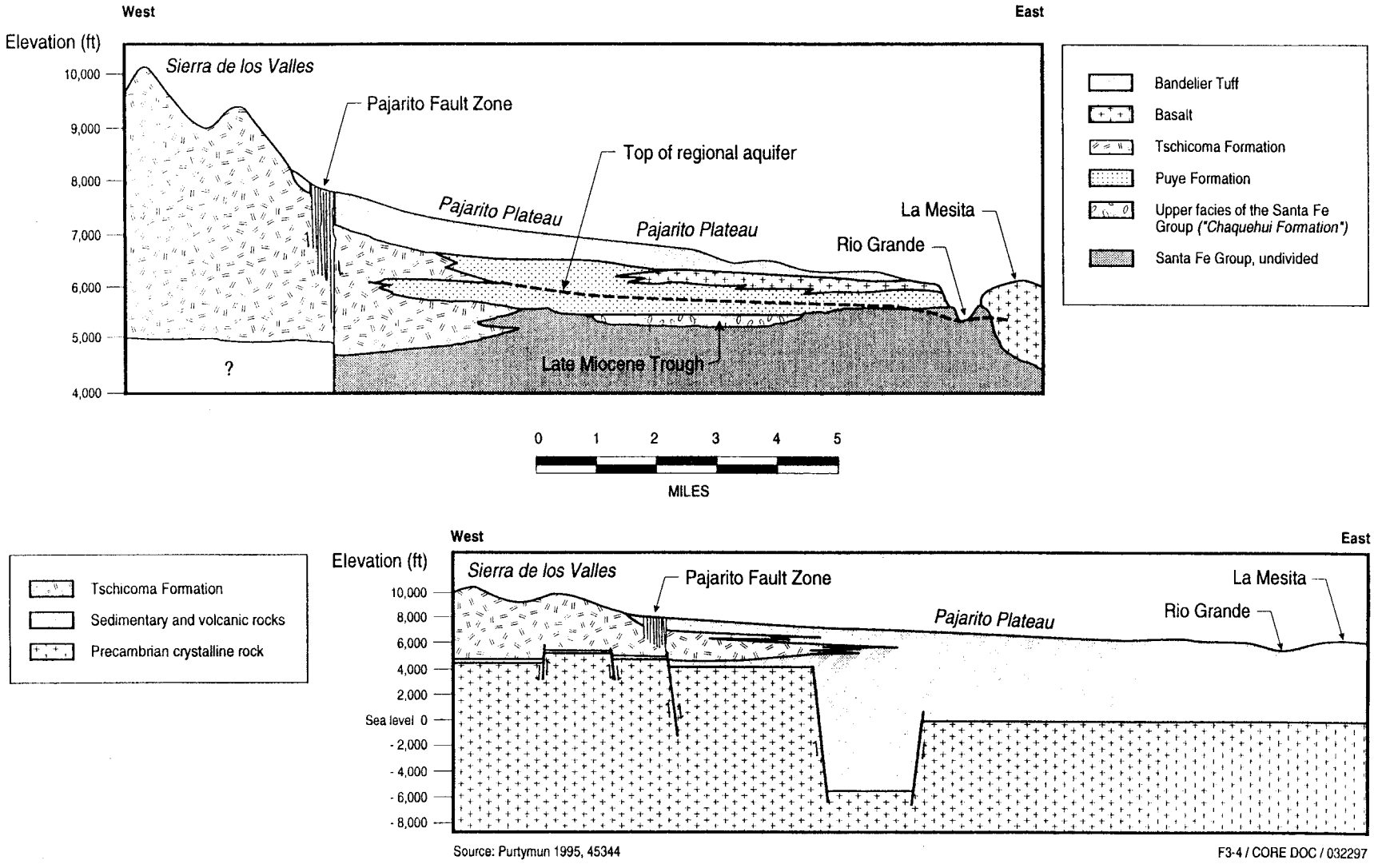


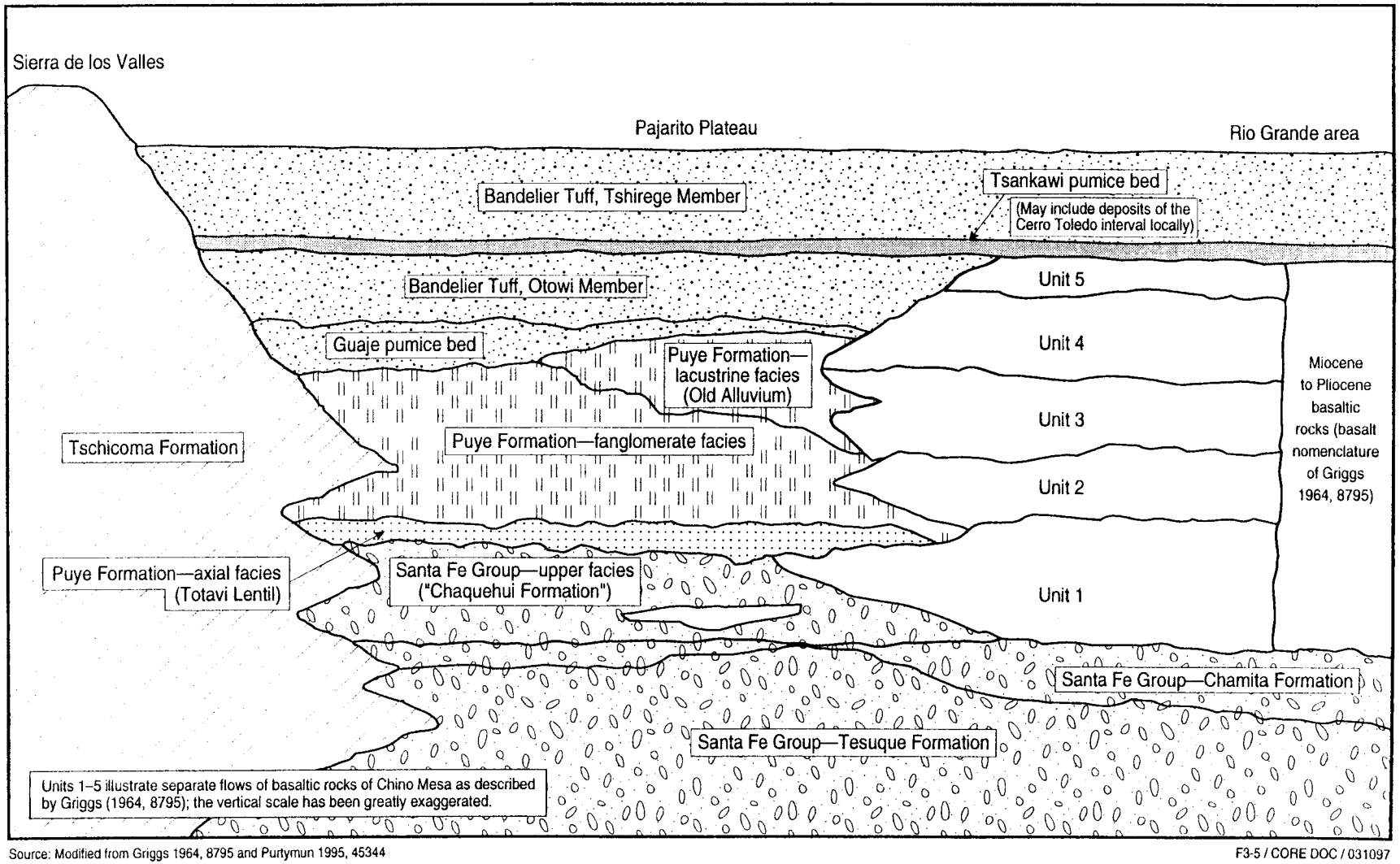
Figure 2-7. General geologic and geographic features of the Pajarito Plateau and surrounding area.



Source: Purtymun 1995, 45344

F3-4 / CORE DOC / 032297

Figure 2-8. Generalized geologic cross sections of the Pajarito Plateau.



Source: Modified from Griggs 1964, 8795 and Purtymun 1995, 45344

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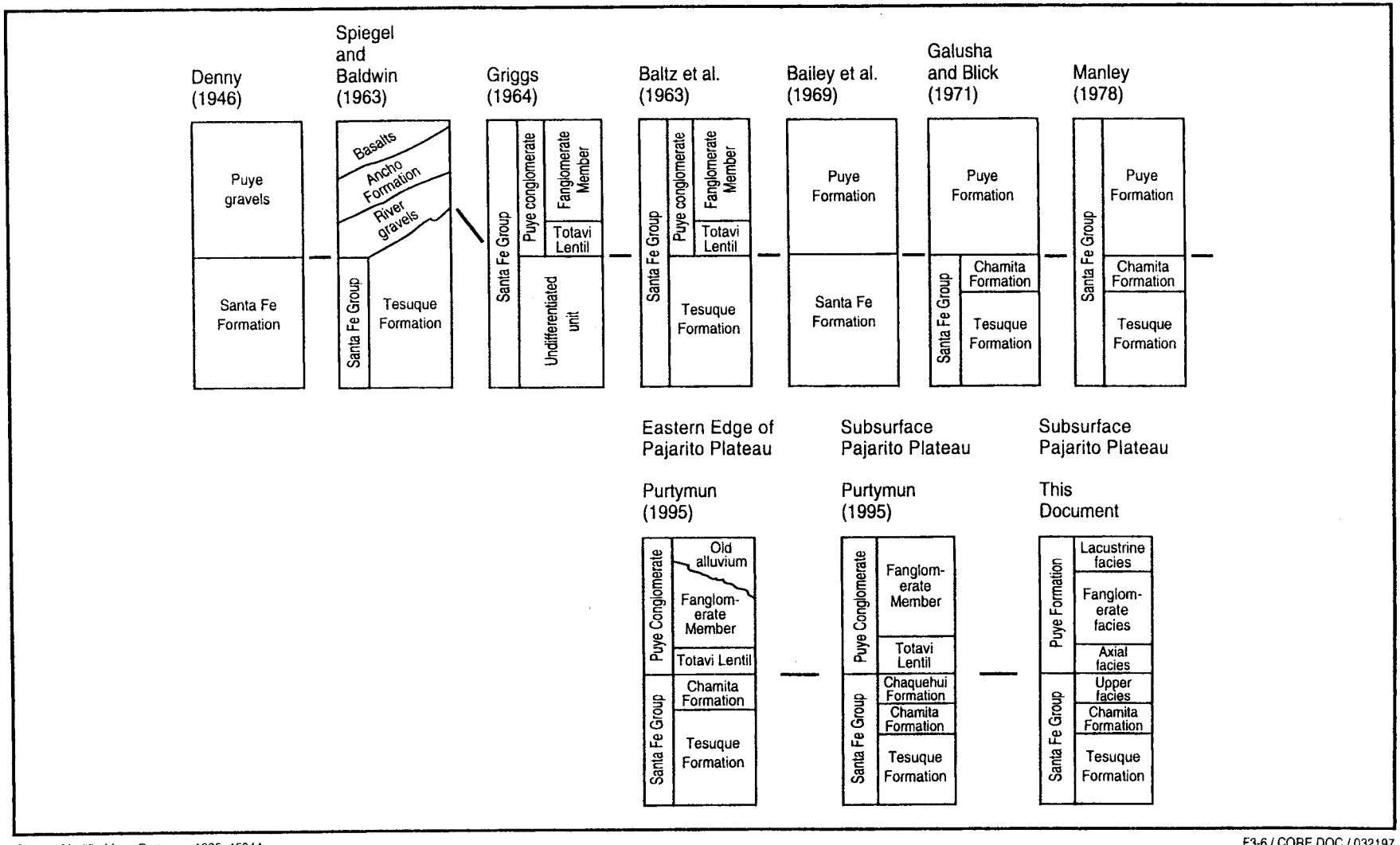
Figure 2-9. Schematic cross section of the Pajarito Plateau showing complex interfingering of volcanic and sedimentary rocks.



Source: Modified from Purtymun 1995, 45344

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Figure 2-10. Stratigraphic relationships and evolution of nomenclature for pre-Bandelier Tuff rocks of the Pajarito Plateau.

correlations, and radiometric measurements provide the approximate ages of most of the bedrock units. The bedrock units and their ranges of approximate radiometric ages are listed below in ascending order.

1. Santa Fe Group: 4 to 21 Ma (Manley 1979, 11714)

2. Tschicoma Formation: 2.53 to 6.7 Ma (Dalrymple et al. 1967, 49924)

3. Puye Formation: 1.7 to 4 Ma (Turbeville et al. 1989, 21587; Spell et al. 1990, 21586), which includes a fanglomerate facies, an axial facies (Manley 1979, 11714; Turbeville et al. 1989, 21587), and a lacustrine facies

4. Basaltic rocks of the Cerros del Rio volcanic field (also known as "basaltic rocks of Chino Mesa") (2 to 3 Ma) (Gardner and Goff 1984, 44021; WoldeGabriel et al. 1996, 54427)

5. Otowi Member of the Bandelier Tuff: 1.61 Ma (Izett and Obradovich 1994, 48817; Spell et al. 1996, 55542)

6. Volcaniclastic sediments and tephras of the Cerro Toledo interval

   The age of this unit is bracketed by the ages of the underlying Otowi Member (1.61 Ma) and the overlying Tshirege Member (1.22 Ma) of the Bandelier Tuff.

7. Tshirege Member of the Bandelier Tuff: 1.22 Ma (Izett and Obradovich 1994, 48817; Spell et al. 1996, 55542)

A geologic map published by Smith et al. (1970, 9752) shows the distribution of these bedrock units across the Pajarito Plateau. Other general geological maps covering this area are those by Griggs (1964, 8795), Kelley (1978, 11659), and Goff et al. (1990, 21574). More detailed geological maps covering portions of the Laboratory include those by Baltz et al. (1963, 8402), Rogers (1995, 54419), Vaniman and Wohletz (1990, 21589), Reneau et al. (1995, 54405), and Goff (1995, 49682). Figure 2-7 shows area locations, and Figure 2-9 and Figure 2-10 illustrate the stratigraphic units referred to in the following sections.

2.4.2.1 The Santa Fe Group

Rocks of the Santa Fe Group crop out in lower Los Alamos Canyon, near the mouth of Guaje Canyon, and along the margins of the Rio Grande from Otowi Bridge south to White Rock. Galusha and Blick (1971, 21526) subdivided the Santa Fe Group into formations and members based on geologic mapping and fossil assemblages of late Tertiary mammals (Figure 2-10). Manley (1979, 11714) refined the stratigraphy of the Santa Fe Group with additional mapping and dates of interbedded volcanic ash layers, lava flows, and dikes. The description herein (see Figure 2-9 and Figure 2-10) follows the nomenclature of Galusha and Blick (1971, 21526) as modified by Manley (1979, 11714) and Purtymun (1995, 45344).

In the vicinity of the Pajarito Plateau, the stratigraphy and geochronology of the Santa Fe Group is poorly understood because of the near continuous blanket of younger volcanic deposits. Based on exposures near the Rio Grande, the Santa Fe Group beneath the Pajarito Plateau is believed to include, in ascending order, the Tesuque Formation and the Chamita Formation. Purtymun (1995,

45344) has also given the name "Chaquehui Formation" to distinctive coarse-grained sediments at the top of the Santa Fe Group on the Pajarito Plateau based on evidence from deep well boreholes on the Pajarito Plateau.

"Chaquehui Formation" is not a formal geologic name at present and there is disagreement among geologists as to whether it should be recognized separately from the Chamita Formation.

2.4.2.1.1 The Tesuque Formation

The Tesuque Formation is a massive, thick unit consisting of arkosic sediments, derived primarily from Precambrian basement and Tertiary volcanic sources to the east and northeast of the Española basin. This unit is a light pink-to-buff siltstone and silty sandstone with a few lenses of pebbly conglomerate and clay. It is poorly to moderately consolidated and has an age range of about 7 to 21 Ma (Manley, 1979, 11714; Cavazza 1989, 21501). Spiegel and Baldwin (1963, 54259) describe the Tesuque Formation at the southern end of the Española basin, including the exposures in the vicinity of Otowi Bridge and along White Rock Canyon. This formation exists in deep well boreholes under the Pajarito Plateau and is the primary aquifer for municipal and industrial water supply in Los Alamos County. The Tesuque Formation contains basalt at a depth of 2,219 ft (67.6 m) in Otowi well O-1 (Purtymun 1995, 45344).

2.4.2.1.2 The Chamita Formation

The Chamita Formation overlies and interfingers with the Tesuque Formation. It consists of arkosic siltstones, sandstones, pebbly conglomerate, and includes two prominent beds of white ash. This formation is thickest in the northern part of the Española basin and thins to less than 30 ft (9.1 m) or is absent under most of the Laboratory. Aldrich and Dethier (1990, 49681) suggest that the Chamita Formation north of the Pajarito Plateau may be as old as 12 Ma and the age estimates for the overlying "Chaquehui Formation" (see below) support that suggestion. However, paleomagnetic data in the area indicate an age range of 4.5 to 6 Ma (MacFadden 1977, 21569), and tephra dates by Manley (1979, 11714) support a younger age of about 5 Ma for at least part of the formation. Because the Chamita and Tesuque Formations may not be distinguishable in borehole cores and cuttings, it is sometimes necessary to group these formations as "undifferentiated Santa Fe Group" during borehole investigations.

2.4.2.1.3 The "Chaquehui Formation"

Sedimentary deposits referred to as the "Chaquehui Formation" by Purtymun (1995, 45344), and shown as upper facies of the Santa Fe Group on Figure 2-9 and Figure 2-10, are made up of mixtures of volcanic debris from the Jemez Mountains and arkosic materials from the highlands to the north and east. Because of their coarse-grained nature, these rocks are an important aquifer for municipal and industrial water supply in the Los Alamos area (Purtymun 1995, 45344). The "Chaquehui Formation" overlies the Chamita Formation in well boreholes on the Pajarito Plateau. However, because it contains interbedded basalt lava flows dated at 8 to 9 Ma (Laughlin et al. 1993, 54424), it is equivalent in age to older parts of the Chamita Formation. The "Chaquehui Formation" forms a transitional interval between older Santa Fe Group rocks and overlying volcaniclastic rocks derived from the Jemez Mountains. The presence of coarse-grained arkosic materials within the "Chaquehui Formation" suggests that these deposits may represent axial deposits of an ancestral Rio Grande within the Chamita Formation.

2.4.2.2 The Tschicoma Formation

The Tschicoma Formation of the Polvadera Group makes up the rugged highlands west of Los Alamos and crops out in the headwaters of the larger canyons that cut the Pajarito Plateau. Deep well boreholes along the western perimeter of the Laboratory intersect this unit at depths of several hundred feet or more, but the Tschicoma Formation is generally absent in boreholes penetrating the central and eastern parts of the Laboratory.

The Tschicoma Formation consists of numerous thick lava flows derived from a series of volcanic domes that predate the Bandelier Tuff. Fragmental deposits of ash and lava debris occur in the distal parts of the formation. It has a variable thickness due to the lenticular shape of its lava flows, and is at least 2,500 ft (762 m) thick in the Sierra de los Valles. The Tschicoma Formation thins eastward under the Bandelier Tuff on the Pajarito Plateau where it interfingers with the penecontemporaneous Puye Formation. The lower parts of the Tschicoma Formation may interfinger with the upper Santa Fe Group.

Tschicoma Formation lava flows range in composition from andesite to low-silica rhyolite but are dominantly dacites. The rocks are mainly gray to purplish gray, but in places they are reddish brown. These flows display pronounced jointing and have bottoms commonly marked by blocky breccia. Lavas contain glassy and microcrystalline groundmass; the glass is generally devitrified giving the rocks a stony appearance.

Radiometric ages for the Tschicoma Formation in the vicinity of Los Alamos range between 3.7 and 6.7 Ma (Dalrymple et al. 1967, 49924). Turbeville et al. (1989, 21587) report an age of 2.53 Ma for a Tschicoma ignimbrite within the Puye Formation. In the northern part of the Jemez volcanic field, the Tschicoma Formation is bracketed in age by the underlying Lobato Basalt (7.4 Ma) and the overlying El Rechuelos Rhyolite (2.0 Ma) (Loeffler et al. 1988, 54409).

2.4.2.3 The Puye Formation

The Puye Formation is a large apron of alluvial fans which were shed eastward from the Jemez volcanic field into the Española basin, covering the Santa Fe Group rocks west of and along the Rio Grande. Intersected by most deep water wells on the Pajarito Plateau (Dransfield and Gardner 1985, 6612; Purtyman 1995, 45344), this formation crops out in canyons north of Los Alamos Canyon. Turbeville et al. (1989, 21587) estimated its areal distribution at 200 km^2 (518 mi^2) and its volume at ~15 km^3 (~3.6 mi^3). Its age is generally placed at between 1.9 and 3.5 Ma, but it may be as young as 1.6 Ma and as old as 6.7 Ma because of its expected temporal and spatial association with eruption of the Tschicoma Formation. The lithology of the Puye Formation is dominated by conglomerates and gravels consisting of subrounded dacitic and andesitic lava clasts in a sandy matrix. At least 25 ash beds of dacitic to rhyolitic composition are interbedded with the conglomerates and gravels (Turbeville et al. 1989, 21587), and basaltic ash and lacustrine layers are present along the eastern margins of this formation. Showing considerable lateral variation in textures and composition, the formation reaches a maximum thickness of ~700 ft (~213 m) in Pueblo Canyon (Griggs 1964, 8795) but thins to 50 ft (15 m) in areas north of the Pajarito Plateau (Dethier and Manley 1985, 21506). In the central and eastern portions of the Laboratory, it is ~600 ft (~183 m) thick and is interbedded with basaltic lavas of the Cerros del Rio volcanic field. The Puye Formation as defined by Griggs (1964, 8795) originally included three units, in ascending order: an axial facies (called the "Totavi Lentil" by Griggs [1964, 8795]); a fanglomerate facies; and a lacustrine facies (called "older alluvium" by Griggs [1964, 8795]) (Figure 2-9 and Figure 2-10).

2.4.2.3.1 Axial Facies of the Puye Formation

The axial facies of the Puye Formation (also called "Totavi Lentil" or "Totavi Formation") overlies the Santa Fe Group and crops out at Totavi and in areas to the east in lower Los Alamos Canyon and within White Rock Canyon to the south (Griggs 1964, 8795). It is generally ~50 ft (~15 m) thick under the eastern Pajarito Plateau but thickens in a northwest direction. It consists of coarse, poorly consolidated conglomerate containing cobbles and boulders of quartzite, granite, and pegmatite. The axial facies forms the oldest deposits in the Puye Formation in many areas but also interfingers with the lower part of the fanglomerate facies.

The axial facies is thought by many geologists to represent ancestral Rio Grande channel gravels and is believed to be a separate unit from either the finer grained Chamita Formation or the fanglomerate facies of the Puye Formation, resulting in considerable disagreement on the preferred nomenclature for this unit. It is a channel fill deposit as opposed to an alluvial fan deposit, which characterizes most of the overlying fanglomerate facies, and its composition is more akin to the Chamita Formation than to the fanglomerate facies, which is of dominantly volcanic rock types. For these reasons Turbeville et al. (1989, 21587) distinguished the Totavi deposits from the Puye Formation and assigned them a formation rank. However, because the stratigraphic uncertainties are not yet fully resolved, this document retains the assignment of these rocks to the Puye Formation as originally defined by Griggs (1964, 8795). The age of the axial facies is poorly constrained but is probably between 2.4 and 3.5 Ma (Turbeville et al. 1989, 21587).

2.4.2.3.2 Fanglomerate Facies of the Puye Formation

The fanglomerate facies is the dominant unit of the Puye Formation beneath most of the Laboratory areas. Fanglomerate is a general term meaning a rock unit composed of conglomerates deposited in an alluvial fan setting. The fanglomerate facies contains angular-to-subangular cobbles and boulders of latite, quartz latite, dacite, rhyolite, and tuff in a matrix of silts, clays, and sands. Lenses of silt, clay, and pumice are common. It is interbedded with basaltic rocks of the Cerros del Rio volcanic field in the eastern and central part of the Laboratory. The fanglomerate facies is widespread beneath the Pajarito Plateau and caps the prominent cliffs (Puye Escarpment) along the Rio Grande north of Otowi Bridge.

2.4.2.3.3 Lacustrine Facies of the Puye Formation

Griggs (1964, 8795) included lake beds (the lacustrine facies) as the uppermost part of the Puye Formation. He differentiated them from the fanglomerate facies based on the presence of lake clays and ancient stream gravels that fill channels cut into the fanglomerates. Basaltic rocks of the Cerros del Rio volcanic field are also found in these channels (Griggs 1964, 8795). The lacustrine facies is present in lower Los Alamos Canyon and extends both northward and southward in discontinuous outcrops for several miles. However, it is apparently of limited extent beneath the Pajarito Plateau, being reported only in the borehole for well PM-1 near the eastern edge of the plateau.

2.4.2.4 Basaltic Rocks of the Cerros del Rio Volcanic Field ("Basaltic Rocks of Chino Mesa")

The basaltic rocks of the Cerros del Rio volcanic field crop out primarily on the eastern side of the Rio Grande, and occur in the subsurface below much of the Pajarito Plateau (Dransfield and Gardner 1985, 6612; Broxton and Reneau 1996, 55429). Outcrops within the Laboratory area occur in most canyons along the southern and eastern margins of the plateau. The stratigraphic nomenclature for these basalts has varied with different workers (e.g., Smith et al. 1970, 9752; Kelley 1978, 11659; Griggs 1964, 8795; Aubele 1978, 54426; Galusha and Blick 1971, 21526). Kelley (1978, 11659) mapped four different units of the Cerros del Rio Basalts, one of which (the Cubero Basalts) includes

the five units of the basaltic rocks of Chino Mesa (Griggs 1964, 8795). Some of the older basalt flows that have been included in this formation may belong to the Santa Fe Group.

The basaltic rocks of the Cerros del Rio volcanic field form thick lava flows separated by interflow breccia, scoria, and ash. The lavas were erupted from numerous vents both east and west of the Rio Grande. In the vicinity of the Pajarito Plateau, these basalts form a north-south trending highland (now buried by the Bandelier Tuff) extending from the western edge of White Rock to the confluence of Los Alamos and Pueblo Canyons (Broxton and Reneau, 1996, 55429). These basalts are interbedded with the upper part of the fanglomerate facies of the Puye Formation. Griggs (1964, 8795) identified five lava-flow units (see Figure 3-5). The lower unit, Unit 1, crops out near river level in White Rock Canyon. Unit 2 overlies Unit 1 and forms the main cliffs along White Rock Canyon. It is the most prominent basalt found in boreholes below the central and eastern portions of the plateau, reaching a maximum thickness of 500 ft (152 m) in well PM-4. Unit 3 includes a series of flows emplaced in old stream channels, cropping out in lower Los Alamos Canyon, Sandia Canyon, and Mortandad Canyon. Unit 4 consists of two lava flows that cap the mesa south of lower Los Alamos Canyon where they overlie the Puye and Tesuque Formations. Unit 5 comprises cinder cones and surface basalt flows on Chino Mesa and on the mesa between lower Ancho Canyon and Chaquehui Canyon.

The basaltic rocks of the Cerros del Rio volcanic field include buried remnants of maar volcanoes in White Rock Canyon (Aubele, 1978, 54426; Heiken et al. 1989, 54425). 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.

2.4.2.5 The Bandelier Tuff

The Bandelier Tuff consists of the Otowi and Tshirege Members, which are stratigraphically separated in many places by the tephras and volcaniclastic sediments of the Cerro Toledo interval. The Bandelier Tuff was emplaced during cataclysmic eruptions of the Valles caldera between 1.61 and 1.22 Ma ago. It is perhaps one of the best studied tuff units in the world, and it has been the subject of numerous geological studies since the early 1960s. The tuff is composed of pumice, minor rock fragments, and crystals supported in an ashy matrix. It is a prominent cliff-forming unit because of its generally strong consolidation. In the Tshirege Member, this consolidation is largely due to compaction and welding at high temperatures after the tuff was emplaced. Its light brown, orange brown, purplish, and white cliffs have numerous, mostly vertical fractures (called joints) that show average spacing of between several feet and several tens of feet. The Tshirege Member includes thin but distinctive layers of bedded sand-sized particles, called surge deposits, that demark separate flow units within the tuff. Most Laboratory facilities are located on the tuff, which is covered by thin discontinuous soils on mesa tops and alluvial deposits of variable thickness on canyon floors. Because the Bandelier Tuff is the most prominent rock type on the Pajarito Plateau, its detailed stratigraphy is of considerable importance and is discussed further below (see also Broxton and Reneau 1995, 49726).

2.4.2.5.1 The Otowi Member

The Otowi Member crops out in several canyons but is most extensive in Los Alamos Canyon and in canyons to the north. Griggs (1964, 8795), Smith and Bailey (1966, 21584), Bailey et al. (1969, 21498), and Smith et al. (1970, 9752) are important references describing the nature and extent of the Otowi Member. It consists of moderately consolidated (indurated), porous, and nonwelded vitric tuff (ignimbrite), that forms gentle, colluvium-covered slopes along the base of canyon walls. The Otowi ignimbrites contain light gray-to-orange pumice, supported in a white-to-tan ash matrix (Broxton et al. 1995, 50119; Broxton et al. 1995, 50121; Goff 1995, 49682). The ash matrix consists of glass shards, broken pumice and crystal fragments, and fragments of perlite.

The Guaje Pumice Bed occurs at the base of the Otowi Member, making a significant and extensive marker horizon in many well boreholes. The Guaje Pumice Bed (Bailey et al. 1969, 21498; Self et al. 1986, 21579) contains well-sorted pumice fragments whose mean size varies between 0.8 and 1.6 in. (2.0 and 4.1 cm). Its thickness averages ~28 ft (~8.5 m) below most of the plateau with local areas of thickening and thinning. Its distinctive white color and texture make it easily identifiable in well borehole cuttings and core, and it is an important marker bed for the base of the Bandelier Tuff.

2.4.2.5.2 Tephras and Volcaniclastic Sediments of the Cerro Toledo Interval

The Cerro Toledo interval is an informal name given to a sequence of volcaniclastic sediments and tephras of mixed provenance that separates the Otowi and Tshirege Members of the Bandelier Tuff (Broxton et al. 1995, 50121; Goff 1995, 49682; Broxton and Reneau 1995, 49726). Although it is intercalated between the two members of the Bandelier Tuff, it is not considered part of that formation (Bailey et al. 1969, 21498). Outcrops of the Cerro Toledo interval generally occur wherever the top of the Otowi Member appears in Los Alamos Canyon and in canyons to the north. The unit contains primary volcanic deposits normally assigned to the Cerro Toledo Rhyolite as described by Smith et al. (1970, 9752) as well as intercalated and reworked volcaniclastic sediments not normally included in the Cerro Toledo Rhyolite. The occurrence of the Cerro Toledo interval is widespread; however, its thickness is variable ranging from several feet to more than 100 ft (30.5 m) thick.

The predominant rock types in the Cerro Toledo interval are rhyolitic tuffaceous sediments and tephra (Stix et al. 1988, 49680; Heiken et al. 1986, 48638; Broxton et al. 1995, 50121; Goff 1995, 49682). The tuffaceous sediments are the reworked equivalents of Cerro Toledo Rhyolite tephra that erupted from the Cerro Toledo and Rabbit Mountain rhyolite domes (see Figure 2-7) located in the Sierra de los Valles. Primary pumice-fall and ash-fall deposits occur in some locations. The pumice falls tend to form porous and permeable horizons within the Cerro Toledo interval, and locally they may provide important pathways for moisture transport in the vadose zone. Clast-supported gravel, cobble, and boulder deposits made up of porphyritic dacite derived from the Tschicoma Formation are interbedded with the tuffaceous rocks, and in some deposits, dacitic materials are volumetrically more important than rhyolitic detritus. These coarse dacitic deposits are generally confined to areas near the axes of paleochannels (Broxton and Reneau 1996, 55429; Broxton et al. 1995, 50121; Goff 1995, 49682).

2.4.2.5.3 The Tshirege Member

The Tshirege Member is the upper member of the Bandelier Tuff and is the most widely exposed bedrock unit of the Pajarito Plateau (Griggs 1964, 8795; Smith and Bailey 1966, 21584; Bailey et al. 1969, 21498; Smith et al. 1970, 9752). Emplacement of this unit occurred during eruptions of the Valles caldera ~1.2 Ma ago (Izett and Obradovich 1994, 48817; Spell et al. 1996, 55542). The Tshirege Member is a multiple-flow, ash-and-pumice sheet that forms the prominent cliffs in most of canyons on the Pajarito Plateau. It also underlies the canyon floor 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 (61 m) thick. Its thickness exceeds 600 ft (183 m) near the southern edge of the Laboratory at TA-49 but is thinner (often <200 ft [<61 m]) to the north and east (Broxton and Reneau 1996, 55429).

The Tshirege Member differs from the Otowi Member most notably in its generally greater degree of welding compaction. Time breaks between the successive emplacement of 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 (Smith and Bailey 1966, 21584; Crowe et al. 1978, 5720, Broxton et al. 1995, 50121). These variations in physical properties reflect zonal patterns of varying degree of welding and glass crystallization that accompanies welding (Smith 1960, 48819; Smith 1960, 48820). The welding and crystallization variability in the Tshirege Member produce recognizable vertical variations in its properties such as density, porosity, hardness, composition, color, and surface weathering patterns.

The Tshirege Member can be divided into mappable subunits (Figure 2-11) based on a combination of hydrologic properties and lithologic characteristics. There is a certain amount of confusion due to the inconsistent use of subunit names for the Tshirege Member (Baltz et al. 1963, 8402; Weir and Purtymun 1962, 11890; Crowe et al. 1978, 5720; Vaniman and Wohletz 1990, 21589; Vaniman 1991, 9995; Goff 1995, 49682; Broxton et al. 1995, 50121). Figure 2-12 shows correlations of subunit designations applied by various workers. To avoid such confusion, this discussion follows the nomenclature of Broxton and Reneau (1995, 49726), which has been adopted by the ER Project.

Broxton et al. (1995, 50121) provide extensive descriptions of the Tshirege Member cooling units. Because the canyons crossing the Pajarito Plateau cut through the Tshirege Member with increasing depth to the east, all of these units crop out at some point in the floors and walls of most canyons. Also, the degree of welding in each of the cooling units generally decreases from west to east, reflecting the higher emplacement temperatures near the tuff's source in the Valles caldera. Densely welded in the Sierra de los Valles, the Tshirege Member shows a gradual decrease in welding eastward, such that only cooling unit 2 shows much welding in most canyons of the Laboratory. The follow paragraphs describe, in ascending order, subunits of the Tshirege Member.

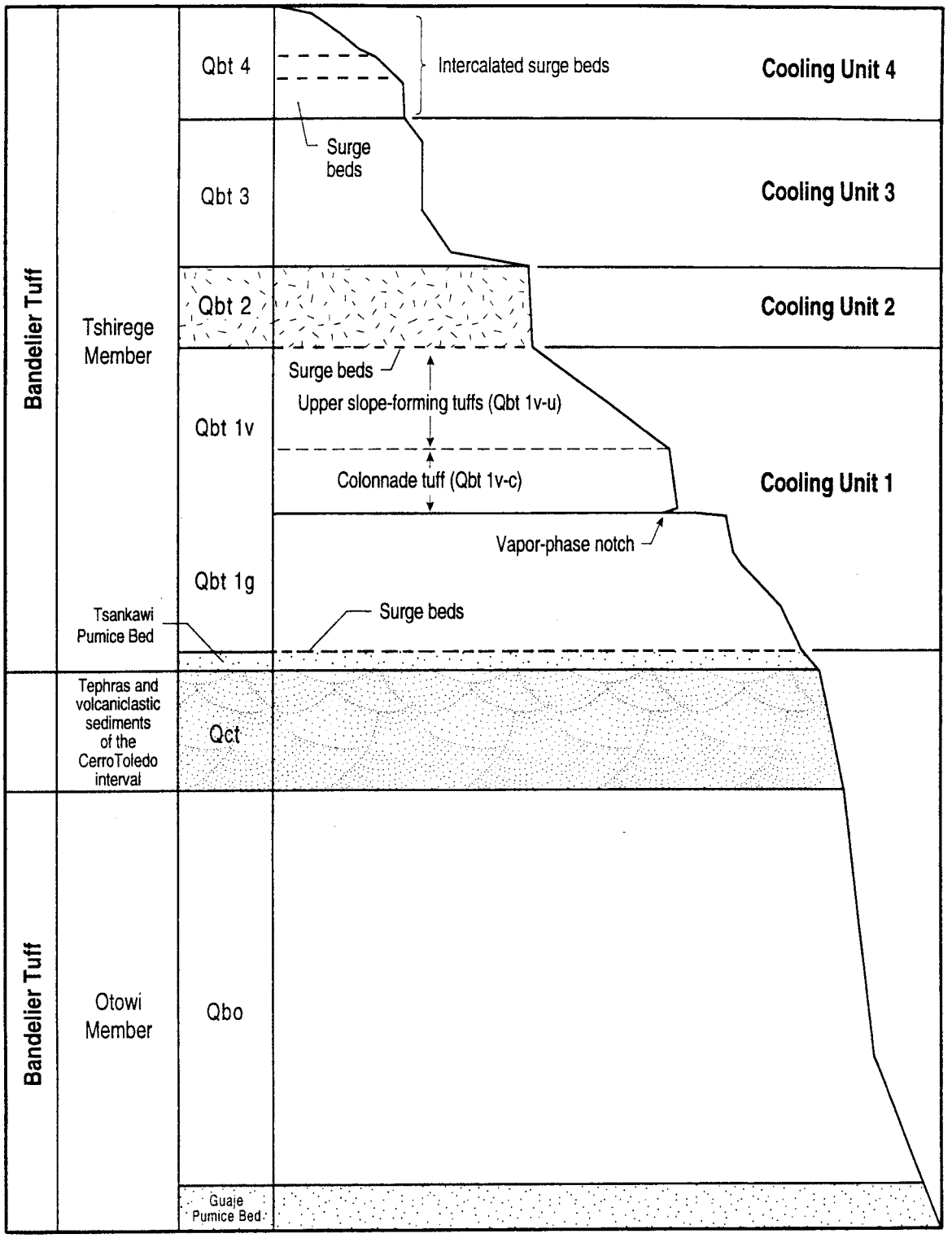
The Tsankawi Pumice Bed forms the base of the Tshirege Member. Where exposed, it is commonly 20 to 30 in. (51 to 76 cm) thick. This pumice-fall deposit contains moderately well sorted pumice lapilli (diameters reaching about 2.5 in. [6.4 cm]) in a crystal-rich matrix. Several thin ash beds are interbedded with the pumice-fall deposits.

Qbt 1g is the lowermost subunit of the thick ignimbrite sheet overlying 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. This unit is poorly indurated but nonetheless forms steep cliffs because of a resistant bench near the top of the unit which forms a harder, protective cap over the softer underlying tuffs. A thin (4 to 10 in. [10 to 25 cm]), pumice-poor, surge deposit commonly occurs at the base of this unit.

Qbt 1v forms alternating cliff-like and sloping outcrops composed of porous, nonwelded, but crystallized tuffs. The "v" stands for vapor-phase crystallization, which together with *in situ* crystallization (devitrification) has converted much of the glass in shards and pumices into microcrystalline aggregates. The base of this unit is a thin, horizontal zone of preferential weathering that marks the abrupt transition from glassy tuffs below to crystallized tuffs above. This feature forms a widespread mappable marker horizon (locally termed the vapor-phase notch) throughout the Pajarito Plateau, which is readily visible in many canyon walls. The lower part of this unit is orange brown, resistant to weathering, and has distinctive columnar (vertical) joints; hence the term colonnade tuff is appropriate for its description. A distinctive white band of alternating cliff- and slope-forming tuffs overlies the colonnade. The tuffs of Qbt 1v are commonly nonwelded (pumices and shards retain their initial equant shapes) 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 surge beds commonly mark its base in the eastern part of the Laboratory, and it displays the greatest degree of welding in the Tshirege Member. It is typically nonporous and has low permeability relative to the other units of the Tshirege Member. Vapor-phase crystallization of flattened shards and pumices is extensive in this unit.

Qbt 3 is a nonwelded to partially welded, vapor-phase altered tuff, which forms many of the upper cliffs in the mid-to-lower reaches of canyons on the Pajarito Plateau. Its base consists of a purple gray, unconsolidated, porous, and crystal-rich nonwelded tuff that underlies a broad, gently sloping bench developed on top of Qbt 2. This basal, nonwelded portion forms relatively soft outcrops that weather into low, rounded mounds with a white color, which contrast with the cliffs of partially welded tuff in the middle and upper portions of Qbt 3.



Source: Broxton and Reneau 1995, 49726

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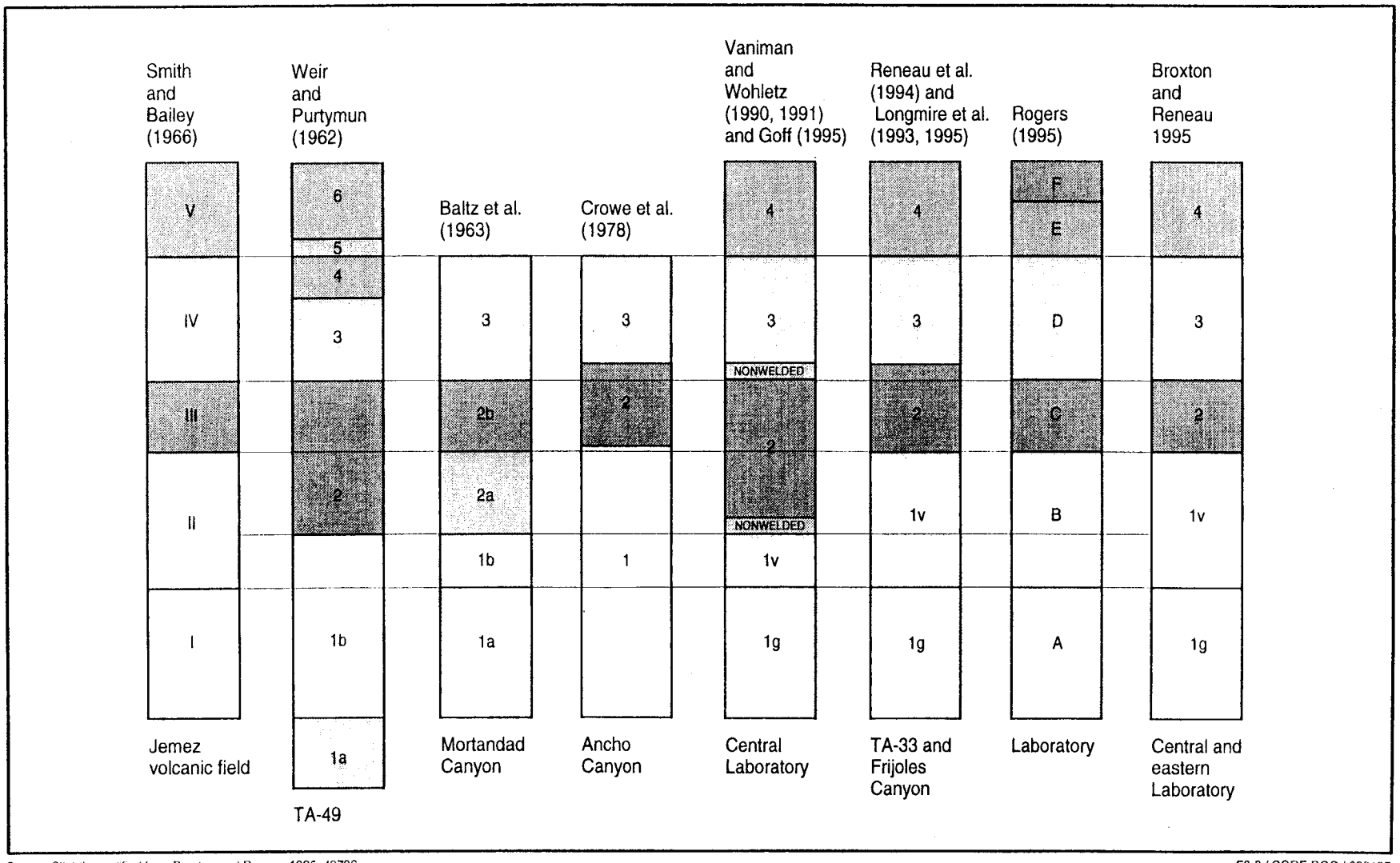
Figure 2-11. Illustration of the Bandelier Tuff weathering profile and unit subdivisions.



Source: Slightly modified from Broxton and Reneau 1995, 49726

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Figure 2-12. Correlation of rock unit names applied to the Tshirege Member of the Bandelier Tuff.

Qbt 4 is a partially welded to densely welded ignimbrite characterized by small, sparse pumices and numerous intercalated surge deposits. This unit crops out on the mesa tops in the western part of the Laboratory, but it is missing from mesa tops over the mid-to-eastern Pajarito Plateau. It forms the bedrock unit in the canyon floors along the western part of the Laboratory near the Sierra de los Valles. Devitrification and vapor-phase alteration are typical in this unit, but thin zones of vitric ignimbrite occur within the upper part of the unit near MDA P.

2.4.2.6 Post-Bandelier Units

Stratigraphically overlying the Bandelier Tuff are discontinuous Quaternary alluvial units that occur as thin deposits (typically less than 15 ft thick) on mesa tops and as deposits in canyons. Alluvial fans consisting mostly of dacite debris are being shed over the Bandelier Tuff at the western boundary of the Laboratory. Well-sorted to poorly sorted sandy and gravelly alluvium occurs in the major drainages of the Pajarito Plateau, ranging up to at least 70 ft thick in some drill holes (Baltz et al. 1963, 8402). Additional, older alluvium occurs on stream terraces on the sides of the canyons, which can be buried by colluvial deposits from the canyon walls. The distribution of alluvial deposits on the mesas has not been mapped, but these deposits are most widespread on the western part of the Pajarito Plateau. Post-Bandelier alluvial units represent a range of ages from 1.1 million years ago to the present. Generally, alluvial units on the surface of the mesas are probably oldest, becoming inactive as drainages were incised into the plateau. Those units lowest in the drainages grade into the active alluvium along canyon bottoms.

The alluvial sediments in the canyon bottoms probably record a complex history of erosion and deposition, in part related to regional climatic changes. In Cabra Canyon, immediately north of Los Alamos, several cycles of erosion and deposition of sediment have occurred over the last 6,000 years, during which most of the previously stored sediment was eroded (Gardner et al. 1990, 48813). Similar cycles of erosion and deposition have been documented in many parts of the southwestern United States, and the older alluvial units in the vicinity of Los Alamos may also record the effects of regional climatic changes (Dethier et al. 1988, 57003).

The mesas of the Pajarito Plateau are also covered in part by deposits of the El Cajete pumice, erupted from El Cajete crater in the Jemez Mountains. Deposits of pumice on the mesas have been mapped by Rogers (1995, 54419). They are generally most common in the southern part of the Laboratory, and the axis of the volcanic dispersal plume is south of Los Alamos County. Available data suggest that the El Cajete pumice is 50,000 to 60,000 years old (Toyoda et al. 1995, 57001; Reneau et al. 1996, 57002).

Pre-El Cajeta, post-Bandelier pumice falls and reworked tuffs have been recently recognized at a number of sites on the Pajarito Plateau. These pumice beds are believed to be associated with eruptions of the Deer Creek and Valle Grande members of the Valles Rhyolite of Bailey et al. (1969, 21498) and Smith et al. (1970, 9752).

2.4.3 Soils

Soils on the Pajarito Plateau were initially mapped and described by Nyhan et al. (1978, 5702. The Nyhan study included only Laboratory-controlled lands and certain United States (US) Forest Service lands within Los Alamos County.

The soils were formed in a semiarid climate and were derived from chemical, biological, and physical weathering of local bedrock units, fallout pumice deposits, eolian deposits, and sediments derived from these geological materials (Nyhan et al. 1978, 5702). A large variety of soils have developed on the Pajarito Plateau as the result of interactions of the underlying bedrock, slope, and climate. The

mineral components of the soils are in large part derived from the Bandelier Tuff, but dacitic lavas of the Tschicoma Formation, basalts of the Cerros del Rio volcanic field, and sedimentary rocks of the Puye Formation are locally important, and additional material may be transported to the canyons from the mesa tops by wind. Alluvium derived from the Pajarito Plateau and from the east side of the Jemez Mountains contributes to soils in the canyons and also to those on some of the mesa tops.

The soils on the slopes between the mesa tops and canyon floors have been mapped as mostly steep rock outcrops consisting of approximately 90% bedrock outcrop and patches of shallow, undeveloped colluvial soils. South-facing canyon walls are steep and usually have little or no soil material or vegetation; in contrast, the north-facing walls generally have areas of very shallow, dark-colored soils and are more heavily vegetated. The canyon floors generally contain poorly developed, deep, well-drained soils (Nyhan et al. 1978, 5702).

2.4.4 Geological Structure

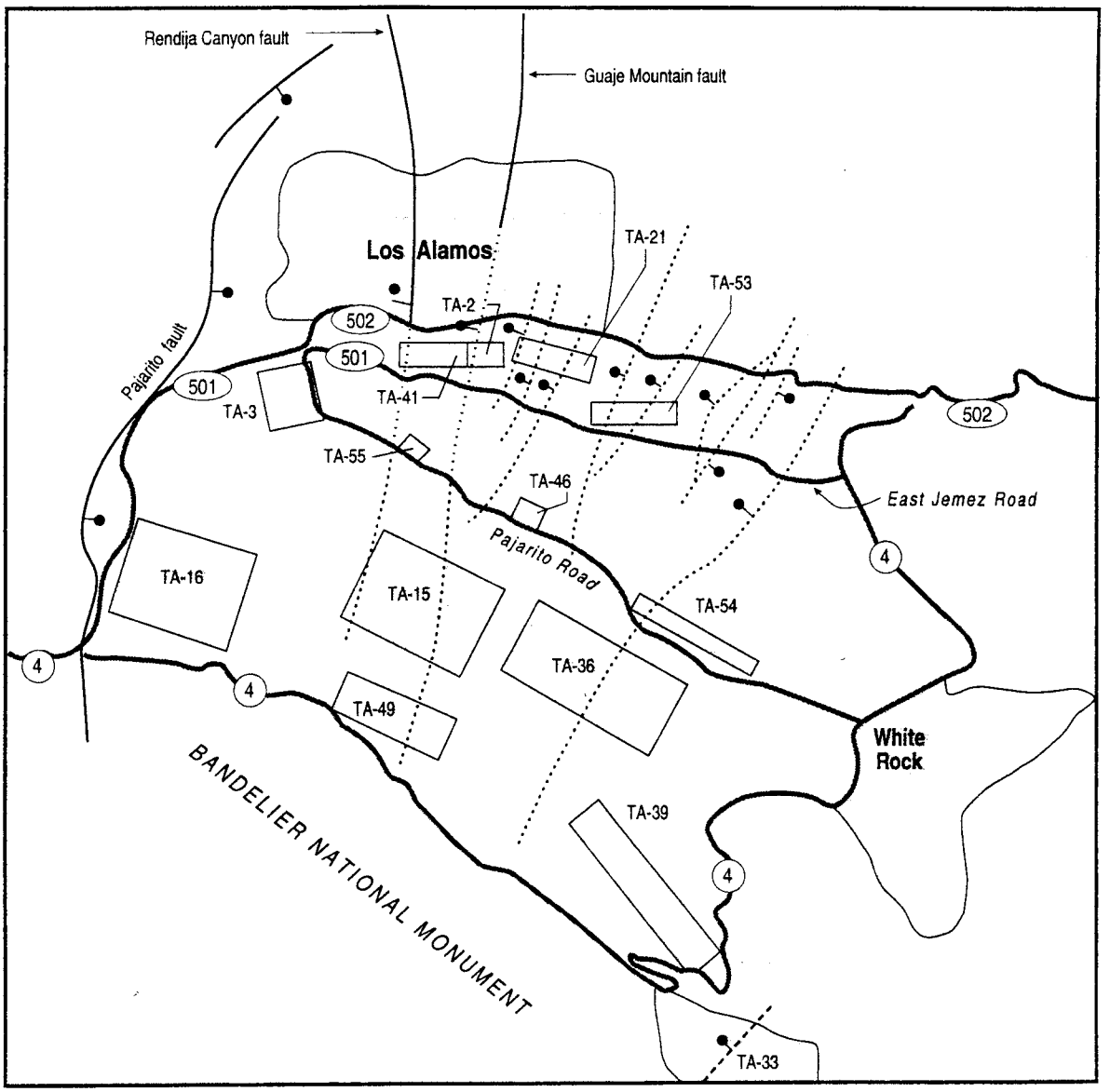
The Pajarito Plateau is on the western margin of the Española basin of the Rio Grande rift, a tectonically active region. The Pajarito fault system, the major border fault on the west side of the basin, delineates the boundary between the eastern Sierra de Los Valles and the western part of the plateau. This fault system has experienced Holocene movement and historic seismicity (Gardner and House 1987, 6682; Gardner et al. 1990, 48813). Characterized by northerly trending normal faults that intertwine along their traces, the Pajarito fault system shows dominantly down-to-the-east movement and produces a series of prominent fault scarps west of the Laboratory (Figure 2-13). The vertical throw on this fault system is over several hundred feet south and west of the Laboratory but decreases northward of Los Alamos Canyon where the fault system is less prominent.

In addition to the main traces of the Pajarito fault system, other faults cut the Pajarito Plateau. The Rendija Canyon fault is a normal fault trending north-south in the west-central part of the plateau; it crosses Pueblo Canyon near its confluence with Acid Canyon and Los Alamos Canyon near TA-41 but does not have clear surface expression south of Sandia Canyon. The Guaje Mountain fault parallels the Rendija Canyon fault and is projected to cross Los Alamos Canyon near TA-2 although there is no clear offset of the Tshirege Member south of North Mesa. North of the Laboratory both of these faults have down-to-the-west movement and zones of gouge and breccia up to several meters wide, and produce visible offset of stratigraphic horizons and recognizable scarps. However, these features are not apparent within most of the Laboratory. Vaniman and Wohletz (1990, 21589) and Wohletz (1995, 54404) project these faults south of Los Alamos Canyon, based on Tshirege Member rock fracture density variations, orientations, and size. Such methods of fault identification in the Tshirege Member may be valuable means by which to help identify other tectonic zones in canyons that could be potential pathways for water infiltration.

Dransfield and Gardner (1985, 6612) integrated a variety of data to produce structure contour maps and paleogeologic maps of the pre-Bandelier-Tuff surface beneath the Pajarito Plateau. Their maps reveal down-to-the-west normal faults cutting subsurface rock units. These buried faults do not obviously displace the overlying Bandelier Tuff south of Los Alamos Canyon, indicating that most of these fault movements predate deposition of the Bandelier Tuff. More recent structure contour maps, isopach maps, and paleogeologic maps of the Pajarito Plateau are presented in Davis et al. (1996, 55446) and Broxton and Reneau (1996, 55429).

2.4.5 Seismicity and Volcanism

The Laboratory lies within a region that possesses a long and rich history of volcanic and tectonic activity dating from the distant past into the Late Pleistocene and present, respectively. Volcanism began in the Jemez Mountains volcanic field more than 13 million years ago and continued without



Sources: Dransfield and Gardner 1985, 6612; Gardner and House 1987, 6682

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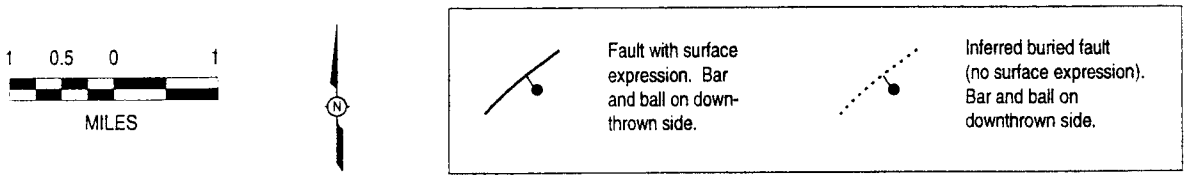


Figure 2-13. Locations of known and inferred faults at the Laboratory and in the surrounding area.

significant hiatus up through about 50,000 years ago (Gardner et al. 1986, 21527; Toyoda et al. 1995, 57001; Reneau et al 1996, 57002). Reports of questionable reliability describe what were apparently phreatic explosions and possible associated earthquakes within the volcanic field around 100 years ago (Santa Fe *Daily New Mexican* 1882, 57005). Regardless, given the long history of spatially focused, geologically continuous volcanic activity, future volcanism can be expected. Although volcanic activity directly affecting the Laboratory may prove unlikely, sufficient data to quantify the probabilities and nature of future volcanism are lacking.

Direct effects of future seismicity at the Laboratory are likely, although quantification of probabilities is not possible at present. Numerous small earthquakes are recorded in the Los Alamos area and northern New Mexico each year (Sanford et al. 1979, 11858; Cash and Wolff 1984, 57041; Gardner and House 1987, 6682). Since establishment of the Laboratory, several earthquakes of Richter magnitude 3 to 4 have shaken Los Alamos (Gardner and House 1987, 6682). Recent work has shown that three fault segments in Los Alamos County are seismically active and that they are capable of generating large earthquakes of about 7 or more on the Richter scale (Gardner and House 1987, 6682; House and Cash 1988, 6878; Gardner et al. 1990, 48813; Gardner and House 1994, 57006). Unknown at this time are how frequently these large earthquakes occur and what their potential is for generating surface rupture and mass wasting (occurrences such as rockfalls and landslides, which are not caused primarily by the movement of water) within the confines of the Laboratory.

2.4.6 Geomorphic Processes

Significant geomorphic processes active on the Pajarito Plateau include (1) erosion of mesa top soils by runoff, (2) retreat of canyon walls by rockfall and landsliding, (3) colluvial transport on sloping portions of canyon walls, and (4) erosion and deposition of sediments by streams in the canyon bottoms. Few data exist on the rates of erosion and landscape change caused by these different processes on the Pajarito Plateau. Estimates of long-term vertical erosion rates on mesa tops have been made based on stripping of overlying units (Purtymun and Kennedy 1971, 4798), but these estimates may be of limited value because the resistant, cliff-forming units may be eroded primarily by lateral cliff retreat rather than by vertical erosion. Erosion rates vary considerably on the mesa tops; the highest rates occur in and near drainage channels and in areas of locally steeper slope gradient, and the lowest rates occur on relatively gently sloping portions of the mesa tops removed from channels. Areas where runoff is concentrated by roads and other development are especially prone to accelerated erosion.

The rates and processes of erosion may differ significantly between the north and south slopes of canyons. Given current vegetation and climate, the more extensive exposures of bedrock on south-facing sides and greater soil cover on north-facing sides suggest that erosion rates of fine-grained material that can be transported by runoff are higher on the drier, less-vegetated, south-facing sides of canyons, although this material is largely retained on the north-facing slopes. No studies have been conducted to quantify the rates and processes of erosion on canyon sides. However, the Laboratory is systematically evaluating the erosion potential in areas associated with potential release sites in order to identify the need for and prioritize stabilization efforts to minimize or eliminate potential contaminant transport.

The recent alluvial history of the canyons on the Pajarito Plateau is complex—some sediments within the stream channels are mobilized during every flood and others adjacent to or deeper beneath the channels are progressively buried and remain stable for long periods (Reneau and McDonald 1996, 55538; Reneau et al. 1996, 55539). For example, a 13-ft-deep (4.0-m-deep) trench excavated in Cabra Canyon, a tributary to Rendija Canyon immediately north of the Los Alamos townsite, revealed cycles of alternating sediment deposition and channel incision over the last 6,000 years (Gardner et al. 1990, 48813). In Cabra Canyon there has been a net accumulation of sediment over this period, although sediment deposition was interrupted by at least three episodes when channels were incised at least 3 to 6 ft (0.9 to 1.8 m), and the previously stored sediments were transported downstream.

In DP Canyon, a tributary to Los Alamos Canyon on the north side of TA-21, up to 6 ft (1.8 m) of sediment has been locally deposited since 1943. These young sediments in DP Canyon have been partially excavated by renewed channel incision (Reneau 1995, 50143), a process also observed in other canyons. In many canyons on the Pajarito Plateau the burial of the base of young trees indicates that a foot or more of historic (post-1942) sediment deposition on floodplains or low terraces (banks) is common. Erosion of sedimentary deposits and associated contaminants is probably caused by both vertical scouring and lateral cutting of streams during large floods. Plateau-wide summaries and syntheses of canyon-floor alluvial history are presented in Reneau and McDonald (1996, 55538) and Reneau et al. (1996, 55539).

Mass wasting processes are potentially important because they can move large volumes of material from the canyon walls to the canyon floors (e.g. Reneau, 1995, 50143; Reneau et al. 1995, 54405; and Reneau and MacDonald, 1996, 55538). In part, they create a geologic hazard in the canyon floors. For example, records for the last four decades indicate that fences in Los Alamos Canyon at TA-2 have been impacted by one boulder weighing 300 pounds or more every two years on average (McLin 1993, 50127). Burial of alluvium by rockfall debris would tend to reduce the ability of the streams to erode and transport the sediment and locally increase the residence times of contaminated sediment in the canyon floors.

2.5 Hydrology

2.5.1 General Surface Water Conditions

The Rio Grande is the primary river in north-central New Mexico. All surface water drainage and groundwater discharge from the plateau ultimately arrives at the Rio Grande. The Rio Grande at Otowi, just east of Los Alamos, has a drainage area of 14,300 mi^2 in southern Colorado and northern New Mexico. The discharge for the period of record has ranged from a minimum of 60 cubic feet per second (cfs) in 1902 to 24,400 cfs in 1920. The river transports about 1 million tons of suspended sediments past Otowi annually (Graf 1993, 23251).

Essentially all Rio Grande flow downstream of the Laboratory passes through Cochiti Reservoir, which began filling in 1976. It is designed to provide flood control, sediment retention, recreation, and fishery development. Flood flows are temporarily stored and released at safe rates. The dam is expected to trap at least 90% of the sediments carried by the Rio Grande (Graf 1993, 23251).

Most Los Alamos surface water occurs as ephemeral, intermittent, or interrupted (alternation of perennial, ephemeral, and intermittent stretches) streams in canyons cut into the Pajarito Plateau. (Ephemeral streams flow in response to precipitation; intermittent streams flow in response to the availability of snowmelt or groundwater discharge; perennial streams flow at all times except during extreme drought.) Springs on the flanks of the Jemez Mountains, west of the Laboratory's western boundary, supply flow to the upper reaches of Cañon de Valle and in Guaje, Los Alamos, Pajarito, and Water Canyons (Purtymun 1975, 11787; Stoker 1993, 56021). These springs discharge water perched in the Bandelier Tuff and Tschicoma Formation at rates from 2 to 135 gal./min (Abeele et al. 1981, 6273). The volume of flow from the springs maintains natural perennial reaches of varying lengths in each of the canyons. Figure 2-14 shows the locations of perennial reaches in the Los Alamos area.

Perennial flow in Guaje Canyon is north of the Laboratory boundary. The perennial reach extends from springs upstream of Guaje reservoir to some distance downstream of the reservoir. The perennial reach in Los Alamos Canyon is above the Los Alamos reservoir and extends to within a few hundred yards of the reservoir. Springs in the upper reaches of Pajarito Canyon support flow in a perennial reach followed by an intermittent reach to within about 0.5 mi of the Laboratory's western boundary. Flow in Water Canyon and Cañon de Valle does not reach the western boundary (Stoker 1993, 56021) (see Figure 2-14).

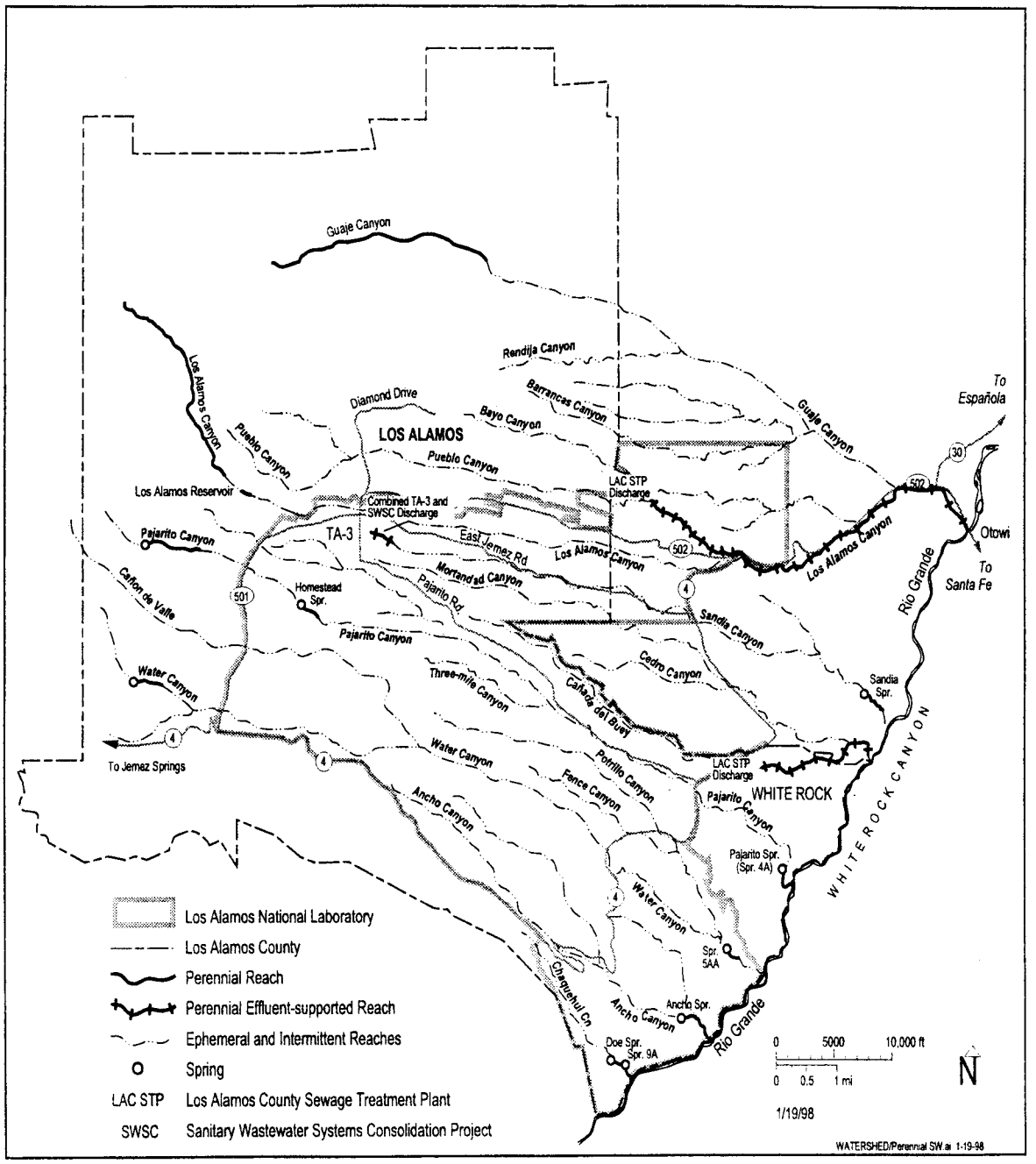


Figure 2-14. Surface water occurrences at Los Alamos (perennial and effluent-supported reaches from Stoker 1993, 56021).

Springs on DOE property near the western Laboratory boundary occur in Pajarito Canyon and Cañon de Valle. Perennial flow has been noted associated with Homestead Spring in Pajarito Canyon. The length of the reach extends for several hundred yards (Stoker 1993, 56021). Additional springs have been located within the Laboratory boundary by Dale et al. (1996, 57014) and others. Further investigation and flow documentation is needed to validate their location and periodicity of flow.

Springs near the Rio Grande in Sandia, Pajarito, Water, Ancho, and Chaquehui Canyons are considered discharge points of the regional aquifer because of similar water chemistry. Flow from these springs maintains natural perennial reaches of varying lengths. Three of these reaches, in Water, Ancho and Chaquehui Canyons, are within the eastern Laboratory boundary. Flows from Ancho Spring in Ancho Canyon and Pajarito Spring (also known as Spring 4A) in Pajarito Canyon are known to reach the Rio Grande. Flow from Spring 9A in Chaquehui Canyon extends to a point where it meets perennial flow from Spring 9. Combined flow from Springs 9 and 9A reaches the Rio Grande (Stoker 1993, 56021). Flow from Sandia Spring in Sandia Canyon extends about 300 ft and does not reach the Rio Grande. Flow from Spring 5AA in Water Canyon is very short and does not reach the Rio Grande.

In addition to these limited natural perennial reaches, three effluent-supported reaches also exist within the watershed. Laboratory and Los Alamos County effluent discharges provide surface water flow to Pueblo and Sandia Canyons, and Cañada del Buey. The Los Alamos County Sewage Treatment Plant discharges effluent into Pueblo canyon. Effluent-supported flow reaches Los Alamos Canyon and is sampled at State Road 4 as part of the environmental surveillance program. By 1993, flow extended to the Rio Grande (Stoker 1993, 56021). Effluent discharged into Cañada del Buey 2 mi up from the confluence with Mortandad Canyon from the Los Alamos County-operated sanitary wastewater treatment plant in White Rock regularly extends to the Rio Grande (Stoker 1993, 56021). Effluent-supported flow in Sandia Canyon results from the discharge of Laboratory-treated sanitary sewage. Flow typically extends 2.5 to 3 mi (Stoker 1993, 56021).

Eleven drainage areas, with a total area of 82 mi^2, pass through the Laboratory's eastern boundary. Runoff from heavy thunderstorms and heavy snowmelt reaches the Rio Grande several times a year in some drainages. Los Alamos, Pajarito, and Water Canyons have drainage areas at the east boundary of greater than 10 mi^2. Pueblo Canyon has approximately 8 mi^2; the rest (Barrancas [a tributary to Guaje Canyon], Bayo, Sandia, Mortandad, Cañada del Buey, Ancho, and Chaquehui Canyons) have less than 6 mi^2 each. Theoretical maximum flood peaks range from 24 cfs for a 2-yr frequency to 686 cfs for a 50-yr frequency (McLin 1992, 12014). The overall flooding risk to community and Laboratory buildings is low because nearly all the structures are located on the mesa tops, from which runoff drains rapidly into the adjacent canyons.

Contaminants enter the surface water drainages by surface runoff, by liquid discharges, and occasionally by air deposition (Becker et al. 1985, 6610; Becker 1986, 6626). Runoff-derived contaminants are largely bound to sediments; their rate of downstream travel is governed by the scouring and carrying power of subsequent runoff events (Lane et al. 1985, 6604). Given sufficient time, these sediments eventually will be moved across the Laboratory boundary.

Several drainages have received liquid industrial or sanitary effluents discharged from the Laboratory. The effluent discharges determine the flow and water quality characteristics in drainages that contain little natural water. With travel downstream, most of the effluent-derived metals and radionuclides become sediment-bound and remain near the surface of the stream channel; other contaminants, such as organic solvents and/or tritium, are lost by evaporation or move downward into the alluvium. Detailed field investigations in Mortandad Canyon, for example, demonstrate that generally more than 99% of the total inventory of transuranic radioactivity discharged from the treatment plant effluents is associated with sediments in or immediately adjacent to the stream channel (Stoker et al. 1991, 7530).

In canyons that have received treated, low-level radioactive effluents (Acid-Pueblo, DP-Los Alamos, and Mortandad Canyons) concentrations of radioactivity in the alluvium are generally highest near the treated effluent outfall and decrease downstream in the canyon as the sediments and radionuclides are transported and dispersed by other treated industrial effluents, sanitary effluents, and surface runoff.

A regional plutonium analysis for the Rio Grande upstream of Elephant Butte Reservoir shows that fallout contributes about 90% of the total plutonium moving through the drainage system in any given year (Graf 1993, 23251). The remaining 10% is from releases at Los Alamos. The contribution to the plutonium budget from Los Alamos is associated with relatively coarse sediment, which often behaves as bedload in the Rio Grande (Graf 1993, 23251).

A study of transport of plutonium by snowmelt runoff published in 1990 (Purtymun et al. 1990, 6992) includes the finding that most plutonium moved by runoff in Los Alamos and Pueblo Canyons that reached the Rio Grande is transported with sediments—about 57% with suspended sediments and 40% with bed sediments. A total of about 600 µCi of plutonium was carried to the Rio Grande by 5 snowmelt runoff events studied during the years 1975 to 1986.

Environmental monitoring for chemical and radiochemical quality in surface water began with USGS investigations (Purtymun 1964, 11822; 1975, 11787; Purtymun and Kunkler 1967, 11782; Purtymun 1967, 8987) and has been continued by the Laboratory (ESG until 1971; Environmental Protection Group 1994, 35363).

2.5.2 General Groundwater Conditions

Groundwater occurs in three modes in the Los Alamos Area: (1) water in shallow alluvium in some of the larger canyons, (2) intermediate perched groundwater (a perched groundwater body lies above a less permeable layer and is separated from the underlying aquifer by an unsaturated zone), and (3) the main aquifer of the Los Alamos area.

Numerous wells have been installed over the past several decades at the Laboratory and in the surrounding area to investigate the presence of groundwater in these three zones and to monitor groundwater quality. The locations of existing wells are shown in Figure 2-15.

2.5.2.1 Perched Groundwater in Alluvium

Intermittent and ephemeral streamflows in the canyons of the Pajarito Plateau have deposited alluvium that ranges in thickness to as much as 100 ft. The alluvium in canyons that head on the Jemez Mountains is generally composed of sands, gravels, pebbles, cobbles, and boulders derived from the Tschicoma Formation and Bandelier Tuff on the flank of the mountains. The alluvium in canyons that head on the plateau is comparatively more finely grained, consisting of clays, silts, sands, and gravels derived from the Bandelier Tuff. Saturated hydraulic conductivity of the alluvium typically ranges from 10^{-2} cm/s for a sand to 10^{-4} cm/s for a silty sand (Abeele et al. 1981, 6273).

In contrast to the underlying volcanic tuff and sediments, the alluvium is quite permeable. Ephemeral runoff in some canyons infiltrates the alluvium until downward movement is impeded by the less permeable tuff and sediments, which results in a buildup of a shallow alluvial groundwater body. Depletion by evapotranspiration and movement into the underlying rocks limit the horizontal and vertical extent of the alluvial water (Purtymun et al. 1977, 11846). The limited saturated thickness and extent of the alluvial groundwater preclude its use as a viable source of municipal and industrial supply

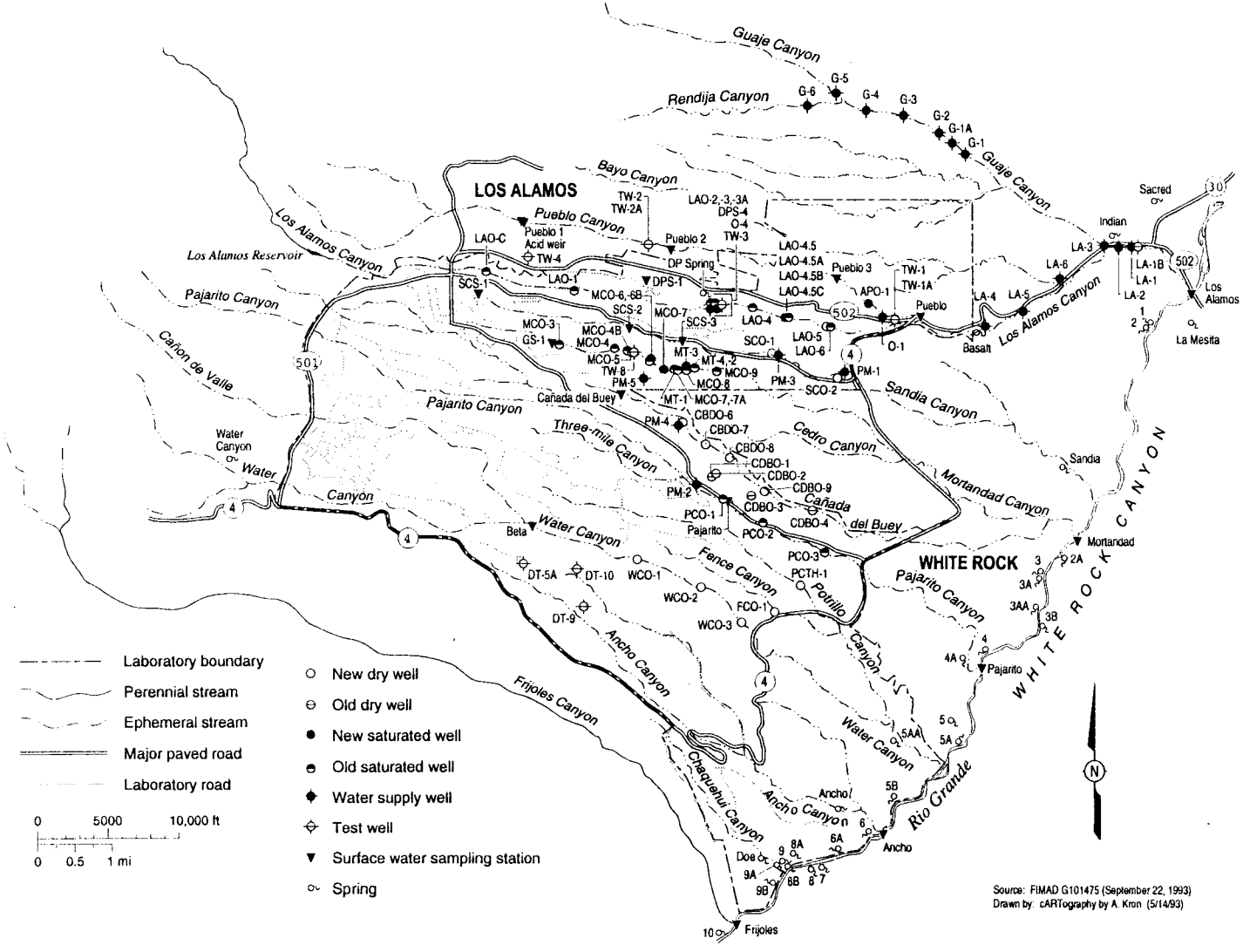


Figure 2-15. Well locations in Los Alamos County and in adjacent locales.

to the community and the Laboratory. Lateral flow of the alluvial perched groundwaters is in an easterly, downcanyon direction. Tracer studies in Mortandad Canyon have shown that the velocity of water ranges from about 60 ft/day in the upper reach to about 7 ft/day in the lower reach of the canyon (Purtymun 1974, 5476).

The water quality in the alluvial perched groundwaters is variable, depending on the location and history of effluent discharges. In Mortandad Canyon, for example, plutonium concentrations fluctuate up and down in response to variations in treatment plant effluent and storm runoff water, which cause some dilution of the shallow alluvial perched groundwater. Tritium concentrations have fluctuated almost in direct response to the average annual concentration of tritium in the TA-50 effluent, with a lag time of about 1 year (Environmental Protection Group 1992, 7004).

Purtymun (1975, 11787; 1973, 4971) has written reviews of alluvial perched groundwaters by drainage area. The results of an extensive monitoring study of the alluvial perched groundwater in Mortandad Canyon are presented by Abrahams et al. (1962, 8140), Baltz et al. (1963, 8402), Purtymun (1973, 4971), Purtymun (1974, 5476), Purtymun et al. (1977, 11846), Purtymun et al. (1983, 6407), and Stoker et al. (1991, 7530).

2.5.2.2 Intermediate Perched Groundwater

Localized bodies of perched groundwater occur beneath several canyons in the eastern portion of the Laboratory, along the eastern flanks of the Jemez Mountains west of the Laboratory, and beneath the mesas and canyons at S-Site (TA-16), located in the southwestern part of the Laboratory near the Jemez Mountains. Perched groundwater may exist beneath other canyons in the south and central portions of the Laboratory, which have not yet been investigated by drilling. These perched groundwater bodies are found in areas where a sufficient water source is present to maintain saturation within the deeper units. Thus perched groundwater beneath canyon bottoms may be maintained by infiltration from the overlying stream, and perched groundwater within the Bandelier Tuff along the Jemez Mountains may be maintained by seepage from streams exiting the mountains. The presence of these perched groundwater bodies is controlled by the occurrence of a perching layer, whose lower permeability causes water to pond in a more permeable horizon above it. Perching layers are found within the interlayered Cerros del Rio Basalt flows and the sediments of the Puye Formation, for example, where they underlie the more permeable Guaje Pumice Bed in Los Alamos Canyon. The presence of perched water at S Site and on the flanks of the Jemez Mountains is evidently controlled by contrasts in lithologic properties within the Bandelier Tuff, which might exist at boundaries between flow units.

Perched water bodies occur in the conglomerates and basalts beneath the alluvium in the mid- and lower reaches of Pueblo and Los Alamos canyons and in the lower reach of Sandia Canyon. Depth to perched water ranges from about 90 ft in the midreach of Pueblo Canyon to about 450 ft in lower Sandia Canyon. The vertical and lateral extent of the perched groundwaters, the nature and extent of perching units, and the potential for migration of perched water to the main aquifer is not yet fully understood.

Patterns of chemical quality and water level measurements indicate that the intermediate perched groundwater in Pueblo Canyon is hydrologically connected to the stream in Pueblo Canyon (Abrahams and Purtymun 1966, 8141). Water from this perched groundwater discharges below the base of the basalt at Basalt Spring, which is located in lower Los Alamos Canyon on San Ildefonso Pueblo land. The rate of movement of the perched groundwater in this vicinity has been estimated at about 60 ft/day or about 6 mo from recharge to discharge (Purtymun 1975, 11787).

It is unknown whether the intermediate perched water systems are hydraulically interconnected. Available data, however, suggest that most of the systems are of limited extent: testing of the perched

system in mid-Pueblo Canyon depleted the perched groundwater after about an hour's pumping at 2 to 3 gal./min (Weir et al. 1963, 11892). Perched water was encountered in mid-Los Alamos Canyon during the drilling of the Otowi 4 supply well (Stoker et al. 1992, 12017), but it was not reported in an adjacent well (Test Well 3) located 300 ft to the east. (However, Test Well 3 was drilled with a cable tool rig in 1947, and the driller may not have noticed the perched groundwater if it was present.)

Measurements of tritium in perched groundwater at intermediate depths demonstrate that recharge to those depths has occurred during the last several decades. The levels of tritium in those locations are high enough to be attributed to recharge of surface water contaminated by effluent or other releases from Laboratory operations.

These observations have been made at four locations in Pueblo and Los Alamos Canyons. For several years, tritium has been observed in Test Well 2A in Pueblo Canyon at levels between 2,000 and 3,000 pCi/L. Starting in 1991, low-detection-limit tritium measurements have consistently revealed tritium at levels of about 150 pCi/L in samples from Test Well 1A, located in lower Pueblo Canyon near its confluence with Los Alamos Canyon, and in Basalt Spring, located in Los Alamos Canyon just downstream from its confluence with Pueblo Canyon. The measurements at these three locations are consistent with previous understanding. The intermediate perched groundwater has long been known to be affected by effluents discharged into Pueblo Canyon, starting with measurements made by the USGS in the 1950s and 1960s (Abrahams et al. 1961, 8134).

The most recent observation of tritium in intermediate-depth groundwater was made in Well LADP-3, completed in 1993 by the Environmental Restoration (ER) Project in the middle reach of Los Alamos Canyon, about 1 mi down gradient of TA-2, the Omega Reactor (Broxton et al. 1995, 50119). Well LADP-3 encountered perched water at a depth of about 320 to 330 ft, above the contact between the Otowi Member and the Puye Formation. Samples of water from that well contained about 6,000 pCi/L tritium, but concentrations had decreased to <1,000 pCi/L by 1996.

Some perched water occurs in volcanics on the flanks of the Jemez Mountains offsite to the west of the Laboratory. This water discharges in several springs (including American and Armistead Springs) and provides flow for the gallery in Water Canyon. The gallery contributed to the Los Alamos water supply for 41 years, producing 23 to 96 million gal. annually.

Several springs have been noted in the area of S-Site by the New Mexico Environment Department (NMED) DOE Oversight Bureau (unpublished data). Some of these springs are located within canyon bottom alluvium where groundwater return flow to the dry stream channel occurs and do not represent springs in the usual sense. In other cases flow issues from canyon walls well above the alluvium. The origin of water supplying these springs is uncertain at present. In some cases the flow may have its source from nearby outfalls. The ER Project and NMED DOE Oversight Bureau (unpublished data) have discovered high-explosives residuals in samples from some of these springs.

2.5.2.3 Regional Aquifer

The regional aquifer of the Los Alamos area is the only aquifer capable of large-scale municipal water supply (Purtymun 1984, 6513). In 1989, water for the Laboratory, the communities of Los Alamos and White Rock, and Bandelier National Monument was supplied from 11 deep wells in 3 well fields. The wells are located on the Pajarito Plateau and in Los Alamos and Guaje Canyons east of the plateau. Municipal and industrial water supply pumpage during 1992 was 1.43 billion gal. Yields from individual wells ranged from about 175 to 1,400 gpm (Stoker et al. 1992, 12017). Purtymun (1984, 6513) summarized the hydraulic characteristics of the aquifer as determined during aquifer tests and during periods of production of supply wells and test holes.

The surface of the regional aquifer rises westward from the Rio Grande within the Santa Fe Group into the lower part of the Puye Formation beneath the central and western part of the Pajarito Plateau

(Figure 2-16). The depths to groundwater below the mesa tops range from about 1,200 ft along the western margin of the plateau to about 600 ft at the eastern margin. The regional aquifer is separated from the alluvial groundwater and intermediate perched zone groundwater by 350 to 620 ft of tuff, basalt, and sediments (Environmental Protection Group 1993, 23249). The regional aquifer exhibits artesian conditions in the eastern part along the Rio Grande (Purtymun 1984, 6513). Continuously recorded water level measurements collected in test wells since the fall of 1992 indicate that, throughout the plateau, the regional aquifer responds to barometric and earth tide effects in the manner typical of confined aquifers.

The hydraulic gradient of the regional aquifer averages about 60 to 80 ft/mi within the Puye Formation but increases to 80 to 100 ft/mi along the eastern edge of the plateau as the groundwater enters the less permeable sediments of the Santa Fe Group. The rate of movement of groundwater in the upper section of the aquifer varies depending on the materials in the aquifer. Aquifer tests indicate that the rate of movement ranges from 20 ft/yr in the Tesuque Formation to 345 ft/yr in the more permeable Puye Formation (Purtymun 1984, 6513). The highest yielding water supply wells are located within the late Miocene trough described by Purtymun (1984, 6513).

The exact source of recharge to the regional aquifer is unknown. Groundwater elevation measurements suggest that groundwater flows from the Jemez Mountains towards the Rio Grande to the east and east-southeast where a portion discharges into the river through seeps and springs (Purtymun 1984, 6513). Springs fed by the regional aquifer discharge an estimated 4,300 to 5,000 acre-ft of water annually into White Rock Canyon along an 11-mi reach between Otowi Bridge at State Road 502 and the mouth of Rito de Frijoles (Cushman 1965, 8584). Major recharge of the regional aquifer from the west is inferred because the piezometric surface slopes downward to the east (Figure 2-16). Cushman (1965, 8584) suggested three sources of recharge: infiltration of runoff in canyons; underflow from the Valles caldera through the Tschicoma Formation; and infiltration on mesas. However, a large quantity of hydrologic, structural, and geochemical data indicate that the caldera may not serve as an appreciable source of recharge to the regional aquifer (Conover et al. 1963, 57044; Griggs 1964, 8795, Goff 1991, 57039). Furthermore, natural recharge through undisturbed Bandelier Tuff on the mesa tops is believed to be insignificant (Purtymun and Kennedy 1971, 4798; Kearl et al. 1986, 8414), and few or no data exist to support an evaluation of canyon runoff as a recharge source.

To estimate recharge rates beneath the Pajarito Plateau, Rogers and Gallaher (1995, 55334) tabulated Bandelier Tuff core hydraulic properties from several boreholes beneath the Laboratory. Rogers et al. (1996, 55543) evaluated the direction and flux of water through the unsaturated zone using hydraulic properties from seven boreholes which had sufficient data. These seven boreholes represent mesa top and canyon bottom locations, which are two of the distinct hydrologic regimes on the Pajarito Plateau. Most head gradients determined for the boreholes are approximately unity, implying that flow is nearly steady state. An exception to the unit gradient was found for boreholes at Material Disposal Area (MDA) G (TA-54), where gradient reversals at depths of about 100 ft suggest that evaporative drying may be taking place. Rogers et al. (1996, 55543) used vertical head gradients and unsaturated hydraulic conductivity estimates (using geometric means) to approximate infiltration rates for liquid water at the seven sites. The flux estimates presume that flow is vertical only; that is, that no lateral flow is occurring along lithologic interfaces. Apparent fluxes beneath mesa top sites range from about 0.06 cm/yr beneath MDA G to 245 cm/yr beneath surface impoundments at TA-53. High precipitation or surface disturbances including disposal ponds lead to higher fluxes beneath some mesas. Natural tracer studies completed on three mesas across the Pajarito Plateau provide compelling evidence of a natural evaporative barrier to vertical liquid flow.

Apparent canyon bottom infiltration rates are about 0.4 to 8.3 cm/yr beneath two dry canyons (Cañada del Buey and Potrillo Canyon), and 1 to 10 cm/yr beneath Mortandad Canyon, the only relatively wet canyon represented. Canyon bottom infiltration rates beneath wetter canyons such as Los Alamos Canyon could be much greater, but no data for those sites are currently available.

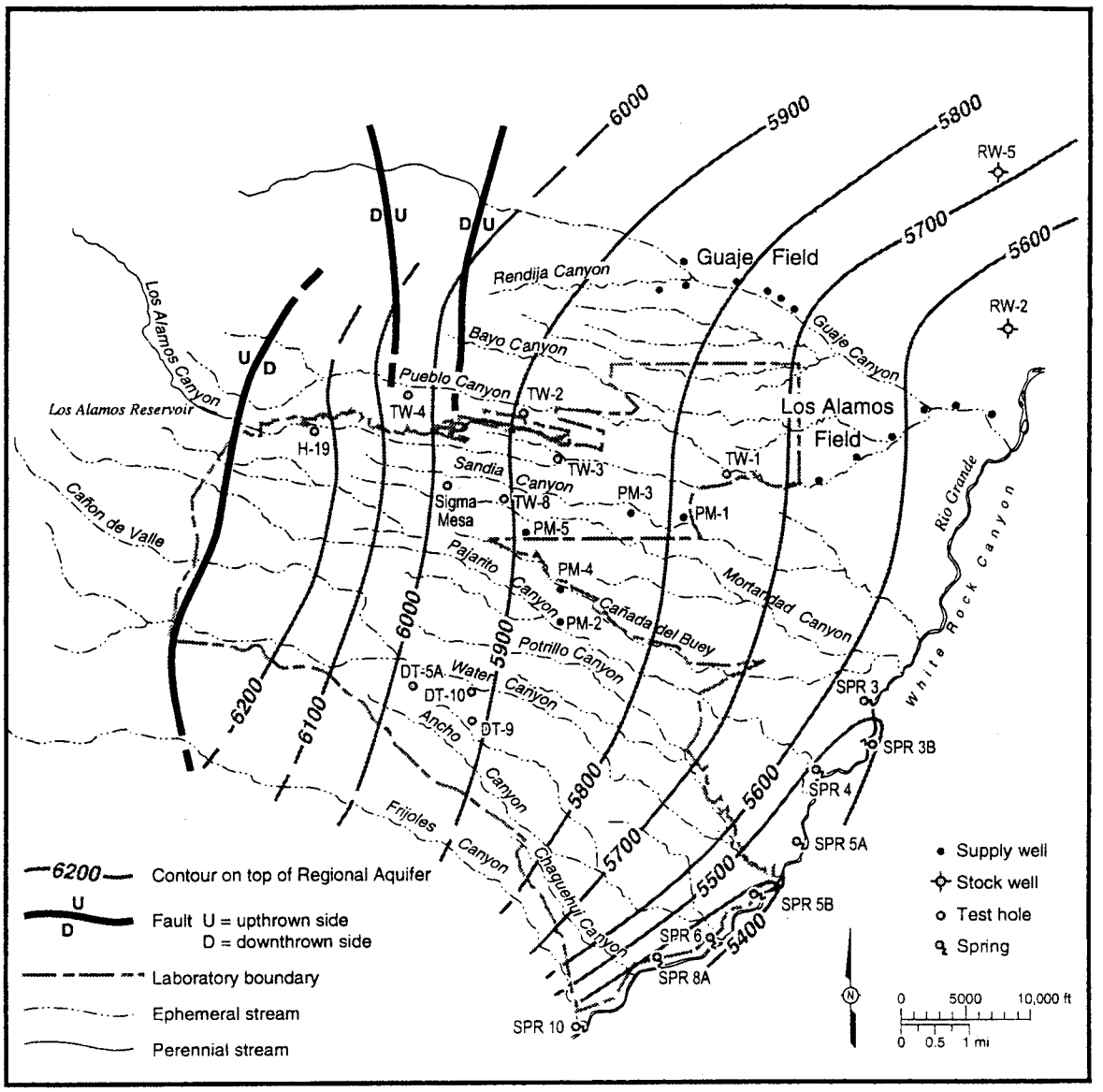


Figure 2-16. Generalized water-level contours on top of the Regional Aquifer (modified from Purtymun 1984, 6513).

Data on stable isotope (deuterium and oxygen-18) geochemistry of groundwaters from the regional aquifer and the Valles caldera indicate that most regional aquifer wells were recharged from elevations lower than the Sierra de los Valles, and do not show the trace elements characteristic of deeper Valles caldera thermal waters (F. Goff, unpublished Los Alamos National Laboratory memo 1991; Blake et al. 1995, 49931). An exception to this pattern of recharge elevations is found at former Los Alamos well field wells LA-6 and LA-1B located near the Rio Grande in lower Los Alamos Canyon (Figure 2-15). These are among the deepest of the wells in this area, and recharge elevations determined from stable isotopes suggest that the recharge area could be the Sangre de Cristo Mountains (Goff and Sayer 1980, 40083; Vuataz and Goff 1986, 40083) as suggested by flow paths in Figure 2-17.

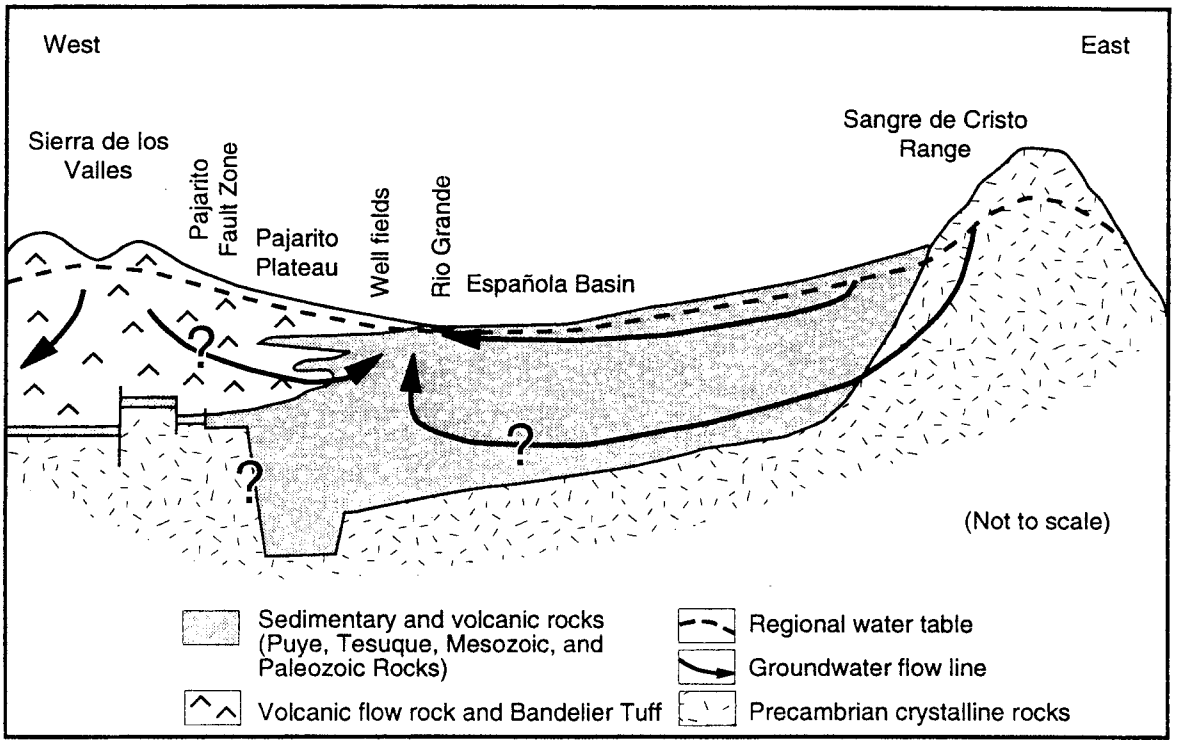


Figure 2-17. Conceptual sketch of groundwater flow paths in the Española portion of the northern Rio Grande Basin (modified from Stephens et al. 1993, 56863).

On the basis of recharge elevations estimated from stable isotope data, Blake et al. (1995, 49931) conclude that most of the regional aquifer recharge comes from the Española Basin or regions to the north along the Rio Grande, but not from the surrounding mountains. Based on stable isotope and other geochemical evidence, the Pajarito Plateau portion of the regional aquifer system appears to be recharged by a combination of lateral flow parallel to the Rio Grande Rift supplemented by inflow from the Sangre de Cristo Mountains (Goff and Sayer 1980, 40083; Vuataz and Goff 1986, 40083; Blake et al. 1995, 49931).

The above-cited studies regarding sources of recharge are inconclusive and require further investigation. The Hydrogeologic Workplan will address recharge issues as part of the characterization of the groundwater system beneath the Pajarito Plateau.

In an effort to better understand the nature of recharge to the regional aquifer, additional isotope and age-dating measurements were made. Samples were collected from test wells and water supply wells that penetrate the regional aquifer. Carbon-14 and low-level tritium measurements permit some tentative estimates of the age of the water in the Regional aquifer at various locations. "Age of water" means the time elapsed since the water, as precipitation, entered the ground to form recharge and became isolated from the atmosphere. The precipitation at the time of entry into the ground is assumed to have contained atmospheric equilibrium amounts of both tritium and carbon. Radioactive carbon-14 comes mainly from natural sources. Tritium comes from both natural sources and fallout from nuclear weapons testing in the atmosphere.

The interpretation of ten carbon-14 analyses indicates that the minimum age of water in the regional aquifer ranges from about 1,000 years under the western portion of the Pajarito Plateau, increasing as it moves eastward, to about 30,000 years near the Rio Grande (Rogers et al. 1996, 54714). It is tempting to conclude that these ages support an easterly flow direction with younger water recharged at the western boundary of the plateau, and flowing towards the east. However, another possibility is that two separate groundwater bodies of different ages are represented, and that a groundwater divide in the regional aquifer lies west of the Rio Grande (Figure 2-17). The radiocarbon data consist of two geographically isolated sets of data. The older ages near the Rio Grande correspond to the region of waters with higher recharge elevations identified by Goff and Sayer (1980, 40083). The much older ages found here could reflect the longer flow path from the possible Sangre de Cristo recharge area, and support the hypothesis that the regional aquifer groundwater divide lies west of the Rio Grande. In addition, a separate flow regime may exist within the late Miocene trough of Purtymun (1984, 6513) (Figure 2-18), with major recharge occurring by southerly groundwater flow of younger water within the Rio Grande rift basin fill.

The existence of two separate groundwater masses of different ages is further supported by a discrepancy between carbon-14 ages and regional aquifer flow rates determined by Purtymun (1984, 6513). The flow rates range from about 250 ft/yr in the Puye Formation near well O-4, to about 20 ft/yr in the Tesuque Formation below the Los Alamos Well Field. For the 5.5 mi distance between wells PM-3 and LA-1B, these flow rates give a range of groundwater travel times between the wells of 115 to 1450 years. These travel times are far shorter than the 22,000 to 27,000 year difference in the carbon-14 ages for these wells (Rogers et al. 1996, 54714).

Several measurements of tritium by extremely low-detection-limit analytical methods appear to show the presence of some recent recharge (within the last 40 years) in groundwater samples taken from five locations in the regional aquifer at locations near Los Alamos (Environmental Protection Group 1994, 35363; 1995, 50276). Another thirty wells show no apparent influence of recent recharge on the regional aquifer. The tritium levels measured range from less than a percent to less than a hundredth of a percent of current drinking water standards and are less than levels that could be detected by the EPA-specified analytical methods normally used to determine compliance with drinking water regulations. The locations where tritium measurements clearly indicate the presence of recent surface recharge to the regional aquifer are (1) TW-1 situated in Pueblo Canyon near the confluence with Los Alamos Canyon; (2) TW-3, in Los Alamos Canyon; (3) in old observation and water supply wells LA-1A and LA-2, located in Los Alamos Canyon near its confluence with the Rio Grande; (4) at TW-8, in Mortandad Canyon located about a mile downstream from the outfall of the Radioactive Liquid Waste Treatment Facility (RLWTF) at TA-50; and (5) in household wells and springs at San Ildefonso Pueblo (Environmental Protection Group 1995, 50276; Blake et al. 1995, 49931).

2.5.3 Preliminary Conceptual Model for the Pajarito Plateau

For purposes of describing a conceptual model for the Laboratory, the hydrogeology of the Pajarito Plateau is broken into four components. Two of the components relate to physiography: mesas and canyons. Mesa tops are for the most part dry (Figure 2-19). Canyons are divided into wet and dry; the

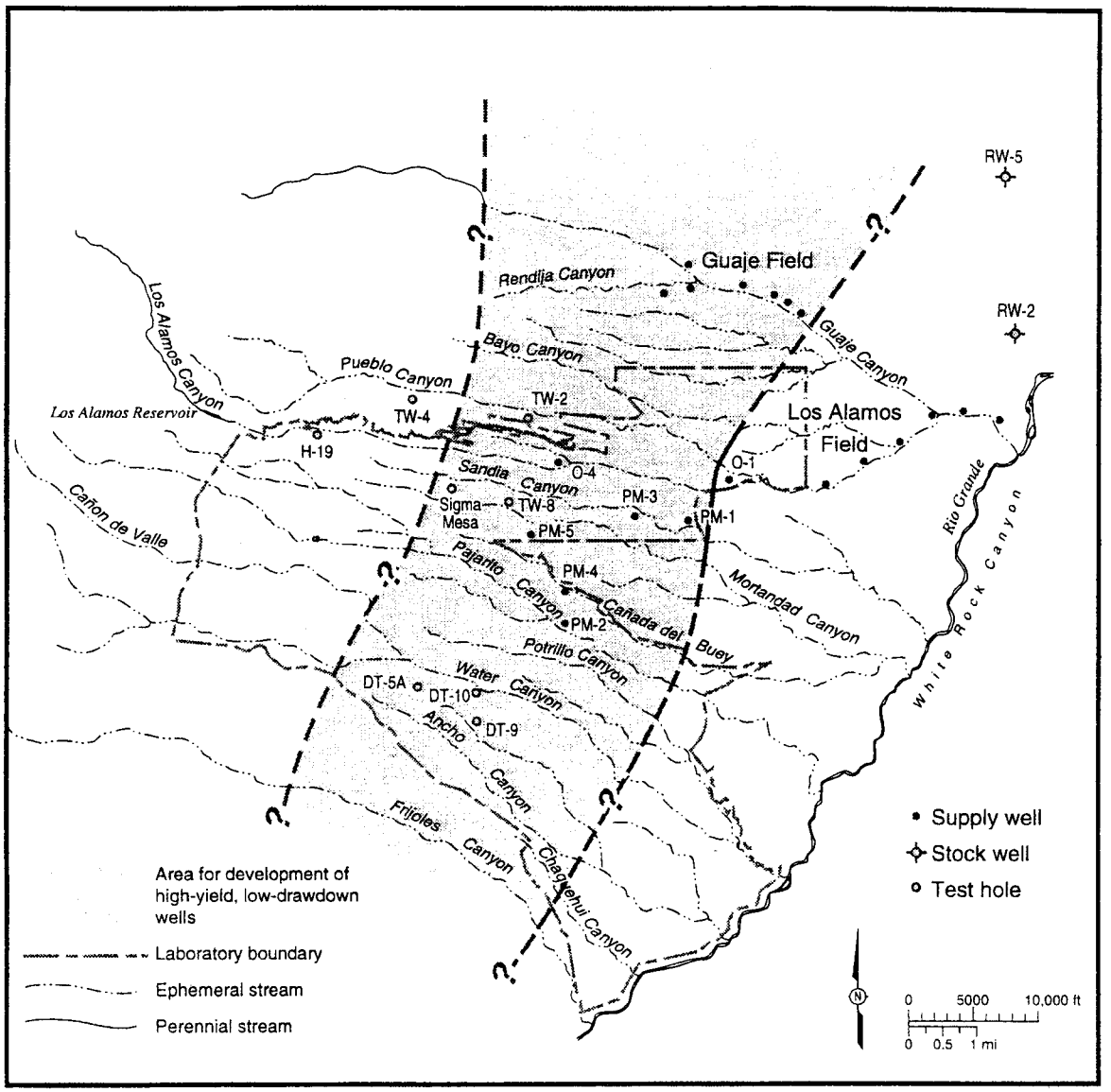
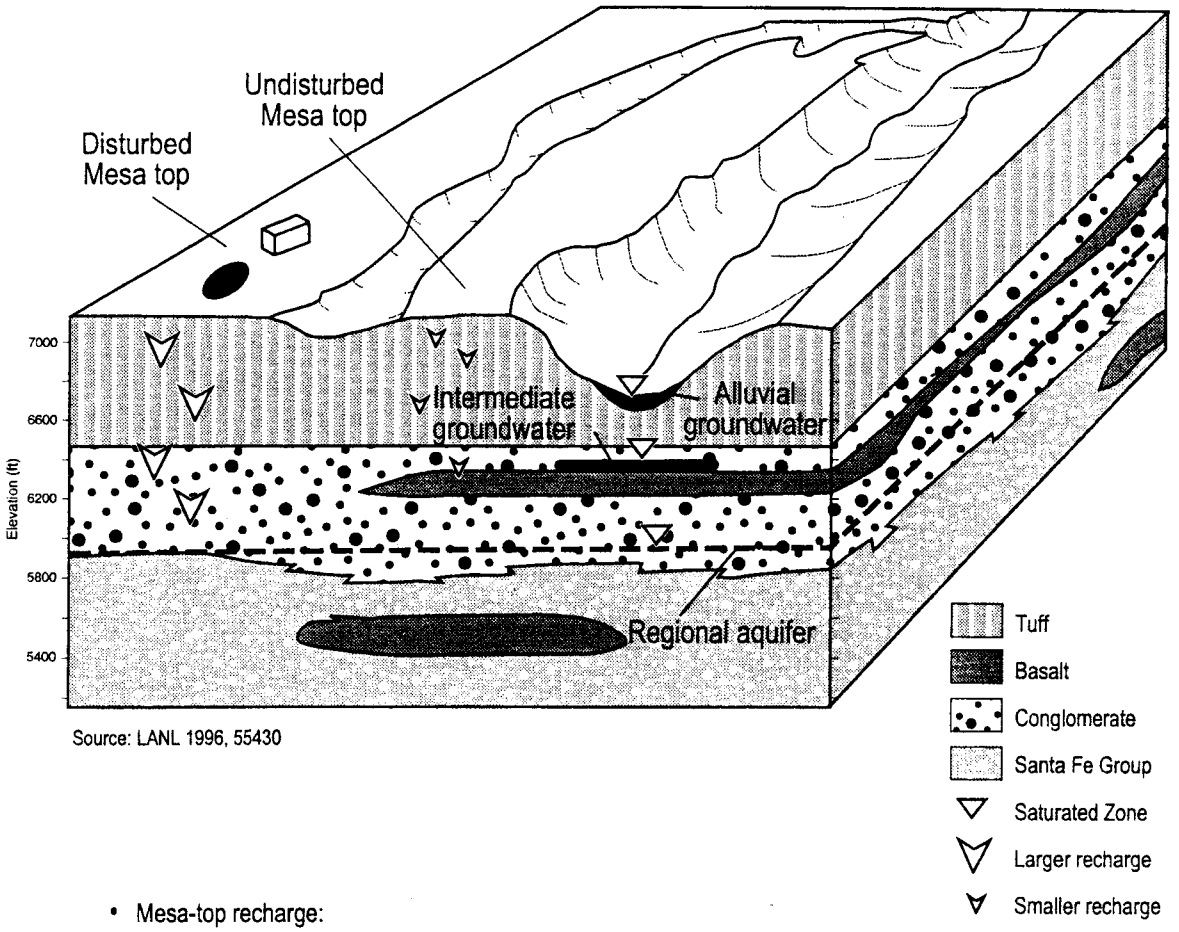


Figure 2-18. Area of inferred Late Miocene trough within upper Santa Fe Group (modified from Purtymun 1984, 6513).



Source: LANL 1996, 55430

- Mesa-top recharge:
  - Small under natural conditions
  - Significant under disturbed surface
  - Fractures do not enhance unless saturated
- Air movement may dry mesa interior
- Vapor-phase contaminant movement possible

Figure 2-19. Hydrogeologic conceptual model for mesas.

wet canyons contain ephemeral streams and contain groundwater in the canyon bottom alluvium (Figure 2-20). A third component, intermediate perched zone groundwater, is found at depths ranging from 100 to 400 ft, and is controlled by lithology. The fourth component, the regional aquifer is found at depths of about 600 to 1200 ft (Figures 2-8, 2-15, 2-17, 2-18). Important aspects of each component of the hydrogeologic system are listed below.

2.5.3.1 Mesas

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

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

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

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

Contaminants in vapor form readily migrate through mesas. Vapors denser than air will sink.

2.5.3.2 Alluvial Groundwater

In drier canyon bottoms, groundwater may occur seasonally in the alluvium, depending on the volume of surface flow from snowmelt, storm runoff, and Laboratory national pollutant discharge elimination system (NPDES) -permitted effluents. As groundwater in the alluvium moves down the canyon, it is depleted by evapotranspiration and infiltration into the underlying rocks.

In wetter canyon bottoms, infiltration of NPDES-permitted effluents and natural runoff reaching the stream channel may maintain shallow groundwater in the alluvium. Groundwater levels are typically highest in late spring due to snowmelt runoff and in mid-to-late summer due to seasonal thunderstorms (Bowen 1990, 6899). Groundwater levels decline during the winter and early summer when runoff is at a minimum.

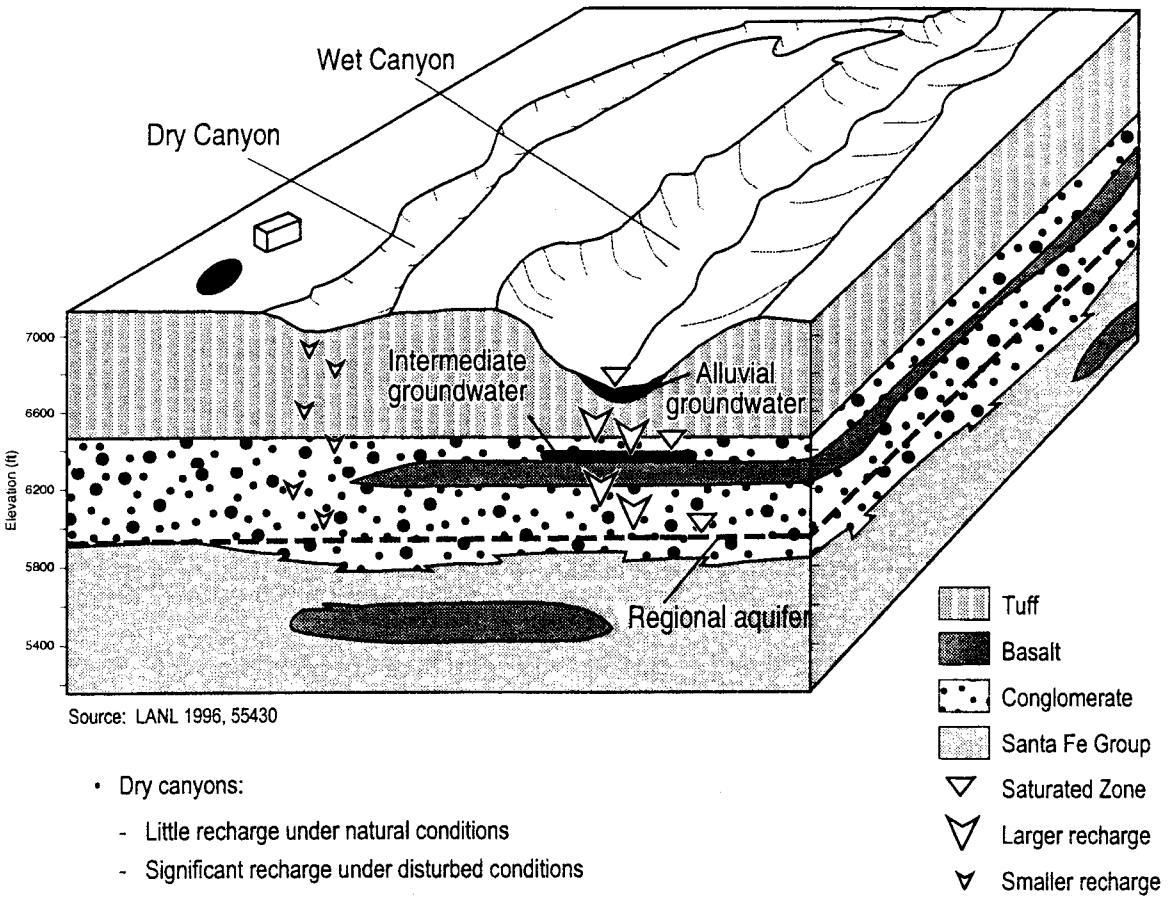
Alluvial groundwater is a source of recharge to underlying intermediate perched zones, usually by unsaturated flow.

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

In a few cases where saturated flow might occur, faults that underlie alluvial saturated zones or intermediate perched zones could provide pathways for downward water movement.

2.5.3.3 Intermediate Perched Zone Groundwater

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



Source: LANL 1996, 55430

- Dry canyons:
  - Little recharge under natural conditions
  - Significant recharge under disturbed conditions
- Wet canyons:
  - Source of recharge to intermediate groundwater and regional aquifer
- Intermediate groundwater:
  - Significant contaminant transport path
  - Source of recharge to main aquifer
  - Occurs in larger canyon systems
  - May exist beneath canyons
  - May be laterally extensive near Jemez Mountains
  - Controlled by subsurface lithology

Figure 2-20. Hydrogeologic conceptual model for canyons.

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

The intermediate perched zones have not been observed to extend laterally beneath mesas. However, some lateral spreading of perched groundwater may occur down gradient, if the canyon course and the dip of the perched zone do not coincide.

Some hydrologic evidence suggests the existence of an intermediate perched zone within the Bandelier Tuff along the western portion of the Laboratory, but this can not be confirmed without further study.

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

2.5.3.4 Regional Aquifer

The slope of the top of the regional aquifer suggests that the flow of groundwater is generally towards the east or southeast, and towards the Rio Grande.

Intermediate perched zone and alluvial groundwater may be minor sources of recharge to the regional aquifer. The hydraulic connection between the regional aquifer and the land surface is not strong. Regional aquifer groundwater within the eastern portion of the Pajarito Plateau (generally along the Rio Grande) is of different recharge origin than under the central part of the Plateau.

Sources of recharge to the regional aquifer are uncertain. Geochemical data show that the Valles Caldera is not the source of major recharge, contrary to statements in earlier Laboratory reports. Major recharge may occur by southerly flow along the late Miocene trough of Purtymun (1984, 6513).

If present, Laboratory-derived contaminants in the regional aquifer are likely to vary in concentration. The contaminant concentrations are probably below maximum contaminant levels (MCLs) for drinking water because; (1) regional aquifer underflow dilutes contaminant concentrations in recharge; and (2) contaminant concentrations in alluvial and intermediate perched zone groundwater are expected to decrease with depth due to dilution and geochemical attenuation along vertical migration pathways.

2.5.4 Hydrologic Properties and Conditions of the Bandelier Tuff

In the central portion of the Laboratory, there is in excess of 1,000 ft or more of unsaturated volcanic tuff, sediments, and basalts of the Bandelier Tuff, the Puye Formation, and the basaltic rocks of Cerros del Rio. Numerous investigations focusing on hydrologic characterization of the upper 100 ft of the Bandelier Tuff have been conducted in the Los Alamos area since the 1950s (e.g., Abrahams et al. 1961, 8134; Weir and Purtymun 1962, 11890; Abrahams 1963, 8149; Purtymun and Koopman 1965, 11839; Purtymun and Kennedy 1971, 4798; Purtymun et al. 1978, 5728; Abeele et al. 1981, 6273; Kearl et al. 1986, 8414; Purtymun et al. 1989, 6889; Stoker et al. 1991, 7530). The vadose zone below about 100 ft has not been adequately characterized.

Most of the investigations of the hydrogeologic properties of the Bandelier Tuff have been conducted on samples of crushed or disturbed tuff. Hydrologic property tests conducted since the mid-1980s largely have been on undisturbed cores (e.g., Kearl et al. 1986, 8414; Stoker et al. 1991, 7530). To aid the reader in evaluating the variablity in hydraulic properties, a summary of hydraulic properties

measured in undisturbed cores from the Bandelier Tuff is presented in Table 2-2.

Table 2-2 includes measured values for bulk density, porosity, and saturated hydraulic conductivity. The values for residual saturation, alpha, and N are the parameters for van Genuchten's formulation of the moisture characteristic curve (van Genuchten 1980, 49927):

$$\tilde{\theta} = \frac{\theta - \theta_r}{\theta_s - \theta_r} = \frac{1}{\left[1 + |\alpha h|^N\right]^M}$$

where

$\tilde{\theta}$	effective saturation,
θ	volumetric moisture content,
θ_s	saturated moisture content,
θ_r	residual moisture content,
h	suction,
α, N	van Genuchten fitting parameters,
M	= 1-1/N.

2.5.4.1 Effects of Physical Characteristics

Physical characteristics of the tuff that affect fluid flow result primarily from the degree of welding and jointing. The degree of welding, which varies markedly within and between tuff units, influences the nature and variability of hydrologic characteristics. Welding results in increased density, decreased porosity, and decreased hydraulic conductivity of the rock matrix (Purtymun and Koopman 1965, 11839). However, welded tuffs tend to be more highly fractured (jointed) than nonwelded tuff, and the overall permeability of the welded tuff may be locally enhanced (Crowe et al. 1978, 5720).

2.5.4.2 Porosity

Porosity measurements by Abrahams (1963, 8149) range from 20% to 60% by volume, generally decreasing with increasing degree of welding. Measurements reported by IT Corporation (1987, 8998) are higher, from approximately 39% to 74%. A great deal of the high porosity occurs whenpumice fragments are incorporated in the tuff. The higher porosities are comparable to those of the upper ranges found in fine clays. Such high porosities, however, are unusual for indurated materials. Extreme changes in porosity over a short vertical distance have been observed (Abrahams 1963, 8149).

2.5.4.3 Moisture Content

A number of hydraulic properties of the Bandelier Tuff vary with changing moisture content. The tuff is only partially saturated throughout the Laboratory, even beneath stream channels containing alluvial perched groundwater systems. The moisture contents of the tuff beneath mesa tops are very low, typically less than 5% by volume (Abrahams 1963, 8149). Abrahams shows that tuff moisture content is higher beneath disturbed soils than beneath undisturbed soils and, generally, moisture content decreases with depth. At sites with relatively high near-surface moisture contents, the volumetric moisture content decreases rapidly with depth to less than 5% (Abrahams 1963, 8149). Moisture contents of the tuff beneath the canyon bottoms are considerably higher than those beneath the mesas and typically range from 20% to 50% by volume (Weir and Purtymun 1962, 11890; Stoker et al. 1991, 7530). Field studies in Mortandad, Sandia, and Potrillo Canyons show that moisture content varies greatly with depth, depending on texture (Stoker et al. 1991, 7530; Environmental Protection Group 1993, 23249). Generally, moisture content decreases with depth below stream channels.

TABLE 2-2
SUMMARY OF HYDRAULIC PROPERTIES DATA FOR BANDELIER TUFF OBTAINED SINCE 1984

	Bulk Density (g/cm^3)	Porosity (%)	Ksat (cm/sec)	van Genuchten Parameters: Residual Saturation (%)[b]	α	N
Tshirege Member						
Minimum	0.94	34.6	5.6×10^{-6}	0.0	0.0011	1.152
Median	1.18	48.8	1.1×10^{-4}	2.3	0.0056	1.696
Harmonic Mean			5.8×10^{-5}			
Maximum	1.49	74.2	3.9×10^{-3}	7.9	0.2312	2.877
Number of Observations	43	63	85	32	32	32
Tsankawi Pumice						
Minimum	0.90	36.7	4.7×10^{-5}	0.0	0.0005	1.106
Median	1.25	46.0	6.8×10^{-4}	0.23	0.0187	1.481
Harmonic Mean			1.7×10^{-4}			
Maximum	1.60	65.6	4.3×10^{-3}	7.28	0.0513	1.890
Number of Observations	18	12	9	9	9	9
Otowi Member						
Minimum	0.98	40.3	1.1×10^{-5}	0.0	0.0039	1.388
Median	1.18	44.0	2.7×10^{-4}	2.5	0.0060	1.653
Harmonic Mean			1.3×10^{-4}			
Maximum	1.49	59.0	7.8×10^{-3}	12.1	0.0185	2.307
Number of Observations	31	25	25	21	21	21

---

a. Samples represent a compilation by D. Rogers and B. Gallaher (1995, 55334) of available hydraulic property determinations on undisturbed core samples taken between 1984 and 1992. Field and laboratory data from USGS work in the 1950s and 1960s and air/water injection tests conducted by Bendix Corporation in the mid-1980s (Kearl et al. 1986, 8414) are not included in the compilation because of concerns relating to the comparability of different measurement techniques.

b. Most cores with $\theta_r > 10$ are omitted because of the absence of thermocouple psychrometer measurements at high matric suctions.

2.5.4.4 Moisture Characteristic Curves

The relationship between moisture content and soil-water potential has been obtained from more than 60 undisturbed mesa top and canyon bottom cores at TA-54 (Rogers and Gallaher, 1995, 55334). The data indicate residual moisture content (0% to 4%). Purtymun and Stoker (1987, 6688) indicate that at TA-49 specific retention (residual moisture content) ranged from 11% to 27%. Detailed analyses in Mortandad Canyon show that there are significant differences in moisture retention characteristics between and within formational units (Stoker et al. 1991, 7530). Abrahams (1963, 8149) determined the energy relationship with moisture content of a moderately welded tuff. The saturated moisture content of the tuff was about 41% by volume. When moisture contents are below about 4%, there is no movement of water; from about 4% to 8%, moisture is redistributed by diffusion; from about 8% to 23%, distribution is governed by gravity and capillarity; and above 23%, movement is controlled by gravity only (Abrahams 1963, 8149).

2.5.4.5 Hydraulic Conductivity

Hydraulic conductivity is the parameter that describes rate of flow of fluid through a porous medium in response to a hydraulic gradient; it is a function of both the fluid and the medium. Saturated hydraulic conductivities have been measured for tuff many times under laboratory and field conditions, with values ranging from 1.9×10^{-5} to 2.3×10^{-2} cm/s (0.054 to 6.5 ft/day), comparable to those of silty sand. In general, nonwelded tuff has greater saturated conductivity than welded tuff, and horizontal conductivities are greater than vertical conductivities (Abrahams 1963, 8149). Unsaturated hydraulic conductivities may be many orders of magnitude lower, typically ranging from 10^{-6} to 10^{-11} cm/s (Stoker et al. 1991, 7530; Rogers and Gallaher 1995, 55334), depending on *in situ* moisture contents.

2.5.4.6 Joints

Joints formed by cooling of the ash flows or by later faulting typically divide the tuff into irregular blocks. The major joint sets are vertical or nearly vertical, with dips greater than 70°, and joint frequency increases with the degree of welding and proximity to faults (Vaniman and Wohletz 1990, 21589). Joints and fractures in moderately welded tuffs generally terminate in nonwelded tuffs (Baltz et al. 1963, 8402). The joints are often vertically limited to a single ash flow or ash fall unit (Purtymun and Kennedy 1971, 4798). Joint apertures range from closed to open as much as 15 cm (Wohletz 1995, 54404). The joints are commonly filled with pedogenic calcite near the surface, grading downward to clay, and may be open to depths greater than 30 ft (Purtymun et al. 1978, 5728; Abeele et al. 1981, 6273). Examination of cores obtained from horizontal drilling beneath a waste disposal site at TA-54 showed that about 80% of the joints were filled or plated with clay or secondary mineralization (Purtymun et al. 1978, 5728). Fracture apertures at TA-54 are typically small, with median values of about 3 mm; median fracture spacing is 1.9–4.0 ft (Reneau and Vaniman, in preparation, 55122). Reneau and Vaniman note the general absence of clay illuviation in any fractures to depths greater than 10–20 ft within an excavated pit at TA-54.

2.5.5 Movement of Moisture in the Bandelier Tuff

The movement of moisture in the Bandelier Tuff is governed by a complex interaction of many factors. Climatic and site-specific land use factors control the supply of moisture available for infiltration, and hydrogeological characteristics control the redistribution of moisture in the tuff.

Perhaps the most significant aspect of the tuff is its ability to imbibe water, i.e., act as a sponge. Most of the pore spaces in the tuff are of capillary size and have a strong tendency to hold water against

gravity by surface tension forces. Thus, a slug of water entering dry tuff is slowed or retained by capillary tension forces.

Water moves through the tuff in two ways: (1) by liquid and vapor movement through the pores of the tuff and (2) by movement through open, interconnected joints (Abrahams 1963, 8149). When moisture content is low, movement in the vapor (gaseous) phase becomes more preponderant, and liquid movement through the rock matrix is extremely slow. Water entering open, interconnected joints might move rapidly downward through the joints; however, to maintain continuous flow through the fractures, it is likely that large volumes and a continuous supply of water are necessary because of the sponge effect of the adjacent tuff that forms the wall of the fracture. The existence of a low-permeability coating on the wall of the fracture, on the other hand, could increase the travel depth of water flowing through fractures (Thoma et al. 1992, 57004). If the joints are not continuous through contacts between subunits of the tuff, the water might be perched above the contact and would tend to move laterally, potentially to the walls of canyons. These factors are discussed as they pertain to subsurface contaminant transport beneath the mesa tops and canyon bottoms.

2.5.5.1 Migration of Moisture Beneath Mesa Tops

The natural moisture content of the tuff forming the mesas between the canyons is generally less than 5% by volume at depths greater than a few tens of feet, the zone affected by seasonal inputs of moisture and evapotranspiration. Weir and Purtymun (1962, 11890) attributed the low moisture content to the protective cap of clay soil derived by weathering of the tuff near the surface, low rainfall, and high evapotranspiration. The existence of low moisture content is further supported historically by the absence of weathering below 10 m (Wheeler et al. 1977, 5577) and the overall absence of perched water in the tuff at potential perching horizons.

Kearl et al. (1986, 8414) concluded that vapor phase transport is the predominant transport mechanism controlling the potential subsurface movement of contaminants beneath the mesa top at TA-54. They also conclude that there is no interconnection or movement of liquid water in the interval of Bandelier Tuff examined (upper 100 ft of the Tshirege Member). Other laboratory analyses on cores of moderately welded tuff support the possibility of vapor phase dominance at most mesa top locations (Abrahams 1963, 8149).

From a waste containment perspective, the possibility of vapor phase dominance is significant: in extremely dry rock, only contaminants existing in a gaseous state, such as tritium or volatile organic solvents, migrate through the rock matrix. Other radionuclides and metals can be removed from their original location only under wetter conditions, when the uninterrupted movement of liquid water (i.e., capillarity) is more predominant.

Few definitive field measurement techniques exist by which to quantify natural recharge through mesa tops. One exception is the use of natural tracer profiles to infer recharge rates by comparing them with analytical solute transport solutions. As an alternative, the flux of liquid water through the rock matrix that could eventually become recharge can be estimated as being approximately equal to the unsaturated hydraulic conductivity, assuming that flow is downward and at steady state.

In situ hydraulic conductivities for tuff beneath the mesa top MDA L at TA-54 were computed by Rogers and Gallaher (1995, 55334) from laboratory analyses of five undisturbed Bandelier Tuff cores obtained from three separate coreholes. Computed *in situ* unsaturated hydraulic conductivities (i.e., fluxes) range from 3.0 x 10-12 to 1.5×10^{-1} cm/sec (3.7×10^{-5} to 1.9×10^{-1} ft/yr). For uniform flow through media with spatially varying hydraulic conductivity, the average hydraulic conductivity lies between the harmonic and arithmetic mean hydraulic conductivity (de Marsily 1986, 57043). The arithmetic and harmonic mean hydraulic conductivities for this set of cores are 4.7×10^{-9} and 8.7×10^{-12} cm/sec (5.8×10^{-2} and 1.1×10^{-4} ft/yr). At the moisture conditions and calculated unsaturated hydraulic conductivities at MDA L, the rates of water movement in the upper part of the mesa top are estimated

to lie between 1.2 and 0.002 ft/yr, based on the assumption that there are no "fast paths" of water movement, such as fracture flow, to significant depths.

These calculated rates, which are relatively low, imply very little water movement from the mesa tops to the main aquifer under natural conditions, which probably also applies to a one-time spill of contaminants at the land surface. Because of geochemical interaction between the rock and dissolved constituents, the rate of constituent movement (except for movement of constituents that are highly soluble) should be lower than that of water.

The greatest concern about subsurface migration at mesa tops is the potential for a large volume of contaminants to be chronically released in the vicinity of open and interconnected joints, which could occur beneath a surface impoundment or a leaky chemical storage tank. The movement of water through joints would negate the protection provided to the groundwater when water moves only through pores in the tuff (Abrahams 1963, 8149).

Filled fractures strongly inhibit moisture movement. Open fractures are effective barriers to liquid phase unsaturated flow but may provide preferential flow paths for vapor transport or rapid movement of liquid under saturated or near-saturated conditions (Abeele et al. 1981, 6273). Roots have been found in joints to depths of at least 42 ft (Weir and Purtymun 1962, 11890), which suggests that joints may be important local infiltration pathways. Several fracture zones at TA-54 show an increase in moisture content relative to adjacent porous media (Kearl et al. 1986, 8414).

Although fractures have a local effect on infiltration in the upper portions of the mesas, it is less clear to what depth they play a role, for three key reasons. First, water passing through a fracture system has a tendency to be "wicked" into the adjacent rock matrix by capillary suction forces in the tuff, provided the fracture/rock interface is not sealed with material of low permeability (Thoma et al. 1992, 57004). Analytical and numerical modeling at TA-54 indicates that transient infiltration pulses in fractures likely affect only the very near surface before being imbibed by the adjacent tuff (Rosenberg et al. 1993, 46223). Second, most of the open fractures occur in the moderately welded to welded Tshirege Member of the Bandelier Tuff, and the underlying nonwelded Otowi Member is significantly less fractured (Baltz et al. 1963, 8402). Flow in the lower portions of the Bandelier Tuff, therefore, is far more likely to be dominated by the relatively slow process of capillarity.

Finally, although fractures may initially provide a pathway for movement of water into the mesas, they may later play a role in removing water (as water vapor) from within the mesa. Under low barometric pressure conditions, air transfers from the tuff to the atmosphere through boreholes (Purtymun et al. 1974, 5477). Barometric and air pressure variations along the canyon walls could cause the exchange of gas and water vapor between the atmosphere and the mesas, especially via interconnected fractures and joints, which are highly permeable to air. Air transfer has been documented in boreholes penetrating the tuff at TA-49 (Purtymun et al. 1974, 5477) and has been observed elsewhere on the plateau.

In conclusion, the combination of the Bandelier Tuff's low moisture content beneath the mesa tops, its associated hydraulic characteristics, and its thickness provides the main aquifer a substantial degree of protection from the mesa tops. At suspected waste sites at which contaminated liquids have not been disposed, the risks to the main aquifer are quite low. Detailed characterization of the subsurface probably is not warranted for most such sites. Site-specific conditions must always be considered, however, before making such a determination. At waste sites with large potential contaminant source terms, such as material disposal areas, phased subsurface investigations should be conducted to verify that the waste is sufficiently contained.

Waste disposal activities that chronically released large volumes of and highly contaminated liquids or that contained volatile contaminants have the potential for migration within the mesas and should also be investigated for subsurface transport. Open fractures may be a key factor in determining

whether contaminants migrate to deeper sections of the tuff or travel laterally to release areas on the mesa walls. All of these subsurface investigations should initially focus on the upper 100 to 200 ft of the vadose zone.

2.5.5.2 Migration of Moisture Beneath Canyon Bottoms

The canyons with alluvial perched groundwaters are presumed to present a greater potential for downward movement than do the mesa tops because there is a constant driving force and because the moisture content of the tuff below the saturated alluvium is significantly higher than that beneath the mesas. Additionally, the depth to the main aquifer in the canyons is several hundred feet less than from the adjacent mesa tops. The effect of this greater potential for fluid flow, though, is somewhat compensated by the general lack of highly concentrated contaminant sources in the canyon bottoms.

Recent investigations provide some important information on the movement of moisture and contaminants in the unsaturated tuff. The best field evidence that can be used to estimate potential downward rates of movement beneath canyon bottoms is obtained from corehole data collected by Stoker et al. (1991, 7530) in Mortandad Canyon. Because treated liquid radioactive effluents have been discharged to the canyon for almost 30 years, the radioactive constituents in effluent from the Laboratory serve as accurate tracers for fluid and contaminant migration studies.

The basic conclusions of the Mortandad study regarding the movement of radioactive contaminants below the alluvial perched groundwater are (1) soluble and particulate radioactive constituents have moved less than about 10 ft into the unsaturated zone beneath the alluvial perched groundwater and (2) tritium, as tritiated water, has moved at least 150 ft below the alluvial perched groundwater to a total depth of 195 ft. Tritium concentrations in Corehole MCM-5.9 (the deepest corehole drilled so far in the canyon) decrease by a factor of about 100 between 150 and 195 ft, suggesting the possibility that tritium has not moved much deeper in the almost 30 years since effluents were first released from the TA-50 treatment plant (Stoker et al. 1991, 7530). The tritium data suggest a downward rate of movement of at least 6 ft/yr. However, this conclusion must be considered tentative until additional, deeper coreholes can confirm the pattern.

Recent drilling of Characterization Well LADP-3 in Los Alamos Canyon has shown that Laboratory-derived tritium has migrated to depths of at least 330 ft beneath the canyon bottom (Broxton et al. 1995, 50119). Because the history of tritium releases to the canyon is uncertain, it is difficult to calculate a downward rate of contaminant movement at this location.

Stoker et al. (1991, 7530) evaluated the moisture content in tuff beneath the alluvial perched groundwater in Mortandad Canyon. Most values for gravimetric moisture content in the Tshirege Member beneath the alluvial perched groundwater ranged from 10% to 30%, corresponding to about 20% to 60% of saturation. Several peaks occurred at higher values, approaching 90% of saturation near the contact with or in the Tsankawi Pumice Bed and fluvial Cerro Toledo deposits on the top of the Otowi Member at depths around 100 ft. In the Otowi tuff, the gravimetric moisture content decreased and leveled off at about 12% to 18%, which corresponds to 20% to 40% saturation. A similar pattern occurred in a corehole farther downstream in Mortandad Canyon, past the end of the alluvial perched groundwater (Stoker et al. 1991, 7530), and also in Sandia and Potrillo Canyons (Environmental Protection Group 1993, 23249).

The data suggest that there are complex variations in hydrologic properties in the layers from the base of the Tshirege Member through to the top of the Otowi Member that significantly affect the movement of moisture in the unsaturated zone. There is also a suggestion that moisture conditions in the Otowi Member become very uniform, with only moderate differences in magnitude, depending on whether there are saturated conditions in overlying layers (Environmental Protection Group 1993, 23249). Additional field data and theoretical interpretation are required to confirm the patterns and quantify movement.

2.5.6 Groundwater Monitoring

The Laboratory has formulated a comprehensive groundwater protection plan (LANL 1995, 50124) for an enhanced set of characterization and monitoring activities. The Hydrogeologic Workplan (LANL 1996, 55430) details the implementation of extensive groundwater characterization across the Pajarito Plateau within an area potentially affected by Laboratory operations. The locations of the characterization wells and their proposed drilling and sampling plans address many areas of concern, in particular,

- delineating individual zones of saturation, and defining the hydraulic interconnection between them;
- delineating the recharge areas for the regional aquifer and intermediate perched zones;
- groundwater flow directions of the regional aquifer and intermediate perched zones, and the influence of resource withdrawal by production wells; and
- assessment of aquifer characteristics using the additional data from wells installed within specific intervals of the various aquifers beneath the Laboratory.

Installation of the boreholes and the information gained from them are coordinated with ongoing Environmental Restoration Project and environmental surveillance activities, including use of common resources and data collection/retrieval techniques. Installation of the 32 proposed boreholes is expected to commence in FY98 and continue through FY02; progress of this schedule is highly dependent on future funding.

References for Chapter 2

Abeele, W. V., M. L. Wheeler, and B. W. Burton, October 1981. "Geohydrology of Bandelier Tuff," Los Alamos National Laboratory Report LA-8962-MS, Los Alamos, New Mexico. **(Abeele et al. 1981, ER ID Number 6273)**

Aubele, J. C., 1978. "Geology of Cerros Del Rio Volcanic Field," in *Guidebook to Rio Grande rift in New Mexico and Colorado*, New Mexico Bureau of Mines and Mineral Resources, Circular 163, Socorro, New Mexico. **(Aubele 1978, ER ID Number 54426)**

Abrahams, J. H., Jr., January 1963. "Physical Properties of and Movement of Water in the Bandelier Tuff, Los Alamos and Santa Fe Counties, New Mexico," US Geological Survey Administrative Release, Albuquerque, New Mexico. **(Abrahams 1963, ER ID Number 8149)**

Abrahams, J. H., and W. D. Purtymun, January 1966. "The Hydrology and Chemical and Radiochemical Quality of Surface and Ground Water at Los Alamos, New Mexico, July 1957 through June 1961," US Geological Survey Administrative Release, Albuquerque, New Mexico. **(Abrahams and Purtymun 1966, ER ID Number 8141)**

Abrahams, J. H., Jr., J. E. Weir, Jr., and W. D. Purtymun, 1961. "Distribution of Moisture in Soil and Near-Surface Tuff on the Pajarito Plateau, Los Alamos County, New Mexico," Article No. 339 in *Geological Survey Research 1961*, Washington, DC. **(Abrahams et al. 1961, ER ID Number 8134)**

Abrahams, J. H., Jr., E. H. Baltz, and W. D. Purtymun, 1962. "Movement of Perched Ground Water in Alluvium near Los Alamos, New Mexico," US Geological Survey Professional Paper 450-B, Article No. 37, Albuquerque, New Mexico. **(Abrahams et al. 1962, ER ID Number 8140)**

Aldrich, M. J., and D. P. Dethier, December 1990. "Stratigraphic and Tectonic Evolution of the Northern Española Basin, Rio Grande Rift, New Mexico," *Geologic Society of America Bulletin*, Vol. 102, No. 12, pp. 1695-1705. **(Aldrich and Dethier 1990, ER ID Number 49681)**

Bailey, R. A., R. L. Smith, and C. S. Ross, 1969. "Stratigraphic Nomenclature of Volcanic Rocks in the Jemez Mountains, New Mexico," in *Contributions to Stratigraphy*, US Geological Survey Bulletin 1274-P, Washington, DC, p. 1. **(Bailey et al. 1969, ER ID Number 21498)**

Baltz, E. H., J. H. Abrahams, and W. D. Purtymun, March 1963. "Preliminary Report on the Geology and Hydrology of Mortandad Canyon near Los Alamos, N. Mex., with Reference to Disposal of Liquid Low-Level Radioactive Waste," US Geological Survey Open File Report, Albuquerque, New Mexico. **(Baltz et al. 1963, ER ID Number 8402)**

Becker, N. M., 1986. "Heavy Metals in Run-off," in *Environmental Surveillance at Los Alamos During 1985*, Los Alamos National Laboratory Report LA-10721-ENV, Los Alamos, New Mexico. **(Becker 1986, ER ID Number 6626)**

Becker, N. M., W. D. Purtymun, and M. Maes, 1985. "Movement of Depleted Uranium by Storm Run-off," in *Environmental Surveillance at Los Alamos During 1984*, Los Alamos National Laboratory Report LA-10421-ENV, Los Alamos, New Mexico. **(Becker et al. 1985, ER ID Number 6610)**

Blake, W. D., F. Goff, A.I. Adams, and D. Counce, 1995. "Environmental Geochemistry for Surface and Subsurface Waters in the Pajarito Plateau and Outlying Areas, New Mexico," Los Alamos National Laboratory Report LA-12912-MS. **(Blake et al. 1995, ER ID Number 49931)**

Bowen, B. M., May 1990. "Los Alamos Climatology," Los Alamos National Laboratory Report LA-11735-MS, Los Alamos, New Mexico. **(Bowen 1990, ER ID Number 6899)**

Broxton, D. E., G. H. Heiken, S. J. Chipera, and F. M. Byers, Jr., June 1995. "Stratigraphy, Petrography, and Mineralogy of Bandelier Tuff and Cerro Toledo Deposits," in *Earth Science Investigation for Environmental Restoration—Los Alamos National Laboratory Technical Area 21*, Los Alamos National Laboratory Report LA-12934-MS, Los Alamos, New Mexico, pp. 33–63. **(Broxton et al. 1995, ER ID Number 50121)**

Broxton, D. E., P. A. Longmire, P. G. Eller, and D. Flores, June 1995. "Preliminary Drilling Results for Boreholes LADP-3 and LADP-4," in *Earth Science Investigation for Environmental Restoration—Los Alamos National Laboratory Technical Area 21*, Los Alamos National Laboratory Report LA-12934-MS, Los Alamos, New Mexico, pp. 93–109. **(Broxton et al. 1995, ER ID Number 50119)**

Broxton, D. E., and S. L. Reneau, August 1995. "Stratigraphic Nomenclature of the Bandelier Tuff for the Environmental Restoration Project at Los Alamos National Laboratory," Los Alamos National Laboratory Report LA-13010-MS, Los Alamos, New Mexico. **(Broxton and Reneau 1995, ER ID Number 49726)**

Broxton, D. E., and S. L. Reneau, 1996. "Buried Early Pleistocene Landscapes Beneath the Pajarito Plateau, Northern New Mexico," in *New Mexico Geological Society Guidebook*, 47th Field Conference, Jemez Mountains Region, New Mexico, pp. 325–334. **(Broxton and Reneau 1996, ER ID Number 55429)**

Cash, D. J., and J. J. Wolff, 1984. "Seismicity of the Rio Grande Rift in Northern New Mexico, 1973-1983," in *New Mexico Geological Society Guidebook*, Santa Fe, New Mexico. **(Cash and Wolff 1984, ER ID Number 57041)**

Cavazza, W., 1989. "Sedimentation Pattern of a Rift-Filling Unit, Tesuque Formation (Miocene), Española Basin, Rio Grande Rift, New Mexico," in *Journal of Sedimentary Petrology*, Vol. 59, No. 2, pp. 287–296. **(Cavazza 1989, ER ID Number 21501)**

Conover, C. S., C. V. Theis, and R. L. Griggs, 1963. "Geology and Hydrology of Valle Grande and Valle Toledo, Sandoval County, New Mexico," US Geological Survey Water-Supply Paper 1619-Y, Washington, DC. **(Conover et al. 1963, ER ID Number 57044)**

Crowe, B. M., G. W. Linn, G. Heiken, and M. L. Bevier, April 1978. "Stratigraphy of the Bandelier Tuff in the Pajarito Plateau, Applications to Waste Management," Los Alamos Scientific Laboratory Report LA-7225-MS, Los Alamos, New Mexico. **(Crowe et al. 1978, ER ID Number 5720)**

Cushman, R. L.,1965. "An Evaluation of Aquifer and Well Characteristics of Municipal Well Fields in Los Alamos and Guaje Canyons near Los Alamos, New Mexico," US Geological Survey Water Supply Paper 1809-D, Washington, DC. **(Cushman 1965, ER ID Number 8584)**

Dale, M. R, S. M. Yanicak, and S. P. Anderson, December 1996. "Ground-Water Oversight at Los Alamos National Laboratory and Surrounding Area, 1994 Through 1995," Doe Oversight Bureau, NMED/DOE/AIP-96-4. **(Dale et al. 1996, ER ID Number 57014)**

Dalrymple, G. B., A. Cox, R. R. Doell, and C. S. Grommé, March 17, 1967. "Pliocene Geomagnetic Polarity Epochs," in *Earth and Planetary Science Letters*, Vol. 2, pp. 163–173. **(Dalrymple et al. 1967, ER ID Number 49924)**

Davis, T. D., S. Hoines, and K. T. Hill, July 1996. "Hydrogeologic Evaluation of Los Alamos National Laboratory," NMED-HRMB-96/1, Hazardous and Radioactive Materials Bureau, New Mexico Environment Department, Santa Fe, New Mexico. **(Davis et al. 1996, ER ID Number 55446)**

de Marsily, G.,1986. Quantitative Hydrogeology: Groundwater Hydrology for Engineers. Academic Press, New York. **(de Marsily 1986, ER ID Number 57043)**

Dethier, D. P., C. D. Harrington, and M. J. Aldrich, June 1988. "Late Cenozoic Rates of Erosion in the Western Española Basin, New Mexico: Evidence from Geologic Dating of Erosion Surfaces," *Geological Society of America Bulletin*, Vol. 100, pp. 928-937. **(Dethier et al. 1988, ER ID Number 57003)**

Dethier, D. P., and K. Manley, 1985. "Geologic Map of the Chili Quadrangle, Rio Arriba County, New Mexico," US Geological Survey Miscellaneous Field Studies Map MF-1814, Washington, DC. **(Dethier and Manley 1985, ER ID Number 21506)**

DOE (US Department of Energy), December 1979. "Final Environmental Impact Statement: Los Alamos Scientific Laboratory Site, New Mexico," DOE/EIS-0018, Washington, DC. **(DOE 1979, ER ID Number 8610)**

Dransfield, B. J., and J. N. Gardner, May 1985. "Subsurface Geology of the Pajarito Plateau, Española Basin, New Mexico," Los Alamos National Laboratory Report LA-10455-MS, Los Alamos, New Mexico. **(Dransfield and Gardner 1985, ER ID Number 6612)**

Environmental Protection Group, December 1990. "Environmental Surveillance at Los Alamos During 1989," Los Alamos National Laboratory Report LA-12000-ENV, Los Alamos, New Mexico. **(Environmental Protection Group 1990, ER ID Number 6995)**

Environmental Protection Group, March 1992. "Environmental Surveillance at Los Alamos During 1990," Los Alamos National Laboratory Report LA-12271-MS, Los Alamos, New Mexico. **(Environmental Protection Group 1992, ER ID Number 7004)**

Environmental Protection Group, August 1993. "Environmental Surveillance at Los Alamos During 1991," Los Alamos National Laboratory Report LA-12572-ENV, Los Alamos, New Mexico. **(Environmental Protection Group 1993, ER ID Number 23249)**

Environmental Protection Group, July 1994. "Environmental Surveillance at Los Alamos during 1992," Los Alamos National Laboratory Report LA-12764-ENV, Los Alamos, New Mexico. **(Environmental Protection Group 1994, ER ID Number 35363)**

Environmental Protection Group, October 1995. "Environmental Surveillance at Los Alamos during 1993," Los Alamos National Laboratory Report LA-12973-ENV, Los Alamos, New Mexico **(Environmental Protection Group 1995, ER ID Number 50276)**

ESG. In this chapter, ESG stands for Environmental Studies Group, which in 1971 was renamed Environmental Surveillance Group. The group prepared annual reports whose titles varied before 1973; from 1973 on, the reports were entitled "Environmental Surveillance at Los Alamos during (Year)." The reports bear a Los Alamos Scientific Laboratory number before January 1, 1981, and a Los Alamos National Laboratory number thereafter.

Galusha, T., and J. C. Blick, April 1971. "Stratigraphy of the Santa Fe Group, New Mexico," Bulletin of the American Museum of Natural History, Vol. 144, Article 1, Lund Humphries, Great Britain, pp. 1-128. **(Galusha and Blick 1971, ER ID Number 21526)**

Gardner, J. N., and F. Goff, 1984. "Potassium-Argon Dates from the Jemez Volcanic Field: Implications for Tectonic Activity in the North-Central Rio Grande Rift," *in New Mexico Geological Society Guidebook, 35th Field Conference, Rio Grande Rift, Northern New Mexico,* Los Alamos National Laboratory Report LA-UR-84-1210, Los Alamos, New Mexico. **(Gardner and Goff 1984, ER ID Number 44021)**

Gardner, J. N., and L. House, October 1987. "Seismic Hazards Investigations at Los Alamos National Laboratory, 1984 to 1985," Los Alamos National Laboratory Report No. LA-11072-MS, Los Alamos, New Mexico. **(Gardner and House 1987, ER ID Number 6682)**

Gardner, J. N., and L. House, April 19, 1994. "Surprisingly High Intensities from Two Small Earthquakes, Northern Rio Grande Rift, New Mexico," poster session presented at the 1994 Spring Meeting of the American Geophysical Union, Vol. 75, No. 16. **(Gardner and House 1994, ER ID Number 57006)**

Gardner, J. N., F. Goff, S. Garcia, and R. C. Hagan, 1986. "Stratigraphic Relations and Lithologic Variations in the Jemez Volcanic Field, New Mexico," *Journal of Geophysical Research*, Vol. 91, pp. 1763-1778. **(Gardner et al. 1986, ER ID Number 21527)**

Gardner, J. N., W. S. Baldridge, R. Gribble, K. Manley, K. Tanaka, J. W. Geissman, M. Gonzalez, and G. Baron, December 1990. "Results from Seismic Hazards Trench #1 (SHT-1) Los Alamos Seismic Hazards Investigations," Report No. EES-1-SH90-19, Los Alamos, New Mexico. **(Gardner et al. 1990, ER ID Number 48813)**

Goff, F., April 3, 1991. "Isotopic Results on Eight White Rock Canyon Springs," Los Alamos National Laboratory Memorandum EES-1, Geology/Geochemistry, from Fraser Goff to Alan Stoker, Los Alamos, New Mexico. **(Goff 1991, ER ID Number 57039)**

Goff, F., June 1995. "Geologic Map of Technical Area 21," in *Earth Science Investigations for Environmental Restoration—Los Alamos National Laboratory Technical Area 21*, Los Alamos National Laboratory Report LA-12934-MS, Los Alamos, New Mexico, pp. 7–18. **(Goff 1995, ER ID Number 49682)**

Goff, F.E. and S. Sayer, 1980. "A Geothermal Investigation of Spring and Well Waters of the Los Alamos Region, New Mexico," Los Alamos National Laboratory Report LA-8326-MS, Los Alamos, NM. **(Goff and Sayer 1980, ER ID Number 40083)**

Goff, F., J. N. Gardner, and G. Valentine, 1990. "Geology of St. Peter's Dome Area, Jemez Mountains, New Mexico," Geologic Map 69, New Mexico Bureau of Mines & Mineral Resources, New Mexico Institute of Mining & Technology, Socorro, New Mexico. **(Goff et al. 1990, ER ID Number 21574)**

Graf, W. L., 1993. "Geomorphology of Plutonium in the Northern Rio Grande," Los Alamos National Laboratory Report LA-UR-93-1963, Los Alamos, New Mexico. **(Graf 1993, ER ID Number 23251)**

Griggs, R. L., 1964. "Geology and Ground-Water Resources of The Los Alamos Area New Mexico," with a section on Quality of Water by John D. Hem, US Geological Survey Water-Supply Paper 1753, Washington, DC. **(Griggs 1964, ER ID Number 8795)**

Heiken, G., F. Goff, J. Stix, S. Tamanyu, M. Shafiqullah, S. Garcia, and R. C. Hagan, 1986. "Intracaldera Volcanic Activity, Toledo Caldera and Embayment, Jemez Mountains, New Mexico," *Journal of Geophysical Research,* Vol. 91, pp. 1799-1815. **(Heiken et al. 1986, ER ID Number 48638)**

Heiken, G., K. Wohletz, R. V. Fisher, and D. P. Dethier, 1989. "Maar Volcanoes of White Rock Canyon—Interaction of Ground and Surface Water with Basaltic Volcanoes of the Rio Grande Rift, New Mexico," Los Alamos National Laboratory Report LA-UR-89-1917, Los Alamos, New Mexico. **(Heiken et al. 1989, ER ID Number 54425)**

Hinojosa, H., and L. K. Nguyen, October 16, 1996. "Threatened, Endangered, and Sensitive Species Profile," Los Alamos National Laboratory Report LA-UR-96-1269, Los Alamos, New Mexico. **(Hinojosa and Nguyen 1996, ER ID Number 57042)**

House, L. S., and D. J. Cash, June 1988. "A Review of Historic and Instrumental Earthquake Activity and Studies of Seismic Hazards near Los Alamos, New Mexico," Los Alamos National Laboratory Report LA-11323-MS, Los Alamos, New Mexico. **(House and Cash 1988, ER ID Number 6878)**

IT Corporation, March 1987. "Hydrogeologic Assessment of Technical Area 54, Areas G and L, Los Alamos National Laboratory," Project No. 301017.02, Los Alamos, New Mexico. **(IT Corporation 1987, ER ID Number 8998)**

Izett, G. A., and J. D. Obradovich, February 10, 1994. "$^{40}Ar/^{39}Ar$ Age Constraints for the Jaramillo Normal Subchron and the Matuyama-Brunhes Geomagnetic Boundary," in *Journal of Geophysical Research*, Vol. 99, No. B2, pp. 2925–2934. **(Izett and Obradovich 1994, ER ID Number 48817)**

Kearl, P. M., J. J. Dexter, and M. Kautsky, March 1986. "Vadose Zone Characterization of Technical Area 54, Waste Disposal Areas G and L, Los Alamos National Laboratory, New Mexico, Report 3: Preliminary Assessment of the Hydrogeologic System," Report GJ-44, Bendix Field Engineering Corporation, Grand Junction, Colorado. **(Kearl et al. 1986, ER ID Number 8414)**

Kelley, V. C., 1978. "Geology of Española Basin, New Mexico," Geologic Map 48, New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico. **(Kelley 1978, ER ID Number 11659)**

Lane, L. J., W. D. Purtymun, and N. M. Becker, April 1985. "New Estimating Procedures for Surface Run-off Sediment Yield and Contaminant Transport in Los Alamos County, New Mexico," Los Alamos National Laboratory Report LA-10335-MS, Los Alamos, New Mexico. **(Lane et al. 1985, ER ID Number 6604)**

LANL (Los Alamos National Laboratory), 1990. "Annotated Bibliography of Geologic, Hydrogeologic, and Environmental Studies Relevant to Solid Waste Management Units at Los Alamos National Laboratory," Los Alamos National Laboratory Report No. LA-UR-90-3216, Los Alamos, New Mexico. **(LANL 1990, ER ID Number 47588)**

LANL (Los Alamos National Laboratory), 1995. "Site Development Plan, Annual Update 1995," Los Alamos National Laboratory Publication, LALP-95-113, Los Alamos, New Mexico. **(LANL 1995, ER ID Number 52976)**

LANL (Los Alamos National Laboratory), October 25, 1995. "Draft Groundwater Protection Management Program Plan," Revision 2.0, prepared by Water Quality and Hydrology Group (ESH-18), Los Alamos National Laboratory Report, Los Alamos, New Mexico. **(LANL 1995, ER ID Number 50124)**

LANL (Los Alamos National Laboratory), December 6, 1996. "Hydrogeologic Workplan," Revision 1.0, Draft, Los Alamos National Laboratory Report, Los Alamos, New Mexico. **(LANL 1996, ER ID Number 55430)**

LANL (Los Alamos National Laboratory), April 1997. "Core Document for Canyons Investigations," Los Alamos National Laboratory Report LA-UR-96-2083, Los Alamos, New Mexico. **(LANL 1997, ER ID Number 55622)**

Laughlin, A. W., G WoldeGabriel, and D. Dethier, October 29, 1993. "Volcanic Stratigraphy of the Pajarito Plateau," Preliminary Report FY93, Los Alamos National Laboratory, Los Alamos, New Mexico. **(Laughlin et al. 1993, ER ID Number 54424)**

Loeffler, B. M., D. T. Vaniman, W. S. Baldridge, and M. Shafiqullah, June 10, 1988. "Neogene Rhyolites of the Northern Jemez Volcanic Field, New Mexico," in *Journal of Geophysical Research*, Vol. 93, No. B6, published by the American Geophysical Union, pp. 6157–6167. **(Loeffler et al. 1988, ER ID Number 54409)**

MacFadden, B. J., 1977. "Magnetic Polarity Stratigraphy of the Chamita Formation Stratotype (Mio-Pliocene) of North-Central New Mexico," in *American Journal of Science*, Vol. 277, pp. 769–800. **(MacFadden 1977, ER ID Number 21569)**

Manley, K., 1979. "Stratigraphy and Structure of the Española Basin, Rio Grande Rift, New Mexico," in *Rio Grande Rift: Tectonics and Magmatism*, R. Riecker (Ed.), American Geophysical Union, Washington, DC, pp. 71–86. **(Manley 1979, ER ID Number 11714)**

McLin, S. G., 1992. "Determination of 100-Year Floodplain Elevations at Los Alamos National Laboratory," Los Alamos National Laboratory Report LA-12195-MS, Los Alamos, New Mexico. **(McLin 1992, ER ID Number 12014)**

McLin, S. G., October 1993. "Analysis of Rockfall Hazards at Los Alamos National Laboratory," in *Fourth DOE Natural Phenomena Hazards Mitigation Conference Proceedings*, CONF-9310102, Vol. 2, Atlanta, Georgia. **(McLin 1993, ER ID Number 50127)**

Nyhan, J. W., L. W. Hacker, T. E. Calhoun, and D. L. Young, June 1978. "Soil Survey of Los Alamos County, New Mexico," Los Alamos Scientific Laboratory Report LA-6779-MS, Los Alamos, New Mexico. **(Nyhan et al. 1978, ER ID Number 5702)**

Purtymun, W. D., August 1964. "Progress Report on the Hydrology of Mortandad Canyon, Disposal System for Treated Low-Level Liquid Radioactive Wastes, July 1961 to June 1963," US Geological Survey Administrative Release, Albuquerque, New Mexico. **(Purtymun 1964, ER ID Number 11822)**

Purtymun, W. D., June 1967. "The Disposal of Industrial Effluents in Mortandad Canyon, Los Alamos County, New Mexico," US Geological Survey Administrative Release, Santa Fe, New Mexico. **(Purtymun 1967, ER ID Number 8987)**

Purtymun, W. D., April 1973. "Regional Survey of Tritium in Surface and Ground Water in the Los Alamos Area, New Mexico, August 1966 through May 1969," Los Alamos Scientific Laboratory Report LA-5234-MS, Los Alamos, New Mexico. **(Purtymun 1973, ER ID Number 4971)**

Purtymun, W. D., September 1974. "Dispersion and Movement of Tritium in a Shallow Aquifer in Mortandad Canyon at the Los Alamos Scientific Laboratory," Los Alamos Scientific Laboratory Report LA-5716-MS, Los Alamos, New Mexico. **(Purtymun 1974, ER ID Number 5476)**

Purtymun, W. D., 1975. "Geohydrology of the Pajarito Plateau with Reference to Quality of Water, 1949-1972," Los Alamos Scientific Laboratory Informal Report, Los Alamos, New Mexico. **(Purtymun 1975, ER ID Number 11787)**

Purtymun, W. D., January 1984. "Hydrologic Characteristics of the Main Aquifer in the Los Alamos Area: Development of Ground Water Supplies," Los Alamos National Laboratory Report LA-9957-MS, Los Alamos, New Mexico. **(Purtymun 1984, ER ID Number 6513)**

Purtymun, W. D., January 1995. "Geologic and Hydrologic Records of Observation Wells, Test Holes, Test Wells, Supply Wells, Springs, and Surface Water Stations in the Los Alamos Area," Los Alamos National Laboratory Report LA-12883-MS, Los Alamos, New Mexico. **(Purtymun 1995, ER ID Number 45344)**

Purtymun, W. D., J. R. Buchholz, and T. E. Hakonson, 1977. "Chemical Quality of Effluents and Their Influence on Water Quality in a Shallow Aquifer," *Journal of Environmental Quality*, Vol. 6, No. 1, pp. 29-32. **(Purtymun et al. 1977, ER ID Number 11846)**

Purtymun, W. D., E. A. Enyart, and S. G. McLin, August 1989. "Hydrologic Characteristics of the Bandelier Tuff as Determined Through an Injection Well System," Los Alamos National Laboratory Report LA-11511-MS, Los Alamos, New Mexico. **(Purtymun et al. 1989, ER ID Number 6889)**

Purtymun, W. D., W. R. Hansen, and R. J. Peters, March 1983. "Radiochemical Quality of Water in the Shallow Aquifer in Mortandad Canyon 1967–1978," Los Alamos National Laboratory Report LA-9675-MS, Los Alamos, New Mexico. **(Purtymun et al. 1983, ER ID Number 6407)**

Purtymun, W. D., and W. R. Kennedy, May 1971. "Geology and Hydrology of Mesita del Buey," Los Alamos Scientific Laboratory Report LA-4660, Los Alamos, New Mexico. **(Purtymun and Kennedy 1971, ER ID Number 4798)**

Purtymun, W. D., and F. C. Koopman, 1965. "Physical Characteristics of the Tshirege Member of the Bandelier Tuff with Reference to Use as a Building and Ornamental Stone," prepared for the Community Action Program, Santa Clara Indian Pueblo, in cooperation with the US Atomic Energy Commission and the University of California, US Geological Survey, Albuquerque, New Mexico. **(Purtymun and Koopman 1965, ER ID Number 11839)**

Purtymun, W. D., F. C. Koopman, S. Barr, and W. E. Clements, October 1974. "Air Volume and Energy Transfer Through Test Holes and Atmospheric Pressure Effects on the Main Aquifer," Los Alamos Scientific Laboratory Report LA-5725-MS, Los Alamos, New Mexico. **(Purtymun et al. 1974, ER ID Number 5477)**

Purtymun, W. D., and J. L. Kunkler, March 1967. "The Chemical and Radiochemical Quality of Surface and Ground Water at Los Alamos, New Mexico, July 1965 through June 1966," US Geological Survey Administrative Release, Albuquerque, New Mexico. **(Purtymun and Kunkler 1967, ER ID Number 11782)**

Purtymun, W. D., and A. K. Stoker, November 1987. "Environmental Status of Technical Area 49, Los Alamos, New Mexico," Los Alamos National Laboratory Report No. LA-11135-MS, Los Alamos, New Mexico. **(Purtymun and Stoker 1987, ER ID Number 6688)**

Purtymun, W. D., R. Peters, and M. N. Maes, July 1990. "Transport of Plutonium in Snowmelt Run-Off," Los Alamos National Laboratory Report LA-11795-MS, Los Alamos, New Mexico. **(Purtymun et al. 1990, ER ID Number 6992)**

Purtymun, W. D., M. L. Wheeler, and M. A. Rogers, May 1978. "Geologic Description of Cores from Holes P-3 MH-1 Through P-3 MH-5, Area G, Technical Area 54," Los Alamos Scientific Laboratory Report LA-7308-MS, Los Alamos, New Mexico. **(Purtymun et al. 1978, ER ID Number 5728)**

Reneau, S. L., June 1995. "Geomorphic Studies at DP Mesa and Vicinity," in *Earth Science Investigation for Environmental Restoration—Los Alamos National Laboratory Technical Area 21*, Los Alamos National Laboratory Report LA-12934-MS, Los Alamos, New Mexico, pp. 65–92. **(Reneau 1995, ER ID Number 50143)**

Reneau, S. L., D. P. Dethier, and J. S. Carney, 1995. "Landslides and Other Mass Movements Near Technical Area 33, Los Alamos National Laboratory," Los Alamos National Laboratory Report LA-12955-MS, Los Alamos, New Mexico. **(Reneau et al. 1995, ER ID Number 54405)**

Reneau, S. L., J. N. Gardner, and S. L. Forman, January 1996. "New evidence for the age of the youngest eruptions in the Valles caldera, New Mexico," *Geology*, Vol. 24, No. 1, pp. 7–10. **(Reneau et al. 1996, ER ID Number 57002)**

Reneau, S. L., and E. V. McDonald, 1996. "Landscape History and Processes on the Pajarito Plateau, Northern New Mexico," Rocky Mountain Cell, Friends of the Pleistocene, Field Trip Guidebook, unpublished Los Alamos National Laboratory Report LA-UR-96-3035, Los Alamos, New Mexico. **(Reneau and McDonald 1996, ER ID Number 55538)**

Reneau, S. L., E. V. McDonald, J. N. Gardner, T. R. Kolbe, J. S. Carney, P. M. Watt, and P. A. Longmire, 1996. "Erosion and Deposition on the Pajarito Plateau, New Mexico, and Implications for Geomorphic Responses to Late Quaternary Climatic Changes," in *New Mexico Geological Society Guidebook,* 47th Field Conference, Jemez Mountains Region, New Mexico, pp. 391–397. **(Reneau et al. 1996, ER ID Number 55539)**

Reneau, S. L. and D. T. Vaniman, in preparation. "Fracture Characteristics in a Disposal Pit on Mesita del Buey," Los Alamos National Laboratory Report, Los Alamos, New Mexico. **(Reneau and Vaniman, in preparation, ER ID Number 55122)**

Rogers, D. B., and B. Gallaher, September 1995. "The Unsaturated Hydraulic Characteristics of the Bandelier Tuff," Los Alamos National Laboratory Report LA-12968-MS, Los Alamos, New Mexico. **(Rogers and Gallaher 1995, ER ID Number 55334)**

Rogers, D. B., B. M. Gallaher, and E. L. Vold, 1996. "Vadose Zone Infiltration Beneath the Pajarito Plateau at Los Alamos National Laboratory," Los Alamos National Laboratory Report LA-UR-96-485, in press: New Mexico Geological Society - 1996 Guidebook, Geology of the Los Alamos - Jemez Mountains Region. **(Rogers et al. 1996, ER ID Number 55543)**

Rogers, D. B., A. K. Stoker, S. G. McLin, and B. M. Gallaher, 1996. "Recharge to the Pajarito Plateau Regional Aquifer System," Los Alamos National Laboratory Report LA-UR-96-486, in press: New Mexico Geological Society - 1996 Guidebook, Geology of the Los Alamos - Jemez Mountains Region. **(Rogers et al. 1996, ER ID Number 54714)**

Rogers, M. A., 1995. "Geologic Map of the Los Alamos National Laboratory Reservation," prepared by Mara, Inc., Los Alamos, New Mexico. **(Rogers 1995, ER ID Number 54419)**

Rosenberg, N. D., W. E. Soll, and H.J. Turin, December 1993. "Potential Transport of PCBs Through Fractured Tuff at Area G," Los Alamos National Laboratory Report LA-UR-94-28, Los Alamos New Mexico. **(Rosenberg et al. 1993, ER ID Number 46223)**

Sanford, A. R., A. J. Budding, J. P. Hoffman, O. S. Alptekin, C. A. Rush, and T. R. Toppozada, 1972. "Seismicity of the Rio Grande Rift in New Mexico," Circular 120, New Mexico State Bureau of Mines and Mineral Resources, Socorro, New Mexico. **(Sanford et al. 1972, ER ID Number 11858)**

Santa Fe *Daily New Mexican,* October 15, 1882. Article on p. 2, Column 2, transcribed by J. Gardner from Microfilm #37, New Mexico State Historical Museum, Santa Fe, New Mexico. **(Santa Fe *Daily New Mexican* 1882, ER ID Number 57005)**

Self, S., F. Goff, J. N. Gardner, J. V. Wright, and W. M. Kite, 1986. "Explosive Rhyolitic Volcanism in the Jemez Mountains: Vent Locations, Caldera Development, and Relation to Regional Structure," in *Journal of Geophysical Research*, Vol. 91, pp. 1779–1798. **(Self et al. 1986, ER ID Number 21579)**

Smith, R. L., June 1960. "Ash Flows," in *Bulletin of the Geological Society of America*, Vol. 71, pp. 795–842. **(Smith 1960, ER ID Number 48820)**

Smith, R. L., 1960. "Zones and Zonal Variations in Welded Ash Flows," US Geological Survey Professional Paper 354-F, pp. 149–159, Washington, DC. **(Smith 1960, ER ID Number 48819)**

Smith, R, L., and R. A. Bailey, 1966. "The Bandelier Tuff: A Study of Ash-Flow Eruption Cycles from Zoned Magma Chambers," *Bulletin Volcanologique*, Vol. 29, pp. 83-104. **(Smith and Bailey 1966, ER ID Number 21584)**

Smith, R. L., R. A. Bailey, and C. S. Ross, 1970. "Geologic Map of Jemez Mountains, New Mexico," US Geological Survey Miscellaneous Investigations Series, Map I-571, Washington, D.C. **(Smith et al. 1970, ER ID Number 9752)**

Sogge, M. K., R. M. Marshall, S. J. Sferra, and T. J. Tibbitts, May 1997. "A Southwestern Willow Flycatcher Natural History Summary and Survey Protocol," National Park Service Technical Report NPS/NAUCPRS/NRTR-97/12 [Online]. Available at http://www.nbs.nau.edu/FNF/PIF/protocol.html **(Sogge et al. 1997, ER ID Number 57040)**

Spell, T. L., T. M. Harrison, and J. A. Wolf, January 18, 1990. "$^{40}Ar/^{39}Ar$ Dating of the Bandelier Tuff and San Diego Canyon Ignimbrites, Jemez Mountains, New Mexico: Temporal Constraints on Magmatic Evolution," *Journal of Volcanology and Geothermal Research*, Vol. 43., pp. 175-193. **(Spell et al. 1990, ER ID Number 21586)**

Spell, T. L., I. McDougall, and A. P. Doulgeris, December 1996. "Cerro Toledo Rhyolite, Jemez Volcanic Field, New Mexico: $^{40}Ar/^{39}Ar$ geochronology of eruptions between two caldera-forming events," in *Geological Society of America Bulletin,* Vol. 108, No. 12, pp. 1549–1566. **(Spell et al. 1996, ER ID Number 55542)**

Spiegel, Z., and B. Baldwin, 1963. "Geology and Water Resources of the Santa Fe Area, New Mexico," abstract from the Rock Mountain Ground Water Conference Proceedings, New Mexico Section, Albuquerque, New Mexico. **(Spiegel and Baldwin 1963, ER ID Number 54259)**

Stephens, D. B., P.M. Kearl, and R.W. Lee, 1993. "Hydrogeologic Review for the Environmental Restoration Program at Los Alamos National Laboratory," Los Alamos National Laboratory Report, 68 p., Los Alamos, New Mexico. **(Stephens et al. 1993, ER ID Number 56863)**

Stix, J., F. Goff, M. P. Gorton, G. Heiken, and S. R. Garcia, June 10, 1988. "Restoration of Compositional Zonation in the Bandelier Silicic Magma Chamber Between Two Caldera-Forming Eruptions: Geochemistry and Origin of the Cerro Toledo Rhyolite, Jemez Mountains, New Mexico," in *Journal of Geophysical Research*, Vol. 93, No. B6, pp. 6129–6147. **(Stix et al. 1988, ER ID Number 49680)**

Stoker, A. K., March 31, 1993. "Direct Testimony of Alan K. Stoker on Behalf of Petitioners," before the New Mexico Water Quality Control Commission, Los Alamos, New Mexico. **(Stoker 1993, ER ID Number 56021)**

Stoker, A. K., S. G. McLin, W. D. Purtymun, M. N. Maes, and B. G. Hammock, 1992. "Water Supply at Los Alamos During 1989," Los Alamos National Laboratory Report LA-12276-PR, Los Alamos, New Mexico. **(Stoker et al. 1992, ER ID Number 12017)**

Stoker, A. K., W. D. Purtymun, S. McLin, and M. Maes, May 1991. "Extent of Saturation in Mortandad Canyon," Los Alamos National Laboratory Report LA-UR-91-1660, Los Alamos, New Mexico. **(Stoker et al. 1991, ER ID Number 7530)**

Thoma, S. G., D. P. Gallegos, and D. M. Smith, 1992. "Impact of Fracture Coatings on Fracture/Matrix Flow Interactions in Unsaturated, Porous Media," Water Resources Research, Vol. 28, No. 5, pp. 1357-1368. **(Thoma et al. 1992, ER ID Number 57004)**

Toyoda, S., F. Goff, S. Ikeda, and M. Ikeya, 1995. "ESR dating of quartz phenocrysts in the El Cajete and Battleship Rock Members of Valles Rhyolite, Valles Caldera, New Mexico," *Journal of Vulcanology and Geothermal Research,* Volume 67, pp. 29–40. **(Toyoda et al. 1996, ER ID Number 57001)**

Turbeville, B. N., D. B. Waresback, and S. Self, February 1989. "Lava-Dome Growth and Explosive Volcanism in the Jemez Mountains, New Mexico: Evidence from the Plio-Pliestocene Puye Alluvial Fan," *Journal of Volcanology and Geothermal Research,* Vol. 36, pp. 267-291. **(Turbeville et al. 1989, ER ID Number 21587)**

van Genuchten, M. Th., 1980. "A Closed-Form Equation for Predicting the Hydraulic Conductivity of Unsaturated Soils," in *Soil Science Society of America Journal,* Vol. 44, p. 892. **(van Genuchten 1980, ER ID Number 49927)**

Vaniman, D., July 29, 1991. "Revisions to Report EES1-SH90-17," Los Alamos National Laboratory Memorandum EES1-SH91-12 to J. Gardner (EES-1) from D. Vaniman (EES-1), Los Alamos, New Mexico. **(Vaniman 1991, ER ID Number 9995)**

Vaniman, D., and K. Wohletz, November 14, 1990. "Results of Geological Mapping/Fracture Studies: TA-55 Area," Los Alamos National Laboratory Memorandum EES1-SH90-17, Los Alamos, New Mexico. **(Vaniman and Wohletz 1990, ER ID Number 21589)**

Vuataz, F.D. and F. Goff, 1986. "Isotope Geochemistry of Thermal and Nonthermal Waters in the Valles Caldera, Jemez Mountains, Northern New Mexico," *Journal of Geophysical Research,* Vol. 91, p. 1835-1853. **(Vautaz and Goff 1986, ER ID Number 40083)**

Weir, J. E., Jr., and W. D. Purtymun, 1962. "Geology and Hydrology of Technical Area 49, Frijoles Mesa, Los Alamos County, New Mexico," US Geological Survey Administrative Release, Albuquerque, New Mexico. **(Weir and Purtymun 1962, ER ID Number 11890)**

Weir, J. E., Jr., J. H. Abrahams, Jr., J. F. Waldron, and W. D. Purtymun, April 1963. "The Hydrology and the Chemical and Radiochemical Quality of Surface and Ground Water at Los Alamos, New Mexico, 1949-55," US Geological Survey Administrative Release, Albuquerque, New Mexico. **(Weir et al. 1963, ER ID Number 11892)**

Wheeler, M. L., W. J. Smith, and A. F. Gallegos, February 1977. "A Preliminary Evaluation of the Potential for Plutonium Release from Burial Grounds at Los Alamos Scientific Laboratory," Los Alamos Scientific Laboratory Report LA-6694-MS, Los Alamos, New Mexico **(Wheeler et al. 1977, ER ID Number 5577)**

Wohletz, K., June 1995. "Measurement and Analysis of Rock Fractures in the Tshirege Member of the Bandelier Tuff along Los Alamos Canyon Adjacent to TA-21," in *Earth Science Investigations for Environmental Restoration—Los Alamos National Laboratory Technical Area 21,* D. E. Broxton and P. G. Eller (Eds.), Los Alamos National Laboratory Report, LA-12934-MS, Los Alamos, New Mexico. **(Wohletz 1995, ER ID Number 54404)**

WoldeGabriel, G., A. W. Laughlin, D. P. Dethier, and M. Heizler, 1996. "Temporal and Geochemical Trends of Lavas in White Rock Canyon and the Pajarito Plateau, Jemez Volcanic Field, New Mexico, USA," Los Alamos National Laboratory Report LA-UR-96-583, Los Alamos, New Mexico. **(WoldeGabriel et al. 1996, ER ID Number 54427)**