INSPECTION COVER SHEET
**Comprehensive Ground Water Monitoring Evaluation**
U.S. Environmental Protection Agency
Region 6, Dallas, Texas

**EPA I.D. No.:** NM089010515

**Name of Facility:** Los Alamos National Laboratory

**Mailing Address:** P.O. Box 1663, Los Alamos, New Mexico 87545

**Location:** Los Alamos Area Office, Los Alamos, New Mexico

**Telephone:** (505) 667-5288

**Type of Facility:** Research facility containing areas designated to work on space technology, nuclear weapons, health and medical research, nuclear reactors, basic nuclear and particle physics, and non-nuclear ordinance.

**Date of Inspection:** August 3 - 6, 1993

**Type of Inspection:** Lead EPA inspection at a Federal Facility as part of a Multi-Media Inspection

**Inspection Participants:**

| NAME | AGENCY/COMPANY | TELEPHONE |
|---|---|---|
| Greg Lyssy | U.S. EPA | 214-655-8317 |
| Steve Alexander | NMED | 505-827-4308 |
| Terry Davis | NMED | 505-671-0448 |
| Alice Barr | Los Alamos | 505-667-0820 |
| Alan Stoker | Los Alamos | 505-667-0818 |

**Report Prepared By:** Greg J. Lyssy GJL **Date:** March 16, 1994

**Concurred By:** Ronald D. Crossland RDC **Date:** March 16, 1994



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## TABLE OF CONTENTS

1. Inspection Cover Sheet ..... Page 1
2. Table of Contents ..... Page 2
3. Inspection Summary ..... Page 3
4. Inspection Recommendations ..... Page 5
5. CME Technical Report
   - Introduction -- (Section 1) ..... Page 6
   - Applicability and Site Characterization -- (Section 2) ..... Page 13
   - Monitoring Well System -- (Section 3) ..... Page 24
6. Figures
   - Figure 1 -- LANL Location Map ..... Page A-1
   - Figure 2 -- General Topographic Features Map ..... Page A-2
   - Figure 3 -- Generalized Geologic Cross-Section ..... Page A-3
   - Figure 4 -- Generalized 3-D Cross-Section ..... Page A-4

## INSPECTION SUMMARY

### GENERAL COMMENTS

- LANL has ground water monitoring waivers on file at the facility for the following areas:

  TA 54 Area L & G
  TA 35 125 Surface Impoundment (SI) & 85 SI
  TA 53 Northwest SI, Northeast SI, & South SI
  TA 16 Area P SI & Area P Landfill

- All of these ground water monitoring waivers should be reviewed by NMED to determine if they are still adequate and appropriate based upon additional information provided from recent investigations and studies at LANL.

### TECHNICAL CONCERNS

- There is insufficient final cover on the Area P landfill in TA 16. The landfill does not appear to have any run-on or run-off controls and there are numerous erosion channels transecting the landfill. These erosion channels are providing a direct path for possible contaminant migration to the wetlands area in Canon de Valle below the landfill. In addition, the wetlands in Canon de Valle appear to bisect the toe of the landfill. The wetland areas could be in direct communication with a potential migration pathway. Numerous intact laboratory chemical bottles were also present in the landfill. Some of these bottles may still contain chemical constituents which could migrate from the landfill. The Area P landfill is currently inactive and pending closure.

- Two wells in TA 54 Area G, due east of Area L, consisted of open steel casings without caps or locks. These open wells are possible contaminant migration pathways and should be properly abandoned. In addition, two soil-gas cluster wells in Area G were not locked.

- Several monitoring wells and/or neutron moisture wells have grout that is cracked and/or pulled away from the casing. These wells may have lost their integrity and should be repaired or replaced. During the inspection, the following wells were noted with grout integrity problems.

| | |
|---|---|
| MCO-4.0 | TW 1-53 |
| MCO-3.0 | TW 3-53 |

### GROUND WATER MONITORING CONCERNS

- The current facility-wide ground water monitoring program does not appear to adequately characterize the ground water flow regime beneath the facility. The recharge areas for the main aquifer and the perched-intermediate aquifer have not been completely identified. It is not known if a significant quantity of water is recharging the main aquifer through the fracture fault zones at Pajarito Plateau. Most RCRA operating permits, closure plans, and annual surveillance reports state that "major recharge to the main aquifer is from the intermontane basin of the Valles Caldera in the Jemez Mountains west of Los Alamos". The

water-level map published by LANL suggests a recharge area to the west. The Pajarito fault zone at the west edge of the plateau could provide a pathway for some of this recharge. However, stable-isotope data suggest that some component of recharge occurs at elevations higher than available in the Jemez Mountains. The Sangre de Cristo Mountains have been suggested as the site of these higher elevations. Further work is needed on this matter.

- The ground water flow directions of the main aquifer and perched intermediate aquifer, as influenced by the numerous production wells in the LANL area, have not been completely determined. There are nineteen public water supply wells in the LANL area. Ground water flow will be towards the pumping supply wells. Ground water potentiometric maps should depict the actual conditions at the facility.

- Recent transducer studies by LANL indicate that barometric pressure influences ground water levels in the main aquifer. This would seem to indicate that the main aquifer is confined or semi-confined. Additional testing should be conducted to verify the confining characteristics of the main aquifer. Previous studies and/or modeling have used the assumption that the aquifer was unconfined. The old studies should be reviewed and revised, as necessary, to utilize the new information, once collected.

- The HSWA portion of the RCRA Permit required the installation of ground water monitoring wells in the Los Alamos Canyon shallow alluvium to determine if the old LAO-series of wells installed in the mid-1960's provide accurate ground water monitoring data. As per the Permit, the new wells were installed and sampled once in 1990. Preliminary results from the one sampling event seem to indicate that there are increases in concentrations of constituents in the ground water in the new HSWA ground water monitoring wells when compared to the old LAO-series of wells. It is therefore recommended that additional sampling events be conducted in both series of wells, so that a statistical comparison can be performed.

- The ground water monitoring waiver for TA 54 Area L & G states: 1) there is not a perched water table at these areas, and 2) there is not any hydraulic connection to the main aquifer. However, there are not any ground water monitoring wells in the vicinity of Area L & G which verify this statement. It is understood that LANL was preparing to install a monitoring well penetrating the main aquifer, just east of TA 54, which could have been used to provide this information. However, it is also understood that due to budget constraints, the proposed installation of this well has been halted. It is recommended that this well be installed as expeditiously as possible in order to verify the ground water conditions in this area.

- LANL has conducted extensive soil-gas monitoring at TA 54 Area L in order to characterize the vapor contamination in the vadose zone. It is recommended that LANL and EPA meet to discuss the results of the soil-gas monitoring.

## INSPECTION RECOMMENDATIONS

- All of the ground water monitoring waivers should be reviewed by NMED to determine if they are still adequate and appropriate based upon additional information provided from recent investigations and studies at LANL. In order to fully evaluate the ground water monitoring waiver at TA-54, a ground water monitoring well may need to be installed downgradient of TA 54 to determine if the main aquifer has been impacted. If a perched ground water table is encountered, a ground water monitoring well should also be installed in the perched zone.

- LANL, NMED, and EPA need to schedule a meeting to discuss the results of LANL's soil-gas monitoring.

- The recharge areas for the main aquifer and the perched intermediate aquifer must be determined to see what impact the waste handling practices of LANL will have on the aquifers. The location of the recharge areas and the rate of recharge must be determined.

- The ground water monitoring wells in the shallow alluvium of Los Alamos Canyon should be resampled for the target analytes to determine the impact of facility operations to the ground water in the Canyon. If the old LAO-series wells are acting as a possible contaminant migration pathway, they should be properly abandoned following NMED requirements.

# CME TECHNICAL REPORT

## SECTION 1 -- INTRODUCTION

**I. Facility:** Los Alamos National Laboratory

**II. Facility Background:**

Los Alamos National Laboratory (LANL) is located west of the Rio Grande in Los Alamos County, approximately forty miles northwest of Santa Fe, New Mexico (Figure 1). Geologically, it is located on the Pajarito Plateau, an area of deeply dissected Quaternary-aged volcanic deposits and Tertiary fill of the Espanola Basin. The volcanics belong primarily to the Bandelier Tuff. The Bandelier Tuff consists of rhyolitic ash flows and pumice falls that were derived from the Valles Caldera in the Jemez Mountains to the west. The basin fill is represented by the Puye Conglomerate (fanglomerate, lake clays, basalt flows, and ash and river gravels) and the Tesuque Formation (mostly poorly-consolidated sand and gravel). The average elevation of the resulting finger-like mesas is approximately 7,000 feet. The area is drained by ephemeral and intermittent streams that flow easterly to the Rio Grande, lying some 1,450 feet below the Plateau. Regional ground water flow is also generally eastward except near the public water supply well fields.

Radioactive and hazardous waste has been generated and disposed of at LANL since its inception in 1943. There are twenty-three Materials Disposal Areas (MDAs): A, B, C, D, E, F, G, H, J, K, L, M, N, P, Q, R, S, T, U, V, W, X, and Y. All such sites are considered potential sources of ground water contamination. A 1975 report summarized burial conditions and environmental monitoring at eight of these MDAs (A, B, C, D, E, F, G and T) in conjunction with an evaluation of monitoring efforts at LANL. A 1977 report made a two-volume compilation of the history and environmental setting of the same MDAs covered by the 1975 report. Volume I includes background (historical) information on the site, the geologic and hydrologic setting, type of waste involved, and the mode of disposal. Volume II consists of Appendices including a list of photos, slides and engineering drawings, LANL's solid radwaste management policy, the guidelines for disposal pit construction, and records of disposal in Tech Area 54, Area G shafts.

Waste-disposal sites were identified by LANL as part of the Comprehensive Environmental Assessment and Response Program (CEARP), under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). A Resource Conservation and Recovery Act (RCRA) Facility Assessment (RFA), conducted by A.T. Kearney in 1987 for the Lab, provided additional information on Solid Waste Management Units (SWMUs) at LANL. In 1988, a draft SWMU report, providing "reasonably available" information, was submitted to the Environmental Protection Agency (EPA). The 1988 draft SWMU report was revised by International Technology Corporation under contract to LANL and includes an update on SWMU's identified at LANL in 1990. The 1990 report identifies 537 SWMU's located in 50 active and former Technical Areas. The current number of potentially contaminated areas at the facility is approximately 2,000. Many of these are minor and will probably be handled under Voluntary Corrective Actions or No Further Action proposals. The RCRA permit was recently modified and LANL is required to investigate 101 SWMU's.

DP-LA Canyon received treated industrial (including radioactive) and sanitary effluent between 1952 and 1984. The effluent, together with natural runoff, resulted in a shallow body of perched ground

water in the alluvium of LA Canyon.

Sandia Canyon received cooling tower blowdown and treated sanitary effluent from TA-3. The stream in the canyon is perennial for a short distance downstream of the outfall in the upper canyon. No perched ground water has been identified in the alluvium of the lower canyon.

Mortandad Canyon received radioactive liquid waste from TA-50. This maintains a perched ground water body in the alluvium on the canyon floor. A 1974 report stated that this water moves at a rate ranging from 59 ft/d in upper reach to 7 ft/d in the lower reach of the canyon. Elevated $NO_3$, Pu, and Tritium ($^3H$) have been identified in Mortandad Canyon.

Acid-Pueblo Canyon received radioactive effluent from 1944 to 1964 and receives treated sanitary effluent from the Los Alamos County Bayo Canyon sewage treatment plant. In 1990, the sewage effluent produced flow in lower Pueblo Canyon and into Los Alamos Canyon for most of the year. However, subsequent sampling in the canyon indicated that Pu values were below detection and $^3H$ content was at background level, which is very near its detection limit.

## III. LANL's Conceptual Ground Water Model:

- Ground water occurs in three situations at LANL:
  - * perched water in alluvium in canyons,
  - * perched water in basalts and sedimentary units of the Puye Conglomerate, and
  - * ground water in the main aquifer.
- The alluvium on canyon floors is recharged by surface-water runoff.
- The main aquifer consists of the Tesuque Formation and the lower parts of the overlying Tschicoma Formation (in the western part of the Pajarito Plateau), and the Tesuque Formation and overlying Puye Conglomerate (in the central and eastern parts of the Pajarito Plateau).
- Water in the main aquifer is separated from that in the shallow alluvium and other perched systems by 250 - 620 feet of unsaturated tuff and sediments.
- There is little or no recharge of the main aquifer from the mesas, the shallow alluvium, or other perched ground water.
- The main aquifer is recharged in the Valles Caldera, west of the LANL.
- Ground water in the main aquifer flows easterly until discharging to the Rio Grande.
- Tritium was found at a depth of approximately 200 feet within the Bandelier Tuff. Other radionuclides have apparently moved only a few feet beneath the alluvial aquifer. No organic contaminants were detected above, in, or below the perched water in the alluvium.
- Saturation is confined to a relatively thin zone in the Mortendad Canyon shallow alluvium, extending 5 - 20 feet above the contact of the alluvium with the underlying Tshirege Member

of the Bandelier Tuff. Thickness of the saturated zone in Mortendad Canyon decreases towards the canyon margins. Since 1960, the saturated portion of the alluvium aquifer in Mortendad Canyon has neither changed significantly in size nor moved down canyon.

## IV. Facility Ground Water Monitoring Network:

LANL's 1990 Surveillance Report identifies forty-three ground water monitoring wells. Of the forty-three, twenty-six are deep and target the main aquifer and seventeen are shallow and monitor perched water in the alluvium. Of the twenty-six deep wells, nineteen are public water supply wells; the remaining seven are test wells which were used to determine aquifer characteristics. The supply wells used for monitoring include seven in the Guaje well field, six in the Los Alamos well field, and six in the Pajarito well field. None of the shallow wells are public water supply wells. In addition to these wells, ground water is also monitored by means of thirty-three springs that primarily discharge along the eastern edge of the plateau in White Rock Canyon.

Different sites at LANL are analyzed for slightly different lists of parameters. Springs in White Rock Canyon are monitored for sixteen non-radioactive parameters ($SiO_2$, Ca, Mg, K, Na, $CO_3$, $HCO_3$, P, $SO_4$, Cl, F, $NO_3$-N, TDS, hardness, pH, specific conductance), six radiochemical parameters (Tritium, $^{137}Cs$, total U, $^{238}Pu$, $^{239/240}Pu$, gross gamma) and twenty trace metals (Ag, Al, As, B, Ba, Be, Cd, Cr, Cu, Fe, Mn, Ni, Pb, Sb, Se, Sr, Tl, U, V, Zn). Ground water in supply wells and the water distribution system at LANL is monitored for six radiochemical parameters (gross alpha, gross beta, Tritium, $^{238}Pu$, $^{239/240}Pu$, and total U), eighteen EPA primary/secondary standards (Ag, As, Ba, Cd, Cr, F, Hg, $N0_3$-N, Pb, Se, Cl, Cu, Fe, Mn, $SO_4$, Zn, TDS, pH), and twenty other parameters (Al, $SiO_2$, Ca, Mg, K, Na, $CO_3$, $HCO_3$, P, hardness, specific conductance, B, Mo, Sr, V, Be, Ni, Sb, Tl, $NO_2$-N). Ground water is also monitored for organic compounds: sixty-eight volatiles, seventy-one semi-volatiles, nineteen pesticides, two herbicides, and four PCB's.

Existing wells are employed in the monitoring network where possible. However, the large number of water-supply wells used for monitoring at LANL is a concern. Wells constructed for supply have large screened intervals in order to maximize water production. Ground water monitoring wells are screened over a narrow interval to provide information on a discrete portion of the aquifer. The wells drilled as part of the RCRA permit requirements are not currently included in LANL's Environmental Surveillance network.

## V. NMED's Assessment of LANL's Ground Water Monitoring

NMED's 1993 *Initial Assessment of the Ground Water Monitoring Program at LANL* Report had the following concerns with LANL's ground water monitoring program:

- The recharge area(s) for the main aquifer under the Pajarito Plateau has not been clearly identified. Most RCRA operating permits, closure plans, and annual surveillance reports state that "major recharge to the main aquifer is from the intermontane basin of the Valles Caldera in the Jemez Mountains west of Los Alamos". The water-level map published by LANL suggests a recharge area to the west. The Pajarito fault zone at the west edge of the plateau could provide a pathway for some of this recharge. However, stable-isotope data gathered by LANL suggest that some component of recharge occurs at elevations higher than available in the Jemez Mountains. The Sangre de Cristo Mountains have been suggested as the site of these higher elevations. Further work is needed on this matter.

- Maps published by LANL show that the main aquifer is generally unconfined, except in a wedge-shaped area near the central part of Los Alamos County. Since unconfined conditions suggest connection with the surface (i.e. atmospheric conditions occur at the water table), the common contention in operating permits and work plans, that the Bandelier Tuff is an impermeable barrier to recharge, does not seem to be valid over most of the plateau. Further work is needed to resolve this issue.

- Perched water beneath the Bandelier Tuff suggests that there is recharge through the tuff. Various methods of monitoring recharge (e.g. chloride mass balance, chlorine 36, etc) should determine if ground water is migrating through the Bandelier Tuff.

- TW-l is a deep ground water observation well that shows a fifty-foot water mound. TW-lA is completed in perched water above the screened interval of TW-l. The perched water from TW-l A and the alluvial water in this area have similar chemistry, different from that in TW-l. This situation raises questions concerning the effectiveness of the Bandelier Tuff as a barrier to vertical migration and needs to be investigated.

- If Tritium has penetrated at least 200 feet beneath the alluvium aquifer in Mortandad Canyon, it seems possible that it could ultimately reach the main aquifer.

- The hydraulic properties of all aquifers should be characterized in the field through properly designed pumping tests, using appropriately constructed and placed wells. Such tests should include wells on both sides of major faults in order to better define the role of these structures as conduits, barriers, or inconsequential.

- Water level maps for the shallow, perched systems should be contoured separately from those for the deep (main) aquifer.

- Previously published water-level maps essentially depict pre-development conditions; no impacts of pumping at production wells (i.e. cones of depression) are indicated. However, water-level changes (i.e. drawdown values) are regularly given in the annual reports on the water supply at LANL. Modeling predicts significant cones of depression in the future as well. As ground water flow is toward such depressions, their position and extent are critical to both designing and evaluating the monitoring network. Water-level maps for LANL should include these features.

- Water-level maps commonly used for closure plans, RCRA Facility Investigation (RFI) Work Plans, operating permit applications, etc, all include data collected over 10 years ago at TA-49 in wells DT-5A, DT-9 and DT-10. The ground water potentiometric levels in the southwestern part of the Pajarito Plateau may not reflect actual conditions. It is understood that this is, in part, because there is no access port for water-level measurement at these wells. This should be remedied such that water levels can be monitored on a regular basis.

## VI. Hazardous Waste Management Units:

| UNIT | Waste Type | Size | Construction | Status/Age |
|---|---|---|---|---|
| TA 54 AREA G | Low-level radioactive materials, small quantities of asbestos, beryllium, empty pesticide containers, PCB contaminated solids | 63 acres | 31 pits; 4 trenches; over 100 shafts; 10 shafts are lined with steel pipe and concrete. Constructed in 1957. | Active. Some pre-1980 units have been possible targets of closure activities during the RFI process. |
| TA 54 AREA L | Organic and inorganic chemicals | 2.5 acres | 1 disposal pit, 1 surface impoundment, and 34 shafts. Constructed in 1964. | Active. Some pre-1980 units have been possible targets of closure activities during the RFI process. |
| TA 54 AREA H | Lithium Hydride 15 pounds | 1 shaft RCRA #9 regulated. 6-feet wide. 60 feet deep. | Filled to 25' below surface as of 3/86. Has a steel cap on top. | Active. Some pre-1980 units have been possible targets of closure activities during the RFI process. |
| TA 35 125 S.I. | Shell Dialia(R) Oil (Dielectic Oil) Received Spills from building 129. Cleaning degreasers were used in Bldg 129. | 29' X 31' 900 ft. sq. 5.7 feet deep 8000 gal | 1978 constructed 1979 used | Certified Clean Closure by LANL. Awaiting approval by NMED. |
| TA 35 85 S.I. | Shell Dialia(R) Oil (Dielectic Oil) Received spills from Building 85. Cleaning degreasers were used in Bldg 85. | 34 X 24' 816 ft sq. 4 feet deep 18,750 gal 7,640 gallons with 2' freeboard | 1985 built 1986 used gunite/ bentonite | LANL has received NOD on clean closure. NMED has requested amended closure plan. LANL has requested extension for submittal for additional 90 days |
| TA 53 NW SI | Sanitary, industrial and RAD wastes until 1989. Rad wastes were not sent to this SI after 1989. They were sent to the south pond | 210 X 210' 6 feet deep 1,629,000 gallons | 1969 built 1969 used gunite sides bentonite clay bottom 4 " thick | Closure pending approval of plan with NMED |
| TA 53 NE SI | Sanitary, industrial and RAD wastes until 1989. Rad wastes were not sent to this SI after 1989. They were sent to the south pond | 210 X 210' 6 feet deep 1,629,000 gallons | 1969 built 1969 used gunite sides bentonite clay bottom 4" thick | Closure pending. NMED has closure plan and it is currently under review. |

| UNIT | Waste Type | Size | Construction | Status/Age |
|---|---|---|---|---|
| TA 53 South Pond | Sanitary, Industrial and Rad wastes until 1989. From 1989 on it received predominantly RAD wastes, but would periodically from two other impoundments to weigh down the liner as well as to avoid concentrating RAD components in liquid. | 305 X 148'<br>6 feet deep<br>2,580,000 gallons | 1985 built<br>1985 used<br>36 mil Hypalon Liner | Active Unit |
| TA 16 SI | Barium liquids, | 60 X 40'<br>8-foot deep<br>2,400 sq ft<br>18,600 gal | 1985 constructed<br>1985 used<br>Hypalon Liner | LANL certified clean closure. NMED is reviewing closure. |
| TA 16 Area P Landfill | Flashed equipment (contaminated with HE)<br>Barium contaminated sands, various lab bottles,<br>Administratively controlled wastes, old equipment, building debris. | 250' X 125'<br>approximately 30 feet deep.<br>Approximately 3 acres for surface area. | 1950s built<br>Used from late 1950s to 1985. | Closure pending. NMED has requested resubmittal of closure plan. Due August 30, 1993. |

**VII. Date of Previous CME:** A CME with a site inspection had not been conducted previously.

**VIII. Facility Status:** LANL was permitted in November 1989. The Permit expires on December 22, 1999.

**IX. Permit conditions and relevant dates pertaining to the ground water monitoring system:**

1. The Permittee was required to install thirteen ground water monitoring wells and one boring in the perched saturated alluvium across seven different canyons. For these wells, the Permittee was to gather ground water elevation data and develop a map to delineate the known extent of the perched ground water at the facility. The Permittee was required to sample each well for Appendix IX constituents and designated radioactive constituents.

2. Annual reports on surface and ground water monitoring are to be submitted to EPA.

3. The Permittee, through the existence of sediment traps or construction of new sediment traps, shall ensure containment of all residual sediment contamination within the facility boundary.

4. Any boring drilled to a depth of 300 feet or deeper shall grout the surface casing to prevent the downward migration of surface contamination along the wellbore. Any well drilled to the main aquifer which encounters a perched zone shall hydraulically isolate the main

aquifer.

5. The Permittee shall continue quarterly sampling of the soil gas plumes and resume vadose zone plume delineation at TA-54.

6. The Permittee shall conduct a subsurface investigation of saturation by drilling test holes through the shallow alluvial perched aquifer in Mortandad Canyon. Construction of the test holes will hydraulically isolate the perched aquifer from the underlying unsaturated tuff. This perched aquifer is recharged in part from waste water treatment discharges located upstream. The investigation shall provide an initial evaluation of the maximum extent of the vertical and horizontal water and contaminant movement into the unsaturated tuff beneath the saturated alluvium. The study shall attempt to recover cores from the tuff to be used to determine laboratory values for unsaturated hydraulic conductivity, conductance, specific retention and specific yield, effective porosity, and saturated permeability. The boring shall be analyzed for applicability of installation of neutron moisture probe access tubes to determine moisture over time. Chemical and radiochemical analyses of the cores shall also be made to assist in the determination of fluid movement from the perched alluvial aquifer into the underlying unsaturated tuff. The chemical analysis shall include Appendix IX constituents, while the radiochemical analysis shall include $^{3}H$, $^{137}Cs$, Total U, $^{238}Pu$, $^{239}Pu$, $^{240}Pu$, $^{241}Am$, Gross Gamma, and Gross Alpha, as appropriate. A report detailing the results of this study shall be submitted within one year of the effective date of this permit.

7. The Permittee was required to submit a reference of all known geologic, hydrogeologic and all environmental studies relevant to potential contamination or migration of contamination from SWMUs, previously performed at and/or by the facility, with a summary of the scope of the study, and significant findings thereof.

## SECTION 2 -- APPLICABILITY AND SITE CHARACTERIZATION

I. **Has a ground water monitoring program (capable of determining the facility's impact on the quality of ground water in the uppermost aquifer underlying the facility) been implemented as per 40 CFR § 265.90. Uppermost aquifer means the geologic formation nearest the natural ground surface that is an aquifer as well as lower aquifers that are hydraulically interconnected with this aquifer within the facility's property boundary.**

No, the facility does not have a ground water monitoring program capable of determining all of the facility's impact on the uppermost aquifer. LANL has ground water monitoring waivers on file for each unit requiring ground water monitoring. LANL followed the requirements of 40 CFR 265.90(c) which states:

(c) *All or part of the ground-water monitoring requirements of this subpart may be waived if the owner or operator can demonstrate that there is a low potential for migration of hazardous waste or hazardous waste constituents from the facility via the uppermost aquifer to water supply wells (domestic, industrial, or agricultural) or to surface water. This demonstration must be in writing, and must be kept at the facility. This demonstration must be certified by a qualified geologist or geotechnical engineer and must establish the following:*

(1) *The potential for migration of hazardous waste or hazardous waste constituents from the facility to the uppermost aquifer, by an evaluation of:*

(i) *A water balance of precipitation, evapotranspiration, runoff, and infiltration; and*

(ii) *Unsaturated zone characteristics (i.e., geologic materials, physical properties, and depth to ground water); and*

(2) *The potential for hazardous waste or hazardous waste constituents which enter the uppermost aquifer to migrate to a water supply well or surface water, by an evaluation of:*

(i) *Saturated zone characteristics (i.e., geologic materials, physical properties, and rate of ground-water flow); and*

(ii) *The proximity of the facility to water supply wells or surface water.*

II. **Has the facility adequately identified the uppermost aquifer?**

No, based upon the reviewed documents, the uppermost aquifer has not been adequately characterized. Additional studies are required. Each ground water monitoring waiver needs to be evaluated to determine its appropriateness. If the ground water monitoring waiver does not meet the requirements of 40 CFR 265.90(c), LANL will be required to submit additional information or install ground water monitoring wells at each regulated unit.

## III. Regional Geology

### A. Regional Geology Background:

LANL is situated on the Pajarito Plateau on the east flank of the Jemez Mountains and on the west side of the Rio Grande valley (Figure 2). The Jemez Mountains are part of the Jemez volcanic field, which consists of some 432 $mi^3$ of volcanic rocks erupted from numerous vents, including a giant, multistage caldera. The Jemez volcanic field occurs at the intersection of the Jemez lineament, a northeast-trending alignment of volcanic fields, and the Rio Grande rift, a major north-trending zone of extensional tectonics.

Two major volcanic eruptions in the Jemez Mountains that occurred about 1.5 and 1.13 million years ago produced widespread and voluminous ash flow sheets: the Otowi and Tshirege members of the Bandelier Tuff. The morphology of the Pajarito Plateau is dominated by a gently eastward-sloping surface, formed on top of the Bandelier Tuff, which is dissected by numerous steep-sided canyons. The Otowi and Tshirege Members of the Bandelier Tuff were erupted concomitantly with the collapse of the Toledo and Valles calderas, respectively. Following the formation of the calderas, volcanism continued with the extrusion of domes along ring fractures. The latest eruption in the Jemez Mountains occurred about 130,000 years ago, producing the El Cajete pumice and Banco Bonito rhyolite flow. Vestiges of volcanic activity continue today, as evidenced by solfataric and hot spring activity both within and outside of the Valles caldera. Studies of P-wave arrival time delays suggest the presence of partially molten rock beneath the Valles caldera, possibly the remnants of the cooling Bandelier magma chamber.

The Pajarito Plateau is in the western part of the Espanola basin of the Rio Grande rift, a major tectonic feature of the western United States. The Espanola basin lacks distinct major faults on its eastern margin; however, faults of major vertical offset may exist within the Precambrian rocks of the Sangre de Cristo uplift. The western margin is characterized by a prominent zone of major faults, which cuts Miocene to Quaternary rocks of the Jemez volcanic field. These border faults exerted strong control on the location and development of the volcanic field.

Rocks formed before the rift developed are exposed around the margins of, and underlie, the Espanola basin. These rocks consist of Mississippian to Permian marine limestones, sandstones, and shales; Mesozoic marine to terrestrial sandstones and shales; and Eocene sandstones, shales, and freshwater limestones. Precambrian rocks -- predominantly quartzite, granitic gneiss and schist, and greenstone -- are exposed in the cores of the flanking Sangre de Cristo, Nacimiento, and Brazos uplifts. The earliest sediments deposited in the Tertiary Espanola basin are those of the Abiquiu, Picuris, and Los Pinos formations, which consist of tuffaceous sandstones and volcaniclastic conglomerates derived largely from volcanic highlands to the north and northeast. These units range in age from about 28 to 17 million years old.

### B. Stratigraphic Units

Beneath a veneer (typically less than fifteen feet) of soils and alluvial deposits, the mesas of the Pajarito Plateau are immediately underlain by the Bandelier Tuff of Pleistocene age,

which is exposed in the canyon walls and is penetrated by numerous drill holes. Beneath the Bandelier Tuff, a sequence of inter-stratified sedimentary and volcanic rocks of Miocene to Pleistocene age occur, which have been penetrated by water supply wells and which have been studied where they outcrop in canyons on the margins of the Pajarito Plateau. These rock units include volcanic rocks of the Paliza Canyon Formation, Tschicoma Formation, and the Cerros del Rio volcanic field, and sedimentary deposits of the Puye Formation, the Totavi Formation, the Cochiti Formation, and the Santa Fe Group (Figures 3 & 4). Individual units are discussed below.

**Santa Fe Group** -- The Santa Fe Group of Miocene and early Pliocene age (formed 18 to 4.5 million years ago) is a thick series of terrestrial conglomerates, sandstones, and mudstones, with minor limestones, evaporites, volcanic tuffs, and intercalated basalts. These rocks are the most extensive units filling the Rio Grande rift, and most production from water wells at Los Alamos is from the Santa Fe Group. Sedimentary rocks usually dominate the Santa Fe Group, although basalts constitute up to 45% of the section penetrated by water supply wells at LANL. In the Espanola basin and underlying the northern part of Los Alamos County, the Santa Fe Group is subdivided into two formations (Tesuque and Chamita formations) and several members, which reflects the diversity of the coalesced alluvial fans deposited in the Espanola basin.

**Keres Group** -- Two formations of the Keres Group, may be important in the pre-Bandelier Tuff subsurface in the southern parts of LANL. These are the Paliza Canyon and Cochiti formations, each about 13 million to about 6 or 7 million years old. The St. Peter's Dome area lies about 3 miles from the southern boundary of LANL and was a major center of Keres Group volcanism. Large volumes of Paliza Canyon andesite were erupted from the St. Peter's dome center and spread to the east and north. It appears that some of the volcanic units encountered in wells at TA-49 may be Paliza Canyon lavas that have been misidentified as Tschicoma and Cerros del Rio units, as discussed below.

Beneath the southern Pajarito Plateau, sedimentary deposits of the Cochiti Formation compose the Miocene basin fill and are therefore laterally equivalent to the sedimentary rocks of part of the Santa Fe Group and possibly also to those of the Puye Formation to the north. The Cochiti Formation consists dominantly of basin fill gravels derived from the volcanic centers of the southern and central Jemez Mountains volcanic field. The transition between the Cochiti, Santa Fe, and Puye formations probably occurs somewhere beneath Los Alamos County, but it is very poorly defined.

**Tschicoma Formation** -- The Tschicoma Formation consists of a sequence of dacitic domes and lavas that were erupted from vents in the central to northeastern Jemez Mountains between about 7 and 3 million years ago. These volcanic rocks outcrop extensively in the mountains immediately west of LANL and are reported in the subsurface beneath the western and southern part of LANL.

**Puye Formation** -- The Puye Formation consists of a Pliocene-to-Pleistocene fanglomerate that was shed eastward from Tschicoma volcanic centers in the northeastern Jemez volcanic field between about 4 and 1.7 million years ago. Earlier work included the Totavi Lentil, now considered a separate formation, as part of the Puye Formation. Most of the Puye conglomerates contain cobbles of dacitic to andesitic composition in a volcanic sand matrix.

The beds include stream flow deposits, debris flow deposits, volcanic ash and block flow deposits, and ash fall and pumice fall deposits. The Puye Formation is best exposed north of the LANL, but lithologically similar rocks have been penetrated in drill holes as far south as Frijoles Mesa. Under parts of LANL, the Puye Formation is inter-stratified with basalts of the Cerros del Rio volcanic field. In Los Alamos water supply wells, the top of the main aquifer is usually within the Puye Formation.

**Totavi Formation** -- Immediately beneath the fanglomerates of the Puye Formation, unconformably overlying the Santa Fe Group, is a section of poorly consolidated fluvial gravels. The gravels contain clasts that differ lithologically from those in the Puye, including abundant well-rounded cobbles and boulders of quartzite, granite, and pegmatite that record a source area distant from the Jemez Mountains; this unit probably represents axial channel gravels of an ancestral Rio Grande. These fluvial gravels have been defined as a separate formation, the Totavi Formation, which also includes lacustrine sediments that are complexly inter-stratified with the upper Puye Formation. In some water supply wells beneath LANL, the Totavi was reported between the Santa Fe and the Puye, occurring at lower elevations in the eastern wells. The presence of the Totavi at these levels suggests that Rio Grande river gravels were deposited on erosional surfaces, a setting analogous to Quaternary terraces of the Rio Grande in the Espanola basin before deposition of the Puye fans, which unconformably overlie older formations.

**Cerros del Rio Basalts** -- Basaltic flows, breccias, and scoria of the Cerros del Rio occur in the subsurface beneath much of the Pajarito Plateau and outcrop in the east and southeast parts of Los Alamos County. These volcanic rocks are associated with the Pliocene-to-Pleistocene Cerros del Rio basalt field, east of the Rio Grande, and rocks from this field have been dated at 4.6 to 2.0 million years old. The youngest lava flows in this area occurred between the two Bandelier Tuff eruptions, 1.5 and 1.1 million years ago. Part of this volcanic field is also known as basaltic rocks of Chino Mesa. The top of the main aquifer beneath LANL is locally within this section of basaltic rocks.

**Otowi Member, Bandelier Tuff** -- The Otowi Member of the Bandelier Tuff underlies the Tshirege Member in the subsurface beneath much of the Pajarito Plateau and outcrops in many of the canyons. The Otowi Member is mostly a nonwelded ash flow tuff that was erupted from the Jemez Mountains 1.5 million years ago. It is highly porous and poorly indurated and is composed of multiple flow units. Where it outcrops, cooling joints are typically absent because of relatively low emplacement temperatures and the lack of induration. The Guaje Pumice Bed generally occurs at the base of the Otowi Member and consists of sorted pumice fragments that average 0.8 to 1.6 inches in size.

**Cerro Toledo Rhyolite and Interbedded Sediments** -- An interbedded sequence of rhyolitic tuffs and sediments commonly occurs between the Otowi and Tshirege members of the Bandelier Tuff. The rhyolitic tuffs were erupted between 1.5 and 1.2 million years ago, predominantly from the Cerro Toledo domes in the northeastern Jemez Mountains. Beneath the Pajarito Plateau, the sediments are epiclastic sands and sandy gravels that lithologically resemble Puye Formation fanglomerates. At LANL, deposits in this interval have sometimes been referred to as "Tsankawi pumice" or "Tsankawi member." These units may play an important role in the migration of water in the subsurface beneath the Laboratory.

Tshirege Member, Bandelier Tuff -- The most widespread rock unit on the Pajarito Plateau is the Tshirege Member of the Bandelier Tuff, which was erupted from the Valles caldera in the Jemez Mountains about 1.1 million years ago. The Tshirege Member is composed of multiple flow units of crystal-rich ashflow tuff and displays significant variations in welding and alteration, both in a single stratigraphic section and with varying distance from the caldera. Individual units tend to be more welded and thicker to the west. Flow units are locally separated by volcanic surge deposits of well-sorted, fine-grained, cross-bedded crystal and pumice fragments. Vapor phase alteration, caused by post-emplacement cooling and migration of entrained magmatic gases, occurs in much of this unit. The base of the Tshirege Member is often marked by 1.5- to 10-foot of bedded, unconsolidated, pumice-rich ash fall tuff of the Tsankawi Pumice Bed. The Tsankawi Pumice Bed is generally poorly recognized in drill bit cuttings because rotary drills commonly grind the soft materials into dust.

The Tshirege Member has been subdivided into a sequence of mappable units based either on erosional characteristics or on primary cooling units. These units have been correlated over large distances on the Pajarito Plateau. However, the boundaries between the units are not always distinct in the field and can be difficult to recognize in drill holes, causing investigators to place the contacts between units at different locations. Furthermore, in the absence of geologic mapping in the intervening areas, the validity of the correlations is uncertain.

Stratigraphic features in the tuff, such as volcanic surge deposits, may locally provide a preferential migration pathway for moisture and contaminants in the subsurface. There are increased rates of vapor phase migration of tritium away from storage shafts at TA54 along a stratigraphic boundary that includes surge layers. Individual flow units in the Tshirege Member contain vertical cooling joints that may or may not cross flow unit boundaries. In ash flow tuffs, cooling joint spacing varies primarily with the thickness of the unit, emplacement temperature, substrate temperature, and topography. Joint density tends to be greatest in welded tuff and least in nonwelded tuff. Hydraulic conductivities are generally greatest in the fractured, welded parts of ash flow tuffs and least in the nonwelded parts.

**Post-Bandelier Units** -- Stratigraphically overlying the Bandelier Tuff are discontinuous Quaternary alluvial units that occur as thin deposits (typically less than fifteen feet) 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 seventy ft thick in some drill holes. 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. 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. 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 not been mapped, but at the Laboratory they are generally most common to the south, and the axis of the volcanic dispersal plume is south of Los Alamos County. Available data suggest that the El Cajete pumice is 130,000 to 170,000 years old.

## IV. Site Hydrogeology

### A. Site Stratigraphy and Ground Water:

Ground water occurs in three modes in the Los Alamos Area: (1) perched water in the shallow alluvium in some of the larger canyons, (2) perched ground water in the volcanic sediments and basalts, and (3) ground water of the main aquifer of the Los Alamos area. Each unit that contains ground water is summarized in the following paragraphs.

#### 1. Perched Ground water in Alluvium

Intermittent and ephemeral stream flows in the canyons of the Pajarito Plateau have deposited alluvium that ranges in thickness to as much as 100 feet. 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.

The alluvium is quite permeable, in contrast to the underlying volcanic tuff and sediments. Ephemeral run-off 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 ground water body. Depletion by evapo-transpiration and movement into the underlying rocks limits the horizontal and vertical extent of the alluvial water. The limited saturated thickness and extent of the alluvial ground water preclude its use as a viable source of municipal and industrial supply to the community and the Laboratory. Lateral flow of the alluvial perched ground water is in an easterly, down-canyon 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.

The water quality in the alluvial perched ground water 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 run-off water, which cause some dilution of the shallow alluvial perched ground water. Tritium concentrations have fluctuated

almost in direct response to the average annual concentration of tritium in the TA50 effluent, with a lag time of about 1 yr.

## 2. Perched Water in Volcanic Sediments and Basalts

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 feet in the midreach of Pueblo Canyon to about 450 feet in lower Sandia. The vertical and lateral extent of the perched ground water, the nature and extent of perching units, and the potential for migration of perched water to the main aquifer is not fully understood.

Patterns of chemical quality and water level measurements indicate that the lower perched ground water in Pueblo Canyon is hydrologically connected to the stream in Pueblo Canyon. Water from this perched ground water discharges at the base of the basalt at Basalt Spring, which is off LANL property in lower Los Alamos Canyon on the San Ildefonso Pueblo. The rate of movement of the perched ground water in this vicinity has been estimated at about 60 ft/day or about 6 months from recharge to discharge.

It is unknown whether the 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 resulted in depletion of the perched ground water after about an hour's pumping at 2 to 3 gal./min. Perched water was encountered in mid-Los Alamos Canyon during the drilling of the Otowi-4 supply well, but it was not reported in an adjacent well (Test Well 3) located 300 feet 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 ground water if it was present.

Some perched water occurs in volcanics on the flanks of the Jemez Mountains off-site to the west of LANL. 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 gallons annually.

## 3. Ground Water in the Main Aquifer

The main aquifer of the Los Alamos area is the only aquifer capable of large-scale municipal water supply. In 1989, water for LANL, the communities of Los Alamos and White Rock, and Bandelier National Monument was supplied from 11 deep wells in three 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 during 1992 was 1.43 billion gallons, with individual well yields ranging from about 175 to 1,400 gpm.

The surface of the main aquifer rises westward from the Rio Grande within the Santa Fe Group into the lower part of the Puye Conglomerate beneath the central

and western part of the plateau. The depths to water below the mesa tops range from about 1,200 feet along the western margin of the plateau to about 600 feet at the eastern margin. The main aquifer is separated from the water in the alluvium and perched water in the volcanics by 350 to 620 feet of tuff and volcanic sediments. The main aquifer exhibits artesian conditions in the eastern part along the Rio Grande. Continuously recorded water level data collected in test wells since the fall of 1992 indicate that, throughout the plateau, the main aquifer responds to barometric and earth tide effects in the manner typical of confined aquifers.

The exact source of recharge to the main aquifer is unknown. Three sources of recharge are proposed: infiltration of run-off 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 main aquifer. Furthermore, natural recharge through undisturbed Bandelier Tuff on the mesa tops is believed to be insignificant, and few or no data exist to support an evaluation of canyon run-off as a recharge source. It is inferred that major recharge of the main aquifer occurs from the west because the piezometric surface slopes downward to the east. Water level elevations suggest that ground water flows from the Jemez Mountains east and east southeast toward the Rio Grande, where a part is discharged into the river through seeps and springs. Springs fed by the main aquifer discharge an estimated 4,300 to 5,000 acre-ft of water annually into White Rock Canyon along an 11-mile reach between Otowi Bridge at State Road 502 and the mouth of Rito de Frijoles.

The hydraulic gradient of the aquifer averages about 60 to 80 ft/mi within the Puye Conglomerate but increases to 80 to 100 ft/mi along the eastern edge of the plateau as the water in the aquifer enters the less permeable sediments of the Santa Fe Group. The rate of movement of water in the upper section of the aquifer varies, depending on the materials in the aquifer. Aquifer tests indicate that the movement ranges from 20 ft/yr in the Tesuque Formation to 345 ft/yr in the more permeable Puye Conglomerate.

In an effort to better understand the nature of recharge to the main aquifer in the Los Alamos area, a series of isotope and age-dating measurements on selected water samples has been initiated LANL and other DOE researchers. To date, low detection limit tritium analyses have been completed on 12 samples from springs in White Rock Canyon and on 5 samples from wells into the main aquifer.

The values for tritium in the ground water range from less than detectable to about 7 pCi/L. The values are all less than values for tritium in contemporary precipitation (about 30 to 60 pCi/L) and much less than the roughly 700 pCi/L that would be present now in water precipitated in northern New Mexico during 1962 and 1963, when tritium from atmospheric nuclear weapons testing was at its maximum. The conclusion is that the water from the main aquifer cannot contain any significant component of recharge from water precipitated during the last several decades. The inference is that the water in the aquifer considerably predates the period when nuclear weapons were tested in the atmosphere.

Preliminary interpretation of $^{14}C$ data for samples from the same five deep wells indicate that the water ranges in age from several thousand years to more than 10,000 years.

## 4. Hydrologic Properties and Conditions of the Bandelier Tuff

At the central portion of LANL, there is in excess of 1,000 feet of unsaturated volcanic tuff, sediments, and basalts of the Bandelier Tuff, the Puye Conglomerate, and the basaltic rocks of Chino Mesa. Numerous investigations focusing on hydrologic characterization of the upper 100 feet of the Bandelier Tuff have been conducted in the Los Alamos area since the 1950s. The vadose zone below about 100 feet has not been adequately characterized.

Most of the initial investigations of 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.

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. However, welded tuffs tend to be more highly fractured and jointed than nonwelded tuffs, and the overall permeability of the welded tuff may be locally enhanced.

Porosity measurements range from 20% to 74% by volume, generally decreasing with increasing degree of welding. A great deal of the high porosity occurs when pumice 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.

A number of hydraulic properties of the Bandelier Tuff vary with changing moisture content. The tuff is only partially saturated throughout LANL, even beneath stream channels containing alluvial perched ground water systems. The moisture contents of the tuff beneath mesa tops are very low, typically less than 5% by volume. Tuff moisture contents are 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%. Moisture contents of the tuff beneath the canyon bottoms are considerably higher than those beneath the mesas, typically ranging from 20% to 50% by volume. Field studies in Mortandad, Sandia, and Potrillo canyons show that moisture content varies greatly with depth, depending on texture. Generally, moisture content decreases with depth below stream channels.

The relationship between moisture content and soil-water potential has been obtained from undisturbed mesa top cores at TA-54. The data indicate (1) extremely high residual moisture contents, ranging up to 80%, and (2) a low air-entry pressure

head. Test results indicate that at TA-49 specific retention (residual moisture content) ranged from 11% to 27%. These latter results are fairly consistent with recent tests on undisturbed tuff samples in Mortandad Canyon. However, detailed analyses in Mortandad Canyon show that there are significant differences in moisture retention characteristics between and within formational units. One report 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 by gravity and capillarity; and above 23%, movement is by drainage from gravity.

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 x $10^{-5}$ to 2.3 x $10^{-2}$ 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. Unsaturated hydraulic conductivities may be many orders of magnitude lower, typically ranging from $10^{-6}$ to $10^{-11}$ cm/s, depending on in-situ moisture contents.

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. Joints and fractures in moderately welded tuffs generally terminate in nonwelded tuffs. The joints are often vertically limited to a single ash flow or ash fall unit. Joint apertures range from closed to open as much as several centimeters. The joints are commonly filled with caliche near the surface, grading downward to clay, and may be open to depths greater than 30 feet. Examination of cores obtained from horizontal drilling beneath a waste disposal site at TA54 showed that about 80% of the joints were filled or plated with clay or secondary mineralization.

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 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. 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. 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.

C. **Is the uppermost aquifer hydraulically connected with deeper aquifer? Describe the connecting strata. If no, describe the Aquitard:**

The upper aquifer is connected with the main aquifer. See the previous sections on site geology.

D. **Was the site investigation and/or data collection conducted by the facility performed by a qualified geologist? (265.90.c.) (Y/N)**

Yes

E. **Does the owner/operator maintain documentation and/or the raw data from the site hydrogeologic assessment? (Y/N)**

Yes

F. **Has the owner/operator prepared a regional map of the area and delineate the facility? (Y/N)**

Yes

G. **Has the owner/operator prepared a regional hydrogeologic map? (Y/N)**

Yes

H. **If yes, does this hydrogeologic map indicate: 1) Major areas of recharge/discharge? 2) Regional ground water flow direction? 3) Potentiometric contours which are consistent with observed water level elevations?**

1) Yes, but the exact recharge area for the main aquifer and the perched intermediate aquifer have not been completely identified.
2) Yes
3) Yes, but because of the small number of wells utilized for potentiometric contouring, the results are not adequate.

I. **Has the owner/operator prepared a facility site map? (Y/N)**

Yes

J. **Did the owner/operator present geologic cross sections of the site? (Y/N)**
Yes

## SECTION 3-- MONITORING WELL SYSTEM

I. General System Status

| | | | |
|---|---|---|---|
| X | Permitted | ____ | Interim Status |
| ____ | Detection | ____ | Detection |
| ____ | Compliance | ____ | Assessment |
| X | Corrective Action | | |

II. **Has at least one monitoring well been installed in the uppermost aquifer hydraulically up-gradient from the limit of the waste management area? 265.91(a)(1) (Y/N)**

No, the facility has filed ground water monitoring waivers for each regulated unit requiring ground water monitoring.

A. **Are ground water samples from the uppermost aquifer, representative of background ground water quality and not affected by the facility (as ensured by proper well number, locations and depths?) (Y/N)**

No

B. **Is designated up-gradient well(s) confirmed as up-gradient? (Y/N)**

Not Applicable

III. **Have at least three monitoring wells been installed hydraulically down-gradient in the uppermost aquifer at the limit of the waste handling or management area? (Y/N)**

No, the facility has filed ground water monitoring waivers for each regulated unit requiring ground water monitoring.

A. **Do well number, locations and depths ensure prompt detection of any statistically significant amounts of HW or HW constituents that could migrate from the waste management area to the uppermost aquifer? (Y/N)**

No

B. **Are designated down-gradient well(s) confirmed as down-gradient? (Y/N)**

Not Applicable

IV. **Have the locations of the waste management unit/areas been verified to conform with information in the ground water program? (Y/N)**

No, the facility has filed ground water monitoring waivers for each regulated unit requiring ground water monitoring.

A. **If the facility contains multiple waste management components, is each component**

adequately monitored? (Y/N)

No

V. **Do the numbers, locations, and depths of the ground water monitoring wells agree with the data in the ground water monitoring system program? If "No", explain discrepancies. (Y/N)**

No, the facility has filed ground water monitoring waivers for each regulated unit requiring ground water monitoring.

# LANL LOCATION MAP

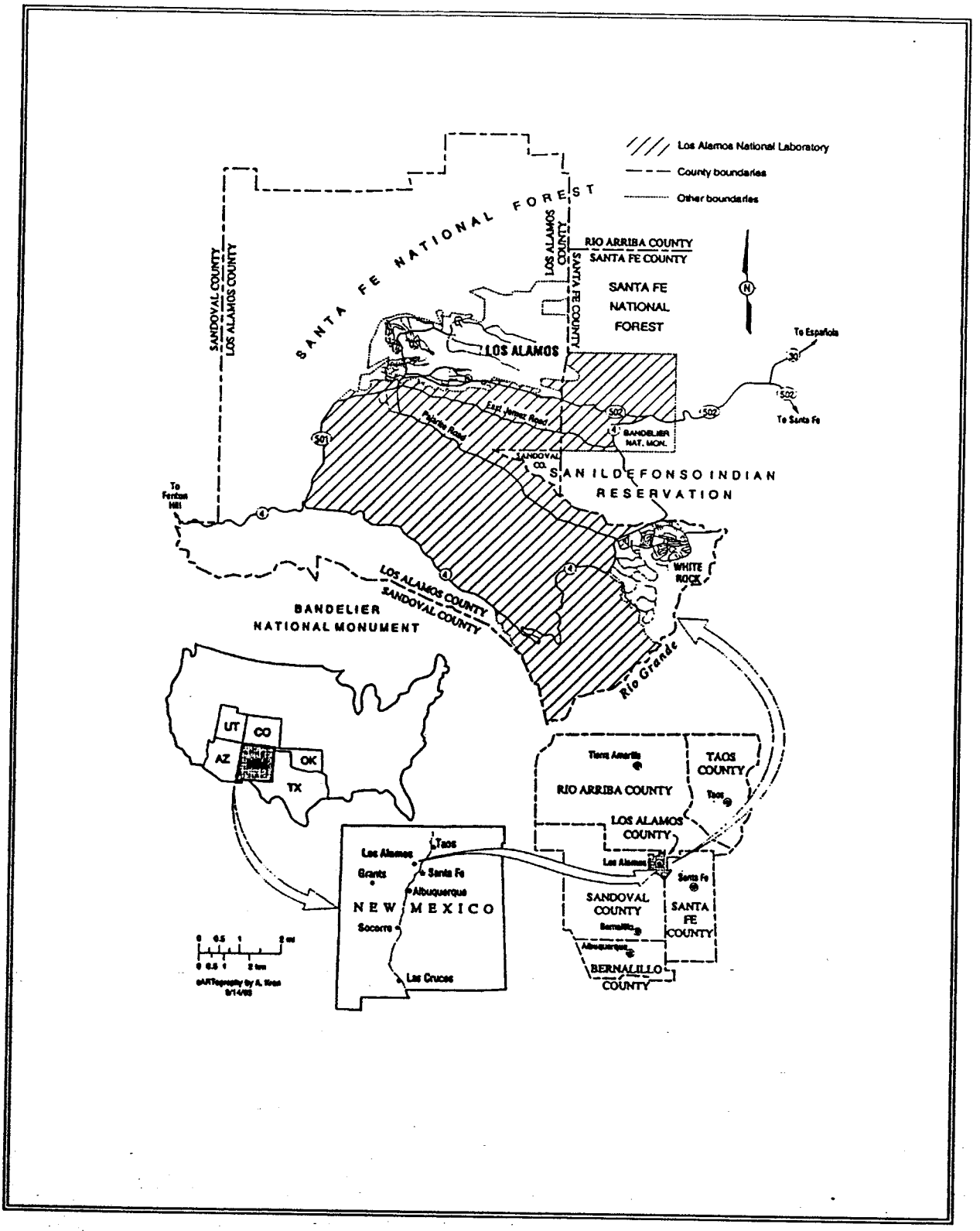



**FIGURE 1 -- LANL Comprehensive Ground Water Monitoring Evaluation Report**

# GENERAL TOPOGRAPHIC FEATURES

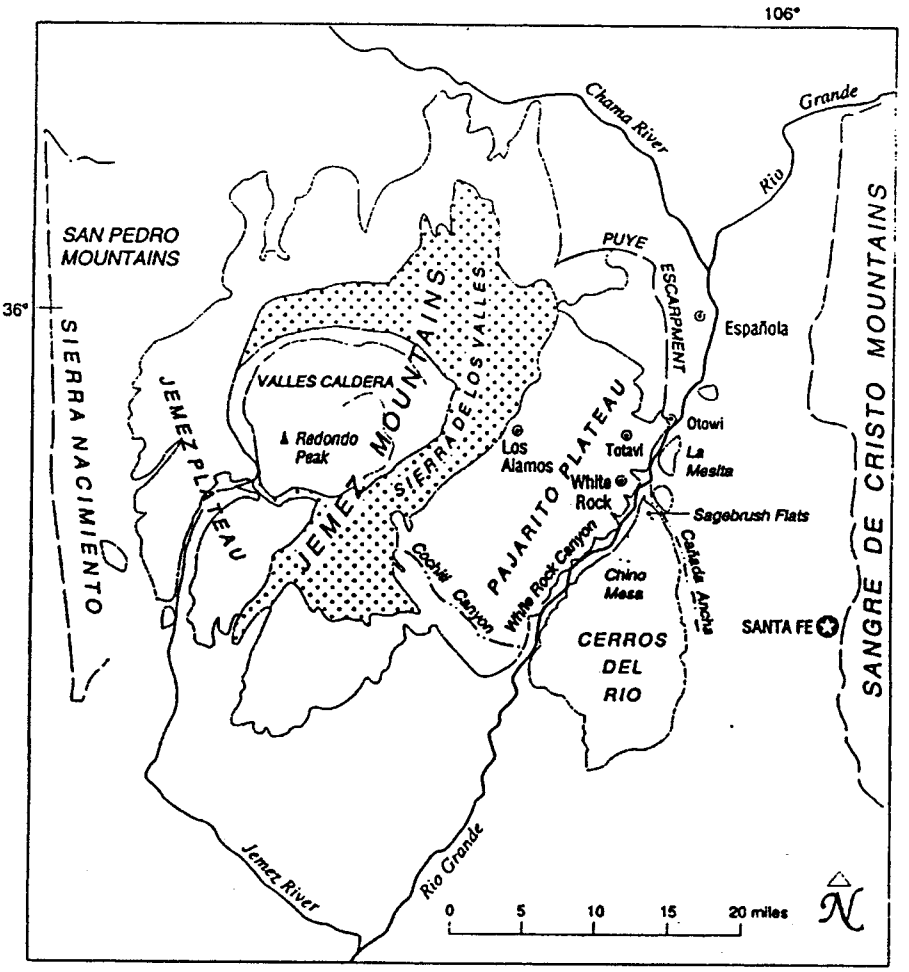



**FIGURE 2 -- LANL Comprehensive Ground Water Monitoring Evaluation Report**

# GENERALIZED GEOLOGIC CROSS-SECTION

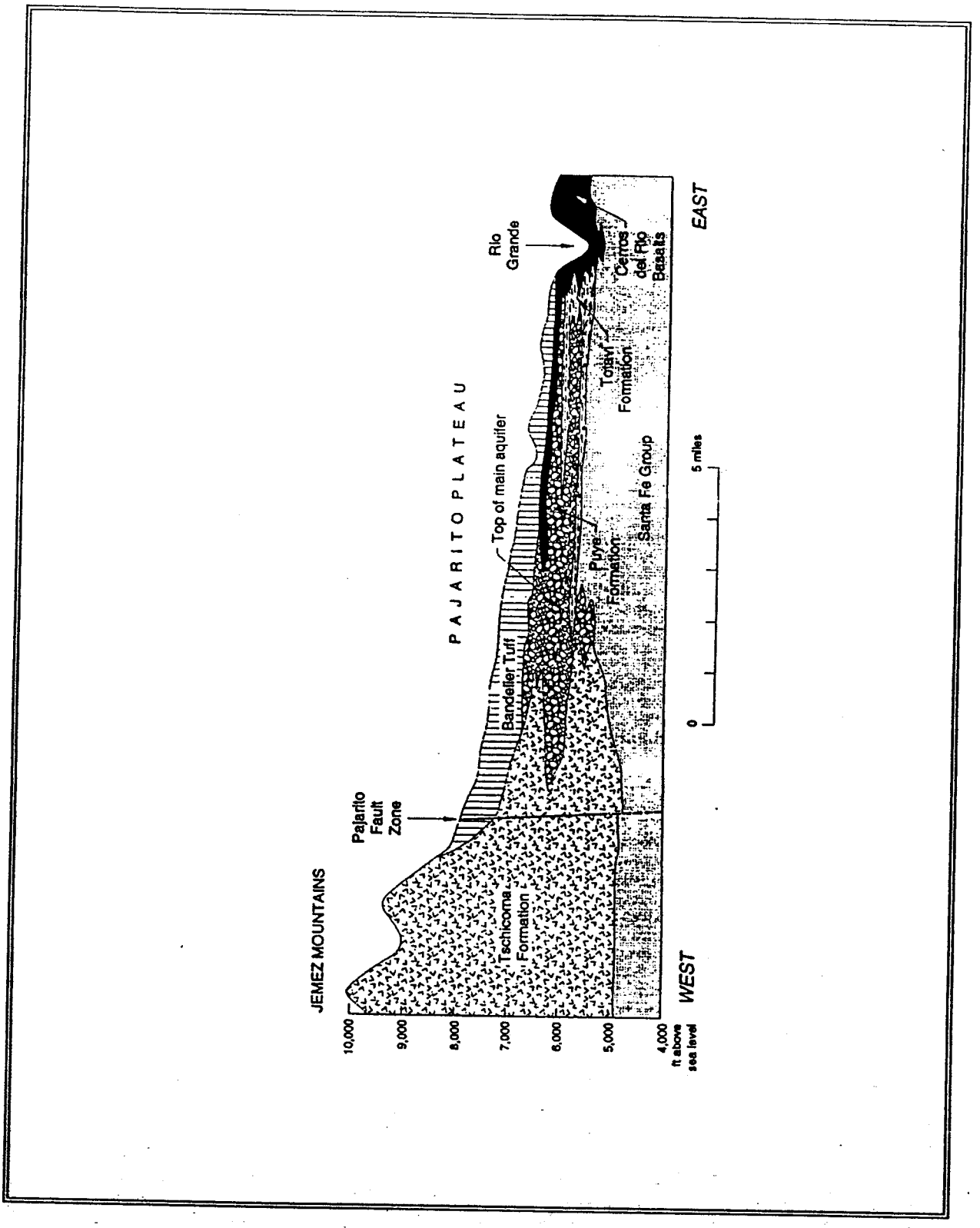
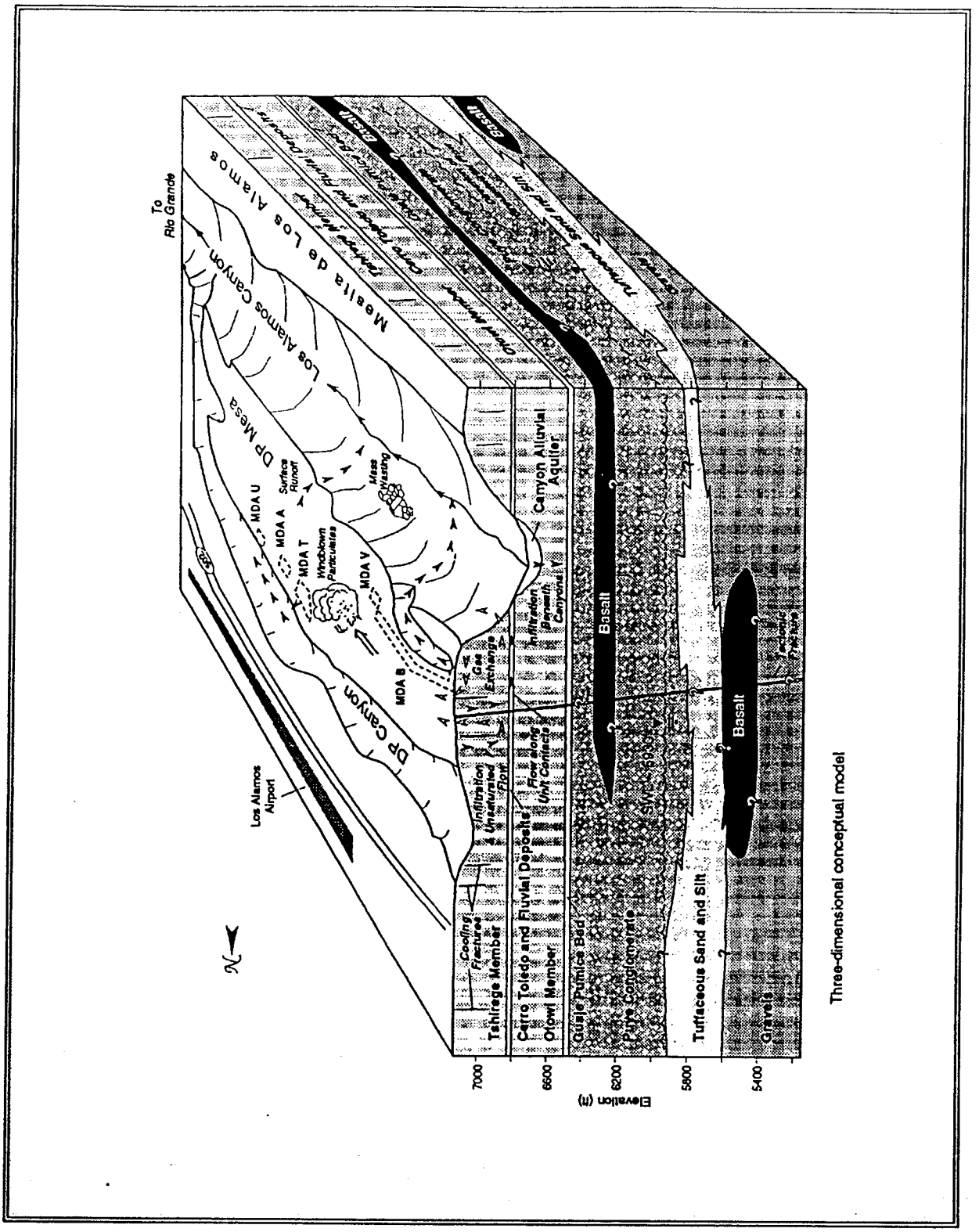



**FIGURE 3 -- LANL Comprehensive Ground Water Monitoring Evaluation Report**

# GENERALIZED 3-D CROSS-SECTION




Three-dimensional conceptual model

**FIGURE 4 -- LANL Comprehensive Ground Water Monitoring Evaluation Report**