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Department of Energy

Albuquerque Operations Office

memorandum

DATE: March 15, 1996

REPLY TO: EPD: KSM

SUBJECT: Approval of the Groundwater Protection Management Program Plan for Los Alamos National Laboratory

TO: Joseph C. Vozella, Assistant Area Manager, Office of Environment and Projects, LAAO

The Groundwater Protection Management Program Plan (GWPMPP) for Los Alamos National Laboratory is approved following our review. The approved GWPMPP is the March 6, 1995 Draft Plan including revisions dated January 31, 1996. This Plan fulfills the three year update of the GWPMPP as required in DOE Order 5400.1. The next three year update of the GWPMPP will be required in 1999.

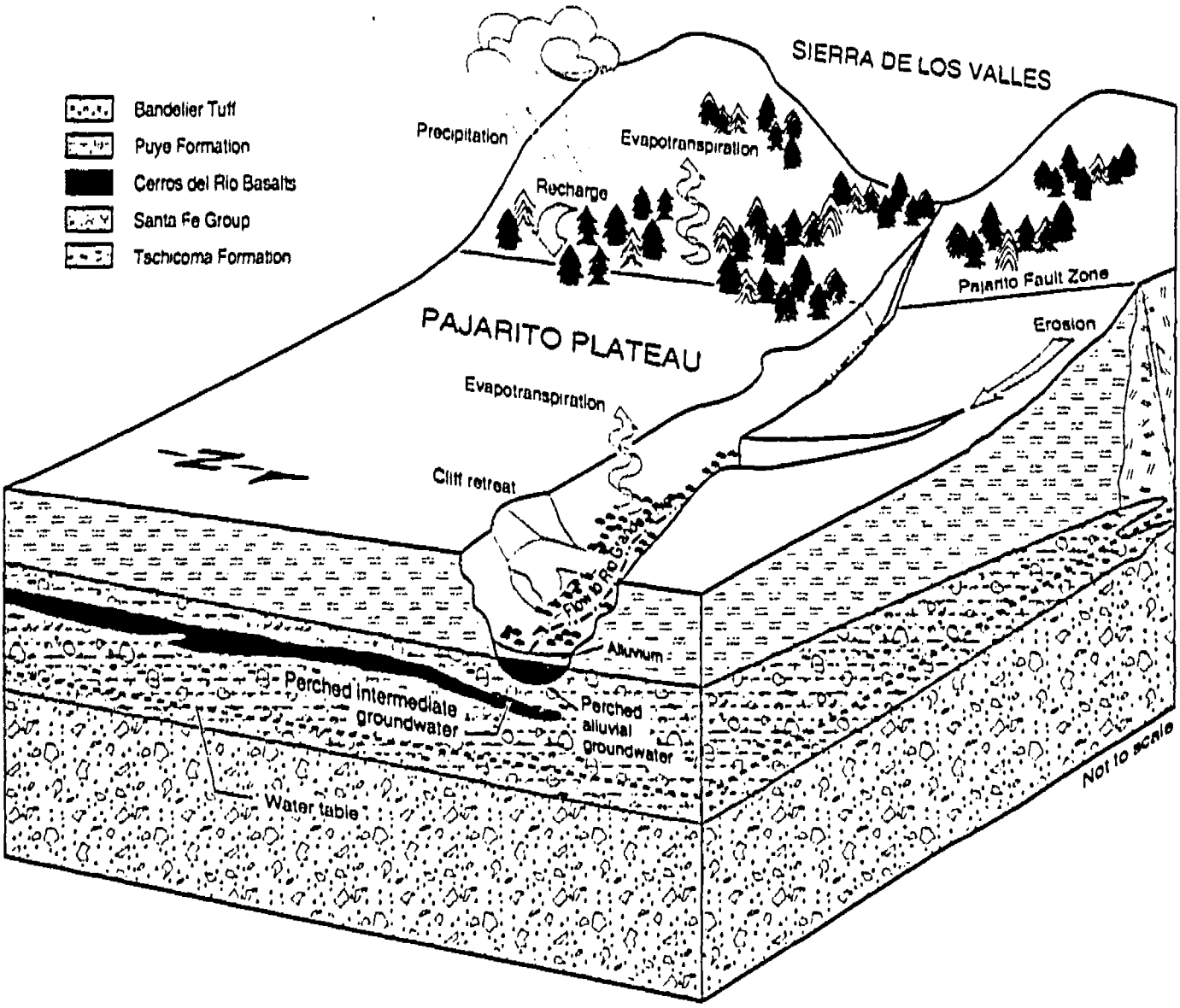
If you have any questions, please call Karen McAda at (505) 845-5588.

Constance L. Soden
Director
Environmental Protection Division

OCT 24 2001

Groundwater Protection Management Program Plan

Los Alamos National Laboratory



Issue Date: January 31, 1996

Revision 0.0

Groundwater Protection Management Program Plan

Los Alamos National Laboratory

Date Issued: January 31, 1996
Revision 0.0

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Executive Summary

The Groundwater Protection Management Program Plan (GWPMPP) provides a detailed framework for consolidating and coordinating groundwater protection activities at Los Alamos National Laboratory. The purpose of the plan is to monitor and protect the main aquifer underlying the Pajarito Plateau from contamination or other adverse impacts resulting from Laboratory operations, and to preserve the quality of water for Los Alamos and surrounding communities in northern New Mexico for future generations.

The GWPMPP addresses the following issues concerning the groundwater situation at the Laboratory: (1) hydrogeological characterization, (2) potential contamination, (3) groundwater monitoring network, (4) water supply, (5) information management, (6) quality assurance, and (7) regulatory compliance. These issues have been discussed in audits, reports, and assessments, and various deficiencies regarding current Laboratory operations have been identified. To remedy the problems, hydrologists, geologists, and consultants, as well as representatives of the New Mexico Environment Department and the Environmental Protection Agency, have examined these issues and have recommended solutions as they pertain to Laboratory operations.

Many of the deficiencies result from a lack of scientific data. Laboratory hydrologists do not have enough information to fully characterize the hydrogeology of the region or the contaminant flow from the technical area sites because the existing network of monitoring wells is not adequate. The primary solution to these problems, therefore, will be to expand the current groundwater monitoring network. By increasing the number of monitoring wells and boreholes and by constructing the wells at select locations across the Pajarito Plateau, hydrologists will be able to collect sufficient data to fully characterize the groundwater of the area. The GWPMPP includes a map of proposed well locations and rationale for each new site.

Other deficiencies involve the collection, dissemination, and accessibility of groundwater information. Groundwater efforts are currently spread among several organizations at the Laboratory; one organization often follows sampling procedures or well construction techniques that are sometimes different from another organization. To remedy these problems, the GWPMPP details the development of a computer database network to ensure that timely groundwater-related information will be accessible to internal and external organizations and other interested parties. Consistency of sampling procedures, well construction and abandonment techniques, and other procedures will also be implemented so that the sharing of groundwater-related information will be facilitated.

The GWPMPP also presents a business plan detailing the organizational hierarchy, roles and responsibilities, accountability and authority, funding allotments, and other financial considerations involved in implementing the plan. The core of the business plan is a prioritized list of groundwater activities, which ranks the activities according to their cost and overall importance. The final list of priorities, then, represents the best attempt to enhance Laboratory environmental operations within budgetary constraints.

In sum, the GWPMPP presents an organized approach to managing and protecting the groundwater in the Los Alamos area. Through a dynamic process of coordinating its activities, the Laboratory will use the plan as an effective guide in responding to changing environmental needs.

Table of Contents

Executive Summary	i
List of Figures	v
List of Tables	vi
List of Acronyms	vii
1.0 Introduction	1-1
1.1 Purpose and Scope	1-1
1.2 Laboratory Environmental Goals	1-2
1.3 GWPMP Mission and Objectives	1-2
2.0 Background	2-1
2.1 Historical Review	2-1
2.2 Geography	2-2
2.3 Geology	2-4
3.0 Summary of Hydrogeological Environment	3-1
3.1 Surface Water	3-1
3.2 Groundwater	3-1
3.2.1 Perched Groundwater in Canyon Alluvium	3-1
3.2.2 Perched Groundwater in Volcanic Sediments and Basalts	3-1
3.2.3 Regional Aquifer	3-4
4.0 Groundwater Protection Efforts at LANL	4-1
4.1 Background	4-1
4.2 Protection Programs	4-1
4.2.1 Environmental Restoration Project	4-1
4.2.2 Decontamination and Decommissioning Program	4-1
4.2.3 RCRA Closures	4-2
4.2.4 Emergency Management and Response	4-2
4.2.5 Compliance with the NPDES Permit	4-2
4.2.6 Corrective Activities Program	4-3
4.3 Monitoring Network	4-3
4.3.1 Regional Aquifer	4-3
4.3.2 Intermediate Perched Groundwater	4-5
4.3.3 Shallow Perched Groundwater in Canyon Alluvium	4-13
4.3.4 Springs	4-15
4.4 Special Studies and Programs	4-20
4.4.1 Hydrogeologic Studies	4-20
4.4.2 Vadose Zone Studies	4-20
4.4.3 Age-of-Water and Recharge Source Studies	4-22
4.4.4 Measurement of Barometric and Earth Tide Responses in Test Wells	4-22
4.4.5 Studies of Surface Water Characteristics	4-22
4.4.6 Environmental Studies at San Ildefonso Pueblo	4-23
4.4.7 Studies at Fenton Hill Geothermal Site	4-23

4.5 Reporting 4-23
4.5.1 Annual Environmental Surveillance Report 4-23
4.5.2 Annual Water Supply Report 4-25
4.6 Conclusions 4-25

5.0 Issues and Solutions 5-1

5.1 Hydrogeological Characterization 5-1
5.1.1 Hydrogeological Characterization Issues 5-1
5.1.2 Hydrogeological Characterization Solutions 5-2
5.2 Potential Contamination 5-21
5.2.1 Potential Contamination Issues 5-21
5.2.2 Potential Contamination Solutions 5-23
5.3 Groundwater Monitoring Network 5-27
5.3.1 Groundwater Monitoring Network Issues 5-27
5.3.2 Groundwater Monitoring Network Solutions 5-28
5.4 Water Supply 5-30
5.4.1 Water Supply Issues 5-30
5.4.2 Water Supply Solutions 5-30
5.5 Information Management 5-31
5.5.1 Information Management Issues 5-31
5.5.2 Information Management Solutions 5-32
5.6 Quality Assurance Plan 5-34
5.6.1 Quality Assurance Plan Issues 5-34
5.6.2 Quality Assurance Plan Solutions 5-34
5.7 Regulatory Compliance 5-36
5.7.1 Regulatory Compliance Issues 5-36
5.7.2 Regulatory Compliance Solutions 5-36

6.0 Business Plan 6-1

6.1 Introduction 6-1
6.2 Management Organization 6-1
6.2.1 Project Leader 6-1
6.2.2 Water Quality and Hydrology Group (ESH Division) 6-3
6.2.3 ER Project (EM Division) 6-3
6.2.4 WM Program (CST Division) 6-3
6.2.5 Utilities Program (FSS Division) 6-3
6.2.6 Earth and Environmental Sciences (EES Division) 6-3
6.2.7 Other Laboratory Organizations 6-4
6.3 Fiscal Organization 6-4
6.3.1 Coordination of Funding 6-4
6.3.2 Environmental Surveillance Program 6-4
6.3.3 Tiger Team Action Plans 6-4
6.3.4 ESH 5-Year Plan 6-4
6.3.5 ER Projects 6-4
6.3.6 WM Programs 6-5
6.4 Customers 6-5
6.5 Cost and Duration Estimates 6-6

6.6 Prioritization 6-6
6.6.1 Methodology 6-6
6.6.2 Prioritized List of Activities 6-8
6.7 Training Program 6-9
6.8 Problem Tracking Mechanism 6-9
6.9 Performance Measures 6-13

7.0 Implementation Plan 7-1

7.1 Technical Review Committee 7-1
7.2 Annual Groundwater Status Reports 7-1
7.3 GWPMP Updates 7-2
7.4 Business Plan Schedule 7-2

8.0 References 8-1

9.0 Glossary 9-1

Appendix A - Regulations and DOE Orders A-1

Appendix B - Hydrolgeology of the Pajarito Plateau: Technical Review B-1

Appendix C - Description of Technical Areas C-1

Appendix D - List of Potential Release Sites D-1

Appendix E - Tables of Wells and Springs in the Los Alamos Area E-1

Appendix F - Groundwater Monitoring Plan F-1

Appendix G - USGS Proposals G-1

Appendix H - Annotated Bibliography of Geologic, Hydrogeologic, and Environmental Studies Relevant to Solid Waste Management Units at Los Alamos National Laboratory H-1

Appendix I - Comments and Recommendations I-1

Appendix J - Monitoring Well Design and Completion Matrix J-1

Appendix K - Proposed Well Map Transparencies K-1

Figures

2-1	Regional Location of Los Alamos	2-3
2-2	Technical Areas at Los Alamos National Laboratory	2-5
2-3	Geologic Location and Cross Section of the Pajarito Plateau	2-6
3-1	Major Surface Water Drainages in the Los Alamos Area	3-2
3-2	Conceptual Illustration of Geologic-Hydrologic Relationships in the Los Alamos Area	3-3
3-3	Conceptual Model of Regional Groundwater Flow Paths (Modified from Abeele 1981)	3-5
4-1	Regional Aquifer Wells and Springs	4-4
4-2	Shallow Alluvial and Intermediate Perched Water Wells and Springs	4-14
4-3	Regional Location of Fenton Hill (TA-57)	4-24
4-4	Surface Water and Groundwater Sampling Locations at Fenton Hill	4-26
5-1	Proposed Regional Aquifer Well Locations	5-7
5-2	Proposed Intermediate Perched Zone Well Locations	5-11
5-3	Proposed Shallow Alluvial Perched Groundwater Wells Locations	5-17
5-4	Flow Chart of the Iterative Well Siting Process	5-20
5-5	Major Fault Zones in the Los Alamos Area	5-25
5-6	Structure of Dual Database System	5-33
6-1	Organization Chart	6-2
6-2	GWPMPP Preliminary 10-Year Schedule	6-12

Tables

2-1	Milestones in the History of Los Alamos National Laboratory	2-1
4-1	Environmental Surveillance Groundwater Monitoring Stations - Wells	4-6
4-2	Environmental Surveillance Groundwater Monitoring Stations - Springs	4-16
4-3	Fenton Hill Water Sampling Locations and Elevations	4-25
5-1	Proposed Regional Aquifer Well Location Rationale and Sampling Objectives	5-3
5-2	Proposed Intermediate Well Location Rationale and Sampling Objectives	5-8
5-3	Proposed Shallow Alluvial Well Location Rationale and Sampling Objectives	5-12
5-4	Hydrogeologic Studies Included in the Draft Site-Wide Studies Plan for Environmental Restoration	5-22
5-5	Wells Considered for Plugging and Abandonment	5-26
5-6	Environmental Restoration (ER) Field Procedures	5-35
6-1	GWPMP Funding Sources	6-5
6-2	GWPMP Preliminary Cost Estimate	6-7
6-3	Well Installation Cost Estimate	6-8
6-4	Prioritized List of Activities for the Section 5.0 Issues and Solutions	6-10
7-1	GWPMP Business Plan Schedule	7-2

Acronyms

AEA	Atomic Energy Act of 1954
AEC	Atomic Energy Commission
AIP	Agreement in Principle
ALARA	As Low As Reasonably Achievable
CEARP	Comprehensive Environmental Assessment and Response Program
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CWA	Clean Water Act
CY	Calendar Year
D&D	Decontamination and Decommissioning
DOE	Department of Energy
DOE/AL	DOE/Albuquerque Operations Office
DOE/HQ	DOE Headquarters
DOE/LAAO	DOE/Los Alamos Area Office
EPA	Environmental Protection Agency
ER	Environmental Restoration Program
ESH	Environment, Safety, and Health
FIMAD	Facility for Information Management, Analysis and Display
FY	Fiscal Year
GMP	Groundwater Monitoring Plan
GWPMP	Groundwater Protection Management Program
GWPMPP	Groundwater Protection Management Program Plan
HSWA	Hazardous and Solid Waste Amendments
HWTF	Hazardous Waste Treatment Facility
LAAO	Los Alamos Area Office
LANL	Los Alamos National Laboratory
LIPS	Laboratory Integration Prioritization System
MDA	Material Disposal Area
MWDF	Mixed Waste Disposal Facility
NEPA	National Environmental Policy Act
NMED	New Mexico Environment Department
NMWQCC	New Mexico Water Quality Control Commission

NPDES	National Pollutant Discharge Elimination System
NRC	Nuclear Regulatory Commission
OB/OD	Open Burning / Open Detonation
PMC	Program Management Committee
QAP	Quality Assurance Plan
QAPP	Quality Assurance Program Plan
RCRA	Resource Conservation and Recovery Act
SARA	Superfund Amendments and Reauthorization Act
SDWA	Safe Drinking Water Act
SOP	Standard Operating Procedure
SPCC	Spill Prevention Control and Countermeasures
SWSC	Sanitary Wastewater Systems Consolidation
SWDA	Solid Waste Disposal Act
SWMU	Solid Waste Management Unit
SWPP	Storm Water Pollution Prevention
TA	Technical Area
TEGD	Technical Evaluation Guidance Document
TRC	Technical Review Committee
TSCA	Toxic Substances Control Act
UC	University of California
USGS	Unites States Geological Survey
WBS	Work Breakdown Structure
WSC	Waste Stream Identification and Characterization
WM	Waste Management

1.0 Introduction

1.1 Purpose and Scope

As a Department of Energy (DOE) facility, Los Alamos National Laboratory (LANL or Laboratory) is required to conduct its operations in an environmentally safe manner. DOE Order 5400.1: "General Environmental Protection Program" establishes environmental protection program requirements, authorities, and responsibilities for all DOE facilities (DOE 1990). The goal of this order is to ensure that operations at DOE facilities comply with all applicable environmental laws and regulations, executive orders, and departmental policies.

In accordance with the requirements of Chapter III, Section 4a, of DOE Order 5400.1, the Laboratory has prepared this Groundwater Protection Management Program Plan (GWPMPP or Plan). The Order requires establishment of a groundwater protection management program which will provide: (1) documentation of the groundwater regime with respect to quantity and quality; (2) design and implementation of a groundwater monitoring program to support resource management and comply with applicable environmental laws and regulations; (3) a management program for groundwater protection and remediation, including specific Safe Drinking Water Act (SDWA), Resource Conservation and Recovery Act (RCRA) and Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) actions; (4) a summary and identification of areas that may be contaminated with hazardous substances; (5) strategies for controlling sources of these contaminants; (6) a remedial action program that is part of the site CERCLA program required by DOE 5400.4: "Comprehensive Environmental Response, Compensation, and Liability Act Requirements"; and (7) decontamination and decommissioning, and other remedial programs contained in DOE directives.

The GWPMPP has also been prepared to fulfill the requirements of Chapter IV, Section 9 of DOE Order 5400.1. This section requires development of a Groundwater Monitoring Plan (GMP) as a specific element of the GWPMPP. The GMP shall identify all DOE requirements and regulations applicable to groundwater protection and include monitoring strategies for sampling, analysis, and data management. The general requirements outlined in Section 9b include: (1) determination of baseline groundwater quality and quantity conditions; (2) demonstration of compliance with, and implementation of, all applicable regulations and DOE Orders; (3) providing data that will allow early detection of groundwater pollution or contamination; (4) providing a reporting mechanism for detection of groundwater pollution or contamination; (5) identifying existing and potential groundwater contamination sources and to maintain surveillance of these sources; and (6) providing data upon which decisions can be made concerning land disposal practices and the management and protection of groundwater resources.

Section 9c of Chapter IV requires that groundwater monitoring needs be determined by site-specific characteristics and, where appropriate, groundwater monitoring programs be designed and implemented in accordance with 40 CFR Part 264, Subpart F, or 40 CFR Part 265, Subpart F. The section also requires that monitoring for radionuclides be in accordance with DOE Orders in the 5400 series dealing with radiation protection of the public and the environment.

This Plan focuses on protection of groundwater resources in and around the Los Alamos area and ensures that all groundwater-related activities comply with the applicable federal, state, and local regulations. These regulations are described in Appendix A.

1.2 Laboratory Environmental Goals

The Laboratory's primary environmental goal is to protect the environment and public from possible adverse effects arising from the Laboratory's operations. As documented in the Laboratory's Environment, Safety, and Health Manual (LANL 1990), the Environment, Safety and Health Division (ESH) maintains a comprehensive program to provide oversight of environmental activities. Laboratory employees are required to observe environmental protection procedures and requirements as specified by their supervisors.

Director's Policy No. 104 (September 1991) states the following:

> Operations at the Laboratory shall be performed in a manner that protects the environment and addresses compliance with applicable federal, state, and local environmental protection regulations. Potential environmental degradation from previous laboratory operations will be identified and mitigated as part of a graded restoration program.

Appendix A lists the requirements of applicable environmental protection and restoration regulations pertaining to groundwater. It includes SDWA, CERCLA, RCRA, and the Hazardous and Solid Waste Amendments (HSWA).

1.3 GWPMP Mission and Objectives

The mission of the Groundwater Protection Management Program (GWPMP or Program) is to provide enhanced groundwater monitoring and program documentation in order to ensure long-term protection of the local and regional groundwater supply.

The specific Program objectives are to:

- Consolidate the activities of different LANL environmental groups to ensure a unified approach to groundwater protection and prevent duplication of effort.
- Establish an information system in which all groundwater-related data will be stored and which will be accessible to different LANL groups and outside customers.
- Address the requirements of the HSWA Permit, Module 8, Task III.
- Provide enhanced groundwater documentation to support a Laboratory-wide Environmental Impact Statement as requested by the DOE under the National Environmental Policy Act (NEPA).
- Maintain ongoing groundwater protection activities and address new issues of concern as they occur.

The purpose of this Plan is to implement these objectives. As such, the Plan will address issues of concern related to groundwater protection that exist at the Laboratory; define the management structure and fiscal organization of the Program; and establish an initial list of prioritized activities to be addressed for the purpose of expanded hydrologic knowledge and groundwater protection in the Los Alamos area.

2.0 Background

2.1 Historical Review

The Laboratory was established in 1943 as Project Y of the Manhattan Engineer District—the secret World War II effort to develop the world's first nuclear weapons. A physics professor at Berkeley, J. Robert Oppenheimer, was selected to head the effort. To keep the project developing in an academic atmosphere, the University of California (UC) was requested to manage the Laboratory.

In 27 months, Oppenheimer and his colleagues successfully completed their mission, and the war against Japan ended. After the war, Congress chose to sustain the Los Alamos site with continued funding. The Atomic Energy Commission (AEC) received control of the Laboratory from the Army and renewed the operating contract with UC. During subsequent years, the Laboratory continued to expand at a steady rate, first under the AEC and later under the Energy Research and Development Association. The Laboratory was designated a national laboratory and has operated under the DOE since 1978.

From its origins during World War II, the Laboratory has evolved into a large, multiprogram, multidisciplinary national laboratory. Table 2-1 shows the major milestones in scientific research that have been accomplished over the years at the Laboratory.

Table 2-1. Milestones in the History of Los Alamos National Laboratory

1943	The Los Alamos Laboratory, under the direction of J. Robert Oppenheimer, begins operation as Project Y of the Manhattan Project. The Bethe-Feynman formula, a simple method for calculating the yield of a fission bomb, is derived.
1944	The world's third nuclear reactor (a uranium-solution-fueled "Water Boiler" named LOPO) achieves criticality.
1945	The world's first nuclear bombs (Little Boy, a gun-type uranium bomb, and Fat Man, an implosion-type plutonium bomb) prove successful. Norris E. Bradbury is named second director of the Laboratory.
1946	The world's first plutonium-fueled nuclear reactor (Clementine) achieves criticality.
1947	The Monte Carlo technique for particle-transport computations is formulated.
1948	Helium-3 is first liquefied.
1951	First thermonuclear reaction is produced in the George shot of the Greenhouse test series.
1952	The MANIAC computer becomes operational. The first thermonuclear explosion is achieved by the Mike shot of the Ivy test series. The first facility for handling liquid hydrogen on a large scale becomes operational. Plutonium-244, plutonium-246, americium-246, einsteinium-253, and fermium-256 are discovered in the debris of the Mike shot.
1953	The Lady Godiva critical assembly achieves prompt criticality. The S_n, or discrete ordinates, method for solving neutron-transport problems is formulated.
1954	The first thermonuclear bomb containing solid fusion fuel is demonstrated in the Bravo shot of the Castle test series.
1955	The Rover Project to investigate nuclear-reactor-powered rockets is initiated.
1956	The neutrino is detected with the help of a recently developed liquid scintillator. The MANIAC II computer and the Omega West reactor become operational.
1957	The particle-in-cell (PIC) method for numerical fluid dynamics is invented.
1958	A helium-3 refrigerator providing temperatures below 0.45 Kelvin is developed.
1959	Plutonium-238 is used as a power source in space.
1960	The KIWI nuclear reactor for the Rover Project is operated at full power.
1961	The Stretch computer is developed in collaboration with IBM.

Table 2-1, Continued

1963	Satellite-borne sensors to verify adherence to the Limited Test Ban Treaty are developed. PHERMEX, the world's highest-intensity x-ray facility, is constructed.
1964	The world's highest-voltage Van de Graaff accelerator is completed.
1965	The Phoebus I-A Rover reactor is tested at full power.
1967	The side-coupled cavity is developed for the LAMPF linear accelerator.
1968	Funding for construction of LAMPF is approved by Congress and President Johnson.
1969	The ultra-high-temperature nuclear reactor (UHTREX) begins operation at 2400 °F.
1970	Harold M. Agnew is named third director of the Laboratory.
1971	Naturally occurring plutonium-244 is isolated.
1972	LAMPF accelerates protons to design energy. Isotopes of uranium are separated by selective laser excitation of UF_6.
1974	Insensitive high explosives for use in nuclear weapons are developed. The Laboratory is named a national resource for stable isotopes.
1976	A portion of the Laboratory site is designated a national environmental research park.
1977	Fusion neutrons are detected in a plasma confined by radiation from a carbon-dioxide laser.
1978	The Hot Dry Rock Program is initiated (Fenton Hill).
1979	Donald M. Kerr is named fourth director of the Laboratory. Universality of the approach to chaos in deterministic systems is discovered.
1980	The University of California establishes a branch of the Institute of Geophysics and Planetary Physics. The center for Nonlinear Studies is established.
1981	The Center for Materials Sciences is established.
1982	The Laboratory is designated a national resource for flow cytometry. GenBank, the national database for nucleic-acid sequences, begins operation. A heavy-fermion superconductor is discovered.
1983	Congress approves long-term visits at LAMPF for citizens of the People's Republic of China.
1984	The radio-frequency quadrupole cavity is developed for a neutral-particle accelerator.
1985	A new technique (CORRTEX) is developed to verify yields of underground nuclear explosions.
1986	Siegfried S. Hecker is named fifth director of the Laboratory. The world's first high-temperature hot-dry-rock system is successfully tested.
1987	The first edition of nucleotide-sequence data for HIV samples is published.
1988	The Laboratory is designated as one of three national DOE centers for human genome studies. A new type of chemical bond is discovered in the binding of molecular hydrogen to the central metal atom in certain metal complexes.
1989	A beam of energetic neutral particles is created in space.
1990	Superconducting tapes and thin films are fabricated.
1991	The Laboratory is designated as one of two centers for research on high performance computing.
1993	Cross section for the scattering of electron neutrinos by electrons is determined experimentally.

2.2 Geography

The Laboratory is located in Los Alamos County in north central New Mexico. It is situated approximately 100 km (60 mi) north-northeast of Albuquerque and 40 km (25 mi) northwest of Santa Fe (Figure 2-1). Most of the Laboratory and community developments are confined to mesa tops. The surrounding land is largely undeveloped with large tracts of land north, west, and south of the Laboratory site held by the Santa Fe National Forest, Bureau of Land

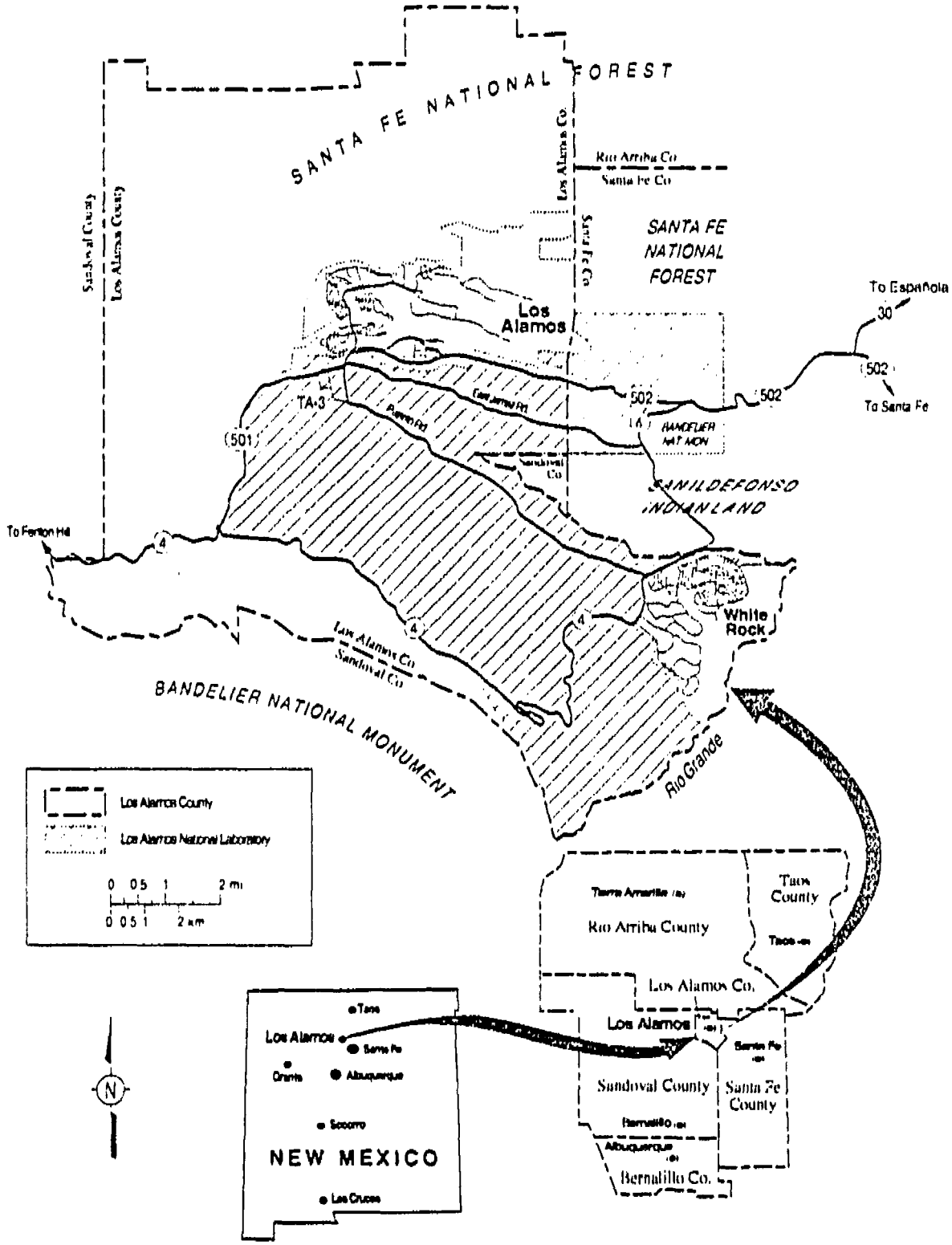

Figure 2-1. Regional location of Los Alamos.

Management, Bandelier National Monument, General Services Administration, and Los Alamos County. San Ildefonso Pueblo borders the Laboratory to the east.

Laboratory land is used for building sites, experimental areas, waste disposal locations, roads, and utility rights-of-way. The facility is divided into technical areas (TAs) each of which has a specific research function or other use (Figure 2-2). The developed sites, however, account for only a small part of the total land area. Most land provides isolation for security and safety purposes and is held in reserve for future use.

2.3 Geology

The 111-km^2 (43-mi^2) Laboratory site and Los Alamos and White Rock communities are situated on the Pajarito Plateau, which consists of a series of finger-like mesas separated by deep, west-to-east oriented canyons cut by ephemeral and interupted streams. Mesa tops range in elevation from approximately 2,400 m (7,800 ft) on the flanks of the Jemez Mountains to about 1,900 m (6,200 ft) at their eastern termination above the Rio Grande Valley (Figure 2-3).

Most of the mesas in the Laboratory area are made up of the Bandelier Tuff Formation which consists of ash fall, ash fall pumice, and rhyolite tuff. The tuff, ranging from nonwelded to welded, is more than 300 m (1,000 ft) thick in the western part of the plateau and thins to about 80 m (260 ft) eastward above the Rio Grande. It was deposited as a result of a series of major volcanic eruptions in the Jemez Mountains about 1.1 to 1.4 million years ago.

The tuff overlaps onto the Tschicoma Formation, which consists of older volcanic substances that form the Jemez Mountains. The tuff is underlain by the conglomerate of the Puye Formation in the central and eastern edge along the Rio Grande. Totavi Formation sediments and Cerros del Rio basalts interfinger with the conglomerate. These formations overlay the sediments of the Tesuque and Chamita Formations, which make up the Santa Fe Group. The Santa Fe Group of sediments extends across the Rio Grande Valley and is more than 1,000 m (3,300 ft) thick. The Pajarito Plateau is bordered on the east by the Rio Grande rift. Because the rift is slowly widening, the area experiences frequent but minor seismic disturbances.

See Appendix B for a more technical discussion of the geology of the Pajarito plateau.

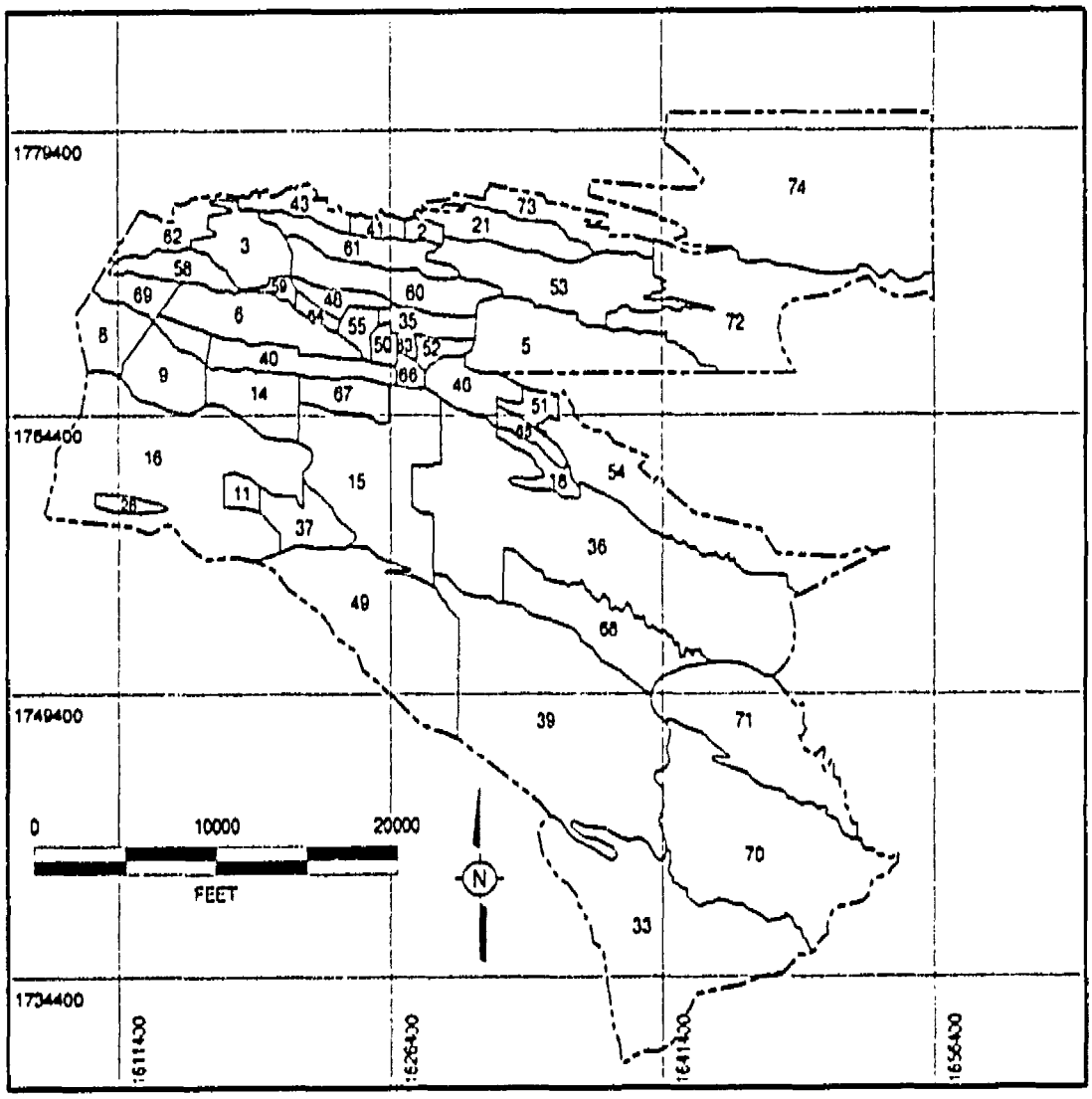

Figure 2-2. Technical areas at the Los Alamos National Laboratory.

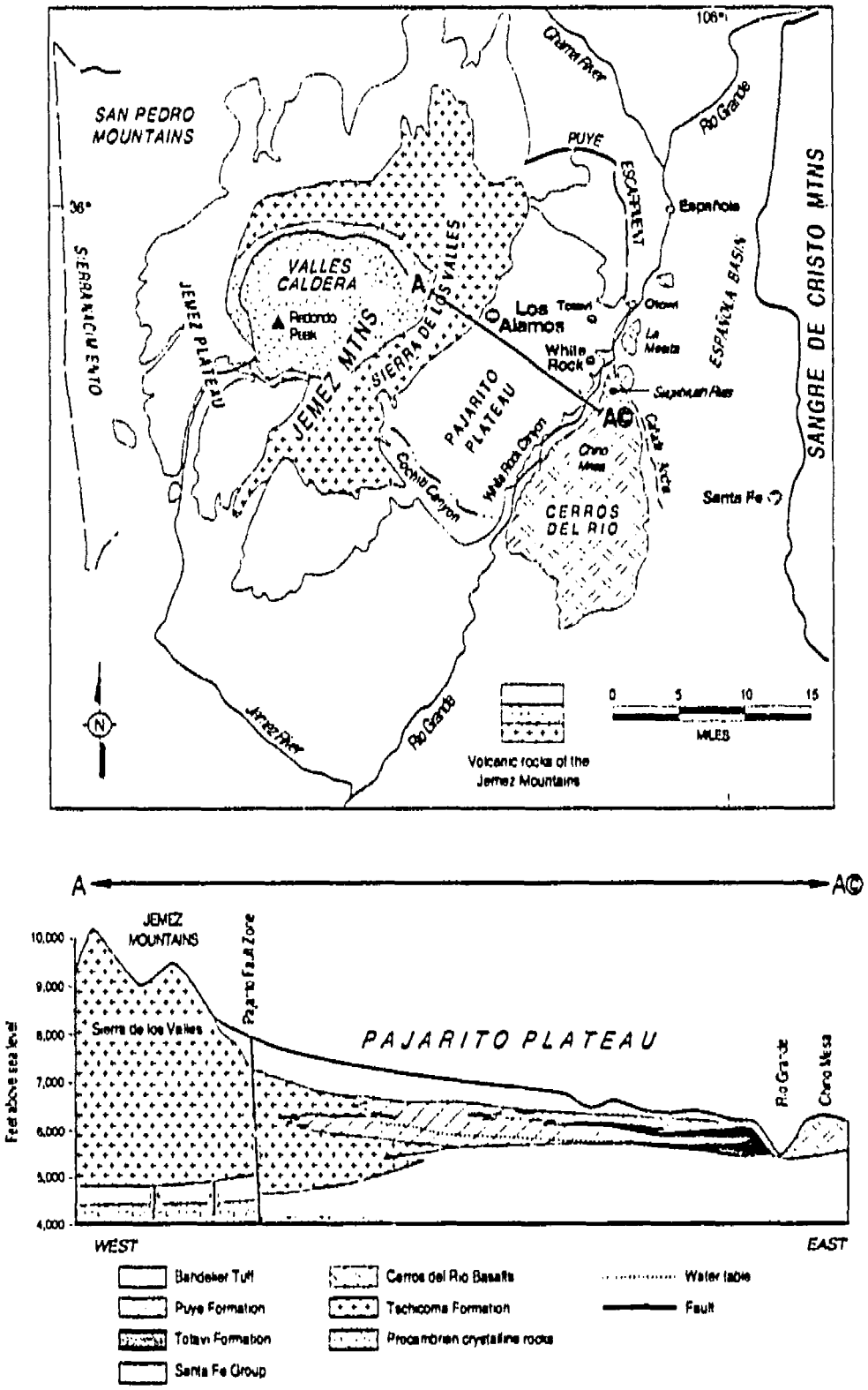

Figure 2-3. Geologic location and generalized cross section of the Pajarito Plateau.

3.0 Summary of Hydrogeological Environment

3.1 Surface Water

Surface water occurs as ephemeral and interrupted streams in the Los Alamos region. Ephemeral reaches flow briefly in response to precipitation or snowmelt in the immediate locality. Intermittent reaches flow seasonally (e.g., during snowmelt in the spring), and perennial reaches flow continuously throughout the year.

Surface water occurs primarily as ephemeral reaches in all of the major canyons, including Guaje, Rendija, Barrancas, Bayo, Pueblo, Los Alamos, Sandia, Mortandad, Pajarito, and Water Canyons (Purtymun 1975). Figure 3-1 shows the major surface drainages in the Los Alamos area. Some reaches of these streams are intermittent during the spring and fall.

Perennial reaches in the Los Alamos region are few. Springs on the flanks of the Jemez Mountains supply base flow throughout the year to the upper reaches of Guaje, Los Alamos, Pajarito, and Water Canyons, and Canyon del Valle. The volume of flow, however, from these springs is insufficient to maintain surface flows across the Laboratory site before being depleted by evaporation, transpiration, and infiltration. Runoff from heavy thunderstorms or heavy snowmelt reaches the Rio Grande in some drainages. Effluents from sanitary sewage plants, industrial waste treatment facilities, and cooling-tower blowdown are released into some canyons at rates sufficient to maintain surface flows for varying distances. These discharges typically do not migrate across the eastern boundaries of the Laboratory.

3.2 Groundwater

Groundwater occurs in three modes in the Los Alamos area: (1) shallow water perched in alluvium in canyons, (2) intermediate depth water perched in volcanic sediments and basalts, and (3) water contained in the regional aquifer. These three groundwater systems, depicted in Figure 3-2, are described below.

3.2.1 Perched Groundwater in Canyon Alluvium

Canyons of the plateau have alluvium deposits that range from 1 m (3 ft) to as much as 30 m (100 ft) in thickness. The composition of these deposits range from sands, gravels, pebbles, cobbles, and boulders in canyons that head on the flanks of the Jemez Mountains to clays, silts, sands, and gravels in canyons that head on the plateau. These alluvial layers are highly permeable, in contrast to the underlying volcanic tuff and sediments. As a result, storm runoff forms shallow perched groundwater zones that move down gradient within the alluvium. As the shallow alluvial perched groundwater moves down the canyons, it is depleted by evapotranspiration and infiltration into the underlying volcanics (Purtymun et al. 1977).

3.2.2 Perched Groundwater in Volcanic Sediments and Basalts

In the Los Alamos area, perched zones occur in the conglomerates and basalts beneath the alluvium in the middle and lower reaches of Pueblo and Los Alamos Canyons and in the lower reach of Sandia Canyon. Studies suggest that infiltration of shallow alluvial perched groundwater is the main source of recharge to the intermediate depth perched groundwater (Purtymun 1975; Abeele et al. 1981). Depth to perched water ranges from about 27 m (90 ft) in the midreach of Pueblo Canyon to about 140 m (450 ft) in lower Sandia Canyon. The vertical and lateral extent of these perched zones, the nature and extent of perching units, and the potential for migration of perched water to the regional aquifer is not fully understood by investigators to date.

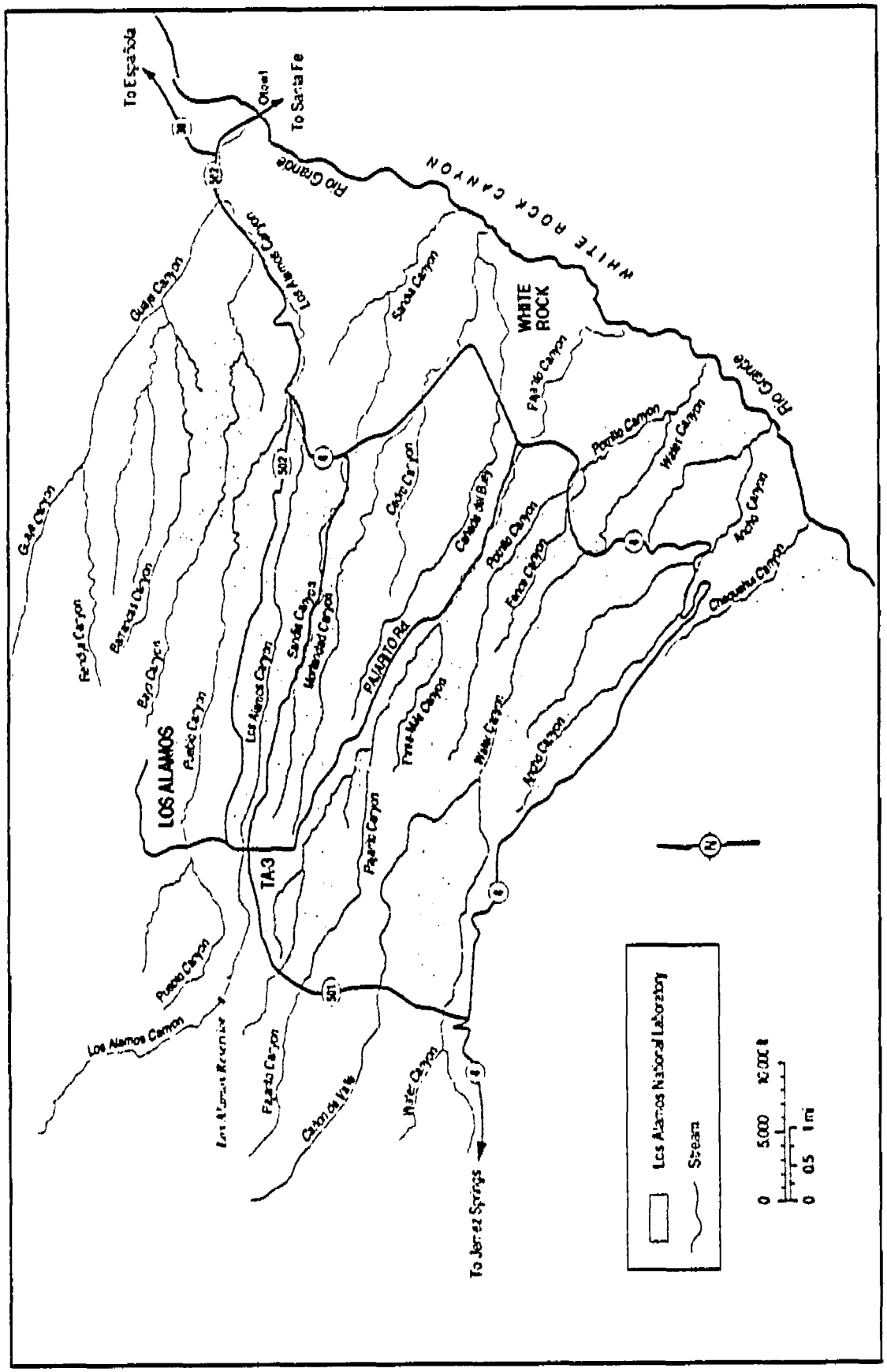

Figure 3-1. Major surface water drainages in the Los Alamos area.

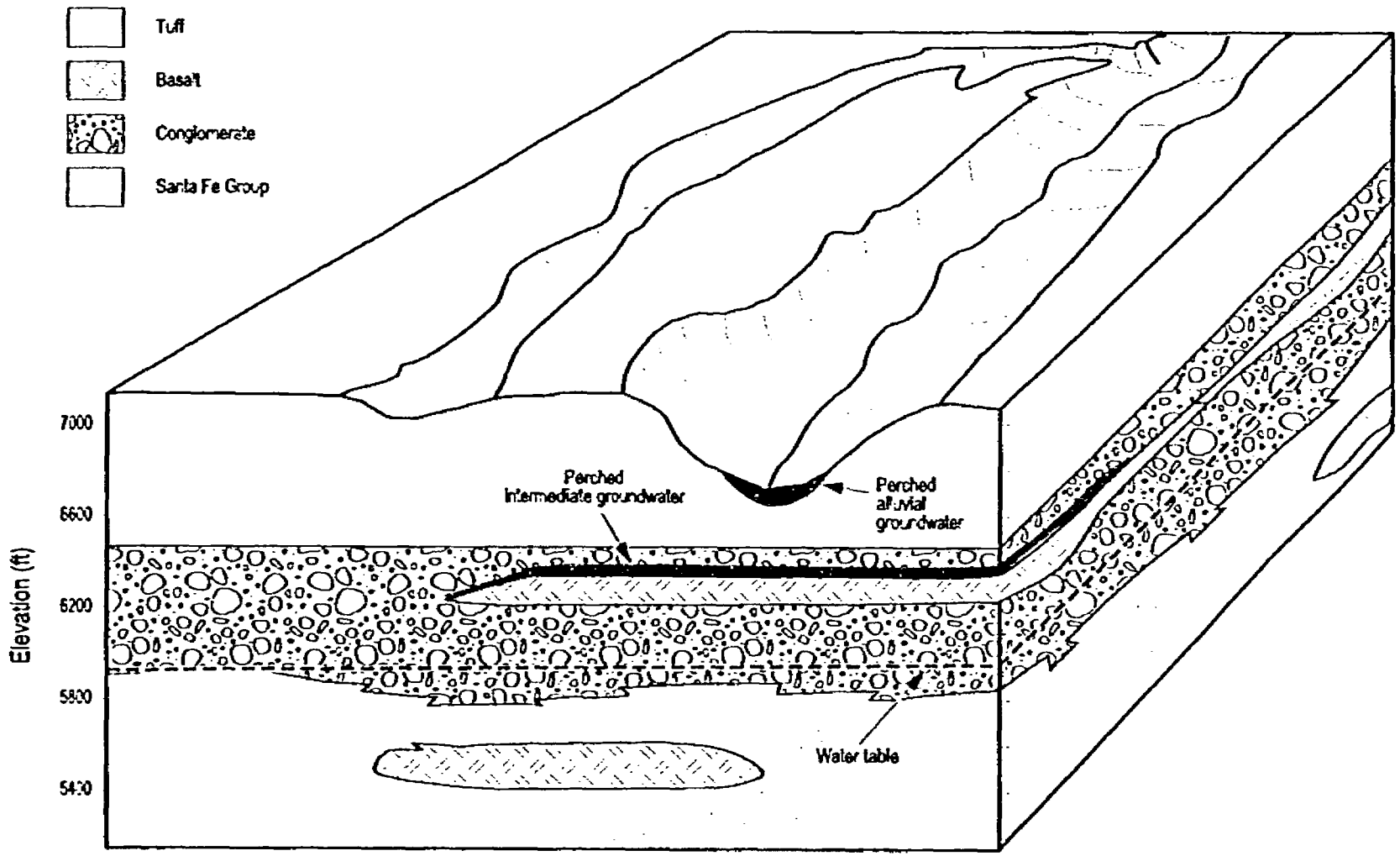

Figure 3-2. Generalized conceptual illustration of geologic-hydrologic relationships in the Los Alamos area.

3.2.3 Regional Aquifer

The regional aquifer beneath the Pajarito Plateau serves as the municipal water supply for Los Alamos and the surrounding communities. 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 plateau. The depths to water below the mesa tops range from 360 m (1,200 ft) along the western margin of the plateau to about 180 m (600 ft) at the eastern margin. The regional aquifer is separated from the perched water in the alluvium and the perched water in the volcanics by 110 m (350 ft) to 190 m (620 ft) of tuff and volcanic sediments which impede the downward migration of surface and perched water. The regional aquifer responds as an unconfined aquifer in the western part of the plateau but exhibits semiartesian to artesian conditions in the eastern part along the Rio Grande. Although the water level in some places is dropping approximately two feet per year, after more than forty years of use, the regional aquifer shows little observed depletion of resources: the piezometric surface has not declined significantly and there are nearly complete water-level recoveries after the wells are shut down.

The mechanism for recharge to the regional aquifer is not well understood. Three hydrological models have been developed to show this mechanism. The first model, proposed by Conover et al. (1963) and Griggs (1964), presents data which support the concept that groundwater discharges from the Valles Caldera to the southwest away from the Los Alamos area, and that the Tschicoma Formation in the Jemez Mountains is completely impermeable to groundwater flow. In this model, Griggs (1964) suggests that the major source of recharge to the regional aquifer is seepage from small streams and rivulets on the lower slopes of the Sierra del los Valles and on the western part of the Pajarito Plateau. A second recharge model, described in more recent Laboratory environment reports (Purtymun 1975; Purtymun et al. 1980; Purtymun et al. 1984), proposes the opposite in that the regional aquifer is recharged primarily by the caldera through the Tschicoma Formation in the Jemez Mountains. In the third model, flow through the Tschicoma Formation from the Valles Caldera is considered likely; however, the major source of recharge is thought to be through the Sangre de Cristo Mountains (Figure 3-3).

See Appendix B for a more detailed discussion of the hydrogeology of the Los Alamos area.

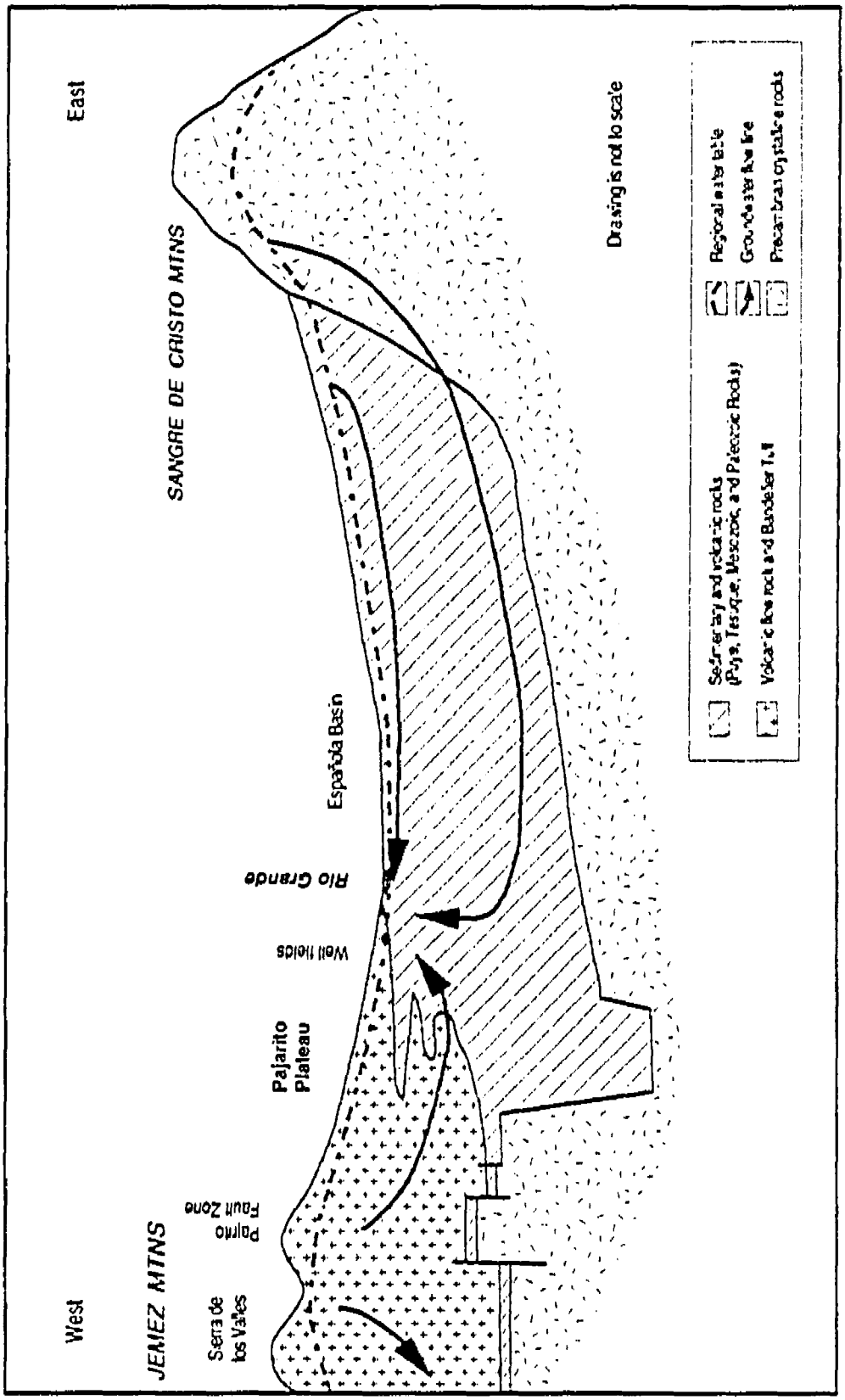

Figure 3-3. Conceptual model of regional groundwater flow paths (modified from Abeele 1981).

4.0 Groundwater Protection Efforts at LANL

4.1 Background

The protection of groundwater in the Los Alamos area has been of paramount importance since the end of World War II, when the AEC needed to develop a reliable water supply. Beginning in 1945, the United States Geological Survey (USGS) became extensively involved in overseeing and conducting various studies for the development of groundwater supplies. Special studies specifically designed to protect and monitor groundwater quality were initiated as joint efforts between the AEC, the Laboratory, and the USGS as early as 1949.

Groundwater monitoring and protection efforts at the Laboratory have evolved from the early programs initiated by the USGS to present efforts including the Environmental Restoration (ER) Project, the Decontamination and Decommissioning (D&D) Program, and emergency management and response programs. Other protection efforts include RCRA closures and compliance with the Laboratory's environmental permits (NPDES, RCRA Part B, and HSWA).

To comply with the National Pollutant Discharge Elimination System (NPDES) permit, the Laboratory has four primary programs: the Sanitary Waste Water Systems Consolidation (SWSC) Project, the Storm Water Pollution Prevention (SWPP) Plan, the Waste Stream Identification and Characterization (WSC) Program, and the Spill Prevention Control and Countermeasures (SPCC) Program. The Laboratory also maintains a groundwater monitoring network in order to detect any effects that Laboratory activities may have on the quality of the regional aquifer. The current GWPMPP addresses environmental monitoring, resource management, aquifer protection, and hydrogeologic investigations.

4.2 Protection Programs

4.2.1 Environmental Restoration Project

The ER Project was established at the Laboratory in 1987 by the DOE. The ER Project implements the DOE's policy to protect natural resources and restore those damaged by contamination from past and present releases of hazardous substances. The ER Project goals include (1) insurance that the environmental impacts of Laboratory activities are thoroughly investigated and that corrective actions are taken; (2) compliance with RCRA, CERCLA, NEPA, the Atomic Energy Act (AEA), and other applicable regulations and orders; and (3) provision of mechanisms through which interested parties can participate in the corrective action review process.

4.2.2 Decontamination and Decommissioning Program

The D&D Program at LANL was established in 1989 to manage nonoperational, contaminated facilities. The D&D Program responsibilities include assessment and cleanup of facilities and equipment not regulated under CERCLA or RCRA. The D&D Program has been integrated with the ER Project to enhance cleanup efforts. All activities are conducted in accordance with federal and state requirements and DOE Orders applicable to nuclear facilities and other facilities that generate radioactive and hazardous materials and wastes.

4.2.3 RCRA Closures

RCRA mandates a program to regulate hazardous wastes from generation through disposal. The program emphasizes the reduction of hazardous waste volume and toxicity and requires treatment of hazardous waste prior to disposal. Several potential release sites and other areas of concern are subject to the corrective action requirements and the closure provision of RCRA.

All corrective measures conducted by LANL are to comply specifically with the RCRA regulation. LANL sites are assessed and, if necessary, remediated by either voluntary corrective actions, corrective measures implementation, or RCRA closure. These activities ensure that releases are identified and either mitigated or eliminated (LANL 1995). The ER Project is responsible for implementing corrective actions at RCRA-regulated land units and RCRA closures, if needed.

4.2.4 Emergency Management and Response

LANL maintains an emergency management and response system that, through emergency planning, preparedness, and effective response capabilities, is capable of responding to and mitigating the potential consequences of emergencies.

4.2.5 Compliance with the NPDES Permit

NPDES was established by the Clean Water Act (CWA) and requires permitting of all point-source effluent discharges into the nation's waters. The primary goal of the CWA is to restore and maintain the chemical, physical, and biological integrity of the nation's waters. Specific criteria for an effluent must be met before that effluent can be discharged into the environment. The Laboratory has two NPDES permits, one for Laboratory facilities and one for operations at the Fenton Hill hot dry rock geothermal facility.

The Laboratory has established the SWSC Project to eliminate violations of the NPDES permit. A new, centralized, sanitary waste water treatment plant was constructed at TA-46 to replace the TA-3 waste water treatment plant and six smaller treatment facilities that consistently failed to meet NPDES discharge regulations. The new treatment plant will also eliminate approximately 30 septic tank systems, and result in a significant savings in operating and maintenance costs.

Storm water discharges associated with industrial activity and storm water discharges from construction sites fall under the NPDES regulations. Facilities covered by NPDES permits must develop SWPP plans. Each plan must identify potential sources of pollution that may reasonably be expected to affect the quality of storm water discharges. In addition, the plan must describe and ensure implementation of practices used to reduce the pollutants in storm water discharges at the facility and ensure compliance with the terms and conditions of the NPDES permit.

The WSC program was conducted during 1992 to verify that each waste stream is properly monitored under the outfall category for which it is permitted and to identify and eliminate noncomplying waste water discharges. Action plans are developed and implemented through the WSC program to bring respective facilities into compliance with NPDES requirements.

The SPCC Plan is required by the CWA. It addresses facility improvements, operational procedures, and mechanisms for reporting hazardous substances and oil spills to the authorities. The SPCC program and LANL requires secondary containment for all above ground storage tanks. The program also provides spill control on drum and container storage, chemical

storage, and equipment containing oil. In 1989, eleven major sites were augmented with secondary containment facilities, and spill prevention and control training lectures were given to more than a dozen operating groups (LANL 1994).

4.2.6 Corrective Activities Program

The Corrective Activities Program includes activities designed to bring active or standby facilities into compliance with ambient air, water, and solid waste regulations and agreements. The program is responsible for compliance with CWA and other requirements for effluent discharge, including WSC and SPCC.

4.3 Monitoring Network

Groundwater protection activities at LANL include an extensive groundwater monitoring system for assessment of water quality and detection of contaminants in the water supply.

The existing groundwater monitoring network in the Los Alamos area consists of a variety of supply wells, test wells and springs located onsite and outside of the Laboratory boundary. Scientists routinely sample and analyze wells and springs for radioactive and toxic constituents for basic water quality and resource depletion. Results are published in the annual environmental surveillance report, e.g., Environmental Surveillance at Los Alamos During 1992 (LANL 1994), and the annual water supply report, e.g., Water Supply at Los Alamos During 1991 (LANL 1994).

Information on groundwater monitoring and sampling requirements, design criteria, and sampling procedures and equipment can be found in the Groundwater Monitoring Plan which exists as Chapter 8 of the Draft Environmental Monitoring Plan (LANL 1995a) and as Appendix F of this document. Networks for sampling the three principal groundwater zones are summarized below. A list of the monitoring stations used for environmental surveillance, the general locations, sampling rationale, and programmatic drivers is given in Table 4-1. Specific locations for these stations are given in Appendix E.

4.3.1 Regional aquifer

The quality of water in the regional aquifer is tested at various locations in and around the Laboratory at least once a year (Figure 4-1). There are eight deep test wells and 14 supply wells which belong to the DOE. There are also several regional aquifer wells near the Rio Grande which do not belong to the DOE. These wells are on San Ildefonso Pueblo land and are sampled under the Memoranda of Understanding (MOU) between the Bureau of Indian Affairs (BIA), the DOE, and the Laboratory. In addition there are many springs along the Rio Grande which are sampled. Springs are discussed in Section 4.3.4.

Deep test wells include TW-1 and TW-2 in Pueblo Canyon, TW-3 in Los Alamos Canyon, TW-4 near Acid Canyon, TW-8 in Mortandad Canyon, and DT-5A, DT-9, and DT-10 on Frijoles Mesa. Test wells TW-1, TW-2, TW-3, TW-4, and TW-8 are located in or near canyons that have received or are now receiving industrial effluents. The test wells were constructed between 1949 and 1960 using cable-tool drilling methods. All test wells are equipped with pumps and continuous recording transducers.

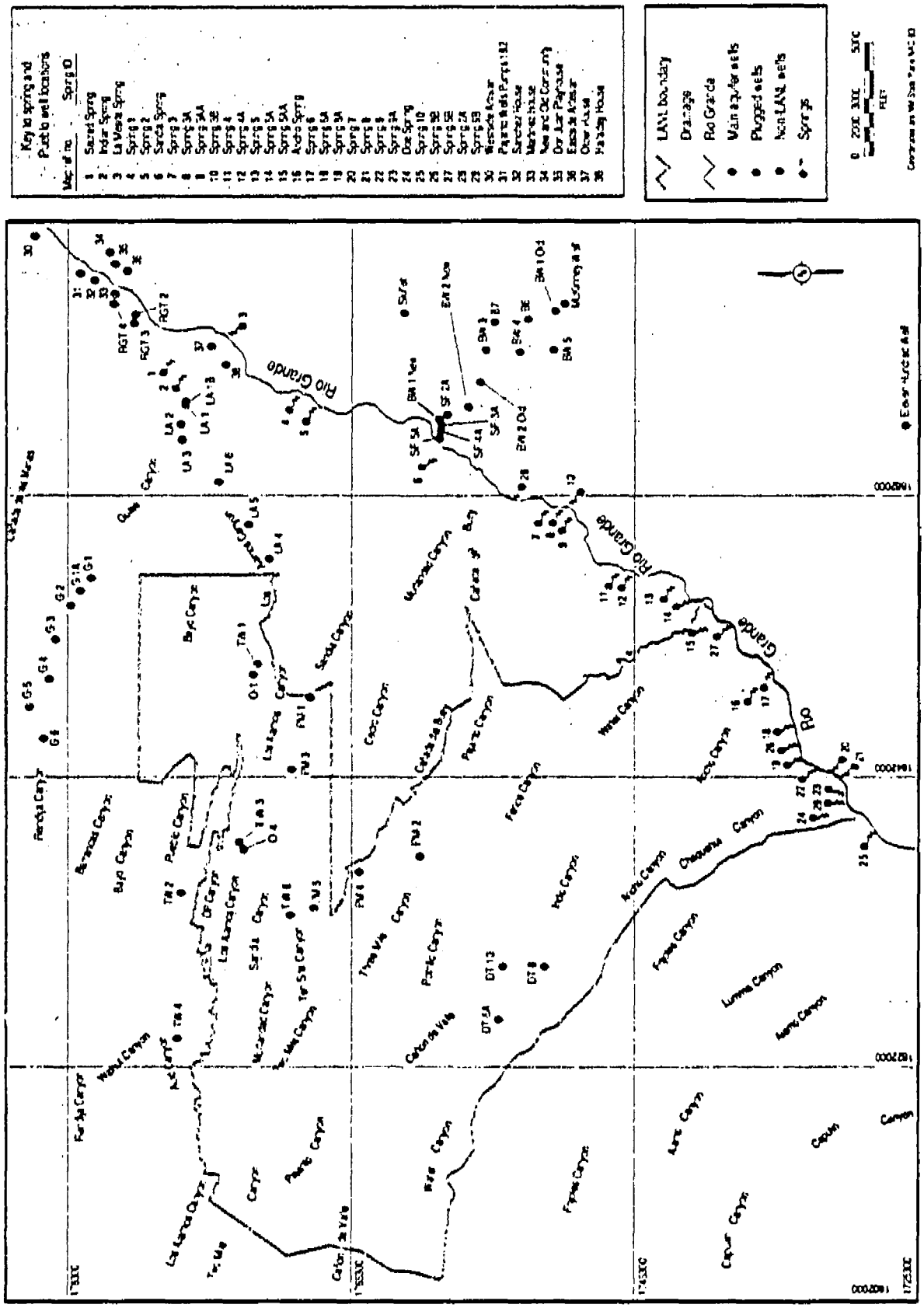

Figure 4-1. Regional aquifer wells and springs.

DOE supply wells include the Guaje well field, the Pajarito Mesa wells, and the Otowi well O-4. The Guaje wells are G-1, G-1A, G-2, G-4, and G-5 in Guaje Canyon and G-6 in Rendija Canyon. The Pajarito Mesa wells are PM-1 and PM-3 in Sandia Canyon, PM-2 in Pajarito Canyon, PM-4 in Cañada del Buey, and PM-5 on Pajarito Mesa. Otowi well O-4 is in Los Alamos Canyon. These wells are also equipped with dedicated pumps and either continuous recording water-level transducers or airline recorders.

Two supply wells which are not currently being used to monitor the regional aquifer are Guaje well G-3 and Otowi well O-1. Well G-3 was taken off line in 1993 because of decline in production and sand in the pump. Well O-1 does not have a turbine pump due to being drilled too crooked to allow for installation of one.

The depth to water varies between wells that are located in canyon bottoms and those located on mesa tops. Depth to water also varies with location on the Pajarito Plateau, depending on how close to the mountains or to the eastern edge of the plateau the well is located. Information on well depths and screened intervals is given in Appendix E.

Regional aquifer wells are sampled for eight radiochemical constituents (^{137}Cs, ^{238}Pu, $^{239,240}Pu$, Total U, ^{3}H, gross gamma activity, gross alpha activity, and gross beta activity), metals (Ag, Al, As, B, Ba, Be, Cd, Co, Cr, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Sb, Se, Sn, Sr, Tl, V, and Zn), general inorganics (SiO_2, Ca, Mg, K, Na, CO_3, HCO_3, PO_4, SO_4, NO_3, CN, total dissolved solids, total hardness, total suspended solids, pH, and electrical conductance), and organics (volatiles, semivolatiles, the 129 priority pollutants, individual herbicides, pesticides, PCBs, and oils or solvents). Regional aquifer supply wells are sampled annually for radiochemistry, metals, and general inorganics and triennially for organics. Regional aquifer test wells are sampled annually for radiochemistry and general inorganics, and triennially for metals and organics. See Table 4-1 for constituents and sampling frequencies associated with each well.

Regional aquifer wells on San Ildefonso Pueblo land which are sampled under the MOU include LA-1A, LA-1B, LA-2, LA-5, Otowi House well, Halladay House well, New Community well, Martinez House well, Sanchez House well, and Pajarito Well Pumps 1 and 2. Wells LA-1A and LA-1B are observation wells, while the others are supply wells for the San Ildefonso Pueblo. Annually, under the MOU it is determined which wells will be sampled. Wells chosen for sampling will vary from year to year. Other San Ildefonso Pueblo wells that are sometimes sampled for special studies are the Old Community well, Westside Artesian well, Eastside Artesian well, and Don Juan Playhouse well.

Under the MOU, wells are sampled annually for the eight radiochemical constituents, metals, and general inorganics, and triennially for ^{241}Am, ^{90}Sr, and organics.

Analytical results from the sampling events are presented in the annual environmental surveillance reports.

4.3.2 Intermediate Perched Groundwater

Perched groundwater systems of limited extent occur in the Guaje Pumace bed at the base of the Bandelier Tuff as well as in the underlying conglomerates and basalts in portions of Pueblo, Los Alamos, and Sandia Canyons. Samples are routinely obtained from two test wells and one spring (discussed in Section 4.3.4). Figure 4-2 shows these locations.

Test Well 1A is located in lower Pueblo Canyon and is completed at a depth of 225 ft into basalts. These basalts are known to have been recharged by effluent from the sewage outfall in Bayo Canyon.

Table 4-1. Environmental Surveillance Groundwater Monitoring Stations—Wells

Well ID	Location	Location Rationale	Environmental Surveillance: Constituents	Environmental Surveillance: Frequency	Environmental Surveillance: Programmatic Drivers	Other Sampling Events: Frequency	Other Sampling Events: Constituents	Other Sampling Events: Reason
Regional Aquifer Wells								
DT 5A	Frijoles Mesa TA 49	Hydrologic Characterization of regional aquifer	Radiochemistry I & III Metals General Inorganics Organics	Annually Triennially Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2)	1987	Pb	Special Study
DT 9	Frijoles Mesa TA 49	Hydrologic Characterization of regional aquifer	Radiochemistry I & III Metals General Inorganics Organics	Annually Triennially Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2)			
DT-10	Frijoles Mesa TA 49	Hydrologic Characterization of regional aquifer	Radiochemistry I & III Metals General Inorganics Organics	Annually Triennially Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2)			
TW 1	LA Canyon	Monitor regional aquifer downgradient of old TA 45 treatment plant	Radiochemistry I & III Metals General Inorganics Organics	Annually Triennially Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2)			
TW 2	Pueblo Canyon	Monitor regional aquifer downgradient of old TA 45 treatment plant	Radiochemistry I & III Metals General Inorganics Organics	Annually Triennially Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2)	Apr 80	Some General Inorganics and Fe, Mn, Li, SO_4, Cl, and F	Special Study - Geothermal Investigation
TW 3	LA Canyon	Monitor regional aquifer below LA Canyon alluvial perched GW zone	Radiochemistry I & III Metals General Inorganics Organics	Annually Triennially Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2)	Apr 80	Some General Inorganics and Fe, Mn, Li, SO_4, Cl, and F	Special Study - Geothermal Investigation
TW 4	Pueblo Canyon	Monitor regional aquifer in vicinity of old TA 21 treatment plant	Radiochemistry I & III Metals General Inorganics Organics	Annually Triennially Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2)			
TW 8	Mortandad Canyon	Monitor regional aquifer below Mortandad Canyon	Radiochemistry I & III Metals General Inorganics Organics	Annually Triennially Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2)			
G 1	Guaje Canyon near confluence with Barranca Canyon	Water supply for LA Townsite and LANL	Radiochemistry I & III Metals General Inorganics Organics	Annually Annually Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2)	Apr 80 Apr 87	Some General Inorganics and Fe, Mn, Li, SO_4, Cl, and F Ca, Mg, and Si	Special Study - Geothermal Investigation Special Study - Power plant water quality
G 1A	Guaje Canyon	Water supply for LA Townsite and LANL	Radiochemistry I & III Metals General Inorganics Organics	Annually Annually Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2)	Apr 80 Apr 87	Some General Inorganics and Fe, Mn, Li, SO_4, Cl, and F Ca, Mg, and Si	Special Study - Geothermal Investigation Special Study - Power plant water quality
G 2	Guaje Canyon	Water supply for LA Townsite and LANL	Radiochemistry I & III Metals General Inorganics Organics	Annually Annually Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2)	Apr 80 Apr 87	Some General Inorganics and Fe, Mn, Li, SO_4, Cl, and F Ca, Mg, and Si	Special Study - Geothermal Investigation Special Study - Power plant water quality

Table 4-1. Environmental Surveillance Groundwater Monitoring Stations—Wells

Well ID	Location	Location Rationale	Environmental Surveillance			Other Sampling Events		
			Constituents	Frequency	Programmatic Drivers	Frequency	Constituents	Reason
G-3*	Guaje Canyon	Water supply for LA Townsite and LANL	Radiochemistry I & III Metals General Inorganics Organics	Annually Annually Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2)	Apr 67	Ca, Mg, and Si	Special Study - Power plant water quality
G-4	Guaje Canyon near confluence with Rendija Canyon	Water supply for LA Townsite and LANL	Radiochemistry I & III Metals General Inorganics Organics	Annually Annually Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2)	Apr 80 Apr 67	Some General Inorganics and Fe, Mn, Li, SO4, Cl, and F Ca, Mg, and Si	Special Study - Geothermal Investigation Special Study - Power plant water quality
G-5	Guaje Canyon	Water supply for LA Townsite and LANL	Radiochemistry I & III Metals General Inorganics Organics	Annually Annually Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2)	Apr 67	Ca, Mg, and Si	Special Study - Power plant water quality
G-6	Rendija Canyon near confluence with Guaje Canyon	Water supply for LA Townsite and LANL	Radiochemistry I & III Metals General Inorganics Organics	Annually Annually Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2)	Apr 80 Apr 67	Some General Inorganics and Fe, Mn, Li, SO4, Cl, and F Ca, Mg, and Si	Special Study - Geothermal Investigation Special Study - Power plant water quality
LA-1A	LA Canyon near confluence with Rio Grande	Observation for San Ildefonso Pueblo	Radiochemistry I & III Radiochemistry II Metals General Inorganics Organics	Annually Triennially Annually Annually Triennially	DOE Order 5400.1 HSWA (Sec. C, Pt 2) MOU			
LA-1B	LA Canyon near confluence with Rio Grande	Observation for San Ildefonso Pueblo	Radiochemistry I & III Radiochemistry II Metals General Inorganics Organics	Annually Triennially Annually Annually Triennially	DOE Order 5400.1 HSWA (Sec. C, Pt 2) MOU	Apr 80 Apr 67	Some General Inorganics and Fe, Mn, Li, SO4, Cl, and F Ca, Mg, and Si	Special Study - Geothermal Investigation Special Study - Power plant water quality
LA-2	LA Canyon near intersection of SR 30 and SR 502	Water supply for San Ildefonso Pueblo	Radiochemistry I & III Radiochemistry II Metals General Inorganics Organics	Annually Triennially Annually Annually Triennially	DOE Order 5400.1 HSWA (Sec. C, Pt 2) MOU	Apr 67	Ca, Mg, and Si	Special Study - Power plant water quality
LA-5	LA Canyon near confluence with Pueblo Canyon	Water supply for San Ildefonso Pueblo	Radiochemistry I & III Radiochemistry II Metals General Inorganics Organics	Annually Triennially Annually Annually Triennially	DOE Order 5400.1 HSWA (Sec. C, Pt 2) MOU	Apr 67	Ca, Mg, and Si	Special Study - Power plant water quality
O-1*	Pueblo Canyon near confluence with LA Canyon	Water supply for LA Townsite and LANL	Radiochemistry I & III Metals General Inorganics Organics	Annually Annually Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2)			
O-4	LA Canyon near confluence with DP Canyon	Water supply for LA Townsite and LANL	Radiochemistry I & III Metals General Inorganics Organics	Annually Annually Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2)			

Table 4-1. Environmental Surveillance Groundwater Monitoring Stations—Wells

Well ID	Location	Location Rationale	Environmental Surveillance			Other Sampling Events		
			Constituents	Frequency	Programmatic Drivers	Frequency	Constituents	Reason
FM-1	Middle Sandia Canyon	Water supply for LA Townsite and LANL	Radiochemistry I & III Metals General Inorganics Organics	Annually Annually Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2)	Apr-80 Apr-87 Mar-89	Some General Inorganics and Fe, Mn, Li, SO4, Cl, and F Ca, Mg, and Si Sand content	Special Study - Geothermal Investigation Special Study - Power plant water quality Special Study - Pajarito sand pumpage
FM-2	Middle Pajarito Canyon	Water supply for LA Townsite and LANL	Radiochemistry I & III Metals General Inorganics Organics	Annually Annually Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2)	Apr-80 Apr-87 Mar-89	Some General Inorganics and Fe, Mn, Li, SO4, Cl, and F Ca, Mg, and Si Sand content	Special Study - Geothermal Investigation Special Study - Power plant water quality Special Study - Pajarito sand pumpage
FM-3	Middle Sandia Canyon	Water supply for LA Townsite and LANL	Radiochemistry I & III Metals General Inorganics Organics	Annually Annually Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2)	Apr-87 Mar-89	Ca, Mg, and Si Sand content	Special Study - Power plant water quality Special Study - Pajarito sand pumpage
FM-4	Upper Canada del Buey	Water supply for LA Townsite and LANL	Radiochemistry I & III Metals General Inorganics Organics	Annually Annually Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2)			
FM-5	Pajarito Mesa	Water supply for LA Townsite and LANL	Radiochemistry I & III Metals General Inorganics Organics	Annually Annually Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2)			
Haladay House	San Ildefonso Pueblo, near LA 18	Water supply for the Haladay house	Radiochemistry I & III Radiochemistry II Metals General Inorganics Organics	Annually Triennially Annually Annually Triennially	DOE Order 5400.1 HSWA (Sec. C, Pt 2) MOU			
Otowi House	San Ildefonso Pueblo, near LA 18	Water supply for the Otowi house	Radiochemistry I & III Radiochemistry II Metals General Inorganics Organics	Annually Triennially Annually Annually Triennially	DOE Order 5400.1 HSWA (Sec. C, Pt 2) MOU			
Martinez house	San Ildefonso Pueblo	Water supply for the Martinez house	Radiochemistry I & III Radiochemistry II Metals General Inorganics Organics	Annually Triennially Annually Annually Triennially	DOE Order 5400.1 HSWA (Sec. C, Pt 2) MOU			
Sanchez House	San Ildefonso Pueblo	Water supply for the Sanchez house	Radiochemistry I & III Radiochemistry II Metals General Inorganics Organics	Annually Triennially Annually Annually Triennially	DOE Order 5400.1 HSWA (Sec. C, Pt 2) MOU			

Table 4-1. Environmental Surveillance Groundwater Monitoring Stations—Wells

Well ID	Location	Location Rationale	Environmental Surveillance			Other Sampling Events		
			Constituents	Frequency	Programmatic Drivers	Frequency	Constituents	Reason
New Community Well	San Ildefonso Pueblo	Near Pueblo drinking water supply for the dwelling	Radiochemistry I & III Radiochemistry II Metals General Inorganics Organics	Annually Triennially Annually Annually Triennially	DOE Order 5400.1 HSWA (Sec. C, Pt 2) MOU			
Pajarito Well Pump 1	San Ildefonso Pueblo	Water supply	Radiochemistry I & III Radiochemistry II Metals General Inorganics Organics	Annually Triennially Annually Annually Triennially	DOE Order 5400.1 HSWA (Sec. C, Pt 2) MOU			
Pajarito Well Pump 2	San Ildefonso Pueblo	Water supply	Radiochemistry I & III Radiochemistry II Metals General Inorganics Organics	Annually Triennially Annually Annually Triennially	DOE Order 5400.1 HSWA (Sec. C, Pt 2) MOU			
Intermediate Perched Zone Wells								
TW 1A	LA Canyon	Monitor intermediate perched zone downgradient of old TA 45 treatment plant	Radiochemistry I, II, & III Metals General Inorganics Organics	Annually Triennially Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2)			
TW 2A	Pueblo Canyon	Monitor intermediate perched zone downgradient of old TA 45 treatment plant	Radiochemistry I, II, & III Metals General Inorganics Organics	Annually Triennially Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2)			
Alluvial Perched Zone Wells								
APCO-1	Pueblo Canyon near confluence with LA Canyon	HSWA permit requirement to investigate extent of saturation and contamination	Radiochemistry I, II, & III Metals General Inorganics Organics	Annually Annually Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2)	Quarterly for 1995	Radiochemistry I, II, & III, Metals General Inorganics Organics	DOE response to EPA request for additional sampling
CDBO 4[illegible]	Canada del Buey	Observation	Radiochemistry I, II, & III Metals General Inorganics Organics	Annually Annually Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2) NMWQR (SWSC Discharge Plan			
CDBO 5[illegible]	Canada del Buey	Observation	Radiochemistry I, II, & III Metals General Inorganics Organics	Annually Annually Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2) NMWQR (SWSC Discharge Plan			
CDBO 6	Canada del Buey	Observation	Radiochemistry I, II, & III Metals General Inorganics Organics	Annually Annually Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2) NMWQR (SWSC Discharge Plan			
CDBO 7[illegible]	Canada del Buey	Observation	Radiochemistry I, II, & III Metals General Inorganics Organics	Annually Annually Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2) NMWQR (SWSC Discharge Plan			
CDBO 8[illegible]	Canada del Buey	Observation	Radiochemistry I, II, & III Metals General Inorganics Organics	Annually Annually Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2) NMWQR (SWSC Discharge Plan			

Table 4-1. Environmental Surveillance Groundwater Monitoring Stations—Wells

			Environmental Surveillance			Other Sampling Events		
Well ID	Location	Location Rationale	Constituents	Frequency	Programmatic Drivers	Frequency	Constituents	Reason
LAO 0.7	LA Canyon TA 41	Observation	Radiochemistry I, II, & III Metals General Inorganics Organics	Annually Annually Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2)			
FCO 1.7	Fence Canyon TA 68	HSWA permit requirement to investigate extent of saturation and contamination				Quarterly for 1995	Radiochemistry I, II, & III, Metals, General Inorganics Organics	DOE response to EPA request for additional sampling
LAO 1	LA Canyon TA 22/21	Observation	Radiochemistry I, II, & III Metals General Inorganics Organics	Annually Annually Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2)			
LAO 2	LA Canyon, near confluence with DP Canyon	Observation	Radiochemistry I, II, & III Metals General Inorganics Organics	Annually Annually Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2)			
LAO 3	LA Canyon, near confluence with DP Canyon	Observation	Radiochemistry I, II, & III Metals General Inorganics Organics	Annually Annually Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2)	Quarterly for 1995	Radiochemistry I, II, & III, Metals, General Inorganics, Organics	DOE response to EPA request for additional sampling
LAO 3A	LA Canyon, near confluence with DP Canyon	HSWA permit requirement to investigate extent of saturation and contamination				Quarterly for 1995	Radiochemistry I, II, & III, Metals, General Inorganics Organics	DOE response to EPA request for additional sampling
LAO 4	LA Canyon	Observation	Radiochemistry I, II, & III Metals General Inorganics Organics	Annually Annually Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2)			
LAO 4.5	LA Canyon	Observation	Radiochemistry I, II, & III Metals General Inorganics Organics	Annually Annually Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2)	Quarterly for 1995 Annual	Radiochemistry I, II, & III, Metals, General Inorganics Organics Metals, General Inorganics, and RCRA Module II organics	DOE response to EPA request for additional sampling
LAO 4.5A	LA Canyon	HSWA permit requirement to investigate extent of saturation and contamination				Quarterly for 1995	Radiochemistry I, II, & III, Metals, General Inorganics Organics	DOE response to EPA request for additional sampling
LAO 4.5B	LA Canyon	HSWA permit requirement to investigate extent of saturation and contamination				Quarterly for 1995	Radiochemistry I, II, & III, Metals, General Inorganics Organics	DOE response to EPA request for additional sampling
LAO 4.5C	LA Canyon	HSWA permit requirement to investigate extent of saturation and contamination				Quarterly for 1995	Radiochemistry I, II, & III, Metals, General Inorganics, Organics	DOE response to EPA request for additional sampling
LAO 6	LA Canyon	Observation	Radiochemistry I, II, & III Metals General Inorganics Organics	Annually Annually Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2)	Quarterly for 1995	Radiochemistry I, II, & III, Metals, General Inorganics Organics	DOE response to EPA request for additional sampling
LAO 6A	LA Canyon	HSWA permit requirement to investigate extent of saturation and contamination				Quarterly for 1995	Radiochemistry I, II, & III, Metals, General Inorganics, Organics	DOE response to EPA request for additional sampling
LAO C	LA Canyon	Observation	Radiochemistry I, II, & III Metals General Inorganics Organics	Annually Annually Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2)			

Table 4-1. Environmental Surveillance Groundwater Monitoring Stations—Wells

Well ID	Location	Location Rationale	Environmental Surveillance			Other Sampling Events		
			Constituents	Frequency	Programmatic Drivers	Frequency	Constituents	Reason
MCO 4	Mortandad Canyon	Observation	Radiochemistry I, II, & III Metals General Inorganics Organics	Annually Annually Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2)	Quarterly for 1995	Radiochemistry I, II, & III, Metals, General Inorganics, Organics	DOE response to EPA request for additional sampling
MCO 4A**	Mortandad Canyon	HSWA permit requirement to investigate extent of saturation and contamination				Quarterly for 1995	Radiochemistry I, II, & III, Metals, General Inorganics, Organics	DOE response to EPA request for additional sampling
MCO 4B	Mortandad Canyon	HSWA permit requirement to investigate extent of saturation and contamination				Quarterly for 1995	Radiochemistry I, II, & III, Metals, General Inorganics, Organics	DOE response to EPA request for additional sampling
MCO 5	Mortandad Canyon	Observation	Radiochemistry I, II, & III Metals General Inorganics Organics	Annually Annually Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2)			
MCO 6	Mortandad Canyon	Observation	Radiochemistry I, II, & III Metals General Inorganics Organics	Annually Annually Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2)	Quarterly for 1995	Radiochemistry I, II, & III, Metals, General Inorganics, Organics	DOE response to EPA request for additional sampling
MCO 6A**	Mortandad Canyon	HSWA permit requirement to investigate extent of saturation and contamination				Quarterly for 1995	Radiochemistry I, II, & III, Metals, General Inorganics, Organics	DOE response to EPA request for additional sampling
MCO 6B	Mortandad Canyon	HSWA permit requirement to investigate extent of saturation and contamination				Quarterly for 1995	Radiochemistry I, II, & III, Metals, General Inorganics, Organics	DOE response to EPA request for additional sampling
MCO 7	Mortandad Canyon	Observation	Radiochemistry I, II, & III Metals General Inorganics Organics	Annually Annually Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2)	Quarterly for 1995	Radiochemistry I, II, & III, Metals, General Inorganics, Organics	DOE response to EPA request for additional sampling
MCO 7A	Mortandad Canyon	HSWA permit requirement to investigate extent of saturation and contamination				Quarterly for 1995	Radiochemistry I, II, & III, Metals, General Inorganics, Organics	DOE response to EPA request for additional sampling
MCO 7S	Mortandad Canyon	Observation	Radiochemistry I, II, & III Metals General Inorganics Organics	Annually Annually Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2)			
MCO 8	Mortandad Canyon	Observation				Annual	Metals, General Inorganics, and RCRA Module II organics	
PCO 1	Pajarito Canyon	Observation	Radiochemistry I, II, & III Metals General Inorganics Organics	Annually Annually Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2)			
PCO 2	Pajarito Canyon	Observation	Radiochemistry I, II, & III Metals General Inorganics Organics	Annually Annually Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2)			
PCO 3	Pajarito Canyon	Observation	Radiochemistry I, II, & III Metals General Inorganics Organics	Annually Annually Annually Triennially	DOE Order 5400.1 and HSWA (Sec. C, Pt 2)	Annual	Metals, General Inorganics, and RCRA Module II organics	
SCO 1**	Sandia Canyon	HSWA permit requirement to investigate extent of saturation and contamination				Quarterly for 1995	Radiochemistry I, II, & III, Metals, General Inorganics, Organics	DOE response to EPA request for additional sampling

Table 4-1. Environmental Surveillance Groundwater Monitoring Stations—Wells

Well ID	Location	Location Rationale	Environmental Surveillance: Constituents	Environmental Surveillance: Frequency	Environmental Surveillance: Programmatic Drivers	Other Sampling Events: Frequency	Other Sampling Events: Constituents	Other Sampling Events: Reason
SCO 2**	Sandia Canyon	HSWA permit requirement to investigate extent of saturation and contamination				Quarterly for 1995	Radiochemistry I, II, & III, Metals, General Inorganics, Organics	DOE response to EPA request for additional sampling
WCO 1**	Water Canyon	HSWA permit requirement to investigate extent of saturation and contamination				Quarterly for 1995	Radiochemistry I, II, & III, Metals, General Inorganics, Organics	DOE response to EPA request for additional sampling
WCO 2**	Water Canyon	HSWA permit requirement to investigate extent of saturation and contamination				Quarterly for 1995	Radiochemistry I, II, & III, Metals, General Inorganics, Organics	DOE response to EPA request for additional sampling
WCO 3**	Water Canyon	HSWA permit requirement to investigate extent of saturation and contamination				Quarterly for 1995	Radiochemistry I, II, & III, Metals, General Inorganics, Organics	DOE response to EPA request for additional sampling
Totavi N	San Ildefonso Pueblo	Observation	Radiochemistry I, II, & III Metals General Inorganics Organics	Annually Annually Annually Triennially	DOE Order 5400.1 HSWA (Sec. C, Pt 2) MOU			
Totavi 1	San Ildefonso Pueblo	Observation	Radiochemistry I, II, & III Metals General Inorganics Organics	Annually Annually Annually Triennially	DOE Order 5400.1 HSWA (Sec. C, Pt 2) MOU			
Totavi 2	San Ildefonso Pueblo	Observation	Radiochemistry I, II, & III Metals General Inorganics Organics	Annually Annually Annually Triennially	DOE Order 5400.1 HSWA (Sec. C, Pt 2) MOU			
BIA 1	San Ildefonso Pueblo	Observation	Radiochemistry I, II, & III Metals General Inorganics Organics	Annually Annually Annually Triennially	DOE Order 5400.1 HSWA (Sec. C, Pt 2) MOU			
BIA 2	San Ildefonso Pueblo	Observation	Radiochemistry I, II, & III Metals General Inorganics Organics	Annually Annually Annually Triennially	DOE Order 5400.1 HSWA (Sec. C, Pt 2) MOU			
BIA 3	San Ildefonso Pueblo	Observation	Radiochemistry I, II, & III Metals General Inorganics Organics	Annually Annually Annually Triennially	DOE Order 5400.1 HSWA (Sec. C, Pt 2) MOU			

* G-3 taken off line in 1989 due to pumpage of sand. O-1 has no pump.

** These wells are dry but are monitored at the given frequency and will be sampled if water is ever present.

Where Radiochemistry I is Cs-137, H-3, Pu-238, Pu-239+240, total U, and gross gamma activity
Radiochemistry II is Am-241, and Sr-90
Radiochemistry III is Gross alpha activity, gross beta activity, and Ra-226 if necessary
Metals are Ag, Al, As, B, Ba, Be, Cd, Co, Cr, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Sb, Se, Sn, Sr, Tl, V, and Zn
General Inorganics are SiO2, Ca, Mg, K, Na, CO3, HCO3, PO4, SO4, NO3, CN, TDS, total hardness, total suspended solids, pH, and electrical conductance
Organics are volatiles, semivolatiles, the 129 priority pollutants, herbicides, pesticides, PCBs, oils or solvents

Test Well 2A is located in the middle of Pueblo Canyon and is completed to a depth of 132 ft into conglomerates.

Intermediate perched groundwater wells are sampled annually for the eight radiochemical constituents plus ^{241}Am and ^{90}Sr, and for general inorganics. They are sampled triennially for metals and organics.

4.3.3 Shallow Perched Groundwater in Canyon Alluvium

Figure 4-2 shows the locations of many wells, borings, and auger holes completed into the alluvium. Shallow alluvial perched groundwater zones are known to exist in Pueblo, Los Alamos, Mortandad, and Pajarito Canyons. The shallow alluvial perched groundwater zones are sampled by means of 23 observation wells and one spring (discussed in Section 4.3.4). Seventeen wells are sampled annually as part of the environmental surveillance activities. Seven of the 17 and six other wells are designated for quarterly sampling in response to an EPA requirement. There are also 14 other shallow alluvial wells which are monitored on a regular basis but are not sampled because they are dry or do not contain enough water. The number of stations sampled may vary from year to year due to monitoring requirements or due to a well being dry.

Shallow alluvial perched groundwater may exist in portions of Water, Sandia, and Potrillo Canyons and Canyon del Valle, however there are no boreholes or wells in likely locations in the canyons to confirm its presence. Again, many other wells and boreholes to the alluvium exist, and some of the data available on them is given in the preliminary well list in Appendix E.

Perched groundwater in the alluvium of Pueblo Canyon is sampled at one observation well above the confluence with Los Alamos Canyon. Well APCO-1 was completed in 1990 as part of the HSWA Special Permit Condition requirements to evaluate the extent of the perched groundwater zone. This and other well locations are shown on Figure 4-2.

Los Alamos Canyon shallow alluvial perched groundwater is sampled at seven observation wells. Well LAO-C is near the western Laboratory boundary, well LAO-4.5 is near the eastern boundary, and wells LAO-0.7, LAO-1, LAO-2, LAO-3, and LAO-4 are spaced across the length of the canyon between. Well LAO-1 is below the site where the Omega West Reactor is located. Wells LAO-2, and LAO-3 are located near the confluence with DP Canyon which received radioactive effluent from TA-21 prior to 1986.

Mortandad Canyon shallow alluvial perched groundwater is also sampled at observation wells. Mortandad Canyon receives waste water and treated effluent from the operations at TA-46 and TA-50. It is the major release area for treated radioactive effluents. Wells MCO-4, MCO-5, MCO-6, MCO-7, and MCO-7.5 are located in the upper part of the canyon and cover about a two mile section corresponding to the known extent of saturation. Well MCO-7.5 is located below the Mortandad Canyon sediment traps.

Pajarito Canyon shallow alluvial perched groundwater is sampled at three observation wells. Wells PCO-1, PCO-2, and PCO-3 are located in the lower part of the canyon near the waste storage and disposal Areas G and L at TA-54.

In Cañada del Buey, well CDBO-6 is the final well sampled as part of the annual environmental surveillance activities. This well was completed in 1992 to monitor effluent releases from the Sanitary Waste Water Systems Consolidation (SWSC) Project. Effluent from the SWSC Project

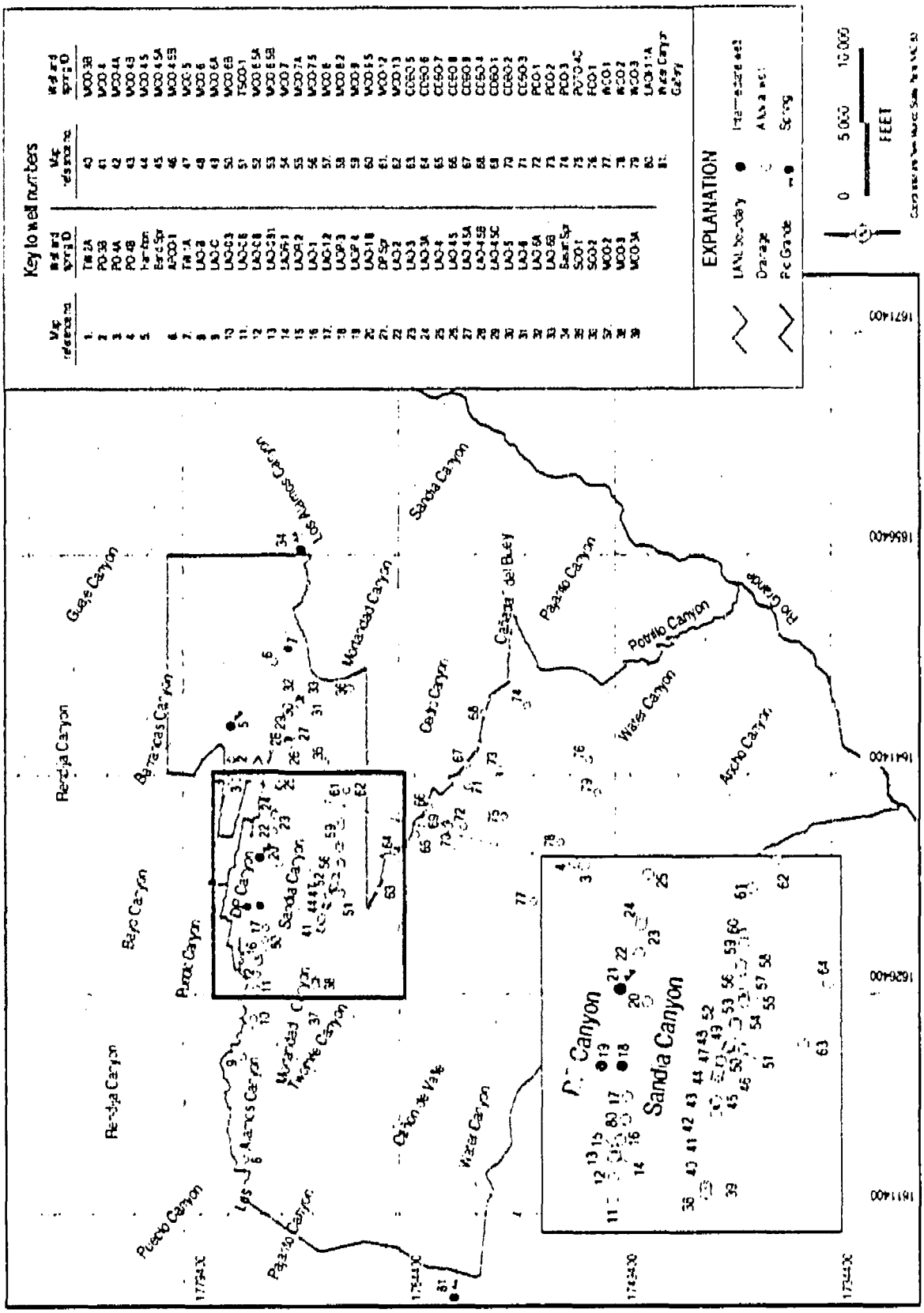

Figure 4-2. Alluvial and intermediate perched water wells and springs.

has never been discharged into Cañada del Buey. The water in CDBO-6 is thought to be from discharge during the start-up of the pump in supply well PM-4 (Purtymun, 1995).

As part of the environmental surveillance activities, shallow alluvial groundwater wells are sampled annually for the eight radiochemical constituents plus ^{241}Am and ^{90}Sr, metals and general inorganics. These wells are also sampled triennially for organics.

Three wells, MCO-8, PCO-3, and LAO-4.5 are sampled under requirements of Module II of the RCRA permit. These wells are sampled annually for radiochemistry, metals, general inorganics and organics.

Other shallow alluvial groundwater wells that were installed as part of the HSWA Special Permit Condition requirements include LAO-3A, LAO-4.5C, LAO-6A, MCO-4B, MCO-6B, and MCO-7A. These wells and their pairs (LAO-3, LAO-4.5, LAO-6, MCO-4, MCO-6, and MCO-7) as well as APCO-1 are sampled on a quarterly basis during 1995 in response to an EPA requirement (DOE, 1994). These wells will be sampled for the 10 radiochemisty constituents, metals, general inorganics, and organics. If no organics are detected in the first sampling event, a more appropriate sampling schedule for organics will be chosen on a well-by-well basis.

Other shallow alluvial wells at the Laboratory are monitored on a regular basis but are not sampled because they are dry or do not contain enough water. These include wells LAO-4.5A, LAO-4.5B, MCO-4A, MCO-6A, SCO-1, SCO-2, FCO-1, WCO-1, WCO-2, WCO-3, CDBO-4, CDBO-5, CDBO-7, and CDBO-8. These wells will be sampled if water is ever present in sufficient amounts.

4.3.4 Springs

There are 32 natural springs in and around the Laboratory which are used to monitor water quality of the regional aquifer, the intermediate perched groundwater zones, and the shallow alluvial perched groundwater zones. Figure 4-1 shows the regional aquifer springs, and Figure 4-2 shows the intermediate springs. Table 4-2 lists the springs, their general location, and sampling constituents and frequencies.

Regional aquifer springs sampled include 24 springs in White Rock Canyon and five springs on San Ildefonso Pueblo land near the confluence of Los Alamos Canyon with the Rio Grande (Figure 4-1). White Rock Canyon springs are sampled annually for six radiochemical constituents (^{137}Cs, ^{238}Pu, ^{239,240}Pu, ^{3}H, Total U, and gross gamma activity) and general inorganics and triennially for metals. Selected springs are sampled for PCBs on an annual basis.

The intermediate perched groundwater zone is regularly sampled at Basalt Spring (Figure 4-2). This spring is located in lower Los Alamos Canyon just outside the Laboratory boundary. As a location specified in Module II of the RCRA operating permit, this spring is sampled annually for the eight radiochemical components plus ^{241}Am and ^{90}Sr, metals, general inorganics and organics.

One set of springs, the Water Canyon Gallery, is located near the western boundary of the Laboratory and is used as part of the Laboratory water supply. The gallery collects discharge from a perched water zone in the volcanics on the flanks of the Jemez Mountains. The gallery is sampled annually for the eight radiochemical constituents and for the general inorganics. The spring is also sampled triennially for metals and for organics.

Table 4-2. Environmental Surveillance Groundwater Monitoring Stations—Springs

Station	Location	Environmental Surveillance: Constituents	Frequency	Programmatic Drivers	Other Sampling Events: Frequency	Constituents	Reason
Main Aquifer System							
Ancho Spring	White Rock Canyon	Radiochemistry I Metals General Inorganics PCBs (Selected Springs)	Annual Triennial Annual Triennial	DOE Order 5400.1 (Sec. C, Pt 2) HSWA	Sep 90	B, Cl, Li, NO_3, and isotopes of H and O	Special isotopic study
Doe Spring	White Rock Canyon	Radiochemistry I Metals General Inorganics PCBs (Selected Springs)	Annual Triennial Annual Triennial	DOE Order 5400.1 (Sec. C, Pt 2) HSWA	Sep 90	B, Cl, Li, NO_3, and isotopes of H and O	Special isotopic study
Rio Spring 2A	White Rock Canyon	Radiochemistry I Metals General Inorganics PCBs (Selected Springs)	Annual Triennial Annual Triennial	DOE Order 5400.1 (Sec. C, Pt 2) HSWA			
Rio Spring 3	White Rock Canyon	Radiochemistry I Metals General Inorganics PCBs (Selected Springs)	Annual Triennial Annual Triennial	DOE Order 5400.1 (Sec. C, Pt 2) HSWA	Sep 90	B, Cl, Li, NO_3, and isotopes of H and O	Special isotopic study
Rio Spring 3A	White Rock Canyon	Radiochemistry I Metals General Inorganics PCBs (Selected Springs)	Annual Triennial Annual Triennial	DOE Order 5400.1 (Sec. C, Pt 2) HSWA			
Rio Spring 3AA	White Rock Canyon	Radiochemistry I Metals General Inorganics PCBs (Selected Springs)	Annual Triennial Annual Triennial	DOE Order 5400.1 (Sec. C, Pt 2) HSWA			
Rio Spring 3B	White Rock Canyon	Radiochemistry I Metals General Inorganics PCBs (Selected Springs)	Annual Triennial Annual Triennial	DOE Order 5400.1 (Sec. C, Pt 2) HSWA	Sep 90	B, Cl, Li, NO_3, and isotopes of H and O	Special isotopic study
Rio Spring 4	White Rock Canyon	Radiochemistry I Metals General Inorganics PCBs (Selected Springs)	Annual Triennial Annual Triennial	DOE Order 5400.1 (Sec. C, Pt 2) HSWA			
Rio Spring 4A	White Rock Canyon	Radiochemistry I Metals General Inorganics PCBs (Selected Springs)	Annual Triennial Annual Triennial	DOE Order 5400.1 (Sec. C, Pt 2) HSWA			
Rio Spring 5	White Rock Canyon	Radiochemistry I Metals General Inorganics PCBs (Selected Springs)	Annual Triennial Annual Triennial	DOE Order 5400.1 (Sec. C, Pt 2) HSWA			
Rio Spring 5A	White Rock Canyon	Radiochemistry I Metals General Inorganics PCBs (Selected Springs)	Annual Triennial Annual Triennial	DOE Order 5400.1 (Sec. C, Pt 2) HSWA			

Table 4-2. Environmental Surveillance Groundwater Monitoring Stations—Springs

Station	Location	Environmental Surveillance: Constituents	Frequency	Programmatic Drivers	Other Sampling Events: Frequency	Constituents	Reason
Rio Spring 5AA	White Rock Canyon	Radiochemistry I Metals General Inorganics PCBs (Selected Springs)	Annual Triennial Annual Triennial	DOE Order 5400.1 HSWA (Sec. C, Pt. 2)			
Rio Spring 5B	White Rock Canyon	Radiochemistry I Metals General Inorganics PCBs (Selected Springs)	Annual Triennial Annual Triennial	DOE Order 5400.1 HSWA (Sec. C, Pt. 2)			
Rio Spring 6	White Rock Canyon	Radiochemistry I Metals General Inorganics PCBs (Selected Springs)	Annual Triennial Annual Triennial	DOE Order 5400.1 HSWA (Sec. C, Pt. 2)			
Rio Spring 6A	White Rock Canyon	Radiochemistry I Metals General Inorganics PCBs (Selected Springs)	Annual Triennial Annual Triennial	DOE Order 5400.1 HSWA (Sec. C, Pt. 2)	Sep 90	B, Cl, Li, NO_3, and isotopes of H and O	Special isotopic study
Rio Spring 7	White Rock Canyon	Radiochemistry I Metals General Inorganics PCBs (Selected Springs)	Annual Triennial Annual Triennial	DOE Order 5400.1 HSWA (Sec. C, Pt. 2)	Sep 90	B, Cl, Li, NO_3, and isotopes of H and O	Special isotopic study
Rio Spring 8	White Rock Canyon	Radiochemistry I Metals General Inorganics PCBs (Selected Springs)	Annual Triennial Annual Triennial	DOE Order 5400.1 HSWA (Sec. C, Pt. 2)	Sep 90	B, Cl, Li, NO_3, and isotopes of H and O	Special isotopic study
Rio Spring 8A	White Rock Canyon	Radiochemistry I Metals General Inorganics PCBs (Selected Springs)	Annual Triennial Annual Triennial	DOE Order 5400.1 HSWA (Sec. C, Pt. 2)			
Rio Spring 8B	White Rock Canyon	Radiochemistry I Metals General Inorganics PCBs (Selected Springs)	Annual Triennial Annual Triennial	DOE Order 5400.1 HSWA (Sec. C, Pt. 2)	Sep 90	B, Cl, Li, NO_3, and isotopes of H and O	Special isotopic study
Rio Spring 9	White Rock Canyon	Radiochemistry I Metals General Inorganics PCBs (Selected Springs)	Annual Triennial Annual Triennial	DOE Order 5400.1 HSWA (Sec. C, Pt. 2)			
Rio Spring 9A	White Rock Canyon	Radiochemistry I Metals General Inorganics PCBs (Selected Springs)	Annual Triennial Annual Triennial	DOE Order 5400.1 HSWA (Sec. C, Pt. 2)			
Rio Spring 9B	White Rock Canyon	Radiochemistry I Metals General Inorganics PCBs (Selected Springs)	Annual Triennial Annual Triennial	DOE Order 5400.1 HSWA (Sec. C, Pt. 2)			
Rio Spring 10	White Rock Canyon	Radiochemistry I Metals General Inorganics PCBs (Selected Springs)	Annual Triennial Annual Triennial	DOE Order 5400.1 HSWA (Sec. C, Pt. 2)			

Table 4-2. Environmental Surveillance Groundwater Monitoring Stations—Springs

Station	Location	Environmental Surveillance: Constituents	Frequency	Programmatic Drivers	Other Sampling Events: Frequency	Constituents	Reason
Sandia Spring	White Rock Canyon	Radiochemistry I Metals General Inorganics PCBs (Selected Springs)	Annual Triennial Annual Triennial	DOE Order 5400.1 (Sec. C, Pt 2) HSWA	Annual	RI, WQ2, Misc, PCBs	MOU[d]
Sacred Spring	Lower LA Canyon	Radiochemistry I Metals General Inorganics PCBs (Selected Springs)	Annual Triennial Annual Triennial	DOE Order 5400.1 (Sec. C, Pt 2) HSWA	Annual	RI, WQ2, Misc, PCBs	MOU[d]
					Apr-80	Some misc and Fe, Mn, Li, SO_4, Cl, and F	Special Study - Geothermal Investigation
Indian Spring[a]	Lower LA Canyon	Radiochemistry I Metals General Inorganics PCBs (Selected Springs)	Annual Triennial Annual Triennial	DOE Order 5400.1 (Sec. C, Pt 2) HSWA	Annual	RI, WQ2, Misc, PCBs	MOU[d]
La Mesita Spring	White Rock Canyon	Radiochemistry I Metals General Inorganics PCBs (Selected Springs)	Annual Triennial Annual Triennial	DOE Order 5400.1 (Sec. C, Pt 2) HSWA	Annual	RI, WQ2, Misc, PCBs	MOU[d]
Rio Spring 1	White Rock Canyon	Radiochemistry I Metals General Inorganics PCBs (Selected Springs)	Annual Triennial Annual Triennial	DOE Order 5400.1 (Sec. C, Pt 2) HSWA	Annual	RI, WQ2, Misc, PCBs	MOU[d]
Rio Spring 2	White Rock Canyon	Radiochemistry I Metals General Inorganics PCBs (Selected Springs)	Annual Triennial Annual Triennial	DOE Order 5400.1 (Sec. C, Pt 2) HSWA	Annual	RI, WQ2, Misc, PCBs	MOU[d]
Intermediate Perched Zone Springs							
Basalt Spring	Lower LA Canyon	Radiochemistry I, II, & III Metals General Inorganics Organics	Annual Triennial Annual Triennial	DOE Order 5400.1 (Sec. C, Pt 2) HSWA	Annual	RI, WQ2, Misc, PCBs	MOU[d]
					Annual	Metals, General Inorganics, Organics	RCRA Module III
					Apr-80	Some misc and Fe, Mn, Li, SO_4, Cl, and F	Special Study - Geothermal Investigation
Water Canyon Gallery	Flank of Jemez Mtns	Radiochemistry I & III Metals General Inorganics Organics	Annual Triennial Annual Triennial	DOE Order 5400.1 (Sec. C, Pt 2) HSWA	Apr-80	Some misc and Fe, Mn, Li, SO_4, Cl, and F	Special Study - Geothermal Investigation

Table 4-2. Environmental Surveillance Groundwater Monitoring Stations—Springs

Station	Location	Environmental Surveillance			Other Sampling Events		
		Constituents	Frequency	Programmatic Drivers	Frequency	Constituents	Reason
Other Springs*							
DP Spring	DP Canyon						
Hamilton Bend Spring	Pueblo Canyon						
Los Alamos Spring	Lower LA Canyon						
Otowi Seep	Pueblo Canyon						
TA 16	TA 16						
SWSC Line Spring	TA 16						
Burning Ground Spring	TA 16						
Bulldog Spring	TA 9						
TA 18 Spring	TA 18						
Homestead Spring							
Stormer Spring							
Charlie Spring							
Starting Rock Spring	Upper LA Canyon						
American Spring	Flank of Jemez Mtns						
Apache Spring	Flank of Jemez Mtns						
Armstead Spring	Flank of Jemez Mtns						
Frijoles Spring 1	Flank of Jemez Mtns						
Frijoles Spring 2	Flank of Jemez Mtns						
Guaje Spring 1	Flank of Jemez Mtns						
Guaje Spring 2	Flank of Jemez Mtns						
PC Spring	Flank of Jemez Mtns						
Quemazon Spring	Flank of Jemez Mtns						
Reservoir Spring	Flank of Jemez Mtns						
Valle Spring 1	Flank of Jemez Mtns						
Valle Spring 2	Flank of Jemez Mtns						

* Springs that flow intermittently but are included as part of the annual environmental surveillance activities

Where
Radiochemistry I is Cs 137, H 3, Pu 238, Pu 239 +240, total U, and gross gamma activity
Radiochemistry II is Am 241, and Sr 90
Radiochemistry III is Gross alpha activity, gross beta activity, and Ra 226 if necessary
Metals are Ag, Al, As, B, Ba, Be, Cd, Co, Cr, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Sb, Se, Sn, Sr, Tl, V, and Zn
General Inorganics are SiO_2, Ca, Mg, K, Na, CO_3, HCO_3, PO_4, SO_4, NO_3, CN, TDS, total hardness
total suspended solids, pH, and electrical conductance
Organics are volatiles, semivolatiles, the 129 priority pollutants, herbicides, pesticides, PCBs, oils or solvents

There are many other springs located in and around the laboratory. There are 12 springs situated on the eastern flank of the mountains and one on San Ildefonso Pueblo land just east of the Laboratory boundary in Los Alamos Canyon (Los Alamos Spring). There are additional springs within the Laboratory boundary including DP Spring, Hamilton Bend Spring, Otowi Seep, Homestead Spring, Stormer Spring, Charlie Spring, Skating Rink Spring, Bulldog Spring, Burning Ground Spring, SWSC Line Spring, TA-16 Spring, and TA-18 Spring which have not yet been surveyed for specific location information. Many of these springs are sampled occasionally for special studies or background water chemistry but are not included as part of the normal environmental surveillance activites.

4.4 Special Studies and Programs

In addition to overseeing the monitoring network, the Laboratory operates a number of special studies and programs related to groundwater protection. These programs include hydrogeologic studies, studies of the vadose zone, age-dating studies of the regional aquifer, surface water studies, and groundwater quality studies at San Ildefonso Pueblo and in the vicinity of the Fenton Hill Geothermal Site. These programs are described below.

4.4.1 Hydrogeologic Studies

Since 1992, ER Project has drilled a number of boreholes to fill gaps in the knowledge of the hydrogeology and the extent of intermediate perched groundwater. Many of the boreholes have been drilled to 300 feet or more.

- Borehole LADP-4 was drilled to a total depth of 800 ft. in DP Canyon. No perched groundwater was encountered, and core samples were analyzed for their hydrologic properties.
- Well LADP-3, drilled to a depth of 350 ft. in Los Alamos Canyon, encountered perched groundwater in the Guaje Pumice Bed of the Otowi Member.
- Well LAOI-1.1A in Los Alamos Canyon, drilled to a total depth of 300 ft. encountered perched groundwater in both the Guaje Pumice Bed and the Puye Formation.
- A deep bore hole at MDA-V, TA-21, is partially completed. Located west of the MDA, it has been drilled through the Guaje Pumice Bed. Some moist zones were encountered but no saturated zones existed.
- At TA-54, there have been six boreholes drilled near MDA L and two deep angle boreholes drilled from Cañada del Buey to beneath Mesita del Buey. One of the deep angle boreholes encountered wet zones beneath Mesita del Buey in the Puye Formation.
- A borehole at TA-49 was drilled to 700 ft. No perched groundwater was encountered.
- A 300 ft. borehole drilled to the top of the basalt at TA-33 encountered no perched groundwater.

4.4.2 Vadose Zone Studies

The occurrence and movement of water in unsaturated conditions (vadose zone) has been studied at numerous locations within the Laboratory starting with special USGS studies in the

1950s. Knowledge of vadose zone processes is relevant to understanding the potential for downward movement of water that could constitute recharge to the regional aquifer and provide a mechanism for downward migration of contaminants.

In general, the vadose zone studies show that there is less than 10% by volume of moisture content in the tuff beneath the mesa tops at depths greater than a few meters, the zone affected by seasonal moisture and evapotranspiration. This carries the implication that very little, if any, recharge from the mesas is able to reach the regional aquifer (LANL 1995).

There is presumed to be greater potential for downward migration of water in canyons which contain shallow alluvial perched groundwater because the perched water provides a watersource. Since the mid 1980s, several studies have been conducted in canyons for RCRA compliance requirements to further define the occurrence of shallow alluvial water and the potential for movement of water or contaminants.

In 1985, vadose zone characterization studies were completed for Areas G and L (Pajarito Canyon and Cañada del Buey). The results indicate that aqueous transport of contaminants through the tuff is not a viable mechanism for contaminant migration at either Area G or L (LANL 1995).

A 1989 study in Sandia, Potrillo, Fence, and Water Canyons revealed no saturated conditions in the alluvium. In 1987, observation wells were installed in Cañon del Valle adjacent to an inactive waste disposal area. Monitoring of the wells revealed no saturation or evidence of leachate or seepage from the landfill to the alluvium.

In 1992, a study in Cañada del Buey was started to monitor conditions in and beneath the alluvium. The SWSC project in Cañada del Buey may at some time discharge treated effluent in the canyon drainage system. Five groundwater monitoring wells and two neutron moisture logging holes were installed within the upper and middle reaches of the drainage. Results of the study, under predischarge conditions, indicate that there is limited shallow alluvial perched groundwater in Cañada del Buey. Along the drainage system, saturation was found within only a 0.8 km (0.5 mi) segment. The apparent source of saturation is purge water from the nearby municipal water supply well PM-4. The alluvium is dry upstream from the point of purge water entry. If effluents are eventually released into the drainage system, infiltration along the stream bottom will create a narrow ribbon of saturation within the alluvium and weathered tuff that will be perched on the underlying unweathered Bandelier Tuff. Continued monitoring of these wells will further define the quality and extent of groundwater in the alluvium (LANL 1994).

Field investigations of the vadose zone under mesa tops are currently underway at five key disposal sites and Solid Waste Management Areas. These include MDAs T and V at TA-21, MDA AB at TA-49, MDAs G and L at TA-54, the proposed Mixed Waste Disposal Facility at TA-67, and the Airport Landfill at TA-73.

At TA-54, angle and vertical boreholes have been drilled from the mesa top to obtain detailed hydrologic and stratigraphic information. Boreholes to depths of 300 feet have been instrumented to measure downhole gas concentrations and pressures and the significance of vapor transport of contaminants. This information has been used for the initial design of a pilot vapor extraction system for MDA L.

Preliminary analyses of hydraulic gradients in the vadose zone at TA-54 suggest that the general direction of water movement within the exposed finger mesa may be upward, with significant implications for long-term waste disposal (Gallaher and Rogers1995). This hypothesis will require additional testing to verify. Movement of water below the adjacent

canyon bottom elevation is downward. Core samples of the Bandelier Tuff from each of the areas have been submitted for hydrologic property testing.

A separate Performance Assessment is ongoing at MDA G. Critical geological, hydrological and geochemical data have been assembled into a basic data report from which a conceptual hydrogeologic model for the site was formulated. Computer simulations forecast long-term performance or the disposal area over thousands of years. The analysis will include an initial evaluation of the role of fractures on contaminant migration within the mesa.

4.4.3 Age-of-Water and Recharge Source Studies

To better understand the nature of recharge to the regional aquifer, researchers have performed age-dating measurements on selected water samples. This cooperative effort, involving several Laboratory divisions and staff from another DOE installation, uses geochemical techniques based on measurements of both radioactive and stable isotopes to help identify specific sources and estimate the age of water in the regional aquifer. Preliminary interpretation of the data indicates that the water ranges in age from more than 1,000 years to more than 30,000 years.

Another series of tests on regional aquifer waters was initiated to sample for ultra-low levels of tritium, chlorine-36, carbon-14, and plutonium and uranium isotopes. These tests can help indicate whether recent recharge has occurred.

4.4.4 Measurement of Barometric and Earth Tide Responses in Test Wells

In October 1992, the Laboratory began measuring and recording water level fluctuations at wells completed in the regional aquifer. The data, which are recorded at hourly intervals using pressure transducers, suggest that the regional aquifer adjacent to the Rio Grande responds like a confined aquifer to small barometric pressure and tidal perturbations. However, at locations farther to the west of this regional groundwater discharge area, the regional aquifer apparently behaves like a phreatic aquifer in some locations and a confined to leaky-confined aquifer in other areas. Data from wells equipped with pressure transducers is given in the environmental surveillance report for 1992 (LANL 1994) and suggest leaky-confined behavior as far west as TA-16. These new data collection and interpretation efforts will continue as part of the Groundwater Protection Management Program and will help to provide a more accurate characterization of the regional aquifer.

4.4.5 Studies of Surface Water Characteristics

The Laboratory is conducting ongoing studies of the surface water characteristics in the Los Alamos region (McLin 1991). These studies include Hydrologic Engineering Center (HEC) computer-based flood models, which project the effects of severe thunderstorms on all of the watersheds in the Los Alamos area. Different precipitation totals have been projected for 2-,5-, 10-, 25-, 50-, and 100-year storm events. The modeling effort predicts the effects of storm runoff on floodplain elevations within canyons and on different Laboratory facilities and structures.

Stream gages were installed in all the major drainages at LANL's upstream and downstream boundaries. Other drainages were also equipped with stream gages on a site-specific basis. These gages will contribute data to help understand the watershed and refine the above-mentioned flood models.

4.4.6 Environmental Studies at San Ildefonso Pueblo

The Laboratory conducts an ongoing environmental studies program at the San Ildefonso Pueblo. As previously mentioned, LANL and the DOE have entered into an MOU with the Pueblo and the Bureau of Indian Affairs to conduct environmental sampling on Pueblo land. Part of the sampling program includes monitoring the water quality in wells located on the Pueblo land and ensuring that the water is safe for consumption and has not been adversely impacted by Laboratory operations.

4.4.7 Studies at Fenton Hill Geothermal Site

The Laboratory operates a program for extracting thermal energy from the hot dry rock geothermal reservoir at the Fenton Hill Geothermal Site (TA-57), which is located about 60 km (35 mi) west of Los Alamos (Figure 4-3). Two systems are located at the site. The first system contains two deep holes drilled into the dry Precambrian rock to a depth of about 3,040 m (10,000 ft). The two holes are connected by a large fracture that was induced by hydraulic pressurization. Water is circulated through this system to extract heat from the fractured areas in the granite. The second system uses a similar method and extracts heat from a depth of about 4,250 m (14,000 ft).

The Laboratory has conducted special studies of the chemical quality of surface water and groundwaters in the vicinity of Fenton Hill since 1974. A preliminary study of the quality of water in the drainage area of the Jemez River and Rio Guadalupe established background data prior to any experiment. The data included chemical analyses from 17 surface water stations, 15 mineral and thermal springs, and 53 groundwater stations.

As a result of the preliminary study in 1974, the Laboratory established 13 surface and 20 groundwater stations to monitor the effects of Fenton Hill operations on the environment. Locations of groundwater sampling at wells and springs are given in Table 4-3 and shown in Figure 4-4. The chemical quality of the surface water and groundwater has been published in a series of yearly LANL reports entitled *Water Quality in the Vicinity of Fenton Hill* through 1988. After 1988, water quality data from Fenton Hill has been published in the environmental surveillance reports. These reports show that the chemical quality of the samples has not changed significantly from average values taken since testing began. Although variations in chemical concentrations have occurred, these variations are within normal seasonal fluctuations (Purtymun et al. 1991).

4.5 Reporting

The results of groundwater sampling and protection efforts at the Laboratory are published in the annual environmental surveillance report and the annual water supply report. These two reports are described below.

4.5.1 Annual Environmental Surveillance Report

The purpose of the environmental surveillance report is to provide a comprehensive source of environmental data collected at the Laboratory. Since the early 1970s, the Laboratory has performed routine samples of air, water, soil, and foodstuffs throughout the Los Alamos area to determine any levels of contamination. The data collected in this program are published annually in the environmental surveillance report for distribution to the public and to local, state, and federal agencies. Included in the report are sections which explain the groundwater

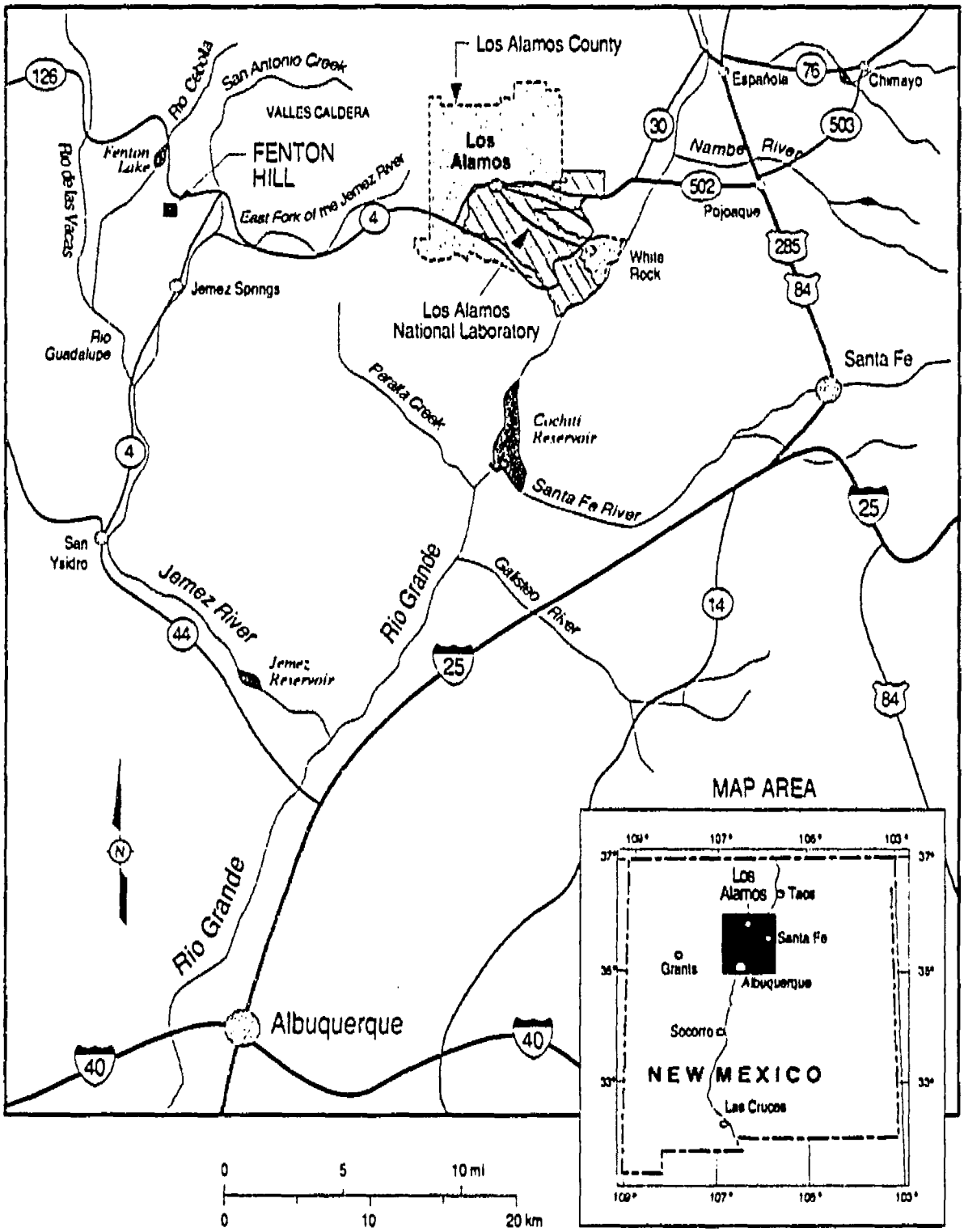

Figure 4-3. Regional location of Fenton Hill (TA-57).

Table 4-3. Fenton Hill Water Sampling Locations and Elevations

Type	X-Coordinate	Y-Coordinate	Elevation
Wells			
FH-1 Supply	1515244.43	1775862.00	8675
FH-2 Observation	1515244.43	1775862.00	8692
Location 27	1524144.37	1773661.99	7650
Location 42	1521644.38	1772361.98	7840
Location 48	1524844.36	1771261.98	7630
Location 53	1529044.34	1776762.00	7635
Location 54	1528444.34	1776262.00	7795
Location 55	1528744.34	1776662.00	7805
Location 4	1522444.38	1773061.99	7760
Location 47	1524844.36	1770761.98	7640
Springs			
Location 6	1523844.37	1772861.99	7670
Location 31	1491144.57	1767261.98	7600
Location 39	1502144.50	1770361.99	7880
Location JF-1	1522544.37	1757561.93	6780
Location JF-5	1510844.41	1743661.89	6400
JS-2 -3	1509544.40	1735761.86	6220
JS-4 -5	1511044.40	1741161.88	6265
RV-2	1523244.39	1796862.07	8360
RV-4	1528044.34	1764761.96	7360
RV-5	1528544.33	1753961.92	7340

monitoring and protection program at the Laboratory and the results of sampling that have occurred in the subject year.

4.5.2 Annual Water Supply Report

The purpose of the Water Supply Report is to ensure a continuing historical record and to provide guidance for the management of water resources in long-range planning for the water supply system. The report publishes data on the amount of water supplied in the Los Alamos area. The conditions of the water supply wells and the hydrologic conditions of the regional aquifer are provided as part of this report. Special studies and documentation of new supply wells are included as well as detailed records of pumping and water level measurements.

4.6 Conclusions

Environmental protection efforts at the Laboratory include the activities of several programs, many of which are under the Laboratory's ER Project. Remediation efforts conducted by these programs help to protect the groundwater supply.

The groundwater monitoring network at the Laboratory has been used for determining the quality of water in the regional aquifer since immediately following World War II. However, because of its limited extent, questions are raised about the effectiveness of the network in detecting early stages of contamination. The controlled development and production of the

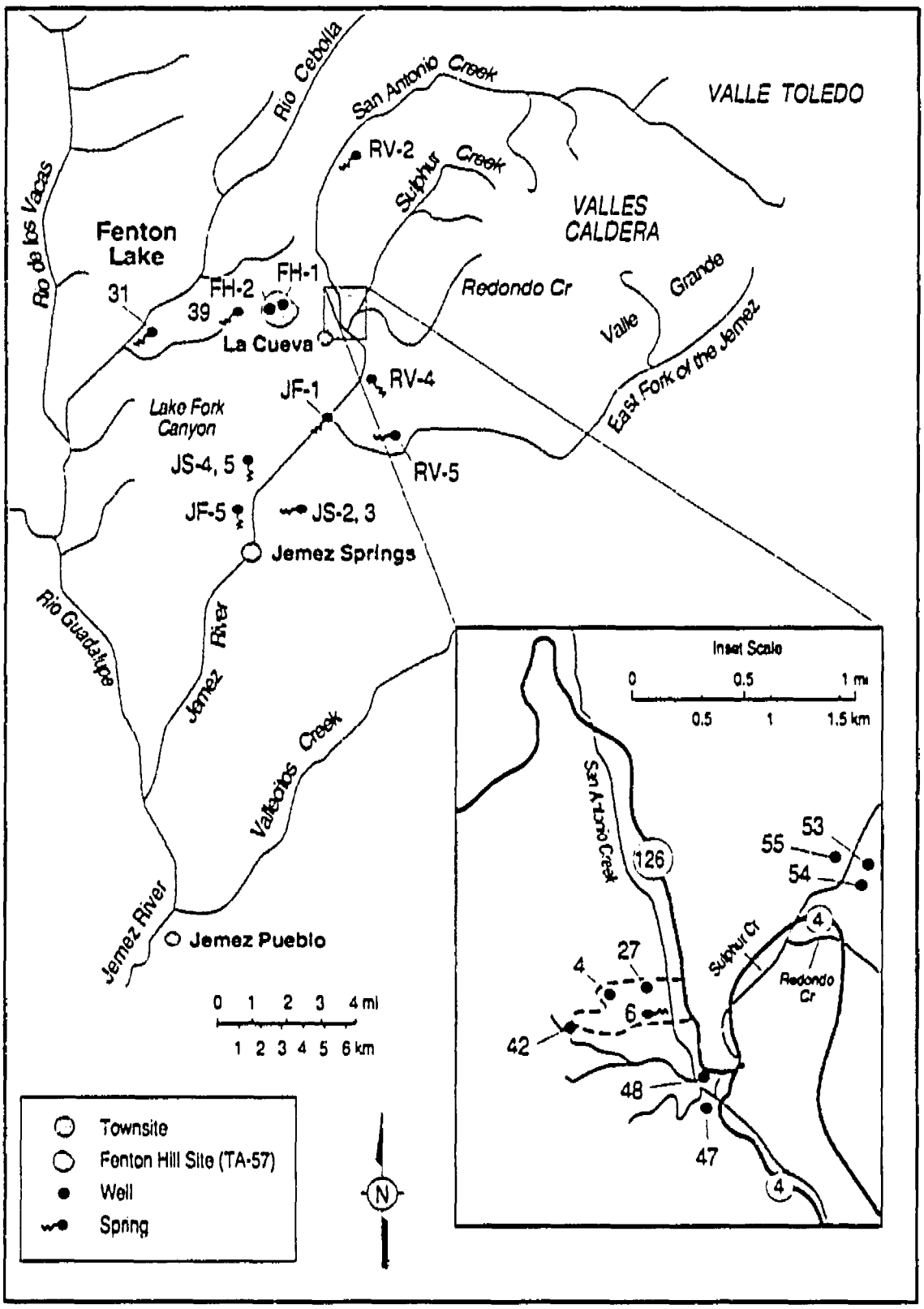

Figure 4-4. Surface water and groundwater sampling locations at Fenton Hill.

water supply has resulted in limited depletion of the resource as there is minor decline of the piezometric surface of the aquifer. Largest drawdowns are localized in the vicinity of the production wells and significant recoveries are observed when wells are shut down for routine maintenance.

The history of Laboratory groundwater protection efforts, however, raises complex issues about the future viability of the groundwater monitoring network. These issues, which have been addressed in the *1991 LANL Self-Assessment*, the *1991 Tiger Team Assessment*, and in other reports and assessments (Appendix I), demonstrate the need for enhancing the current groundwater monitoring network. The issues and possible solutions are discussed in the next section.

5.0 Issues and Solutions

The following section discusses LANL's groundwater-related practices, policies, and procedures. The issues are divided into seven major categories: (1) hydrogeological characterization, (2) potential contamination, (3) groundwater monitoring network, (4) water supply, (5) information management, (6) quality assurance, and (7) regulatory compliance. Possible corrective actions and solutions follow each discussion of an issue.

A number of reports, assessments, and correspondence memoranda between LANL, the DOE and the NMED were used to prepare this section. The *1991 Tiger Team Assessment* (DOE 1991), the *1991 LANL Self-Assessment* (LANL 1991), the *1993 New Mexico Environment Department (NMED) Initial Assessment* (NMED 1993), and the *Hydrogeologic Review for the Environmental Restoration Program at LANL* (Stephens et al. 1993) were all used as guides. These documents are reproduced in Appendix I, *Comments and Recommendations*, which has been formatted to include reference numbers in the right-hand margins. The numbers correspond to sections of the GWPMPP in which a particular issue is discussed.

5.1 Hydrogeologic Characterization

5.1.1 Hydrogeologic Characterization Issues

Recharge Mechanisms

The primary issue concerning hydrogeologic characterization of the Pajarito Plateau is that the recharge mechanisms for the regional aquifer are not well understood. The geologic setting is relatively complex, and researchers have considered several potential recharge areas to the regional aquifer. These areas include the Valles Caldera, the canyon bottoms, the mesa tops, the Pajarito Fault Zone, other faults and fractures on the plateau, and the Sangre de Cristo Mountains (Stephens et al. 1993; Purrymun et al. 1994; Goff 1991) as well as flow along the Rio Grande rift. Studies of recharge to the regional aquifer are complicated because of the numerous potential recharge sites and the lack of an extensive monitoring-well network. Preliminary studies provide some information on probable recharge areas.

The potentiometric surface of the regional aquifer slopes downward toward the Rio Grande, leading some investigators to conclude that underflow from the Valles Caldera through the Tschicoma Formation is the primary recharge mechanism for the regional aquifer. However, isotopic and geochemical studies show that the regional aquifer waters near the Rio Grande differ from the waters in the Valles Caldera. Based on these studies, Stephens et al. (1993) concluded that underflow through the Tschicoma Formation is not likely to be the major source of recharge to the regional aquifer.

Regional aquifer waters have been dated using a ^{14}C method. The dating suggests that water in the aquifer is from 1,000 to 30,000 years old. But recent measurements of tritium in regional aquifer waters at four locations (TW-1, -4, -8, and LA-1) by extremely low-detection-limit analytical methods suggest recharge within the last 40 years. Although mechanisms for recharge are not understood, the presence of tritium in the intermediate perched groundwater zone (TW-1A, TW-2A, LADP-3, and Basalt Spring [Stoker 1994]) indicates some degree of connectivity between the shallow alluvial and intermediate perched zones.

Recharge to the regional aquifer may be occurring through the canyon bottoms. A study in Mortandad Canyon determined that Laboratory-derived tritiated waters have infiltrated at least 60 m (200 ft) into the volcanic tuff (Stoker et al. 1991). Low-level tritium analysis of samples from a test well in Mortandad Canyon to the regional aquifer clearly shows the presence of

recent recharge (Stoker 1994). Vadose zone studies show that the moisture content of the tuff beneath the canyons is greater than that beneath the mesa tops, and the depth to the regional aquifer is several hundred feet less than on the mesa tops (LANL 1995). Also, because many of the canyons contain intermittent or ephemeral streams throughout the year, they are more likely to contribute some component of recharge to the regional aquifer.

Stable isotopic studies ($\delta^{18}O$, $\delta^{2}H$) indicate that the source of the regional aquifer water is meteoric water and has recharge components from both high and low elevations (Goff 1991; Stephens et al. 1993). These data have been used to postulate that the Sangre de Cristo mountains may be the source for the waters in the eastern portion of the aquifer, along the west side of the Rio Grande.

None of the studies described above are conclusive, and additional investigations will be required to identify the recharge area(s). It is possible that recharge to the regional aquifer is from multiple sources, and testing and evaluation should consider all of the potential recharge areas that have been proposed.

Hydrogeologic Data

Another issue concerning the regional aquifer is the lack of hydrogeologic data. Not enough wells are completed to the regional aquifer to understand local and regional hydrogeologic properties. The depth and continuity of the regional aquifer is not well understood. Also, information is not available on the vertical stratification of the aquifer materials. Studies of the storage and transmissivity of the aquifer, as well as the physical characteristics of aquifer materials, need to be performed.

In sum, little data are available for characterizing recharge to and hydrogeology of the regional aquifer. Much of the available data are limited due to the age of the wells, the lack of information on well construction, and the lack of core samples for hydrologic property analyses. Stephens et al. (1993) suggest that the available data indicate that there may be multiple sources of recharge to the regional aquifer. It is also possible that the recharge mechanisms operating today are different than those that were in place several thousand years ago when much of the regional aquifer waters were introduced.

5.1.2 Hydrogeological Characterization Solutions

The primary solution to hydrogeological characterization problems is to construct a more extensive monitoring well network. Construction of monitoring wells in potential recharge areas will provide useful information in groundwater sampling and hydrologic testing and will help to determine if the sites are, in fact, recharge areas for the regional aquifer.

The ESH Water Quality and Hydrology Group has proposed construction of 23 wells to the regional aquifer, 14 wells to the intermediate perched groundwater zone, and about 50 wells into the shallow alluvial perched groundwater zone. Of the 23 wells to the regional aquifer, one is a proposed ER Project well at TA-54, Area G. Information obtained from the drilling and sampling of these wells should provide increased knowledge of recharge through the plateau. Tables 5-1, 5-2, and 5-3 give the general locations, rationale, and sampling objectives for each of the proposed wells. Figures 5-1, 5-2, and 5-3 show the planned locations of the wells. The DOE-OB (Oversight Bureau, formerly the NMED-AIP) has reviewed these proposed well locations and has provided comments and recommendations (see Memorandum to Mr. Joseph Vozella from W. Stone et al., July 11, 1995 in Appendix I). Many of these recommendations have been incorporated into Tables 5-1 and 5-2. Where LANL is not in agreement, reasoning is given in Appendix I next to the recommendation.

Table 5-1. Proposed Regional Aquifer Well Location Rationale and Sampling Objectives

Map Ref #	Well ID	Proposed Location	Location Rationale	Sampling Information: Frequency	Sampling Information: Constituents	Sampling Information: Programmatic Drivers	WL Measurements: Frequency	WL Measurements: Method
	Water Quality and Hydrology Group							
1	PLATS-1	Los Alamos Townsite	Hydrogeologic control, off-site monitoring for background water quality, recharge information	Quarterly[a]	Radiochemistry I Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Dedicated transducer
2	PGC-1	Guaje Canyon near well field	Observation, address HSWA groundwater issues (top of water table)	Quarterly[a]	Radiochemistry I & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Dedicated transducer
3	PLAC-1	Upper Los Alamos Canyon near well H-19, TA 3	Hydrogeologic control, background water quality, recharge information	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Dedicated transducer
4	FFFZ-1	East Pajarito Fault Zone	Recharge information from fault zone, hydrogeological control near west boundary	Quarterly[a]	Radiochemistry I Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Dedicated transducer
5	PCDV-1	Upper Canon de Valle, TA-16/ TA-14	Address HSWA groundwater issues near Area P, answer questions left by drilling of SHB-3, hydrogeologic control in the west part of the laboratory	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Dedicated transducer
6	PPC-1	Near new MWDF, Pajarito Canyon, TA 67	Hydrogeologic control, address HSWA groundwater issues near new MWDF facility, observation	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Dedicated transducer
7	PPC-2	Near new HWTF, Pajarito Canyon, TA-67	Address HSWA groundwater issues near new HWTF facility, observation	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Dedicated transducer

Table 5-1. Proposed Regional Aquifer Well Location Rationale and Sampling Objectives

Map Ref #	Well ID	Proposed Location	Location Rationale	Sampling Information: Frequency	Sampling Information: Constituents	Sampling Information: Programmatic Drivers	WL Measurements: Frequency	WL Measurements: Method
8	PTSC-1	Near HWTF, Ten Site Canyon, TA-35	Address HSWA groundwater issues near TA-35 and waste discharge from existing HWTF facility	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Dedicated transducer
9	PLAC-3	Middle Los Alamos Canyon TA-72	AIP suggested well to monitor deep zones downgradient from Los Alamos and DP Canyons	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Dedicated transducer
10	PPC-3	Area J, Pajarito Canyon, TA-54	Address HSWA groundwater issues, upgradient from Area L (chemical waste) and Area G (rad waste)	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Dedicated transducer
11	FMC-1	Near sediment traps, Mortandad Canyon, TA-5	Address HSWA groundwater issues, downgradient from sediment traps	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Dedicated transducer
12	PSC-1	Near lagoons, Sandia Canyon, TA-53	Address HSWA groundwater issues associated with discharge from lagoons, monitor for possible contamination from Los Alamos Canyon	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Dedicated transducer
13	FPBC-1	Upgradient of well TW-1, Pueblo Canyon, TA-74	Replace TW-1	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. C 2) HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Dedicated transducer
14	PLAC-2	In LA well field near LA-5	Observation well for contaminant monitoring in Los Alamos Canyon	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Dedicated transducer

Table 5-1. Proposed Regional Aquifer Well Location Rationale and Sampling Objectives

Map Ref #	Well ID	Proposed Location	Location Rationale	Sampling Information: Frequency	Sampling Information: Constituents	Sampling Information: Programmatic Drivers	WL Measurements: Frequency	WL Measurements: Method
15	FPFZ-2	West of Pajarito Fault Zone	Recharge information from fault zone, hydrogeologic control near west boundary	Quarterly[a]	Radiochemistry I Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Dedicated transducer
16	FPC-4	Mesita del Buey, east of Area G, TA-54	Address HSWA groundwater issues downgradient of radioactive waste disposal area	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Dedicated transducer
17	FMC-2	In White Rock Townsite, Mortandad Canyon	Hydrogeologic control, downgradient of sediment traps, observation near Rio Grande	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Dedicated transducer
18	PCDB-1	Below White Rock, near Rio Grande and Cañada del Buey	Hydrogeologic control, downgradient of sediment traps, observation near Rio Grande	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Dedicated transducer
19	PPOC-2	Near SR 4, Potrillo Canyon, TA 36	Address surface water loss questions	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Dedicated transducer
20	PWC-2	Water Canyon, TA-68	Address surface water loss questions	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Dedicated transducer
21	FAC-1	Below TA-33, Ancho Canyon, TA-70	Contaminant monitoring below TA-33 main site and MDA K tritium release site	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Dedicated transducer

Table 5-1. Proposed Regional Aquifer Well Location Rationale and Sampling Objectives

Map Ref #	Well ID	Proposed Location	Location Rationale	Sampling Information: Frequency	Sampling Information: Constituents	Sampling Information: Programmatic Drivers	WL Measurements: Frequency	WL Measurements: Method
22	FBHQ-1	Near Bandelier Head Quarters	Hydrogeologic control, off-site monitoring for background water quality, recharge information	Quarterly[a]	Radiochemistry I & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Dedicated transducer
23	FFBC-2	Pueblo Canyon, TA-74	Hydrogeologic control, contaminant detection monitoring	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Dedicated transducer
	Environmental Restoration Project							
	No. of Wells							
---	6	Los Alamos/Pueblo Canyons	ER characterization of nature and extent of contamination					
---	6	Mortandad Canyon	ER characterization of nature and extent of contamination					
---	3	Pajarito Canyon	ER characterization of nature and extent of contamination					
---	3	Sandia Canyon/Cañada del Buey	ER characterization of nature and extent of contamination					

[a] Sampling will be quarterly for a sufficient amount of time to determine if seasonal variations in water quality exist. After that time, sampling frequencies will be determined on a well by well basis.

[b] If no organics are found in the first sampling event, their sampling schedule will be modified on a well by well basis.

Where Radiochemistry I is Cs-137, H-3, Pu-238, Pu-239+240, total U, and gross gamma activity
Radiochemistry II is Am-241, and Sr-90
Radiochemistry III is Gross alpha activity, gross beta activity, and Ra-226 if necessary
Metals are Ag, Al, As, B, Ba, Be, Cd, Co, Cr, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Sb, Se, Sn, Sr, Tl, V, and Zn
General Inorganic are SiO2, Ca, Mg, K, Na, CO3, HCO3, PO4, SO4, NO3, CN, TDS, total hardness, total suspended solids, pH, and electrical conductance
Organics are volatiles, semivolatiles, the 129 priority pollutants, herbicides, pesticides, PCBs, oils or solvents

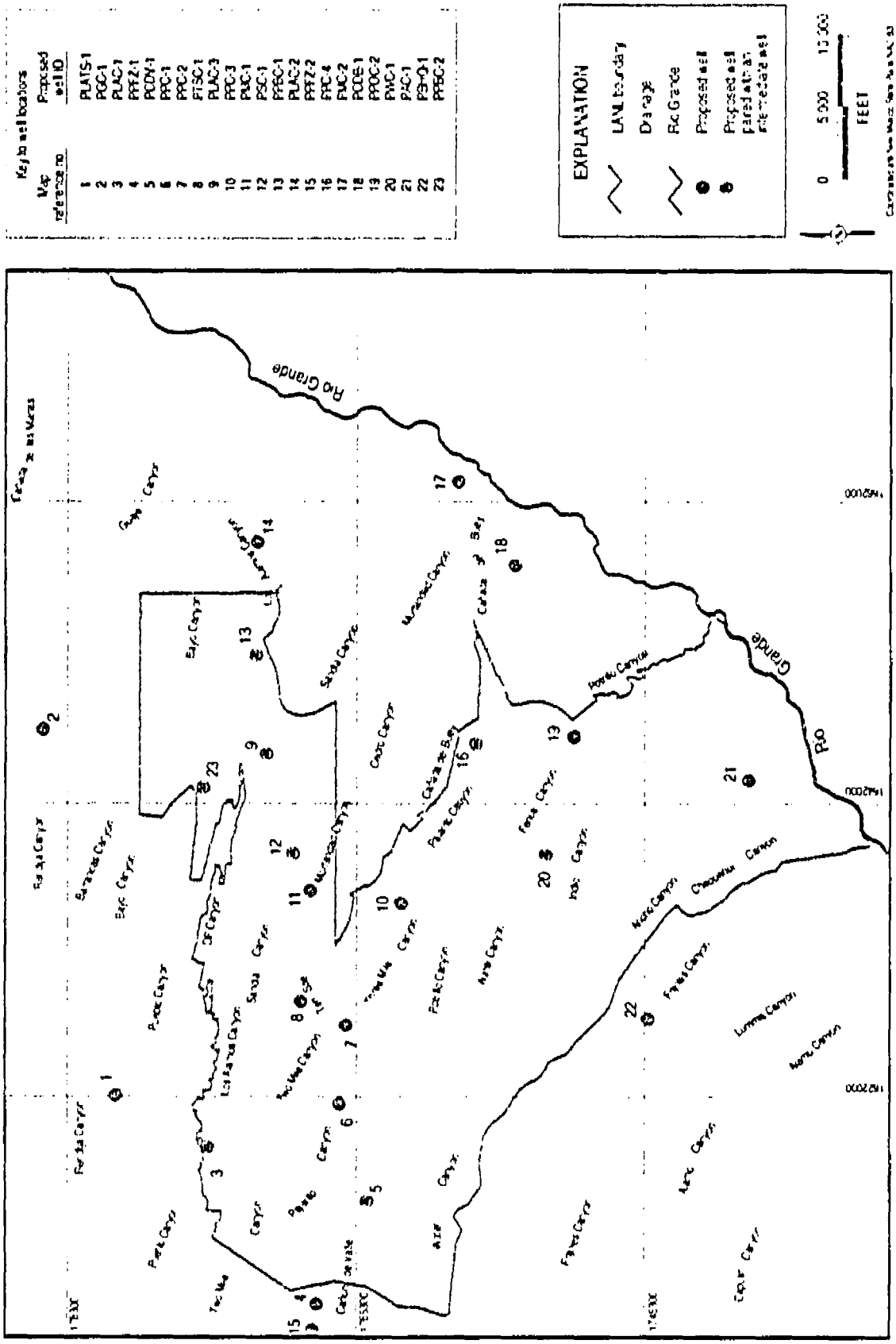

Figure 5-1. Proposed regional aquifer well locations.

Table 5-2. Proposed Intermediate Well Location Rationale and Sampling Objectives

Map Ref #	Well ID	Proposed Location	Location Rationale	Sampling Information: Frequency	Sampling Information: Constituents	Sampling Information: Programmatic Driver	WL Measurements: Frequency	WL Measurements: Method
1	*PiBC-1	Middle Bayo Canyon, TA-74	To investigate continuity of perched zone	Quarterly[a]	Radiochemistry I & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Dedicated transducer
2	PiPBC-1	Near TW-2, Pueblo Canyon	**Replacement for TW-2A	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. C 2) HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Dedicated transducer
3	PiPBC-2	Lower Pueblo Canyon, TA-74	Near proposed regional aquifer well FPBC-1, part of RFI Work Plan for OU 1098	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Dedicated transducer
4	PiPBC-3	Near TW-1, Pueblo Canyon, TW-74	Replacement of TW-1A, near proposed regional aquifer well PPBC-2	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. C 2) HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Dedicated transducer
5	PILC-1	Upper Los Alamos Canyon, TA-43	Identification of source for water discovered in the Puye Formation during drilling of LAOI-1.1A, near proposed regional aquifer well PLAC-1	Quarterly[a]	Radiochemistry I & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Dedicated transducer
6	PILC-2	Near TW-3 and O-4, Los Alamos Canyon, TA-73	Investigate perched groundwater encountered during drilling of O-4, monitor downgradient of Los Alamos and DP Canyons	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Dedicated transducer

Table 5-2. Proposed Intermediate Well Location Rationale and Sampling Objectives

Map Ref #	Well ID	Proposed Location	Location Rationale	Sampling Information: Frequency	Constituents	Programmatic Drivers	WL Measurements: Frequency	Method
7	PILC-3	Middle Los Alamos Canyon, TA-72	Investigate continuity of perched zone encountered during drilling of O-4 and TW-1A, near proposed regional aquifer well PLAC-3	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Dedicated transducer
8	PISC-1	Middle Sandia Canyon, TA-72	Address groundwater issues associated with lagoon discharge effects on perched zone, near proposed regional aquifer well PSC-1	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Dedicated transducer
9	PISC-2	Near FM-1, Sandia Canyon, TA-72	Investigate perched groundwater encountered during drilling of FM-4	Quarterly[a]	Radiochemistry I & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Dedicated transducer
10	PIMC-1	Middle Mortandad Canyon, TA-35	Address surface water loss and contaminant migration issues	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Dedicated transducer
11	PIPC-1	Lower Pajarito Canyon, TA 54, near Area G	Near proposed regional aquifer well PPC-4 to address possible presence of perched groundwater	Quarterly[a]	Radiochemistry I & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Dedicated transducer
12	PICDV-1	Upper Cañon de Valle, TA-16	Near proposed regional aquifer well PVC-1 to answer questions left by drilling of SHB-3 and investigate possible perched groundwater	Quarterly[a]	Radiochemistry I & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Dedicated transducer
13	PIWC-1	Upper Water Canyon, TA-68	Near proposed main aquifer well PWC-1 to answer water loss questions and investigate possible perched groundwater	Quarterly[a]	Radiochemistry I & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Dedicated transducer

Table 5-2. Proposed Intermediate Well Location Rationale and Sampling Objectives

Map Ref #	Well ID	Proposed Location	Location Rationale	Sampling Information: Frequency	Constituents	Programmatic Drivers	WL Measurements: Frequency	Method
14	PIPOC-1	Near confluence of Portrillo and Fence Canyons, TA-36	500 ft downgradient from "discharge sink" to monitor releases from TAs 15 and 36 per AIP request	Quarterly[a]	Radiochemistry I & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch IV, Sec. 9)	Quarterly	Dedicated transducer

[a] Sampling will be quarterly for a sufficient amount of time to determine if seasonal variations in water quality exist. After that time, sampling frequencies will be determined on a well by well basis.

[b] If no organics are found in the first sampling event, their sampling schedule will be modified on a well by well basis

Where: Radiochemistry I is Cs-137, H-3, Pu-238, Pu-239 +240, total U, and gross gamma activity

Radiochemistry II is Am-241, and Sr-90

Radiochemistry III is Gross alpha activity, gross beta activity, and Ra-226 if necessary

Metals are Ag, Al, As, B, Ba, Be, Cd, Co, Cr, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Sb, Se, Sn, Sr, Tl, V, and Zn

General Inorganic are SiO2, Ca, Mg, K, Na, CO3, HCO3, PO4, SO4, NO3, CN, TDS, total hardness total suspended solids, pH, and electrical conductance

Organics are volatiles, semivolatiles, the 129 priority pollutants, herbicides, pesticides, PCBs, oils or solvents

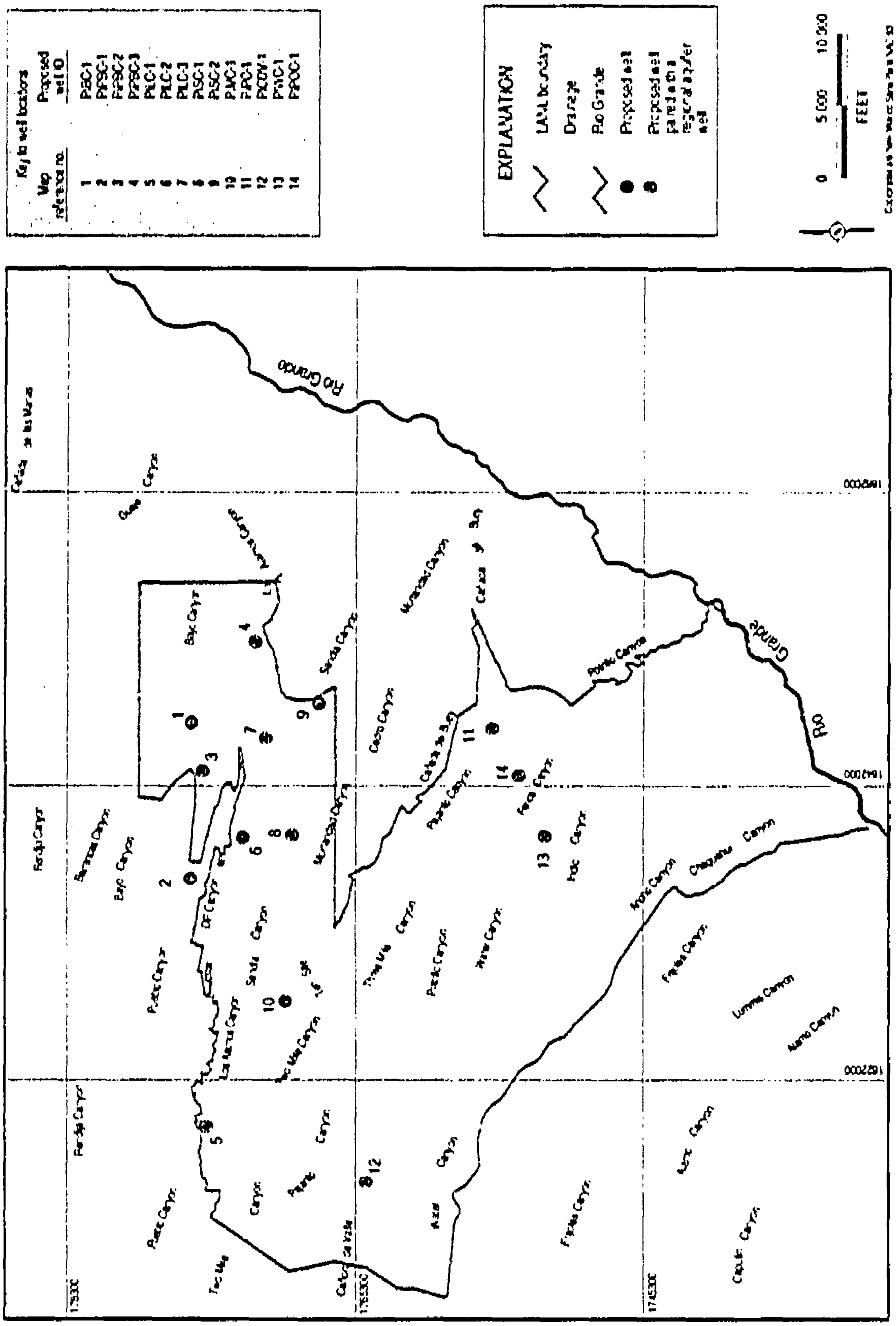

Figure 5-2. Proposed intermediate zone well locations.

Table 5-3. Proposed Shallow Alluvial Well Location Rationale and Sampling Objectives

Map Ref #	Well ID	Proposed Location	Rationale	Sampling Information: Frequency	Sampling Information: Constituents	Sampling Information: Programmatic Drivers	WL Measurements: Frequency	WL Measurements: Method
1	PALC-1	Upper Los Alamos Canyon, TA-43	Replace monitoring well LAO-C	Quarterly[a]	Radiochemistry I & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. C.2) HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Water level indicator
2	PALC-2	Middle Los Alamos Canyon, TA-21 / TA-21	Replace monitoring well LAO-1	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. C.2) HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Water level indicator
3	PALC-3 through PALC-5C	Middle Los Alamos Canyon, TA-21	Transect consisting of 4 to 6 wells across the width of the Canyon for lateral control on extent of moisture across canyon and under mesa	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Water level indicator
4	PALC-4	Middle Los Alamos Canyon, TA-73	Replace monitoring well LAO-2	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. C.2) HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Water level indicator
5	PALC-5	Middle Los Alamos Canyon, TA-73	Replace monitoring well LAO-3	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. C.2) HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Water level indicator
6	PALC-6	Middle Los Alamos Canyon TA-73	Replace monitoring well LAO-4	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. C.2) HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Water level indicator
7	PALC-7	Middle Los Alamos Canyon TA-72	Replace monitoring well LAO-4.5	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. C.2) HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Water level indicator

Table 5-3. Proposed Shallow Alluvial Well Location Rationale and Sampling Objectives

Map Ref #	Well ID	Proposed Location	Rationale	Sampling Information: Frequency	Sampling Information: Constituents	Sampling Information: Programmatic Drivers	WL Measurements: Frequency	WL Measurements: Method
8	PAPBC-1	Lower Pueblo Canyon TA-72	Replace monitoring well APCO-1	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec C 2) HSWA (Sec P, Task III A) NMWQR (Part 3) DOE Order 5400 1 (Ch III, Sec 4a and Ch IV, Sec 9)	Quarterly	Water level indicator
9	PASC-1 through PASC-1C	Middle Sandia Canyon, TA-60	Transect consisting of 4 to 6 wells across the width of the Canyon for lateral control on extent of moisture across canyon and under mesa	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec P, Task III A) NMWQR (Part 3) DOE Order 5400 1 (Ch III, Sec 4a and Ch IV, Sec 9)	Quarterly	Water level indicator
10	PAMC-1	Upper Mortandad Canyon, TA 60	Replace monitoring well MCO-3	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec C 2) HSWA (Sec P, Task III A) NMWQR (Part 3) DOE Order 5400 1 (Ch III, Sec 4a and Ch IV, Sec 9)	Quarterly	Water level indicator
11	PAMC-2 through PAMC-2D	Upper Mortandad Canyon, TA 60	Transect consisting of 4 to 6 wells across the width of the Canyon for lateral control on extent of moisture across canyon and under mesa	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec P, Task III A) NMWQR (Part 3) DOE Order 5400 1 (Ch III, Sec 4a and Ch IV, Sec 9)	Quarterly	Water level indicator
12	PAMC-3	Upper Mortandad Canyon, TA 60	Replace monitoring well MCO-4	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec C 2) HSWA (Sec P, Task III A) NMWQR (Part 3) DOE Order 5400 1 (Ch III, Sec 4a and Ch IV, Sec 9)	Quarterly	Water level indicator
13	PAMC-4	Upper Mortandad Canyon, TA 5	Replace monitoring well MCO-5	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec C 2) HSWA (Sec P, Task III A) NMWQR (Part 3) DOE Order 5400 1 (Ch III, Sec 4a and Ch IV, Sec 9)	Quarterly	Water level indicator
14	PAMC-5	Upper Mortandad Canyon, TA-5	Replace monitoring well MCO-6	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec C 2) HSWA (Sec P, Task III A) NMWQR (Part 3) DOE Order 5400 1 (Ch III, Sec 4a and Ch IV, Sec 9)	Quarterly	Water level indicator

Table 5-3. Proposed Shallow Alluvial Well Location Rationale and Sampling Objectives

Map Ref #	Well ID	Proposed Location	Rationale	Sampling Information: Frequency	Constituents	Programmatic Drivers	WL Measurements: Frequency	Method
15	PAMC-6	Upper Mortandad Canyon, TA-5	Replace monitoring well MCO-7	Quarterly[a]	Radiochemistry I, II & III Meta's General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. C 2) HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400 1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Water level indicator
16	PAMC-7	Upper Mortandad Canyon, TA-5	Replace monitoring well MCO-7.5	Quarterly[a]	Radiochemistry I, II & III Meta's General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. C 2) HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400 1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Water level indicator
17	PACDB-1 though PACDB-1D	Upper Canada del Buey, TA 54	Transect consisting of 4 to 6 wells across the width of the Canyon for lateral control on extent of moisture across canyon and under mesa	Quarterly[a]	Radiochemistry I, II & III Meta's General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400 1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Water level indicator
18	PAPC-1	Upper Pajarito Canyon, TA-14	Investigate extent of saturated alluvium	Quarterly[a]	Radiochemistry I, II & III Meta's General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400 1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Water level indicator
19	PAPC-2	Upper Pajarito Canyon, TA 67	Investigate extent of saturated alluvium	Quarterly[a]	Radiochemistry I, II & III Meta's General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400 1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Water level indicator
20	PAPC-3	Middle Pajarito Canyon, TA-45	Investigate extent of saturated alluvium	Quarterly[a]	Radiochemistry I, II & III Meta's General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400 1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Water level indicator
21	PAPC-4	Middle Pajarito Canyon, TA-18	Investigate extent of saturated alluvium	Quarterly[a]	Radiochemistry I, II & III Meta's General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400 1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Water level indicator

Table 5-3. Proposed Shallow Alluvial Well Location Rationale and Sampling Objectives

Map Ref #	Well ID	Proposed Location	Rationale	Sampling Information: Frequency	Sampling Information: Constituents	Sampling Information: Programmatic Drivers	WL Measurements: Frequency	WL Measurements: Method
22	PAPC-5 through PAPC-5C	Middle Pajarito Canyon, TA-18	Transect consisting of 4 to 6 wells across the width of the Canyon for lateral control on extent of moisture across canyon and under mesa	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Water level indicator
23	PAPC-6	Middle Pajarito Canyon, TA-36	Investigate extent of saturated alluvium	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Water level indicator
24	PAPC-7	Middle Pajarito Canyon, TA-36	Replace monitoring well PCO-1	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. C.2) HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Water level indicator
25	PAPC-8	Lower Pajarito Canyon, TA-36	Replace monitoring well PCO-2	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. C.2) HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Water level indicator
26	PAPC-9	Lower Pajarito Canyon, TA-36	Replace monitoring well PCO-3	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. C.2) HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Water level indicator
27	PACDV-1	Lower Cañon de Valle, TA-15	Investigate extent of saturated alluvium	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Water level indicator
28	PAWC-1	Upper Water Canyon, TA-28	Investigate extent of saturated alluvium	Quarterly[a]	Radiochemistry I, II & III Metals General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec. P, Task III A) NMWQR (Part 3) DOE Order 5400.1 (Ch. III, Sec. 4a and Ch. IV, Sec. 9)	Quarterly	Water level indicator

Table 5-3. Proposed Shallow Alluvial Well Location Rationale and Sampling Objectives

Map Ref #	Well ID	Proposed Location	Rationale	Sampling Information: Frequency	Constituents	Programmatic Drivers	Wl. Measurements: Frequency	Method
29	PAWC-2	Upper Water Canyon, TA-16	Investigate extent of saturated alluvium	Quarterly[a]	Radiochemistry I, II & III Metal's General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec P, Task III A) NMWQR (Part 3) DOE Order 5400 1 (Ch III, Sec 4a and Ch IV, Sec 9)	Quarterly	Water level indicator
30	PAWC-3	Upper Water Canyon, TA-37	Investigate extent of saturated alluvium	Quarterly[a]	Radiochemistry I, II & III Metal's General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec P, Task III A) NMWQR (Part 3) DOE Order 5400 1 (Ch III, Sec 4a and Ch IV, Sec 9)	Quarterly	Water level indicator
31	PAWC-4	Middle Water Canyon, TA-15	Investigate extent of saturated alluvium	Quarterly[a]	Radiochemistry I, II & III Metal's General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec P, Task III A) NMWQR (Part 3) DOE Order 5400 1 (Ch III, Sec 4a and Ch IV, Sec 9)	Quarterly	Water level indicator
32	PAWC-5	Lower Water Canyon, TA-71	Investigate extent of saturated alluvium	Quarterly[a]	Radiochemistry I, II & III Metal's General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec P, Task III A) NMWQR (Part 3) DOE Order 5400 1 (Ch III, Sec 4a and Ch IV, Sec 9)	Quarterly	Water level indicator
33	PAAC-1	Lower Ancho Canyon, TA-70, near State Road 4	A/P requested well to verify no perched water	Quarterly[a]	Radiochemistry I, II & III Metal's General Inorganics Organics[b]	40 CFR 264 and 265 HSWA (Sec P, Task III A) NMWQR (Part 3) DOE Order 5400 1 (Ch III, Sec 4a and Ch IV, Sec 9)	Quarterly	Water level indicator

[a] Sampling will be quarterly for a sufficient amount of time to determine if seasonal variations in water quality exist. After that time, sampling frequencies will be determined on a well by well basis.

[b] If no organics are found in the first sampling event, their sampling schedule will be modified on a well by well basis.

Where Radiochemistry I is Cs-137, H-3, Pu-238, Pu-239 +240, total U, and gross gamma activity

Radiochemistry II is Am-241, and Sr-90

Radiochemistry III is Gross alpha activity, gross beta activity, and Ra 226 if necessary

Metal's are Ag, Al, As, B, Ba, Be, Cd, Co, Cr, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Sb, Se, Sn, Sr, Tl, V, and Zn

General Inorganic are SiO2, Ca, Mg, K, Na, CO3, HCO3, PO4, SO4, NO3, CN, TDS, total hardness, total suspended solids, pH, and electrical conductance

Organics are volatiles, semivolatiles, the 129 priority pollutants, herbicides, pesticides, PCBs, oils or solvents

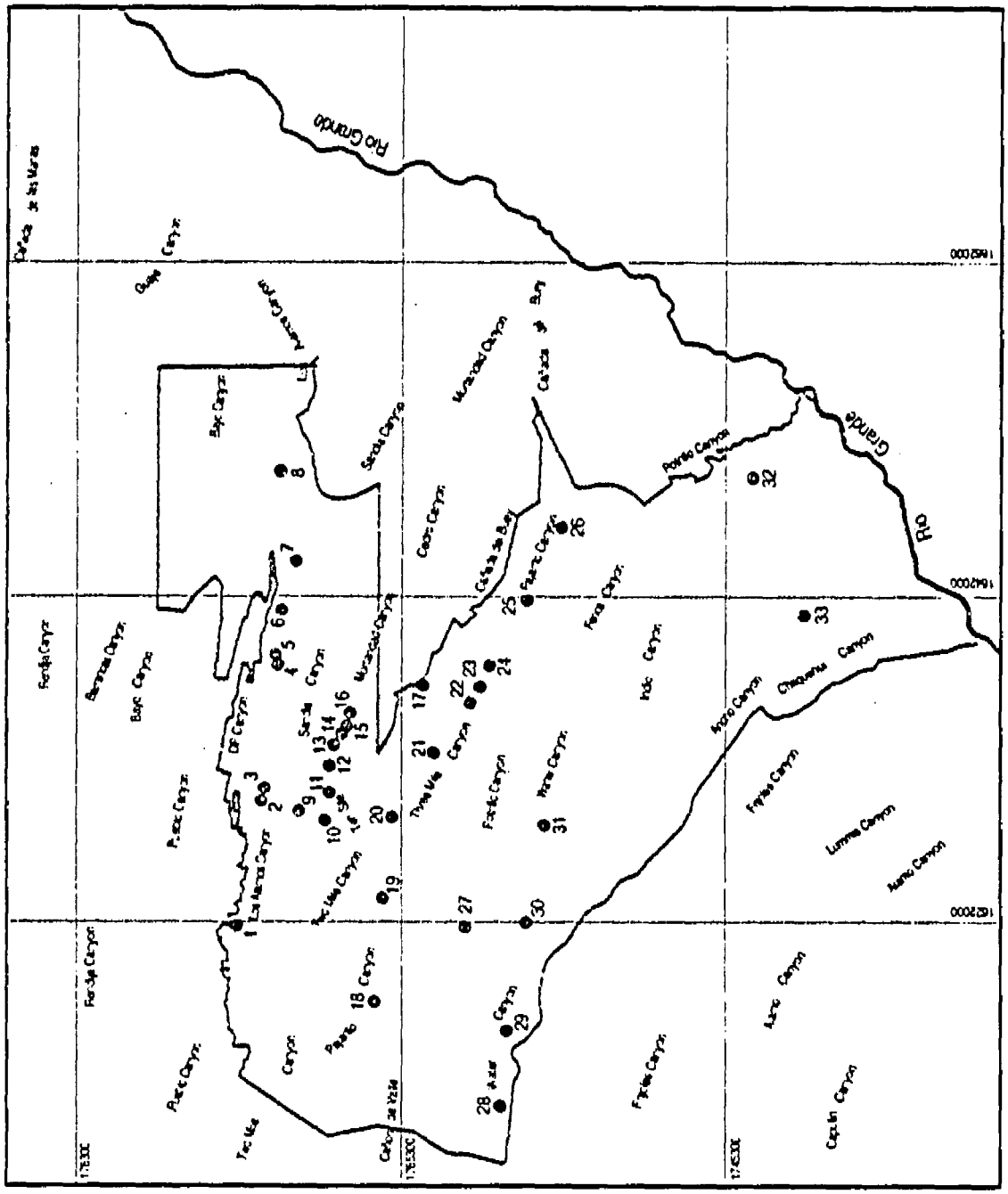

Figure 5-3. Proposed shallow alluvial perched groundwater wells locations.

Two types of rationale were used to choose the initial proposed well locations. One type of rationale includes contaminant monitoring and detection issues. Wells were proposed for location near treatment facilities, locations downgradient of known areas of contamination, and locations within groundwater flow paths so that chances of contaminant detection are maximized on a facility site-specific basis.The other type of rationale includes needs for hydrogeologic information. Wells were proposed in locations were hydrogeologic information is needed. These wells will provide stratigraphic information and water level monitoring capabilities. Where possible, an effort was made to locate the hydrogeologic information wells in areas where they would also provide contaminant monitoring on a laboratory site-wide basis.

The procedure for siting proposed well locations will be an iterative one. The current placement of proposed wells is based on the best available information to date. These locations are approximate and will change during the siting process. The first step of the process will be the analysis of existing data and development of a preliminary hydrogeologic conceptual model. From the preliminary model, the need for further data and studies will be identified. Primary locations will then be refined and wells will be sited appropriately.

The hydrogeologic conceptual model will be continuously updated with new information from drilling and completed studies. In this fashion, the model will be used as a tool to further refine remaining proposed well sites. The iterative process is shown in Figure 5-4.

Drilling and sampling objectives for regional, intermediate, and shallow alluvial wells will be designed to provide as much multipurpose hydrogeologic data as reasonably possible. Many proposed well locations were chosen to fill known hydrogeologic data gaps. Objectives for drilling and sampling differ for each well at each proposed location. The amount of hydrogeologic information varies across the facility and even over small distances. In some areas the shallow alluvial system may be intensely studied while the lower zones have relatively little information available. This variability of information means that the objectives of each well must be examined on a case-by-case basis. Objectives for each of the wells may include all or some of the following:

- Geohydrologic analyses of core samples (e.g., hydraulic conductivity, moisture content, moisture characteristic curve, specific particle density, air permeability, and unsaturated conductivity).
- Isotopic analyses and geochemical properties of core and aquifer water samples (e.g., $^{2}H/H$, $^{18}O/^{16}O$, stable and radioactive chlorine isotopes, tritium, and total organic carbon/dissolved organic carbon, cation exchange capacity, bromine, pH, and nitrogen).
- Total hole air flow anemometry.
- Borehole geophysics (e.g., epithermal neutron, gamma-gamma, natural gamma, spectral gamma, magnetic susceptibility, and electro-magnetic induction).
- Full suite of radiologic analyses for selected samples including groundwater.
- Full suite of geochemical analyses for selected water samples (e.g., Na, K, Mg, Ca, SO_4, HCO_3, Cl, alkalinity, Fe, Mn, Al, SiO_2, trichloroethene, trichloroethane, and other volatile and semi-volatile organics).
- Aquifer testing (e.g., testing of discrete water-bearing zones, pump tests, slug tests, etc.).

- Monitoring (sampling for geochemical, radiochemical, and isotopic constituents on a quarterly basis for a sufficient amount of time to determine if variations in quality exist, or monitoring to determine if fluctuations of the potentiometric surface exist).

Intermediate wells are proposed for the purpose of gathering perched groundwater data, characterizing recharge and contaminant transport pathways, and determining extent and character of intermediate perched groundwater zones. Construction and completion of proposed wells will be dependent upon the main purpose of the well, information obtained during drilling, and whether groundwater is encountered.

Shallow alluvial zone wells are proposed for the purpose of identifying and characterizing shallow alluvial zone perched groundwater and for understanding connectivity between shallow alluvial and intermediate zone groundwater. These wells are also proposed to evaluate the hydraulic relationship between water-bearing zones under the mesas and canyons. For these reasons, drilling and completion of shallow alluvial zone wells is dependent on the information desired at each location. If groundwater is encountered, the well will be completed in accordance with Environmental Protection Agency (EPA) Guidelines (EPA Technical Enforcement Guidance Document [TEGD]), and applicable LANL Standard Operating Procedures (SOPs). A Well Completion Matrix presenting criteria from current and proposed LANL ER SOPs, New Mexico Monitoring Well Construction and Abandonment Well Standards, the HSWA permit and EPA Guidelines is given in Appendix J.

Before any of the proposed wells are drilled, ER Project and WM Program needs should be evaluated so as to minimize duplication of effort. One role of the Groundwater Protection Management Program is to coordinate groundwater protection activities at the Laboratory, including installation of new wells. Final decisions on placement of the proposed wells will be made by a Technical Review Committee (TRC) consisting of representatives from Laboratory groups (e.g., the Water Quality and Hydrology Group, the ER Project, the WM Program, the Utilities Program, and the Earth and Environmental Sciences division) and other groups (e.g., the DOE-OB, the Pueblos and other stakeholders). The TRC is discussed in further detail in Section 7.0 Implementation Plan.

In addition to these Laboratory efforts, the USGS has proposed a study of groundwater recharge and flow system (Appendix G). The study will specifically target the question of recharge from the Sierra de los Valles to the west of the Laboratory and include several wells on either side of the Pajarito Fault Zone. The influence of the fault zone on surface-water flow will be monitored through the use of stream gaging stations above and below the fault zone. Downward migration of water will be monitored through well clusters. The estimated cost and duration of these proposed USGS activities is $2.24 million over six years.

Information gathered from the installation of these monitoring wells will also help in the development of a more comprehensive hydrogeologic model of the Pajarito Plateau and the surrounding area. This modeling effort should include both basic water movement and contaminant transport in saturated and unsaturated zones. The model should be updated as new information is generated. All new wells installed should become part of the groundwater monitoring network and be sampled as part of the Laboratory's annual environmental surveillance activities. Potentiometric surface maps should be generated from data collected and be updated as more information becomes available. Also, a geologic map at the water table might be helpful in understanding potential recharge pathways.

Other activities are suggested for further evaluation and characterization of recharge to the regional aquifer. Sampling of perched waters beneath the canyon bottoms and within tuff units

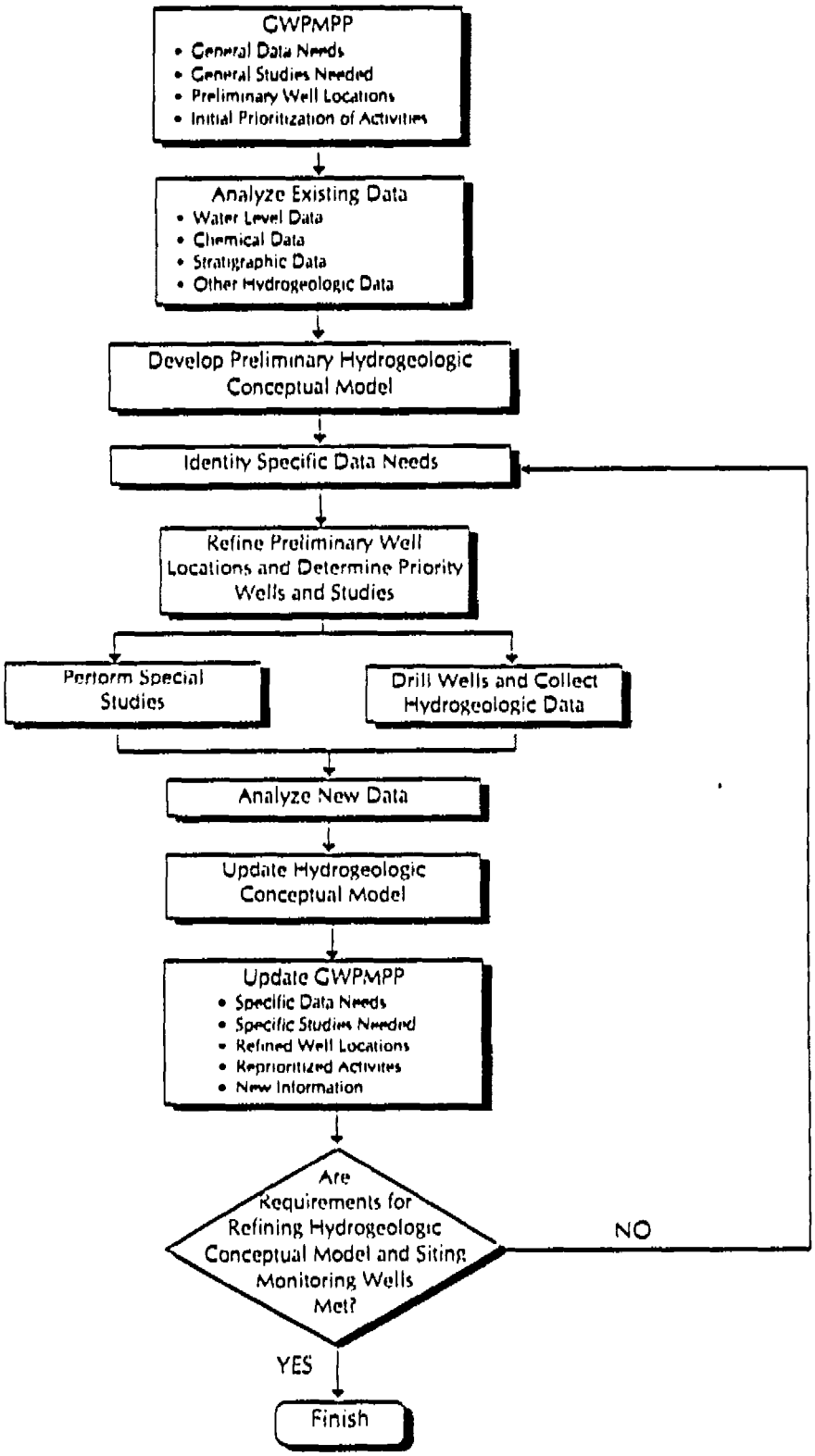

Figure 5-4. Flow chart of the iterative well siting process.

beneath the mesas would be useful for determining the potential for regional aquifer recharge from perched water. Additional ^{14}C dating of water in the potential recharge areas, the regional aquifer, perched zones, and seeps and springs would provide additional information on potential recharge rates and mechanisms. An evaluation of flow and infiltration from perennial and ephemeral streams will help assess whether the canyon bottoms are recharge areas.

Coordination of vadose zone studies conducted by different Laboratory groups and consolidation of the data generated would greatly augment the level of understanding of possible recharge though the vadose zone. The number of vadose zone studies are increasing but are being conducted over short intervals. Also, most of the study efforts do not extend below 45 to 60 m (150 to 200 ft), leaving a data gap between there and the top of the regional aquifer. An extended field program, one capable of spanning a time frame as long as a decade, is necessary to understand unsaturated flow conditions at Los Alamos. Coordination of these studies and consolidation of data is a planned activity of the GWPMP Program.

The ER Project has released the Draft Site-Wide Studies Plan for Environmental Restoration (LANL 1995c). The plan is expected to be finalized by early 1996. The purpose of the plan is to identify site-wide studies that will enhance the quality of technical work and reduce the overall costs of supporting present and future environmental restoration activities at the Laboratory. The studies are designed to provide qualitative and quantitative knowledge of the environmental setting and processes relevant to current and future distributions of contaminants. Thus the plan identifies many studies with a direct bearing on hydrogeological characterization.

Inputs for the plan came from many sources including representatives from ER Project Field Unit teams, a Laboratory team of specialists from the geological, hydrological, and environmental sciences, risk assessment statisticians and analysts, and ER Project managers. The studies comprise nine general topics: four topics concern the environmental setting; four emphasizing environmental processes; and one focuses on uses of data collected during studies in the above eight topics. The draft site-wide plan gives complete details of the proposed studies. Studies which could aid in hydrogeological characterization are shown in Table 5-4.

Currently underway is the development of a Site-Wide Hydrogeologic Work Plan. This work plan, requested by the NMED, will be a source for relevant site-wide hydrogeologic studies once completed.

5.2 Potential Contamination

5.2.1 Potential Contamination Issues

Recent analyses of low-level tritium in samples from various wells definitely show parts of the regional aquifer have recent recharge (Stoker 1994). Although the exact recharge mechanism(s) has not been proven, possible transport pathways suggest that the contamination issue should address the possibility of (1) contaminants moving through the unsaturated (vadose) zone, (2) contaminants infiltrating areas of high fault or fracture density, and (3) contaminants infiltrating along well shafts or boreholes.

Potential Sources

Radioactive and hazardous waste has been generated and disposed at LANL since the Laboratory's inception in 1943 (Kelly 1975). Twenty-three Materials Disposal Areas were identified by Rogers (1977) and all such sites are considered potential sources of groundwater contamination. An extensive list of PRSs was identified early in the ER Project and is updated

Table 5-4. Hydrogeologic Studies Included in the Draft Site-Wide Studies Plan for Environmental Restoration

EP Program Study	Major Benefit
Evaluation of hydraulic properties of geologic units	Model for prediction of site-specific parameters
Location and nature of springs	Depth and condition of uppermost groundwater
Location and nature of perched aquifers	Information to construct site conceptual geohydrologic model
Surface geology—Geologic mapping of the Bandelier tuff	Surface and 3-D geology model
Surface geology—Geologic mapping of the post-Bandelier tuff units	Surface and 3-D geology model
Surface geology—Bandelier tuff stratigraphy studies	Surface and 3-D geology model
Subsurface geology—Logging, sampling, and analysis of selected deep boreholes	3-D geology model; validate site-wide stratigraphy and background values
Subsurface geology—Geochronology of pre-Bandelier tuff units	Enhance spatial reconstruction of aquifers
Geochemical setting—Natural background distributions of elements and solutes	Prediction of background values
Hydrologic processes—Development and validation of an integrated subsurface	Define sub-surface pathways; provide tools to predict contaminant migration
Hydrologic processes—Hydrologic connectivity	Input to 3-D geohygeologic model
Hydrologic processes—Fracture flow and transport studies	Define importance of fracture flow as pathway
Hydrologic processes—Vapor-phase flow and transport studies	Define processes of vapor-phase transport and importance as transport pathway
Hydrologic processes—Recharge of the regional aquifer	Determine probable and eliminate unreasonable sources of recharge; input to 3-D geohydrologic model
Geochemical processes—Interaction of contaminants with the environment	Conceptual model of geochemical process relevant to contaminant migration; quantification of relevant geochemical processes
Data analysis—Three-dimensional geohydrologic model	Visualization of 3-D data and models of contamination migration and remediation
Data analysis—Data uncertainties	Resource to incorporate data and model uncertainties in complex pathways analyses

on a regular basis (see Appendix D). An additional possible source of groundwater contamination is the historic and current practice of discharging treated effluents in canyons near the northern boundary of the Laboratory. While all canyons have received some industrial and sanitary discharges, Los Alamos, Sandia, Mortandad, and Pueblo Canyons are particular areas of concern because they are considered to be the most likely areas of potential recharge to the regional aquifer.

Limited Current Information

The understanding of contaminant transport pathways is limited. Several reports (Purtymun 1984; Purtymun 1989; Purtymun and Stoker 1987; Devaurs and Purtymun 1985) describe the

regional aquifer as being isolated by a barrier of dry volcanic rock that inhibits infiltration or downward migration of moisture from the surface or from perched water zones. However, monitoring of the regional aquifer and intermediate perched zone has shown low levels of tritium in Test Wells 1, 1A, 2, 2A, 4, and 8, observation well LA-1A, and former supply well LA-2. The transport pathways through the Bandelier Tuff have not yet been determined and could include saturated flow mechanisms as well as vapor phase migration through unsaturated geologic materials. Vapor phase migration through unsaturated tuff is supported by the finding of tritium down to 60 m (200 ft) below one mesa top at TA-33.

Plugging and Abandonment

One of the possible transport pathways is along the well bore of inadequately constructed or inappropriately designed wells. As mentioned before, many of the wells at the Laboratory were constructed as early as the 1940s. These wells may be in poor condition due to age or just because of an inappropriate construction for the type of monitoring which needs to be conducted at the Laboratory. Tritium has been detected in samples taken from observation well LA-1A and Test Wells TW-1, -1A, -2, -2A, -4, and -8. In all of these cases, it is possible that tritiated waters from the surface have seeped along the well bore due to an inadequate seal. This may be because there was insufficient grouting emplaced during the cable tool drilling.

These wells may need to be plugged and abandoned in accordance with the New Mexico Environment Department (NMED) and New Mexico State Engineer Office requirements to insure that contaminant transport pathways to intermediate depth perched groundwater and the regional aquifer are properly closed off. These plugging and abandonment procedures need to be applied to all wells that cannot be refurbished, as well as borings and coreholes that might present a pathway for contamination.

Monitoring Well Network

The location and distribution of monitoring wells are inadequate for assessing contaminant transport. Potential sources of contamination are often located in troublesome areas — zones of high fault or fracture density, near cliffs, and in canyon bottoms — in which few or no monitoring wells are located. For example, there are no monitoring wells completed in the zones of shallow alluvial perched groundwater near the Los Alamos County Landfill.

Perched Zone Characterization

The characterization of contaminant transport into intermediate and shallow alluvial perched zones is also not complete. The understanding of contaminant transport pathways is essential for understanding canyon-specific perched water zones. For example, the Cerro Toledo alluvial deposit within the Bandelier Tuff ("epiclastic unit") outcrops near the confluence of Acid and Pueblo Canyons, and may serve as a pathway for discharges from the Larry Walkup Aquatic

Center and a decommissioned radioactive waste treatment facility. The characterization of contaminant transport into perched zones in Los Alamos Canyon, which may ultimately outcrop as seeps and springs near the Rio Grande, is also not complete.

5.2.2 Potential Contamination Solutions

The primary solution to understanding the extent of the effects of Laboratory activities on the regional aquifer is to construct more monitoring wells (Figures 5-1, 5-2, and 5-3 are maps of the proposed well locations). Once constructed, the new monitoring wells should provide data for researchers to gain a better understanding of how contaminants are transported from discharge sites. The data will be used to model contaminant transport using hypothetical leaks or spills.

Analyses of subsurface data have shown that numerous faults cut across the Pajarito Plateau (Dransfield and Gardner 1985). The major fault zones within the Laboratory are shown in Figure 5-5. Although these fault zones have been identified, they have not been fully characterized as to their role in contaminant transport (i.e., they could act as either contaminant barriers or contaminant pathways). A site-wide study is needed to identify additional faults and fractures that may exist and to characterize their role in contaminant transport. This information is needed to support a contaminant transport model.

As previously mentioned, the USGS has proposed a study of groundwater recharge that includes characterization of the Pajarito Fault Zone. In addition to this the USGS has also proposed a study to collect, compile, and evaluate hydrologic data in and around the Los Alamos area. This data will be used for current and future studies, including groundwater flow and contaminant transport modeling. Estimated cost is about $1.7 M over five years.

A special study of seeps and springs is being proposed for fiscal year 1995. This special study should help to characterize how contaminants travel downstream through the alluvium in select canyons to discharge points near the Rio Grande. This study should greatly assist in understanding contaminant transport along the shallow alluvial perched zones, and it should be among the highest priorities of the GWPMP.

More special studies of the vadose zone are needed to characterize the contaminant pathways through unsaturated areas. These studies would provide a much better understanding of how tritium percolated to 60 m (200 ft.) beneath the Mortandad Canyon bottom and the mesa at TA-33. These studies will also help to determine if tritium (and other contaminants) moves in the liquid or vapor phase. Additional sampling and analyses for tritium in the vadose zone, potential recharge areas, and the regional aquifer waters are necessary to determine the significance of tritium in the regional aquifer.

Core samples collected during vadose zone studies should be analyzed for both naturally-occurring and anthropogenic isotopic tracers. This will provide an indication of infiltration rates and depths in the vadose zone, and help to evaluate hydrologic properties and whether vapor-phase transport of contaminants to the regional aquifer is occurring.

Additional sampling of groundwaters for low-level tritium analyses are being planned. Continuing discussions with the Pueblos of San Ildefonso, Santa Clara, Cochiti, and Jemez, and with the Pueblo Office of Environmental Protection are expected to lead to a major sampling effort. This sampling will include groundwater sources on and adjacent to the pueblos that have not previously been analyzed for low-level tritium. Most of the groundwater sources in the vicinity of Los Alamos will be resampled to add confidence to the validity of the measurements.

Uranium and plutonium groundwater samples collected in 1994 are being analyzed by an extremely sensitive mass spectrometry technique to identify specific isotopes of uranium and plutonium. The ratios of uranium isotopes or merely the presence of some isotopes is an indication of the source (e.g., anthropogenic or natural). The analyses can also indicate the origin, such as atmospheric fallout or industrial effluent.

This information can also be used to resolve connectivity questions. Preliminary results indicate no detectable plutonium in any of the samples from the regional aquifer as measured by low-level mass spectrometry. Measurements of samples from the shallow alluvial perched

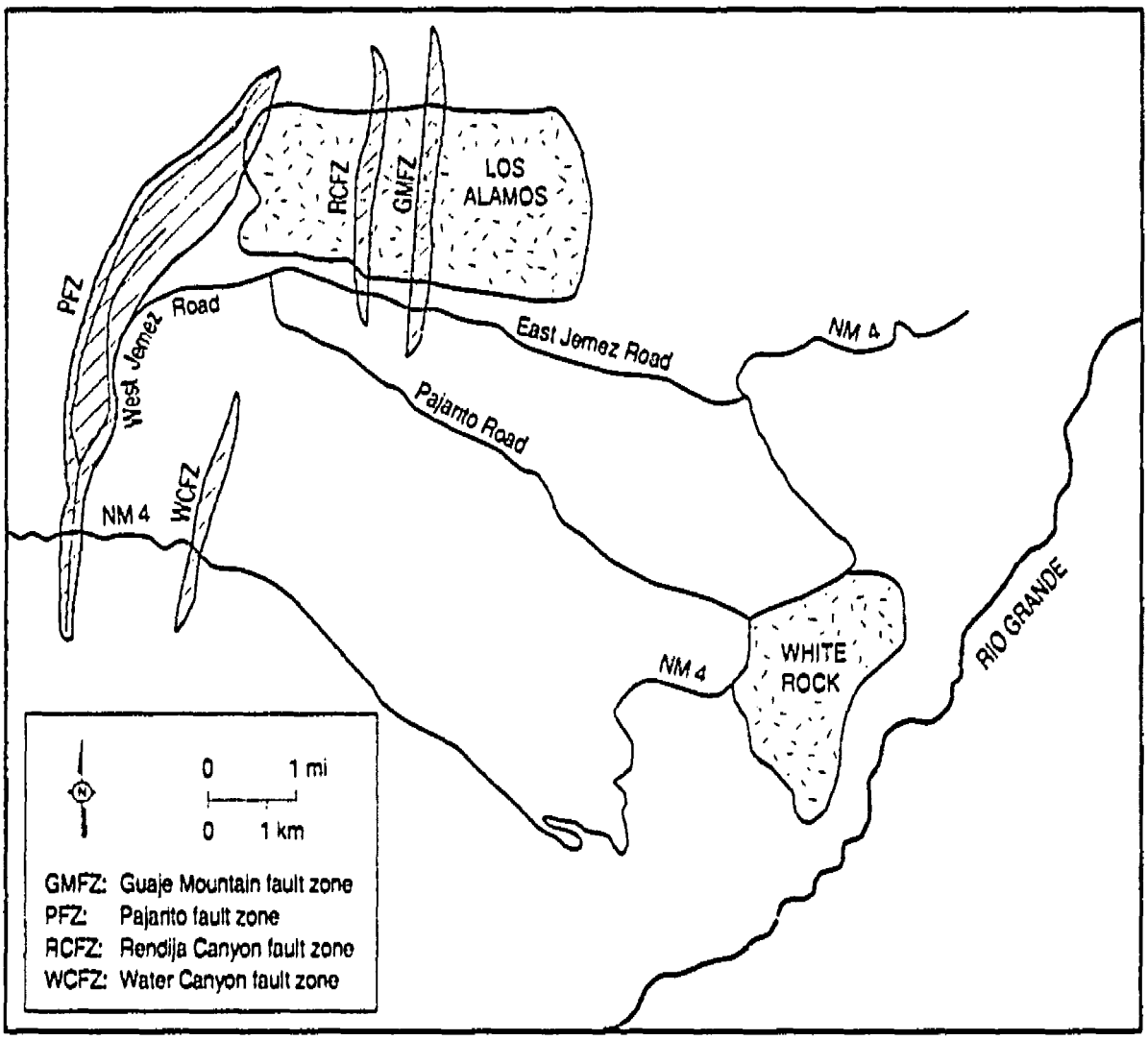

Figure 5-5. Major fault zones in the Los Alamos area

groundwater in Pueblo, Los Alamos, and Mortandad Canyons confirm previous measurements by other methods and demonstrate the usefulness of the isotopic ratios to clearly distinguish different sources. Extensive additional work using this analytic method is planned.

The Laboratory is currently in the process of developing standard procedures for well plugging and abandonment. A program specifically designed to address plugging of contaminant transport pathways (coreholes and borings) and abandonment of inadequate wells needs to be developed. This program would be responsible for implementing the plugging and abandonment SOPs. Initial funding has been requested for nine wells to be plugged and replaced over the next five years. Additional funding will be requested as plugging and abandonment needs arise.

Plugging and abandonment activities should be prioritized. Plugging of a well should not be done until funding is available to replace that well. First priority should be given to those wells in which the presence of tritium or other contaminants could be due to a leaking seal or inadequate well construction. This could include the test wells discussed above (TW-1, -1A, -2, -2A, -4, -8), TW-2B which is an open hole to the intermediate zone, and DT-5A in which lead was found at higher levels than earlier background concentrations. Next priority should be given to wells, coreholes, and borings that are most likely to provide a contamination pathway to groundwater because of their location in areas that receive or have received liquid or solid waste. Final priority should be given to other wells that were constructed using cable tool drilling methods but are not located in areas that directly receive waste. This includes TW-3, DT-9, and -10. Table 5-5 is a prioritized list of wells considered for plugging and abandonment, along with justification. A technical discussion of the plugging and abandonment procedures will be included upon completion of the Laboratory's plugging and abandonment SOP.

Table 5-5. Wells Considered for Plugging and Abandonment

Priority*	Well ID	Justification
1	TW-2B	Inadequate well construction, well open to intermediate zone
2	TW-2A	Presence of tritium in well, inadequate well construction suspected
3	TW-1A	Presence of tritium in well, inadequate well construction suspected
4	TW-2	Presence of tritium in well, inadequate well construction suspected
5	TW-1	Presence of tritium in well, inadequate well construction suspected
6	TW-4	Presence of tritium in well, inadequate well construction suspected
7	TW-8	Presence of tritium in well, inadequate well construction suspected
8	DT-5A	Presence of high Pb levels, inadequate well construction suspected
9	TW-3	Inadequate well construction suspected

* Priority subject to change upon collection of further information.

5.3 Groundwater Monitoring Network

5.3.1 Groundwater Monitoring Network Issues

Regional Aquifer Monitoring Network

The main issue concerning the groundwater monitoring network is that the number and construction of wells used to characterize the hydrogeology in the Los Alamos region is insufficient. A total of 22 wells constitutes the DOE-owned network for monitoring the regional aquifer — 14 supply wells and 8 test wells. As shown earlier in the text (Figure 4-1), none of these wells are located at the eastern or western ends of the facility. This absence means that comprehensive data for water-level measurements, contaminant migration, and other parameters cannot be collected.

Shallow alluvial and Intermediate Monitoring Network

These issues also apply to the shallow alluvial and intermediate wells. Not enough wells are drilled into the shallow alluvial perched zones (Figure 4-2) to characterize how surface-flow contaminants infiltrate the shallow alluvial perched zones in some historically contaminated canyons. More wells are also needed at intermediate depths, where groundwater may occur, to characterize the connectivity between shallow alluvial perched groundwater zones, and the intermediate groundwater zones. This lack of wells limits the understanding of how seeps and springs are recharged along the canyon bottoms.

Environmental Surveillance Monitoring

Another issue of concern is the effectiveness of environmental surveillance monitoring efforts at the Laboratory. There are not enough wells penetrating the regional aquifer that are specifically for monitoring purposes, and those that do exist are not appropriately distributed within the Laboratory boundary. Over half of the wells used for environmental surveillance monitoring at the Laboratory are also supply wells for Los Alamos County. The use of supply wells for monitoring purposes is a concern because supply wells are screened over a much larger depth interval than monitoring wells and the pumps are high capacity pumps. Also, the continued pumping of these wells induces a large component of dilution of any potential contaminants which might be introduced at the uppermost levels. As a result, water samples from supply wells do not provide the same quality of data as do samples from monitoring wells which produce from discrete intervals of the water bearing zone.

Routine environmental surveillance monitoring is conducted at LANL. The details and structure of the Environmental Surveillance Program are outlined in the *Draft Environmental Monitoring Plan* (1995) and the results of monitoring efforts are reported in the annual environmental surveillance reports (e.g., Environmental Surveillance at Los Alamos during 1992). In some special cases, a well or spring may be sampled several times in one year for selected constituents. The Laboratory intends to review records to best understand where the monitoring frequency should be increased to more than annually. It is expected that the frequency of monitoring for new wells and some existing wells that are in probable contamination areas, or where contamination has already been found (e.g., tritium), or that exist as a transect or a well nest, may be quarterly for a limited time to examine the variability of certain parameters.

Well Structure and Condition

The condition of many of the wells is another problem with the existing groundwater monitoring network. Many were constructed more than 40 years ago and do not meet current standards required by regulatory agencies. For example, the casing on older wells is inappropriate for the sampling of organics and trace metals; these older wells were not logged

and cored according to contemporary standards. Many of the older wells are also not sealed properly to prevent contaminant infiltration along the casing.

Springs

In addition to these well problems, there are some problems associated with the labeling and sampling of springs. First, not all of the springs in and around Los Alamos have been identified, named, and surveyed for location information so that they may be included as part of the spring inventory. Secondly, in the past, designations of springs as groundwater rather than surface water has not been consistent. Finally, spring sampling stations have not been adequately marked in the field with a permanent monument to avoid major deviation in the sampling points over time.

Groundwater Monitoring Plan

In 1991, reviewers identified LANL's Groundwater Monitoring Plan as inadequate according to the criteria in DOE Order 5400.1 (see Appendix I-Comments and Recommendations). Although the plan addressed frequencies, locations, and radioactive and hazardous constituents to be sampled, it needed to more fully address field SOPs and other procedures. The Laboratory was also required to complete a full inventory and map of active, abandoned, or sampled wells on the Pajarito Plateau.

5.3.2 Groundwater Monitoring Network Solutions

A complete inventory of all wells, active, abandoned, or plugged, was completed in 1995 (LANL 1995). As mentioned above, the Laboratory is expanding the groundwater monitoring network to include more wells in the vicinity of contamination areas (Figures 5-1, 5-2, and 5-3). Two intermediate-depth coreholes, and one monitoring well to the regional aquifer, are being drilled near TA-54, Materials Disposal Area G. In addition, the following projects have been proposed and funded: two to six intermediate-depth core holes near TA-21, two intermediate-depth core holes near TA-2 and TA-41, and two intermediate-depth coreholes near TA-49. This program will help researchers to understand contaminant flow in the vicinity of these sites. Monitoring wells have been proposed for other historically contaminated areas as well.

All new monitoring wells will be included as part of the annual environmental surveillance activities at the Laboratory. The sampling frequencies for new wells should be determined individually based on the presence of certain radiochemical constituents. If these constituents are present, the well may be sampled quarterly for these constituents. If, after sufficient time (e.g., three years), no significant variations in groundwater quality are noted, the sampling frequency for these constituents may be adjusted to an annual or other appropriate basis. Exceptions may include wells that are placed in known contamination areas or are part of a transect or well nest. In this case, quarterly sampling for certain constituents may be appropriate.

Sampling frequencies of existing wells may need to be altered on an individual basis. Wells that are located in probable contamination areas (e.g., locations where sources of contamination are nearby) may have their sampling frequencies increased to quarterly. Next priority for quarterly sampling are those wells which, from a review of existing data, show a variation in water quality. Priority will also be given to wells where contamination has already been detected or that are part of a transect or well nest. Many of the existing wells have shown no variation in groundwater quality during several years of sampling, therefore increased sampling of all wells within and around the Los Alamos area may not be appropriate at this time.

The expanded network will include more wells at the east and west ends of the facility (Figures 5-1, 5-2, and 5-3). The GWPMPP includes provisions for replacing or refurbishing old wells in the supply and monitoring-well network and outlines a drilling plan that will be implemented over a 5-year period. When complete, the expanded network will greatly assist hydrologists in understanding the mechanisms of recharge to the regional aquifer. Sampling and monitoring of new wells will become part of the annual environmental surveillance activities.

Two of the USGS proposals previously mentioned include the installation of monitoring wells around the Los Alamos area.

The Laboratory will consider the following factors in the construction of new wells:

- *Placement.* Monitoring wells should be placed in areas that are historically contaminated or that require greater hydrogeologic control. Laboratory environmental groups should concur on well placement, drilling methods, and construction techniques to reduce costs and duplication of effort.
- *Dedicated Equipment.* Monitoring wells should be outfitted with dedicated equipment. This equipment should include transducers, pumps, access tubes, and other devices that might become damaged if maintained as portable units. This would also eliminate the concern of cross-contamination.
- *Casing.* Monitoring wells should be constructed with casing materials that extend the lifetime of the well. Different casing materials (e.g., steel and plastic) should be examined in selecting the most appropriate material for a particular well.
- *Screened Intervals.* Monitoring wells should be constructed to monitor discrete hydrologic intervals. This technique should eliminate the problem of using supply wells for monitoring purposes; these are screened over too large an interval to collect appropriate data. The EPA recommends a screen interval less than 15 feet to comply with RCRA.

A Well Completion Matrix presenting criteria from current and proposed LANL ER SOPs, New Mexico Monitoring Well Construction and Abandonment Well Standards, the HSWA permit and National EPA Guidelines is given in Appendix J.

Springs in and around the Los Alamos area should be identified, named and surveyed for location information. This information should be included in a database along with sampling information. All springs should be designated as groundwater sampling stations. All spring sampling stations should be adequately marked in the field with as permanent a monument as possible to avoid major deviation in sampling points through time.

The Groundwater Monitoring Plan (GMP) as it exists in the draft Environmental Monitoring Plan (LANL 1995) has been approved by the DOE. As required by DOE Order 5400.1, the GMP is updated on an annual basis and the updated version is included as Appendix F of the GWPMPP. Principal procedures and methodologies used to carry out the groundwater monitoring program are described and information about stations, analytes, sampling frequencies and analytical procedures is included. Currently, the Laboratory is developing a set of standard procedures for constructing, maintaining, and abandoning wells. In addition, the ESH Water Quality and Hydrology Group is developing a set of surface water and groundwater sampling procedures.

5.4 Water Supply

5.4.1 Water Supply Issues

Long-Term Usage

The main issue concerning water supply in Los Alamos is that the regional effects of supply-well pumping are uncertain. Laboratory hydrologists are uncertain whether the regional aquifer is being depleted faster than it is being naturally recharged. An apparent 0.6 m (2 ft) per year water-level decline has been observed in some wells. Other supply wells, however, show no decline in water levels (Purtymun et al. 1994).

Another issue concerning water supply is the decline in productivity of supply wells over time. Many of the supply wells at the Laboratory have been used as a water source for over 40 years. After years of pumping, the production of the well and quality of the water supply begins to decline due to build-up of sediment in the bottom of the well. Production from wells G-1 and G-1A has decreased noticably over the last 3 years and well G-3 was taken off-line in 1993 because of excess sediment production.

Water Level Data

The problems associated with the monitoring-well network have already been described (Section 5.3.1). Water level measurements taken from pumping wells are questionable, and it is not possible to measure hydraulic gradients and direction of flow under pumping conditions. Data from test wells is sparse. Most of the regional aquifer wells are located in the northeast portion of the facility or offsite to the north and east. Three test wells, DT-5A, -9, and -10, are located on mesas near the southwestern boundary of the Laboratory. This well arrangement does not provide adequate data for mapping the potentiometric surface and determining groundwater flow near the west and southeast portions of the Laboratory. This information is important for understanding how much water will be available for future Laboratory and townsite activities.

Previous Contamination

Another issue involves contamination observed in some supply wells. Noncoliform bacteria have been found in some of the Laboratory's production wells, and high levels of naturally occurring arsenic were found in a supply well (LA-6) in Los Alamos Canyon. The source of the bacteria and reasons for fluctuation in counts are unknown. Well LA-6 has since been plugged, and the LA Well Field has been replaced.

5.4.2 Water Supply Solutions

Currently, three new supply wells are proposed for the Guaje and Otowi Well Fields. Two of the wells are proposed to replace or supplement existing wells in the Guaje Well Field and one well is proposed for the Otowi Well Field. If the first well drilled in the Guaje Well Field does not meet production expectations, then the remaining two wells will be drilled in the Otowi Well Field instead.

In conjunction with the drilling activity, an attempt will be made to bring well O-1 on line. As previously mentioned, this well was drilled too crooked to allow the installation of a standard high-volume production pump. A smaller submersible pump may fit and provide some production from the well.

When the new production wells are on line, decisions will be made as to the future status of the existing Guaje wells; i.e., maintain them as monitoring wells, or plug and abandon them.

Recently the Laboratory has supplied all regional aquifer test wells with continuously-recording pressure transducers to monitor changes in water level. This data will allow a better understanding of pumping effects on the aquifer and on the long-term water supply. Still more pumping and observation wells to the regional aquifer need to be constructed to ensure a viable water supply for the Laboratory and townsite. The observation wells should be distributed inside and outside laboratory boundaries in order to gain better potentiometric control and constructed with dedicated transducers or access ports for water-level measurements.

As previously discussed, the ESH Water Quality and Hydrology Group has proposed installing 23 monitoring wells to the regional aquifer over the next five years, some of which are specifically intended to increase knowledge of the water supply, as well as monitor water quality (Figures 5-1, 5-2, and 5-3). The ER Project has also proposed the installation of wells strictly for monitoring purposes (Table 5-1).

A special study relating to long-range water supply for the Los Alamos area was completed in 1986 by the U.S. Corps of Engineers for the DOE. In this report, waters from the San Juan and Chama rivers were considered as a short-term supplement to the water supply. Other special studies are needed to answer questions pertaining to naturally occurring biological and mineral contaminants in the regional aquifer wells.

5.5 Information Management

5.5.1 Information Management Issues

Central Database

The main issue concerning information management is that the Laboratory does not have a recognized, central database for storing hydrologic, geologic, water quality, and other related data. Each group uses its own unique manual or electronic method for storing basic groundwater data. Some groundwater information is obtainable by contacting a specific supplier or the Facility for Information Management, Analysis, & Display (FIMAD). However, greater centralization and coordination of this information management process is needed so that external and internal customers can access the relevant groundwater data.

Data Format

The process of centralizing information is complicated by other factors. Groundwater data conventions, such as units, labels, or qualifying remarks, are often unique to a particular LANL group, resulting in a lack of consistent data reporting. In addition, the use of different hardware and software applications throughout the Laboratory makes sharing, access, and integration of data difficult.

QA Procedure

Quality assurance of data is another issue concerning a central database. Different LANL groups use different methods for evaluating data quality, but centralization of data would require an approved and speedy method of data quality assurance. In addition, much of the historic data from Laboratory activities is contained in various publications and reports, many of which are out of print or unobtainable. These data need to be centralized so that interested parties, internal and external, can have access.

Timely Access to Data

Stakeholders and other groups outside of the Laboratory often do not have timely access to LANL database information. The turnaround time for many of the Laboratory environmental or groundwater reports is up to two years after the information was originally collected. Also,

Laboratory groups do not have timely access to hydrogeologic data collected in the Los Alamos area by the NMED or USGS.

5.5.2 Information Management Solutions

The ER Project is in the initial stages of implementing a computer network database system. This database could serve as a central repository and archive for all groundwater-related data and provide appropriate access for internal and external customers. Presently, some water quality and hydrogeologic data is stored in the ORACLE and ARC/INFO databases through FIMAD. The computer database will be shared with the USGS and the NMED, who will supply hydrologic data, well information, and other data to the database.

The following are suggested features of the database:

- *Dual system.* In the dual database system (shown in Figure 5-6) the rough data is first supplied to a draft database. After being reviewed, the data is then transferred to a quality-assured database accessible by customers.
- *Information management standards.* Standard nomenclature and units of measure should facilitate the transfer of information. Standard file formats (e.g., ASCII files) should be used for data that must be transferred electronically.
- *Quality assurance process.* The quality assurance process for groundwater data should be established and criteria developed. The quality assurance process needs to be timely, stepwise, and cumulative. The data should be qualified with remarks of validity by the source and users of the data, and then pass through a timely, formal process of approval before input to the quality-assured database. Criteria need to be developed for the quality and acceptance of the data.
- *Database content and access.* The database should incorporate data from all groundwater programs at LANL, including spatial data (mapping), relevant hydrogeologic data, well-completion information, results of chemical analyses, radiological data, and modeling data and results. The database should be accessible to Laboratory employees, universities, regulators, and stakeholders. Use of the database should facilitate communication and co-ordination of efforts between groups and individuals that are studying groundwater issues.
- The FIMAD group is currently entering historical environmental surveillance, water quality, and other data from old or out-of-print LANL reports into the database where it can be accessed by interested groups or individuals.

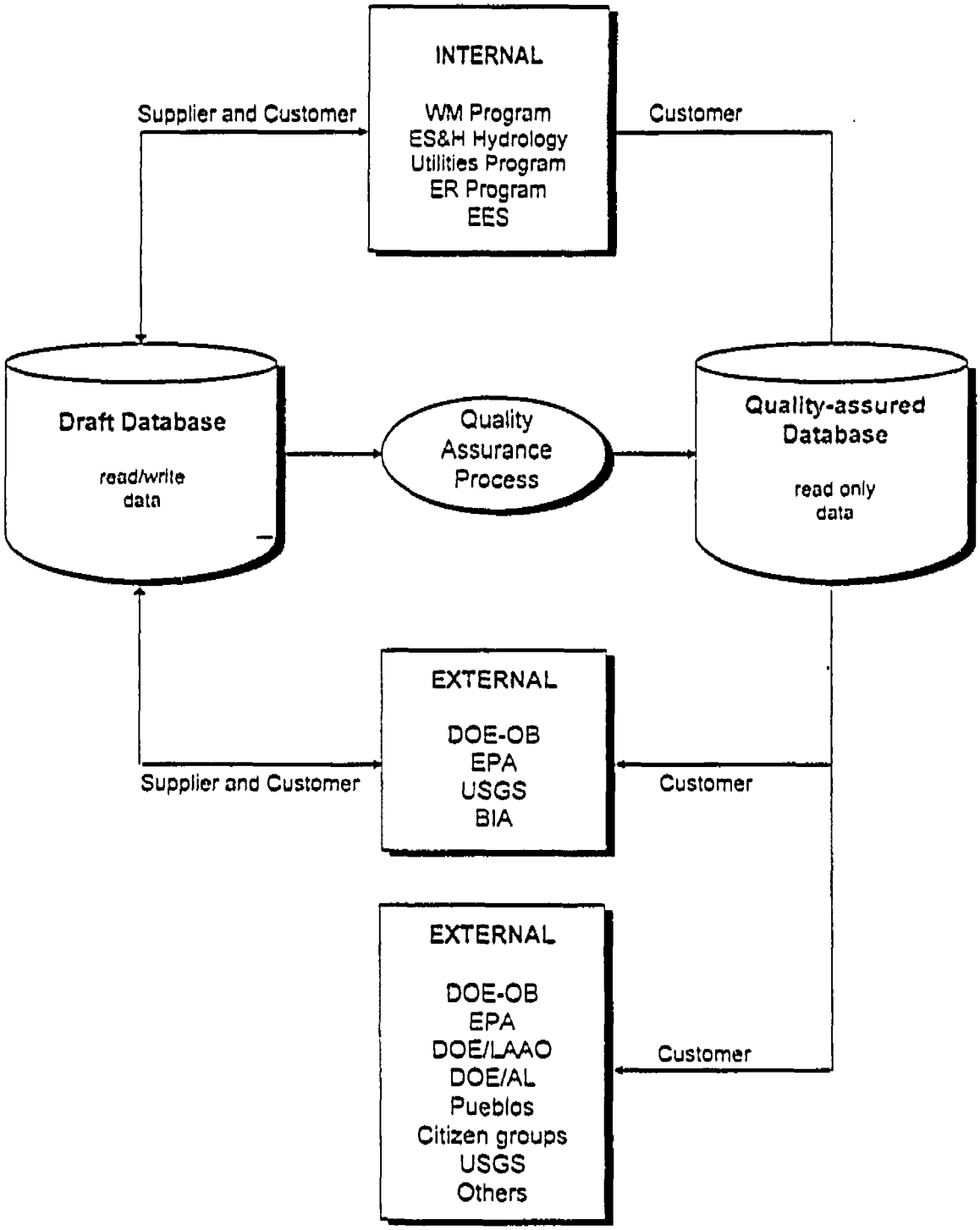

Figure 5-6. Structure of Dual Database System

5.6 Quality Assurance Plan

5.6.1 Quality Assurance Plan Issues

Quality Assurance Plan

A Quality Assurance Plan (QAP) needs to be developed for the GWPMP. A QAP is needed to provide a procedural framework for the program and to document program management activities. No method exists for planning management and group activities, monitoring progress of the program or projects, or defining roles and responsibilities of contributing Laboratory groups.

Laboratory-Wide SOPs

In addition to documenting management activities, the QAP needs to provide field SOPs. These procedures would describe methods for sampling, constructing wells, purging wells, maintaining and abandoning wells, and interpreting sampling data. Currently, each Laboratory group operates under its own unique set of procedures for field operations.

Quality Assurance Officer

The GWPMP also lacks a Quality Assurance Officer to implement the QAP. Such a designated officer would be necessary to achieve quality technical performance and reliable data collection. In addition, the Quality Assurance Officer would ensure that all activities receive proper documentation for traceability and standard defensibility of data.

5.6.2 Quality Assurance Plan Solutions

A QAP will be implemented for the GWPMP. The QAP will be designed to comply with the requirements for structure and content of DOE Order 5700.6C, Quality Assurance, (DOE 1992). The QAP will integrate all management, technical, and quality aspects of the program to include planning, implementation, and assessment, and will document the sampling, monitoring, analysis, and reporting processes to ensure quality data.

The document will include four elements:

- *Program management.* This element states the program objective and goals, roles and responsibilities of participants, and program planning documentation requirements.
- *Measurement/data acquisition.* This element ensures that appropriate methods for sampling, analysis, data handling, and quality control are used and documented.
- *Assessment.* This element ensures the QAP is implemented as prescribed.
- *Data validation and usability.* This element ensures that data elements conform to specified criteria.

The QAP will ensure the collection and analysis of data that are valid, complete, traceable, and defensible. The following quality assurance documents are additional references for guidance and content in the preparation of the GWPMP QAP:

- 923-C006, QAPP/LANL, "QAPP for Technical Support Services to LANL Environmental Restoration Program."
- LA-UR-91-1844, "QAPP and QAPjP for the Environmental Restoration Program."

Standard operating procedures will be established for calibration and control of test and measurement equipment; handling, storage, shipping and preservation; inspection, test and

operating status; and documentation. The SOPs for sampling and well drilling, maintenance, and abandonment are to be adapted from the ER SOPs. Table 5-6 is a partial listing of the applicable field SOPs.

Table 5-6. Environmental Restoration (ER) Field Procedures

Procedure Numbers	Procedure
General Instructions	
LANL-ER-SOP-01.02,R0	Sample Containers and Preservation
LANL-ER-SOP-01.03,R1	Handling, Packaging, and Shipping of Samples
LANL-ER-SOP-01.04,R2	Sample Control and Field Documentation
LANL-ER-SOP-01.05,R2	Field Quality Control Samples
Drilling, Excavating, sampling and Logging	
LANL-ER-SOP-04.01,R2	Drilling Methods and Drill Site Management
Well Installation/Development And Water Sampling Techniques	
LANL-ER-SOP-05.01,R2	Monitor Well Construction
LANL-ER-SOP-05.02,R2	Well Development
Sampling Techniques	
LANL-ER-SOP-06.01,R0	Purging of Wells for Representative Sampling of Groundwater
LANL-ER-SOP-06.02,R0	Field Analytical Measurements of Groundwater Samples
LANL-ER-SOP-06.03,R0	Sampling for Volatile Organics
LANL-ER-SOP-06.04,R0	Sampling Commercial/Municipal/Domestic Wells
LANL-ER-SOP-06.05,R0	Soil Water Samples
Subsurface Hydrogeological Site Characterization	
LANL-ER-SOP-07.01,R0	Pressure Transducers
LANL-ER-SOP-07.02,R0	Fluid Level Measurements
LANL-ER-SOP-07.03,R0	Well Slug Tests
LANL-ER-SOP-07.04,R0	Aquifer Pumping Tests
Geotechnical Analysis	
LANL-ER-SOP-011.01,R0	Measurement of Bulk Density, Dry Density, Water Content, and Porosity in Soil
LANL-ER-SOP-011.02,R0	Particle Size Distribution of Soil/Rock Samples
LANL-ER-SOP-011.03,R0	Permeability of Granular Soils
LANL-ER-SOP-011.04,R0	Soil and Core pH
LANL-ER-SOP-011.05,R0	Total Organic Carbon
LANL-ER-SOP-011.06,R0	Cation-Exchange Capacity
Curatorial Management Activities	
LANL-ER-SOP-12.01,R0	Field Logging, Handling, and Documentation of Borehole Materials
LANL-ER-SOP-12-02,R0	Transportation, Receipt, and Admittance of Borehole Samples for the Sample Management Facility

5.7 Regulatory Compliance

5.7.1 Regulatory Compliance Issues

DOE Order 5400.1

In accordance with DOE Order 5400.1 (DOE 1990), the Laboratory is required to comply with all of the applicable federal, state, and local environmental regulations. The three primary regulatory drivers for the Laboratory's groundwater related activities are (1) RCRA, (2) HSWA, and (3) New Mexico Water Quality Control Commission (NMWQCC) regulations. (See Appendix A for other pertinent regulatory drivers.) The Laboratory's compliance with these three regulations is discussed below.

RCRA Permit

The RCRA permit requires the Laboratory to follow specific procedures in the handling, treatment, monitoring, and disposal of hazardous waste. RCRA was amended in 1984 with HSWA to include requirements for hazardous waste volume and toxicity reduction and to minimize the land disposal of hazardous waste.

HSWA Permit

The HSWA permit (Task III of Module VIII) requires the Laboratory to conduct a program to evaluate hydrogeologic conditions at the facility to supplement and verify existing information on the Laboratory's environmental setting. Because most of the wells completed in the regional aquifer are located in the northeast and east section of the Laboratory, regional data for hydrogeologic characteristics affecting groundwater flow beneath the facility cannot be obtained. Many of the existing wells are used for water supply purposes and are therefore not adequate for obtaining hydrogeologic data required for compliance with this section of the HSWA permit (e.g., water-level measurements). Sufficient hydrogeologic data have not been collected to understand possible contaminant migration pathways through unconsolidated sand and gravel deposits, zones of fracturing or channeling, or zones of high or low permeability as required by the HSWA permit.

Anticipated Regulatory Requirements

The Laboratory also needs to comply with present and anticipated state regulatory requirements. Under the NMWQCC regulations, which pertain to industrial and municipal discharges onto or below the surface of the ground, the NMED can request a Groundwater Discharge Plan for new and existing facilities. The plan would require a site investigation, characterization of the waste stream, and justification that discharge activities will not degrade groundwater.

The Laboratory has two sanitary treatment facilities and over 100 industrial outfalls. A Groundwater Discharge Plan could be requested by the NMED for any of these facilities, and the Laboratory would need to comply within 120 days after the request.

In addition 10 CFR 834 is scheduled to become law. It is anticipated that the content will be similar to DOE Order 5400.4. Ninety days after the document is presented for public review, it could become law, and LANL will be required to be in compliance.

5.7.2 Regulatory Compliance Solutions

In order to fulfill the requirements of the RCRA and HSWA permits, the Laboratory needs to gather more comprehensive groundwater-related data. Wells completed to the regional aquifer are needed to provide this hydrogeologic information and should be constructed for the specific purpose of monitoring and sample collecting or for aquifer test purposes. Other wells and borings to intermediate or deep depths are needed for understanding hydrologic recharge and

contaminant migration pathways through the various geologic formations and structures within and around the Laboratory boundary.

The Laboratory has two approved Groundwater Discharge Plans to meet NMWQCC regulations, one for TA-57 (Fenton Hill) and one for the TA-46 Sanitary Wastewater Treatment Plant which is the location for the SWCS Project (DOE 1992). The Laboratory should still be prepared to produce Groundwater Discharge Plans for discharges from other facilities as well as a Notice of Intent to Discharge for all new activities. Part A of the NMED Discharge Plan Application requires the following information:

- Location.
- Type of operation and type of treatment or storage.
- Quantity and quality of planned discharge.
- Locations of supply wells, monitoring wells, injection wells, seeps, springs, bodies of water or water courses within one mile radius.
- Depth to groundwater.
- Flooding potential and flooding protection measures.
- Geologic description of discharge site.
- Actions for minimization of potential contaminant seepage.
- Proposed monitoring system.
- Contingency plan.

To comply with the NMWQCC regulations, the Laboratory needs to gather background information including site characterization, depth to groundwater, geologic stratigraphy, and the number of wells in the area. The Laboratory also needs to determine potential pathways through which effluent could enter the regional aquifer or the intermediate and shallow alluvial perched groundwater zones. This would require a hydrogeological study of known fractures and other potential recharge pathways to the regional aquifer and intermediate perched groundwater zone. Because the regulations also protect surface waters that are fed by groundwater inflow, an investigation is needed to determine all new and existing discharge points for the shallow alluvial and intermediate perched groundwater zones, the two zones most likely to be affected by Laboratory actions.

LANL needs to be prepared to comply with 10 CFR 834. This stipulates that an Environmental Radiation Protection Plan (ERPP) be established for all DOE facilities that handle radioactive materials. The ERPP will define each site's program designed to limit radiation exposures to members of the public and the environment to the limits established in 10 CFR 834. Paragraph 215 (10 CFR 834.215) pertains to groundwater. The guidelines allow this section to reference a Groundwater Protection Plan. However, the site must review the Groundwater Protection Plan to ensure it meets the requirements of 10 CFR 834.215.

6.0 Business Plan

6.1 Introduction

This business plan provides a framework for the coordination of all Laboratory groundwater monitoring and protection activities. These activities are now spread among different organizations; in the future, a project leader will be responsible for coordinating the various activities. In addition, the business plan defines the roles and responsibilities of the contributing Laboratory organizations and provides a list of prioritized groundwater activities, cost estimates, and schedules for activity completion. The business plan will be further refined as the Program is developed and implemented.

6.2 Management Organization

The GWPMP Program has been established as an institutional program of the Laboratory residing within the ESH Division. The Project Leader for the GWPMP is assigned by the ESH-18 Group Leader (Water Quality and Hydrology Group) upon concurrence with the ESH Division Director. The Division Director delegates authority to the Project Leader, yet is still ultimately accountable for the actions of the Project Leader and Program activities. As shown in Figure 6-1, the Stakeholder Involvement Office of the Laboratory and the ESH Branch of DOE at the Los Alamos Area Office (LAAO) will interact with the Program through the ESH Division. Internal suppliers such as the Water Quality and Hydrology Group, the ER Project, the WM Program, Engineering, Earth and Environmental Sciences, and the Utilities Program will contribute monitoring wells, special studies, and other resources related to groundwater protection under their programs. External suppliers such as NMED and USGS will contribute the same. These activities will be coordinated through the GWPMP with the Water Quality and Hydrology Group providing primary program support. External customers include DOE/LAAO, DOE/AL (Abuquerque), NMED, DOE-OB, EPA, USGS, pueblos, and other citizens groups.

6.2.1 Project Leader

The Project Leader will serve as the Laboratory's primary liaison for groundwater-related issues and provide the technical and professional leadership required for implementation of the program. He or she is appointed by the ESH Division Director through a nomination process and is accountable to the ESH-18 Group Leader and the ESH Division Director for project execution. The Project Leader will coordinate all Laboratory groundwater monitoring and protection activities, and will report directly to the ESH-18 Group Leader.

The Project Leader will be responsible for developing and implementing the GWPMP Plan. He or she will have the authority to appoint additional project leaders if needed and to allocate funds to capability organizations for execution of program activities. The Project Leader will serve as coordinator for all monitoring efforts and hydrogeologic studies related to groundwater protection at the Laboratory to ensure a unified approach and prevent duplication of effort among the different Laboratory programs. The Project Leader will prioritize and track groundwater activities, estimate costs, and provide schedules for completion of activities with input from contributing organizations. The Project Leader will be responsible for updating the Plan and serve as a focal point for consistency and quality of groundwater data and reports. The Project Leader will interact with internal Laboratory organizations and serve as the primary point of contact for DOE/LAAO, DOE-OB, USGS, pueblos, and citizen

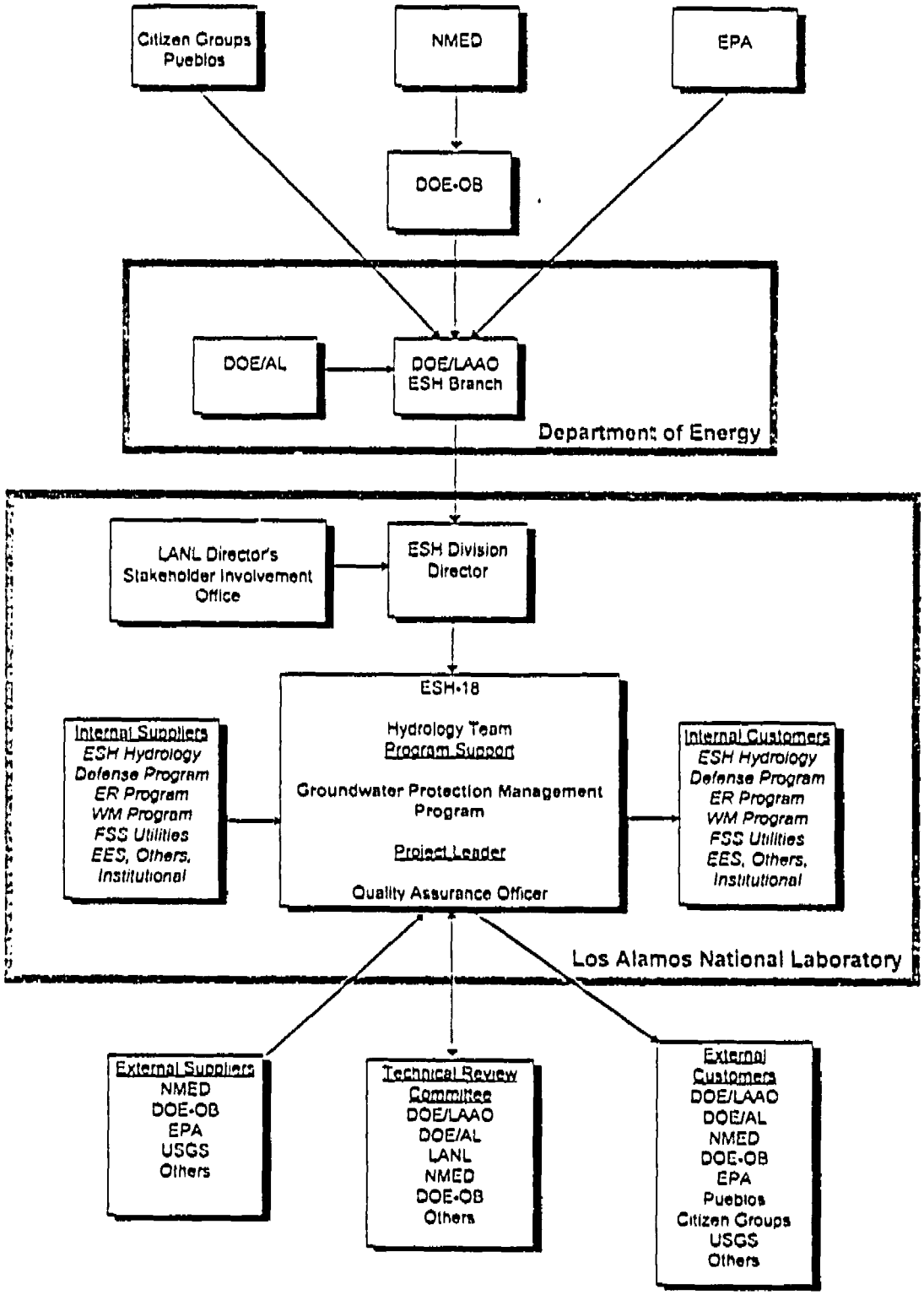

Figure 6-1. Organization Chart

groups on groundwater-related matters, including generating informative reports. The Project Leader will determine program needs and be responsible for addressing those needs in order to ensure successful operation.

6.2.2 Water Quality and Hydrology Group (ESH Division)

The ESH Water Quality and Hydrology Group will serve as the home organization for the Project Leader and will provide primary support for the Program. The Group will assist the Project Leader in integrating contributions from the other Laboratory technical programs into a comprehensive groundwater monitoring, modeling, and characterization effort. The Water Quality and Hydrology Group will work with the Project Leader to prioritize and track groundwater activities, estimate resource requirements, and develop schedules for a coordinated Program. Existing groundwater monitoring programs conducted by the Water Quality and Hydrology Group as part of environmental surveillance activities will serve as the basis for the Program. As ER, WM, USGS and other monitoring wells are developed, these facilities will become a part of the Laboratory's routine monitoring program.

6.2.3 ER Project (EM Division)

The ER Project will provide a detailed compilation of ER-planned, scheduled, and funded activities that contribute information on site-specific groundwater conditions and to the general understanding of groundwater at the Laboratory. The ER Project will provide similar information from work plans that are now under development or in the approval process. ER Project staff will work with the Project Leader and other contributing Laboratory organizations to integrate studies and other activities that expand the usefulness of ER-generated information under the Program. ER Project staff will work with the Project Leader to expand the FIMAD mapping and geographic information system into an integrated Laboratory-wide system to support the Program.

6.2.4 WM Program (CST Division)

The WM Program will identify specific WM-planned, scheduled, and funded groundwater monitoring systems and site-specific groundwater studies for the Program. In addition, the WM Program will identify WM-related data needs which are required to support existing and proposed facilities (i.e., the Mixed Waste Disposal Facility [MWDF] and the Hazardous Waste Treatment Facility [HWTF]). The WM Program staff will work with the Project Leader and other contributing organizations to integrate studies and other activities into the Program.

6.2.5 Utilities Program (FSS Division)

The Utilities Program will provide water resources information for integration of Laboratory and Los Alamos County water supply data into the Program. The Utilities Program will provide the basic data required for water supply planning and hydrologic modeling to evaluate pumping effects on regional aquifer and water rights. The Utilities Program will assist the Project Leader and other contributing Laboratory organizations in improving and automating hydrologic data collection from water supply wells.

6.2.6 Earth and Environmental Sciences (EES Division)

The EES staff will contribute and integrate groundwater information obtained from technical studies undertaken in behalf of ER and other programs. These studies include stable isotope recharge studies, geologic mapping, computer modeling, and other groundwater studies. The

EES staff will assist the Project Leader and other contributing organizations to develop specific projects to be implemented by EES as part of the Program.

6.2.7 Other Laboratory Organizations

Other Laboratory organizations will contribute groundwater information collected under their programs to the Program.

6.3 Fiscal Organization

6.3.1 Coordination of Funding

Funding identified for groundwater protection activities under the current Environmental Surveillance Program, Tiger Team Action Plans, ESH 5-Year Plan, ER Project, WM Program, Utilities Program and other programs will be coordinated under the Program. A Project Control System and Work Breakdown Structure (WBS) will be utilized to identify and track contributions from each program involved in groundwater protection. An integrated approach will be used in order to avoid overlap and duplication of effort.

6.3.2 Environmental Surveillance Program

The indirect budget for FY95 for groundwater monitoring conducted by the ESH Water Quality and Hydrology Group under the Environmental Surveillance Program is $1500 K. Of this amount, approximately $200 K is dedicated to GWPMP management activities. Approximately $300 K is required for groundwater monitoring analytical work, and $200 K is to support existing activity levels. An additional $800 K is slated to support Tiger Team Action Plan activities. The $1500 K total represents the base funding for groundwater monitoring which will be coordinated under the Program. This funding source and others are shown in Table 6-1.

6.3.3 Tiger Team Action Plans

Many of the elements of the GWPMP are identified as planned actions under Tiger Team Action Plan C-EM-01 "Environmental Surveillance" and Action Plan C-EM-17 "Ground Water Discharge Plan Compliance" (Appendix I). These Action Plans were not funded in FY93 or in FY94. Funding for further development and implementation of these elements of the GWPMP Plan will be requested in FY95. Reprioritization will be requested in view of the recent discovery of low levels of tritium in the intermediate groundwater and regional aquifer in Los Alamos Canyon. Work on these Action Plans will be coordinated under the Program.

6.3.4 ESH 5-Year Plan

Direct funding of some groundwater monitoring and related activities may be available in FY96 under the ESH 5-Year Plan. An initial request of $2 million per year in additional operating funds for groundwater protection and $5 million per year in line item funds for installation of new monitoring wells was included in the current ESH 5-Year Plan. Direct funding provided under the ESH 5-Year Plan will be coordinated and will support the Program.

6.3.5 ER Projects

Direct funding of groundwater monitoring and related activities provided by the ER Project will be coordinated under the Program.

6.3.6 WM Programs

Direct funding of groundwater monitoring and related activities provided by the WM Program will be coordinated under the Program.

Table 6-1. GWPMP Funding Sources

Tiger Team Action Plans FY92 through FY2002	C-EM-01 Environmental Surveillance - 11 year period (Includes all Environmental Surveillance activities)	$14,200 K	Requested
	C-EM-01 Environmental Surveillance 11 year period (Groundwater activities only)	$7,000 K	Requested
	C-EM-17 Groundwater Discharge Plan 4 year period (Groundwater activities only)	$1,600 K	Requested
	Total Tiger Team Groundwater Activities FY92 to FY02	$8,600 K	Requested
Indirect Budget FY95	Environmental Surveillance FY95 Base (Groundwater activities only)	$700 K	Requested
	C-EM-01 Environmental Surveillance (Groundwater activities only)	$300 K	Requested
	C-EM-17 Groundwater Discharge Plan (Groundwater activities only)	$500 K	Requested
	Total Groundwater Activities FY-95	$1,500 K	Requested
Direct Budget FY96 (ESH 5-year Plan)	ESH 5-Year Plan Core with Burden (Groundwater activities only)	$1,400K	Requested
	ESH 5-Year Plan Compliance (Groundwater activities only)	$2,000 K	Requested
	ESH 5-Year Plan Line Item (Install monitoring wells)	$5,000 K	Requested
	Total ESH 5-Year Plan (Groundwater Activities FY-96)	$8,400 K	Requested

6.4 Customers

The primary customers for the Program are external to the Laboratory and include the DOE/LAAO, DOE/AL, NMED, DOE-OB, EPA, USGS, Pueblos, Citizen Groups, and other Stakeholders. The DOE/LAAO is the primary focus and audience for the Plan. Participation of the DOE/LAAO and the DOE-OB will be required during development and implementation of the Plan in order to produce an acceptable product.

Participation of stakeholder groups will be sought and facilitated through the Laboratory's Stakeholder Involvement Office. Communication with stakeholders during development and implementation of the Plan will be essential for public acceptance of the GWPMP as a viable means of protecting their groundwater interests. A training element will be required in the Program to properly present technical data in the context of general environmental protection.

The Program will be of particular benefit to internal customers including the Water Quality and Hydrology Group, ER Project, WM Program, Utilities Program and other contributing organizations. Groundwater data, special studies, and other information will be made readily accessible to these organizations, which should improve communication and reduce duplication of effort.

6.5 Cost and Duration Estimates

Table 6-2 shows costs based upon current budgets and anticipated costs of GWPMP activities. Additional groundwater protection activities in FY95 will depend upon allocation of indirect funding. Additional activities including installation of new monitoring wells in FY96 and beyond will depend upon allocation of direct funding under the ESH 5-Year Plan. Contributions from the ER Project, WM Program, and other programs are being determined under the GWPMP Plan.

Table 6-3 shows costs based upon well drilling experience and projected costs for installing and equipping monitoring wells. This estimate includes costs for monitoring wells at new locations and replacement wells for existing wells which are deficient or improperly constructed for effective groundwater characterization. The estimated cost for new and replacement wells to completely upgrade the Laboratory's groundwater monitoring system is $25 million. This estimate includes two intermediate zone wells proposed by the ER Project.

6.6 Prioritization

6.6.1 Methodology

This section describes the methods used to develop a list of prioritized activities for the 1994 GWPMPP. First, Laboratory reviewers developed a comprehensive list of all of the groundwater-related issues. This process involved meeting with regulatory and other groups (NMED, DOE-OB, EPA, and stakeholder groups), reviewing periodicals, and consulting hydrological experts. Second, the reviewers arranged the issues into logically related groups. For example, all of the issues concerning monitoring wells (condition, lack, and location of wells) were placed under a Groundwater Monitoring Network heading. These issues of concern have been previously discussed in detail in Section 5: Issues and Solutions. Next, the reviewers developed a list of activities to solve each of the issues discussed and assigned costs and schedules to each activity. The activites correspond to the discussion of solutions in Section 5. After analyzing the projected cost, time, and benefit of each activity, the reviewers assembled a final prioritized list.

Table 6-2. GWPMP Preliminary Cost Estimate

	1994	1995	1996	1997	1998	1999	2000	2001	2002
Operating Expenses	705	1,500	3,400	3,400	3,400	3,400	3,400	3,400	3,400
GWPMP Management									
Program Manager	50	125	250	250	250	250	250	250	250
GWPMP Plan Development	155	75							
Testing of Samples									
Existing Testing	300	300	300	300	300	300	300	300	300
Additional Testing			900	900	900	900	900	900	900
Environmental Surveillance Activities									
Existing Activity Level	200	200	400	400	400	400	400	400	400
Additional Support Act. (Sampling, Reporting, etc.)			300	300	300	300	300	300	300
* Tiger Team Action Plan Support Activities		800							
** GW Studies and Reporting			1,000	1,000	1,000	1,000	1,000	1,000	1,000
** Information System and Archiving			250	250	250	250	250	250	250
Line Item Costs			5,000	5,000	5,000	5,000	5,000		
Install 23 New Test Wells to Regional Aquifer			3,680	3,680	3,680	3,680	3,680		
Remove Casing and Plug 9 Existing Wells			180	180	180	180	180		
Install 14 New Test Well to Intermediate Zone			840	840	840	840	840		
Install 50 New Test Wells to Shallow Alluvium			300	300	300	300	300		
Total	705	1,500	8,400	8,400	8,400	8,400	8,400	3,400	3,400

Notes: All years are fiscal years.
All costs are in thousand dollars.
Outyear costs do not include escalation or inflation.
1994 and 1995 costs are indirect costs.
1996 through 2002 costs are indirect dollars with burden included for existing activities.
* Not yet funded for Action Plans C-EM-01 and C-EM-17.
** These costs are estimates of required GWPMP and ESH-8 Hydrology Team enhanced activities.
Further funding may be required for as yet unidentified monitoring, testing, studies, reports, etc.

The process was an informal one. Future GWPMPP managers may want to consider more structured methodologies. For example, the Laboratory has developed a software package called the Laboratory Integration Prioritization System (LIPS) that provides a formal process of determining priorities. LIPS is a risk-based prioritization system, which integrates and prioritizes the spending of Laboratory resources while considering the concerns of diverse stakeholders. The system is based on the fundamental principles of decision analysis and uses multiattribute theory to quantify and compare the benefits of activities. The LIPS approach is a formal way of quantifying the benefits of proposed activities.

Table 6-3. Well Installation Cost Estimate

	Test Well at New Location	Test Well to Replace Deficient Test Well	Test Well to Replace Production Well	Extended Amount
Install New Test Wells to Regional Aquifer (23 @ $800K each)	$4000K (5 Wells)*	$7200K (9 Wells)	$7200K (9 Wells)	18400K (23 Wells)
Plug Existing Deficient Test Wells (9 @ $100K each)				$900K (9 Wells)
Install New Test Wells to Intermediate Zone (14 @ $300K each)	$3600K (12 Wells)**	$600K (2 wells)		$4200K (14 Wells)
Install New Test Wells in Shallow Alluvium (50 @ $30K each)	$600K (20 Wells)	$900K (30 Wells)		$1500K (50 Wells)
Total	$8200K	$9600K	$7200K	$ 25000K

Notes: All costs in thousand dollars.
Well installation includes design, drilling, development, casing, gravel pack, core, analysis, pump and instrumentation.
Well plugging includes cutting and removal of casing and gravel pack, and grouting to prevent vertical movement of groundwater.
* Includes one well proposed by the ER Program for Area G.
**Includes two wells proposed by the ER Program.

Whatever method is chosen, the manager must ensure that all participants agree to the ground-rules governing the process. That way, as priorities are chosen, the participants will understand the underlying methodology.

6.6.2 Prioritized List of Activities

Priority levels have been developed and assigned to each activity assuming that adequate resources are available to conduct this work. These priority levels are based on the following criteria:

- *Priority 1 Items*. These items represent the most important and most pressing activities identified by the Laboratory, the DOE, and the NMED to ensure the regional aquifer is protected from contamination. Priority one items are scheduled to start immediately, assuming resources are available, with a goal of completion within 18 months.
- *Priority 2 Items*. These items represent significant groundwater-related activities that do not have the same urgency as priority one. Priority two items include projects that may already be underway or have a good likelihood of being funded for completion within a given duration. Priority two items are scheduled to start as soon as practical with a goal of completion or significant progress within five years.

- *Priority 3 Items*. These items represent long-term projects aimed primarily at extending the level of technical understanding of the regional groundwater system. These activities may not yet be funded or may require a phased approach for completion. Information gathered during the completion of higher priority projects will be use as a basis for completion of these longer term projects. Priority three items are scheduled to start within the next five years and show significant progress within 10 years.

Table 6-4 shows a prioritized list of proposed activities based on the needs identified by the Laboratory, DOE, and NMED. Each activity is assigned to one of the prioritization categories listed above. Section 5 page numbers are given to reference where each issue is described and solutions are discussed.

Figure 6-2 shows a preliminary 10-year schedule for completing the GWPMP activities.

6.7 Training Program

A training program will be implemented to familiarize Laboratory employees with the general purpose and structure of the Program. The training program will focus on Laboratory programs and external organizations that function as suppliers to or customers of the Program.

The training program should emphasize how the Program will benefit the Laboratory, the DOE, the state, and the pueblos and citizen groups. The training program will make clear the roles and responsibilities of the Laboratory programs with respect to the Program. It will also define the lines of communication between division and program leaders and the Project Leader, and between the Project Leader and the ESH Division Leader, DOE, the state, and pueblos and citizen groups. The training program will also specify the types of data needed from each program, the mechanism for transfer of information, and criteria for data quality assurance.

6.8 Problem Tracking Mechanism

New issues of concern related to groundwater will arise as the GWPMPP is implemented. A problem tracking mechanism will be developed to ensure that these new issues are addressed and measures are taken to mitigate circumstances that may lead to contamination of the regional aquifer.

The Project Leader will be responsible for tracking the status of groundwater-related problems and invoking the necessary and appropriate actions for resolution. In addition, the Project Leader will ensure that all groundwater-related correspondence is "tracked"—that is, all queries receive consideration, follow-up actions, and replies. It will also be the Project Leader's responsibility to generate the appropriate status reports.

Table 6-4. Prioritized List of Activities for the Section 5.0 Issues and Solutions

Issues	Solution/Activity		Activity Priority	GWPMPP Section
5.1 Hydrogeological Characterization				
• Hydrogeologic Data • Recharge Mechanisms	• Inventory existing data	• Compile existing hydrogeological data	1	5.1/5.5
		• Consolidate data in central database	2	
	• Study recharge pathways to regional aquifer	• Initiate study of recharge from shallow alluvial perched zone	1	5.1.2
		• Initiate study of recharge from intermediate perched zone	1	
		• Initiate study of recharge from mesa tops	1	
		• Initiate study of recharge from faults and fractures	1	
		• Determine recharge from regional sources	3	
	• Study seeps and springs	• Identify new seeps and springs	1	5.1.2
		• Survey new seeps and springs	1	
		• Sample all seeps and springs	1	
	• Study aqueous isotope geochemistry	• Sample wells	2	5.1.2
		• Sample seeps and springs	2	
	• Create hydrogeological information maps	• Construct piezometric surface map	1	5.1.2
		• Construct geologic map at piezometric surface	1	
	• Update hydrogeologic model		1	5.1.2
5.2 Potential Contamination				
• Potential Sources • Limited Current Information • Plugging and abandonment	• Study contaminant transport	• Study vadose zone pathways	2	5.2.2
		• Study fault and fracture pathways	2	
		• Study borehole contamination	2	
• Monitoring Well Network	• Study trace constituents in wells	• Evaluate historical well data	2	5.2.2
		• Perform trend analysis	2	
• Perched Zone Characterization	• Study trace constituents in seeps and springs		2	5.2.2
	• Develop plugging and abandonment program	• Develop plugging and abandonment SOPs	1	5.2.2
		• Plug and abandon nine wells already identified	1	
5.3 Groundwater Monitoring Network				
• Regional Aquifer Monitoring Network	• Inventory all wells and borings	• Collect all well-related data	1	5.3.2

Table 6-4. Continued

Issues	Solution/Activity		Activity Priority	GWPMPP Section
•		•		
• Shallow Alluvial and Intermediate Monitoring Network		• Construct map of all wells and borings	1	
		• Evaluate monitoring network deficiencies	1	
• Environmental Surveillance Monitoring	• Develop drilling plan for new monitoring wells		1	5.3.2
• Condition of Wells • Groundwater Monitoring Plan	• Construct new monitoring wells		2	5.3.2
	• Environmental Surveillance Monitoring	• Include new wells in Environmental Surveillance Monitoring Plan	1	5.3.2
	• Update Groundwater Monitoring Plan (annually)		2	5.3.2
5.4 Water Supply				
• Usage • Water Level Data	• Construct or refurbish supply wells		3	5.4.2
• Previous Contamination	• Study origin of micro-biological constituents		3	5.4.2
5.5 Information Management				
• Central Database • Data Format • QA Procedure • Timely Access to Data	• Develop dual database system	• Consolidate newly collected hydrogeological and well-related data	1	5.5.2
		• Develop consistent database format	1	
		• Establish mechanism for timely input of quality data	1	
		• Establish information transfer pathways for internal and external customers	1	
5.6 Quality Assurance				
• Quality Assurance Plan	• Develop a Quality Assurance Plan for field activities	• Develop SOPs for Well Installation	1	5.6.2
• Laboratory-Wide SOP • QA Officer		• Develop SOPs for Water Sampling	1	
		• Develop SOPs for Hydrogeological Site Characterization	1	
		• Develop SOPs for Geotechnical Analysis	1	
		• Develop SOPs for Curatorial Management Activities	1	
	• Develop a Quality Assurance Plan for GWPMPP managerial activities	• Develop procedural framework for management activities	1	5.6.2
		• Develop documentation for management activities	1	
		• Develop specific managerial roles and responsibilities	1	

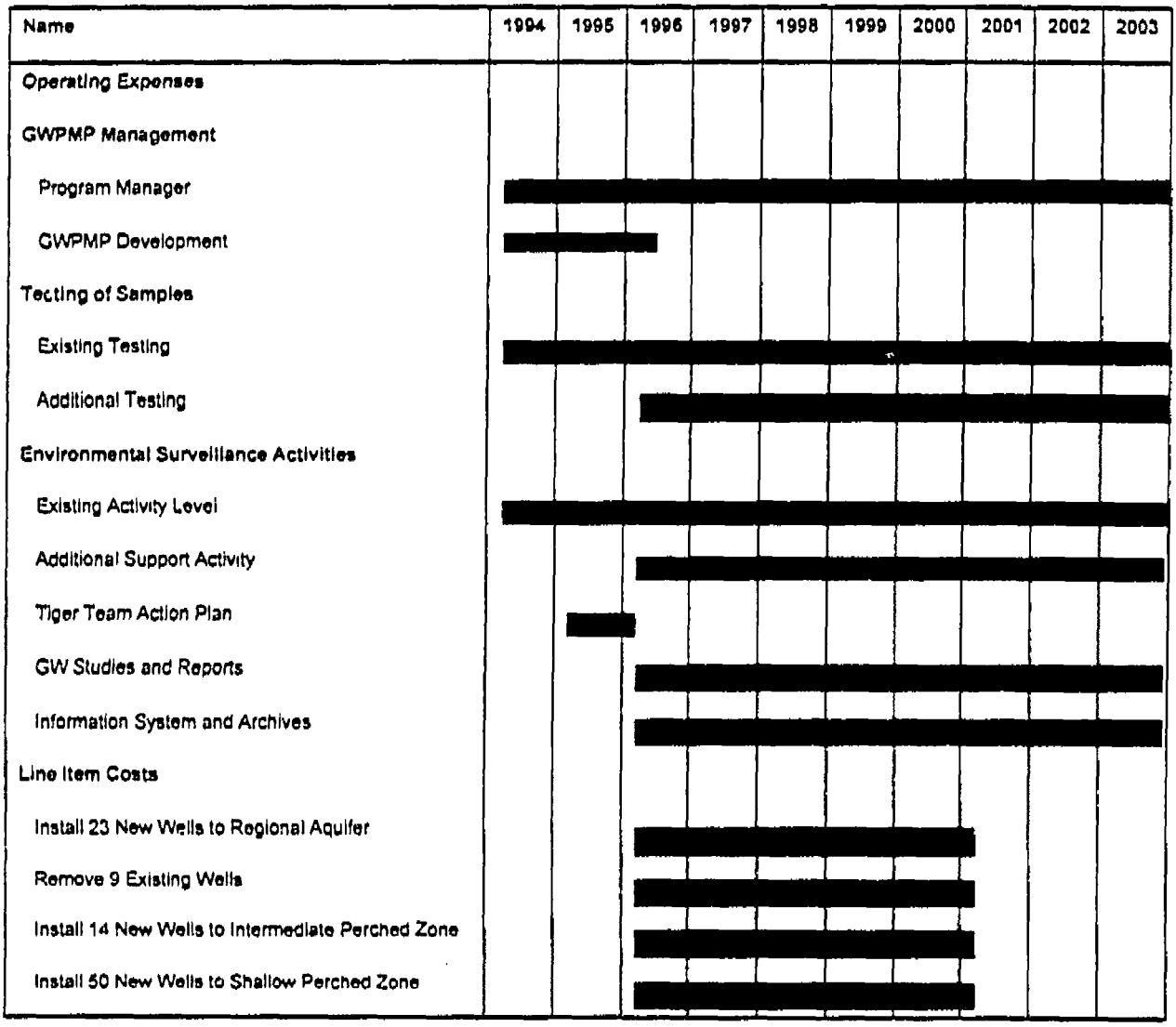

Figure 6-2. GWPMPP Preliminary 10-Year Schedule

6.9 Performance Measures

Performance of the GWPMP must be measured and customer feedback provided in order to assure that an effective program is in place. The following performance measures will be used:

- Compliance with DOE Order 5400.1 "General Environmental Protection Program" and DOE Order 5480.1B "Environment, Safety, and Health Program for Department of Energy Operations."
- Ability to address issues discussed in the Laboratory's RCRA Part B Operating permit relating to groundwater protection and management.
- Ability to address issues discussed in Task III of Module IV of the Laboratory's RCRA Part B Operating permit, i.e., the HSWA Module.
- Compliance with NMWQCC Regulations Section 3-100 "Regulations for Discharge Onto or Below the Surface of the Ground." Although preparation of Groundwater Discharge Plans for individual laboratory facilities has not yet been required, the ability to comply will be used as a performance measure.
- Internal Customer Satisfaction (Water Quality and Hydrology Group, ER Project, WM Program, Utilities Program, and other programs). The following questions will be asked of customers: Was the GWPMP effective in coordinating groundwater protection activities at the Laboratory? Did the GWPMP help to improve communication and reduce duplication of effort among different programs? Was the GWPMP effective in complementing the programs of contributing organizations?
- External Customer Satisfaction (DOE/LAAO, DOE-OB, pueblos, and other stakeholders). The following question will be asked: Were previously noted deficiencies and unfunded activities properly addressed?

7.0 Implementation Plan

Implementation of the GWPMPP will be assisted by input and guidance from a Technical Review Committee. Once implementation has begun, a groundwater status report will be produced annually, and the GWPMPP will be updated annually. A description of the committee, reports, and updates is provided below along with a business plan schedule.

A Technical Review Committee will be responsible for providing guidance to Laboratory groups and assisting in the implementation of the GWPMPP. A description of the committee, as well as various reporting requirements, is provided below.

7.1 Technical Review Committee

The Technical Review Committee (TRC) is responsible for evaluating the technical aspects of the GWPMP. The committee will review the list of prioritized activities in the plan and revise the list based on new or changing technical requirements. During this process, the TRC will solicit recommendations from various LANL groups (i.e., Water Quality and Hydrology Group, ER Project, WM Program, Utilities Program, and Earth and Environmental Sciences) and incorporate the groups' suggestions for revising technical goals and priorities. The GWPMP Project Leader will chair the TRC sessions. The members will meet regularly to review the list of priorities and will, at a minimum, consider the following issues:

1) *Current Status of Groundwater Activities.* The costs, schedules, and technical aspects of each of the prioritized activities will be evaluated. The technical effectiveness of various activities, such as sampling and testing, quality assurance of data, and monitoring well construction procedures, will also be determined. Based on this analysis, the TRC will assign priority one, two, or three to each activity.

2) *Alternatives to Activities.* Alternative technical activities will be considered for priorities that do not meet regulatory requirements, are not cost effective, or do not meet intended technical goals.

3) *New List of Priorities.* A revised list of priorities will be created at the completion of the re-evaluation process.

After making proposed changes to the list of priorities, the TRC will document the new list of priorities and send copies to internal or external customers. The TRC may use the LIPS method (described in Section 6.0 Business Plan) or some other method in developing changes to the list of priorities.

7.2 Annual Groundwater Status Reports

The Project Leader will provide an annual groundwater status report to the DOE summarizing the groundwater protection activities in the GWPMPP. The report, due December 31 of every year, will include descriptions of TRC meetings, and any recommended courses of action that were decided upon. An analysis of budgeted groundwater activities versus actual costs and schedules will also be provided. Cost and schedule variances will be justified with stated action plans to correct variances. In addition, discussions of pertinent regulatory compliance or managerial issues will be provided in this report.

7.3 GWPMPP Updates

The Project Leader and TRC will review and update the GWPMPP on an annual basis. At a minimum, the revised GWPMPP will include current hydrogeologic data, status reports on issues and solutions, reports on newly identified activities with related cost and scheduling information, and a reprioritized list of issues.

Management reports will be generated from the information system. The reports will provide cumulative and project-specific information regarding project status, scheduling and costs; and newly planned projects and proposed costs. The information system and management reports will be continually updated to provide current and accurate information. The information system will be upgraded as needed to provide new and existing data fields in identified configurations.

7.4 Business Plan Schedule

Table 7-1 shows the primary milestones and target dates for implementing the GWPMP Business Plan. Those activities without target dates must be rescheduled for a later time.

Table 7-1. GWPMP Business Plan Schedule

Description	Target Date
Establish management organization for the GWPMP and define the Project Leader's role, home organization, and roles and responsibilities of groups	Completed
Provide initial funding for hiring Project Leader and for GWPMP Plan development ($205K Indirect Funding from ESH-DO)	Completed
Establish GWPMP as a Laboratory Institutional Program (Present Business Plan to ES&H Council)	Completed
Obtain DOE/LAAO approval of Business Plan	Completed
Appoint acting Project Leader for GWPMP	Completed
Hire Project Leader for GWPMP	Completed
Request Tiger Team Action Plan funding for groundwater protection activities in FY95	Completed
Request ES&H 5-Year Plan funding for groundwater protection activities in FY96	Completed
Complete update of GWPMP Plan	Completed
Begin implementation of GWPMP Plan through indirect funding	Completed
Begin enhanced sampling and monitoring through ES&H 5-Year Plan funding	October 1, 1996
Begin installation of new monitoring wells through ES&H 5-Year Plan funding	October 1, 1998

8.0 REFERENCES

Abeele et al., 1981: Abeele, W.V., M.L. Wheeler, B.W. Burton, "Geohydrology of Bandelier Tuff", LANL LA-8962-MS, 1981.

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

Devaurs and Purtymun 1985: Devaurs, M. and Purtymun, W.D. "Hydrologic Characteristics of the Alluvial Aquifers in Mortandad, Canada del Buey and Pajarito Canyons", 1985.

DOE 1990: U.S. Department of Energy, "General Environmental Protection Program: U.S. Department of Energy Order 5400.1", June 1990.

DOE 1991: U.S. Department of Energy, "Tiger Team Assessment of the Los Alamos National Laboratory", Washington DC , November 1991.

DOE 1991a: U.S. Department of Energy, "Quality Assurance: U.S. Department of Energy Order 5700.6C", July 1991.

DOE 1992: U.S. Department of Energy, "Groundwater Discharge Plan Application for Sanitary Wastewater Systems Consolidation Project," March 1992.

Dransfield and Gardner 1985: Dransfield, B.J. and Gardner, J.N., "Subsurface Geology of the Pajarito Plateau, Espanola Basin, New Mexico", 1985.

Goff 1991: Goff, F., "Isotopic Results on Eight White Rock Canyon Springs," LANL Memorandum EES-1, Geology/Geochemistry, from Fraser Goff to Alan Stoker, Los Alamos, New Mexico, April 3, 1991.

Griggs 1964: Griggs, R.L., "Geology and Ground Water Resources of the Los Alamos Area, New Mexico," US Geological Survey Water Supply Paper 1753, Albuquerque, New Mexico, 1964.

Kelly 1975: Kelly, T.E., "Evaluation of Monitoring of Radioactive Solid-Waste Burial Sites at Los Alamos, New Mexico", USGS Open-File Report, 1975.

LANL 1990: Chapter 1, The Laboratory Manual: Environment, Safety, and Health, October 1990.

LANL 1991: "1991 LANL Self-Assessment", (need complete reference)

LANL 1995: "Installation Work Plan for Environmental Restoration", LANL LA-UR-95-470.

LANL 1995a: "Draft Environmental Monitoring Plan", LANL, Submitted for DOE review June 1995.

LANL 1995c: "Draft Site-Wide Studies for Environmental Restoration", 1995.

LANL 1994: "Environmental Surveillance at Los Alamos during 1992", LANL LA-12764-ENV, 1994.

McLin 1991: McLin, S., "Runoff Hydrograph by Unit Hydrograph Methodology", Mortandad Canyon Sediment Detention Structures, LANL, output from: Quick Hydrograph Program Version 1.01, August 9, 1991.

NMED 1993: "Initial Assessment of the Ground Water Monitoring Program at Los Alamos National Laboratory, New Mexico", January 1993.

Purtymun 1975: Purtymun, W.D., "Geohydrology of the Pajarito Plateau with Reference to Quality of Water, 1949-1972, LASL Informal Report LA-5744, Los Alamos, New Mexico, 1975.

Purtymun et al., 1977: Purtymun, W.D., J.R. Bucholz, and T.E. Hakonson. "Chemical Quality of Effluents and the Influence on Water Quality in a Shallow Aquifer." *Journal of Environmental Quality* 6(1), January-March 1977.

Purtymun et al., 1980: Purtymun, W.D., R.J. Peters, and J.W. Owens, "Geohydrology of White Rock Canyon of the Rio Grande from Otowi to Frijoles Canyon," LASL LA-8635-MS, Los Alamos, New Mexico, December 1980.

Purtymun et al., 1980b: Purtymun, W.D., R.J. Peters, and A.K. Stoker, "Radioactivity in Soils and Sediments in and Adjacent to the Los Alamos Area, 1974-1977," Los Alamos Scientific Laboratory report LA-8234-MS, February 1980.

Purtymun 1984: Purtymun, W.D., "Hydrologic Characteristics of the Main Aquifer in the Los Alamos Area: Development of Ground Water Supplies," LANL, LA-9957-MS, January 1984.

Purtymun et al., 1984: Purtymun, W.D., N. M. Becker, M. Maes, "Water Supply at Los Alamos During 1982", 1984.

Purtymun and Stoker 1987: Purtymun, W.D. and A. Stoker, "Environmental Studies of TA-49", Environmental Surveillances at Los Alamos During 1986.

Purtymun 1989: Purtymun, W.D., E.A. Enyart, and S.G. McLin, "Hydrologic Characteristics of the Bandelier Tuff as Determined Through an Injection Well System", 1989.

Purtymun et al., 1990: Purtymun, W.D., R. Peters, and M.N. Maes, "Transport of Plutonium in Snowmelt Run-Off" LANL LA-11795-MS, Los Alamos, New Mexico, July 1990.

Purtymun et al., 1991: Purtymun, W.D., R.W. Ferenbaugh, M.N. Maes, and M.C. Williams, "Water Quality in the Vicinity of Fenton Hill, 1987 and 1988", LA-12030-PR, March 1991.

Purtymun et al., 1994: Purtymun, W.D., S.G. McLin, A.K. Stoker, M.N. Maes, "Water Supply at Los Alamos during 1991," LANL LA-12770-PR, June 1994.

Rogers and Gallaher 1995: Rogers, D.B. and B.M. Gallaher, "The Unsaturated Hydraulic Characteristics of the Bandelier Tuff", LA-12968-MS, 1995.

Rogers 1977: Rogers, M.A., "History and Environmental Setting of LASL Near-Surface Land Disposal Facilities for Radioactive Wastes (Areas A,B,C,D,E,F,G, and T)," LASL LA-6848-MS, Volumes I and II, Los Alamos, New Mexico, June 1977.

Stephens et al., 1993: Stephens, D.B., P.M. Kearl, and R.W. Lee, "Hydrogeologic Review for the Environmental Restoration Program at Los Alamos National Laboratory," prepared for LANL by Daniel B. Stephens & Associates, Inc., Albuquerque, New Mexico, April 21, 1993.

Stoker 1990: Stoker, A.K., "Quality Assurance Project Plan: Water, Soil, Sediments, and Water Supply Monitoring at Los Alamos National Laboratory," Environmental Protection Group (HSE-8), April 1990.

Stoker et al., 1991: Stoker, A.K., W.D. Purtymun, S. McLin, and M. Maes, "Extent of Saturation in Mortandad Canyon," LANL, LA-UR-91-1660, May 1991.

Stoker 1994: Stoker, A.K., "Fact Sheet - Measurements of Tritium in Groundwater at Los Alamos", LANL, June 1994.

Williams 1990: Williams, M.C., "Handbook for Sample Collection, Preservation, and Instrumental Techniques", LANL LA-11738-M, February 1990.

Glossary

Alluvial	Pertaining to or composed of alluvium (clay, silt, sand, gravel, or similar unconsolidated detrital material deposited during comparatively recent geologic time by a stream or other body of running water as a sorted or semisorted sediment in the bed of the stream), or deposited by a stream or running water.
Alluvial Perched Groundwater	This term is used to refer to the localized bodies of shallow groundwater that occur in the alluvial materials in the bottoms of the canyons cutting across the Pajarito Plateau. The alluvial is typically from 10 or 20 feet to over 100 feet wide and from 10 to 40 or more feet thick. The water in the alluvium is perched on the underlying tuff or basalts and has a surface that fluctuates in elevation as a direct response to input or loss from stream channels. None of the water in the canyons within the Laboratory is used for municipal, industrial, or agricultural supply.
Aquifer	A body of rock that contains sufficient saturated permeable material to conduct water to yield economically significant quantities of water to wells and springs.
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980. Also known as Superfund, this law authorizes the federal government to respond directly to releases of hazardous substances that may endanger health or the environment. The EPA is responsible for managing Superfund.
CFR	Code of Federal Regulation. A codification of all regulations developed and finalized by federal government agencies in the *Federal Register*.
COC	Chain-of-Custody. A method for documenting the history and possession of a sample from the time of collection, through analysis and data reporting, to its final disposition.
Confluence	A place of meeting of two or more streams; the point where the tributary joins the main stream.
Contamination	The deposition of unwanted radioactive or hazardous material on the surface of structures, areas, objects, or personnel.
Controlled Area	Any Laboratory area to which access is controlled to protect individuals from exposure to radiation and radioactive materials.
Continuous Stream	A stream that does not have interruption in space; it may be perennial, intermittent, or ephemeral, but it does not have wet and dry reaches.
Direct Runoff	The runoff reaching stream channels immediately after rainfall or snowmelt.
DOE	U.S. Department of Energy. The federal agency that sponsors energy research and regulates nuclear materials used for weapons production.
Downstream	Toward, at, or from a point near the mouth of a stream; in a direction toward which a stream (or glacier) is flowing.
EA	Environmental Assessment. A report that identifies potentially significant

	environmental impacts from any federally approved or funded project that may change the physical environment. If an EA shows significant impact, an Environmental Impact Statement is required.
Effluent	A liquid discharged as a waste, such as contaminated water from a factory or the outflow from a sewage works; water discharged from a storm sewer or from land after irrigation.
EIS	Environmental Impact Statement. A detailed report, required by federal law, on the significant environmental impacts that proposed major federal action would have on the environment. An EIS must be prepared by a government agency when a major federal action that will have significant environmental impacts is planned.
Environmental Surveillance	The collection and analysis of samples of air, water, soil, foodstuffs, biota, and other media to determine environmental quality of an industry or community. It is commonly performed at sites containing nuclear facilities.
EPA	Environmental Protection Agency. The federal agency responsible for enforcing environmental laws. Although state regulatory agencies may be authorized to administer some of this responsibility, EPA retains oversight authority to ensure protection of human health and the environment.
Ephemeral Stream	A stream or reach of a stream that flows briefly in direct response to precipitation or snowmelt in the immediate locality; its channel bed is always above the water table of the region adjoining the stream.
Flow	Relative to streams, it is natural flow ensuing from the earth's hydrologic cycle, i.e., atmospheric precipitation resulting in surface and/or groundwater runoff. Natural in-stream flow may be interrupted or eliminated by dams and diversions.
Groundwater	That part of the subsurface water that is the zone of saturation, including underground streams.
Groundwater Runoff	The runoff that has entered the ground, become groundwater, and been discharged into a stream channel.
Hazardous Waste	The specific substance in a hazardous waste that makes it hazardous and therefore subject to regulation under Subtitle C of RCRA. Wastes exhibiting any of the following characteristics: ignitability, corrosivity, reactivity, or EP-toxicity (yielding toxic constituents in a leaching test). In addition, EPA has listed as hazardous other wastes that do not necessarily exhibit these characteristics. Although the legal definition of hazardous waste is complex, the term more generally refers to any waste that EPA believes could pose a threat to human health and the environment if managed improperly. Resource Conservation and Recovery Act (RCRA) regulations set strict controls on the management of hazardous wastes.
HSWA	Hazardous and Solid Waste Amendments of 1984 to RCRA. These amendments to RCRA greatly expand the scope of hazardous waste

	regulation. In HSWA, Congress directed EPA to take measures to further reduce the risks to human health and the environment caused by hazardous waster.
Hydrology	The science dealing with the properties, distribution, and circulation of natural water systems.
Intermittent Stream	A stream or reach of a stream that flows only at certain times of the year, such as when it receives water flow from springs or some surface source, melting snow, or localized precipitation.
Interrupted Stream	A stream that contains perennial reaches with intervening intermittent or ephemeral reaches.
NPDES	National Pollutant Discharge Elimination System. This federal regulation, under the Clean Water Act, requires permits for discharge into surface waterways.
Outfall	The vent or end of a drain, pipe, sewer, ditch, or other conduit that carries waste water, sewage, storm runoff, or other effluent into a stream.
Perched Groundwater	Unconfined groundwater separated from an underlying main body of groundwater by an unsaturated zone. Perched groundwater most typically forms over a perching bed; that is a body of rock, usually stratiform, with a permeability sufficiently low that the perched water does not readily permeate.
Perennial Stream	A stream or reach of a stream that flows continuously throughout the year in all years. Its upper surface, in general, is lower than the water table of the region adjoining the stream.
Piezometric Surface	This is also called potentiometric surface. This is the level to which water will rise in a well tightly cased into an aquifer.
QA	Quality assurance. The routine application of procedures within environmental monitoring and measurement to obtain required standards of performance. QA procedures include calibration of instruments, control charts, and analysis of replicate and duplicate samples.
RCRA	Resource Conservation and Recovery Act of 1976. RCRA is an amendment to the first federal solid waste legislation, the Solid Waste Disposal Act of 1965. In RCRA, Congress established initial directives and guidelines for EPA to regulate hazardous wastes.
Runoff	That part of precipitation appearing in surface streams. It is more restrictive than streamflow as it does not include stream channels affected by artificial diversions, storage, or other works of man.
SARA	Superfund Amendments and Reauthorization Act of 1986. This act modifies and reauthorizes CERCLA. Title II of this act is also know as the Emergency Planning and Community Right-to-Know Act of 1986.
Snowmelt	The water resulting from the melting of snow.
Streamflow	A type of channel flow applied to that part of surface runoff traveling in

	a stream, whether or not it is affected by diversion or regulation.
Stream Channel	The hollow bed where a natural stream of water runs or may run; the long, narrow, sloping trough-like depression shaped by the concentrated flow of a stream and covered continuously or periodically by water.
Subsurface Water	Water in the lithosphere in solid, liquid, or gaseous form; includes all water beneath the land surface and beneath bodies of surface water.
Surface Runoff	The runoff that travels over the soil surface to the nearest surface stream; runoff that has not passed beneath the surface since precipitation.
SWMU	Solid Waste Management Unit. Any discernible unit at which solid wastes have been placed at any time, irrespective of whether the unit was intended for the management of solid or hazardous waste. Such units include any area at or around a facility at which solid wastes have been routinely and systematically released. Potential release sites include, for example, waste tanks, septic tanks, firing sites, burn sites, sumps, land fills (material disposal areas), outfall area, LANL canyons, and contaminated areas resulting from leaking product storage tanks (including petroleum).
Tritium	^{3}H. A radionuclide of hydrogen with a half-life of 12.3 years. The very low energy of its radioactivity decay makes it one of the least hazardous radionuclides.
Tuff	Rock of compacted volcanic ash and dust.
Vadose Zone	Also unsaturated zone or zone of aeration. The partially saturated or unsaturated region above the water table that does not yield water to wells. Water and/or gases contained are usually under less than atmospheric pressure.
Water Rights	New Mexico water law is based on the doctrine of prior appropriation, and the rights to use water are established through the State Engineer's Office.
Water Table	The water level surface below the ground at which the unsaturated zone ends and the saturated zone begins. It is the level to which a well is screened in the unconfined aquifer and would fill with water.
Water Year	October through September.
Watershed	The region draining into a river, river system, or body of water.
Wetland	A lowland area, such as a marsh or swamp, that is inundated or saturated by surface water or groundwater sufficient to support hydrophytic vegetation typically adapted for life in saturated soils.

APPENDIX A

Regulations and DOE Orders

Regulations and DOE Orders

Atomic Energy Act

The Atomic Energy Act of 1954 (AEA), as amended, gives the Nuclear Regulatory Commission (NRC), the Department of Energy (DOE), and the Environmental Protection Agency (EPA) the authority to establish standards and instructions (by rule, regulation, or order) to govern the possession and use of source, special nuclear, or by-product material to promote common defense and security; to protect health; and to minimize danger to life or property.

The DOE ensures that its facilities comply with the AEA requirements by issuing department orders concerning radioactive material and waste management. DOE departmental orders on radioactive material and waste management apply to all DOE elements, contractors, and subcontractors. The DOE is authorized by the AEA to control radioactive operations at DOE facilities. The DOE is responsible for keeping radionuclide emissions at its facilities as low as reasonably achievable (ALARA). The DOE has developed Derived Concentration Guides for comparison to measured radionuclide concentrations in air and water. The DOE assures that its operations are within its operating guidelines by requiring facilities to maintain radiation monitoring systems and to report the results in an annual summary report.

Clean Water Act and New Mexico Water Quality Act

The goal of the Clean Water Act (CWA) is to restore and maintain the chemical, physical, and biological integrity of the nation's waters. The regulations specify water quality standards and effluent limitations. To comply with the CWA, the Laboratory has two primary programs: the National Pollutant Discharge Elimination System (NPDES) permit program and the Spill Prevention Control and Countermeasures (SPCC) program. The Laboratory operates under two NPDES permits issued and enforce by EPA, Region 6. Through a joint federal and state agreement and grant, New Mexico acts as the agent for the EPA and performs compliance inspections and reporting. Other ongoing Laboratory compliance activities are management of the Federal Facility Compliance Agreement and construction of Sanitary Wastewater Systems Consolidation (SWSC) Project.

Resource Conservation and Recovery Act

The Resource Conservation and Recovery Act (RCRA) became law in 1976 as a means to regulate toxic waste disposal for the prevention of water and soil contamination due to poor disposal practices. Subtitle C of RCRA regulates hazardous waste from generation to disposal. RCRA was amended in 1984 by the Hazardous and Solid Waste Amendments (HSWA) to include requirements for hazardous waste volume and toxicity reduction, and to minimize the land disposal of hazardous waste. Under RCRA, the EPA has granted regulatory power to the states, including regulation of mixed wastes defined as RCRA regulated hazardous wastes with a radioactive component, but did not include granting regulatory power for the HSWA to the states.

New Mexico State authority for hazardous waste regulatory power comes from the Hazardous Waste Act and the Hazardous Waste Management Regulations. Through these, New Mexico adopts the Codified Federal Regulations (40 CFR) pertaining to hazardous waste. Currently the state is operating under the 40 CFR of July 1990. However, the Laboratory's permitted hazardous waste units are operating under the July 1988 regulations that were in effect as of the November 1989 permit. Since 1989, the Laboratory has been operating under this RCRA permit issued jointly by the State of New Mexico and EPA.

Hazardous and Solid Waste Amendments

The HSWA portion of the RCRA permit was issued by EPA in March 1990. The permit sets conditions for the management of newly generated hazardous waste treatment and storage units, waste minimization land disposal restrictions, and corrective actions at solid waste management units. The Laboratory has submitted Part A of its permit application for mixed waste activities and Part B for three mixed waste management units as required by state regulations.

Task III of Module 8 of the HSWA permit requires that the permittee (a) collect information to supplement and verify existing information on the environmental setting at the facility, (b) collect analytical data to completely characterize wastes and areas where wastes have been placed, and (c) collect analytical data on groundwater, soils, surface water, sediments, and subsurface gas contamination to characterize contamination.

In accordance with Task III, Section A.1, the permittee is required to conduct a program to evaluate hydrogeologic conditions and to provide the following information:

- A description of regional and facility specific geologic and hydrogeologic characteristics affecting groundwater flow beneath the facility;
- An analysis of any topographic features that might influence the groundwater flow system;
- An analysis of fractures within the tuff, addressing tectonic trend fractures versus cooling fractures;
- Based on field data, tests, and cores, a representative and accurate classification and description of the hydrogeologic units which may be part of the migration pathways at the facility (e.g., the aquifers and any intervening saturated and unsaturated units);
- Based on field studies and cores, structural geology and hydrogeologic cross sections showing the extent (depth, thickness, lateral extent) of hydrogeologic units which may be part of the migration pathways identifying (1) unconsolidated sand and gravel deposits, (2) zones of fracturing or channeling in consolidated or unconsolidated deposits, and (3) zones of high permeability or low permeability that might direct and restrict the flow of contaminants;
- Based on data obtained from groundwater monitoring wells and piezometers installed upgradient and downgradient of the potential contaminant source, a representative description of water level or fluid pressure monitoring;
- A description of manmade influences that may affect the hydrogeology of the site; and
- Analysis of available geophysical information and remote sensing information such as infrared photography and Landsat imagery.

In accordance with Task III, Section A.2, the permittee is required to conduct a program to characterize soil conditions above the water table in the vicinity of a contaminant release and to provide the following information:

- Surface soil distribution;
- Soil profile, including ASTM classification of soils;
- Transects of soil stratigraphy;
- Saturated hydraulic conductivity;

- Porosity;
- Cation exchange capacity;
- Soil pH;
- Particle size distribution;
- Depth of water table;
- Moisture content;
- Effect of stratifications on unsaturated flow;
- Infiltration;
- Evapotranspiration;
- Residual concentration of contaminants in soil;
- Mineral and metal content;
- Trace element geochemistry as a means of differentiating units within the tuff; and
- Water balance scenarios.

Task III, Section C.1, requires the permittee to conduct a groundwater investigation to characterize any plumes of contamination at the facility. This investigation shall include the collection of sufficient data to define:

- A description of the extent of contamination;
- Rate and direction of contaminant movement;
- Concentration profiles of applicable constituents and radiochemical constituents in the plume;
- An evaluation of factors influencing plume migration; and
- An extrapolation of future contaminant movement.

Task III, Section C.2, states that the permittee is required to conduct an investigation characterizing the contamination of the soil above the water table in order to provide:

- A description of the extent of contamination;
- A description of contaminant and soil chemical properties within the contaminant source area and plume migration and transformation;
- Specific contaminant concentrations;
- Rate and direction of contaminant movement; and
- Worst case scenarios for future contaminant movement over the life of the contaminant.

The data shall include time and location of sampling, media sampled, concentrations found, conditions during sampling, and identity of the individuals performing the sampling and analysis.

New Mexico Water Quality Control Commission Regulations

The New Mexico Water Quality Control Commission (NMWQCC) regulations set quality standards for surface and groundwaters for protection of the public health or welfare, to enhance the quality of water, and to serve the purposes of the Water Quality Act. The NMWQCC publishes regulations to prevent or abate water pollution and to govern the disposal of septage and sludge.

The NMWQCC publishes regulations controlling discharges onto or below the surface of the ground for the purpose of protecting all groundwater of the state which has an existing concentration of 10,000 mg/L or less Total Dissolved Solids, for the present and potential future use as a domestic and agricultural water supply, and to protect those segments of surface waters which are gaining because of groundwater inflow, for uses designated in the New Mexico Water Quality Standards. The regulations are written so that in general:

- if the existing concentration of any water contaminant in groundwater is in conformance with the standard of Section 3-103 of these regulations, degradation of the groundwater up to the limit of the standard will be allowed; and
- if the existing concentration of any water contaminant in groundwater exceeds the standard of Section 3-103, no degradation of the groundwater beyond the existing concentration will be allowed.

Safe Drinking Water Act

The Safe Drinking Water Act (SDWA) of 1974 as amended was established to provide safe drinking water to the public. Primary and secondary drinking water standards have been established for public water supply systems. The SDWA also provides for protection of underground sources of drinking water by controlling subsurface injection of potential contaminants. Regulations have been issued whereby states establish Underground Injection Control Programs to ensure that contaminants in water supplies do not exceed National Drinking Water Standards and to prevent endangerment of any underground source of drinking water. National Interim Primary Drinking Water Standards were adopted in 1975. Regulations covering radionuclides were added in 1976 while regulations covering trihalomethanes were prepared in 1977. Secondary regulations in 1979 established guidelines to states for the protection of the non-health-related qualities of drinking water. The New Mexico Water Supply Regulations implement the provisions of the SDWA.

National Environmental Policy Act

The National Environmental Policy Act (NEPA) of 1969 requires federal agencies to consider the potential environmental impacts of proposed activities during the planning stages so that agencies' decisions reflect environmental values as well as cost and mission. Potential adverse impacts of proposed new projects are evaluated so that measures can be taken, if necessary, to lessen those impacts. An Environment, Safety, and Health questionnaire form developed by the Laboratory is used to provide initial information on environmental protection, industrial hygiene, radiation protection, and other safety and health compliance issues relative to a proposed project.

The issuance of Secretary of Energy Notice (SEN) 15 changed the DOE's requirements for compliance with NEPA. The SEN centralized all authority to approve NEPA documents at DOE Headquarters, required that each activity be presented as a unique event regardless of whether or not it duplicated an earlier event, discontinued the use of memorandums to document that a decision and a proposed activity would not cause a significant impact, and required that activities

not falling into the remaining categorical exclusions be documented in an Environmental Assessment. New regulations for implementing NEPA were proposed in November 2, 1990, and these regulations will be implemented when final.

National Historic Preservation Act

The National Historic Preservation Act, Section 106, requires that Laboratory activities be evaluated in consultation with the State Historic Preservation Officer for possible effects to cultural or historic resources.

Endangered/Threatened/Protected Species and Floodplains/Wetlands Protection

The Laboratory must comply with the Endangered Species Act of 1973 as amended and with Executive Orders 11988 "Floodplain Management" and 11990 "Protection of Wetlands". These compliance activities involve review of proposed activities for potential impact on critical habitats, floodplains, and wetlands.

Comprehensive Environmental Response, Compensation, and Liability Act

Investigation and remediation of abandoned waste disposal sites are required by the Comprehensive Environmental Response, Compensation, and Liability Act of 1976 (CERCLA, the Superfund Act) and/or Section 3004 (u) of RCRA (Hazardous and Solid Waste Amendments Act of 1984 permit). The Laboratory's Environmental Restoration (ER) Program has begun an extensive investigation of abandoned solid waste management units (SWMU) within the facility and around the Los Alamos townsite. Although LANL is not listed by the EPA on the CERCLA National Priorities List (the most contaminated sites in the United States) and, therefore, not required by law to meet CERCLA cleanup standards, the ER Program voluntarily incorporates these standards during investigations and remediation of SWMUs. The Superfund Amendments and Reauthorization Act of 1986 (SARA) requires LANL to maintain an inventory list of hazardous materials and report certain spills of these materials to local agencies.

Emergency Planning and Community Right-to-Know

Title III, Section 313 of the Emergency Planning Community-Right-to-Know Act exempts facilities not meeting certain Standard Industrial Classification code criteria from reporting requirements. However, DOE policy requires the Laboratory to report releases under the remaining provisions of Section 313. All research operations at the Laboratory are exempt under other provisions of the regulation; only one operation at the Laboratory has reported releases under SARA.

DOE Order 5400.1 General Environmental Protection Programs

DOE Order 5400.1 establishes environmental protection program requirements, authorization, and responsibilities for DOE operations to assure DOE facilities comply with applicable federal, state and local environmental regulations and laws, executive orders and internal department policies. The provisions of the Order apply to everyone within the DOE system including contractors and subcontractors. It is DOE's policy to conduct its operations in an environmentally safe manner. DOE is committed to ensuring that national environmental protection goals will be incorporated in the planning and implementation of DOE programs. In addition to conducting its operations in compliance with the applicable environmental regulations, statutes and standards, DOE is committed to good environmental management of its programs and facilities, to correct existing

environmental problems, to minimize risks to the environment or public health, and to anticipate and address potential environmental problems before they pose a threat to the environment or public welfare.

DOE Order 5400.2A Environmental Compliance Issues Coordination

DOE Order 5400.2A establishes the requirements for coordination of significant environmental compliance issues to ensure timely development and consistent application of environmental policy and guidance. The provisions of this Order apply to everyone within the DOE system including contractors and subcontractors where DOE has authority to establish and enforce environmental protection, safety, and health protection requirements. Significant environmental compliance issues are those whose resolution has the potential of setting precedence, is controversial, and/or involves DOE Headquarters notification, concurrence, or approval. The coordination process is the method which ensures that significant environmental compliance issues are resolved or disseminated so that timely development and consistent application of environmental policy and guidance can be obtained.

DOE Order 5400.5 Radiation Protection of the Public and the Environment

DOE Order 5400.5 establishes standards and requirements for operations of the DOE and DOE contractors with respect to protection of members of the public and the environment against undue risk from radiation. It is the policy of the DOE to implement legally applicable radiation protection standards and to consider recommendations by authoritative organizations (e.g., the National Council on Radiation Protection and Measurements and the International Commission on Radiological Protection). It is the policy of the DOE to adopt and implement standards generally consistent with those of the NRC for DOE facilities and activities not subject to licensing authority.

10 CFR Part 834 Radiation Protection of the Public and the Environment

10 CFR Part 834, proposed by the DOE, sets standards for the protection of the public and the environment against radiation. The requirements are applicable to the control of radiation exposures to the public and to the environment from normal operations under the control of DOE and DOE contractor personnel.

10 CFR Part 834 covers four basic areas relating to radiation protection of the public and the environment:

- It establishes dose limits for exposure of members of the public to radiation and requires reporting of doses above specified levels. In addition, it requires the assessment of all releases of radioactive material and all doses and potential doses to the public from DOE activities to ensure that they are managed in accordance with the Department's "as low as reasonably achievable" (ALARA) policy.
- It provides requirements for the management of radioactive materials in liquid waste discharges, in soil columns, and in selected solid waste containing radioactive materials and requires sites to establish groundwater protection programs.
- It provides requirements for decontamination, survey, management, storage, disposal and release of buildings, land, equipment, personal property containing residual radioactive material.

- It requires an Environmental Radiological Protection Program (ERPP) for each DOE activity to set forth the program, plans, and other processes to protect the public from exposure to radiation. In particular, it requires effluent monitoring and environmental surveillance programs as part of the ERPP.

APPENDIX B

Hydrogeology of the Pajarito Plateau: Technical Review

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-mi² 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, 0051). The Department of Energy (DOE) controls the area within the Laboratory's boundaries and has the option of completely restricting access.

2.2 Mission of Los Alamos National Laboratory

The Laboratory is administered for the DOE by the University of California (UC). Since its inception in 1943, the principal mission of the Laboratory has been the design, development, and testing of weapons for the nation's nuclear arsenal. This effort is supported by research programs in nuclear physics, hydrodynamics, conventional explosives, chemistry, metallurgy, radiochemistry, and biology. In addition to the weapons program, Laboratory personnel are involved in medium-energy physics; space nuclear systems; controlled thermonuclear fusion; laser research; environmental research; geothermal, solar, and fossil energy research; nuclear safeguards; biomedical research; and space physics. A map showing active technical areas at the Laboratory is shown in Figure 2-2.

In August 1977, the Laboratory site was dedicated as a National Environmental Research Park. The ultimate goal of programs associated with this research facility is to encourage environmental research that will contribute understanding of how people can best live in balance with nature while enjoying the benefits of technology. Park resources are available to individuals and organizations outside the Laboratory to facilitate self-supported research on these subjects. In 1994, the Laboratory revised its mission, as stated below:

> "The Los Alamos National Laboratory is dedicated to developing world-class science and technology and applying them to the nation's security and well-being. The Laboratory will continue its special role in defense, particularly in nuclear weapons technology, and will increasingly use its multidisciplinary capabilities to solve important civilian problems."

Included in these civilian problems is the need to remediate sites at the Laboratory contaminated by hazardous and/or radioactive waste.

2.3 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

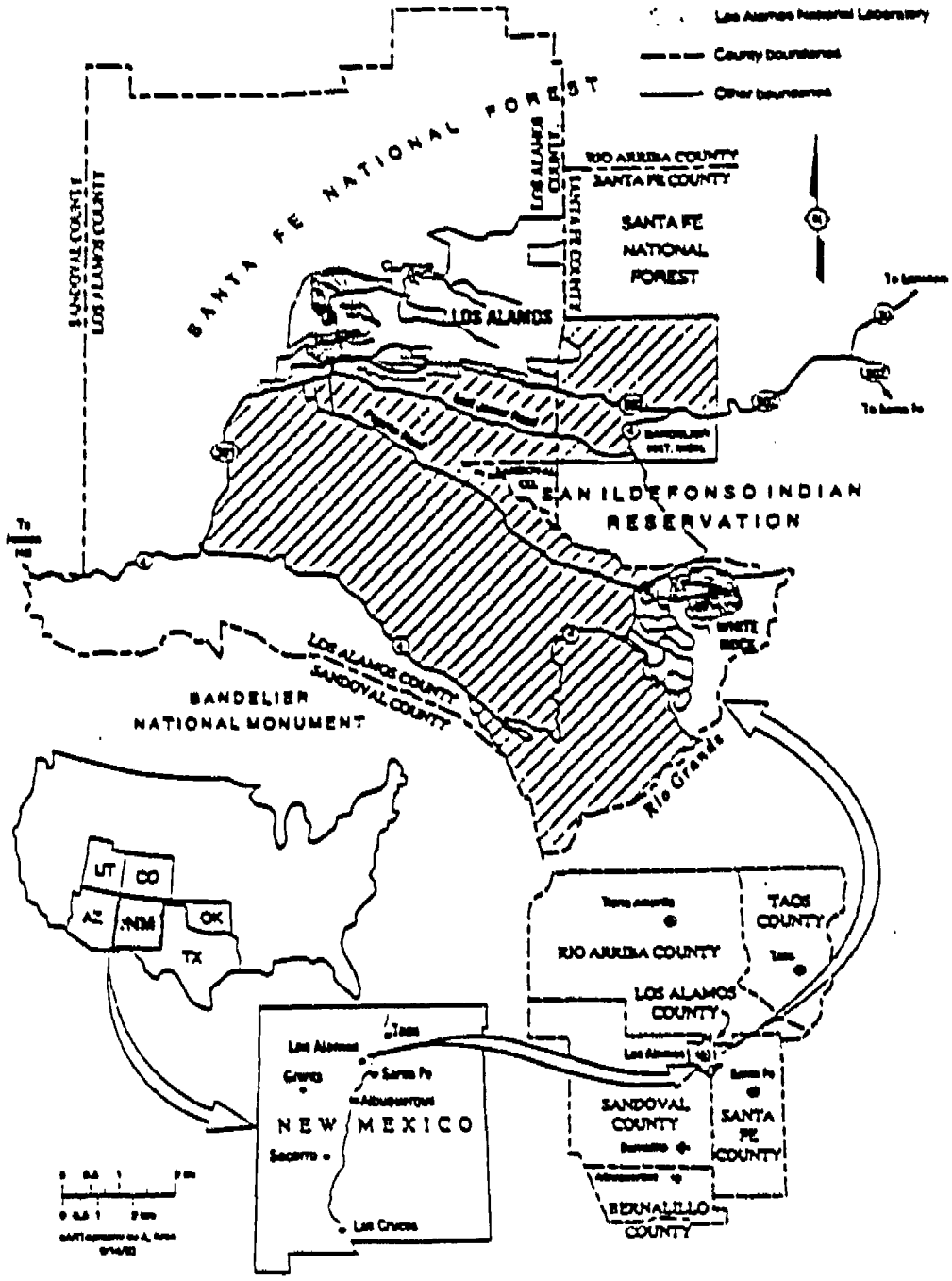

Figure 2-1. Location map of Los Alamos National Laboratory.

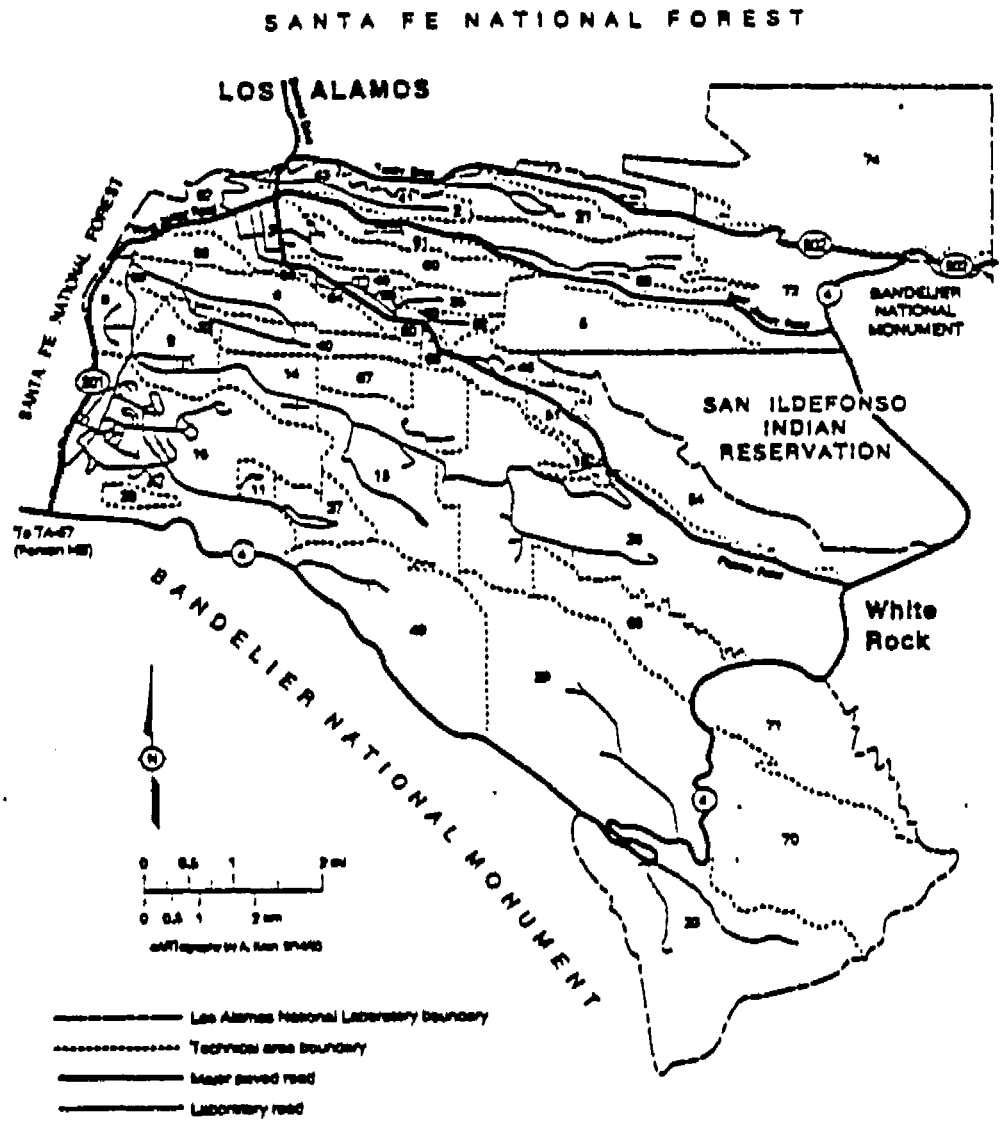

Figure 2-2. Technical areas at Los Alamos National Laboratory.

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 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.

2.4 Overview of the Environmental Setting

2.4.1 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.

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 1994, 1171) ensures adequate planning for 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, boaters, and hunters, 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.

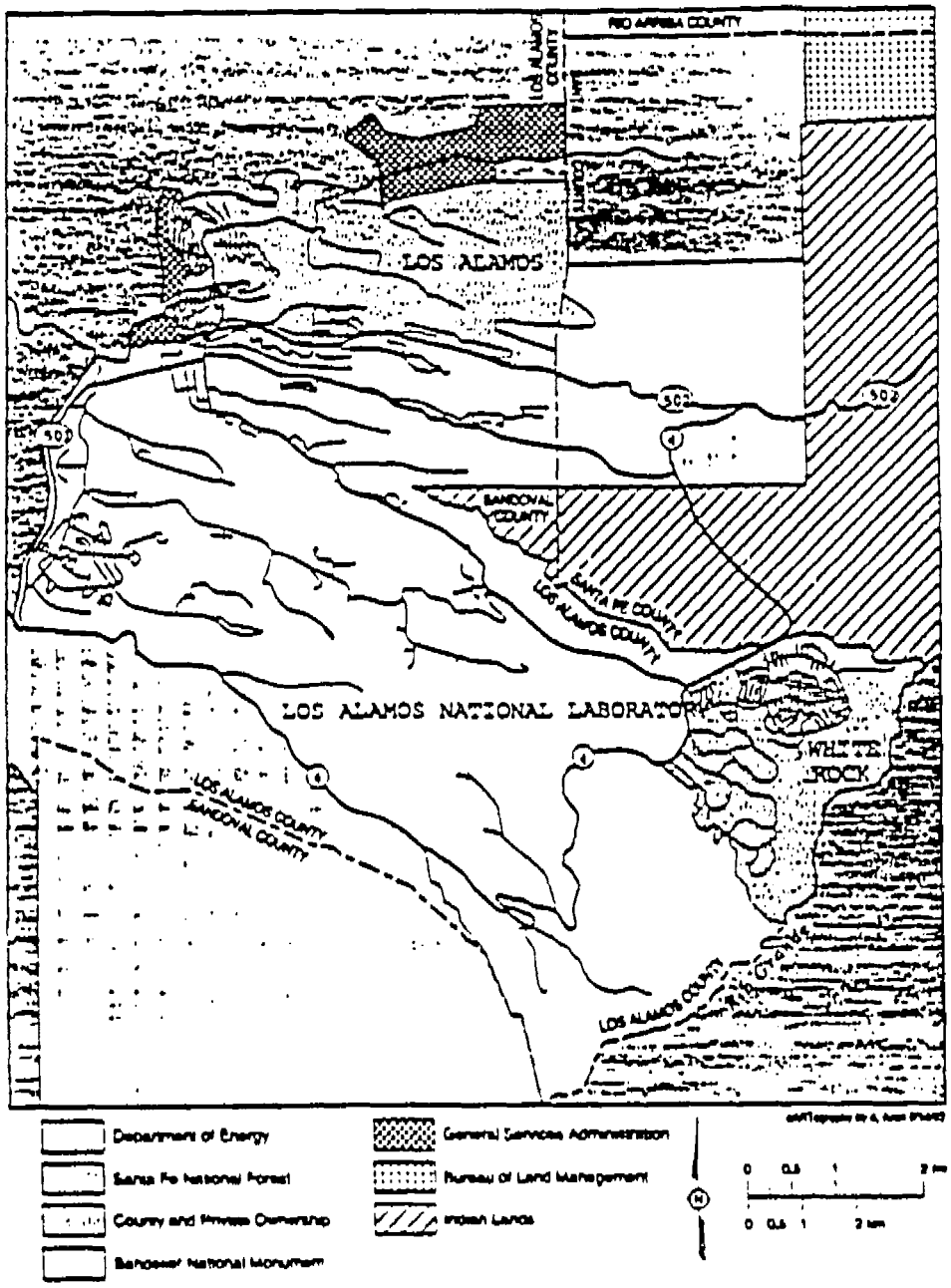

Figure 2-3. Land use map for the Laboratory and adjacent lands.

2.4.2 Ecology

Understanding of the structural and functional relationships among Los Alamos area ecosystems is limited, partly because of the wide diversity of ecosystems. This diversity has been created by the pronounced 4,920-ft elevation gradient that extends from the Rio Grande on the east to the Jemez Mountains 12 mi to the west. Many canyons, with abrupt changes in surface slope, parallel this gradient. 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. Section 2.5.2 provides a detailed overview of the hydrogeological environment at Los Alamos.

2.4.2.1 Flora

Six major vegetative complexes (community types) are found in Los Alamos County. A piñon-juniper forest surrounds most of the Laboratory. Within the confines of the Laboratory's border, the predominant community types are ponderosa pine woodland (6,900 to 7,500 ft in the western third of the reservation), piñon-juniper (6,200 to 6,900 ft in the central third), and juniper-grassland (5,600 to 6,200 ft in the eastern third).

Less is known about ecosystems other than the piñon-juniper woodland. Hakonson et al. (1973, 0118) provide a general description of the Laboratory and environs. Almost 900 plant species have been identified, and species lists have been prepared. Special studies have described the past and current status of the flora of the complex (Foxx and Tierney 1980, 0101; 1984, 0102; 1985, 0103). Past and present uses of the Laboratory and adjacent lands have resulted in structural changes in plant communities. Laboratory uses have had, and will continue to have, important consequences for local ecosystems. Few construction and waste disposal activities have occurred in the flood plains of canyons in and near the Laboratory. Natural wetland areas occur in some canyons, and more extensive wetlands have developed as a result of effluent outfalls.

The grama grass cactus, which is proposed for inclusion in the federal endangered species list, has been found on the dry mesa tops of Los Alamos County at elevations of about 6,000 to 6,400 ft. However, it has not been found on Laboratory property. Penalties exist for transporting plants protected under the 1985 New Mexico Rule No. NRD:85-3. Among the species protected under this rule, nine have been documented in the vicinity of Los Alamos County. To date, none has been found on Laboratory property.

2.4.2.2 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 deer and elk, and adjacent timbered canyon slopes provide cover for these species. Sheer canyon walls at lower elevations serve as important nesting habitats for birds of prey. Generally, larger mammals, reptiles, and invertebrates are most sensitive to variations in elevations and are confined to smaller ranges.

Information on the fauna within the Laboratory complex is largely qualitative. Species lists have been compiled from observational data and published data (DOE 1979, 0051), but the occurrence of some species has not been verified. Special studies are currently under way to provide a more comprehensive survey of vertebrate fauna.

Based on published reports and ongoing surveys, at least two federally listed animal species, the peregrine falcon (endangered) and the Mexican spotted owl (threatened), are known to inhabit Los Alamos County. The peregrine falcon establishes breeding territories near cliffs in areas of ponderosa and piñon pine. An historical aerie exists within the county, and peregrines are known to forage on Laboratory lands. Mexican spotted owls have recently been documented nesting on US Forest Service lands in Los Alamos County. Nesting spotted owls inhabit mixed-conifer and ponderosa pine-Gambel oak forest in mountains and canyons. Nesting Mexican spotted owls have not been confirmed on Laboratory lands, but surveys are still ongoing.

Other federal candidate and state-listed fauna species have been documented for Los Alamos County. They are the northern goshawk (federal candidate species) and Jemez Mountain salamander (federal candidate species and state endangered species). The northern goshawk nests primarily in dense mature or old coniferous forest. Nesting goshawks have been found on Santa Fe National Forest land in the northwest portion of Los Alamos County. Goshawk post-fledging areas and foraging areas are known to overlap on Laboratory lands.

The Jemez Mountain salamander is endemic to north-central New Mexico and is known only from the Jemez Mountains. The salamander has been found in the moist upper reaches of the canyons that dissect the plateau. In 1985, one specimen was collected and recorded as having been found on Laboratory lands. During a salamander survey conducted in 1991, a Jemez Mountain salamander was found immediately adjacent (within 0.1 mi) to the Laboratory boundary on Forest Service property.

The southwestern willow flycatcher has recently been upgraded from a federal candidate species to a species proposed for the federal endangered list. This species was identified in an area of Bandelier National Monument during the early summer of 1994. Survey efforts are under way to determine its potential for inhabiting wetland areas within Laboratory boundaries.

2.4.2.3 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. A detailed on-the-ground and historical analysis of single sites is

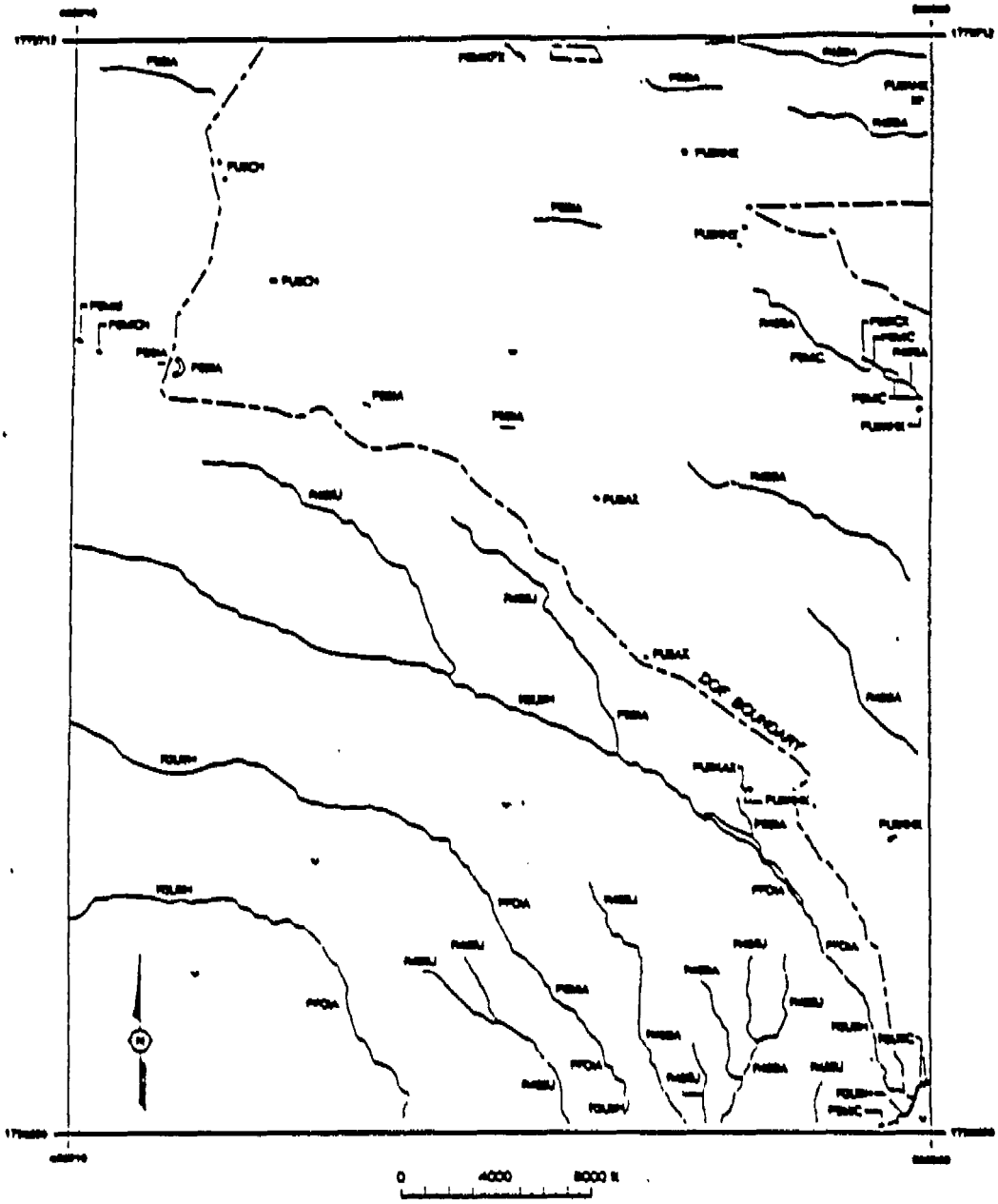

Figure 2-4. Map of wetlands for Los Alamos County (p. 1 of 2).

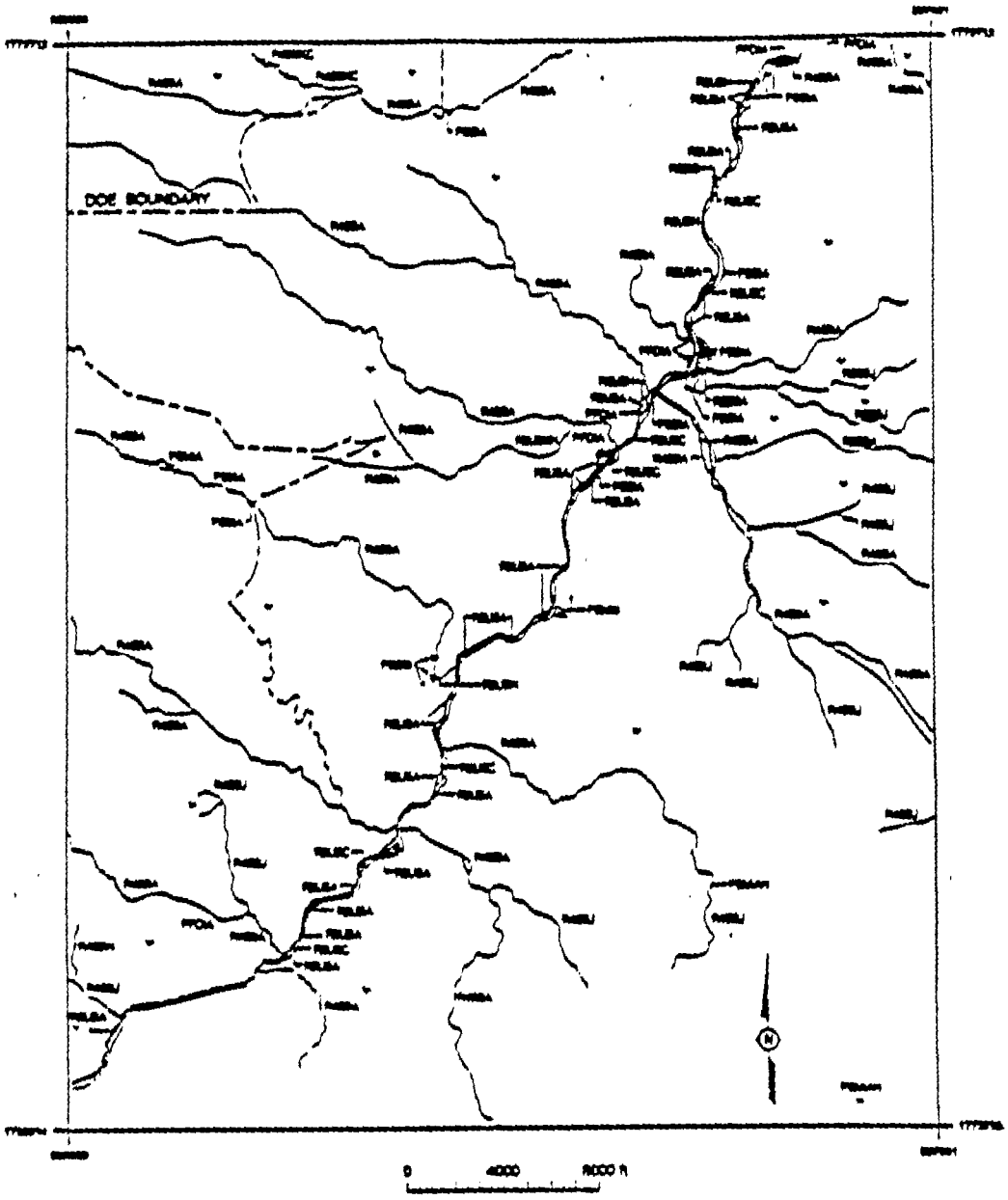

Figure 2-4. Map of wetlands for Los Alamos County (p. 2 of 2).

being conducted by personnel in the Environmental Protection Group (EM-8) to delineate and characterize individual 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.

Figure 2-5 shows the locations of wells in Los Alamos County and in adjacent locales. Wells LA-1, LA-3, LA-4, and LA-6 have been abandoned and plugged. The symbols on the map indicate where these wells were located.

2.4.3 Climate

Bowen (1990, 0033) 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 2-6, from Environmental Protection Group 1990, 0497). 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.

CORRECTION

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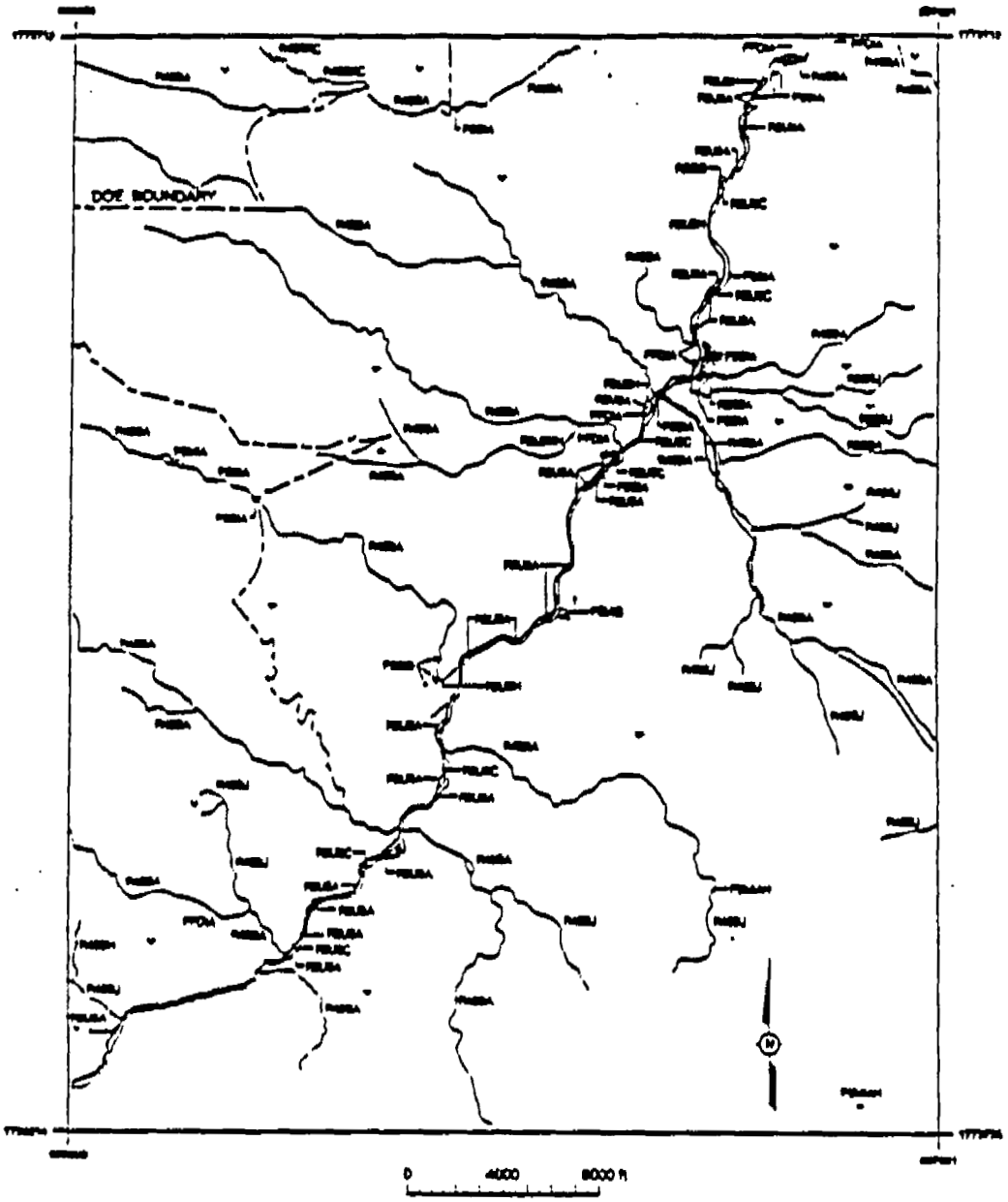

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Bowen (1990, 0033) has compiled and interpreted climatological data for the Los Alamos area, and this information is summarized below.

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 2-6, from Environmental Protection Group 1990, 0497). 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,

CORRECTION

END

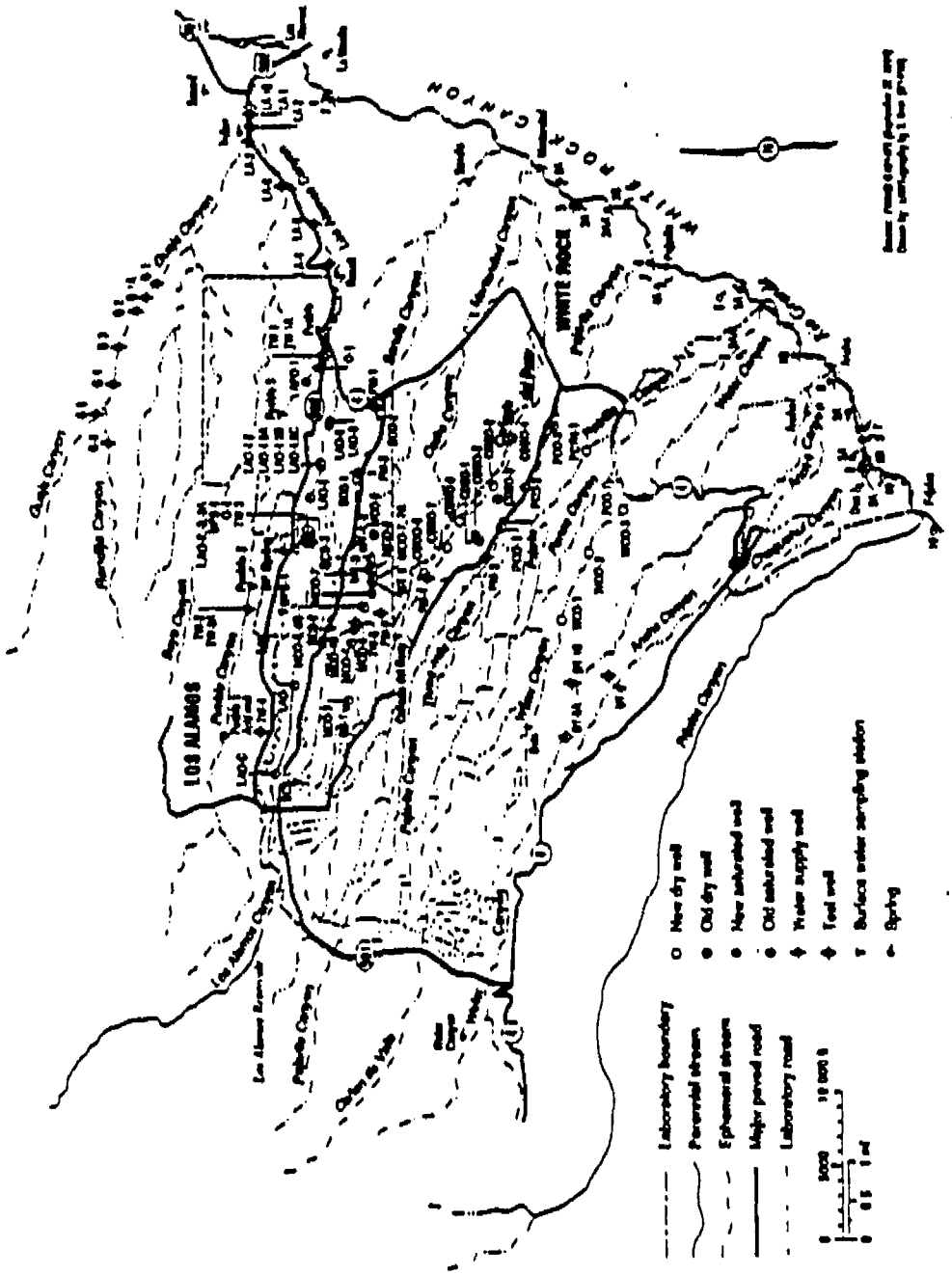


Figure 2-5. Well locations in Los Alamos County and in adjacent locales.

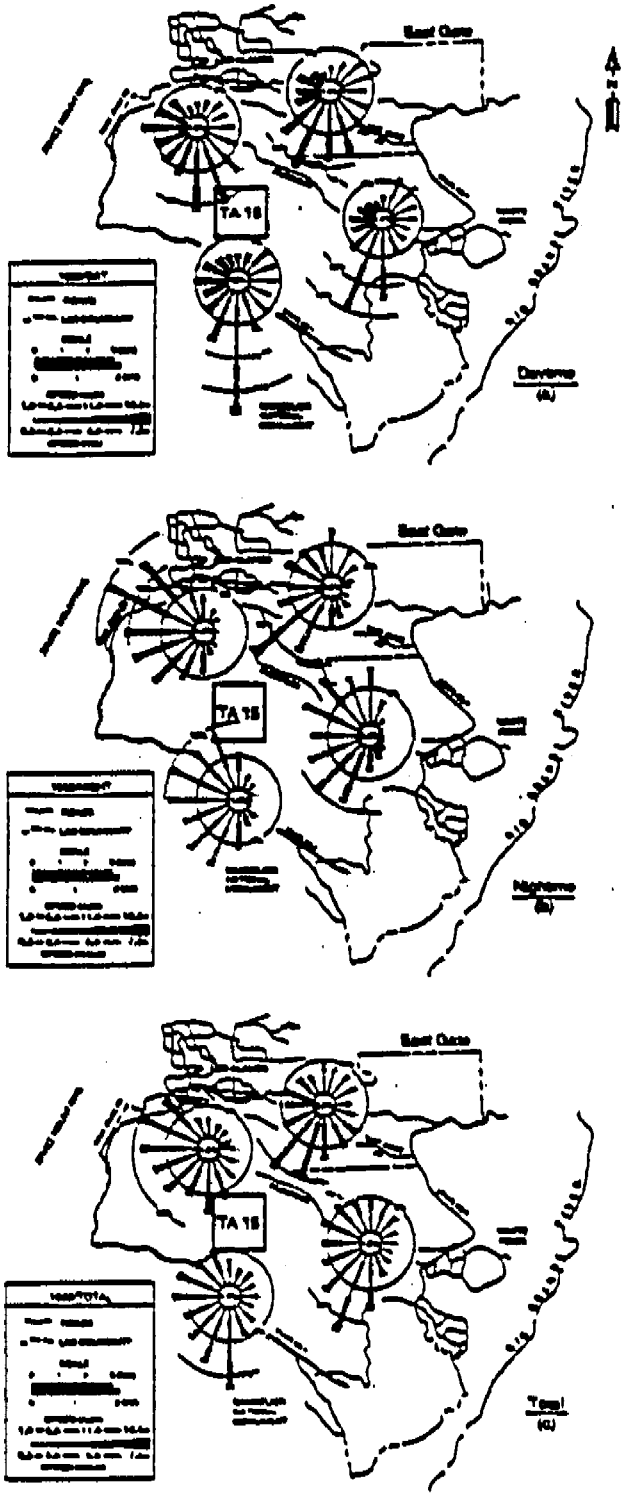


Figure 2-6. Wind roses at Laboratory stations during 1989.

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 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 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.

2.4.4 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, 1179). 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 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

TABLE 2-1

1992 POPULATION WITHIN 50 KM OF LOS ALAMOS

	Distance from TA-53 (km)								
Direction	1–2	2–4	4–8	8–15	15–20	20–30	30–40	40–50	50–60
N	1	0	0	0	0	0	1,169	0	379
NNE	0	0	0	862	0	886	1,781	1,880	227
NE	1	0	0	0	336	15,880	1,039	1,170	3,986
ENE	0	0	0	2,031	1,809	2,843	2,827	1,222	2,267
E	0	0	87	38	862	1,189	729	0	1,422
ESE	0	0	0	0	0	306	34,239	1,091	1,511
SE	0	0	6,798	0	0	0	86,036	2,368	8
SSE	0	0	0	0	0	0	446	4,861	99
S	0	0	0	80	0	347	670	7,363	0
SSW	0	0	0	20	0	891	219	8,991	36,507
SW	0	0	0	0	0	0	343	4,532	0
WSW	0	0	0	0	0	343	341	2,776	225
W	0	0	0	0	0	0	0	179	144
WNW	0	1,443	6,872	0	0	0	0	0	3,369
NW	0	538	1,731	0	0	0	0	1,481	0
NNW	0	891	862	0	0	0	0	65	94
1992 Population Distribution	2	2,360	15,798	2,709	2,517	22,347	69,836	37,818	50,176

Note: total population within 50 km of Los Alamos is 223,723.

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, 1179).

2.5 Geologic and Hydrologic Setting

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, 0143). This bibliography was submitted to EPA in September 1990. The bibliography and the literature it describes are available for review in the Environmental Restoration (ER) Project's public reading room located at 1350 Central Avenue, Suite 101, in Los Alamos.

2.5.1 Geology

2.5.1.1 Regional Setting

The Laboratory 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 2-7). 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 (Gardner et al. 1986, 0310). 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 (Aldrich 1986, 0554).

Two major volcanic eruptions in the Jemez Mountains, which 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 (Smith and Bailey 1966, 0377; Spell et al. 1990, 0607). 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 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 (Gardner et al. 1986, 0310; Self et al. 1988, 0500). Vestiges of volcanic activity continue today, as evidenced by solfataric and hot spring activity both within and outside of the Valles caldera (Goff et al. 1989, 0774). 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 (Roberts et al. 1991, 0775).

The Pajarito Plateau is in the western part of the Española basin of the Rio Grande rift, a major tectonic feature of the western United States. The Española basin lacks distinct major faults on its eastern margin, but faults of major vertical offset may exist within the Precambrian rocks of the Sangre de Cristo uplift (Vernon and Riecker 1989, 0558; Biehler et al. 1991, 0528). The western margin is characterized by a prominent zone of major faults, which cuts Miocene to Quaternary rocks of the Jemez volcanic field (Smith et al. 1960, 0776; Gardner and Goff 1984, 0719; Goff et al. 1990, 0557). These border faults exerted strong control on the location and development of the volcanic field (Gardner and Goff 1984, 0719; Gardner et al. 1986, 0310).

Rocks formed before the rift developed are exposed around the margins of and underlie the Española 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 (Kelley 1978, 0641). The earliest sediments deposited in the Tertiary Española basin are those of the Abiquiu, Picuris, and Los Piños 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 (Baldridge et al. 1980, 0527; May 1984, 0536; Ingersoll et al. 1990, 0533).

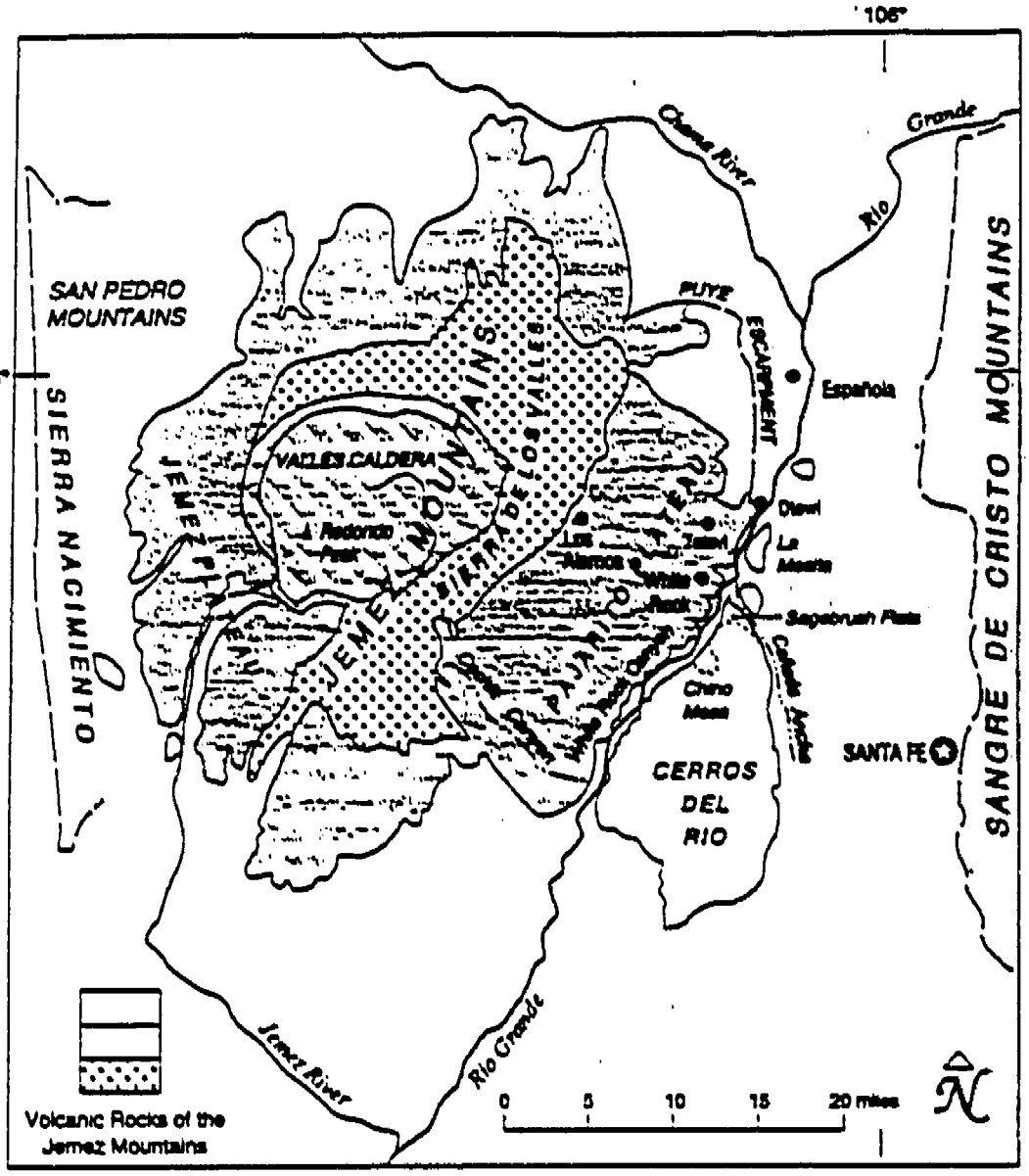


Figure 2-7. General geographic location map showing topographical features in the vicinity of Los Alamos.

2.5.1.2 Stratigraphic Units

Beneath a veneer 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 interstratified 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. These units are briefly discussed below. Figure 2-8 is a generalized geologic cross section from west to east of the Laboratory's geologic setting.

2.5.1.2.1 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 (Griggs and Hem 1964, 0313; Purtymun 1984, 0196). Sedimentary rocks usually dominate the Santa Fe Group, although basalts constitute up to 45% of the section penetrated by water supply wells at the Laboratory (Purtymun et al. 1984, 0713). In the Española 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 Española basin (Galusha and Blick 1971, 0108; Ingersoll et al. 1990, 0533). Early investigators inferred that all Santa Fe Group rocks exposed around the flanks of the Pajarito Plateau and intersected by water wells beneath the plateau belonged to the Tesuque Formation (Griggs and Hem 1964, 0313; Cooper et al. 1965, 0495), although more recent investigations suggest that some of the upper Santa Fe Group in the vicinity of Los Alamos is instead Chamita Formation (Turbeville et al. 1989, 0221).

2.5.1.2.2 Keres Group

Two formations of the Keres Group (Bailey et al. 1969, 0019; Gardner et al. 1986, 0310), may be important in the pre-Bandelier Tuff subsurface in the southern parts of the Laboratory. 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 mi from the southern boundary of the Laboratory and was a major center of Keres Group volcanism (Goff et al. 1990, 0557). 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 (Weir and Purtymun 1962, 0228) 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 (Section 2.5.1.2.4) to the north (Gardner et al. 1986, 0310). The

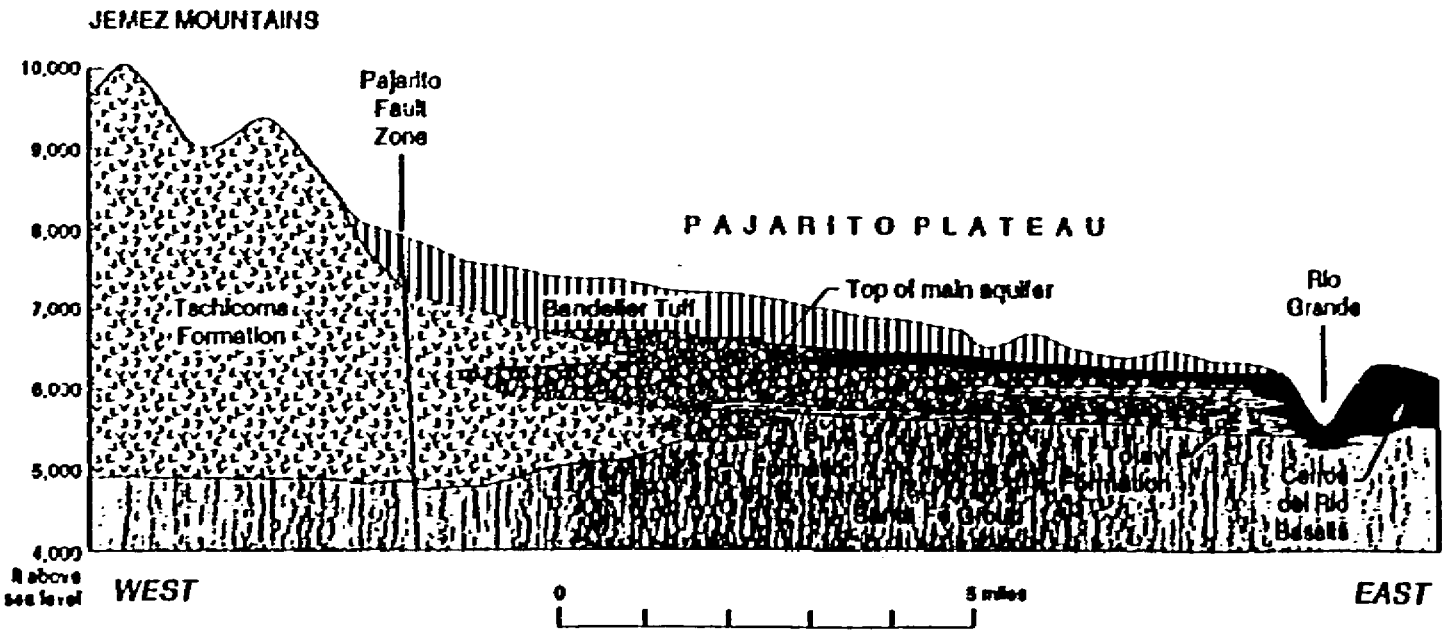


Figure 2-8. Generalized geologic section showing stratigraphy and structure from the Sierra de Los Valles across the Pajarito Plateau.

Cochiti Formation consists predominantly 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; however, it is very poorly defined.

2.5.1.2.3 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 (Gardner et al. 1986, 0310). These volcanic rocks outcrop extensively in the mountains immediately west of the Laboratory and are reported in the subsurface beneath the western and southern part of the Laboratory (Weir and Purtymun 1962, 0228; Griggs and Hern 1964, 0313; Dransfield and Gardner 1985, 0082).

2.5.1.2.4 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 workers (e.g., Griggs and Hern 1964, 0313) included the Totavi Lentil, now considered a separate formation (Section 2.5.1.2.5), 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 (Waresback and Turbeville 1990, 0543). The Puye Formation is best exposed north of the Laboratory, but lithologically similar rocks have been penetrated in drill holes as far south as Frijoles Mesa (Weir and Purtymun 1962, 0228; Dransfield and Gardner 1985, 0082). Under parts of the Laboratory, the Puye Formation is interstratified 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.

2.5.1.2.5 Totavi Formation

Immediately beneath the fanglomerates of the Puye Formation, unconformably overlying the Santa Fe Group, is a section of poorly consolidated fluvial gravels, which Griggs originally named the Totavi Lentil of the Puye Formation (Griggs and Hern 1964, 0313). 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. Recently, Waresback and Turbeville (1990, 0543) redefined these fluvial gravels as a separate formation, the Totavi Formation, which also includes lacustrine sediments that are complexly interstratified with the upper Puye Formation ("old alluvium" of Griggs and Hern 1964, 0313). In some water supply wells beneath the Laboratory, the Totavi was reported between the Santa Fe and the Puye, occurring at lower elevations in the eastern wells (Cooper et al. 1965, 0495; Purtymun et al. 1983, 0712; Purtymun et al. 1984, 0713). 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 Española basin described by Dethier et al. (1988, 0773) before deposition of the Puye fans, which unconformably overlie older formations.

2.5.1.2.6 Cerros del Rio Basalts

Basaltic flows, breccias, and scoria of the Cerros del Rio occur in the subsurface beneath much of the Pajarito Plateau (Dransfield and Gardner 1985, 0082) and outcrop in the east and southeast parts of Los Alamos County (Griggs and Hem, 1964, 0313). 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 (Gardner et al. 1986, 0310). The youngest lava flows in this area occurred between the two Bandelier Tuff eruptions, 1.5 and 1.13 million years ago ("basaltic andesite of Tank Nineteen" described by Smith et al. (1960, 0776). Part of this volcanic field is also known as basaltic rocks of Chino Mesa (Griggs and Hem 1964, 0313). The top of the main aquifer beneath the Laboratory is locally within this section of basaltic rocks.

2.5.1.2.7 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 (Griggs and Hem 1964, 0313). The Otowi Member is mostly a nonwelded ash flow tuff (ignimbrite) that was erupted from the Jemez Mountains 1.5 million years ago (Spell et al. 1990, 0607). 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 in. in size (Crowe et al. 1978, 0041).

2.5.1.2.8 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 (Heiken et al. 1986, 0316). Beneath the Pajarito Plateau, the sediments are epiclastic sands and sandy gravels that lithologically resemble Puye Formation tanglomerates. At the Laboratory, 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 (Stoker et al. 1991, 0715).

2.5.1.2.9 Tshirege Member, Bandelier Tuff

The most widespread rock unit on the Pajarito Plateau is the Tshirege Member of the Bandelier Tuff (Griggs and Hem 1964, 0313), which was erupted from the Valles caldera in the Jemez Mountains about 1.13 million years ago (Spell et al. 1990, 0607). The Tshirege Member is composed of multiple flow units of crystal-rich ignimbrite 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 postemplacement 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 ft of bedded, unconsolidated, pumice-rich ash fall tuff of the Tsankawi Pumice Bed (Bailey et al. 1969, 0019; Crowe et al. 1978, 0041). 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 (Weir and Purtymun 1962, 0228; Baltz et al. 1963, 0024; Purtymun and Kennedy 1971, 0200) or on primary cooling units (Crowe et al. 1978, 0041). 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 (Purtymun 1973, 0710; Crowe et al. 1978, 0041). Purtymun (1973, 0710) noted increased rates of vapor phase migration of tritium away from storage shafts at TA-54 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 (Crowe et al. 1978, 0041).

2.5.1.2.10 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, 0024). 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, 0639). 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, 0773).

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 (Self et al. 1988, 0500).

2.5.1.3 Soils

A large variety of soils have developed on the Pajarito Plateau as the result of interactions of the underlying bedrock, slope, and climate (Nyhan et al. 1978, 0161). 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. 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. Layers of pumice derived from El Cajete in the Jemez Mountains and windblown sediment derived from other parts of New Mexico are also significant components of many soils on the Pajarito Plateau.

Soils formed on the tops of mesas on the Pajarito Plateau include the Carjo, Frijoles, Hackroy, Nyjack, Pogna, Prieta, Seaby, and Tocal series. These soils typically have loam or sandy loam surface horizons and clay or clay loam subsurface horizons. Some, including the Frijoles, Hackroy, and Seaby soils, contain abundant pumice. Others, including the Prieta soils, contain abundant wind-deposited sediment. Soils on the mesas can vary widely in thickness and are typically thinnest near the edges of the mesas, where bedrock is often exposed. Soils formed from alluvial and colluvial deposits include the Potrillo, Puye, and Totavi series and are generally loose and sandy. The slopes between the mesa tops and canyon bottoms often consist of steep rock outcrops 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 (Nyhan et al. 1978, 0161).

Soil-forming processes extend along fractures in bedrock, and coatings of clay and calcium carbonate on fractures record the transport of water to significant depths in the tuff. For example, at TA-54, Area G, calcium carbonate has been observed as deep as 39 ft and clay coatings as deep as 46 ft below the ground surface (Purtymun et al. 1978, 0207). Roots have also been observed at similar depths along fractures in core holes and pits, suggesting that these soil-forming processes continue at depth today.

2.5.1.4 Geologic Structure

As mentioned earlier, the Laboratory is on the Pajarito Plateau, which lies at the western margin of the Española basin of the Rio Grande rift, a major tectonic feature of the North American continent. The Pajarito fault system forms the western margin of the Española basin and exhibits Holocene movement and historic seismicity (Gardner and House 1987, 0 0; Gardner et al. 1990, 0639; Gardner and House, in preparation, 0720). The fault system is made up of over 65 mi of mapped fault traces and connects with regional structures that extend at least as far as Cochiti to the south and Taos to the northeast (Gardner and House 1987, 0110).

Within Los Alamos County, the Pajarito fault system consists of three active, or potentially active, fault segments: the Frijoles Canyon, Rendija Canyon, and Guaje Mountain segments. The Frijoles Canyon fault segment is a zone of faulting over 0.25 mi in width, whose major scarp forms the western boundary of the Laboratory. Near the southwestern corner of the Laboratory, the major scarp of the Frijoles Canyon segment is over 410 ft high in rocks about 1 million years old. Movement on this fault segment is normal-oblique, and the fault's eastern side is relatively downdropped. Where exposed north of Los Alamos Canyon, the Rendija Canyon and Guaje Mountain faults are characterized by zones of gouge and breccia, generally 100 to 150 ft wide. Both fault segments produce visible offsets of stratigraphic horizons and are dominantly normal-oblique faults, whose west sides are downdropped. There are some indications of strike-slip movements on the Guaje Mountain fault segment (Wachs et al. 1988, 0502; Aldrich and Dethier 1990, 0017; Gardner et al. 1990, 0639). The youngest movements on the Guaje Mountain segment have been constrained to between roughly 4,000 and 6,000 years ago (Gardner et al. 1990, 0639). Displacement on the Guaje Mountain and Rendija Canyon faults apparently decreases south of Los Alamos Canyon, and narrow zones of faulting are replaced by wide (over 300 ft) zones of intense brecciation and fracturing superimposed on the network of cooling joints in the Bandelier Tuff (Vaniman and Wohletz 1990, 0541). In contrast to cooling joints, these tectonic fractures cross flow unit and lithologic unit boundaries; thus, tectonic fractures may provide more continuous and more deeply penetrating flow paths for groundwater migration than do cooling joints.

Dransfield and Gardner (1985, 0082) integrated a variety of data to produce structure contour and paleogeologic maps of the pre-Bandelier Tuff surface beneath the Pajarito Plateau. Their maps reveal that subsurface rock units are cut by a series of down-to-the-west normal faults; the overlying Bandelier Tuff is not obviously displaced by these buried faults. However, where detailed fracture studies have been done on the plateau, they have shown that fracture abundances and apertures increase in the Bandelier Tuff over fault projections, which indicates the tectonic fracturing mentioned above (Vaniman and Wohletz 1990, 0541). In addition, small-scale offsets along fractures have been observed in various parts of the Laboratory, including Area G at TA-54 (Rogers 1977, 0216), which suggest additional unmapped fault zones. Unfortunately, detailed fracture studies on the Pajarito Plateau are few.

2.5.1.5 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 significant hiatus up through about 130,000 years ago (Gardner et al. 1986, 0310). 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, 0780). 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, 0540; Cash and Wolff 1984, 0530; Gardner and House 1987, 0110). Since establish-

ment of the Laboratory, several earthquakes of Richter magnitude 3 to 4 have shaken Los Alamos (Gardner and House 1987, 0110). 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, 0110; House and Cash 1988, 0132; Gardner et al. 1990, 0639; Gardner and House, in preparation, 0720). 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.

2.5.1.6 Geomorphic Processes

Significant geomorphic processes active on the Pajarito Plateau include (1) erosion of mesa top soils by run-off, (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, 0200), 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 run-off 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 run-off are higher on the drier, less-vegetated, south-facing sides of canyons, although this material is largely retained on the north-facing slopes. However, no studies have been conducted to quantify the rates and processes of erosion on canyon sides.

Cliff faces retreat primarily by dislodgement of blocks bounded by joints and, to a lesser extent, by large-scale landsliding, including the formation of huge toreva blocks in White Rock Canyon. At present, the rates of cliff retreat have not been documented. Neither is it known to what extent cliff retreat rates may vary with climatic changes, with evolution of the canyons, or with proximity to side drainages.

Thicknesses, detailed stratigraphy, and ages of alluvium in canyon bottoms are, in general, poorly known, and therefore the rates of deposition, erosion, and transport of sediments through canyons are largely unknown. Available studies that have examined alluvial stratigraphy on the Pajarito Plateau reveal multiple cycles of extensive erosion of sediment, followed by renewed deposition, in the past 6,000 years (Gardner et al. 1990, 0639). At Cabra Canyon, north of Los Alamos, the last few hundred years has been marked by the net accumulation of sediment in the canyon bottom (Gardner et al. 1990, 0639), but it is not known how long this sediment will stay in storage before being mobilized by floods and transported downcanyon. It is possible that these erosional cycles are climatically driven and regional in extent, but more extensive data from additional canyons are needed before this determina-

tion can be made. On a longer time scale, evidence from the adjacent Española basin does suggest a strong climatic control on periods of alluviation and canyon incision over the last million years (Dethier et al. 1988, 0773).

2.5.2 Hydrology

2.5.2.1 General Surface Water Conditions

The Rio Grande is the master stream 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 mi² 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.

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.

Figure 2-9 shows the location of the major surface water drainages in the Los Alamos Canyon. Los Alamos surface water occurs primarily as ephemeral streams in canyons cut into the Pajarito Plateau. Only four of the canyons contain perennial reaches inside Laboratory boundaries: Pajarito, Water, Ancho, and Chaquehui canyons. Of these four reaches, only Pajarito Canyon occurs upstream (to the west) of any Laboratory facilities or effluent discharge points. Other perennial reaches occur outside Laboratory lands in the drainage areas of Guaje, Los Alamos, Sandia, Pajarito, Water (and its tributary, Cañon de Valle), Ancho, and Chaquehui canyons.

Within Laboratory boundaries, perennial reaches in the lower portions of Ancho and Chaquehui canyon are close enough to the Rio Grande that they extend to the Rio Grande without being depleted. In lower Water Canyon, the perennial reach is very short, extends into an intermittent reach that is also short, and does not extend to the Rio Grande. In Pajarito Canyon, about 1 mi east of State Road 501, a spring sometimes called Homestead Spring feeds a perennial reach a few hundred yards long, followed by an intermittent reach that flows varying distances, depending on climate conditions. (The lower part of DP Canyon also contains a short perennial reach sustained by discharge from DP Spring; however, at present, it is unknown whether the origin of the springflow is natural or artificial.)

Essentially all other reaches of canyons within the Laboratory's boundaries are ephemeral; that is, they flow naturally only briefly in response to precipitation or snowmelt in the immediate locality. Some other reaches are intermittent, especially those that flow during part of the year as the result of snowmelt. This snowmelt recharges the alluvial perched groundwater, and discharge from the perched systems supports intermittent stream flow for a somewhat longer period.

Springs between elevations of 7,900 and 8,900 ft mean sea level on the flanks of the Jemez Mountains supply base flow throughout the year to the upper reaches of Cañon de Valle and in Guaje, Los Alamos, Pajarito, and Water canyons (Purtymun 1975, 0184). These springs discharge water perched in the Bandelier Tuff and

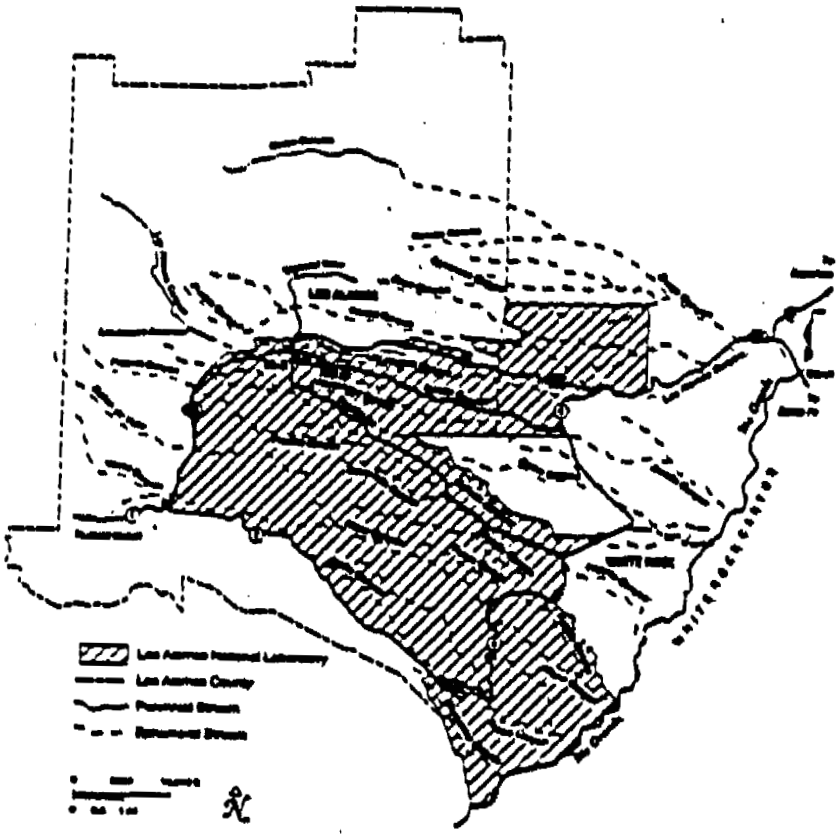


Figure 2-9. Location of the major surface water drainages in the Los Alamos area.

Tschicoma Formation at rates from 2 to 135 gal./min (Abeele et al. 1981, 0009). The volume of flow from the springs is insufficient to maintain surface flow within more than the western third of the canyons before it is depleted by evaporation, transpiration, and infiltration into the underlying alluvium.

Eleven drainage areas, with a total area of 82 mi², pass through the Laboratory's eastern boundary. Run-off 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 mi²; Pueblo Canyon has 8 mi²; the rest have less than 5 mi². Theoretical maximum flood peaks range from 24 cfs for a 2-yr frequency to 686 cfs for a 50-yr frequency (McLin 1992, 0825). The overall flooding risk to community and Laboratory buildings is low because nearly all the structures are located on the mesa tops, from which run-off drains rapidly into the deep canyons. Further discussion of natural surface flow characteristics by drainage may be found in Revision 3 of the Installation Work Plan (LANL 1993, 1017).

Contaminants enter the surface water drainages by surface run-off, by liquid discharges, and occasionally by air deposition (Becker et al. 1985, 0029; Becker

1986, 0027). Run-off-derived contaminants are largely bound to sediments; their rate of downstream travel is governed by the scouring and carrying power of subsequent run-off events (Lane et al. 1985, 0140). Given sufficient time, these sediments eventually will be moved across the Laboratory boundary.

Nearly every drainage has 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 nitrate, 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, 0715).

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 run-off.

A study of transport of plutonium by snowmelt run-off published in 1990 (Purtymun et al. 1990, 0215) includes the finding that most plutonium moved by run-off 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 mCi of plutonium was carried to the Rio Grande by 5 snowmelt run-off events studied during the years 1975 to 1986.

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, 1161). 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, 1161).

Environmental monitoring for chemical and radiochemical quality in surface water began with USGS investigations (Purtymun 1964, 0183; 1975, 0194; Purtymun and Kunkler 1967, 0202; Purtymun 1967, 0188) and has been continued by the Laboratory (ESG until 1971; Environmental Protection Group 1993, 0829).

2.5.2.2 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) perched groundwater (groundwater body above a less permeable layer that separates it from the underlying main aquifer by an unsaturated zone), and (3) the main aquifer of the Los Alamos area.

2.5.2.2.1 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^{-3} cm/s for a sand to 10^{-4} cm/s for a silty sand (Abeele et al. 1981, 0009).

In contrast to the underlying volcanic tuff and sediments, the alluvium is quite permeable. 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 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, 0206). The limited saturated thickness and extent of the alluvial groundwater preclude its use as a viable source of municipal and industrial supply 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, 0192).

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 run-off 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, 0740).

Purtymun (1975, 0194; 1973, 0191) 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, 0231), Baltz et al. (1963, 0024), Purtymun (1973, 0191), Purtymun (1974, 0192), Purtymun et al. (1977, 0206), Purtymun et al. (1983, 0209), and Stoker et al. (1991, 0715).

2.5.2.2.2 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 ft in the midreach of Pueblo Canyon to about 450 ft in lower Sandia. 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 by investigators. Only the body in lower Pueblo and Los Alamos canyons has been studied in some detail.

Patterns of chemical quality and water level measurements indicate that the lower perched groundwater in Pueblo Canyon is hydrologically connected to the stream in Pueblo Canyon (Abrahams and Purtymun 1966, 0014). Water from this perched groundwater discharges at the base of the basalt at Basalt Spring, which is off the Laboratory site in lower Los Alamos Canyon on the San Ildefonso Pueblo. 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 (Abrahams and Purtymun 1966, 0014).

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 depleted the perched groundwater after about an hour's pumping at 2 to 3 gal/min (Weir et al. 1963, 0395). Perched water was encountered in mid-Los Alamos Canyon during the drilling of the Otowi 4 supply well (Stoker et al. 1992, 0826), 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, 0015).

The most recent observation of tritium in intermediate-depth groundwater was made in Well LADP-3, completed in 1993 by the ER Project in the middle reach of Los Alamos Canyon about 1 mi downgradient of TA-2, the Omega Reactor site (Broxton et al., in preparation, 1162). Well LADP-3 encountered perched water at a depth of about 320 to 330 ft, just at the contact of the Otowi Tuff and the Puye Conglomerate. Samples of water from that well contained about 6,000 pCi/L.

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.

2.5.2.2.3 Main Aquifer

The main aquifer of the Los Alamos area is the only aquifer capable of large-scale municipal water supply (Purtymun 1984, 0196). 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 during 1992 was 1.43 billion gal. Yields from individual wells ranged from about 175 to 1,400 gpm (Stoker et al. 1992, 0826). Purtymun (1984, 0196) summarizes aquifer hydraulic characteristics as determined during aquifer tests or during periods of production of supply wells and test holes.

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 ft along the western margin of the plateau to about 600 ft 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 ft of tuff and volcanic sediments (Environmental Protection Group 1993, 0629). The main aquifer exhibits artesian conditions in the eastern part along the Rio Grande (Purtymun 1984, 0196). 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. Cushman (1965, 0042) suggested three sources of recharge: 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 (Conover et al. 1963, 0246; Griggs and Hem 1964, 0313; Goff 1991, 1020). Furthermore, natural recharge through undisturbed Bandelier Tuff on the mesa tops is believed to be insignificant (Purtymun and Kennedy 1971, 0200; Kearl et al. 1986, 0135), 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 groundwater 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 (Purtymun et al. 1980, 0208). 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-mi reach between Otowi Bridge at State Road 502 and the mouth of Rito de Frijoles (Cushman 1965, 0042).

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 (Purtymun 1984, 0196).

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 by Laboratory and other DOE researchers. The study is attempting to apply a range of geochemical and geochronological techniques to help identify potential sources and ages of water in the main aquifer. Samples have been collected from the test wells and from the water supply wells that penetrate the main aquifer. Investigators are using a variety of radioactive and stable isotope measurements. At present, a number of measurements of carbon-14 and low-level tritium measurements are available that permit some preliminary estimates of the age of the water in the main 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.

Preliminary interpretation of the results of 7 carbon-14 analyses indicates that the minimum age of water in the main 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. These values are consistent with the general understanding of the Los Alamos main aquifer, based on physical and geologic conditions, which indicate flow from west to east, with major recharge occurring from the west.

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 water samples taken from 5 wells in the main aquifer at locations near Los Alamos. Another 30 wells show no apparent influence of recent recharge on the main aquifer. The 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 first location is Test Well 1, located in Pueblo Canyon near the confluence with Los Alamos Canyon. Consistent analytical results indicate that tritium is present at this location; however, the pathway mechanisms are not yet understood. This well has been suspected for several years of having a well-bore leakage or other communication from the surface, as inferred from other types of data (Abrahams et al. 1961, 0015). One possible route of communication is along the ungrouted cable-tool-installed casing. Another possibility is a downward movement through the rock beneath the canyon.

The second location is in Los Alamos Canyon near its confluence with the Rio Grande. An observation well (LA-1A), an old water supply well (LA-2), and a domestic well show the presence of tritium.

The third location is at Test Well 8 in Mortandad Canyon. Test Well 8 is located about a mile downstream of the outfall of the Laboratory's radioactive liquid waste treatment plant at TA-50. The well was sampled at the end of 1993 as part of the Environmental Surveillance Program. The well was completed in 1960 to a depth of 1,065 ft. The upper part of the well penetrates shallow alluvial perched groundwater that contains the residual contaminants discharged by the TA-50 treatment plant. Tritium levels in the alluvial groundwater in the vicinity of Test Well 8 have been about 100,000 pCi/L in the last few years, ranging to as much as 1,000,000 pCi/L in the mid-1970s.

At least three possible pathways exist by which tritium in Mortandad Canyon could move toward the main aquifer: (1) migration down the wellbore outside the steel casing because cable tool drilling does not include an annular seal, (2) saturated movement through fractures or faults, and (3) movement in unsaturated flow through the vadose zone (the vadose zone is the zone between the land surface and the main aquifer). Tritium is known to be migrating downward in the unsaturated zone beneath the alluvial perched groundwater in Mortandad Canyon, based on measurement of cores collected to a depth of 100-200 ft at locations farther west (Stoker et al. 1991, 0715).

2.5.2.3 Hydrologic Properties and Conditions of the Bandelier Tuff

At the central portion of the Laboratory, there is in excess of 1,000 ft 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 ft of the Bandelier Tuff have been conducted in the Los Alamos area since the 1950s (e.g., Abrahams et al. 1961, 0015; Weir and Purtymun 1962, 0228; Abrahams 1963, 0011; Purtymun and Koopman 1965, 0201; Purtymun and Kennedy 1971, 0200; Purtymun et al. 1978, 0207; Abeele et al. 1981, 0009; Kearl et al. 1986, 0135; Purtymun et al. 1989, 0214; Stoker et al. 1991, 0715). 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, 0135; Stoker et al. 1991, 0715). To aid the reader in evaluating the variability 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, 1193):

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

where

$\bar{\theta}$	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.

2.5.2.3.1 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, 0201). 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, 0041).

2.5.2.3.2 Porosity

Porosity measurements by Abrahams (1963, 0011) range from 20% to 60% by volume, generally decreasing with increasing degree of welding. Measurements reported by IT Corporation (1987, 0327) are higher, from approximately 39% to 74%.

TABLE 2-2

SUMMARY OF HYDRAULIC PROPERTIES DATA FOR BANDELIER TUFF OBTAINED SINCE 1984[a]

	Bulk Density (g/cm³)	Porosity (%)	Ksat (cm/sec)	van Genuchten Parameters: Residual Saturation (%)[b]	van Genuchten Parameters: α	van Genuchten Parameters: 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^{-6}			
Maximum	1.49	74.2	3.9×10^{-3}	7.9	0.2312	2.677
Number of Observations	43	83	85	32	32	32
Tsankawi Pumice						
Minimum	0.90	36.7	4.7×10^{-6}	0.0	0.0005	1.106
Median	1.25	46.0	6.8×10^{-4}	0.23	0.0167	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^{-6}	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 (in preparation, 1182) 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, 0135) are not included in the compilation because of concerns relating to the comparability of different measurement techniques.

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

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 (Abrahams 1963, 0011).

2.5.2.3.3 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, 0011). 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, 0011). 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, 0228; Stoker et al. 1991, 0715). Field studies in Mortandad, Sandia, and Potrillo canyons show that moisture content varies greatly with depth, depending on texture (Stoker et al. 1991, 0715; Environmental Protection Group 1993, 0829). Generally, moisture content decreases with depth below stream channels.

2.5.2.3.4 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, in preparation, 1182). The data indicate residual moisture content (0% to 4%). Purtymun and Stoker (1987, 0204) 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, 0715). Abrahams (1963, 0011) 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, 0011).

2.5.2.3.5 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^{-4} 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, 0011). Unsaturated hydraulic conductivities may be many orders of magnitude lower, typically ranging from 10^{-6} to 10^{-11} cm/s (Stoker et al. 1991, 0715; Rogers and Gallaher, in preparation, 1182), depending on in-situ moisture contents.

2.5.2.3.6 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, 0541). Joints and fractures in moderately welded tuffs generally terminate in nonwelded tuffs (Baltz et al. 1963, 0024). The joints are often vertically limited to a single ash flow or ash fall unit (Purtymun and Kennedy 1971, 0200). Joint apertures range from closed to open as much as 15 cm (Wohletz, in preparation, 1183). The joints are commonly filled with caliche near the surface, grading downward to clay, and may be open to depths greater than 30 ft (Purtymun et al. 1978, 0207; Abeele et al. 1981, 0009). 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, 0207). 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, 1181). 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.

2.5.2.4 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, 0011). 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, 0827). 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.

2.5.2.4.1 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, 0228) 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, 0628) and the overall absence of perched water in the tuff at potential perching horizons.

Kearl et al. (1986, 0135) 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, 0011).

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 Material Disposal Area (MDA) L at TA-54 were computed by Rogers and Gallaher (in preparation, 1182) 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 3.0×10^{-12} to 1.5×10^{-8} cm/sec (3.7×10^{-6} 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, 1163). 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, 0011).

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, 0009). Roots have been found in joints to depths of at least 42 ft (Weir and Purtymun 1962, 0228), 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, 0135).

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, 0827). 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, 1180). 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, 0024). 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, 0651). 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, 0651) and has been observed elsewhere on the plateau; however, studies at TA-54 have been inconclusive (Abeele et al. 1981, 0009; Kearl et al. 1986, 0135).

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 and highly contaminated liquids or that contain 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.

2.5.2.4.2 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, 0715) 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, 0715). 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., in preparation 1162). 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, 1715) evaluated the moisture content in tuff beneath the alluvial perched groundwater in Mortandad Canyon. Most values for gravimetric moisture content in the Tshirege tuff 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 tuff and fluvial Cerro Toledo rhyolite deposits on the top of the Otowi member of the tuff 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, 0715) and also in Sandia and Potrillo canyons (Environmental Protection Group 1993, 0829).

The data suggest that there are complex variations in hydrologic properties in the layers from the base of the Tshirege through to the top of the Otowi tuff that significantly affect the movement of moisture in the unsaturated zone. There is also

a suggestion that moisture conditions in the Otowi tuff become very uniform, with only moderate differences in magnitude, depending on whether there are saturated conditions in overlying layers (Environmental Protection Group 1993, 0829). Additional field data and theoretical interpretation are required to confirm the patterns and quantify movement.

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, 0009)

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, 0011)

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, 0014)

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, 0015)

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, 0231)

Aldrich, M. J., Jr., February 10, 1986. "Tectonics of the Jemez Lineament in the Jemez Mountains and Rio Grande Rift," in Journal of Geophysical Research, Vol. 91, No. B2, pp. 1753-1762. (Aldrich 1986, 0554)

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, 0017)

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, 0019)

Baldridge, W. S., P. E. Damon, M. Shafiqullah, and R. J. Bridwell, 1980. "Evolution of the Central Rio Grande Rift, New Mexico: New Potassium-Argon Ages," in *Earth and Planetary Science Letters*, Vol. 51, pp. 309-321. (Baldridge et al. 1980, 0527)

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, 0024)

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, 0027)

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, 0029)

Biehler, S., J. Ferguson, W. S. Baldridge, G. R. Jiracek, J. L. Aldern, M. Martinez, R. Fernandez, J. Romo, B. Gilpin, L. W. Braile, D. R. Hersey, S. P. Luyendyk, and C. L. Aiken, March 1991. "A Geophysical Model of the Española Basin, Rio Grande Rift, New Mexico," in *Geophysics*, Vol. 56, No. 3, pp. 340-353. (Biehler et al. 1991, 0528)

Bowen, B. M., May 1990. "Los Alamos Climatology," Los Alamos National Laboratory Report LA-11735-MS, Los Alamos, New Mexico. (Bowen 1990, 0033)

Broxton, D.E., P.G. Eller, and D. Flores, in preparation. "Preliminary Drilling Results for Bore Holes LADP-3 and LADP-4 at Technical Area 21, Los Alamos National Laboratory, New Mexico." Los Alamos National Laboratory Report, Los Alamos, New Mexico. (Broxton et al., in preparation, 1162)

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, 0530)

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, 0246)

Cooper, J. B., W. D. Purymun, and E. C. John, July 1965. "Records of Water Supply Wells Guaje Canyon 6, Pajarito Mesa 1, and Pajarito Mesa 2, Los Alamos, New Mexico, Basic Data Report," US Geological Survey, Albuquerque, New Mexico. (Cooper et al. 1965, 0495)

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, 0041)

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, 0042)

de Marsily, G.,1986. Quantitative Hydrogeology: Groundwater Hydrology for Engineers. Academic Press, New York. (de Marsily 1986, 1163)

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, 0773)

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, 0051)

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, 0082)

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, 0497)

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, 0740)

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, 0829)

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, 1179)

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.

Foxx, T. S., and G. D. Tierney, May 1980. "Status of the Flora of the Los Alamos Environmental Research Park," Los Alamos National Laboratory Report No. LA-8050-NERP, Vol. I, Los Alamos, New Mexico. (Foxx and Tierney 1980, 0101)

Foxx, T. S., and G. D. Tierney, September 1984. "Status of the Flora of the Los Alamos National Environmental Research Park: A Historical Perspective," Los Alamos National Laboratory Report No. LA-8050-NERP, Vol. II, Los Alamos, New Mexico. (Foxx and Tierney 1984, 0102)

Foxx, T. S., and G. D. Tierney, June 1985. "Status of the Flora of the Los Alamos National Environmental Research Park, Checklist of Vascular Plants of the Pajarito Plateau and Jemez Mountains," Los Alamos National Laboratory Report LA-8050-NERP, Vol. III, Los Alamos, New Mexico. (Foxx and Tierney 1985, 0103)

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, 0108)

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*, University of New Mexico, Albuquerque, New Mexico. (Gardner and Goff 1984, 0719)

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, 0110)

Gardner, J. N., and L. S. House, in preparation. "Unusually High Modified Mercalli Intensities from Two Small Earthquakes on the Pajarito Fault System, Los Alamos County, New Mexico," Los Alamos National Laboratory, Los Alamos, New Mexico. (Gardner and House, in preparation, 0720)

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, 0310)

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, 0639)

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, 1020)

Goff, F., J. N. Gardner, W. S. Baldridge, J. B. Hulen, D. L. Nielson, D. Vaniman, G. Heiken, M. A. Dungan, and D. Broxton, May 1989. "Volcanic and Hydrothermal Evolution of Valles Caldera and Jemez Volcanic Field," in Field Excursions to Volcanic Terranes in the Western United States, Volume I: Southern Rocky Mountain Region, Memoir 46, C. E. Chapin, and J. Zidek (Eds.), New Mexico Bureau of Mines & Mineral Resources, Socorro, New Mexico, pp. 381-434. (Goff et al. 1989, 0774)

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, 0557)

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, 1161)

Griggs, R. L., and J. D. Hem, 1964. "Geology and Ground-Water Resources of the Los Alamos Area, New Mexico," US Geological Survey Water Supply Paper 1753, Albuquerque, New Mexico. (Griggs and Hem 1964, 0313)

Hakonson, T. E., J. W. Nyhan, L. J. Johnson, and K. V. Bostick, May 1973. "Ecological Investigation of Radioactive Materials in Waste Discharge Areas at Los Alamos for the Period July 1, 1972, Through March 31, 1973," Los Alamos Scientific Laboratory Report LA-5282-MS, Los Alamos, New Mexico. (Hakonson et al. 1973, 0118)

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, 0316)

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, 0132)

Ingersoll, R. V., W. Cavazza, W. S. Baldridge, and M. Shafiqullah, September 1990. "Cenozoic Sedimentation and Paleotectonics of North-Central New Mexico: Implications for Initiation and Evolution of the Rio Grande Rift," in *Geological Society of America Bulletin*, Vol. 102, pp. 1280-1296. (Ingersoll et al. 1990, 0533)

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, 0327)

Kearl, P. M., J. J. Dexter, and M. Kaunsky, 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, 0135)

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, 0641)

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, 0140)

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, 0143)

LANL (Los Alamos National Laboratory), November 1993. "Installation Work Plan for Environmental Restoration," Revision 3, Los Alamos National Laboratory Report LA-UR-93-3987, Los Alamos, New Mexico. (LANL 1993, 1017)

LANL (Los Alamos National Laboratory), 1994. "Site Development Plan, Annual Update 1994," Los Alamos National Laboratory Publication, LALP-94-21, Los Alamos, New Mexico. (LANL 1994, 1171)

May, S. J., 1984. "Miocene Stratigraphic Relations and Problems Between the Abiquiu, Los Pinos, and Tesuque Formations Near Ojo Caliente, Northern Española Basin," in New Mexico Geological Society Guidebook, Santa Fe, New Mexico. (May 1984, 0536)

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, 0825)

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, 0161)

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, 0183)

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, 0188)

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, 0191)

Purtymun, W. D., 1973. "Underground Movement of Tritium From Solid-Waste Storage Shafts," Los Alamos Scientific Laboratory Report LA-5286-MS, Los Alamos, New Mexico. (Purtymun 1973, 0710)

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, 0192)

Purtymun, W. D., 1975. "Geohydrology of the Pajarito Plateau with Reference to Quality of Water, 1949-1972," Los Alamos Scientific Laboratory Informal Report LA-5744, Los Alamos, New Mexico. (Purtymun 1975, 0194)

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, 0196)

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, 0200)

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, 0201)

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, 0202)

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, 0204)

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, 0651)

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, 0206)

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, 0207)

Purtymun, W. D., R. J. Peters, and J. W. Owens, December 1980. "Geohydrology of White Rock Canyon of the Rio Grande from Otowi to Frijoles Canyon," Los Alamos Scientific Laboratory Report LA-8635-MS, Los Alamos, New Mexico. (Purtymun et al. 1980, 0206)

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, 0209)

Purtymun, W. D., N. M. Becker, and M. Maes, May 1983. "Water Supply at Los Alamos During 1981," Los Alamos National Laboratory Report LA-9734-PR, Los Alamos, New Mexico. (Purtymun et al. 1983, 0712)

Purtymun, W. D., N. M. Becker, and M. Maes, January 1984. "Water Supply at Los Alamos During 1982," Los Alamos National Laboratory Report LA-9896-PR, Los Alamos, New Mexico. (Purtymun et al. 1984, 0713)

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, 0214)

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, 0215)

Reneau, Steven L. and David 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, 1181)

Roberts, P. M., K. Aki, and M. C. Fehler, December 10, 1991. "A Low-Velocity Zone in the Basement Beneath the Valles Caldera, New Mexico," *Journal of Geophysical Research*, Vol. 96, No. B13, pp. 21,583- 21,596. (Roberts et al. 1991, 0775)

Rogers, D. B. and B. Gallaher, in preparation. "Hydrologic Properties of Unsaturated Bandelier Tuff," Los Alamos National Laboratory Report, Los Alamos, New Mexico. (Rogers and Gallaher, in preparation, 1182)

Rogers, M. A., June 1977. "History and Environmental Setting of LASL Near-Surface Land Disposal Facilities for Radioactive Wastes (Areas A, B, C, D, E, F, G, and T)," Los Alamos Scientific Laboratory Report LA-6848-MS, Vols. I and II, Los Alamos, New Mexico. (Rogers 1977, 0216)

Rosenberg, N. D., W. E. Soll, and H.J. Tunn, 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, 1180)

Sanford, A. R., K. H. Olsen, and L. H. Jaksha, 1979. "Seismicity of the Rio Grande Rift." (Sanford et al. 1979, 0540)

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, 0780)

Self, S., D. E. Kircher, and J. A. Wolff, June 10, 1988. "The El Cajete Series, Valles Caldera, New Mexico," in *Journal of Geophysical Research*, Vol. 93, No. B6, pp. 6113-6127. (Self et al. 1988, 0500)

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, 0377)

Smith, R. L., R. A. Bailey, and C. S. Ross, 1980. "Geologic Map of Jemez Mountains, New Mexico: US Geological Survey Miscellaneous Investigations Series, Map I-571, Washington, D.C. (Smith et al. 1980, 0776)

Spell, T. L., T. M. Harrison, and J. A. Wolff, 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, 0607)

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, 0715)

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, 0826)

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, 0827)

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-Pleistocene Puye Alluvial Fan," *Journal of Volcanology and Geothermal Research*, Vol. 36, pp. 267-291. (Turbeville et al. 1989, 0221)

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, 1193)

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, 0541)

Vernon, J. H., and Robert E. Riecker, March 1989. "Significant Cenozoic Faulting, East Margin of the Española Basin, Rio Grande Rift, New Mexico," in *Geology*, Vol. 17, pp. 230-233. (Vernon and Riecker 1989, 0558)

Wachs, D., C. D. Harrington, J. N. Gardner, L. W. Maassen, February 1988. "Evidence of Young Fault Movements on the Pajarito Fault System in the Area of Los Alamos, New Mexico," Los Alamos National Laboratory Report LA-1156-MS, Los Alamos, New Mexico. (Wachs et al. 1988, 0502)

Warnebeck, D. B., and B. N. Turbeville, March 1990. "Evolution of a Plio-Pleistocene Volcanogenic-Alluvial Fan: The Puye Formation, Jemez Mountains, New Mexico," in *Geological Society of America Bulletin*, Vol. 102, pp. 298-314. (Warnebeck and Turbeville 1990, 0543)

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, 0228)

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, 0395)

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, 0828).

Wohletz, K., in preparation. "Measurement and Analysis of Rock Fractures in the Tshirege Member of the Bandelier Tuff along Los Alamos Canyon Adjacent to TA-21," Los Alamos National Laboratory Report, Los Alamos, New Mexico. (Wohletz, in preparation, 1183)

APPENDIX C

Description of Technical Areas

Descriptions of Technical Areas

TA-2, Omega Site — The Omega West Reactor, an 8-MW nuclear research reactor, is located at TA-2. The reactor provides neutrons for fundamental studies in nuclear physics and associated fields.

TA-3, South Mesa Site — The main technical area of the Laboratory, TA-3 includes the Administration Building in which the Director's office and other administrative offices and laboratories for several divisions are located. Other buildings house the central computing facility, administrative offices, materials division, science museum, chemistry and materials science laboratories, physics laboratories, technical shops, cryogenics laboratories, a Van de Graaff accelerator, and the main cafeteria.

TA-6, Two-Mile Mesa South Site — Two-Mile Mesa Site is one of three sites (TA-22 and TA-40 are the other two) used in the development of special detonators to initiate high-explosive systems. Fundamental and applied research conducted at this site includes investigating phenomena associated with initiating high explosives and research in rapid shock-induced reactions.

TA-8, GT Site (or Anchor Site West) — Nondestructive testing is conducted at this site for the entire laboratory. The test facilities maintain capability in all modern nondestructive testing techniques to ensure the quality of material ranging from test weapons components to high-pressure dies and molds. The principal activities involve radiographic techniques (using x-ray machines to 1,000,000 V and a 24-MeV betatron), radioactive isotope techniques, ultrasonic and penetrant testing, and electromagnetic test methods.

TA-9, Anchor Site East — At this site, the physical properties and feasibility of fabricating explosives are explored, and new organic compounds are investigated for possible use as explosives. Storage and stability problems are also studied.

TA-11, K Site — The facilities at this site test explosive components and systems under a variety of extreme physical environments. The facilities are arranged so that testing may be controlled andobserved remotely and so that devices containing explosives or radioactive materials, as well as those containing nonhazardous materials, may be tested.

TA-14, Q Site — This firing site is used for running various tests on relatively small explosive charges and for determining the impact of fragments.

TA-15, R Site — This site is the home of PHERMEX, a multiple-cavity electron accelerator capable of producing a very large flux of x-rays for certain weapons development problems and tests. The site is also used for investigating how weapons function and systems behave in nonnuclear tests, principally by electronic recording means.

TA-16, S Site — The facilities at this site house the development, engineering design, pilot production, and environmental testing of nuclear weapons warhead systems. Other functions include stockpile production liaison; development and testing of high explosives, plastics, and adhesives; and research on process development for manufacture of items using these and other materials.

TA-18, Pajarito Laboratory Site — The fundamental behavior of nuclear chain reactions with simple low-power reactors called critical assemblies is studied here in buildings known as kivas. Experiments are operated by remote control and are observed by closed-circuit television. The reactors are used primarily to provide a controlled means of assembling a critical amount of fissionable materials to study the effects of various shapes, sizes, and configurations. The machines are also used to produce large quantities of fission neutrons for experimental purposes.

TA-21, DP Site — This site has two primary research areas: DP-West, a chemistry research facility, and DP-East, a research site for high-temperature chemistry and tritium.

TA-22, TD Site — See TA-6.

TA-28, Magazine Area A — The Laboratory uses this site as one of two storage areas for explosives.

TA-33, HP Site — A major high-pressure tritium-handling facility is located at HP Site. Laboratory and office space for the Geosciences Division's hot dry rock geothermal project is also located at this site.

TA-35, Ten Site — Nuclear safeguards research and development conducted here are concerned with nondestructive techniques for detecting, identifying, and analyzing fissionable isotopes. Research in reactor safety and laser fusion also occurs at this site.

TA-36, Kappa Site — Various explosive phenomena, such as detonation velocity, are investigated at Kappa Site.

TA-37, Magazine Area C — See TA-28.

TA-39, Ancho Canyon Site — Nonnuclear weapons behavior is studied here, primarily by photographic techniques. Various phenomenological aspects of explosives, interactions of explosives, and explosions involving other materials are also investigated at this site.

TA-40, DF Site — See TA-6.

TA-41, W Site — Personnel at this site are engaged primarily in engineering design and development of nuclear components, including fabrications and evaluation of test materials for weapons.

TA-43, Health Research Laboratory — The Biomedical Research Group does research here in cellular radiobiology, biophysics, mammalian radiobiology, and mammalian metabolism. A large medical library, special counters used to measure radioactivity in humans and animals, and quarters for dogs, mice, and monkeys are also located in this building.

TA-46, WA Site — Applications for photochemistry, which include development of technology for laser isotope separation and laser enhancement of chemical processes, are investigated here. Solar energy research, particularly in the area of passive solar heating for residences, also occurs at this site.

TA-48, Radiochemistry Site — Using analytical and physical chemistry, scientists and technicians at this site study the nuclear properties of radioactive materials. Radioactive substances are measured in hot cells, which permit remote handling of radioactive materials.

TA-49, Frijoles Mesa — Frijoles Mesa has been used primarily as the site of underground hydronuclear experiments, conducted in 1960 and 1961, and as a buffer zone for nearby firing sites. The site is currently used for high-power microwave research and for training the Laboratory's hazardous devices team.

TA-50, Waste Management Site — Personnel at this site have responsibility for treating and disposing of most industrial liquid waste received from Laboratory technical areas, for developing improved methods of solid waste treatment, and for containing the radioactive materials removed by treatment. Radioactive liquid waste from most technical areas is piped to this site for treatment.

TA-51, Environmental Research Site — Experiments conducted at this facility explore waste cover and stabilization alternatives, land reclamation, contaminant movement, and ecology.

TA-52, Reactor Development Site — A wide variety of activities related to nuclear reactor performance and safety is conducted at this site.

TA-53, Meson Physics Facility — The Los Alamos Meson Physics Facility, a linear particle accelerator, is used to conduct research in areas of basic physics, cancer treatment, materials studies, and isotope production. The Los Alamos Neutron Scattering Center and the proton storage ring are also located on this site.

TA-54, Waste Disposal Site — Solid radioactive and toxic wastes that meet regulatory acceptance criteria are disposed at this site.

TA-55, Plutonium-Processing Facilities — These facilities process plutonium and house research in plutonium metallurgy.

TA-57, Fenton Hill Site — The Laboratory's hot dry rock geothermal project is located at Fenton Hill, where scientists are studying the possibility of producing energy by circulating water through hot, dry rock located hundreds of meters below the earth's surface. After the water is heated, it is brought to the surface to drive electric generators.

TA-59, Environment, Safety, and Health Site — Occupational health and environmental science activities are conducted at this site.

TA-60, East Jemez Road — This area contains physical support facilities for the Laboratory, including the existing landfill.

TA-63, Pajarito Road Service Site — This area contains physical support facilities operated by World Services, Inc.

TA-74, Los Alamos Airport — This area contains the DOE-owned airport that serves the Laboratory.

APPENDIX D

List of Potential Release Sites

FIELD UNIT ONE

Former OU 1071

PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
0-026	0	No	Landfill	None
0-027	0	No	Storage area	None
0-028(a)	0	Yes	Effluent discharge	None
0-028(b)	0	Yes	Effluent discharge	None
0-029(a)	0	No	Transformer	None
0-029(b)	0	No	Transformer	None
0-029(c)	0	No	Transformer	None
0-030(a)	0	Yes	Septic system	None
0-030(b)	0	Yes	Septic system dirt fill	Rad, Haz
0-030(c)	0	No	Septic system	Haz
0-030(d)	0	No	Septic system	None
0-030(e)N	0	No	Septic system	Haz
0-030(e)S	0	No	Septic system	Haz
0-030(f)	0	No	Septic system	Haz
0-030(g)	0	Yes	Septic system	Rad
0-030(h)	0	No	Septic system	Rad
0-030(i)	0	No	Septic system	Haz
0-030(j)	0	No	Septic system	None
0-030(k)	0	No	Septic system	Rad

FIELD UNIT ONE

Former OU 1071

PRS Number	T.A	HSWA SWMU	Unit Description	Potential Contaminants
C-0-036(c)	0	No	disposal	None
C-0-036(d)	0	No	disposal	None
e-0-041	0	No	Asphalt and tar remnant site	
C-036	0	No	Surface disposal	None
19-001	19	Yes	Septic system	Haz
19-002	19	Yes	Surface disposal site	None
19-003	19	Yes	Septic tank	None
C-19-001	19	No	Soil contamination	None
26-001	26	Yes	Surface disposal site	None
26-002(a)	26	Yes	Tank and/or assoc. equip.	Rad, Haz
26-002(b)	26	Yes	Ind. or san. waste water treat.	Rad, Haz
26-003	26	Yes	Septic tank	Rad, Haz
73-001(a)	73	Yes	Landfill	Rad, Haz, HE, other
73-001(b)	73	Yes	Surface disposal site	None
73-001(c)	73	Yes	Landfill	None
73-001(d)	73	Yes	Landfill	None
73-002	73	Yes	Incinerator & surface disposal	None
73-003	73	No	Operational laundry	None
73-004(a)	73	Yes	Septic tank	None

FIELD UNIT ONE

Former OU 1078

PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
1-001(a)	01	Yes	Septic tank 134	None
1-001(b)	01	Yes	Septic tank 136	None
1-001(c)	01	Yes	Septic tank 137	Rad
1-001(d)	01	Yes	Septic tank 138	Rad, Haz
1-001(e)	01	Yes	Septic tank 139	Rad, Haz
1-001(f)	01	Yes	Septic tank 140	Rad
1-001(g)	01	Yes	Septic tank 141	None
1-001(h)	01	Yes	Septic tank 142	None
1-001(i)	01	Yes	Septic tank 143	None
1-001(j)	01	Yes	Septic tank 144	None
1-001(k)	01	Yes	Septic tank 268	None
1-001(l)	01	Yes	Septic tank 269	None
1-001(m)	01	Yes	Septic tank 275	None
1-001(n)	01	Yes	Septic tank 276	None
1-001(o)	01	Yes	Ind. or san. waste water treat.	None
1-001(p)	01	No	Septic system	None
1-001(q)	01	No	Septic system	None
1-001(r)	01	No	Septic system	None
1-001(s)	01	Yes	Septic system	Rad, Haz

FIELD UNIT ONE

Former OU 1078 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
1-006(h)	01	Yes	Drain lines and outfall	Hex
1-006(i)	01	No	Drain lines and outfall	None
1-006(j)	01	No	Drain lines and outfall	None
1-006(k)	01	No	Drain lines and outfall	None
1-006(l)	01	No	Drain lines and outfall	None
1-006(m)	01	No	Drain lines and outfall	None
1-006(n)	01	Yes	Drain lines and outfall	None
1-006(o)	01	Yes	Drain lines and outfall	None
1-006(p)	01	No	Drain lines and outfall	None
1-006(q)	01	No	Drain lines and outfall	None
1-006(r)	01	No	Drain lines and outfall	None
1-006(s)	01	No	Drain lines and outfall	None
1-006(t)	01	No	Drain lines and outfall	None
1-007(a)	01	Yes	Soil contamination area	None
1-007(b)	01	Yes	Soil contamination area	None
1-007(c)	01	Yes	Soil contamination area	None
1-007(d)	01	Yes	Soil contamination area	Rad
1-007(e)	01	Yes	Soil contamination area	None
1-007(f)	01	No	Soil contamination area	None

FIELD UNIT ONE

Former OU 1079 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
10-001(a)	10	Yes	Firing Site	Rad, Haz, HE
10-001(b)	10	Yes	Firing Site	Rad, Haz, HE
10-001(c)	10	Yes	Firing Site	Rad, Haz, HE
10-001(d)	10	Yes	Firing Site	Rad, Haz, HE
10-001(e)	10	No	Detonation Test Area	None
10-002(a)	10	Yes	Disposal pit	Rad, Haz
10-002(b)	10	Yes	Disposal pit	Rad, Haz
10-003(a)	10	Yes	Disposal pit	Rad, Haz
10-003(b)	10	Yes	Disposal pit	Rad, Haz
10-003(c)	10	Yes	Disposal pit	Rad, Haz
10-003(d)	10	Yes	Disposal pit	Rad, Haz
10-003(e)	10	Yes	Disposal pit	Rad, Haz
10-003(f)	10	Yes	Disposal pit	Rad, Haz
10-003(g)	10	Yes	Manholes	Rad, Haz
10-003(h)	10	Yes	Manholes	Rad, Haz
10-003(i)	10	Yes	Septic tank	Rad, Haz
10-003(j)	10	Yes	Tank	Rad, Haz
10-003(k)	10	Yes	Tank	Rad, Haz
10-003(l)	10	Yes	Tank	Rad, Haz

FIELD UNIT ONE

Former OU 1079

PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
C-45-001	45	No	Parking lot of Former Treatment Plant	Rad, Haz

FIELD UNIT ONE

Former OU 1106 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
21-010(b)	21	Yes	Waste treatment facility	None
21-010(c)	21	Yes	Waste treatment facility	None
21-010(d)	21	Yes	Waste treatment facility	None
21-010(e)	21	Yes	Waste treatment facility	None
21-010(f)	21	Yes	Waste treatment facility	None
21-010(g)	21	Yes	Waste treatment facility	None
21-010(h)	21	Yes	Waste treatment facility	None
21-011(a)	21	Yes	Waste treatment facility	Rad, Haz
21-011(b)	21	Yes	Sump	Rad, Haz
21-011(c)	21	Yes	Tank	Rad, Haz
21-011(d)	21	Yes	Aboveground tank	Rad, Haz
21-011(e)	21	Yes	Aboveground tank	Rad, Haz
21-011(f)	21	Yes	Aboveground tank	Rad, Haz
21-011(g)	21	Yes	Aboveground tank	Rad, Haz
21-011(h)	21	No	Aboveground tank	Rad, Haz
21-011(i)	21	Yes	Aboveground tank	Rad, Haz
21-011(j)	21	Yes	Aboveground tank	Rad, Haz
21-011(k)	21	Yes	Outfall	Rad, Haz
21-012(a)	21	Yes	Dry well	None

FIELD UNIT ONE

Former OU 1106

PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
21-019(b)	21	No	Filter system	None
21-019(c)	21	No	Filter system	None
21-019(d)	21	No	Filter system	None
21-019(e)	21	No	Filter system	None
21-019(f)	21	No	Filter system	None
21-019(g)	21	No	Filter system	None
21-019(h)	21	No	Filter system	None
21-019(i)	21	No	Filter system	None
21-019(j)	21	No	Filter system	None
21-019(k)	21	No	Filter system	None
21-019(l)	21	No	Filter system	None
21-019(m)	21	No	Filter system	None
21-020(a)	21	No	Filter system	None
21-020(b)	21	No	Filter system	None
21-021	21	Yes	Systematic release site	None
21-022(a)	21	Yes	Waste lines	Rad, Haz
21-022(b)	21	Yes	Waste lines	Rad, Haz
21-022(c)	21	Yes	Waste lines	Rad, Haz
21-022(d)	21	Yes	Waste lines	Rad, Haz

FIELD UNIT ONE

Former OU 1106

PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
21-024(j)	21	Yes	Septic system	Rad, Haz
21-024(k)	21	Yes	Septic system	Rad, Haz
21-024(l)	21	Yes	Ind. or san. waste water treat.	None
21-024(m)	21	Yes	Ind. or san. waste water treat.	None
21-024(n)	21	Yes	Ind. or san. waste water treat.	Rad, Haz
21-024(o)	21	Yes	Ind. or san. waste water treat.	Rad, Haz
21-025(a)	21	No	Operational facility	None
21-025(b)	21	No	Operational facility	None
21-026(a)	21	Yes	Ind. or san. waste water treat.	Rad, Haz
21-026(b)	21	Yes	Surface disposal site	Rad, Haz
21-026(c)	21	No	Waste water treatment facility	Rad, Haz
21-026(d)	21	No	Outfall	Rad, Haz
21-027(a)	21	Yes	Ind. or san. waste water treat.	None
21-027(b)	21	Yes	Ind. or san. waste water treat.	None
21-027(c)	21	Yes	Ind. or san. waste water treat.	None
21-027(d)	21	Yes	Ind. or san. waste water treat.	None
21-028(a)	21	No	Container storage	None
21-028(b)	21	No	Container storage	None
21-028(c)	21	No	Container storage	None

FIELD UNIT ONE

Former OU 1106 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
C-21-017	21	No	Storage area	None
C-21-018	21	No	Storage area	None
C-21-019	21	No	Storage area	None
C-21-020	21	No	Storage area	None
C-21-021	21	No	Storage area	None
C-21-022	21	No	Laboratory	None
C-21-023	21	No	Laboratory	None
C-21-024	21	No	Warehouse	None
C-21-025	21	No	Building	None
C-21-026	21	No	Building	None
C-21-027	21	No	Machinery	None
C-21-028	21	No	Tank	None
C-21-029	21	No	Aboveground tank	None
C-21-030	21	No	Aboveground tank	None
C-21-031	21	No	Tank	None
C-21-032	21	No	Machinery and tanks	None
C-21-033	21	No	One-time spill	None
C-21-034	21	No	Tank	None
C-21-035	21	No	Aboveground tank	None

FIELD UNIT ONE

Former OU 1114 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
3-001(a)	03	Yes	<90 day storage	None
3-001(b)	03	Yes	Satellite storage	None
3-001(c)	03	Yes	<90 day storage	None
3-001(d)	03	No	Container storage area	None
3-001(e)	03	No	<90 day storage	None
3-001(f)	03	No	Satellite storage	None
3-001(g)	03	No	Satellite storage	None
3-001(h)	03	No	Satellite storage	None
3-001(i)	03	No	Satellite storage	Haz
3-001(j)	03	No	Satellite storage	None
3-001(k)	03	Yes	Satellite storage	None
3-001(l)	03	No	<90 day storage	None
3-001(m)	03	No	Satellite storage	Haz
3-001(n)	03	No	Satellite storage	None
3-001(o)	03	No	Satellite storage	None
3-001(p)	03	No	Satellite storage	None
3-001(q)	03	No	Satellite storage	None
3-001(r)	03	No	Satellite storage	None
3-001(s)	03	No	Satellite storage	None

FIELD UNIT ONE

Former OU 1114 PRS Number	TA	NEWA SWMU	Unit Description	Potential Contaminants
3-003(j)	03	No	Storage area	None
3-003(k)	03	No	Storage area	None
3-003(l)	03	No	Storage area	Other
3-003(m)	03	No	Storage area	None
3-003(n)	03	No	Storage area	Other
3-003(o)	03	No	Storage area	None
3-003(p)	03	No	Storage area	None
3-004(a)	03	No	Container storage	None
3-004(b)	03	No	Container storage	None
3-004(c)	03	No	Storage area	Rad, Haz
3-004(d)	03	No	Storage area	Rad, Haz
3-004(e)	03	No	Storage area	None
3-004(f)	03	No	Storage area	None
3-006	03	No	Burn site	None
3-007	03	No	Firing site	HE
3-008(a)	03	No	Firing site	None
3-008(b)	03	No	Firing site	None
3-009(a)	03	Yes	Surface disposal	None
3-009(b)	03	Yes	Surface disposal	None

FIELD UNIT ONE

Former OU 1114

PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
3-013(e)	03	No	Operational release	None
3-013(f)	03	No	Operational release	None
3-013(g)	03	No	Operational release	None
3-013(h)	03	No	Operational release	None
3-014(a)	03	Yes	Waste water treatment facility	Rad, Haz
3-014(a2)	03	No	Waste water treatment facility	Haz
3-014(b)	03	Yes	Waste water treatment facility	Haz
3-014(b2)	03	No	Outfall	Rad, Haz
3-014(c)	03	Yes	Waste water treatment facility	Haz
3-014(c2)	03	No	Outfall	Rad, Haz
3-014(d)	03	Yes	Waste water treatment facility	Haz
3-014(e)	03	Yes	Waste water treatment facility	Rad, Haz
3-014(f)	03	Yes	Waste water treatment facility	Haz
3-014(g)	03	Yes	Waste water treatment facility	Haz
3-014(h)	03	Yes	Waste water treatment facility	Haz
3-014(i)	03	Yes	Waste water treatment facility	Haz
3-014(j)	03	Yes	Waste water treatment facility	Haz
3-014(k)	03	Yes	Waste water treatment facility	Haz
3-014(l)	03	Yes	Waste water treatment facility	Haz

FIELD UNIT ONE

Former OU 1114 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
3-018(e)	03	No	Septic system	None
3-018(f)	03	No	Septic system	None
3-018	03	Yes	Septic system	None
3-019	03	Yes	Septic tank	None
3-020(a)	03	Yes	Disposal pit	None
3-020(b)	03	No	Surface disposal site	None
3-021	03	Yes	Surface disposal site	Haz
3-022	03	No	Sump	Haz
3-023	03	No	Sump	Haz
3-024	03	Yes	Tank and/or assoc. equipment	None
3-025(a)	03	Yes	Tank and/or assoc. equipment	None
3-025(b)	03	Yes	Tank and/or assoc. equipment	Rad
3-025(c)	03	No	Tank and/or assoc. equipment	Rad, Haz
3-026(a)	03	No	Sump	Haz
3-026(b)	03	Yes	Sumps	Haz
3-026(c)	03	Yes	Tank and/or assoc. equipment	None
3-026(d)	03	Yes	Tank and/or assoc. equipment	Haz
3-027	03	No	Separation site	None
3-028	03	Yes	Surface impoundment	None

FIELD UNIT ONE

Former OU 1114 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
3-037	03	Yes	Underground tank	Haz
3-038(a)	03	Yes	Acid tank	Rad, Haz
3-038(b)	03	Yes	Acid tank	Rad, Haz
3-038(c)	03	No	Waste lines	Rad
3-038(d)	03	No	Waste lines	Rad
3-038(e)	03	No	Waste lines	None
3-038(f)	03	No	Waste lines	Rad
3-039(a)	03	Yes	Silver recovery unit	None
3-039(b)	03	No	Silver recovery unit	None
3-039(c)	03	No	Silver recovery unit	None
3-039(d)	03	No	Silver recovery unit	None
3-039(e)	03	No	Silver recovery unit	None
3-040(a)	03	No	Storage area	None
3-040(b)	03	No	Storage area	None
3-041	03	No	Underground tank	None
3-042	03	No	Sump	Haz
3-043(a)	03	No	Aboveground tank	None
3-043(b)	03	No	Aboveground tank	None
3-043(c)	03	Yes	Tank and/or assoc. equipment	None

FIELD UNIT ONE

Former OU 1114 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
3-047(b)	03	No	Storage area	None
3-047(c)	03	No	Storage area	None
3-047(d)	03	No	Storage area	None
3-047(e)	03	No	Storage area	None
3-047(f)	03	No	Storage area	None
3-047(g)	03	No	Storage area	None
3-047(h)	03	No	Storage area	None
3-047(i)	03	No	Satellite storage area	None
3-047(j)	03	No	Container storage area	None
3-047(k)	03	No	Container storage area	None
3-048	03	No	Satellite storage area	None
3-049(a)	03	Yes	Outfall	HaZ
3-049(b)	03	Yes	Operational release	Rad, HaZ
3-049(c)	03	Yes	Outfall	None
3-049(d)	03	Yes	Outfall	None
3-049(e)	03	Yes	Outfall	None
3-050(a)	03	Yes	Off-gas scrubber of HEPA filter sys.	Rad, HaZ
3-050(b)	03	No	Off-gas scrubber of HEPA filter sys.	None
3-050(c)	03	No	Off-gas scrubber of HEPA filter sys.	None

FIELD UNIT ONE

Former OU 1114 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
3-054(e)	03	Yes	Outfall	Haz
3-055(a)	03	Yes	Outfall	None
3-055(b)	03	No	Outfall	None
3-055(c)	03	Yes	Outfall	None
3-055(d)	03	Yes	Outfall	None
3-056(a)	03	Yes	Storage area	None
3-056(b)	03	No	Container storage area	Haz
3-056(c)	03	Yes	Transformer storage area	Haz, other
3-056(d)	03	Yes	Container storage area	None
3-056(e)	03	No	Container storage area	None
3-056(f)	03	No	Container storage area	None
3-056(g)	03	No	Satellite storage area	None
3-056(h)	03	No	Transformer storage area	None
3-056(i)	03	No	Container storage area	None
3-056(j)	03	No	Storage area	None
3-056(k)	03	No	Container storage area	Rad
3-056(l)	03	Yes	Operational release	None
3-056(m)	03	Yes	Container storage area	None
3-056(n)	03	Yes	Container storage area	None

FIELD UNIT ONE

Former OU 1114 PRS Number	TA	NSWA SWMU	Unit Description	Potential Contaminants
C-3-018	03	No	Underground diel. tank.	None
C-3-019	03	No	Underground tank	None
C-3-020	03	No	Underground tanks	None
C-3-021	03	No	Underground tank	None
C-3-022	03	No	Tank	None
30-001	30	No	Surface disposal and landfill	None
59-001	59	Yes	Septic system	None
59-002	59	No	Container storage area	None
59-003	59	No	Sump	None
59-004	59	No	Outfall	Rad, Haz
C-59-001	59	No	Transformer	None
60-001(a)	60	No	Storage area (Active storage)	None
60-001(b)	60	No	Storage area (Active Storage)	None
60-001(c)	60	No	Storage area (Active storage)	None
60-001(d)	60	No	Storage area Postcase Shed	None
60-002	60	Yes	Storage area	None
60-003	60	No	Oiewater separator	None
60-004(a)	60	No	Storage area	None
60-004(b)	60	No	Storage area	Haz

FIELD UNIT ONE

Former OU 1114 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
61-004(b)	61	No	Septic tank	None
61-004(c)	61	No	Septic system	None
61-005	61	Yes	Landfill	Haz
61-006	61	Yes	Waste oil tank	Haz
61-007	61	Yes	Systemetic tank	None
C-61-001	61	No	Transformer storage area	None
64-001	64	No	Storage area	None

FIELD UNIT TWO

Former OU 1065 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
12-001(a)	12	Yes	Firing site	Rad, Haz
12-001(b)	12	Yes	Firing site	Rad, Haz
12-002	12	Yes	Open burning ground	
12-003	12	No	Storage area	
12-004(a)	12	No	Radiation Test facility	Rad, Haz
12-004(b)	12	No	Pipe	Rad, Haz
C-12-001	12	No	Building	Haz, HE
C-12-002	12	No	Building	Haz, HE
C-12-003	12	No	Building	Haz, HE
C-12-004	12	No	Building	Haz
C-12-005	12	No	Building	HE
C-12-006	12	No	Pole	
14-001(a)	14	No	Firing site	Rad, Haz
14-001(b)	14	No	Firing site	Rad, Haz
14-001(c)	14	No	Firing site	Rad, Haz
14-001(d)	14	No	Firing site	Rad, Haz
14-001(e)	14	No	Firing site	Rad, Haz
14-001(f)	14	No	Firing site	Rad, Haz
14-001(g)	14	No	Firing site	Rad, Haz

FIELD UNIT TWO

Former OU 1085 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
C-14-004	14	No	Building	Haz, HE
C-14-005	14	No	Building	Rad, Haz
C-14-006	14	No	Building	Haz, HE
C-14-007	14	No	Building	Haz, HE
C-14-008	14	No	Building	Haz, HE
C-14-009	14	No	Building	Haz, HE

FIELD UNIT TWO

Former OU 1086 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
15-006(d)	15	Yes	Firing site R-45	Rad, Haz
15-006(e)	15	No	Not in TA-15	
15-007(a)	15	Yes	Landfill MDA-N	Rad, Haz
15-007(b)	15	Yes	Landfill MDA-Z	Rad, Haz
15-007(c)	15	Yes	Shaft	
15-007(d)	15	Yes	Shaft	
15-008(a)	15	Yes	Surface disposal	Rad, Haz
15-008(b)	15	Yes	Surface disposal	Rad, Haz
15-008(c)	15	Yes	Surface disposal	Rad, Haz
15-008(d)	15	Yes	Surface disposal	Haz
15-008(e)	15	No	Surface disposal	
15-008(f)	15	No	Not in TA-15	
15-008(g)	15	No	Surface disposal	Rad, Haz
15-009(a)	15	Yes	Septic system	Haz
15-009(b)	15	Yes	Septic system	Haz
15-009(c)	15	Yes	Septic tank	Haz
15-009(d)	15	No	Septic tank	
15-009(e)	15	Yes	Septic tank	Haz
15-009(f)	15	Yes	Septic tank	Haz

FIELD UNIT TWO

Former OU 1085 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
15-014(e)	15	No	Ind. or sani. waste water treat.	
15-014(f)	15	No	Ind. or sani. waste water treat.	
15-014(g)	15	No	Ind. or sani. waste water treat.	
15-014(h)	15	No	Outfall	Haz
15-014(i)	15	Yes	Outfall	Haz
15-014(j)	15	Yes	Outfall	Haz
15-014(k)	15	Yes	Outfall	Haz
15-014(l)	15	Yes	Outfall	
15-014(m)	15	Yes	Outfall	
C-15-001	15	No	Surface disposal	Rad, Haz
C-15-002	15	No	Surface disposal	
C-15-003	15	No	Surface disposal	
C-15-004	15	No	Transformers	Other
C-15-005	15	No	Laboratory and building	Rad, Haz
C-15-006	15	No	Building	Haz
C-15-007	15	No	Non-intentional release	Haz
C-15-008	15	No	Non-intentional release	
C-15-009	15	No	Underground tank	
C-15-010	15	No	Underground tank	Haz

FIELD UNIT TWO

Former OU 1083

PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
18-001(a)	18	Yes	Lagoon	None
18-001(b)	18	Yes	Sewer lines	None
18-001(d)	18	Yes	Sump	None
18-002(a)	18	Yes	Firing site	None
18-002(b)	18	Yes	Firing site	None
18-002(c)	18	No	Drop tower	None
18-003(a)	18	Yes	Settling pit	Rad, Haz
18-003(b)	18	Yes	Septic system	Rad, Haz
18-003(c)	18	Yes	Septic system	Rad, Haz
18-003(d)	18	Yes	Septic system	Rad, Haz
18-003(e)	18	Yes	Septic system	Rad, Haz
18-003(f)	18	Yes	Septic system	Rad, Haz
18-003(g)	18	Yes	Septic system	None
18-003(h)	18	Yes	Septic system	None
18-004(a)	18	Yes	Waste lines containment	None
18-004(b)	18	Yes	Pit	None
18-005(a)	18	Yes	Storage area	None
18-005(b)	18	No	Storage area	None
18-005(c)	18	No	Storage area	None

FIELD UNIT TWO

Former OU 1083

PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
18-013	18	No	Waste Tank	None
C-18-001	18	No	Laboratory	None
C-18-002	18	No	Building	None
C-18-003	18	No	Storage area	None
27-001	27	Yes	Buried naval guns	None
27-002	27	Yes	Firing sites	None
27-003	27	Yes	Bazooka impact area	HE
27-004	27	No	Building	None

FIELD UNIT TWO

Former OU 1100 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
53-001(d)	53	No	Storage area	Haz
53-001(e)	53	No	Storage area	Haz
53-001(f)	53	No	Storage area	None
53-001(g)	53	No	Storage area	Haz
53-001(h)	53	No	Storage area	None
53-001(i)	53	No	Storage area	None
53-001(j)	53	No	Storage area	Haz
53-001(k)	53	No	Storage area	Haz
53-001(l)	53	No	Storage area	Rad, Haz
53-001(m)	53	No	Storage area	None
53-001(n)	53	No	Storage area	None
53-001(o)	53	No	Storage area	None
53-002(a)	53	Yes	Disposal lagoon RCRA closure	Rad, Haz
53-002(b)	53	Yes	Disposal lagoon RCRA closure	Rad, Haz
53-003	53	No	Septic tank	None
53-004	53	No	Operational facility	None
53-005	53	Yes	Disposal pit	Haz, other
53-006(a)	53	No	Underground tank	Rad, Haz
53-006(b)	53	Yes	Underground tank	Rad, Haz

FIELD UNIT TWO

Former OU 1100 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
53-012(f)	53	No	Outfall	None
53-012(g)	53	No	Outfall	None
53-012(h)	53	No	Outfall	None
C-53-001	53	No	Transformer	None
C-53-002	53	No	Transformer	None
C-53-003	53	No	Transformer	None
C-53-004	53	No	Transformer	None
C-53-005	53	No	Transformer	None
C-53-006	53	No	Transformer	None
C-53-007	53	No	Transformer	None
C-53-008	53	No	Transformer	None
C-53-009	53	No	Transformer	None
C-53-010	53	No	Transformer	None
C-53-011	53	No	Transformer	None
C-53-012	53	No	Transformer	None
C-53-013	53	No	Transformer	None
C-53-014	53	No	Transformer	None
C-53-015	53	No	Transformer	None
C-53-016	53	No	Transformer	None

FIELD UNIT TWO

Former OU 1130 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
36-001	36	Yes	Material disposal area	None
36-002	36	Yes	Sump	Haz, HE
36-003(a)	36	Yes	Septic system	Rad, Haz
36-003(b)	36	Yes	Septic system	None
36-003(c)	36	Yes	Septic system	None
36-003(d)	36	No	Septic system	None
36-004(a)	36	No	Firing site	Rad, Haz
36-004(b)	36	No	Firing site	Rad, Haz
36-004(c)	36	No	Firing site	Rad, Haz
36-004(d)	36	No	Firing site	Rad, Haz
36-004(e)	36	No	Firing site	Rad, Haz
36-004(f)	36	No	Firing site	Rad, Haz
36-005	36	Yes	Surface disposal site	Rad, Haz
36-006	36	Yes	Surface disposal site	Haz
36-007(a)	36	No	Storage area	None
36-007(b)	36	No	Storage area	None
36-007(c)	36	No	Storage area	None
36-007(d)	36	No	Storage area	None
36-007(e)	36	No	Storage area	None

FIELD UNIT TWO

Former OU 1122 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
39-001(a)	39	Yes	Landfill	Rad, Haz, other
39-001(b)	39	Yes	Asbestos disposal area	Rad, Haz, other
39-002(a)	39	Yes	Storage area	None
39-002(b)	39	No	Storage area	None
39-002(c)	39	No	Storage area	None
39-002(d)	39	No	Storage area	None
39-002(e)	39	No	Storage area	None
39-002(f)	39	No	Storage area	None
39-002(g)	39	No	Storage area	None
39-003	39	Yes	Incinerator	None
39-004(a)	39	Yes	Firing site	Rad, Haz, HE, other
39-004(b)	39	Yes	Firing site	Rad, Haz, HE, other
39-004(c)	39	Yes	Firing site	Rad, Haz, HE, other
39-004(d)	39	Yes	Firing site	Rad, Haz, HE, other
39-004(e)	39	Yes	Firing site	Rad, Haz, HE, other
39-005	39	Yes	Seepage pit	Haz, HE
39-006(a)	39	Yes	Septic system	Haz
39-006(b)	39	Yes	Septic system	None
39-007(a)	39	Yes	Storage area	None

FIELD UNIT THREE

Former OU 1082 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
11-001(a)	11	Yes	Firing site	Rad, Haz, HE
11-001(b)	11	Yes	Firing site	Rad, Haz, HE
11-001(c)	11	Yes	Firing site	Rad, Haz, HE
11-002	11	Yes	Burn site	Rad, Haz, HE
11-003(a)	11	No	Mortar impact area	None
11-003(b)	11	No	Firing range	Haz
11-004(a)	11	Yes	Drop tower	Rad, Haz, HE, other
11-004(b)	11	Yes	Drop tower	Rad, Haz, HE, other
11-004(c)	11	Yes	Drop tower	Rad, Haz, HE, other
11-004(d)	11	Yes	Drop tower	Rad, Haz, HE, other
11-004(e)	11	Yes	Drop tower	Rad, Haz, HE, other
11-004(f)	11	No	Drop tower	Rad, Haz, HE, other
11-005(a)	11	Yes	Septic system	Rad, Haz
11-005(b)	11	Yes	Septic system	Rad, Haz
11-005(c)	11	Yes	Ind. or san. wastewater treat.	Rad, Haz
11-006(a)	11	Yes	Sump	Rad, Haz, HE, other
11-006(b)	11	Yes	Tank and/or assoc. equip.	Rad, Haz, HE, other
11-006(c)	11	Yes	Tank and/or assoc. equip.	Rad, Haz, HE, other
11-006(d)	11	Yes	Tank and/or assoc. equip.	Rad, Haz, HE, other

FIELD UNIT THREE

Former OU 1082 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
13-003(b)	13	No	Septic system	Rad, Haz, HE
13-004	13	Yes	Dumping pit	Rad, Haz, HE, other
16-001(a)	16	Yes	Tank	Haz
16-001(b)	16	Yes	Dry wells	Haz
16-001(c)	16	Yes	Tank	Haz
16-001(d)	16	Yes	Dry well	Haz
16-001(e)	16	Yes	Dry well	Haz, HE
16-003(a)	16	Yes	Sump	Rad, Haz, HE
16-003(b)	16	Yes	Sump	Rad, Haz, HE
16-003(c)	16	Yes	Sump	Haz
16-003(d)	16	Yes	Sump	Haz
16-003(e)	16	Yes	Sump	Haz
16-003(f)	16	Yes	Sump	Haz
16-003(g)	16	Yes	Sump	Haz
16-003(h)	16	Yes	Sump	Rad, Haz, HE
16-003(i)	16	Yes	Sump	Haz
16-003(j)	16	Yes	Sump	Rad, Haz, HE
16-003(k)	16	Yes	Sump	Rad, Haz, HE
16-003(l)	16	Yes	Sump	Haz

FIELD UNIT THREE

Former OU 1082 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
16-005(i)	16	Yes	Septic tank (same as 13-003(a))	None
16-005(j)	16	Yes	Septic tank	Rad, Haz, HE
16-005(k)	16	Yes	Septic tank	Haz
16-005(l)	16	Yes	Grease trap	Haz, HE
16-005(m)	16	Yes	Chemical pit	Rad, Haz, HE
16-005(n)	16	Yes	Septic system	None
16-005(o)	16	Yes	Septic system	None
16-006(a)	16	Yes	Septic system	Rad, Haz
16-006(b)	16	Yes	Septic system	None
16-006(c)	16	Yes	Septic system	Rad, Haz
16-006(d)	16	Yes	Septic system	Rad, Haz, HE
16-006(e)	16	Yes	Septic system	Rad, Haz, HE
16-006(f)	16	Yes	Septic system	None
16-006(g)	16	Yes	Septic tank	Rad, Haz, HE
16-006(h)	16	Yes	Pump pit	None
16-006(i)	16	Yes	Septic tank	None
16-007(a)	16	Yes	Surface impoundment	Rad, Haz, HE
16-007(b)	16	No	Surface disposal site	None
16-008(a)	16	Yes	Surface impoundment	Rad, Haz, HE

FIELD UNIT THREE

Former OU 1082 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
16-012(b)	16	Yes	Container storage	None
16-012(c)	16	Yes	Container storage	None
16-012(d)	16	Yes	Satellite storage	None
16-012(e)	16	Yes	Container storage	None
16-012(f)	16	Yes	Container storage	None
16-012(g)	16	Yes	Container storage	None
16-012(h)	16	Yes	Container storage	None
16-012(i)	16	Yes	Satellite storage	None
16-012(j)	16	Yes	Satellite storage	None
16-012(k)	16	Yes	Container storage	None
16-012(l)	16	Yes	Satellite storage	None
16-012(m)	16	Yes	Satellite storage	None
16-012(n)	16	Yes	Satellite storage	None
16-012(o)	16	Yes	Container storage	None
16-012(p)	16	Yes	Container storage	None
16-012(q)	16	Yes	Container storage	None
16-012(r)	16	Yes	Container storage	None
16-012(s)	16	Yes	Container storage	None
16-012(t)	16	Yes	Satellite storage	None

FIELD UNIT THREE

Former OU 1082 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
16-018	16	Yes	Material disposal area; RCRA closure.	Haz, HE
16-019	16	Yes	Material disposal area	Rad, Haz
16-020	16	Yes	Sewer recovery unit	Haz
16-021(a)	16	Yes	Systemhold release site	Haz
16-021(b)	16	No	Systemhold tank	Haz, HE
16-021(c)	16	Yes	Ind. or san. waste water treatment	Haz, HE
16-022(a)	16	No	Underground tank	None
16-022(b)	16	No	Underground tank	None
16-023(a)	16	No	Incinerator	None
16-023(b)	16	No	Incinerator	Haz, HE
16-024(a)	16	No	Magazine	Haz, HE
16-024(b)	16	No	Magazine	Haz, HE
16-024(c)	16	No	Magazine	Haz, HE
16-024(d)	16	No	Magazine	Haz, HE
16-024(e)	16	No	Operational laundry	Haz, HE
16-024(f)	16	No	Magazine	None
16-024(g)	16	No	Magazine	Haz, HE
16-024(h)	16	No	Magazine	Rad, Haz, HE
16-024(i)	16	No	Magazine	Haz, HE

FIELD UNIT THREE

Former OU 1082 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
16-025(d)	16	Yes	Abandoned building & appurtenances	Haz, HE
16-025(d2)	16	Yes	Abandoned building & appurtenances	Rad, Haz, HE
16-025(e)	16	Yes	Abandoned building & appurtenances	Haz, HE
16-025(e2)	16	Yes	Abandoned building & appurtenances	None
16-025(f)	16	Yes	Abandoned building & appurtenances	Haz, HE
16-025(f2)	16	Yes	Abandoned building & appurtenances	None
16-025(g)	16	Yes	Abandoned building & appurtenances	Haz, HE
16-025(g2)	16	Yes	Abandoned building & appurtenances	None
16-025(h)	16	Yes	Abandoned building & appurtenances	Haz, HE
16-025(h2)	16	Yes	Abandoned building & appurtenances	None
16-025(i)	16	Yes	Abandoned building & appurtenances	Haz, HE
16-025(j)	16	Yes	Abandoned building & appurtenances	Haz, HE
16-025(k)	16	Yes	Abandoned building & appurtenances	Haz, HE
16-025(l)	16	Yes	Abandoned building & appurtenances	Haz, HE
16-025(m)	16	Yes	Abandoned building & appurtenances	Rad, Haz, HE
16-025(n)	16	Yes	Abandoned building & appurtenances	Rad, Haz, HE
16-025(o)	16	Yes	Abandoned building & appurtenances	Rad, Haz, HE
16-025(p)	16	Yes	Abandoned building & appurtenances	Haz, HE
16-025(q)	16	Yes	Abandoned building & appurtenances	Haz, HE

FIELD UNIT THREE

Former OU 1082 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
16-026(f)	16	Yes	Outfall	None
16-026(f2)	16	Yes	Outfall	None
16-026(g)	16	Yes	Outfall	None
16-026(g2)	16	Yes	Outfall	None
16-026(h)	16	Yes	Outfall	None
16-026(h2)	16	Yes	Outfall	Haz, HE
16-026(i)	16	Yes	Outfall	Haz, HE
16-026(i2)	16	Yes	Outfall	None
16-026(j)	16	Yes	Outfall	Haz, HE
16-026(j2)	16	Yes	Outfall	Haz, HE
16-026(k)	16	Yes	Outfall	None
16-026(k2)	16	Yes	Outfall	Rad, Haz, HE
16-026(l)	16	Yes	Outfall	None
16-026(m)	16	Yes	Outfall	Haz
16-026(n)	16	Yes	Outfall	Haz
16-026(o)	16	Yes	Outfall	Haz
16-026(p)	16	Yes	Outfall	Haz
16-026(q)	16	Yes	Outfall	Rad, Haz, HE
16-026(r)	16	Yes	Outfall	Haz

FIELD UNIT THREE

Former OU 1082 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
16-029(b)	16	Yes	Sump	Haz
16-029(b2)	16	Yes	Sump	Haz, HE
16-029(c)	16	Yes	Sump	Haz
16-029(c2)	16	No	Sump	Rad, Haz, HE
16-029(d)	16	Yes	Sump	Haz
16-029(d2)	16	No	Sump	Haz, HE
16-029(e)	16	Yes	Sump	Haz
16-029(e2)	16	No	Sump	Haz, HE
16-029(f)	16	Yes	Sump	Haz
16-029(f2)	16	Yes	Outfall	Haz, HE
16-029(g)	16	Yes	Sump	Haz
16-029(g2)	16	Yes	Pump pit	None
16-029(h)	16	Yes	Sump	Haz
16-029(h2)	16	No	Drain line and outfall	Haz, HE
16-029(i)	16	Yes	Outfall	None
16-029(j)	16	Yes	Outfall	Rad, Haz, HE
16-029(k)	16	Yes	Sump	Haz
16-029(l)	16	Yes	Sump	Haz
16-029(m)	16	No	Sump	Haz, HE

FIELD UNIT THREE

Former OU 1082 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
16-030(g)	16	No	Outfall	Haz
16-030(h)	16	Yes	Ind. or san. waste water treatment	Haz
16-031(a)	16	Yes	Ind. or san. waste water treatment	Haz
16-031(b)	16	Yes	Ind. or san. waste water treatment	Haz
16-031(c)	16	Yes	Ind. or san. waste water treatment	Haz
16-031(d)	16	Yes	Ind. or san. waste water treatment	Haz
16-031(e)	16	Yes	Ind. or san. waste water treatment	None
16-031(f)	16	Yes	Ind. or san. waste water treatment	None
16-031(g)	16	Yes	Ind. or san. waste water treatment	None
16-031(h)	16	Yes	Ind. or san. waste water treatment	None
16-032(a)	16	No	Sump	Rad, Haz, HE
16-032(b)	16	No	Shed	None
16-032(c)	16	No	Sump	Haz, HE
16-032(d)	16	Yes	Sump	None
16-032(e)	16	Yes	Water pump pit	None
16-033(a)	16	No	Underground tank	None
16-033(b)	16	No	Underground tank	Haz
16-033(c)	16	No	Underground tank	None
16-033(d)	16	No	Tank and/or assoc. equip	None

FIELD UNIT THREE

Former OU 1082 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
16-034(n)	16	Yes	Soil contamination area	HAZ, HE
16-034(o)	16	Yes	Soil contamination area	HAZ, HE
16-034(p)	16	Yes	Soil contamination area	HAZ
16-035	16	Yes	Soil contamination area	HAZ, HE, other
16-036	16	Yes	Soil contamination area	Rad, HAZ, other
16-037	16	No	Aboveground tank	None
C-16-001	16	No	Building	None
C-16-002	16	No	Building	HAZ
C-16-003	16	No	Septic system	None
C-16-004	16	No	Building	None
C-16-005	16	No	Building	HAZ
C-16-006	16	No	Building	HAZ
C-16-007	16	No	Building	None
C-16-008	16	No	Building	None
C-16-009	16	No	Building	None
C-16-010	16	No	Building	None
C-16-011	16	No	Building	None
C-16-012	16	No	Building	None
C-16-013	16	No	Storage area	None

FIELD UNIT THREE

Former OU 1082 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
C-16-033	16	No	Warehouse	None
C-16-034	16	No	Aboveground tank	None
C-16-035	16	No	Aboveground tank	None
C-16-036	16	No	Septic system	None
C-16-037	16	No	Storage area	None
C-16-038	16	No	Storage area	None
C-16-039	16	No	Building	None
C-16-040	16	No	Building	None
C-16-041	16	No	Building	None
C-16-042	16	No	Manhole	None
C-16-043	16	No	Manhole	None
C-16-044	16	No	Manhole	None
C-16-045	16	No	Manhole	None
C-16-046	16	No	Manhole	None
C-16-047	16	No	Transport area	None
C-16-048	16	No	Manhole	None
C-16-049	16	No	Building	None
C-16-050	16	No	Building	None
C-16-051	16	No	Transport area	None

FIELD UNIT THREE

Former OU 1082 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
C-16-071	16	No	One-time spill	None
C-16-072	16	No	Tank	Haz
C-16-073	16	No	Underground tank	Haz
C-16-074	16	No	Storage	Rad, Haz, HE
25-001	25	No	Disposal pit	None
C-25-001	25	No	Building	None
37-001	37	No	Septic system	None

FIELD UNIT THREE

Former OU 1122 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
33-004(h)	33	Yes	Outfall	None
33-004(i)	33	Yes	Outfall	Haz
33-004(j)	33	Yes	Outfall	None
33-004(k)	33	Yes	Outfall	None
33-004(l)	33	No	Outfall	None
33-004(m)	33	Yes	Septic system	None
33-004(n)	33	No	Septic system	None
33-005(a)	33	Yes	Septic system	Haz
33-005(b)	33	Yes	Septic system	Haz
33-005(c)	33	Yes	Septic system	Haz
33-006(a)	33	Yes	Firing site	None
33-006(b)	33	Yes	Firing range	None
33-007(a)	33	Yes	Firing range	None
33-007(b)	33	Yes	Firing range	None
33-007(c)	33	Yes	Firing range	Rad
33-008(a)	33	Yes	Landfill	None
33-008(b)	33	Yes	Landfill	None
33-009	33	Yes	Surface disposal	Haz
33-010(a)	33	Yes	Surface disposal	None

FIELD UNIT THREE

Former OU 1122 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
33-016	33	Yes	Sump	Haz
33-017	33	Yes	Operational release	Haz
C-33-001	33	No	Transformer	None
C-33-002	33	No	Transformer	None

FIELD UNIT THREE

Former OU 1140 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
46-004(f)	46	Yes	Outfall	None
46-004(g)	46	Yes	Outfall/Black Smokers	None
46-004(h)	46	Yes	Outfall/Black Smokers	None
46-004(i)	46	No	Outfall	None
46-004(j)	46	No	Outfall	None
46-004(k)	46	No	Outfall	None
46-004(l)	46	No	Outfall	None
46-004(m)	46	Yes	Outfall	None
46-004(n)	46	No	Outfall	None
46-004(o)	46	No	Outfall	None
46-004(p)	46	Yes	Sump	HAZ, other
46-004(q)	46	Yes	Outfall	None
46-004(r)	46	Yes	Outfall	None
46-004(s)	46	Yes	Outfall	None
46-004(t)	46	Yes	Outfall	None
46-004(u)	46	Yes	Outfall	None
46-004(v)	46	Yes	Outfall	None
46-004(w)	46	Yes	Outfall	None
46-004(x)	46	Yes	Outfall	None

FIELD UNIT THREE

Former OU 1140 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
46-009(a)	46	Yes	Surface disposal	None
46-009(b)	46	Yes	Surface disposal	None
46-010(a)	46	No	Storage area	None
46-010(b)	46	No	Storage area	None
46-010(c)	46	No	Storage area	None
46-010(d)	46	Yes	Operation release	None
46-010(e)	46	No	Storage area	None
46-010(f)	46	No	Storage area	None
46-010mac	46	No	Storage area	None
C-46-001	46	No	One-time spill	None
C-46-002	46	No	Stack Emissions	None
C-46-003	46	No	Stack Emissions	None

FIELD UNIT FOUR

Former OU 1049 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
0-001	Canyon Site	Yes	Sediment Traps	Rad, Haz
C-0-001	Canyon Site	No	Guaje Canyon	HE, Haz
C-0-002	Canyon Site	No	Rendija Canyon	HE, Haz
C-0-003	Canyon Site	No	Barranca Canyon	HE, Haz
C-0-004	Canyon Site	No	Bayo Canyon	Rad, Haz
C-0-005	Canyon Site	No	Pueblo Canyon	Rad, Haz
C-0-006	Canyon Site	No	Los Alamos Canyon	Rad, Haz
C-0-007	Canyon Site	No	Sandia Canyon	Rad, Haz
C-0-008	Canyon Site	No	Mortandad Canyon	Rad, Haz
C-0-009	Canyon Site	No	Canada del Buey	Rad, Haz, HE
C-0-010	Canyon Site	No	Two Mile Canyon	Rad, Haz, HE
C-0-011	Canyon Site	No	Pajarito Canyon	Rad, Haz
C-0-012	Canyon Site	No	Three Mile Canyon	Rad, Haz, HE
C-0-013	Canyon Site	No	Portillo Canyon	Rad, Haz
C-0-014	Canyon Site	No	Canon de Valle	Rad, Haz, HE
C-0-015	Canyon Site	No	Fence Canyon	Rad, Haz, HE
C-0-016	Canyon Site	No	Water Canyon	Rad, Haz, HE
C-0-017	Canyon Site	No	Indio Canyon	Rad, Haz, HE
C-0-018	Canyon Site	No	Ancho Canyon	Rad, Haz, HE

FIELD UNIT FOUR

Former OU 1098 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
2-001	02	No	Open burning ground.	None
2-002	02	No	Storage area	None
2-003(a)	02	No	Reactor facility	Rad, Haz
2-003(b)	02	No	Reactor facility	Rad, Haz
2-003(c)	02	No	Reactor facility	Rad, Haz
2-003(d)	02	No	Reactor facility	Rad, Haz
2-004(a)	02	No	Reactor facility	Rad, Haz
2-004(b)	02	No	Reactor facility	Rad, Haz
2-004(c)	02	No	Reactor facility	Rad, Haz
2-004(d)	02	No	Reactor facility	Rad, Haz
2-004(e)	02	No	Reactor facility	Rad, Haz
2-004(f)	02	No	Reactor facility	Rad, Haz
2-004(g)	02	No	Aboveground tank	Rad, Haz
2-005	02	Yes	Bypassed leak Cooling tower blowdown—Cr^{+6}	Haz
2-006(a)	02	Yes	Ind. or san. waste water treat.	Rad, Haz
2-006(b)	02	Yes	Ind. or san. waste water treat.	Rad, Haz
2-006(c)	02	No	Waste line	Rad, Haz
2-006(d)	02	No	Waste line	Rad, Haz
2-006(e)	02	No	Waste line	Rad, Haz

FIELD UNIT FOUR

Former OU 1098 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
41-002(9)	41	Yes	Waste water treatment facility	Rad, haz
41-002(6)	41	Yes	Waste water treatment facility	Rad, haz
41-003	41	No	Sump	Haz
41-004	41	No	Container storage	None
C-41-001	41	No	Sump	None
C-41-002	41	No	Underground tank	None
C-41-003	41	No	Underground tank	None
C-41-004	41	No	Storm drains	Haz
C-41-005	41	No	Underground tank Mystery tank	Haz

FIELD UNIT FOUR

Former OU 1129 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
5-006(f)	05	No	Soil contamination beneath bridge.	HE
5-006(g)	05	No	Soil contamination beneath bridge.	HE
5-006(h)	05	Yes	Soil contamination beneath bridge.	Rad, Haz, HE
C-5-001	05	No	Buildings	Haz Unknown
35-001	35	No	Material disposal area	liquid sodium with Pu-239
35-002	35	Yes	Material disposal area	Haz
35-003(a)	35	Yes	Waste water treatment facility	Rad, Haz
35-003(b)	35	Yes	Waste water treatment facility	Rad, Haz
35-003(c)	35	Yes	Waste water treatment facility	Rad, Haz
35-003(d)	35	Yes	Waste water treatment facility	Rad, Haz
35-003(e)	35	Yes	Waste water treatment facility	Rad, Haz
35-003(f)	35	Yes	Waste water treatment facility	Rad, Haz
35-003(g)	35	Yes	Waste water treatment facility	Rad, Haz
35-003(h)	35	Yes	Waste water treatment facility	Rad, Haz
35-003(i)	35	Yes	Waste water treatment facility storage tanks	None
35-003(j)	35	Yes	Waste water treatment facility	Rad, Haz Unknown
35-003(k)	35	Yes	Waste water treatment facility	Rad, Haz Unknown
35-003(l)	35	Yes	Waste water treatment facility	Rad, Haz
35-003(m)	35	Yes	Waste water treatment facility	Rad, Haz

FIELD UNIT FOUR

Former OU 1129 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
35-004(c)	35	No	Container storage area	Haz
35-005(a)	35	No	Surface impoundment	Haz
35-005(b)	35	No	Surface impoundment	Haz
35-006	35	Yes	Surface impoundment	Haz
35-007	35	No	Waste oil treatment	Haz
35-008	35	Yes	Surface disposal and landfill	Haz
35-009(a)	35	Yes	Septic system	Haz
35-009(b)	35	Yes	Septic system	Haz
35-009(c)	35	Yes	Septic system	Haz, Rad
35-009(d)	35	Yes	Septic system	Haz, Rad
35-009(e)	35	Yes	Septic system	Haz
35-010(a)	35	Yes	Sanitary lagoon & sand filters	Rad, Haz
35-010(b)	35	Yes	Sanitary lagoon & sand filters	Rad, Haz
35-010(c)	35	Yes	Sanitary lagoon & sand filters	Rad, Haz
35-010(d)	35	Yes	Sanitary lagoon & sand filters	Rad, Haz
35-010(e)	35	No	Discharge headwall	Rad, Haz
35-011(a)	35	Yes	Underground storage tank	Haz
35-011(b)	35	No	Underground storage tank	Haz
35-011(c)	35	No	Underground storage tank	Haz

FIELD UNIT FOUR

Former OU 1129 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
35-015(b)	35	Yes	Waste oil treatment	Haz
35-016(a)	35	Yes	Drains and outfalls	Unknown
35-016(b)	35	No	Outfall	Haz
35-016(c)	35	Yes	Outfall	Unknown
35-016(d)	35	Yes	Outfall	Haz
35-016(e)	35	No	Outfall	Unknown
35-016(f)	35	No	Storm drain	Haz
35-016(g)	35	No	Outfall	Haz, Rad
35-016(h)	35	No	Storm drain	Rad
35-016(i)	35	Yes	Drains and outfalls	Unknown
35-016(j)	35	No	Storm drain	Haz
35-016(k)	35	Yes	Drains and outfalls	Unknown
35-016(l)	35	No	Storm drain	Rad
35-016(m)	35	Yes	Drains and outfalls	Haz
35-016(n)	35	No	Storm drain	Haz
35-016(o)	35	Yes	Drains and outfalls	Rad, Other
35-016(p)	35	Yes	Outfall	Unknown
35-016(q)	35	Yes	Drains and outfalls	Rad, Haz
35-017	35	No	Soil contamination from Reactor	Rad, Haz

FIELD UNIT FOUR

Former OU 1129 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
48-002(b)	48	Yes	Container storage area	Haz
48-002(c)	48	No	Container storage	Haz
48-002(d)	48	No	Container storage	Rad
48-002(e)	48	No	Container storage	Haz
48-003	48	Yes	Septic system	Rad, Haz
48-004(a)	48	Yes	Sumps and tanks	Haz
48-004(b)	48	Yes	Sumps and tanks	Rad, Haz
48-004(c)	48	Yes	Sumps and tanks	Haz
48-004(d)	48	No	Sumps and tanks	None
48-005	48	Yes	Waste lines	Haz, Rad
48-006	48	No	Septic system	None
48-007(a)	48	Yes	Drains and outfalls	Haz
48-007(b)	48	Yes	Drains and outfalls	Unknown
48-007(c)	48	Yes	Drains and outfalls	Unknown
48-007(d)	48	Yes	Drains and outfalls	Haz
48-007(e)	48	No	Drains and outfalls	Haz
48-007(f)	48	Yes	Drains and outfalls	Unknown
48-008	48	No	Transformer leak	Haz
48-009	48	No	Soil contamination	Haz

FIELD UNIT FOUR

Former OU 1129 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
55-001	55	No	Cement plant	Rad
55-002(a)	55	No	Rad waste storage area	Rad
55-002(b)	55	No	Rad waste storage area	None
55-002(c)	55	No	Rad waste storage area	Rad
55-003	55	No	Containment area	None
55-004	55	No	Evaporator	Rad
55-005	55	No	Filtration Unit	None
55-006	55	No	Glass Breaker	None
55-007	55	No	Thermal combustion unit	None
55-008	55	Yes	Sumps and tanks	Rad
55-009	55	Yes	Sumps and tanks	Haz
55-010	55	No	Solvent spills	Rad, Haz
55-011(a)	55	No	Outfall	Rad, Haz
55-011(b)	55	No	Outfall	Rad, Haz
55-011(c)	55	No	Outfall	Rad, Haz
55-011(d)	55	No	Outfall	Rad, Haz
55-011(e)	55	No	Outfall	Rad, Haz
55-012	55	No	Storage area	None
55-013(a)	55	No	Storage area	None

FIELD UNIT FIVE

Former OU 1111 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
6-001(a)	06	Yes	Septic system	Rad, Haz
6-001(b)	06	Yes	Septic system	Rad, Haz
6-002	06	Yes	Septic system	Haz, HE
6-003(a)	06	Yes	Firing site	Rad, Haz
6-003(b)	06	No	Firing site	None
6-003(c)	06	Yes	Firing site	Rad, Haz
6-003(d)	06	Yes	Firing site	Haz, HE
6-003(e)	06	Yes	Firing site	Haz, HE
6-003(f)	06	Yes	Firing site	Rad, Haz
6-003(g)	06	Yes	Firing site & building	Haz, HE
6-003(h)	06	Yes	Firing site NOSUCH IN WORK PLAN!	
6-004	06	No	Sump	None
6-005	06	Yes	Firing site (pit)	Rad, Haz
6-006	06	Yes	Storage area	Haz, other
6-007(a)	06	Yes	Material disposal sites	Rad, Haz
6-007(b)	06	Yes	Landfill	Rad, Haz
6-007(c)	06	Yes	Landfill	Rad, Haz
6-007(d)	06	Yes	Landfill	Rad, Haz
6-007(e)	06	Yes	Landfill	Rad, Haz

FIELD UNIT FIVE

Former OU 1111 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
C-6-019	06	No	Building	Haz, HE
C-6-020	06	No	Building	None
C-6-021	06	No	Building	Haz, HE
7-001(a)	07	Yes	Firing site	Haz, HE
7-001(b)	07	Yes	Firing site	Haz, HE
7-001(c)	07	Yes	Firing site	Haz, HE
7-001(d)	07	Yes	Firing site	Haz, HE
22-001	22	No	Building	None
22-003(a)	22	No	Satellite storage	None
22-003(b)	22	No	Satellite storage	None
22-003(c)	22	No	Satellite storage	None
22-003(d)	22	No	Satellite storage	None
22-003(e)	22	No	Satellite storage	None
22-003(f)	22	No	Satellite storage	None
22-003(g)	22	No	Satellite storage	None
22-010(a)	22	Yes	Septic system	Rad, Haz
22-010(b)	22	No	Septic system	Rad, Haz
22-011	22	Yes	Disposal pit	None
22-012	22	Yes	Decontamination facility	Haz, HE

FIELD UNIT FIVE

Former OU 1111 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
40-006	40	Yes	Sump	Haz, HE
40-008(a)	40	Yes	Firing site	Rad, Haz
40-008(b)	40	Yes	Firing site	Rad, Haz
40-008(c)	40	Yes	Firing site	Rad, Haz
40-007(a)	40	No	Storage area	Haz, HE
40-007(b)	40	No	Storage area	Haz, HE
40-007(c)	40	No	Storage area	Haz, HE
40-007(d)	40	No	Storage area	Haz, HE
40-007(e)	40	No	Storage area	Haz, HE
40-008	40	No	Storage area	None
40-009	40	Yes	Landfill	Rad, Haz
40-010	40	Yes	Surface disposal site	Rad, Haz
C-40-001	40	No	Usage site	None

FIELD UNIT FIVE

Former OU 1144 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
49-009	49	No	Underground tank	Haz

FIELD UNIT FIVE

Former OU 1148 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
54-007(e)	54	No	Septic system	Haz
54-008	54	No	Underground tank	None
54-009	54	No	Aboveground tanks	Haz
54-010	54	No	Underground tank	None
54-012(a)	54	No	Reduction site	Rad, Haz
54-012(b)	54	Yes	Reduction site	Haz
54-013(a)	54	Yes	Decontamination facility	None
54-013(b)	54	Yes	Disposal Pit	Rad, Haz
54-014(a)	54	No	Storage shafts	Rad, Haz
54-014(b)	54	Yes	Storage pit	Rad, Haz
54-014(c)	54	Yes	Storage shafts	Rad, Haz
54-014(d)	54	Yes	Storage trenches	Rad, Haz
54-015(a)	54	No	Storage area	Rad
54-015(b)	54	No	Storage area	Rad
54-015(c)	54	No	Storage area	Rad
54-015(d)	54	No	Storage area	Rad
54-015(e)	54	No	Storage area	Rad
54-015(f)	54	No	Storage area	Rad
54-015(g)	54	No	Storage area	None

FIELD UNIT FIVE

Former OU 1147 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
50-006(e)	50	No	Aboveground tank	None
50-007	50	No	Incinerator	None
50-008	50	No	Production site	None
50-009	50	Yes	Material disposal area	Rad, Haz
50-010	50	No	Decontamination facility	Rad, Haz
50-011(a)	50	Yes	Septic system	Rad, Haz
50-011(b)	50	No	Septic system	Rad, Haz
C-50-001	50	No	Transformer	None

FIELD UNIT FIVE

Former OU 1154 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
57-001(a)	57	No	Surface impoundment	None
57-001(b)	57	No	Surface impoundment	
57-001(c)	57	No	Surface impoundment	
57-002	57	No	Landfill	Haz
57-003	57	No	Storage area	None
57-004(a)	57	No	Surface impoundment	
57-004(b)	57	No	Surface impoundment	Haz
57-005	57	No	Filter system	None
57-006	57	No	Drum Cansana	Haz
57-007	57	No	Leach Field	Haz

FIELD UNIT FIVE

Former OU 1157 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
8-009(b)	08	No	Ind. or san. wastewater treat.	None
8-009(c)	08	No	Storm drain and outfall	Haz
8-009(d)	08	Yes	Ind. or san. wastewater treat.	Haz
8-009(e)	08	Yes	Ind. or san. wastewater treat.	Haz
8-009(f)	08	No	Outfall	Haz
8-010(a)	08	No	Storage area	None
8-010(b)	08	No	Storage area	None
8-010(c)	08	No	Storage area	None
8-011(a)	08	No	Underground tank	None
8-011(b)	08	No	Underground tank	None
C-8-001	08	No	Building	None
C-8-002	08	No	Building	None
C-8-003	08	No	Building	None
C-8-004	08	No	Building	None
C-8-005	08	No	Building	None
C-8-006	08	No	Building	None
C-8-007	08	No	Building	None
C-8-008	08	No	Building	None
C-8-009	08	No	Building	None

FIELD UNIT FIVE

Former OU 1157 PRS Number	TA	HSWA SWMU	Unit Description	Potential Contaminants
9-003(d)	09	Yes	Settling tank	Haz, HE
9-003(e)	09	Yes	Settling tank	Haz, HE
9-003(f)	09	Yes	Settling tank	None
9-003(g)	09	Yes	Settling tank	Haz, HE
9-003(h)	09	Yes	Settling tank	Haz, HE
9-003(i)	09	Yes	Settling tank	Haz, HE
9-004(a)	09	Yes	Settling tank	Haz, HE
9-004(b)	09	Yes	Settling tank	Haz, HE
9-004(c)	09	Yes	Settling tank	Haz, HE
9-004(d)	09	Yes	Settling tank	Haz, HE
9-004(e)	09	Yes	Settling tank	Haz, HE
9-004(f)	09	Yes	Settling tank	Haz, HE
9-004(g)	09	Yes	Settling tank	Haz, HE
9-004(h)	09	Yes	Settling tank	Haz, HE
9-004(i)	09	Yes	Settling tank	Haz, HE
9-004(j)	09	Yes	Settling tank	Haz, HE
9-004(k)	09	Yes	Settling tank	Haz, HE
9-004(l)	09	Yes	Settling tank	Haz, HE
9-004(m)	09	Yes	Settling tank	Haz, HE

FIELD UNIT FIVE

Former OU 1157

PRS Number	TA	NRWA SWMU	Unit Description	Potential Contaminants
9-011(b)	09	No	Storage area	Haz, HE
9-011(c)	09	No	Storage area	Haz, HE
9-012	09	No	Disposal pit	Rad, Haz
9-013	09	Yes	Material disposal area	Rad, Haz, HE, other
9-014	09	No	Firing site	Rad, Haz, HE
9-015	09	No	Manhole	None
9-016	09	No	Underground tank	None
C-9-001	09	Yes	Soil contamination	Haz
C-9-002	09	No	Buildings	None
C-9-003	09	No	Buildings	None
C-9-004	09	No	Building	None
C-9-005	09	No	Building	None
C-9-006	09	No	Buildings	None
C-9-007	09	No	Building	None
C-9-008	09	No	Underground tank	None
C-9-009	09	No	Non-intentional release	None
C-9-010	09	No	Burn site	None
C-9-011	09	No	Burn site	None
69-001	69	Yes	Incinerator and assoc. equip.	Haz

APPENDIX E

Tables of Wells and Springs in the Los Alamos Area

Note: This is a preliminary effort to compile data on wells and springs in and around the Los Alamos National Laboratory. Existing information will be included as it is found. This table will be updated to include locations and information on new wells drilled and new springs discovered during the implementation of the Groundwater Protection Management Program.

Wells in Los Alamos and Surrounding Area

STATION	DATE INSTALLED	X-COORDINATE	Y-COORDINATE	ELEVATION	DEPTH CASE	SCREEN INTERVAL	PURPOSE	COMMENTS
Main								
BW 1 new	1977	1667244	1759262	5500				
BW 1 old	1971	1674752	1750944	5860				
BW 2 new	1977	1668044	1757062	5535				Flowing
BW 2 old		1669944	1756262	5620				
BW 3	1972	1670299	1758095	5820				
BW 4	1972	1672031	1753387	5650				Flowing
BW 5		1672118	1750941	5680				
BW 6	1972	1674202	1752890	5720				Flowing
BW 7	1972	1674157	1755217	5710				
DT-10	1960	1628988	1754449	7020	1419	1080-1390	Test	To be plugged
DT-5A	1960	1625310	1754789	7144	1821	1172-1392	Test	To be plugged
DT 9	1960	1628994	1751493	6936	1501	1040-1500	Test	To be plugged
Eleven Hundred	1952 ?	1666744	1726182	6636	1086		Stock	Also called T-Ack Well
G 1	1950	1656191	1783609	5973	2000	282-1980	Supply	
G-1A	1954	1655241	1784353	6014	1519	272-1513	Supply	
G 2	1954	1654210	1785123	6056	1970	281-1960	Supply	
G 3	1951	1651576	1786218	6139	1792	441-1785	Supply	Not in use
G 4	1951	1648949	1786452	6229	1930	426-1925	Supply	
G 5	1951	1646950	1787907	6308	1840	462-1830	Supply	
G 6	1964	1644824	1786851	6472	1530		Supply	
LA 1	1946	1668082	1776927	5624	870	80-865	Supply	Plugged 1993
LA 1A							Observation	
LA 1B	1960	1668248	1776952	5602	1750	326-1690	Supply	No pump
LA 2	1946	1666924	1777219	5651	870	105-865	Supply	Pump
LA 3	1947	1665991	1777185	6578	870	105-865	Supply	Plugged 1993
LA 4	1948	1657448	1771233	5375	1964	754-1964	Supply	Plugged 1993
LA 5	1948	1659828	1772533	5840	1750	440-1740	Supply	No pump
LA 6	1948	1662082	1774593	5770	1490	420-1778	Supply	Plugged 1993
McKinney		1675247	1750237	8050				
O-1	1991	1649398	1772232	8398	2497	1017-2477	Supply	
O-4	1991	1637337	1772995	8627	2598	1115-2598	Supply	

STATION	DATE INSTALLED	X-COORDINATE	Y-COORDINATE	ELEVATION	DEPTH CASE	SCREEN INTERVAL	PURPOSE	COMMENTS
PM 1	1965	1647734	1768112	6520	2499	945 2479	Supply	
PM 2	1965	1636786	1760326	6715	2300	1001-2280	Supply	
PM 3	1966	1642631	1769426	6640	2552	958 2532	Supply	
PM 4	1981	1635717	1764674	6929	2875	1290-2854	Supply	
PM 5	1982	1633083	1767809	7055	3093	1440-3073	Supply	
RGT-2	1946	1674678	1780561	5525			Test Hole	Open hole
RGT-3	1946	1674074	1780579	5545			Test Hole	Open hole
RGT 4	1946	1675268	1781956	5537			Test Hole	Open hole
SF-2A	1986	1667580	1758621	5540	1872	1850-1860	Observation	
SF-3A	1987	1664344	1768562	5490	264	274 264	Observation	
SF-4A	1988	1667744	1780862	5470	280	260-270	Observation	
SF-5A	1988	1661244	1799062	5455	300	280-290	Observation	
Skiff	1972	1674657	1761458	5869	1700		Observation	Remarker 1972
TW 1	1950	1650041	1772077	6369	842	832 842	Test	To be plugged
TW 2	1949	1634231	1777268	6648	834	779 780	Test	Screen removed 1980, to be plugged
TW 3	1949	1637727	1773138	6595	815	805 815	Test	To be plugged
TW 4	1950	1624028	1777680	7258	1205	1195-1205	Test	To be plugged
TW 8	1960	1632574	1766507	6678	1065	953-1065	Test	To be plugged
Intermediate								
LADP 3	1993	1632593	1773469	6755	328	318-325	Test	-
LADP 4	1993	1775718	1633176	7051			Test	
LAOI-11A	1994						Observation	
TW 1A	1950	1650057	1772066	6369	225	215-225	Test	To be plugged
TW 2A	1949	1634185	1777268	6650	132	127-132	Test	To be plugged
Alluvial								
APCO 1	1990	1649210	1773020	6368	157	47-147	Observation	HMAR Special Permit
CDBO 1	1985	1637969	1760944	6758	13	5-13	Observation	
CDBO 2	1985	1638119	1761103	6748	12	6-18	Observation	
CDBO 3	1985	1640577	1759611	6670	12	2-12	Observation	
CDBO 4	1985	1645475	1758547	6565	12	6-12	Observation	
CDBO 5	1992	1633583	1765818	6879	17	7-17	Observation	
CDBO 6	1992	1638208	1764780	6817	49	34-44	Observation	Water from PM-4 pump starting
CDBO 7	1992	1637400	1763301	6871	44	29-38	Observation	Water from PM-4 pump starting

2

STATION	DATE INSTALLED	X-COORDINATE	Y-COORDINATE	ELEVATION	DEPTH CASE	SCREEN INTERVAL	PURPOSE	COMMENTS
CDEO 8	1992	1639294	1762366	6722	23	13 23	Observation	
CDEO 9	1992	1653119	1759703	6634	34	19 29	Observation	
FCO 1	1989	1642412	1751182	6509	12 4	2 4 12 4	Observation	Dry HSWA Special Permit
LAO 0 3	1994	1624799	1774512	5968	8 33	5 9 10 9	Observation	
LAO 0 6	1994	1626748	1774333	6910	10 54	8 0 13 0	Observation	
LAO 0 8	1994	1627700	1774275	6887	7 5	7 5 12 5	Observation	
LAO 0 91	1994	1628654	1774207	6862	9 5	9 5 14 5	Observation	
LAO 1	1966	1629395	1773956	6836	25 4	8 20	Observation	
LAO 1 2	1969	1632644	1773956	6740	18	8 18	Observation	
LAO 1 8	1969	1635446	1172961	6680	18	8 18	Observation	
LAO 2	1966	1637608	1773096	6593	29	12 32	Observation	
LAO 3	1966	1638011	1773098	6578	24	16 32	Observation	
LAO 3A	1989	1637981	1773100	6579	15	4 7-14 7	Observation	
LAO 4	1966	1640752	1772729	6519	24	14 24	Observation	
LAO 4 5	1969	1643659	1772088	6452	40	10-40	Observation	Obstruction in well
LAO 4 5A	1989	1643500	1772062	6460	18 5	8 5-18 5	Observation	Dry HSWA Special Permit
LAO 4 5B	1989	1643512	1772065	6459	34 9	24 9 34 9	Observation	Dry HSWA Special Permit
LAO 4 5C	1989	1643547	1772077	6458	23 3	13 3 23 3	Observation	HSWA Special Permit
LAO 5	1966	1646203	1771425	6395	25	5 25	Observation	Dry
LAO 6	1966	1646222	1771330	6395	18	8-18	Observation	Dry
LAO 6A	1989	1546222	1771344	6396	14 2	4 2 14 2	Observation	HSWA Special Permit
LAO B	1994	1615149	1775179	7323	14 24	11 8 26 8	Observation	
LAO C	1970	1622158	1775250	7050	12 2	3 13	Observation	
LAOR 1		1628595	1774282	6865			Observation	
LAOR 2		1628875	1774202	6853			Observation	
MCO 12	1971	1640444	1768182	6702	108	88-108	Observation	Replaces original MCO 12
MCO 13	1980	1641290	1767460	6674	107	87-107	Observation	Dry
MCO 2	1960	1634044	1768652	7133	9	2 9	Observation	Abandoned
MCO 3	1967	1627363	1770237	7053	12	2 12	Observation	Damaged & fixed 1994
MCO 4	1963	1631214	1769788	6900	19	14 19	Observation	
MCO 4A	1989	1632029	1769700	6888	19 4	9 4 19 4	Observation	HSWA Special Permit
MCO 4B	1990	1632036	1769697	6888	33 9	8 9 28 9	Observation	HSWA Special Permit
MCO 5	1965	1632468	1769538	6848	46	31 46	Observation	
MCO 8	1974	1633635	1769013	6878	47	27 47	Observation	Replaces original MCO 8
MCO 8 5A	1981	1634144	1768762	6840	45	25 45	Observation	

STATION	DATE INSTALLED	X-COORDINATE	Y-COORDINATE	ELEVATION	DEPTH CASE	SCREEN INTERVAL	PURPOSE	COMMENTS
MCO 6 58	1961	1624144	1768762	6839	42	22 42	Observation	
MCO 6A	1989	1633633	1768962	6850	36	22 7-32 7	Observation	HSWA Special Permit
MCO 6B	1990	1633631	1768964	6850	47 1	22 42	Observation	HSWA Special Permit
MCO 7	1960	1634518	1768510	6827	69	39 69	Observation	
MCO 7 5	1961	1635455	1768441	6808	60	35 60	Observation	
MCO 7A	1989	1634503	1768509	6828	44 8	34 8-44 8	Observation	HSWA Special Permit
MCO 8	1960	1636021	1768529	6795	84	64 84	Observation	Damaged beyond repair 1978
MCO 8 2	1961	1636044	1768562	6782	70	60 70	Observation	
MCO 9	1961	1638058	1768378	6747	55	45 55	Observation	Dry
MCO 9 5	1961	1639644	1768352	6740	46	26 46	Observation	Dry
FCO 1	1965	1637918	1759951	6687	12 3	4 3-12 3	Observation	
FCO 2	1965	1641700	1757443	6618	9 5	1 5-9 5	Observation	
FCO 3	1965	1646089	1755499	6547	17 7	5 7-17 7	Observation	
FO 3B	1966	1642444	1776062	6250	59	49 59	Observation	
FO 4A	1966	1641044	1775762	6524	21	12 21	Observation	
FO 4B	1966	1625444	1776162	6542	36	31 36	Observation	
POTO 4C	1989	1638644	1757062	6620	46	26 36	Observation	
SCO 1	1989	1642298	1766502	6619	19 3	9 3-19 3	Observation	Dry, HSWA Special Permit
SCO 2	1989	1647259	1767864	6501	19 4	9 4-19 4	Observation	Dry, HSWA Special Permit
SMO 1	1990	1641799	1756653	6650	104	50 80	Observation	Dry
TSCO 1	1961	1633344	1768462	6857	35	15 35	Observation	
WCO 1	1989	1632759	1755059	6618	34 4	24 4-34 4	Observation	Dry, HSWA Special Permit
WCO 2	1989	1636870	1753220	6625	23 5	13 5-23 5	Observation	Dry, HSWA Special Permit
WCO 3	1989	1640213	1750620	6438	12 4	9 14	Observation	Dry
No map designation								
EAO 0 7							Observation	
MCO 4 9	1973	1632372	1769669	6880	30		Observation	
MT-1	1988	1635263	1768496	6812	69	39 59		Test
MT 2	1988	1636022	1768547	6797	64	44 54		Test
MT-3	1988	1635082	1768659	6787	74	44 84		Test
MT 4	1988	1638559	1768634	6785	74	54 84		Test
POTO 4A	1989	1639644	1757062	6620	174	154 164	Observation	
POTO 4B	1988	1638644	1757062	6620	99	79 89	Observation	
POTO 5A	1988	1638644	1757062	6620	77 5	57 5-67 5	Observation	
POTO 5B	1988	1638644	1757062	6620	27	7-17	Observation	

STATION	DATE INSTALLED	X-COORDINATE	Y-COORDINATE	ELEVATION	DEPTH CASE	SCREEN INTERVAL	PURPOSE	COMMENTS
SF 2B	1986	1667580	1758621	5543	824	802 812	Observation	
SF-2C	1986	1667580	1758621	5543	356	324 334	Observation	
SF-3B	1986	1587244	1778062	5480	169	149 159	Observation	
SF-3C	1986	1584244	1773062	5480	60	40 50	Observation	
SF-4B	1986	1571244	1788062	5470	110	110-120	Observation	Flowing
SF 4C	1986	1570244	1804062	5470	60	40-50	Observation	
SF-5B	1986	1584244	1794062	5455	160	140-150	Observation	
SF-5C	1986	1504144	1762562	5455	69	49 59	Observation	
Fenton Hill								
FH 1	1976	1515244	1775862	8690	450		Supply	
Location 27		1524144	1773662	7650			Observation	Artesian well overflow bare tank
Location 4		1522444	1773062	7760			Observation	Hulbahn, Community water source
Location 42		1521644	1772362	7840			Observation	Gallatine well
Location 47		1524844	1770762	7640			Observation	Lewis well
Location 48		1524844	1771262	7630			Observation	La Cueva lumber yard well
Location 53		1529044	1776762	7935			Observation	Crest Sulphur Creek well
Location 54		1528444	1778262	7795			Observation	Hansen, Sulphur Creek well
Location 55		1528744	1776662	7805			Observation	Olsen, Sulphur Creek well
No map designation								
FH 2	1980	1515244	1775862	8691	450		Supply	
FH 3	1980	1515244	1775862	8692	460		Supply	

Springs In Los Alamos Area

STATION	DESCRIPTION	X-COORDINATE	Y-COORDINATE	ELEVATION
Alluvial				
DP Spring	DP Canyon	1836615	1773713	
Hamilton Bend Spring	Lower Pueblo Canyon	1642614	1776162	
Intermediate				
Bessil Spring	Lower LA Canyon	1656544	1770762	6000
Water Canyon Gallery	Flank of mountains	1604144	1762562	6000
Main				
Ancho Spring	Group I	1645644	1739062	5700
Doe Spring	Group II	1642325	1733598	5600
Indian Spring	Lower LA Canyon	1665944	1777262	5640
La Mesita Spring	Group IV	1656544	1770782	5580
Rio Spring 1	Group III	1667928	1767957	5615
Rio Spring 10	Group II	1638023	1728182	5360
Rio Spring 2	Group III	1667312	1756348	5600
Rio Spring 3	Group I	1661487	1753562	5560
Rio Spring 3A	Group I	1661520	1753298	5560
Rio Spring 3AA	Group I	1661261	1751050	5560
Rio Spring 3B	Group IV	1661354	1740814	5500
Rio Spring 4	Group I	1656028	1747887	5570
Rio Spring 4A	Group I	1656144	1747882	5570
Rio Spring 5	Group I	1656056	1742541	5770
Rio Spring 5A	Group II	1655365	1742005	5395
Rio Spring 5AA	Group I	1651144	1742562	5780
Rio Spring 6	Group II	1648882	1735517	5380

STATION	DESCRIPTION	X-COORDINATE	Y-COORDINATE	ELEVATION
Rio Spring 6A	Group II	1646562	1734272	5375
Rio Spring 7	Group II	1645044	1733562	5370
Rio Spring 8	Group II	1644444	1733462	5370
Rio Spring 8A	Group II	1643819	1733508	5520
Rio Spring 9	Group II	1643435	1733317	5485
Rio Spring 9A	Group II	1642742	1733147	5525
Sacred Spring	Lower LA Canyon	1670044	1780062	5640
Sandia Spring	Group I	1663182	1781490	5700
No map designation American Spring	Group I	1601044	1760062	8280
Ancha Spring	Group IV	0	0	0
Apache Spring	Flank of mountains	1596144	1753862	8320
Armstead Spring	Flank of mountains	1599744	1782782	8218
Bulldog Spring	TA 9			
Burning Ground Spring	TA 16			
Canada Spring	Group IV			5780
Charlie Spring				
Frijoles Spring 1	Flank of mountains	1592344	1759562	8430
Frijoles Spring 2	Flank of mountains	1589344	1759362	8430
Guaje Spring 1	Flank of mountains	1600444	1797782	8850
Guaje Spring 2	Flank of mountains	1600444	1798062	8840
Homestead Spring				
JS 2,3	Fenton Hill	1509544	1735762	8220
JS 4,5	Fenton Hill	1511544	1741162	8265
Location 31	Fenton Hill	1431145	1787262	7800
Location 39	Fenton Hill	1502145	1773362	7880
Location 6	Fenton Hill	1523844	1772862	7870
Location JF-1 (Hot Spring)	Fenton Hill	1522544	1757562	8780

STATION	DESCRIPTION	X-COORDINATE	Y-COORDINATE	ELEVATION
Location JF 5 (Pict Spring)	Fenton Hill	1510844	1743062	6400
Los Alamos Spring	Lower LA Canyon	1657444	1770962	6000
Otowi Seep	TA 74			
PC Spring	Flank of mountains	1601544	1773262	8660
Quemazon Spring	Flank of mountains	1603044	1786462	8660
Reservoir Spring	Flank of mountains	1606944	1775862	8000
Rio Spring 2A	Group IV	1662644	1754862	5495
Rio Spring 5B	Group II	1651044	1738162	5390
Rio Spring 8B	Group II	1643244	1733562	5480
Rio Spring 9B	Group II	1642437	1732938	
RV 2 (Pict Spring)	Fenton Hill	1523244	1795862	8360
RV 4 (Pict Spring)	Fenton Hill	1528044	1764762	7360
RV 5 (Pict Spring)	Fenton Hill	1528544	1753962	7340
Shaling Rock Spring	Upper LA Canyon			
Stonzer Spring				
SWSC Line Spring	TA 18			
TA 15	TA 18			
TA 18 Spring	TA-18	1634183	1795782	
Valle Spring 1	Flank of mountains	1604144	1766462	8260
Valle Spring 2	Flank of mountains	1604344	1766562	8240
VG Spring 4	Valle Grande	1587244	1778062	8600
VG Spring 5	Valle Grande	1584244	1773062	8524
VG Spring 6	Valle Grande	1567744	1780962	8640
VG Spring 7	Valle Grande	1571244	1788062	8700
VT Spring 1	Valle Toledo	1570244	1804062	8570
VT Spring 2	Valle Toledo	1581244	1799062	8732
VT Spring 3	Valle Toledo	1584244	1794062	8868

APPENDIX F

Groundwater Monitoring Plan

GROUNDWATER MONITORING

This chapter documents the scope of the groundwater monitoring program at the Laboratory. Groundwater may accumulate contaminants from discharges to surface water or from leakage of liquid effluent storage systems. Though hydrogeologic conditions at the Laboratory greatly protect the main aquifer from near-surface activities, groundwater monitoring is conducted to detect any threats to the resource.

A. Rationale and Monitoring Requirements

Groundwater monitoring is conducted within and near the Laboratory to provide indications of the potential for human and environmental exposure from contaminated groundwater sources. Various standards and guidelines are used as a basis for assessing the water quality of surface water and groundwaters. In addition, by comparing monitoring results with those of previous years, a significant decline in the quality of water would be indicated and corrective action would be implemented.

Groundwater resource management and protection at Los Alamos is focused on the main aquifer underlying the region. The aquifer has been of paramount importance to Los Alamos since the days following the World War II Manhattan Engineering District, when the Atomic Energy Commission (AEC) needed to develop a reliable water supply. The US Geological Survey (USGS) was extensively involved in overseeing and conducting various studies for development of groundwater supplies starting in 1945—46. Studies specifically aimed at protecting and monitoring groundwater quality were initiated as joint effort between the AEC, the Los Alamos Scientific Laboratory, and the USGS in about 1949. Several hundred reports and articles document the program elements and the data germane to groundwater and the related Los Alamos environmental setting.

The controlled development and production of the water supply have not resulted in any significant depletion of the resource as there is no widespread major decline of the piezometric surface of the aquifer. Drawdowns are localized in the vicinity of the production wells; nearly complete recoveries are observed when wells are shutdown for routine maintenance.

This program is required by Laboratory's Hazardous and Solid Waste Amendments (HSWA) and Resource Conservation Recovery Act (RCRA) Hazardous Waste Facility Permit, Module VIII, and by DOE Orders 5400.1 (DOE 1990a) and (DOE 1990b) and Regulatory Guide DOE/EH-0173T (DOE 1991). The Laboratory's HSWA Permit specifically requires monitoring of the canyon alluvial groundwater systems in Pueblo, Los Alamos, Sandia, Mortandad, Potrillo, Fence, and Water Canyons. The HSWA Permit also requires that the present Environmental Surveillance Program, carried out in accordance with DOE orders, shall be continued, in order to demonstrate protection of the main aquifer system. Task III of the Laboratory's HSWA Permit requires the Laboratory to collect information to supplement and verify existing information on the environmental setting at the facility, including hydrogeology and to collect analytical data on groundwater, soils, surface water, sediment, and subsurface gas contamination.

B. Design Criteria

The objectives of the groundwater surveillance program include

- protection of the main aquifer system (as required by the Laboratory's HSWA Permit);
- evaluation of propagation of present and past releases of radionuclides into canyon bottoms within the facility boundary, including accidental releases and effluent streams (as required by the Laboratory's HSWA Permit and DOE Orders);

- evaluation of water quality and contaminant migration within the alluvial groundwater systems, which may be protectable under New Mexico Water Quality Control Commission (NMWQCC 1993, NMWQCC 1994) standards, and (in light of evidence of off-site groundwater contamination due to Laboratory operations) which could have a deleterious effect on the water supply systems of communities adjacent to the facility.

The routine groundwater monitoring program consists of an annual sampling of a network of 65 fixed monitoring stations generally located within 6 km (4 mi) of the Laboratory. Monitoring of groundwater quality is conducted by sampling shallow and deep wells, and sampling natural groundwater discharge areas (springs).

Groundwaters will be monitored to provide routine surveillance of Laboratory operations. Concentrations of radionuclides in water samples will be compared with concentration guides derived from DOE's Radiation Protection Standards.

Routine chemical analyses of water samples include those inorganic constituents covered by State and Federal drinking water regulations. These analyses have been done for a number of years and will be a screening tool to detect significant changes in the chemical quality of water. Additionally, analytical results will be interpreted by comparison with drinking water standards.

Groundwater monitoring of the main aquifer at Los Alamos was implemented as an integral part of the comprehensive monitoring of shallow alluvial groundwater in canyons, surface water, soils, and sediments. These other media are indicators of potentials for groundwater contamination and document the range of possible pathways.

Groundwater resource monitoring also routinely documents conditions of the water supply wells and the main aquifer as part of the overall Groundwater Protection Management Program (LANL 1990). (Note: The LANL Groundwater Protection Management Plan has a newer version, also have revision 1, in draft form, March 6, 1995). This information is documented in an annual series of reports providing detailed records of pumping and water-level measurements.

1. Action Levels

This Section concerns the evaluation of environmental water samples. Some of these samples are drawn from public water supply wells. Compliance of the public water supply system with the Safe Drinking Water Act is discussed in Section 6.

Concentrations of radionuclides in environmental water samples from the main aquifer, the alluvial perched water in the canyons, and the intermediate depth perched systems, whether collected within the Laboratory boundaries or off site, may be evaluated by comparison with derived concentration guides (DCGs) for ingested water calculated from DOE's public dose limits (PDLs) (see Section V.C.2 of EPG 1994). Concentrations of radioactivity in samples of water from the water supply wells completed in the Los Alamos main aquifer are also compared to New Mexico Environment Department (NMED), New Mexico Environmental Improvement Board (NMEIB), and Environmental Protection Agency (EPA) drinking water standards or to the DOE DCGs applicable to radioactivity in DOE drinking water systems, which are more restrictive in a few cases.

The concentrations of nonradioactive chemical quality parameters may be evaluated by comparing them to NMEIB and EPA drinking water standards (maximum concentration levels [MCLs]), even though these

standards are only directly applicable to the public water supply. The supply wells in the main aquifer are the source of the Los Alamos public water supply. Although it is not a source of municipal or industrial water, the shallow alluvial groundwater results in return flow to surface water and springs used by livestock and wildlife, and may be compared to the Standards for Groundwater or the Livestock and Wildlife Watering Standards established by the NMWQCC (NMWQCC 1993, NMWQCC 1994). These standards are discussed in Section 7, under surface water standards.

A compilation of these limits is given in Table 8-1. If samples are found to exceed one half of the relevant MCL or Action Level, follow up sampling or analysis of the environmental conditions are conducted.

TABLE 8-1 Regulatory Limits For Chemical Constituents in Groundwater and Water Supply Systems.

Constituent	Detection Limit	Action Level	Maximum Contaminant Level (MCL)	MCL Source
Radioactive Constituents				
Gross Alpha	3 pCi/L	5*	15 pCi/L	40 CFR 141
Gross Beta	3 pCi/L	50*	4 mrem/yr	40 CFR 141
Gross Gamma			none	
^{137}Cs	2 pCi/L	120 pCi/L*	none	DOE 5400.5
Tritium	0.4 nCi/L		20,000 pCi/L*	40 CFR 141
^{239}Pu	0.02 pCi/L	1.6 pCi/L*	none	DOE 5400.5
$^{239,240}Pu$	0.02 pCi/L	1.2 pCi/L*	none	DOE 5400.5
total U	0.1 ug/L		20 ug/L	40 CFR 141
^{241}Am	0 02 pCi/L	1.2 pCi/L*	none	DOE 5400.5
^{90}Sr	3 pCi/L		8 pCi/L*	40 CFR 141
Metals				
Ag	10 ug/L		50 ug/L	NMWQCC 1993
Al	100 ug/L		50-200 ug/L*	40 CFR 143
As	2 ug/L		50 ug/L	40 CFR 141
B	10 ug/L		750 ug/L	NMWQCC 1993
Ba	100 ug/L		1000 ug/L	NMWQCC 1993
Be	1 ug/L		4 ug/L	40 CFR 141
Cd	3 ug/L		5 ug/L	40 CFR 141
Co	2 ug/L		50 ug/L	NMWQCC 1993
Cr	4 ug/L		50 ug/L	NMWQCC 1993
Cu	4 ug/L	1300 ug/L*	1000 ug/L	NMWQCC 1993
Fe	100 ug/L		300 ug/L*	40 CFR 143
Hg	0.2 ug/L		2 ug/L	40 CFR 141
Mn	2 ug/L		50 ug/L*	40 CFR 143
Mo	8 ug/L		1000 ug/L	NMWQCC 1993
Ni	20 ug/L		100 ug/L	40 CFR 141
Pb	5 ug/L	15 ug/L*		40 CFR 141
Sb	2 ug/L		6 ug/L	40 CFR 141
Se	2 ug/L		50 ug/L	40 CFR 141

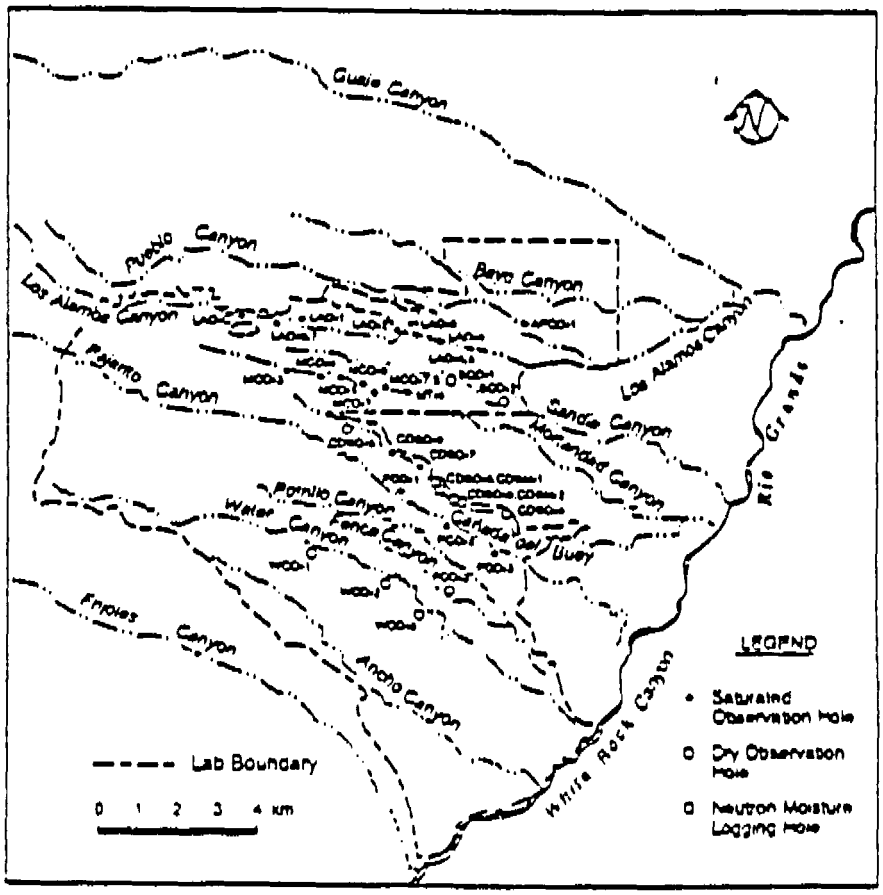
Constituent	Detection Limit	Action Level	Maximum Contaminant Level (MCL)	MCL Source
Sr	100 ug/L	25-90 mg/L[f]		
Tl	1 ug/L		2 ug/L	40 CFR 141
V	10 ug/L	80-110 ug/L[f]		
Zn	20 ug/L		5 mg/L[e]	40 CFR 143
General Inorganic Constituents				
Ca			none	
Cl	10 mg/L		250 mg/L[e]	40 CFR 143
CN	10 ug/L		200 ug/L	40 CFR 141
CO_3			none	
HCO_3			none	
F	100 ug/L		1600 ug/L	NMWQCC 1993
Mg			none	
K			none	
Na			20 mg/L[f]	
NO_3-N	100 ug/L		10 mg/L	40CFR 141
PO_4			none	
SiO_2			none	
SO_4	50 mg/L		250 mg/L[e]	40 CFR 143
pH			6.5 - 8.5[e]	40 CFR 143
Hardness as $CaCO_3$			none	
TSS			none	
TDS			500 mg/L[e]	40 CFR 143
Conductivity			none	
Organic Constituents				
Volatile Organic Compounds			varies, multiple contaminants	40 CFR 141
Semivolatile Organic Compounds			varies, multiple contaminants	40 CFR 141
Priority Pollutants			none	
Herbicides			varies, multiple contaminants	40 CFR 141
Pesticides			varies, multiple contaminants	40 CFR 141
PCBs	0.01 ug/L		0.01 ug/L	40 CFR 141
Oils			none	
Solvents			none	

a EPA screening level
b DOE DCG applicable to DOE Drinking Water System
c Average Annual Concentration set by 40 CFR 141.16 Table A
d EPA action level
e EPA secondary drinking water standard
d EPA action level
e EPA secondary drinking water standard
f EPA Health Advisory

2. Sampling of Shallow Perched Alluvial Groundwater Systems

Groundwater samples will be collected from approximately 18 wells completed in narrow perched groundwater systems found in alluvium within canyon bottoms (Figure 8-1, Table 8-2). The groundwater systems are perched on the underlying Bandelier Tuff and recharged by the infiltration of liquid effluents and/or natural runoff. An additional 12 observation wells and 2 neutron moisture holes have remained dry. The alluvial perched groundwaters in five canyons are sampled by means of shallow observation wells as part of the routine monitoring program. Pueblo and Los Alamos canyons are former radioactive effluent release areas, and Mortandad Canyon presently receives treated radioactive effluents. The fourth is Pajarito Canyon, immediately south of the existing solid waste management areas at TA-54 on Mesita del Buey. The fifth is Cañada del Buey, immediately north of the existing solid waste management areas at TA-54 on Mesita del Buey, and downstream of the Laboratory's new Sanitary Wastewater Systems Consolidation project. All of these alluvial perched groundwater sampling locations are on site. The extent of saturation in the alluvial groundwater systems varies seasonally, in response to variations in runoff from snowmelt, summer thunderstorms, and discharges from the Laboratory's National Pollutant Discharge Elimination System (NPDES)-permitted outfalls. In any given year, some of these alluvial observations wells may be dry, and thus no water samples can be obtained. Wells in four other canyons, Sandia Canyon, Bayo Canyon, Fence Canyon, and Water Canyon, have remained dry.

Figure 8-1 Alluvial Observation Wells and Neutron Moisture Holes



a. Effluent Release Areas

As discussed in Section 7.B.1.c., the canyons that presently receive or have received treated industrial effluents are Acid-Pueblo, DP-Los Alamos, Sandia, and Mortandad.

Groundwater in the alluvium of Pueblo Canyon is sampled at one observation well. Acid Canyon, a small tributary of Pueblo Canyon, received untreated and treated industrial effluent that contained residual radionuclides from 1944 to 1964 (ESG 1981). Pueblo Canyon currently receives treated sanitary effluent from the Los Alamos County Bayo sewage treatment plant in the middle reach of Pueblo Canyon. Water occurs seasonally in the alluvium, depending on the volume of surface flow from snowmelt, thunderstorm runoff, and sanitary effluents. One sampling point, Hamilton Bend Spring, which in the past discharged from alluvium in the lower reach of Pueblo Canyon, has been dry since 1990, probably because there was no discharge from the older, almost abandoned Los Alamos County Pueblo sewage treatment plant. Further east, at the location of Well APCO-1, the alluvium is continuously saturated, mainly because of infiltration of effluent from the Los Alamos County Bayo sanitary sewage treatment plant. At APCO-1, the alluvium is about 3.4 m (11 ft) thick and depth to water is about 1.8 m (6 ft).

The on-site reach of Los Alamos Canyon presently carries flow from the Los Alamos Reservoir to the west of the Laboratory, as well as NPDES-permitted effluents from TA-2, TA-53, and TA-21. In the past, Los Alamos Canyon received treated and untreated industrial effluents containing some radionuclides. An industrial liquid waste treatment plant at TA-21 discharged effluent containing radionuclides into DP Canyon, a tributary to Los Alamos Canyon, from 1952 to 1986. In Los Alamos Canyon, sampling stations consist of six or more observations wells completed into alluvium (about 6 m [20 ft] thick). Water levels decline in DP-Los Alamos Canyon during the winter and early summer as natural storm runoff is at a minimum (ESG 1981).

In Sandia Canyon, two monitoring holes in the lower canyon just west of State Road 4 indicated no perched water in the alluvium in this area, which receives sanitary sewage and power plant blow down.

Mortandad Canyon has a small drainage area that heads at TA-3. Its drainage area presently receives inflow from natural precipitation and a number of NPDES-permitted effluents including those from the existing radioactive liquid waste treatment plant at TA-50. These effluents infiltrate the stream channel and maintain a saturated zone in the alluvium extending about 3.5 km (2.2 mi) downstream from the TA-50 outfall. The easternmost extent of saturation is on site, about 1.6 km (1 mi) west of the Laboratory boundary with the Pueblo of San Ildefonso. Monitoring stations in Mortandad Canyon include six observation wells completed in the shallow alluvial groundwater system. The wells in the lower reach of the canyon are dry. The top of the main aquifer is about 290 m (950 ft) below the perched groundwater system (Purtymun 1974).

b. Non-effluent Release Areas

Three observation wells in Pajarito Canyon are used to monitor the perched water in the alluvium (about 4 m (12 ft)thick). Water in the alluvium is perched on the underlying tuff and is recharged through storm runoff. The observation wells will be utilized to determine if technical areas in the canyon or adjacent mesas (e.g., TA-54) are affecting the quality of shallow groundwater system.

In 1992, a Groundwater Discharge Plan DP-857 (NMED 1992) was approved by the New Mexico Environment Department for the Sanitary Wastewater Systems Consolidation Plant's proposed discharges

of sanitary effluent into Cañada del Buey. In 1985, four monitoring wells were installed in Cañada del Buey, to evaluate possible contamination from adjacent mesas (e.g., TA-54). In 1992, five additional alluvial wells were installed to meet the terms of the Groundwater Discharge Plan. Also in 1992, two deeper moisture monitoring wells were installed to monitor depths of 58 m and 30 m (189 ft and 99 ft). To date, all but two wells are dry. Two alluvial wells had saturation. One well (CDBO-6) had enough saturation to merit installing a bladder pump; this well was added to the surveillance network. The Groundwater Discharge Plan committed the Laboratory to a schedule of routine groundwater monitoring at five wells (CDBO-4, 5, 6, 7, and 8), two neutron probe moisture monitoring tubes (CDBM-1 and 2), and a main aquifer water supply well (PM-4). The specific monitoring parameters and frequencies are presented in Table 2 of DP-857 (NMED 1992).

Since the Sanitary Wastewater Systems Consolidation Plant started up in August 1992, its effluent has been pumped to TA-3 for reuse or discharge at the Sandia Canyon outfall. No discharges of effluent have been made into Cañada del Buey. In spite of this deviation from the discharge plan's original intent, the Laboratory is committed to continuing the groundwater monitoring program for Cañada del Buey.

Three alluvial observation wells in Water Canyon and one well in Fence Canyon are located downstream from firing sites, from which depleted uranium, beryllium, barium, and lead have been dispersed. All four of the observation wells have remained dry. The wells are monitored in the event that saturation should occur in the alluvium.

3. Sampling of Perched Groundwater in Basalts and Conglomerate

Perched groundwater of limited extent occurs in the conglomerates and basalts beneath the alluvium in portions of Pueblo, Los Alamos, and Sandia Canyons. Samples are obtained from two test wells and one spring. Perched water in the basaltic rocks is sampled at Test Well 2A (Figure 8-2) in Upper Pueblo Canyon, at Test Well 1A in Lower Pueblo Canyon, and at Basalt Springs in lower Los Alamos Canyon. Recharge to the perched groundwater system in the basalt occurs near Hamilton Bend Springs and consists mainly of sanitary effluents from the Bayo Treatment Plant near Hamilton Bend Springs. Travel time from the recharge area near Hamilton Bend Spring to Test Well 1A is estimated to be one to two months and another two to three months to Basalt Springs. Test Well TW-2A (drilled to a depth of 40.5 m [133 ft]), penetrates the alluvium and Bandelier Tuff and is completed into the Puye Conglomerate. Aquifer tests indicate the perched groundwater system is of limited extent. Water level measurements over a period of time indicate the perched groundwater system is hydrologically connected to the stream in Pueblo Canyon.

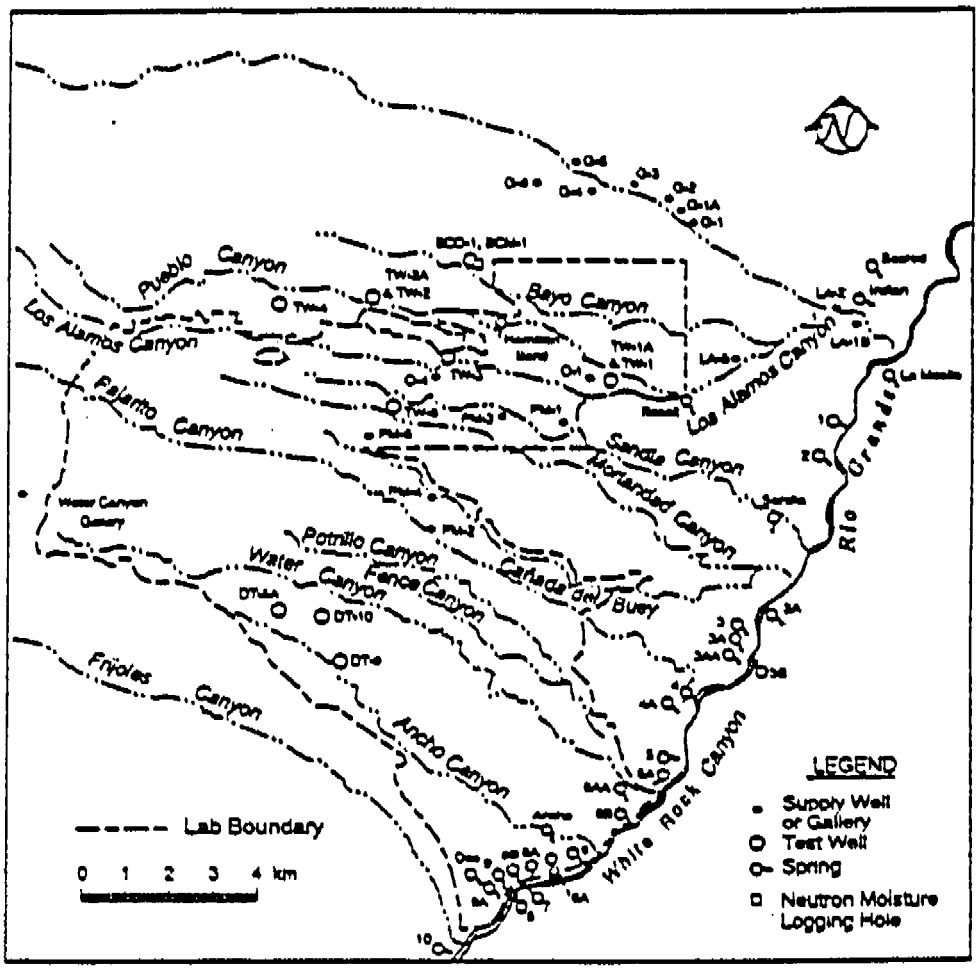
4. Sampling of Perched Water in Jemez Volcanics Water Canyon Gallery

The gallery is west of the Laboratory on the flanks of the mountains. The Water Canyon gallery collects spring discharge from a perched water zone in the volcanics on the flanks of the mountains west of Los Alamos and Pajarito Plateau. Since 1988, the gallery supplies makeup water for the steam plant at TA-16. Water samples are collected from the water spigot near the micro strainer at the gallery storage tanks.

5. Sampling of Perched Groundwater in the Guaje Pumice

Bayo Canyon was the site of the Ra-La shots, which dispersed radium and lanthanum, as well as depleted uranium and explosives. Several wells drilled during Environmental Restoration cleanup activities found no saturation in the alluvium. Two wells (about 58.5 m (65 ft) deep) were retained for the surveillance network, one of which was completed as a neutron probe moisture monitoring tube (BCM-1). The wells penetrated 34.2 m (38 ft) of alluvium and 21.6m (24 ft) of the Guaje Pumice Bed, and are monitored in the event that saturation should occur in these strata

Figure 8-2 Monitor Wells



6. Sampling of Main Aquifer

The main aquifer is the only aquifer in the area capable of municipal and industrial water supply.

a. Test Wells

Seven test wells, originally drilled as hydrogeologic exploratory holes, will be utilized as main aquifer monitor wells (Figure 8-2). These test wells were drilled by cable tool methods in the 1940s and 1950s. Groundwater pumped from test wells is not used for municipal, industrial, or irrigation supply.

Test Wells 1 and 2 are in the lower and middle reach of Pueblo Canyon. Depths to the top of the main aquifer are 181 to 231 m (594 and 758 ft), respectively. Test Well 3 is in the middle reach of Los Alamos Canyon with a depth of 228 m (748 ft) to the top of the main aquifer. These wells are in canyons that have received (Pueblo Canyon) or are now receiving (Los Alamos Canyon) industrial effluents. Test Wells DT-5A, DT-9, and DT-10 are at the southern edge of the Laboratory. Depths to the top of the main aquifer are 359 and 332 m (1,180 and 1,090 ft), respectively. Test Well 8 is in the middle reach of Mortandad Canyon, an area that receives industrial effluents. The top of the aquifer lies at about 295 m (968 ft).

b. Supply Wells

To supplement monitoring coverage provided by the dedicated monitoring (test) wells, municipal supply wells additionally are sampled (Figure 8-2). Water for the Laboratory and community is supplied from 14 deep wells in three well fields (Otowi, Pajarito, and Guaje) and one gallery (see above). Wells in the Los Alamos field have been plugged (LA-1, LA-3, LA-4, and LA-6) or turned over to San Ildefonso Pueblo for monitoring and water supply (LA-1B, LA-2, and LA-5).

The Guaje Well Field is composed of seven producing wells; only 3 or 4 wells were in service during 1993 and 1994. Wells in the field range in depth from 463 to 610 m (1,530 to 2,001 ft). Movement of water in the upper 430 m (1,410 ft) of the aquifer is southeastward at about 11 m/yr (36 ft/yr) (Purtymun 1984).

The Pajarito Well Field is composed of five wells. Wells range in depth from 701 to 942 m (2,300 to 3,090 ft). Movement of water in the upper 535 m (1,755 ft) of the aquifer is eastward at 29 m/yr (95 ft/yr).

Two new water supply wells were completed in 1990. These are the first wells in a new field designated as the Otowi Well Field. These wells were designated Otowi-1 and Otowi-4. No production from these wells occurred during 1992. Otowi-4 was connected to the distribution system during 1993.

c. Sampling of Springs

A principal natural discharge area for the main aquifer is along White Rock Canyon (Figure 8-2), adjacent to the Rio Grande (Purtymun 1980). This area represents a major uncontrolled contaminant release zone, should the main aquifer become contaminated. Sampling of groundwater, therefore, is conducted at 22 springs in White Rock Canyon (Fig. 8-2, Table 8-2).

The stations are composed of four groups of springs. Three groups (Group I, II, and III) have similar aquifer-related chemical quality. Water from these springs is part of the main aquifer beneath the Pajarito Plateau (Purtymun 1980). Chemical quality of Spring 3B (Group IV) reflects local conditions in the aquifer discharging through a fault in volcanics. Discharge at these springs range from less than 1 L/sec (0.25 gal/sec) to 37 L/sec (10 gal/sec) (Purtymun, 1980).

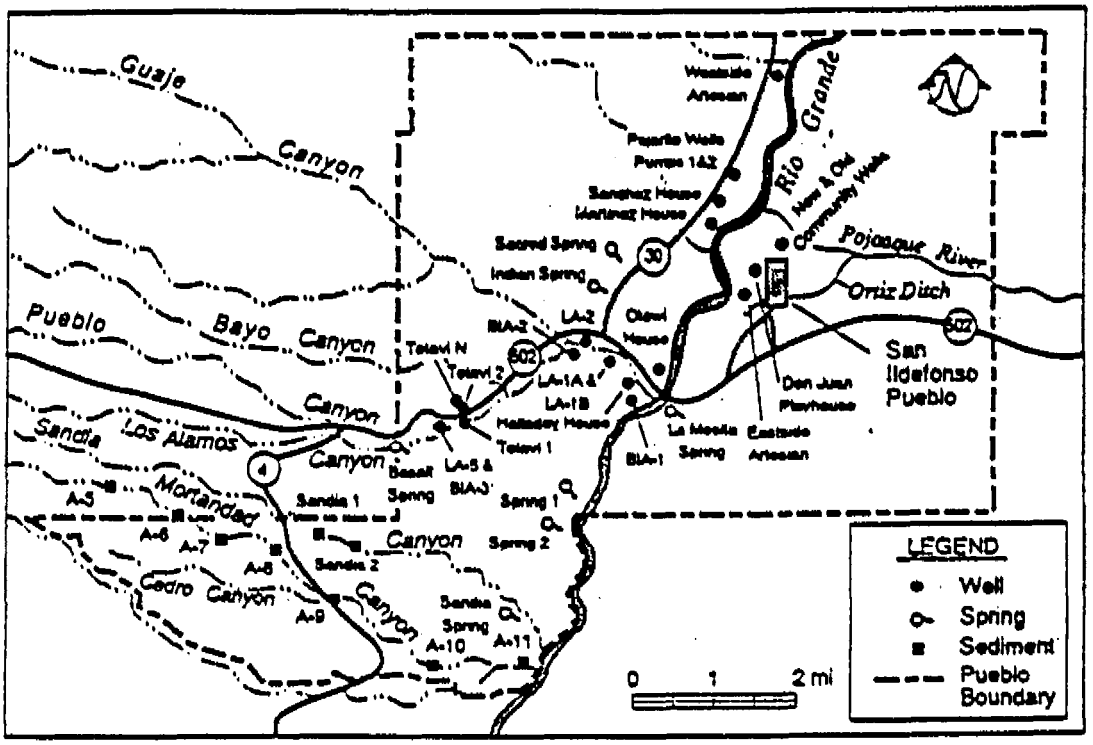
Additional sampling of three other nearby springs is conducted. La Mesita Spring is east of the Rio Grande. Indian and Sacred Springs are west of the river in lower Los Alamos Canyon. The springs discharge from faults in the siltstones and sandstones of the Tesuque Formation and form small seep areas. Total discharge at each spring is probably less than 1 L/s (0.25 gal/s).

7. Special Sampling

a. San Ildefonso Memorandum of Understanding

Groundwater monitoring is conducted on San Ildefonso Pueblo land (Figure 8-3) as a part of a broader environmental monitoring program (see Section 7.B.1.d). In 1992, eight wells were sampled. A list of wells that may be sampled is provided in Table 8-2. The Los Alamos Well Field wells LA-1B, LA-2, and LA-5 were turned over to San Ildefonso Pueblo in 1992.

Figure 8-3 Sediment and Groundwater Stations and Springs on San Ildefonso Pueblo Land



b. Fenton Hill (TA-57)

The chemical quality of groundwaters in the vicinity of the Fenton Hill Geothermal Site has been monitored since the early 1970s. Groundwater stations include five springs and three wells (see Figure 7-3).

C. Program Implementation

1. Routine Monitoring Station Network

Groundwater sampling locations have been selected upon consideration of the probable mode of contaminant transport and contaminant source locations. Emphasis is placed on monitoring both the shallow (perched) groundwater systems and the deep main aquifer, as well as intermediate-depth groundwater systems, where present.

Although most facilities at the Laboratory are located on mesa tops, the general location with the highest potential for groundwater contamination to occur is in the canyon bottoms. Waterborne contaminants are more likely to be present in the canyon bottoms because of the release of liquid effluents and the collection of snowmelt and summer runoff in the canyons. The potential for contaminants on the mesa tops to migrate downward under the influence of natural precipitation is greatly diminished by the thickness and extreme dryness of the underlying rock.

The groundwater sampling network is comprised of 17 saturated shallow (perched groundwater system) observation wells, 12 dry alluvial wells, two dry neutron moisture logging holes, 7 deep (main aquifer) test wells, 2 intermediate test wells, 14 deep municipal supply wells and a gallery, and 28 springs. Sampling station locations are presented in Figures 7-3, 8-1, 8-2, and 8-3 and Table 8-2.

Sampling stations are grouped by hydrogeologic unit, beginning with the shallowest unit. For consistency, water samples from a given station usually will be collected in the same month from year to year. Samples will be collected for the routine environmental surveillance program according to the schedule in Table 8-2.

Stations and samples will be assigned a unique alphanumeric identifier to provide chain-of-custody control during the transfer of samples from the time of collection through the analysis and reporting.

New monitoring wells will be designed and installed according to the specifications of the American Society for Testing and Materials guidance document (ASTM 1990), or the EPA National Water Well Association Handbook (EPA 1989), or according to approved Laboratory Environmental Restoration Program Safe Operating Procedures. Monitoring wells which are to be abandoned will follow the specifications of the New Mexico Environment Department and New Mexico State Engineer Office (NMEID 1990).

TABLE 8-2: Groundwater sampling stations, analytes, and sampling frequencies.

Station Name	Analytes	Frequency
Main Aquifer On Site		
Test Wells:	Radiochemistry I & III	Annual
Test Well 1	Metals	Triennial
Test Well 3	General Inorganic	Annual
Test Well 8	Organics	Triennial
Test Well DT-5A		
Test Well DT-9		
Test Well DT-10		
Water Supply Wells:	Radiochemistry I & III	Annual
O-4	Metals	Annual
PM-1	General Inorganic	Annual
PM-2	Organics	Triennial
PM-3		
PM-4		
PM-5		
Main Aquifer Off Site		
Test Wells:	Radiochemistry I & III	Annual
Test Well 2	Metals	Triennial
Test Well 4	General Inorganic	Annual
	Organics	Triennial
Water Supply Wells:	Radiochemistry I & III	Annual
Well G-1	Metals	Annual
Well G-1A	General Inorganic	Annual
Well G-2	Organics	Triennial
Well G-3		
Well G-4		
Well G-5		
Well G-6		
Main Aquifer Springs		
	Radiochemistry I	Annual
	Metals	Triennial
	General Inorganic	Annual
	PCBs (selected springs)	Annual
White Rock Canyon Group I:		
Sandia Spring		
Spring 3		
Spring 3A		
Spring 3AA		
Spring 4		
Spring 4A		
Spring 5		
Spring 5AA		
Ancho Spring		

Station Name	Analytes	Frequency
White Rock Canyon Group II:		
Spring 5A		
Spring 5B		
Spring 6		
Spring 6A		
Spring 7		
Spring 8		
Spring 8A		
Spring 8B		
Spring 9		
Spring 9A		
Doe Spring		
Spring 10		
White Rock Canyon Group III:		
Spring 1		
Spring 2		
White Rock Canyon Group IV:		
La Mesita Spring		
Spring 2A		
Spring 3B		
Other Off-Site Springs:		
Sacred Spring		
Indian Spring		
Alluvial Canyon Groundwater Systems		
	Radiochemistry I, II, & III	Annual
	Metals	Annual
	General Inorganic	Annual
	Organics	Triennial
Acid Pueblo Canyons:		
Hamilton Bend Spring		
APCO-1		
Cañada del Buey:		
CDBO-4		
CDBO-5		
CDBO-6		
CDBO-7		
CDBO-8		
CDBO-9		
CDBM-1	(moisture hole)	
CDBM-2	(moisture hole)	
DP-Los Alamos Canyons:		
LAO-C		
LAO-1		
LAO-2		
LAO-3		
LAO-4		

Station Name	Analytes	Frequency
LAO-4.5		
Fence Canyon FCO-3	(well is dry)	
Mortandad Canyon: MCO-3 MCO-4 MCO-5 MCO-6 MCO-7 MCO-7.5		
Pajarito Canyon: PCO-1 PCO-2 PCO-3		
Sandia Canyon: SCO-1 SCO-2	(wells are dry)	
Water Canyon: WCO-1 WCO-2 WCO-3	(wells are dry)	
Intermediate Perched Groundwater Systems		
Pueblo/Los Alamos/Sandia Canyon Area Perched System in Conglomerates and Basalt: Test Well 1A Test Well 2A Basalt Spring	Radiochemistry I, II, & III Metals General Inorganic Organics	Annual Triennial Annual Triennial
Perched Groundwater System in Volcanics: Water Canyon Gallery	Radiochemistry I & III Metals General Inorganic Organics	Annual Triennial Annual Triennial
Bayo Canyon: BCO-1 BCM-1	(well is dry) (moisture hole)	
Fenton Hill (TA-57)		
Wells: Fenton Hill Well: FH-1 Hofheins Well: Loc. 4 La Cueva Well: Loc. 27 *Springs:* Jemez Village Spring: JS-4,5 Jemez Canyon Hot Spring: JF-1 Soda Dam Hot Spring: JF-5	Metals General Inorganic	Triennial Annual

Station Name	Analytes	Frequency
Spence Spring: RV-4 Cold Springs: Loc. 31 LF Tank: Loc. 39		
San Ildefonso Pueblo		
Water Supply and Monitoring Wells: Well LA-1A Well LA-1B Well LA-2 Well LA-5 Westside Artesian Well Eastside Artesian Well Halladay House Well Pajarito Well (Pump 1) Pajarito Well (Pump 2) Don Juan Playhouse Well Martinez House Well Otowi House Well New Community Well Old Community Well Sanchez House Well	Radiochemistry I & III Radiochemistry II Metals General Inorganic Organics	Annual Triennial Annual Annual Triennial
Alluvial Observation Wells: Totavi N Totavi 1 Totavi 2 BIA 1 BIA 2 BIA 3	Radiochemistry I, II, & III Metals General Inorganic Organics	Annual Annual Annual Triennial

Radiochemistry I = ^{137}Cs, $^{238,239,240}Pu$, tritium, total U, and gross gamma activity.
Radiochemistry II = ^{241}Am and ^{90}Sr.
Radiochemistry III = Gross alpha activity, gross beta activity, and ^{226}Ra if necessary.
Metals = Ag, Al, As, B, Ba, Be, Cd, Co, Cr, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Sb, Se, Sn, Sr, Tl, V, and Zn
General Inorganic Constituents = SiO_2, Ca, Mg, K, Na, CO_3, HCO_3, PO_4, SO_4, NO_3, CN, total dissolved solids, total hardness, total suspended solids, pH, and electrical conductance
Organics = volatiles, semivolatiles, the 129 priority pollutants, herbicides, pesticides, PCBs, oils or solvents.

2. Sampling Procedures and Equipment

JCI's Utilities Department is the utility support contractor to the Los Alamos National Laboratory. JCI maintains and operates the water supply system, and routinely obtains groundwater level measurements from water supply wells.

All samples will be collected and handled in accordance with approved Laboratory Environmental Restoration Program Safe Operating Procedures or approved ESH-18 procedures. Samples from wells will be collected after sufficient water has been pumped or bailed to ensure that the sample is representative of the groundwater system (a minimum of three casing volumes of standing water). Spring samples

(groundwater) will be collected at the discharge point. Fluid measurements of temperature, pH and specific conductance will be made at each sampling site.

Duplicate samples, when needed, will be collected independently at the same location and time by the method described above.

Before and after the groundwater well samples are collected, the pH, temperature and specific conductance will be measured. Analysis will be conducted for total recoverable metals and radiochemicals. Samples to be analyzed for radiochemicals and metals are appropriately preserved. Samples for leachable constituents will be preserved in the field and delivered to the laboratory as soon as possible in order to meet the holding time limits of the sample. Those samples then will be filtered at the laboratory.

Details of container and preservation requirements, and identification of EPA methodology for each analysis are contained in the CST-9 publication "Handbook for Sample Collection, Preservation, and Instrumental Techniques" (Williams 1990).

All samples will be chilled at collection for transport to the CST-9 sample receiving room. Samples will be maintained at a temperature of approximately 4°C (37°F).

Collection of samples for chemical and radiochemical analyses follow a set procedure to ensure proper sample collection, documentation, submittal for chemical analyses, and posting of analytical results. Further details may be found in the water sampling Quality Assurance Project Plan (Stoker, 1990) and Groundwater Sampling Draft SOP (LANL-ESH-18-601, R0) maintained by ESH-18. The procedures include:

- All samples will be handled using chain-of-custody procedures both in the field and the laboratory.
- A minimum of 5% (with a goal of 10%) of all samples submitted for laboratory analysis will be for quality control purposes.

3. Chemical Analysis Procedures

Procedures for laboratory analyses are documented by CST-9 analytical procedures manual (Gautier 1993). These methods are based on EPA methods when available, or generally recognized and accepted institutions such as the American Public Health Association or American Society for Testing and Materials. In general, water samples will be analyzed using EPA method SW-846 (EPA 1987), with other methods specified through the LANL references.

4. Data Handling, Validation, Maintenance, and Reporting

Laboratory analytical results will be electronically transferred to ESH-18 to minimize manual data transcription errors.

Analytical data will be reviewed by project staff, compiled and tabulated for inclusion in the annual report, Environmental Surveillance Report at Los Alamos (EPG 1994) or in publications associated with special studies. The annual surveillance report is reviewed internally within the ESH-18 Group, ESH Division Office, and Department of Energy offices in Los Alamos and Albuquerque. The reviewers of the annual surveillance report provide internal quality control checks for the environmental programs.

5. Preoperational Surveys

For all new or modified facilities coming on-line, DOE Orders require that a preoperational assessment be made and be documented in the site Environmental Monitoring Plan. These requirements will be met where requested during the planning stages for new or modified facilities.

6. Program Changes since the 1991 EMP

During FY 1992 and 1993, the following quality control improvements were completed for the wells:

- Dedicated (bladder) pumps were installed in all wells that previously were sampled with bailers.
- All monitoring wells were equipped with locking caps.
- Test wells were retrofitted with access ports to allow for accurate water level measurement and collection of non-aerated samples for volatile organic analyses. Supply well samples are collected from spigots.
- All wells have air-line water-level measurement devices or pressure transducers installed.
- See discussion in Section 7.C.5. regarding the development of Surveillance Database and Report Writer.

D. Quality Assurance and Control

The Quality Assurance Plan maintained by ESH-18 details the process which will govern Quality Assurance activities for groundwater monitoring (Stoker 1990).

1. Field Activities

All samples will be collected and handled in accordance with approved Laboratory Environmental Restoration Program Standard Operating Procedures or approved ESH-18 procedures.

2. Analytical Laboratory

Most water samples are analyzed by CST-9. Their overall quality program is governed by the CST-9 Environmental Chemistry Quality Assurance Plan and its supporting administrative procedures. Specific Quality Control requirements are documented in each analytical method (Gautier 1993). See Stoker (1991) for procedures regarding duplicate samples.

Samples for low levels of tritium are analyzed by the University of Miami, and their Quality Assurance program is documented in Safe Operating Procedures (Tritium Laboratory, 1994).

3. Data Reduction, Validation, and Verification

Laboratory analytical results will be electronically transferred to ESH-18 to minimize manual data transcription errors.

E. Anticipated Program Enhancements

1. Equipment Improvements

During FY 1995, all monitoring wells will be equipped with permanent identification markers.

2. Establishment of Action/Alarm Levels

As was discussed in Section 8.B.1, if samples are found to exceed one half of the relevant MCL or Action Level, follow up sampling or analysis of the environmental conditions are conducted. This also applies to stations generally having analyte values below the action levels, but with anomalous values higher than

previous values. These cases will be determined on the basis of statistical analysis of previous data. At present, further Quality Assurance of the historical data is needed, to evaluate effects such as past changes in detection limits and analytical uncertainty.

3. Establishment of Records Storage Procedures

See discussion in Section 7.C.5.

4. Changes in Preservation and Filtration Procedures

Regulatory and guidance criteria for collecting and analyzing filtered vs. unfiltered water samples differ for media (i.e. water supply systems vs. groundwater systems) and between regulatory agencies. A review of how these regulations affect surveillance sampling and analysis is underway. As part of this review, several parallel data sets have been compiled for the purpose of comparing filtered and unfiltered analyses and for the possibility of establishing background values:

- The Environmental Restoration program has analyzed a set of filtered samples from canyon bottom perched alluvial groundwater systems which will be compared to environmental surveillance samples.
- Ongoing sampling of the canyon bottom perched alluvial groundwater systems includes both a set of filtered and unfiltered samples.
- The Earth and Environmental Sciences Division has analyzed a set of filtered samples from main aquifer springs and wells which will be compared to environmental surveillance samples.
- The State Agreement in Principal DOE Oversight Program has analyzed a set of split filtered samples from a variety of locations which will be compared to environmental surveillance samples.
- The Bureau of Indian Affairs has analyzed several sets of split filtered samples from the Pueblo of San Ildefonso which will be compared to environmental surveillance samples.

5. Addition of Springs to Surveillance Network

Where new springs are discovered on or near the facility, pertinent information will be reviewed in order to evaluate whether the springs should be incorporated into the existing surveillance network.

F. References

ASTM 1990: American Society for Testing and Materials, "Standard Guide for Design and Installation of Groundwater Monitoring Wells in Groundwater systems," ASTM D-5092-90 (1990).

DOE 1990a: US Department of Energy, "General Environmental Protection Plan," DOE Order 5400.1 (June 1990).

DOE 1990b: US Department of Energy, "Radiation Protection of the Public and the Environment," DOE Order 5400.5 (February 1990).

DOE 1991: US Department of Energy, "Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance," DOE publication DOE/EH-0173T (January 1991).

EPA 1987: "Test Methods for Evaluating Solid Waste Physical/Chemical Methods," US Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, D.C., SW-846, third edition, Proposed Update Package for third edition, (December 1987).

EPA 1989: "Handbook of Suggested Practices for the Design and Installation of Groundwater Monitoring Wells," National Water Well Association and Environmental Monitoring Systems Laboratory, EPA Report EPA 600/4-89/034, (1989).

EPA 1990: Module VIII of RCRA Permit No. NM0890010515, EPA Region VI, issued to Los Alamos National Laboratory, Los Alamos, New Mexico, EPA Region VI, Hazardous Waste Management Division, Dallas, Texas, (effective May 23, 1990).

EPG 1994: Environmental Surveillance Group, "Environmental Surveillance at Los Alamos during 1992," Los Alamos National Laboratory report LA-12764-ENV/US Department of Energy report DOE/EV-0005/30 (July 1994).

ESG 1981: Environmental Surveillance Group, "Radiological Survey of the Site of a Former Radioactive Liquid Waste Treatment plant (TA-45) and the Effluent Receiving Areas of Acid, Pueblo, and Los Alamos Canyons, Los Alamos, New Mexico, Final Report," Los Alamos National Laboratory report LA-8890-ENV (May 1981).

Gautier 1993: M.A. Gautier and E.S. Gladney, "Health and Environmental Chemistry at Los Alamos: Analytical Techniques, Data Management, and Quality Assurance," Los Alamos National Laboratory report LA-10300-M, Vols. 1 - 4 (January 1986, Revised April 1993).

LANL 1990: "Groundwater Protection Management Program Plan," Los Alamos National Laboratory (April 27, 1990).

NMED 1992: "Groundwater Discharge Plan Application for Sanitary Wastewater Systems consolidation Project," New Mexico Environment Department approval number DP-857 (July 1992).

NMEID 1990: "New Mexico Environmental Improvement Division - Groundwater Section, Monitor Well Construction and Abandonment Guidelines" (November 1, 1990).

NMWQCC 1993: New Mexico Water Quality Control Commission, "New Mexico Water Quality Control Commission Regulations" (effective November 18, 1993).

NMWQCC 1994: New Mexico Water Quality Control Commission, "Water Quality Standards for Interstate and Intrastate Streams in New Mexico" (December 12, 1994).

Purtymun 1974: W. D. Purtymun, "Dispersion and Movement of Tritium in a Shallow Aquifer in Mortandad Canyon," Los Alamos Scientific Laboratory report LA-5716-MS (September 1974).

Purtymun 1980: W. D. Purtymun, R. J. Peters, and J. W. Owens, "Geohydrology of White Rock Canyon of the Rio Grande from Otowi to Frijoles Canyon," Los Alamos Scientific Laboratory report LA-8635-MS (December 1980).

Purtymun 1984: W. D. Purtymun, "Hydrologic Characteristics of the Main Aquifer in the Los Alamos Area: Development of Groundwater Supplies," Los Alamos National Laboratory report LA-9957-MS (January 1984).

Tritium Laboratory 1994: "Standard Operating Procedure: Collection and Analysis of Water Samples for Tritium," Tritium Laboratory, Rosenstiel School of Marine and Atmospheric Science, 4600 Rickenbacker Causeway, Miami, Florida (November 1994).

Stoker 1990: A. K. Stoker, "Quality Assurance Project Plan: Water, Soil, Sediments, and Water Supply Monitoring at Los Alamos National Laboratory," (Revision 2, 01/10/90), in *Quality Assurance Project Plans*, Los Alamos National Laboratory report LA-UR-87-1076 (February 1987):

Williams 1990: M. C. Williams, "Handbook for Sample Collection, Preservation, and Instrumental Techniques," Los Alamos National Laboratory manual LA-11738-M (February 1990).

APPENDIX G

USGS Proposals

Proposal NM93C
Revised July 1994

Ground-water Recharge and Flow System determination west of the Los Alamos National Laboratory area, Los Alamos County, New Mexico

Prepared by David W. Wilkins

Introduction:

Los Alamos National Laboratory (LANL) is located on the east flank of the Jemez Mountains near the west side of the Rio Grande in north central New Mexico (fig. 1). The Jemez mountains are described as volcanic pile that rests on and rises above a zone of faults at the western edge of the Rio Grande depression (Griggs, 1964). LANL is located on the Pajarito Plateau (fig. 1) which is a topographic high that slopes gently eastward to the Rio Grande. The west boundary of the Pajarito Plateau is the Sierra de los Valles.

The Tschicoma Formation of Pliocene age and the Bandelier Tuff of Pleistocene age are major volcanic units in the area. The Tschicoma Formation forms the mountains of the Sierra de los Valles, between the Valles Caldera and the Pajarito Plateau, and is present beneath the surface of the western edge of the plateau. The formation is composed of latite, quartz-latite flows, and pyroclastic rocks. The Tschicoma Formation is overlain by the Bandelier Tuff along the flanks of the mountains. The Bandelier Tuff is a series of ash flows and ash falls of rhyolitic tuff and caps the Pajarito Plateau and overlies the Puye Formation and basaltic rocks of Chino Mesa in the central and eastern edge of the plateau (Purtymun and Johansen, 1974).

The plateau is formed by rocks of the Santa Fe Group of middle (?) Miocene to Pleistocene (?) age and volcanic rocks of Pliocene and Pleistocene age (Griggs, 1964, fig. 8). The Santa Fe Group comprises the Tesuque and the Puye Formations and the basaltic rocks of Chino Mesa. The Tesuque Formation consists of friable to moderately well cemented siltstone and sandstone with lenses of conglomerate and clay and some interbedded basalt flows. The Puye Formation is a poorly consolidated conglomerate channel-fill deposit overlain by a fanglomerate composed of volcanic debris. The basaltic rocks of Chino Mesa consist of basalt and basalt breccia that overlie the Puye along the Rio Grande and interfingers with the conglomerate to the west beneath the Pajarito Plateau (Purtymun and Cooper, 1969). The Bandelier Tuff overlies the Tesuque Formation in the study area. It is the Tewa Group of the Jemez volcanic dome (Kelley, 1978) that resulted from the products of the explosion and subsequent eruptions of the Valles caldera west of the Sierra de los Valles.

The Pajarito Fault Zone lies near the western edge of the Pajarito Plateau. South of the LANL area the Bandelier Tuff on the east side of the fault is downthrown about 300 feet in relation to the tuff on the west side of the fault. To the north the fault splits into two smaller subparallel faults, both downthrown to the east. Displacement decreases northward until both faults die out.The fault

1

planes dip steeply to the east (Griggs, 1964). Kelley, (1978) shows a fault zone throughout the Espanola Basin. The downthrown block is to the east from the southern boundary of the basin to the Chama River. The downthrown block and dip are to the west north of the Chama River.

The main aquifer of the Pajarito Plateau is composed of the Tesuque Formation and the lower part of the Puye Formation. The upper surface of the main aquifer rises westward from the Rio Grande through the Tesuque into the lower part of the Puye Formation beneath the central and western parts of the plateau. The water is unconfined in the western edge of the plateau and becomes confined as water in the aquifer moves below the less permeable sediments of the Tesuque Formation along the eastern edge of the plateau and along the Rio Grande (Purtymun and Johansen, 1974). The first water supply wells drilled in the Los Alamos area were in Los Alamos and Guaja Canyons at the eastern edge of the Pajarito Plateau. These wells were finished in the Tesuque Formation and produced less than 500 gallons per minute. As more water was needed, additional wells were drilled, to the west, on the plateau. These new wells were finished in the lower Puye and upper Tesuque and produced about 1,500 gallons per minute (Purtymun and Cooper, 1969).

Problem:

Recharge areas to the plateau aquifer system and mechanism for recharge have not been determined (Stone, Davis, and Katzman, 1993, p. 7). Purtymun and Cooper (1969) speculated that the intermountain basins formed by the Valles Caldera are the recharge areas. Griggs, (1964) citing the loss of flow in intermittent streams flowing from Sierra de los Valles as an indication of recharge, believed the source of recharge was from these streams.

Frazier Goff (written communication) has sampled and analyzed water from many wells and springs in the area. Based on deuterium and oxygen-18 data he has concluded that recharge to the plateau aquifer system cannot be from the Valles Caldera and that recharge to the plateau aquifer system is probably from a lower elevation than the caldera. Differences in chemical quality of the water in the caldera and in the plateau aquifer system is another reason he gives for no recharge from the caldera. He also concludes that the ring-fracture/collapse faults of the caldera depression and the Pajarito fault zone restricts horizontal flow from the caldera to the plateau aquifer system.

The Pajarito Fault zone intersects the area between the Jemez Mountains and the area around Los Alamos. The fault zone may provide a conduit that allows deep geothermal water to enter the shallow aquifer system or water recharged in the Sierra de los Valles may be intercepted and allowed to flow to the plateau aquifer system. The influence the fault zone has on recharge and on the surface- and ground-water flow systems has not been investigated.

Titus, (1961) questioned the permeability of the Bandelier tuff that overlies most of the Pajarito Plateau. Purtymun and Johnson (1974) point out that the Tschicoma Formation, the Bandelier Tuff and the rocks of the Chino Mesa all overlie the aquifer system. They maintain that only small amounts of perched water are in these units implying that water will not percolate to the water table through these units. To determine recharge areas of the aquifer system, the degree of permeability of the Tschicoma, Bandelier Tuff, and rocks of Chino Mesa and the secondary permeability

2

supplied by interstices, faults, and fractures need to be known

The city of Los Alamos and LANL have grown over the last twenty years and more production wells have been drilled on the plateau. During the operation of LANL, hazardous materials have been disposed of in sediments of the plateau. Current government regulations require documentation of locations of disposal sites, types of materials in the disposal sites, and impact of disposed materials on the ground and on surface and ground water; and eventually clean up of contaminated sites. Before impacts on the hydrologic system can be determined and contaminated ground water cleaned up, the ground-water flow system must be known. Purtymun and Johansen (1974) show a water-level contour map that indicates direction of flow. There are no contours west of Los Alamos indicating a lack of ground-water flow information on the western edge of the plateau and the Sierra de los Valles. This area is hydrologically important because it is a possible recharge area for the plateau.

Objectives:

Specific objectives of this study are:

1. Determine recharge areas of the aquifer system

2. Determine the influence of the Pajarito Fault zone on the surface- and ground-water flow systems

3. Determine hydrologic characteristics of faults and fractures in the Tschicoma Formation, Bandelier Tuff, and Rocks of Chino Mesa that overly the local aquifer system

4. Create a ground-water monitoring network that can be used for future definition of the flow system and to determine the flow system of the local aquifer system.

Approach:

To determine the influence of surface flows on recharge areas and the influence of the Pajarito Fault zone on the surface- and ground-water systems eight surface-water stations will be installed on two major drainages that head in the Sierra de los Valles and flow onto the Pajarito Plateau. These drainages may be the Los Alamos and Guaje. The drainages and sites for the gages will be determined in consultation with staff of LANL Two gages will be installed above the Pajarito Fault and two below the fault in each drainage. The purpose of each set of gages, in a drainage, is to determine the gain or loss of surface flow for the selected reaches of the channel. Data from gages immediately upstream and downstream of the fault will be used to determine the influence of the fault on surface-water flow. Data from gages defining reaches upstream and downstream of the fault will be used in establishing infiltration rates in the Tschicoma Formation and the Bandelier Tuff in the arroyo channels.

To assist in determining the recharge areas for the aquifer system, the influence of the Pajarito Fault zone, hydrologic characteristics of faults and fractures in the formations overlying the Tesu-

que Formation, and to create a ground-water monitoring network eight wells will be drilled. Two wells, one about 1,000 feet into the Tesuque formation and one about 50 feet into the formation, will be drilled west of the Pajarito fault in the floodplain of one of the selected drainages where surface water gages are installed, east of Pajarito Mountain. The deep well will be about 2,500 feet deep and shallow well will be about 1,500 feet deep. These two wells will be used to monitor water levels and the data will result in knowledge of the vertical gradient upstream of the fault and down gradient of the Valles Caldera area. Two wells will be drilled east of the fault in the floodplain of the same selected drainage. The deep well will be about 1,500 feet deep and penetrate about 1,000 feet of the Tesuque Formation. The shallow well will probably be finished in the Puye Formation with a total depth of about 500 feet. These two wells will be monitored for water levels yielding vertical gradients east of the fault and horizontal gradients between the two sets of wells in the floodplain at two depths in the aquifer system.

Four wells will be drilled on the mesa. A deep and a shallow well will be drilled west of the fault and east of Pajarito Mountain. These two wells will be drilled to depths within the aquifer about equal to the wells west of the fault in an arroyo channel. A deep and a shallow well will be drilled east of the fault on the mesa. These wells will be drilled to depths within the aquifer comparable to the wells drilled in the arroyo channel, east of the fault. These wells, on the mesa, will be monitored for water levels and the data will allow vertical gradients to be determined at each site and horizontal gradients between other wells on Pajarito Plateau.

Vertical gradients will be determined for all deep and shallow well clusters. The vertical gradients will be compared to those found in other well clusters in and out of arroyo channels. This comparison of vertical gradients along with the streamflow data will be used to determine if recharge is through arroyo channels, from the caldera, to the west, or from both. If vertical gradients are the same for wells in and out of the arroyos appreciable recharge is not coming from loss of water in arroyo channels and most recharge is from the caldera. If vertical gradients are greater for wells in the arroyo and there is surface water losses then most recharge is through arroyo channels. If horizontal gradients are from arroyo channels to mesa areas then recharge is from arroyo channels.

Water-level data for the eight wells will be used to evaluate regional recharge and regional horizontal gradients. Data from these wells and from existing wells in the area will allow a piezometric-surface map to be constructed for the area between Sierra del los Valles and Los Alamos. This map will allow a more accurate determination of the direction of ground-water flow to be made. The wells will be used to monitor changes in the piezometric surface over time.

Each well will be drilled using a U.S. Geological Survey drill rig. Each hole will be cored at major lithologic changes. Ten feet of core will be taken. The core samples will be analyzed for moisture content, porosity, permeability, and will be used to calibrate borehole geophysical logs. Moisture content of the core samples will be used to calibrate the neutron log so it can be used to estimate the depth to which potential recharge water penetrates. Permeability will be useful in determining the volume of water which would be able to pass through the particular sediment type. Porosity will assist in calibrating the neutron log for neutron porosity. Each hole will be drilled to the top of the Puye or Tesuque sediments and the drill stem removed form the hole. Acoustic televiewer logs will then be run in all holes using the USGS Central Region logger and evaluated by staff of the Central Region Logging Unit. The televiewer logs will be evaluated for the occurrence of frac-

4

tures in the unsaturated zone and fracture strike, dip, and size In conjunction with the televiewer logs a temperature-fluid conductance log will be run. This log will be used to determine if water is flowing into the borehole through fractures or faults. Inflowing water from fractures or faults may have a different temperature or fluid conductance than the fluid in the borehole. An attempt will be made to remove the drilling mud and replaced with a less dense fluid, if the hole will stay open. Replacing the dense drilling mud might allow water to flow from fractures and faults into the well bore. Several passes using the temperature-fluid conductance log will be made. These data will allow an estimate of ground-water flow, if any, through fractures and faults that might be recharging the local aquifer system. A statistical evaluation of the occurrence, strike, dip, and frequency of fractures and faults will be done. This evaluation will consider the regional stress field and may result in information about the orientation of faults and fractures that will most likely transmit water.

Each well will be cased with 4-inch steel casing. All wells will be cemented from the bottom of the hole to 5 feet below the bottom of the screened interval. Each well will have 10 feet of screen installed at the bottom of the well above 20 feet of blank casing that will be a trap for sediment and particulates. Each well will be gravel packed from five feet below the screened interval to 10 feet above the top of the screen. The remainder of the annular space to land surface will be cemented. Drillers logs will be recorded during drilling. Caliper, resistivity, temperature, neutron, gamma, and gamma-gamma logs will be run after drilling but before completion and development in all deep holes

If data collected from the 8 wells installed for this project indicate that recharge to the local aquifer system is from west of the Sierra de los Valles then deep wells should be drilled on the west side of Pajarito Mountain, in or near the Valles Caldera. At least 2 wells should be drilled into the local aquifer system so horizontal gradients can be determined.These wells will be about 5,000 feet deep and penetrate the Tesuque Formation. Water-level data from these wells will be used to determine ground-water gradients between wells in the caldera and the next well or wells to the east. The depth of these holes may require a large commercial drill rig. Since the drilling of these wells is not determined to be necessary the specifications for the holes and the costs will not be included in this proposal.

Duration of the Project:

The project is designed for six years. The attached work plan shows beginning and ending times for specific tasks and the length of time required to complete a specific task. Monitoring is a long-term task but it is not shown beyond the fifth year. In general terms, the first year of the project will be used to select sites and install and operate eight stream-gaging stations. During the second year four wells will be cored and drilled in the floodplain of the selected drainage. Borehole geophysical logs will be run and analyzed. In the third year five wells will be cored and drilled. One well will be drilled west of Pajarito Mountain and four on the plateau east of Pajarito Mountain. In all holes borehole geophysical logs will be run and analyzed. Data collection will start in the first year and continue through the fifth year. The last year is for report preparation and publication. Water-level data collection is expected to continue indefinitely. Long-term stream-gage operation may not be necessary depending on the need for long-term data. The decision to continue gage

operation after 1997 will be made with staff of LANL.

6

Project Costs:

Costs for the investigation are for federal fiscal years-October through September. Costs include all manpower, equipment, travel, well drilling, gage installation, and training.

Fiscal year 1995	
Personnel	$63,300
Surface water gage construction and operation	$111,800
Travel	$3,300
Total	$178,400
Fiscal year 1996	
Personnel	$126,000
Drilling four wells	$346,500
Surface water gage operation	$68,400
Travel	$21,200
Vehicles	$5,700
Recorder purchase and rental	$6,300
Vehicles	$5,700
Total	$579,800
Fiscal year 1997	
Personnel	$137,300
Drilling four wells	$363,000
Surface water gage operation	$70,800
Travel	$23,500
Vehicles	$6,400
Recorder Purchase and rental	$9,600
Total	$610,600
Fiscal year 1998	
Personnel	$124,800
Surface water gage operation	$79,600
Travel	$8,700
Vehicles	$2,500
Recorder rental	$6,100
Total	$221,700
Fiscal year 1999	
Personnel	$246,000
Surface water gage operation	$86,400
Travel	$6,600
Vehicles	$3,400
Recorder rental	$6,400
Total	$348,800

Fiscal year 2000

Personnel	$281,500
Travel	$3,300
Vehicles	$1,800
Printing	$12,800
Total	$299,400

Products:

After the end of the fourth year (1998) a Open-File data report will be produced. This report will present all data collected in the first four years. There will be no interpretation included. In the sixth year a Water-Resources Investigation report will be written and approved for publication. The report will include data for the fifth year and interpretations concerning recharge areas, process of recharge, permeability of the overlying sediments, and a piezometric surface contour map will be presented.

Manpower:

All work for this project will be supplied by the U.S. Geological Survey. Drill crews are supplied by the Geologic Division. The New Mexico District currently has the manpower required for this project and will consist of:

Project Supervisor	GS 13
Project Chief	GS 12
Hydrologist	GS 11
Instrumentation Technician	GS 11
Drilling Technician	GS 7

References:

Kelley, V.C., 1978, Geology of Espanola Basin, New Mexico: New Mexico Bureau of Mines & Mineral Resources, Geologic Map 48.

Griggs, R.L., 1964, Geology and ground-water resources of the Los Alamos area New Mexico: U.S. Geological Survey Water-Supply Paper 1753.

Purtymun, W.D. and Cooper, J.B., 1969, Development of ground-water supplies on the Pajarito Plateau, Los Alamos County, New Mexico: U.S. Geological Survey Professional Paper 650-B.

Purtymun, W.D. and Johansen, Steven, 1974, General geohydrology of the Pajarito Plateau: New Mexico Geological Society Twenty-fifth Field Conference

Stone, W.J., Davis, T.D., and Katzman, D., 1993, Initial assessment of the ground water monitoring program at Los Alamos National Laboratory, New Mexico: New Mexico Environment Department Publication NMED/GWB-93/1

Titus, F.B., 1961, Ground-water geology of the Rio Grande trough in north-central New Mexico,

with sections of the Jemez Caldera and the Lucero Uplift: New Mexico Geological Society Twelfth Field Conference.

DOE/LANL/GPMP

9

Work Plan for study of recharge west of Los Alamos National Laboratory

Federal Year	1995				1996				1997				1998				1999				2000			
Quarter	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Work Element																								
Literature review			X	X																				
Gage site selection			X	X																				
Gage installation				X																				
SW data collection				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				
Well site selection			X	X																				
Well drilling							X	X			X	X												
Geophysical logging							X	X			X	X												
Water-level instrumentation							X	X			X	X												
GW data collection							X	X	X	X	X	X	X	X	X	X	X	X	X	X				
Core sample analysis								X	X			X	X											
Open-File report preparation																X	X							
Open-File report approval																		X						
Final report preparation																		X	X	X	X	X	X	
Final report approval																								X

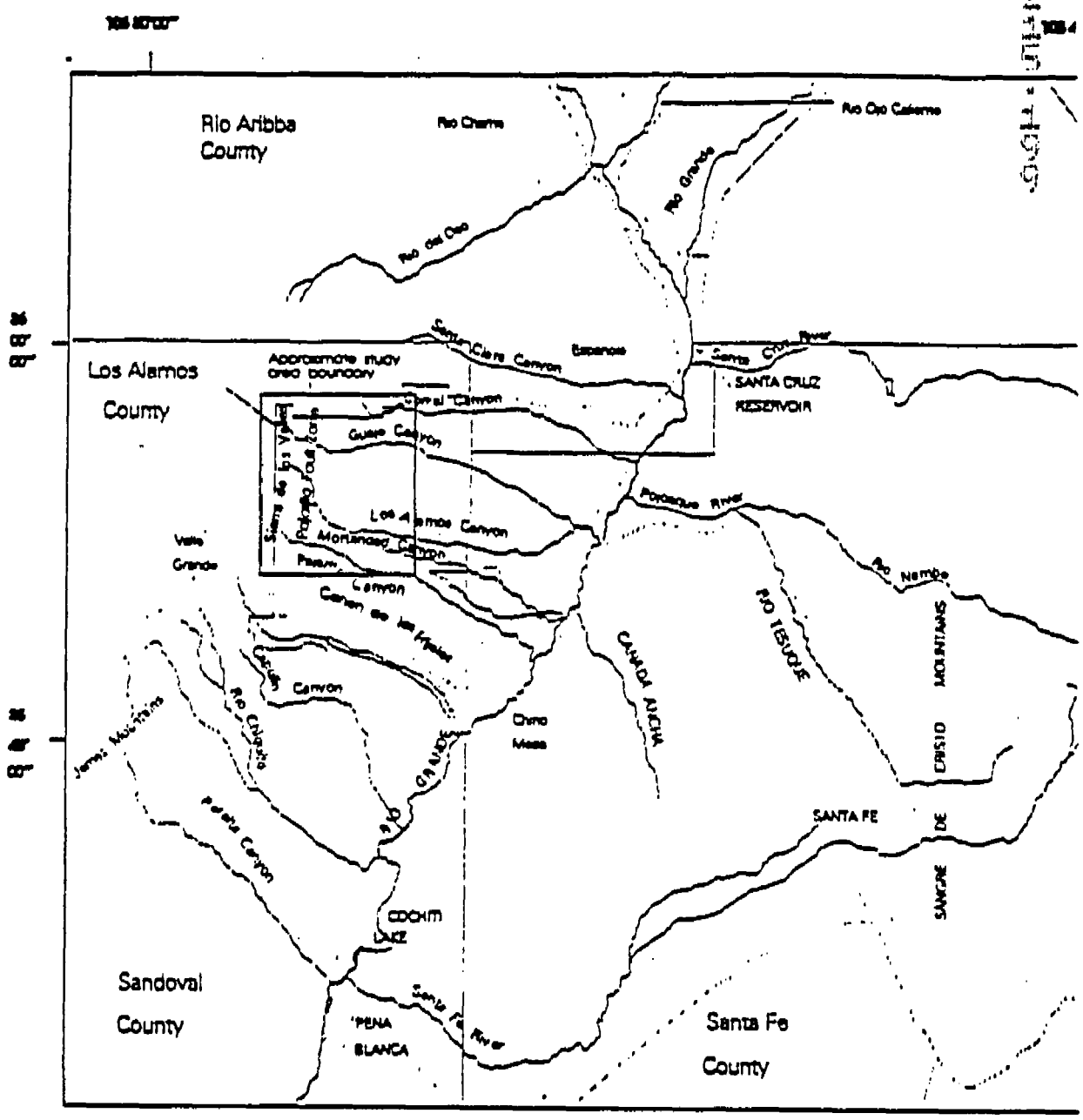


Figure 1.–Approximate study area and geographic features

August 1994

Proposal NM94

Evaluation, compilation, and collection, of hydrologic data in and around the Los Alamos National Laboratory, New Mexico

Prepared by David W. Wilkins

Introduction:

Los Alamos National Laboratory (LANL) is in the Espanola Basin. The Espanola Basin is a north-south trending basin with the northern boundary at a constriction to the Rio Grande near Embudo, New Mexico. The basin is about 45 miles long with the southern boundary at White Rock Canyon, east of Los Alamos. The Sangre de Cristo Mountains form the east boundary and the Jemez Mountains form the west boundary (fig. 1). The basin in the Basin and Range Province situated between the eastern and western prongs of the Southern Rocky Mountains.

LANL is located on the east flank of the Jemez Mountains near the west side of the Rio Grande depression in north central New Mexico. The Jemez mountains are described as volcanic pile that rests on and rises above a zone of faults at the western edge of the Rio Grande depression (Griggs, 1964). LANL is located on the Pajarito Plateau (fig. 1) which is a topographic high that slopes gently eastward to the Rio Grande. The west boundary of the Pajarito Plateau is the Sierra de los Valles.

The Tschicoma Formation of Pliocene age and the Bandelier Tuff of Pleistocene age are major volcanic units in the area. The Tschicoma Formation forms the mountains of the Sierra de los Valles, between the Valles Caldera and the Pajarito Plateau, and is present beneath the surface of the western edge of the plateau. The Tschicoma Formation is overlain by the Bandelier Tuff along the flanks of the mountains. The Bandelier Tuff is a series of ash flows and ash falls of rhyolitic tuff that caps the Pajarito Plateau and overlies the Puye Formation and basaltic rocks of Chino Mesa in the central and eastern edge of the plateau (Purtymun and Johansen, 1974).

The Santa Fe Group comprises the Tesuque and the Puye Formations and the basaltic rocks of Chino Mesa. The Tesuque Formation consists of friable to moderately well cemented siltstone and sandstone with lenses of conglomerate and clay and some interbedded basalt flows. The Puye Formation is a poorly consolidated conglomerate channel-fill deposit overlain by a fanglomerate composed of volcanic debris. The basaltic rocks of Chino Mesa consist of basalt and basalt breccia that overlie the Puye along the Rio Grande and interfingers with the conglomerate to the west beneath the Pajarito Plateau (Purtymun and Cooper, 1969).

The Pajarito Fault Zone lies near the western edge of the Pajarito Plateau. South of the LANL area the Bandelier Tuff on the east side of the fault is downthrown about 300 feet in relation to the tuff on the west side of the fault. To the north the fault splits into two smaller subparallel faults, both downthrown to the east. Kelley, (1978) shows a fault zone throughout the Espanola Basin. The

downthrown block is to the east from the southern boundary of the basin to the Chama River. The downthrown block and dip are to the west north of the Chama River.

The sediments of the Santa Fe Group are the main aquifer of the Espanola Basin. Borton (1974, p. 353) reported maximum thickens of the Santa Fe to be about 12,000 feet near Espanola. Cordell (1979, p. 61) report low density rocks he considered primarily Santa Fe sediments to be between 8,200 and 16,400 feet thick in a graben just south of Espanola. South and east of Los Alamos Cordell (1979, p. 62) reported low density sediments between 7,900 and 19,000 feet thick. The main aquifer of the Pajarito Plateau is composed of Santa Fe Group sediments, the Tesuque Formation and the lower part of the Puye Formation. The upper surface of the main aquifer rises westward from the Rio Grande through the Tesuque into the lower part of the Puye Formation beneath the central and western parts of the plateau. The water is unconfined in the western edge of the plateau and becomes confined as water in the aquifer moves below the less permeable sediments of the Tesuque Formation along the eastern edge of the plateau and along the Rio Grande (Purtymun and Johansen, 1974). The first water supply wells drilled in the Los Alamos area were in Los Alamos and Guaje Canyons at the eastern edge of the Pajarito Plateau. These wells were finished in the Tesuque Formation and produced less than 500 gallons per minute. As more water was needed, additional wells were drilled, to the west, on the plateau. These new wells were finished in the lower Puye and upper Tesuque and produced about 1,500 gallons per minute (Purtymun and Cooper, 1969).

Problem:

Stone, Davis, and Katzman (1993) conducted an assessment of the ground-water monitoring program at LANL. Their emphasis was to evaluate the ground-water data collection program for the purpose of determining ground-water contamination from specific contamination sources. An evaluation of the need for ground- and surface-water data to be used in a definitive conceptualizing of the ground-water and surface-water system on and around LANL needs to be done.

Ground-water data, such as depth to water, chemical, and physical characteristics of the water, hydraulic conductivity, and storage coefficients are systematically collected in and around LANL. Surface-water stage-discharge and chemical and physical characteristics of the water are being collected in the LANL area. Thousands of pieces of hydrologic data currently exist for the LANL area. These data are stored in many formats by individual investigators and by organizational units at LANL. Ground-water flow and transport models that simulate ground water and water quality conditions in and around LANL are planned for development in the near future. These models require a wide variety of hydrologic data, both current and historic. A comprehensive data base that is designed to store, evaluate, display, and report ground-water, surface-water, and water-quality would be useful for scientists at LANL (Stone, Davis, and Katzman, 1993, p.7). Computer communications between the system on which the proposed data base resides and the computer systems used by LANL investigators would have to be established if a comprehensive data base were to be developed.

As described in the Introduction of this proposal LANL and Los Alamos County areas are not isolated from the Espanola Basin to the north, from the Jemez Mountains to the west and south, or from the Rio Grande and associated tributaries and underlying sediments to the east. Figure 1

2

shows locations of wells in the general area of the Espanola Basin. The density of wells in the area of LANL show that ground-water data collection are minimal in the LANL area because of the lack of wells that are measured or sampled. Figure 2 shows the location of stream gages that collect stage-discharge and water quality data in and around the LANL area. The area near LANL has restricted opportunities for data collection.

Objectives:

Objectives of the proposed study were selected to meet the needs defined in the "Problem" section of the proposal. The overall objective of this proposal is to evaluate the need for specific hydrologic data and compile, collect, and store the needed data in a USGS designed and operated comprehensive data base.

Specific objectives of the proposed study are:

1. Populate the USGS National Water Information System (NWIS) data base with existing hydrologic data in and around LANL.

2. Establish communications between LANL computer systems and the USGS compute. system.

3. Evaluate current and future hydrologic data needs at LANL.

4. Establish a plan for the installation of monitoring wells and surface flow gaging stations at LANL.

5. Install test and observation wells and surface flow gaging stations at LANL

6. Evaluate the need for and frequency of ground- and surface-water data collection adjacent to LANL.

7. Establish a data collection net work and collection schedule for sites adjacent to LANL.

8. Collect data from the selected sites for the schedule selected adjacent to LANL.

Purpose:

The purpose of the proposed study is to develop and maintain a comprehensive hydrologic data base that will be used by LANL scientists to store and retrieve data. An evaluation of the hydrologic data needs, both for current and for future needs, will be made resulting in a data collection plan that will supply the kinds and amounts of data needed for current and future studies, including ground-water flow and ground-water transport models.

Scope:

This proposed study will encompass most of the Espanola Basin. Existing data will be compiled

3

and entered into the data base for the Espanola Basin. Actual data collection will be from an area decided upon by staff of LANL and USGS after existing and current data availability are compared to expected data needs. The project is designed for five years.

Approach:

Approaches will be discussed in the order that the objectives of the proposed project were presented. The USGS NWIS data base is designed for entry and retrieval of all types of hydrologic data. The primary requirement for data entry is a unique number for each site. This number is based on the latitude and longitude of the site so a location for each site is mandatory. There are also other characteristics of the site and specific data that are mandatory for entry into the data base. With a location a site identifier can then be established in the data base. All data entered into the data base for a site are associated with the site identifier.

The first task to meet objective 1 will be to accumulate all hydrologic data at LANL, in consultants reports, and in files of state and local government offices. To obtain the LANL data, internal letters from the Environmental Protection Group (EM-8) to all LANL departments that may have or are currently collecting data will be sent requesting information about data in their possession. The request letter will explain the data compilation and collection study, the data base that will be used to store the data, and the advantages on using the data base. Department responses will need to specify the type of data available, the format of the data, an estimate of the number of sites that have data, and a contact at that unit to assist in obtaining the data. USGS personnel will meet with the contact person and arrange for the data to be transferred to USGS personnel. Depending on format, the data will be entered into the data base. Digital data will be entered using computer techniques. Data that is on paper copy will be coded on to the proper coding form and manually entered into the data base.

Reports from LANL contracted consultants that contain hydrologic data will be obtained through the Environmental Protection Group. Bibliography searches will be used to determine which consultant reports, not associated with LANL, but specific to the study area will be needed. These reports will be obtained through libraries, from the consultant that did the work, or from their clients. These data will be entered into the data base using computer transfer of the data, if in digital format or by coding the data on the appropriate form and manual entry into the data base.

USGS personnel will contact state and local agencies that have data in the Espanola Basin. These data will be obtained and entered into the data base.

Communication between LANL computers and the USGS computer on which the data base is loaded can be established using the Internet system. Access to the USGS computer will be established in the second quarter of the first year of the study. The USGS will furnish LANL with one copy of the data base users manual for each department at LANL that desires access to the data base. A two day data base users training class will be conducted at LANL before objective 1 has been completed.

With historical data in the data base and information available as to the type, location, and frequency of data being collected by LANL or other organizations, an evaluation of short- and long-

term data collection needs and the existing data collection networks will be made. This evaluation will done by LANL staff, determined by the Environment Protection Group, USGS staff, and state or local government agency staff suggested by LANL or the USGS. The purpose of the evaluation will be to determine the short- and long-term hydrologic data needs of LANL in the context of current and future studies in and around LANL. For example, a ground-water flow model of LANL and adjacent area is likely to be developed as will be a ground-water transport model, the data collection network evaluation will consider these probable projects and compare data that are in the data base and current data collection at LANL to data that will be needed to develop and calibrate these two types of models. For each probable hydrologic investigation that might be conducted in or around LANL an evaluation of the data needs will be made.

USGS staff will compile information from the evaluations. A USGS Open-File Report will be prepared that describes the suggested hydrologic investigation, the data needs for that investigation, and the short- and long-term data needs of each probable project. The report will also contain a summary of the available data, the data currently being collected, and suggestions for future data collection (type, location, and frequency).

For those sites that are necessary to be established within the next 4 years (Federal fiscal years 1996-1999), both ground and surface water, a plan will be developed for the establishment and operation of each site. Specific drilling date, drilling procedures, construction, testing, finishing, and data collection at each test and observation well site will be established. For surface-water sites location, type of control, type of data to be collected, and data collection frequency will be detailed. This information will be included in the Open-File Report mentioned above.

Data collection from existing sites at LANL will continue by the LANL department that has been collecting the data. If there are sites that are not being used for data collection but the evaluation results in conclusions that data should be collected at these sites then LANL or USGS staff will begin data collection from that site. These data will be entered into the data base quarterly.

From 1996 through 1998 the recommended ground- and surface-water sites will be constructed and operated. For each well drilled, tested, and finished a USGS Open-File Report will be completed. The report will contain descriptions of the drilling operation, geologists descriptions of the cuttings or of any core that might have been collected from the hole, geophysical logs, aquifer test procedures and results of the aquifer tests, and descriptions of the data collection methods.

USGS or LANL staff will collect the specified data from each of the wells that were drilled. The data will be collected at a frequency chosen by the evaluation group. All data will be entered into the data base on a quarterly basis and will be available to LANL staff through the communication link with the USGS computer. Each year, starting the fourth year, an Open-File Data Report will be prepared that summarizes the ground-water data collected from all observation wells in the network for the previous water year (October-September. Surface-water sites and the data collected at each of those sites will be included in the USGS Annual Report for New Mexico.

From figure 1 it can be seen that there are many wells adjacent to LANL. Most of these wells are not measured for depth to water or are not sampled for water quality determinations on a regular basis. Figure 2 shows the location and type of surface-water data collected in and adjacent to

LANL. As discussed in the approach for meeting objective 3, the data needs of LANL, in the context of current and future hydrologic investigations, will be evaluated. The USGS will supply to the evaluation group tables and maps that give pertinent information about each of the wells and surface-water gages in the USGS data base for the area of interest. The evaluation group will consist of approximately the same type of members as for objective 3. The evaluation group will select candidate wells and surface-water sites for the network and the type of data to be collected and the frequency of data collection.

USGS staff will field check each of the candidate wells and obtain any needed information. If a candidate well is no longer available or access to the well cannot be obtained another well in the area will be found, if possible. The USGS will supply information about the candidate wells to the evaluation group. If any of the surface-water sites shown on figure 2 are not currently being operated the site will be visited to determine condition of the site and data that could be collected. If operated by another agency, information about the site will be obtained from that agency. All surface-water information will also be reported to the evaluation group. The evaluation group will make a final decision from which wells to collect data, type of data collected, and frequency of data collection. Any construction of new surface-water gages or any change in operation procedures for existing gages will be handled by the USGS.

The USGS will collect data in the selected wells adjacent to LANL. Data from these wells will be included in the annual Open-File Report discussed above. All data will be entered into the data base on a quarterly basis and will be available to LANL staff through the communication link with the USGS computer.

Duration of the Project:

The project is designed for five years. The attached work plan shows beginning and ending times for specific tasks and the length of time required to complete a specific task. Monitoring is a long-term task but it is not shown beyond the fifth year. It is expected that monitoring will continue indefinitely.

In general terms, the first year of the project will be used collect and compile existing data and enter the data into the data base. During the second year the evaluation group will select existing ground- and surface-water sites at LANL that are not being monitored but that should be included in a monitoring network. Data collection will begin at the selected sites. The evaluation group will also select new ground- and surface-water sites that are to be established. The USGS will prepare the report that presents the short- and long-term data collection plan.

During the third year installation of wells and gaging stations will begin at LANL and the data collection network evaluation adjacent to LANL will be accomplished. An Open-File Report will be prepared that presents lithologic, drilling, and completion data for all wells drilled during that year. Data collection at sites adjacent to LANL will also begin.

In the fourth year installation of wells and gages will continue as will data collection at and adjacent to LANL. The first of the annual Open-File Reports that present the data collected in the previous year will be produced in the fourth year. During the fifth year data collection should be

taking place from all sites on and adjacent to LANL. The annual data report will be prepared.

Project Costs:

Costs for the investigation are for federal fiscal years-October through September. Costs include all manpower, equipment, and travel. For the first two years the cost estimates are based on specific tasks and costs of completing those task. For years 3 through 5 the number of wells to be drilled or the number of surface-water sites to be installed are unknown. Contract costs have been estimated that will be used to drill wells or establish surface-water gages. It is also assumed that drilling will require the manpower, travel, and transportation costs shown.

Specific costs and needed funding for drilling and surface gage installation can be better estimated once the data needs at LANL have been evaluated and a plan for installation of the needed sites developed. By the end of the second year detailed costs for the agreed upon work will be made. These estimates will be presented to LANL and the project agreement amended as needed.

Fiscal year 1995	
Labor	$170,500
Travel	3,400
Transportation	2,500
Totals	$176,400
Fiscal year 1996	
Labor	$146,300
Travel	3,100
Transportation	3,800
Printing	6,500
Supplies	1,100
Equipment	4,300
ADR Rental1	1,000
Total	$166,100
Fiscal year 1997*	
Labor	$188,900
Travel	30,400
Transportation	9,500
Communications	1,300
Contracts	254,000
Supplies	41,400
Equipment	7,800
ADR Rental	5,600
Geophysical logging	10,000
Total	$548,900
Fiscal year 1998*	
Labor	$206,000
Travel	34,400

7

Transportation	11,900
Communications	1,300
Printing	8,600
Contracts	266,000
Supplies	45,000
Equipment	8,600
ADR Rental	11,700
Geophysical logging	12,000
Total	$605,500

Fiscal year 1999**

Labor	$167,800
Travel	12,500
Transportation	8,900
Printing	10,800
Equipment	4,300
ADR Rental	13,100
Total	$217,400

* Costs are based on the assumption that observation wells and surface-water gages will be installed as suggested in the report produced during the second year of the project. Costs estimates for drilling and surface-water gage installation are based on having $200,000 net dollars available in 1997 and $210,000 net dollars available in 1998 for well and gage installation. Most of the remainder of the expenses in these two years are associated with installation and instrumentation of the wells and gages. Some costs in these two years are for data collection on and adjacent to LANL.

** Costs are based on the assumption that wells and gages are installed at LANL in 1997 and 1998 and that these sites are monitored throughout this year. It is also assumed that wells and gages adjacent to LANL are monitored throughout this year.

Products:

During the second year (1996) a Open-File Report will be produced. This report will summarize hydrologic data available at LANL and the adjacent area. This report will also present results of a data collection network evaluation.

Assuming that test and observation wells are drilled at LANL there will be two Open-File Reports produced that present drilling, testing, and finish information about the wells and the sediments the holes penetrated. One report that presents the well data will be produced in 1998 and another in 1999.

Starting in 1998 annual Open-File Reports will be completed that summarizes the ground-water data collected in the previous year. Surface-water data will be presented in the Annual Report for New Mexico.

8

Manpower:

All work for this project will be supplied by the U.S. Geological Survey. Drill crews are supplied by the Geologic Division. The New Mexico District currently has the manpower required for this project and will consist of:

Project Supervisor	GS 13
Project Chief	GS 11
Hydrologic Technician	GS 7
Hydrologic Technician	GS 9
Instrumentation Technician	GS 11
Drilling Technician	GS 7

References:

Borton, R.L., 1974, General geology and ground water conditions in the Truchas-Espanola-Valarde area of Rio Arriba County, New Mexico, in Guidebook of Ghost Ranch: New Mexico Geological Society, 25th Field Conference, p. 351-354.

Cordell, Lindrith, 1979, Gravimetric expression of the graben faulting in Santa Fe County and the Espanola Basin, New Mexico, in Guidebook of the Santa Fe Country: New Mexico Geological Society, 30th Field Conference, p. 59-64.

Kelley, V.C., 1978, Geology of Espanola Basin, New Mexico: New Mexico Bureau of Mines & Mineral Resources, Geologic Map 48.

Griggs, R.L., 1964, Geology and ground-water resources of the Los Alamos area New Mexico: U.S. Geological Survey Water-Supply Paper 1753.

Purtymun, W.D. and Cooper, J.B., 1969, Development of ground-water supplies on the Pajarito Plateau, Los Alamos County, New Mexico: U.S. Geological Survey Professional Paper 650-B.

Purtymun, W.D. and Johansen, Steven, 1974, General geohydrology of the Pajarito Plateau: New Mexico Geological Society Twenty-fifth Field Conference

Stone, W.J., Davis, T.D., and Katzman, D., 1993, Initial assessment of the ground water monitoring program at Los Alamos National Laboratory, New Mexico: New Mexico Environment Department Publication NMED/GWB-93/1

Titus, F.B., 1961, Ground-water geology of the Rio Grande trough in north-central New Mexico, with sections of the Jemez Caldera and the Lucero Uplift: New Mexico Geological Society Twelfth Field Conference.

Work Plan for Data Compilation and Collection in and around Los Alamos National Laboratory

Federal Year	1995				1996				1997				1998				1999			
Quarter	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Work Element																				
Literature review	X																			
LANL data search	X	X																		
LANL data compilation		X	X																	
LANL data entry			X	X																
Consultant reports data search		X																		
Consultant data compilation			X																	
Consultant data entry				X																
State and local agency data search		X																		
State and local data compilation			X																	
State and local data entry				X																
Establish the LANL-USGS data link		X																		
Conduct 2 day data base training			X																	
Evaluation of LANL data collection needs					X	X														
Prepare data summary and data collection plan report						X	X													

Federal Year	1995				1996				1997				1998				1999			
Quarter	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Data collection on LANL							X	X	X	X	X	X	X	X	X	X	X	X	X	X
Entry of LANL data							X	X	X	X	X	X	X	X	X	X	X	X	X	
Installation of data collection sites									X	X	X	X	X	X	X	X				
Well installation Open-File Reports													X				X			
Preperation of data site information adjacent to LANL									X											
Evaluation of data collection needs adjecent to LANL										X										
Field check candidate data collection sites											X									
Final selection of data collection sites adjacent to LANL												X								
Data collection adjacent to LANL												X	X	X	X	X	X	X	X	X
Entry of data adjacent to LANL													X	X	X	X	X	X	X	X
Prepare annual data report													X				X			

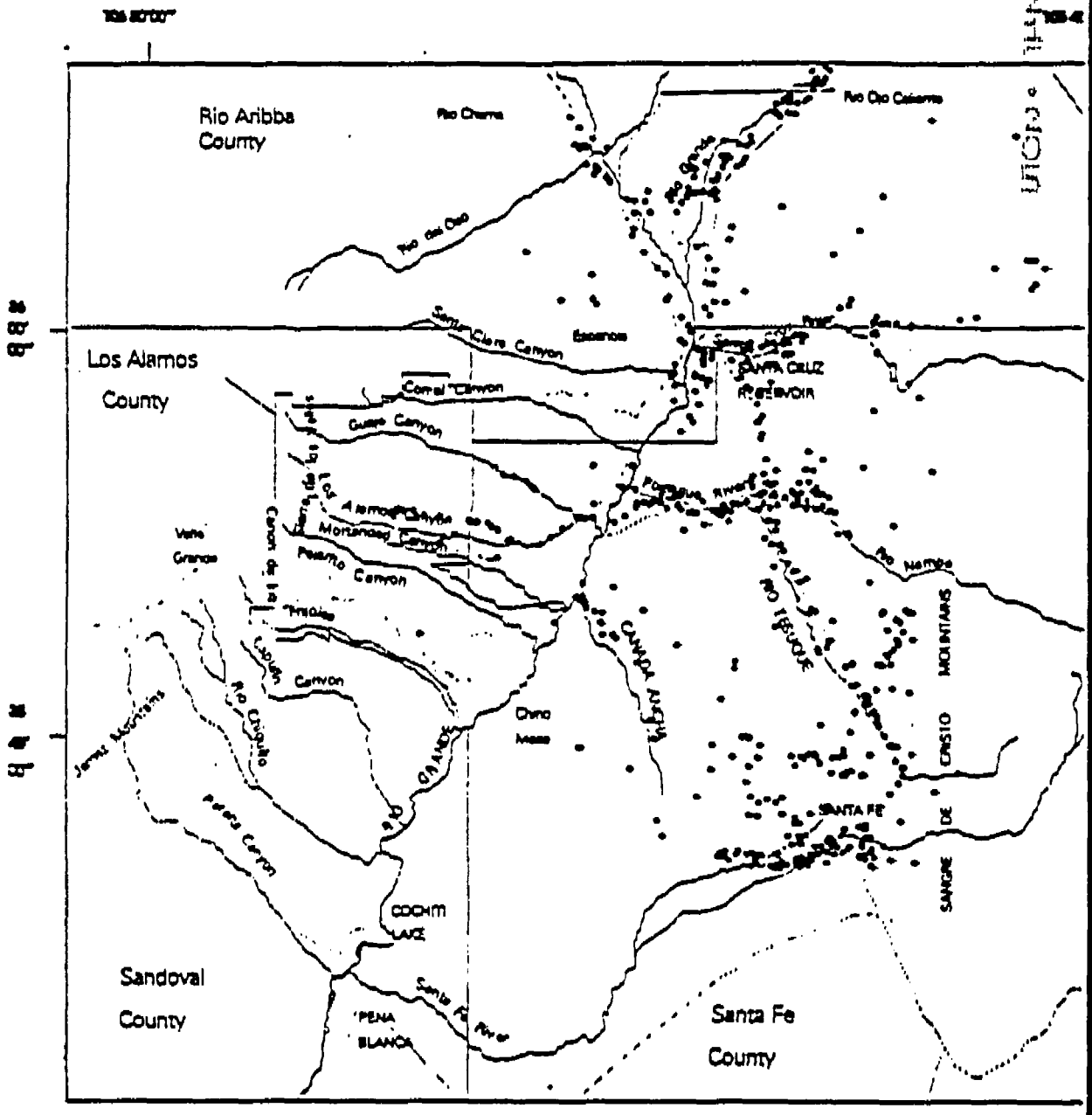


Figure 1.–Well locations on and adjacent of Los Alamos National Laboratory

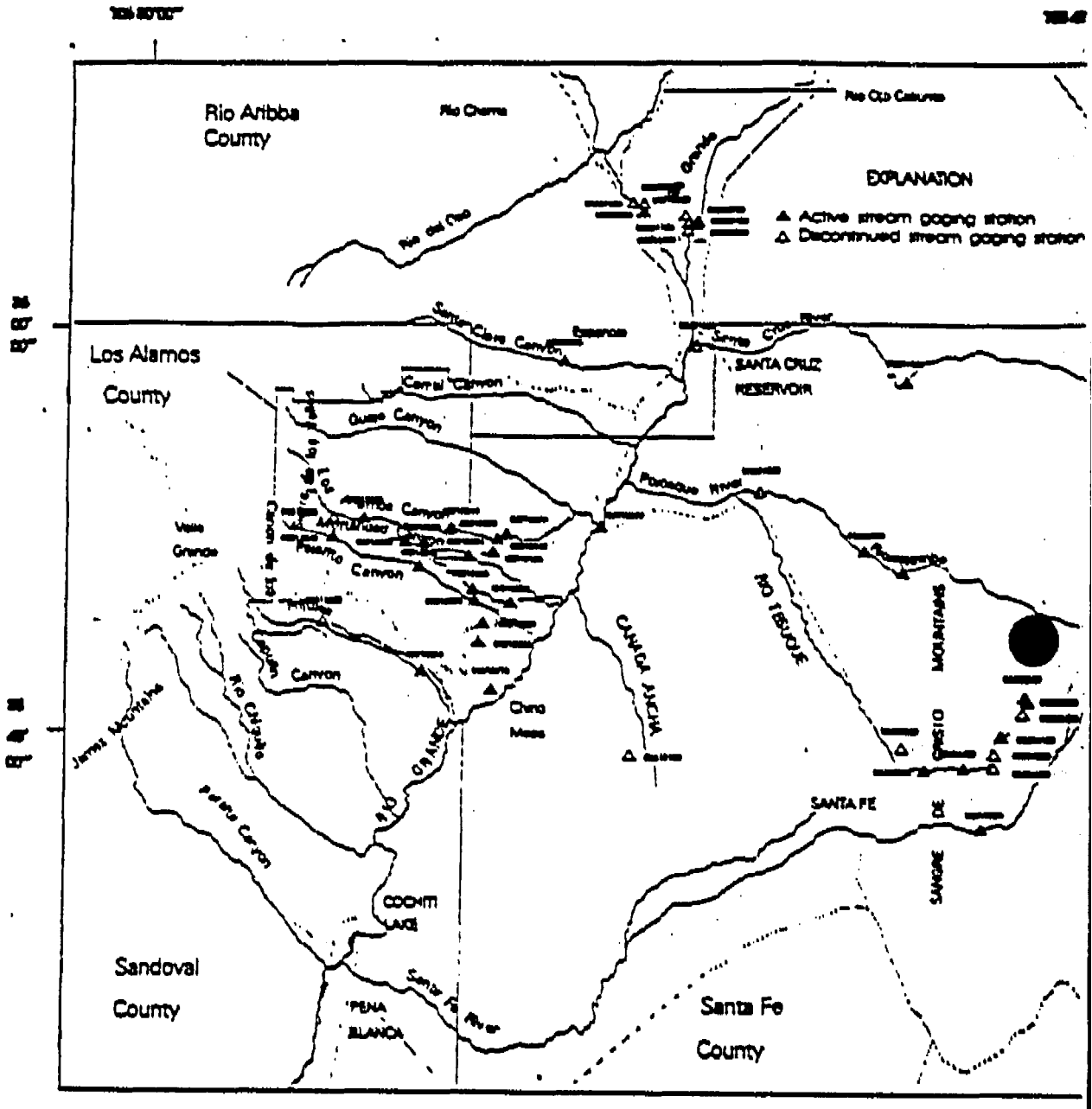


Figure 2.–Surface-water gage locations on and adjacent of Los Alamos National Laborat

NM94-S

PRELIMINARY ESTIMATION OF GROUND-WATER-FLOW PATH LINES IN THE MAIN AQUIFER, LOS ALAMOS COUNTY, NORTH CENTRAL NEW MEXICO

Proposal by Peter F. Frenzel

INTRODUCTION

Los Alamos, is located in north-central New Mexico, on the Pajarito Plateau in the Espanola Basin. The Pajarito Plateau (fig. 1) is a topographic high that slopes gently eastward to the Rio Grande. The Pajarito Plateau is on the eastern slope of the Jemez mountains which are described as volcanic pile that rests on and rises above a zone of faults at the western edge of the Rio Grande depression (Griggs, 1964). Los Alamos, Santa Fe, and other communities in the area use ground water from the Santa Fe Group sediments that fill the Espanola Basin. The Espanola Basin is one of a series of grabens and structural basins along the length of the Rio Grande from its headwaters in Colorado through New Mexico and Texas. Research at Los Alamos National Laboratory (LANL) is the main activity at Los Alamos. LANL is a Federally-owned (Department of Energy) facility that is operated under contract by the University of California. LANL developed the atomic bomb and has engaged in related or similar research for the past 50 years. Laboratory wastes are stored or buried near the lab. Wise and effective management of radioactive substances has long been a concern of LANL. This proposal is concerned with ground-water-flow path lines which would be useful for development of a chemical transport model.

GEOLOGY AND HYDROLOGY

The Espanola Basin is a north- to northwest-trending and plunging, asymmetric faulted synclinal sag (Baltz, 1978, p. 213). The basin is filled to an unknown depth with semiconsolidated to unconsolidated Tertiary and Quaternary sediments of the Santa Fe Group. The Santa Fe Group in the Espanola Basin is comprised of Tesuque, Puye, and Ancha Formations of Tertiary age (Manley, 1978, p. 202).

The Tesuque Formation of the Santa Fe Group is the principal aquifer in the Espanola Basin. The Tesuque Formation was deposited mainly as coalescing alluvial-fan deposits derived from the highlands to the north and east. In the eastern half of the basin, the Tesuque dips westward between 4 and 10 degrees as measured in outcrops. Dip in the western part of the basin is generally unknown because the Tesuque is overlain by the Puye Formation of the Santa Fe Group.

The Tertiary Puye Formation of the Santa Fe Group (Griggs, 1964, p. 28; Purtymun and Johansen, 1974, p. 347-349) is younger than the Tesuque Formation and is present on the western side of the Rio Grande. The formation consists mainly of gray sand and small pebbles derived from rocks varying in composition from basaltic to rhyolitic that were associated with the volcanics of the Jemez Mountains. The deposits form high-terraced escarpments deeply incised by east-west-trending washes extending from the Jemez Mountains to the Rio Grande. In Los Alamos, wells have penetrated water in the Puye Formations as well as in the underlying Tesuque Formation. The Puye and Tesuque Formations are hydraulically connected.

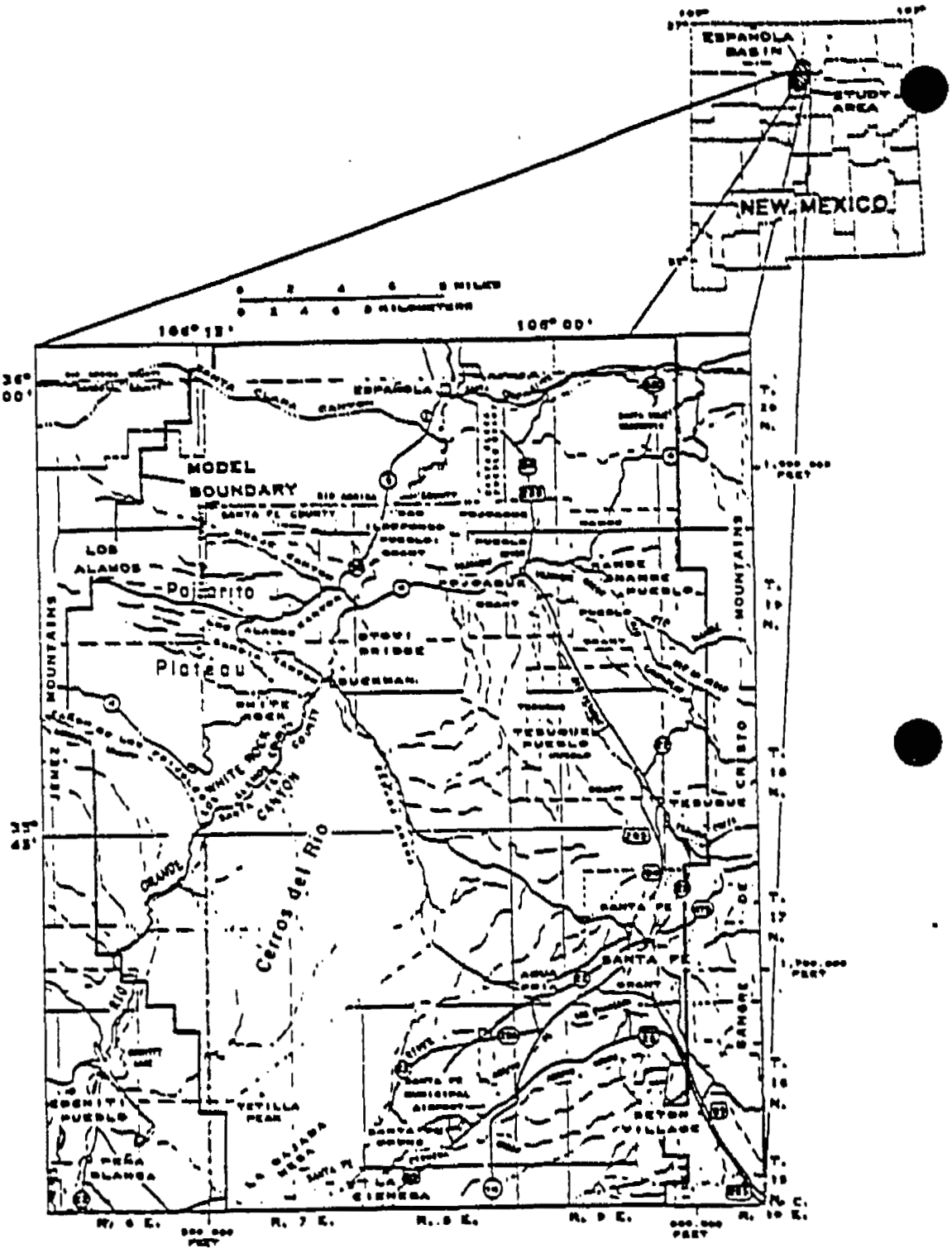


Figure 1.– Location of the study area (from McAda and Wasiolek, 1988).

The Ancha Formation of the Santa Fe Group (Spiegel and Baldwin, 1963, p. 45) is a Tertiary high pediment gravel deposited unconformably on the Tesuque Formation in the southern part of the Espanola Basin. The Ancha Formation is mainly south and west of Santa Fe and under the city itself. The Ancha is coarser than the Tesuque, but is mainly unsaturated except in the southern part of the basin.

The Tschicoma Formation of Pliocene age and the Bandelier Tuff of Pleistocene age are major volcanic units in the Pajarito Plateau. The Tschicoma Formation is approximately the same age as the Puye Formation (Kelley, 1978). The Tschicoma forms the mountains west of Los Alamos and is present beneath the surface of the western edge of the Pajarito Plateau. The Tschicoma is composed of latite, quartz-latite flows, and pyroclastic rocks.

The Bandelier Tuff overlies the Tschicoma Formation along the flanks of the mountains and overlies the Puye Formation and basaltic rocks in the central and eastern edge of the Pajarito Plateau. The Bandelier is a series of ash flows and ash falls of rhyolitic tuff and caps the Pajarito Plateau (Purtymun and Johansen, 1974). The Bandelier Tuff and possibly the eastern edge of the underlying Tschicoma Formation generally occupy the unsaturated zone at Los Alamos.

The Pajarito Fault Zone lies near the western edge of the Pajarito Plateau. South of the LANL area the east side of the fault is downthrown about 300 feet in relation to the west side of the fault. To the north, the fault splits into two smaller subparallel faults, both downthrown to the east. Displacement decreases northward until both faults die out. The downthrown block is to the east from the southern boundary of the basin to the Chama River. The downthrown block and dip are to the west north of the Chama River. Although the Pajarito Fault Zone has been considered to be the western boundary of the Espanola basin by Hearne, McAda and Wasiolek, and Finch and Fleming, the possible westward extent of the Tesuque Formation, and its hydraulic continuity westward beyond the Pajarito Fault zone is unknown.

Water supply in the Espanola Basin is from surface and ground water. Most irrigation is from surface water and most domestic, municipal and industrial supplies are from ground water withdrawn from the Santa Fe Group sediments. However, Santa Fe is partly supplied from surface flows of the Santa Fe River. Los Alamos is supplied mainly by ground water with some irrigation of ornamentals supplied from surface flows of several canyons. Smaller communities and individual supplies in the Espanola Basin depend on ground water except for agricultural irrigation.

In the Pajarito Plateau area, several aquifers have been identified. The main aquifer, is more or less continuous with water-bearing sediments elsewhere in the Espanola Basin. Additionally, perched aquifers have been identified in the Tschicoma and Puye Formations, in the basaltic rocks of Chino Mesa, and in the Bandelier Tuff (Griggs, 1964, p. 102). Ground water in the alluvium of canyons on the Pajarito Plateau also is perched to some extent (Baltz, Abrahams, and Purtymun, 1963). The degree of hydraulic connection through a zone that is mostly unsaturated between the perched aquifers and the main aquifer generally is unknown. The main aquifer is composed of the Tesuque Formation and the lower part of the Puye Formation. The upper surface of the main aquifer rises westward from the Rio Grande through the Tesuque into the lower part of the Puye Formation beneath the central and western parts of the plateau. The water is unconfined in the western edge of the plateau and becomes semi-confined as water in the aquifer moves below the

less permeable sediments of the Tesuque Formation along the eastern edge of the plateau and along the Rio Grande (Purtymun and Johansen, 1974). Recharge of the main aquifer may be through the Bandelier Tuff and/or the Tschicoma Formation near the west side of the Pajarito Plateau, though the exact location of recharge is unknown. Discharge is to the Rio Grande.

Ground-water flow in the Espanola Basin has been simulated previously by four models. Hearne (1980) simulated most of the Espanola Basin with a model that included Los Alamos at the periphery. The central area of concern of the Hearne model was the Pojoaque river basin, a tributary of the Rio Grande. Model layering in the Hearne model was assigned in such a way as to account for the tilting of beds in the Tesuque Formation on the eastern side of the basin. Because Los Alamos was outside the area of interest, model blocks and layer thicknesses were large for the area of Los Alamos. McAda and Wasiolek (1988) simulated the Espanola Basin, in an area centered slightly south of the area of the Hearne model, with a model that also included Los Alamos at the periphery. The main area of concern in the McAda-Wasiolek model was the Buckman-Santa Fe area, and the model did not account for recent transmissivity and storage data from the well fields at Los Alamos. Finch and Fleming (1992) modified the McAda Wasiolek model to better account for more recent mountain-front recharge estimates by Anderholm (U.S. Geological Survey, written commun., 1990) that was based on a chloride balance. The Finch-Fleming modification also accounted for more recent transmissivity data near the southern boundary of the McAda-Wasiolek model. Frenzel (in preparation) modified the McAda-Wasiolek model to account for recent data collected in the vicinity of Los Alamos and projected the effects of alternatively replacing production from the aging Guaje well field with increased production from the Pajarito well field or replacing the aging wells with new wells so as to keep the Guaje field in production. All of these models were mainly concerned with the drawdowns resulting from ground-water withdrawals. None estimated path lines. This proposal is for the second phase of a two-phase study originally proposed in 1993, the first phase of which resulted in the Frenzel (in preparation) modification of the McAda-Wasiolek model.

PROBLEM

Geologic formations thus far appear to have protected the Espanola Basin and other ground-water basins from any known significant contamination by radioactive substances. However the study of potential ground-water transport of contaminants needs to be pursued. If water-soluble contaminants were to enter the main aquifer, they could possibly follow the paths of ground-water flow to natural discharge areas or to discharging water wells. The use of a chemical transport model is foreseen. However, a detailed ground-water flow model is needed to estimate path lines. It is critical to chemical transport modeling that path lines accurately indicate the paths of ground-water flow because of potential reactions of the transported chemical with the various rocks that it may pass through.

OBJECTIVE

- To estimate ground-water-flow path lines in the main aquifer of the Pajarito Plateau.

PURPOSE AND SCOPE

- The purpose of this study will be to estimate ground-water-flow path lines using a ground water-flow model that can be revised as easily as possible to account for new data. The area modeled will include enough of the central and southern Espanola Basin to avoid artificial boundary effects in the Pajarito Plateau area. Although the purpose of the flow model is to estimate paths of ground-water flow, the data necessary to define path lines accurately enough for a transport model probably does not yet exist. Therefore, the path lines estimated are termed "preliminary". The model will become obsolete as additional data are collected and concepts of the ground-water system change. Although the model will be made as easily-modified as possible, data and new concepts that may be brought forth after the first 24 months of this study may not be included in the final product. Although the model will be constructed with the idea of providing a basis for a solute transport model, this model will be limited to ground-water flow below the water table in the main aquifer, and will treat flow in the vadose zone only as a boundary condition.

APPROACH

In general, path lines will be estimated from a finite-difference ground-water flow model using MODFLOW (McDonald and Harbaugh, 1988) and MODPATH (Pollack, 1989). The approach will be made in 3 steps. The first step will be to study the geologic and hydrologic literature of the Espanola Basin, and compile existing data. The second step will be to assemble a geographic information system data base. The third step will be to calibrate a ground-water flow model and estimate the path lines.

The first step will begin with the literature review. The literature review will include selected literature that could lead to conclusions about ground-water path lines in the main aquifer of the Pajarito Plateau, and might include several disciplines. The review will concentrate on gathering information about the study area that will lead to development of a ground-water flow model, not on theoretical considerations of path-line calculation. The area of the Pajarito Plateau will be emphasized with a lesser degree of emphasis on more distant parts of the Espanola Basin. Part of the first step will be to locate and compile existing data that were not compiled by previous projects. Existing stress data might include ground-water pumpage, the fate of Santa Fe and Los Alamos public supply water (irrigation, private disposal systems, public disposal effluent locations and rates), and possibly other hydrologic features such as water impounded in Cochiti Reservoir which occasionally backs up onto an area of the Espanola Basin. Existing hydrogeologic data might include lithologic well logs and estimated hydraulic conductivities. Other existing data relating to path lines might include ground-water age, altitude of recharge, penetration of tracers into the aquifer system, degree of saturation, surface geophysics, borehole geophysics, fracture studies, and water-bearing characteristics of cores. The literature review will be preserved as an annotated bibliography and published as an Open File Report. Annotations will relate to the determination of path lines and will not necessarily indicate the full content of the literature reviewed. Part of the first step will be development of the conceptual model, which will be modified throughout the project, preserved as the geohydrology section of the model report, and published by the end of the project.

The second step will be to identify the main kinds of spacially variant geohydrologic data in the study area and build a geographic information system (GIS) data base. Spacially variant data might include hydraulic heads, hydrologic characteristics, land cover, land use, irrigated areas, phreatophyte areas, ground-water withdrawals, altitudes of open intervals in production wells, artificial-recharge locations, and the altitudes of geologic and lithologic units from which surfaces of geohydrologic units can be estimated. A GIS can be used for model preparation and to facilitate the incorporation of masses of spacially variant data into model input (Kernodle and Philip, 1987). As data become available concepts of a geohydrologic system change. As this occurs, and as interests in specific zones of the aquifer change, it is sometimes advantageous to change the spacial discretization of a flow model. Although in theory the spacial discretization of a ground-water flow model can be changed, in practice, it is time consuming. A unique advantage of GIS-assisted model preparation is that it is more practical to modify the spacial discretization of the model. GIS techniques will help allow the size and complexity of the model to more nearly approach that required to estimate path lines with the accuracy suitable for a chemical transport model. The GIS used will be ARC/INFO. (The use of brand names is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.)

The third step will be to build, test, and document a ground-water flow model. Spacially variant model input will be generated from the GIS data base using existing, modified, or custom-made preprocessing programs. Although some of these preprocessors exist, they may need to be modified or enhanced to meet the specific needs of this study. To take some of the subjectivity out of model calibration, and possibly to speed the calibration process, parameter estimation (Hill, 1992) will be used if appropriate. Parameter estimation uses a statistical approach to optimize user-specified parameters, such as the hydraulic conductivity of a specified zone of the model, and to estimate the degree of optimization achieved. Path lines will be estimated using MODPATH (Pollack, 1989), which computes values of the principle components of the velocity vector at every point in the flow field based on the intercell flow rates from the finite-difference model. MODPATH uses linear interpolation to compute principal velocity components within a cell. Estimated path lines will be preliminary and subject to revision.

MANPOWER, COSTS, AND WORKPLAN

The total duration of the investigation is 45 months; 3 years for the study with 9 additional months for final report preparation. Costs are almost entirely to cover salaries for personnel, and are concentrated in the first 3 years of the investigation. Manpower is available within the New Mexico district and consists of the project chief (GS-12), a consulting modeling and GIS expert (GS-13), a computer specialist (GS-11), and a student helper (GS-4). The project chief will be 80 percent available the first year and 100 percent available for the remainder of the project.

Costs in dollars*	
Fiscal year 1995	
Personnel	$140,000
Vehicle**	5,700
Copy/purchase documents	1,300
Total	$147,000
Fiscal year 1996	
Personnel	$171,000
Vehicle**	1,000
Printing of bibliography	8,500
Total	$180,500
Fiscal year 1997	
Personnel	$175,000
Vehicle**	1,000
Total	$176,000
Fiscal year 1998	
Personnel	$76,000
Vehicle**	300
Printing of model reports	19,000
Total	$95,300
Project total	$598,800

Workplan*																
Federal Fiscal Year		1995				1996				1997				1998		
Quarter	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Work Element																
Literature review and preparation of bibliography	X	X	X	X	X											
Compilation of existing data	X	X	X	X	X											
Identify data for GIS data base			X	X	X											
Development of conceptual flow model		X	X	X	X	X	X	X								
Begin "hydrology" section of model report			X	X	X	X										
Population of GIS with data					X	X	X	X								
Publication of bibliography report						X	X	X								
Preparation of model input preprocessors using GIS							X	X	X	X						
Model calibration									X	X	X					
Final preparation model documentation report											X	X	X			
Final preparation model listings report													X			
Publication of model reports														X	X	X

*Costs and workplan assume a starting date of October 1, 1994.

** Travel includes vehicle rental and mileage (9,650 vehicle miles during FY95, 2,150 miles during FY96, 2,000 miles during FY97, and 750 miles during FY98). Purpose of travel will be to locate, and copy or review documents; and to meet with LANL staff.

REPORTS

Three reports will be published. The first will be an annotated bibliography which will be drafted by the end of the fifth quarter of the study and will be published as an Open File Report within the second year. The second report will be the model documentation, drafted by the end of the third year of the project, and published as a Water-Resources Investigations Report by the end of the project. The third will be a GIS data base and model input listings report, drafted by the end of the third year of the project and published as an Open File Report by the end of the project. The third report will preserve the data base and model input/output on an appropriate electronic medium such as data cartridge in commonly used formats such as ASCII. Because the listings report will not document or defend the model, it will not be available before the model-documentation report. However, consistent with U.S.G.S. policy, un interpreted data will generally be available on request.

REFERENCES

Baltz, E.H., 1978, Resume of the Rio Grande Depression in north-central New Mexico, in Guidebook to Rio Grande rift in New Mexico and Colorado: New Mexico Bureau of Mines and Mineral Resources Circular 163, p. 210-228.

Finch, Steven T., and Fleming, W.M., 1992, Recalibration of the USGS-SEO Santa Fe ground-water model using revised recharge estimates: John W. Shomaker, Inc., consulting report for Santa Fe Metropolitan Water Board, 25 p. with a 22-p. appendix.

Griggs, R.L., 1964, Geology and ground-water resources of the Los Alamos area New Mexico: U.S. Geological Survey Water-Supply Paper 1753, 107 p., 1 pl.

Hearne, G.A., 1980, Mathematical model of the Tesuque aquifer system underlying Pojoaque River basin and vicinity, New Mexico: U.S. Geological Survey Open-File Report 80-1023, 181 p.

Hill, M.C., 1992, A computer program (MODFLOWP) for estimating parameters of a transient, three-dimensional, ground-water flow model using nonlinear regression: U.S. Geological Survey Open-File Report 91-484, 358 p.

Kelley, V.C., 1978, Geology of Espanola Basin, New Mexico: New Mexico Bureau of Mines & Mineral Resources, Geologic Map 48.

Kernodle, J.M., and Philip, R.D., 1987, Using a geographic information system to develop a ground-water flow model: *in* Regional aquifer systems of the United States--Aquifers of the western mountain area, Papers presented at 23rd annual AWRA conference and symposium, November 1-6, 1987, AWRA Monograph Series No. 14, p. 191-202.

Manley, Kim, 1978, Cenozoic geology of the Espanola Basin, in Guidebook to Rio Grande rift in New Mexico and Colorado: New Mexico Bureau of Mines and Mineral Resources Circular 1963, p. 201-210.

McAda, D.P., and Wasiolek, Maryann, 1988, Simulation of the regional geohydrology of the Tesuque aquifer system near Santa Fe, New Mexico: U.S. Geological Survey Water-Resources Investigations Report 87-4056, 71 p.

McDonald, M.G., and Harbaugh, A.W., 1984, A modular three-dimensional finite-difference ground-water flow model: U.S. Geological Survey Open-File Report 83-875, 528 p.

Pollack, D.W., 1989, Documentation of computer programs to compute and display pathlines using results from the U.S. Geological Survey modular three-dimensional finite-difference ground-water flow model: U.S. Geological Survey Open File Report 89-381, 188 p.

Purtymun, W.D. and Cooper, J.B., 1969, Development of ground-water supplies on the Pajarito Plateau, Los Alamos County, New Mexico: U.S. Geological Survey Professional Paper 650-B.

Purtymun, W.D. and Johansen, Steven, 1974, General geohydrology of the Pajarito Plateau, in Guidebook to Ghost Ranch (central-northern New Mexico): New Mexico Geological Society Twenty-fifth Field Conference, p. 347-349.

Spiegel, Zane, and Baldwin, Brewster, 1963, Geology and water resources of the Santa Fe area, New Mexico: U.S. Geological Survey Water-Supply Paper 1525, 258 p.

APPENDIX H

Annotated Bibliography of Geologic, Hydrogeologic and Environmental Studies Relevant to Solid Waste Management Units at Los Alamos National Laboratory

LA-UR-90-3216

Los Alamos National Laboratory

Environmental Restoration

A Department of Energy environmental clean up program

Annotated Bibliography of Geologic, Hydrogeologic, and Environmental Studies Relevant to Solid Waste Management Units at Los Alamos National Laboratory

I. GEOLOGY

Abeele, W.V., 1978,
The Influence of Access Hole Parameters on Neutron Moisture Probe Readings.

Abeele, W.V., 1984,
Geotechnical Aspects of Mackrey Sandy Loam and Crushed Tuff.

Abeele, W.V., 1984,
Geotechnical Characteristics of Bentonite/Sandy Silt Mixes for Use in Waste Disposal Sites.

Abeele, W.V., 1985,
Consolidation and Shear Failure Leading to Subsidence and Settlement: Part I.

Abeele, W.V., and Nyhan, J.W., 1985,
Evaluation of Subsidence Constraints and Controls.

Abeele, W.V., et al., 1986,
Consolidation and Shear Failure Leading to Subsidence and Settlement.

Abeele, W.V., Wheeler, M.L., and Burton, B.W., 1981,
Geohydrology of Bandelier Tuff.

Abrahams, J.H., Jr., 1963,
Geologic and Hydrologic Environment of Radioactive Waste Disposal Sites at Los Alamos, New Mexico.

Albright, J.N., 1979,
"Earthquake Monitoring", Summary of Talks, 2nd Annual Hot Dry Rock Geothermal Conference.

Bailey, R.A., Smith, R.L., and Ross, C.S., 1969,
Stratigraphic Nomenclature of Volcanic Rocks in the Jemez Mountains, New Mexico.

Balagna, J., Charles, R., and Vidale, R., 1976,
Geothermal Chemistry Activities at LASL, January-December 1975.

Baldridge, W.S., Perry, F.V., and Gladney, E.S., 1982,
Petrology and Geochemistry of the Cat Hills Volcanic Field, Central Rio Grande Rift, New Mexico.

Baltz, E.H., Abrahams, J.H., and Purtymun, W.D., 1963,
Preliminary Report on the Geology and Hydrology of Mortandad Canyon near Los Alamos, New Mexico, with Reference to Disposal of Liquid Low-Level Radioactive Waste.

Barton, R.L., 1968,
General Geology and Hydrology of North-Central Santa Fe County, New Mexico.

Brookins, D.G., et al., 1977,
Rb-Sr, K-Ar, and Fission-Track Geochronological Studies of Samples from LASL Drill Holes GT-1, GT-2 and EE-1.

Brown, F., et al., 1988,
Site Geology and Hydrology of Technical Area 16, Area P.

Brown, M.C., et al., 1979,
Hot Dry Rock Geothermal Development Program Annual Report Fiscal Year 1978.

Budding, A.J., 1978,
Gravity Survey of the Pajarito Plateau Los Alamos and Santa Fe Counties, New Mexico.

Budding, A.J., and Beers, C.A., 1973,
Faults in the Los Alamos Area and Their Relation to Seismicity.

Budding, A.J., and Purtymun, W.D., 1976,
Seismicity of the Los Alamos Area Based on Geologic Data.

Burton, B.W., 1982,
Geologic Evolution of the Jemez Mountains and Their Potential for Future Volcanic Activity.

Cabot, E.C., 1938,
Fault Border of the Sangre de Cristo Mountains North of Santa Fe New Mexico.

Crowe, B.M., et al., 1978,
Stratigraphy of the Bandelier Tuff in the Pajarito Plateau.

Dames and Moore, 1972,
Report of Geologic, Foundation, Hydrologic and Seismic Investigation Plutonium Processing Facility Los Alamos Scientific Laboratory, Los Alamos, New Mexico.

Dransfield, B.J., and Gardner, J.N., 1985,
Subsurface Geology of the Pajarito Plateau, Espanola Basin, New Mexico.

Earth Environmental Consultants, 1978,
Soil Survey of the Bandelier National Monument.

Eichelberger, J.C., 1976,
Geosciences at Los Alamos Scientific Laboratory (LASL), July 1-December 31, 1975.

Fisher, N.H., 1979,
"An Analysis of the Pressure Transient Testing of the Fenton Hill Reservoir", Summary of Talks, 2nd Annual Hot Dry Rock Geothermal Conference.

Galusha, T., and Blick, J.C., 1971,
"Stratigraphy of the Santa Fe Group".

Gardner, J.N., and House, L., 1987,
Seismic Hazards Investigations at Los Alamos National Laboratory, 1984 to 1985.

Gardner, J.N., et al., 1987,
Core Lithology Valles Caldera #1, New Mexico.

Ciffels, and Rossetti, Inc., 1966,
Foundation Investigation (Subsurface Soil Borings) for Los Alamos Meson Physics Facility, Los Alamos, New Mexico.

Golombek, M.P., 1981,
Structural Analysis of the Pajarito Fault Zone in the Espanola Basin of the Rio Grande Rift, New Mexico.

Griggs, R.L., 1953,
Geology and Ground Water Resources of the Los Alamos Area, New Mexico..

Grigsby, C.O., 1979,
"Hot Dry Rock Geochemistry", Summary of Talks, 2nd Annual Hot Dry Rock Geothermal Conference.

Gutschick, V., and Rea, K., 1978,
Environmental Assessment of Dissolved Gases in LASL's Hot Dry Rock Geothermal Source Demonstration Project.

Heiken, G., 1975,
Solid Earth Geosciences Research Activities at LASL, January 1 - June 30, 1975.

Heiken, G., 1985,
Workshop on Recent Research in the Valles Caldera; Los Alamos National Laboratory, Los Alamos, New Mexico, October 15-18, 1984.

Hof, G.J., 1962,
The Effect of the Constant Natural Earth Movement on Numerically-Controlled Machine Tools.

House, L.S., and Cash, D.J., 1988,
A Reveiw of Historic and Instrumental Earthquake Activity and Studies of Seismic Hazards near Los Alamos, New Mexico.

International Technology Corporation, 1987,
Geologic Assessment of Technical Area 54, Areas G and L, Los Alamos National Laboratory.

Izett, G.A., et al., 1978,
K-Ar and Fission-Track Zircon Ages of Cerro Toledo Rhyolite Tephra Units in the Jemez Mountains, North Central New Mexico.

Keller, M.D., 1968,
Deformation Characteristics of the Bandelier Tuff.

Keller, M.D., 1968,
Geologic Studies and Material Properties Investigations of Mesita de Los Alamos.

Keller, M.D., Foster, E.S., and Werner, F.N., 1969,
Ground Vibration Characteristics of Mesita de Los Alamos.

Kelley, V.C., 1948,
Los Alamos Project-Pumice Investigation-Field Survey; Geology and Pumice Deposits of the Pajarito Plateau, Sandoval, Santa Fe, and Rio Arriba Counties, New Mexico.

Kelley, V.C., 1978,
Geology of Espanola Basin, New Mexico.

Kelley, V.C., 1979,
"Tectonics, Middle Rio Grande Rift, New Mexico", Rio Grande Rift: Tectonics and Magmatism.

Kintzinger, P.R., et al., 1978,
Seismic Reflection Surveys Near LASL Geothermal Site.

Koopman, F.C., and Purtymun, W.D., 1963,
Preliminary Report on the MECHANICS OF AIR FLOW WITHIN THE BANDELIER TUFF with Special Reference to THE INJECTION DISPOSAL OF GASEOUS WASTES INTO UNSATURATED MEDIA..

Koopman, F.C., and Purtymun, W.D., 1966,
Volume and Energy Within Air Exchanged Through Test Holes in the Bandelier Tuff, Near Los Alamos, N. Mex..

Kunkler, J.L., 1969,
Measurement of Atmospheric Pressure and Subsurface-Gas Pressure in the Unsaturated Zone of the Bandelier Tuff, Los Alamos, New Mexico.

Kunkler, J.L., 1969,
The Sources of Carbon Dioxide in the Zone of Aeration of the Bandelier Tuff, Near Los Alamos, New Mexico.

Larkin, K.P., and Speake, J.L., 1976,
Horizontal Monitoring Holes Los Alamos, New Mexico.

Laughlin, A.W., and Eddy, A., 1977,
Petrography and Geochemistry of Precambrian Rocks from GT-2 and EE-1.

Manley, K., 1979,
"Stratigraphy and Structure of the Espanola Basin, Rio Grande Rift, New Mexico", Rio Grande Rift: Tectonics and Magmatism.

McGetchin, T.R., 1975,
Solid Earth Geosciences Research Activities at LASL, June1 - Dec 31, 1974.

Newton, C.A., et al., 1976,
LASL Seismic Programs in the Vicinity of Los Alamos, New Mexico.

Nyman, J.W., 1978,
"Soil Survey Techniques Used to Characterize the National Environmental Research Park at Los Alamos", National Environmental Research Park Symposium: Natural Resource Inventory, Characterization, and Analysis.

Nyhan, J.W., and Hiers, F.R., 1974,
"Characterization of Soil", Annual Report of the Biomedical and Environmental Research Program of the LASL Health Division: January through December 1973.

Nyhan, J.W., et al., 1978,
Soil Survey of Los Alamos County, New Mexico.

Olsen, K.H., Keller, G.R., and Stewart, J.N., 1978,
"Crustal Structure Along the Rio Grande Rift from Seismic Refraction Profiles", 1978 International Symposium on the Rio Grande Rift, October 8-17, 1978, Santa Fe, New Mexico, USA.

Purtymun, W.D., 1966,
Geology and Hydrology of White Rock Canyon from Otowi to the Confluence of Frijoles Canyon, Los Alamos and Santa Fe Counties, New Mexico..

Purtymun, W.D., 1967,
Geology and Physical Properties of the Near-Surface Rocks at Mesita de Los Alamos, Los Alamos County, New Mexico.

Purtymun, W.D., 1973,
Geology of the Jemez Plateau West of Valles Caldera.

Purtymun, W.D., 1973,
Underground Movement of Tritium from Solid-Waste Storage Shafts.

Purtymun, W.D., and Johansen, S., 1974,
"General Geohydrology of the Pajarito Plateau", New Mexico Geologic Society Guidebook, 25th Field Conference.

Purtymun, W.D., and Jordan, H.S., 1973,
Seismic Program of the Los Alamos Scientific Laboratory.

Purtymun, W.D., and Kennedy, W.R., 1971,
Geology and Hydrology of Mesita del Buey.

Purtymun, W.D., and Koopman, F.C., 1965,
Physical Characteristics of the Tshirege Member of the Bandelier Tuff with Reference to Use as a Building and Ornamental Stone.

Purtymun, W.D., West, F.G., and Pettitt, R.A., 1974,
Geology of Geothermal Test Hole GT-2 Fenton Hill Site, July 1974.

Purtymun, W.D., Wheeler, M.L., and Rogers, M.A., 1978,
Geologic Description of Cores from Holes P-3 MH-1 Through P-3 MH-5, Area G, Technical Area 54.

Reynolds, C.B., 1977,
Experimental Shallow Seismic Reflection Survey Los Alamos Area, New Mexico.

Ross, C.S., Smith, R.L., and Bailey, R.A., 1961,
"Outline of the Geology of the Jemez Mountains, New Mexico".

Sanford, A.R., 1972,
Seismicity on the Los Alamos Region Based on Seismological Data.

Sanford, A.R., et al., 1972,
Seismicity of the Rio Grande Rift in New Mexico.

Sanford, A.R., Olsen, K.H., and Jaksha, L.H., 1979,
"Seismicity of the Rio Grande Rift", Rio Grande Rift: Tectonics and Magmatism.

Savage, W.U., Ely, R.W., and Tocher, D., 1977,
Review of the Los Alamos Seismic Monitoring Program in Relation to the Hot Dry Rock Geothermal Project.

Shankland, T.J., 1978,
"Simultaneous Consideration of Electrical and Elastic Anomalities in Rift Zones", 1978 International Symposium on the Rio Grande Rift, October 8-17, 1978, Santa Fe, New Mexico, USA.

Slemmons, D.B., 1975,
Fault Activity and Seismicity near the Los Alamos Scientific Laboratory Geothermal Test Site, Jemez Mountains, New Mexico.

Spiegel, Z., 1961,
"Late Cenzoic Sediments of the Lower Jemez River".

Strantford, A.R., 1976,
Seismicity of the Los Alamos Region Based on Seismological Data.

Theis, C.V., Conover, C.S., and Griggs, R.L., 1950,
Preliminary Report on the Geology and Hydrology of the Valle Grande Area, New Mexico.

Wachs, D., et al., 1988,
Evidence of Young Fault Movements on the Pajarito Fault System in the Area of Los Alamos, New Mexico.

Weir, J.E., and Purtymun, W.D., 1962,
Geology and Hydrology of Technical Area 49, Frijoles Mesa, Los Alamos County, New Mexico.

West, F.G., 1973,
Regional Geology and Geophysics of the Jemez Mountains.

Williston, McNeil and Associates, 1979,
A Time Domain Survey of the Los Alamos Region, New Mexico.

II. HYDROLOGY

Abeele, W.V., 1979,
Determination of Hydraulic Conductivity in Crushed Bandelier Tuff.

Abeele, W.V., 1979,
Determination of Relative Hydraulic Conductivity from Moisture Retention Data Obtained in the Bandelier Tuff.

Abeele, W.V., 1983,
Testing of Lateral Flow.

Abeele, W.V., 1984,
Hydraulic Testing of Crushed Bandelier Tuff.

Abeele, W.V., and DePoorter, G.L., 1983,
Field Scale Determination of the Saturated and Unsaturated Hydraulic Conductivity of Porous Materials, I. Crushed Bandelier Tuff.

Abeele, W.V., and DePoorter, G.L., 1984,
Testing of Lateral Water Flow in a Moisture Barrier.

Abeele, W.V., DePoorter, G.L., and Nyhan, J.W., 1986,
Laboratory and Large Scale Hydraulic Testing of a Sandy Silt Used in Shallow Land Burial.

Abrahams, J., Jr., Weir, J., Jr., and Purtyman, W., 1961,
"Distribution of Moisture in Soil and Near-Surface Tuff on the Pajarito Plateau, Los Alamos County, New Mexico" Short Papers in the Geologic and Hydrologic Sciences, Articles 293-435.

Abrahams, J.H., Baltz, E.H., and Purtyman, W.D., 1962,
Movement of Perched Ground Water in Alluvium Near Los Alamos, New Mexico.

Abrahams, J.H., Jr., 1959,
Production of Water and Changes in Water Level in the Los Alamos, New Mexico, Well Fields July through December 1958.

Abrahams, J.H., Jr., 1963,
Physical Properties of and Movement of Water in the Bandelier Tuff, Los Alamos and Santa Fe Counties, New Mexico.

Abrahams, J.H., Jr., 1964,
Equipment Used to Study the Movement of Water in the Bandelier Tuff at Los Alamos, New Mexico.

Abrahams, J.H., Jr., 1966,
The Hydrology and the Chemical and Radiochemical Quality of Surface and Ground Water at Los Alamos, New Mexico, January 1956 through June 1957.

Abrahams, J.H., Jr., and Purtyman, W.D., 1966,
The Hydrology and Chemical and Radiochemical Quality of Surface and Ground Water at Los Alamos, New Mexico, July 1957 through June 1961.

Abraham, J.R., Weir, J.E., and Purtymun, W.D., 1961,
Distribution of Moisture in Soil and Near Surface Tuff in the Pajarito Plateau, Los Alamos, New Mexico..

Becker, N.M., Purtymun, W.D., and Ballance, W.C., 1981,
Aquifer Evaluation at Fenton Hill, October and November 1980.

Cooper, J.B., Purtymun, W.D., and John, E.C., 1965,
Records of Water Supply Wells Guaje Canyon 4, Pajarito Mesa 1, and Pajarito Mesa 2, Los Alamos, New Mexico.

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.

Cushman, R.L., and Purtymun, W.D., 1975,
Evaluation of Yield and Water-Level Relations.

Daniel B. Stephens and Associates, Inc., 1988,
Final Data Report on Laboratory Analyses of Soil Hydraulic Properties of Welded Tuffs at Los Alamos National Laboratory.

Devaurs, M., 1985,
Core Analyses and Observation Well Data From Mesita Del Buey Waste Disposal Areas and in Adjacent Canyons.

Devaurs, M., and Purtymun, W.D., 1985,
Hydrologic Characteristics of the Alluvial Aquifers in Mortandad, Canada del Buey and Pajarito Canyons.

Emvert, F.A., and Purtymun, W.D., 1966,
Movement of Water Injected into Tuff.

Fuentes, H.R., and Polzer, W.L., 1987,
Interpretative Analysis of Data for Solute Transport in the Unsaturated Zone.

Fuentes, H.R., Polzer, W.L., and Springer, E.P., 1987,
Effects from Influent Boundary Conditions on Tracer Migration and Spatial Variability Features in Intermediate-Scale Experiments.

Gruber, J., 1988,
"Natural Geochemical Isolation of Neutron-Activated Waste: Scenarios and Equilibrium Models".

Nakonson, T.E., 1981,
"Hydrological Transport of Sediments", Environmental Surveillance at Los Alamos During 1980.

HSE Division, Facilities Eng. Division, 1988,
Long-Range Water Supply Plan: A Program to Develop Water Resources for Los Alamos County and the Laboratory to Year 2030.

HydroGeologic, Inc., 1989,
Pathway Analysis at Material Disposal Area T Los Alamos National Laboratory (LANL) Los Alamos, New Mexico.

John, E.C., 1966,
Pumpage and Water Levels in Los Alamos Supply Wells, 1965.

Keeri, P.M., Dexter, J.J., and Kautsky, M., 1986,
Vadose Zone Characterization of Technical Area 54, Waste Disposal Areas G and L, Los Alamos National Laboratory, Los Alamos, New Mexico, Report 3: Preliminary Assessment of the Hydrologic System.

Keeri, P.M., Dexter, J.J., and Kautsky, M., 1986,
Vadose Zone Characterization of Technical Area 54, Waste Disposal Areas G and L, Los Alamos National Laboratory, Los Alamos, New Mexico, Report 4: Preliminary Assessment of the Hydrologic System through Fiscal Year 1986.

Kelly, T.E., 1971,
Pumpage and Water Levels in Supply Wells, 1970.

Kelly, T.E., 1974,
Reconnaissance Investigation of Ground Water in the Rio Grande Drainage Basin - With Special Emphasis on Saline Ground-Water Resources.

Koopman, F.C., and Purtymun, W.D., 1965,
Hydrologic Characteristics of the Tshirege Member of the Bandelier Tuff with Reference to the Injection of Treated Low-level Radioactive Liquids.

Koopman, F.C., and Purtymun, W.D., 1969,
Pumpage and Water Levels in Supply Wells, 1968.

Lane, L.J., 1983,
Preliminary Report on Water and Contaminant Transport in the Subsurface Zone--A Joint Los Alamos/USDA-Agricultural Service Study.

Lane, L.J., 1984,
Surface Water Management: A User's Guide to Calculate a Water Balance Using the CREAMS Model.

Lane, L.J., and Nakonson, T.E., 1982,
"Influence of Particle Sorting in Transport of Sediment Associated Contaminants", Proceedings of the Symposium on Waste Management.

Lane, L.J., and Nyman, J.W., 1984,
Water and Contaminant Movement: Migration Barriers.

Lane, L.J., Purtymun, W.D., and Becker, N., 1982,
Development of Procedures to Estimate Surface Runoff, Sediment Yield, and Contaminant Transport at Los Alamos, New Mexico.

Lane, L.J., Purtymun, W.D., and Becker, N.M., 1985,
New Estimating Procedures for Surface Runoff, Sediment Yield, and Contaminant Transport in Los Alamos County, New Mexico.

McLin, S., McInroy, D., and Griggs, A., 1988,
"Vadose Zone Characterization at TA-16, Area P", Los Alamos National Laboratory Environmental Surveillance 1987.

New Mexico Environmental Improvement Division, 1984,
A Reasonable Worst-Case Water Balance for LANL Hazardous Waste Disposal Areas, with Emphasis on TA-54.

Nyhan, J.W., 1989,
A Hydrologic Modeling Study of Water Balance Relationships at the Area P Landfill in Los Alamos, New Mexico.

Nyhan, J.W., 1989,
Hydrologic Modeling to Predict Performance of Shallow Land Burial Cover Designs at the Los Alamos National Laboratory.

Nyhan, J.W., and Drennon, R., 1989,
The Measurement of Soil Water Tension in a Hydrologic Study of Waste Disposal Site Design.

Nyhan, J.W., and Drennon, B.J., 1990,
"Tensiometer Data Acquisition System for Hydrologic Studies Requiring High Temporal Resolution".

Nyhan, J.W., Drennon, B.J., and Gaylor, R.H., 1987,
Field Evaluation of a Tensiometer Data Aquisition System for Hydrologic Studies of Waste Disposal Site Design.

Nyhan, J.W., et al., 1983,
"Environmental Migration of Long Lived Radionuclides Beneath a Former Los Alamos Liquid Waste Disposal Site After 33 years".

Nyhan, J.W., et al., 1983,
"Transport of Soil Particles by Overland Flow from Trench Caps Used to Cover Low-Level Radioactive Wastes".

Nyhan, J.W., et al., 1986,
A Joint DOE/NRC Field Study of Tracer Migration in the Unsaturated Zone.

Nyhan, J.W., Hakonson, T.E., and Drennon, B.J., 1990,
"A Water Balance Study of Two Landfill Cover Designs for Semiarid Regions".

Pearson, C.F., 1981,
Investigation of a Shallow Aquifer Near the Fenton Hill Hot Dry Rock Site Using DC Resistivity.

Penrose, W.R., et al., 1990,
"Mobility of Plutonium and Americium through a Shallow Aquifer in a Semiarid Region".

Perkins, S., Travis, B., and DePoorter, G., 1985,
Validation of the TRACKD Code for Soil Water Flow Under Saturated/Unsaturated Conditions in Three Experiments.

Perkins, B.L., and Cokal, E.J., 1986,
Subsurface Moisture Regimes and Tracer Movement Under Two Types of Trench-Cap Designs for Shallow Land Burial Sites.

Polzer, W.L., and Essington, E.H., 1983,
Mobility of Waste Actinides in the Shallow Aquifer of Mortandad Canyon, Los Alamos, New Mexico.

Polzer, W.L., and Fuentes, H.R., 1985,
Coupling Equilibrium Sorption to Flow Dynamics in Porous Media..

Polzer, W.L., and Fuentes, H.R., 1985,
Field Studies and Modeling of Chemical Processes in the Unsaturated Zone.

Polzer, W.L., and Fuentes, H.R., 1987,
The Use of a Heterogeneity-Based Isotherm to Interpret the Transport of Reactive Radionuclides in Volcanic Tuff.

Polzer, W.L., and Lane, L.J., 1984,
Field Studies and Modeling of Chemical Processes in the Unsaturated Zone: Test Plan for Technical Support Studies.

Polzer, W.L., et al., 1984,
"Geochemical Mechanisms of Contaminant Transport ", Environmental Surveillance at Los Alamos During 1983.

Polzer, W.L., et al., 1986,
Modeling Study of Solute Transport in the Unsaturated Zone: Information and Data Sets.

Polzer, W.L., et al., 1987,
Characterization of Crushed Tuff for the Evaluation of the Fate of Tracers in Transport Studies in the Unsaturated Zone.

Porzucek, C., and Springer, E., 1987,
VAPTOC - Vapor Phase Transport of Organic Chemicals I. Model Development.

Purtymun, W.D., 1962,
The Distribution of Moisture in the Soil and Underlying Tuff at Technical Area 49, Frijoles Mesa, Los Alamos County, New Mexico.

Purtymun, W.D., 1964,
Progress Report on the Hydrology of Mortandad Canyon, Disposal System for Treated Low-level Liquid Radioactive Wastes; July 1961 to June 1963.

Purtymun, W.D., 1966,
The Chemical and Radiochemical Quality of Surface and Ground Water at Los Alamos, New Mexico, July 1961 through June 1962.

Purtymun, W.D., 1966,
The Chemical and Radiochemical Quality of Surface and Ground Water at Los Alamos, New Mexico, July 1962 through June 1963.

Purtymun, W.D., 1966,
The Chemical and Radiochemical Quality of Surface and Ground Water at Los Alamos, New Mexico, July 1963 through June 1964.

Purtymun, W.D., 1967,
Pumpage and Water Levels in Supply Wells, 1966.

Purtymun, W.D., 1967,
Record of Water-Supply Well PM-3 Los Alamos, New Mexico.

Purtymun, W.D., 1967,
The Disposal of Industrial Effluents in Mortandad Canyon, Los Alamos County, New Mexico.

Purtymun, W.D., 1968,
Pumpage and Water Levels in Supply Wells, 1967.

Purtymun, W.D., 1969,
Chemical and Radiochemical Analyses of Water in Los Alamos Area, New Mexico, Made by the U.S. Geological Survey, 1960 through 1968.

Purtymun, W.D., 1969,
Schedule for the Collection and Analyses of Surface and Ground-water Samples in the Los Alamos Area, New Mexico.

Purtymun, W.D., 1973,
Regional Survey of Tritium in Surface and Ground Water in the Los Alamos Area, New Mexico; August 1966 through May 1969.

Purtymun, W.D., 1973,
Water Supply at Los Alamos During 1972.

Purtymun, W.D., 1974,
Dispersion and Movement of Tritium in a Shallow Aquifer in Mortandad Canyon at the Los Alamos Scientific Laboratory.

Purtymun, W.D., 1974,
Storm Runoff and Transport of Radionuclides in DP Canyon, Los Alamos County, New Mexico.

Purtymun, W.D., 1974,
Water Supply at Los Alamos During 1973.

Purtymun, W.D., 1975,
Geohydrology of the Pajarito Plateau with Reference to Quality of Water, 1949-1972.

Purtymun, W.D., 1975,
Water Supply at Los Alamos During 1974.

Purtymun, W.D., 1976,
Water Supply at Los Alamos During 1975.

Purtymun, W.D., 1977,
Hydrologic Characteristics of the Los Alamos Well Field, with Reference to the Occurrence of Arsenic in Well LA-6.

Purtymun, W.D., 1977,
Water Supply at Los Alamos During 1976.

Purtymun, W.D., 1978,
Water Supply at Los Alamos During 1977.

Purtymun, W.D., 1979,
Water Supply at Los Alamos During 1978.

Purtymun, W.D., 1980,
Water Supply at Los Alamos During 1979.

Purtymun, W.D., 1984,
Hydrologic Characteristics of the Main Aquifer in the Los Alamos Area: Development of Ground Water Supplies.

Purtymun, W.D., Adams, W.H., and Owens, J.W., 1975,
Water Quality in the Vicinity of Fenton Hill Site, 1974.

Purtymun, W.D., Adams, W.H., and Stoker, A.K., 1978,
Water Quality in the Vicinity of Fenton Hill Site, 1976.

Purtymun, W.D., and Abrahams, J.H., Jr., 1963,
Hydrologic Characteristics of an Ash Flow Tuff at Frijoles Mesa, Los Alamos County, New Mexico.

Purtymun, W.D., and Adams, N., 1980,
Geohydrology of Bandelier National Monument, New Mexico.

Purtymun, W.D., and Cooper, J.B., 1963,
Locations for Five Water-Supply Wells at Los Alamos, New Mexico.

Purtymun, W.D., and Cooper, J.B., 1969,
Development of Ground-Water Supplies on the Pajarito Plateau, Los Alamos County, New Mexico.

Purtymun, W.D., and Cushman, R.L., 1961,
Site Location for a Los Alamos Supply Well Near the 10-inch Water Main that Parallels State Highway 4 Between Pueblo Canyon and White Rock.

Purtymun, W.D., and Cushman, R.L., 1963,
Site Location for a Municipal Supply Well in Guaje Canyon or Rendija Canyon near Los Alamos, New Mexico.

Purtymun, W.D., and Enyart, E.A., 1966,
The Chemical and Radiochemical Quality of Surface and Ground Water at Los Alamos, New Mexico, July 1964 through June 1965.

Purtymun, W.D., and Mercer, J.E., 1972,
Summary of Los Alamos Municipal Well-Field Characteristics, 1947-1971.

Purtymun, W.D., and Mercer, J.E., 1972,
Water Supply at Los Alamos During 1971.

Purtymun, W.D., and Jenn, E., 1964,
Site for a Municipal Supply Well in Pajarito Canyon near Los Alamos, New Mexico.

Purtymun, W.D., and Kunkler, J.L., 1967,
The Chemical and Radiochemical Quality of Surface and Ground Water at Los Alamos, New Mexico, July 1965 through June 1966.

Purtymun, W.D., and Kunkler, J.L., 1969,
The Chemical and radiochemical Quality of Surface and Ground Water at Los Alamos, New Mexico, July 1966 through June 1967.

Purtymun, W.D., and Stoker, A.E., 1988,
Water Supply at Los Alamos: Current Status of Wells and Future Water Supply.

Purtymun, W.D., Becker, N.M., and Maes, M., 1983,
Water Supply at Los Alamos During 1981.

Purtymun, W.D., Becker, N.M., and Maes, M., 1984,
Water Supply at Los Alamos During 1982.

Purtymun, W.D., Becker, N.M., and Maes, M., 1985,
Water Supply at Los Alamos During 1983.

Purtymun, W.D., Becker, N.M., and Maes, M., 1986,
Water Supply at Los Alamos During 1984.

Purtymun, W.D., Becker, N.M., and Maes, M., 1986,
Water Supply at Los Alamos During 1985.

Purtymun, W.D., Buchholz, J.R., and Nakonson, T.E., 1977,
Chemical Quality of Effluents and Their Influence on Water Quality in a Shallow Aquifer.

Purtymun, W.D., Buchholz, J.R., Nakonson, T.E., 1975,
Chemical Quality of Effluents and Their Influence on Water Quality in Mortandad Canyon.

Purtymun, W.D., Enyart, E.A., and McLin, S.G., 1989,
Hydrologic Characteristics of the Bandelier Tuff as Determined Through an Injection Well System.

Purtymun, W.D., et al., 1974,
Air Volume and Energy Transfer Through Test Holes and Atmospheric Pressure Effects on the Main Aquifer.

Purtymun, W.D., et al., 1976,
Water Quality in the Vicinity of Fenton Hill Site, 1975.

Purtymun, W.D., et al., 1978,
Water Quality in the Vicinity of Fenton Hill Site, 1977.

Purtymun, W.D., et al., 1980,
Water Quality in the Vicinity of Fenton Hill Site, 1978.

Purtymun, W.D., et al., 1980,
Water Quality in the Vicinity of Fenton Hill Site, 1979.

Purtymun, W.D., et al., 1983,
Water Quality in the Vicinity of Fenton Hill Site, 1981 and 1982.

Purtymun, W.D., et al., 1988,
Water Quality in the Vicinity of Fenton Hill, 1985 and 1986.

Purtymun, W.D., Fernbough, R.W., and Maes, M., 1988,
Quality of Surface and Ground Water at and Adjacent to the Los Alamos National Laboratory: Reference Organic Compounds.

Purtymun, W.D., Maxwell, W.R., and Peters, R.J., 1983,
Radiochemical Quality of Water in the Shallow Aquifer in Mortandad Canyon 1967-1978.

Purtymun, W.D., Maes, M.N., and Peters, R., 1984,
"Distribution of Moisture, Tritium and Plutonium in the Alluvium, Aquifer and Underlying Tuff in Mortandad Canyon", Environmental Surveillance at Los Alamos During 1984.

Purtymun, W.D., Peters, R.J., and Owens, J.W., 1980,
Geohydrology of White Rock Canyon of the Rio Grande from Otowi to Frijoles Canyon.

Purtymun, W.D., Stoker, A.K., and Maes, M.N., 1987,
Water Supply at Los Alamos During 1986.

Purtymun, W.D., West, F.G., and Adams, W.H., 1974,
Preliminary Study of the Quality of Water in the Drainage Area of the Jemez River and Rio Guadalupe.

Rodgers, J.C., et al., 1984,
Maintenance Free Vegetative Systems for Landfill Covers.

Smith, M.C., 1971,
A Preliminary Study of the Nuclear Subterrene.

Schelt, L., Jacobsen, E., and Brown, F., 1987,
"Storm Water Run-Off Sampling", Environmental Surveillance at Los Alamos During During 1986.

Schelt, L., Jacobsen, E., and Brown, F., 1988,
"Storm Water Runoff Sampling", Health, Safety and Environment Division Annual Report 1987.

Stoerma, H.T., 1948,
Ground-Water Supplies for Los Alamos, New Mexico.

Theis, C.V., and Conover, C.S., 1962,
Pumping Tests in the Los Alamos Canyon Well Field Near Los Alamos, New Mexico.

Travis, B.J., 1984,
TRACR3D: A Model of Flow and Transport in Porous/Fractured Media.

Weir, J.E., et al., 1963,
The Hydrology and the Chemical and Radiochemical Quality of Surface and Ground Water at Los Alamos, New Mexico.

Weir, J.E., Jr., et al., 1963,
The Hydrology and the Chemical and Radiochemical Quality of Surface and Ground Water at Los Alamos, New Mexico, 1949-55..

III. WASTE MANAGEMENT

Abeele, W.V., et al., 1986,
Low-Level Integrated System Test.

Burton, E.W., et al., 1982,
Overview Assessment of Nuclear Waste Management..

Devaurs, N., 1985,
Use of CREAMS Model in Experimental Designs for Shallow Land Burial of Low Level Wastes.

Dreesen, D.R., 1981,
Biogeochemistry of Uranium Mill Wastes Program Overview and Conclusions.

Elder, J., et al., 1986,
Radioactive Liquid Waste Lines Removal Project at Los Alamos (1981-1986).

Environmental Science Group, 1975,
Transuranic Waste Management Programs: July - December 1974.

Environmental Science Group, 1990,
"Calibration of the CREAMS Model for Landfill Cover Designs Limiting Infiltration of Precipitation at Waste Repositories".

Environmental Studies Group, 1973,
Quarterly Report Transuranic Waste Research Development Program March-June 1973 and Annual Report FY 1973 Transuranic Contaminated Solid Waste Treatment Program.

Environmental Studies Group, 1974,
Transuranic Solid Waste Management Research Programs: April-June 1974.

Environmental Studies Group, 1974,
Transuranic Solid Waste Management Research Programs: January-March 1974.

Environmental Studies Group, 1974,
Transuranic Solid Waste Management Research Programs: July-September 1973.

Environmental Studies Group, 1974,
Transuranic Solid Waste Management Research Programs: October - December 1973.

Environmental Studies Group, 1976,
Transuranic Solid Waste Management Research Programs: January - June 1975.

Environmental Studies Group, 1976,
Transuranic Solid Waste Management: July - December 1975.

Environmental Studies Group, 1977,
Development Activities on Shallow Land Disposal of Solid Radioactive Waste: January-December 1976.

Essington, E.H., et al., 1986,
Leaching of Solutes from Ion-Exchange Resins Buried in Bandelier Tuff.

Essington, E.H., Polzer, W.L., and Fowler, E.B., 1983,
Estimation of Ionic Charges Associated with Radionuclides in Waste Burial Solutions.

Fowler, E.B., Essington, E.H., and Polzer, W.L., 1979,
Interactions of Radioactive Wastes with Soils - A Review.

Fowler, E.B., Essington, E.H., and Polzer, W.L., 1981,
"The Interactions of Low-Level Liquid Radioactive Wastes With Soils: 1. Behavior of Radionuclides in Soil-Waste Systems".

Fowler, E.B., et al., 1973,
Transuranic Waste Research and Development Program.

Fowler, E.B., Polzer, W.L., and Essington, E.H., 1978,
Characteristics of Wastes and Soils Which Affect Transport of Radionuclides Through the Soil and Their Relationship to Waste Management.

Fowler, E.B., Polzer, W.L., and Essington, E.H., 1981,
Characteristics of Wastes and Soils Affecting Transport of Radionuclides Through the Soil and Their Relationship to Waste Management.

Hakonson, T.E., 1986,
Evaluation of Geologic Materials to Limit Biological Intrusion into Low-Level Radioactive Waste Disposal Sites.

Hakonson, T.E., 1987,
Trench Cover Systems for Manipulating Water Balance on Low-Level Radioactive Waste Site.

Hakonson, T.E., and Gladney, E.S., 1982,
"Biological Intrusion of Low-Level Waste Trench Covers", The Scientific Basis for Nuclear Waste Management.

Hakonson, T.E., Cline, J.F., and Rickard, W.H., 1982,
"Biological Intrusion Barriers For Large Volume Waste Disposal Sites", Low-Level Waste Disposal; Facility Design, Construction and Operating Practices..

Hakonson, T.E., et al., 1982,
Remedial Action Technology-Arid.

Hansen, W.R., and Rodgers, J.C., 1983,
"Risk Analyses for Shallow Land Burial and Greater Confinement of Alpha-Contaminated Wastes".

Healy, J.W., and Rodgers, J.C., 1979,
Limits for the Burial of the Department of Energy Transuranic Wastes.

Neely, J.W., et al., 1972,
Transuranic Waste Repository Studies.

Johnson, L.J., 1980,
Los Alamos Scientific Laboratory Waste Management Technology Development Activities: Summary Progress Report 1979.

Johnson, L.J., and Deslieta, B.N., 1979,
Nuclear Waste Management Technology Development Activities: January - December 1978.

Johnson, L.J., and Lewis, N.M., 1978,
Nuclear Waste Management Technology Development Program: January-December 1977.

Kelly, T.E., 1975,
Evaluation of Monitoring of Radioactive Solid-Waste Burial Sites at Los Alamos, New Mexico.

Kosiewicz, S., et al., 1979,
Studies of Transuranic Waste Storage Under Conditions Expected in the Waste Isolation Pilot Project (WIPP).

Kosiewicz, S.T., Barraclough, B., and Zerweth, A., 1979,
Studies of Transuranic Waste Storage Under Conditions Expected in the Waste Isolation Pilot Plant (WIPP).

Nelson, D.C., and West, J.L., 1980,
Contamination Control Demonstration for Radioactive Pipeline Decommissioning.

Nyhan, J.W., 1989,
Development of Technology for the Long-Term Stabilization and Closure of Shallow Land Burial Sites in Semiarid Environments.

Nyhan, J.W., and Abeele, W.V., 1983,
Corrective Measures Technology Program: Arid Sites Used for the Shallow Land Burial of Low-Level Radioactive Wastes.

Nyhan, J.W., and Barnes, F., 1989,
Development of a Prototype Plan for the Effective Closure of a Waste Disposal Site in Los Alamos, New Mexico.

Nyhan, J.W., and Barnes, F.J., 1987,
"Development of an Arid Site Closure Plan", Proceedings of the Ninth Annual DOE Low-Level Radioactive Waste Management Conference.

Nyhan, J.W., and Lane, L.J., 1986,
Erosion Control Technology: A User's Guide to the Use of the Universal Soil Loss Equation at Waste Burial Facilities.

Nyhan, J.W., Drennon, B., and Nakonson, T., 1989,
Field Evaluation of Two Shallow Land Burial Trench Cap Designs for Long-Term Stabilization and Closure of Waste Repositories at Los Alamos, New Mexico.

Nyhan, J.W., et al., 1982,
"Use of USLE Plots to Evaluate Management Alternatives for Trench Caps Used to Cover Low Level Radioactive Wastes at Los Alamos.".

Nyhan, J.W., et al., 1984,
"Development of Corrective Measures Technology for Shallow Land Burial Facilities at Arid Sites", Proceedings of the Sixth Annual Participants' Information Meeting DOE Low-Level Waste Management Program.

Nyhan, J.W., et al., 1984,
"Erosion of Earth Covers Used in Shallow Land Burial at Los Alamos, New Mexico".

Nyhan, J.W., et al., 1985,
Development of Technology for the Design of Shallow Land Burial Facilities at Arid Sites.

Nyhan, J.W., et al., 1986,
Technology Development for the Design of Waste Repositories at Arid Sites: Field Studies of Biointrusion and Capillary Barriers.

Nyhan, J.W., et al., 1989,
Development of Corrective Measures Technologies for the Long-Term Stabilization of Shallow Land burial Sites in Semiarid Environments.

Nyhan, J.W., Hakonson, T.E., and Lopez, E.A., 1986,
Corrective Measures Technology for Shallow Land Burial at Arid Sites: Field Studies of Biointrusion Barriers and Erosion Control.

Perkins, B.L., 1982,
Disposal of Liquid Radioactive Waste Through Wells or Shafts.

Perkins, B.L., 1982,
Evaluation of Environmental Control Technologies for Commercial Nuclear Fuel Conversion (UF6) Facilities.

Perkins, B.L., 1983,
Evaluation of Environmental Control Technologies for Commercial Uranium Nuclear Fuel Fabrication Facilities.

Rodgers, J.C., and Hansen, W.R., 1982,
On the Feasibility of Various Disposal Techniques for Selected Los Alamos Store and Buried TRU Wastes.

Walker, L.J., et al., 1981,
Alternative Transuranic Waste Management Strategies at Los Alamos National Laboratory.

Warren, J.L., and Zerwekh, A., 1985,
TRU Waste-Sampling Program.

WESTON, 1986,
Surface Geophysical Investigations Utilizing Magnetometry and Ground Penetrating at Area F, Technical Area 6.

Wheeler, M.L., and Smith, W.J., II, 1975,
"Considerations for the Long-Term: Perpetual is not Forever".

Wheeler, M.L., and Warren, J.L., 1975,
Tritium Containment After Burial of Contaminated Solid Waste.

White, J., et al., 1988,
"Underground Storage Tanks", Environmental Surveillance at Los Alamos During 1987.

Williams, J.A., 1986,
Results of the Geophysical Investigation Conducted at Los Alamos Labs Facility, Los Alamos, New Mexico.

Zerwekh, A., and Warren, J.L., 1986,
Gas Generation and Migration Studies Involving Recently Generated Z38-Pu-Contaminated Waste for the TRU Waste Sampling Program.

Zerwekh, A., Kosiewicz, S., and Barraclough, B., 1978,
Experimental studies of the Degradation of RAD-Wastes for the Sandia Laboratories Waste Isolation Pilot Project (WIPP).

IV. ENVIRONMENTAL STUDIES

Abeele, W.V., 1980,
Future Credible Precipitation Occurrences in Los Alamos, New Mexico.

Abeele, W.V., 1982,
Diurnal Variability of Wind Velocity Increase with Height.

Abeele, W.V., 1982,
Emanation of Tritiated Water from Disposal Sites at Los Alamos, New Mexico.

Abeele, W.V., and Wynan, J.W., 1986,
The Influence of the Emanation and Dispersal of Tritiated Water on the Concentration of Tritium in the Atmosphere.

Abeele, W.V., and Wynan, J.W., 1987,
"Emanation and Dispersal of Tritiated Water from Disposal Shafts".

Ahlquist, A.J., Stoker, A.K., and Trocki, L.K., 1977,
Radiological Survey and Decontamination of the Former Main Technical Area (TA-1) at Los Alamos, New Mexico.

Anderson, L.R., et al., 1982,
A Study of the Potential Health and Environmental Impacts from the Development of Liquid-Dominated Geothermal Resources.

Apt, K.E., and Lee, V.J., 1976,
"Radionuclide in Rio Grande Sediments and Fish", Environmental Surveillance at Los Alamos During 1975.

Archuleta, J., et al., 1978,
Some Atmospheric Tracer Experiments in Complex Terrain at LASL..

Archuleta, J.A., et al., 1978,
Northwest New Mexico Boundary Layer Experiment.

Arganbright, K., 1987,
Population Dynamics and Mortality Factors in a Colony of Mexican Free-Tailed Bats (Tadarida brasiliensis) in Bandelier National Monument.

Barnes, F., et al., 1984,
Designing Stable Vegetative Cover Systems for Shallow Land Burial of Hazardous Waste.

Barr, A., Griggs, A., and McInroy, D., 1988,
"Vadose Zone Characterization at Areas L and G", Environmental Surveillance at Los Alamos During 1987.

Barr, S., and Clements, W.E., 1977,
"Terrian Influence on Low-Level Meteorological Transport", Biomedical and Environmental Research Program of the LASL Health Division: January - December 1976.

Barr, S., and Gedayloo, T., 1979,
Proceedings of the Atmospheric Tracers and Tracer Application Workshop, Los Alamos Scientific Laboratory, Los Alamos, New Mexico, May 22-24, 1979.

Barr, S., et al., 1978,
"Fluorescent Particle Tracer Experiment", Biomedical and Environmental Research Program of the LASL Health Division January - December 1977.

Barton, L.L., et al., 1988,
Plasmids in Sulfur-Reducing Bacteria.

Becker, N.M., 1986,
"Heavy Metals in Runoff", Environmental Surveillance at Los Alamos During 1985.

Becker, N.M., Purtymun, W.D., and Moss, M., 1985,
"Movement of Depleted Uranium by Storm Runoff", Environmental Surveillance at Los Alamos During 1984.

Bendix Field Engineering Corporation, 1985,
Vadose Zone Characterization of Technical Area 54, Waste Disposal Areas G and L, Los Alamos National Laboratory, New Mexico, Report 2: Downhole Instrumentation and Pore-Gas-Sampling/Data-Collection Procedures.

Bendix Field Engineering Corporation, 1985,
Vadose Zone Characterization of Technical Area 54, Waste Disposal Areas G and L, Los Alamos National Laboratory, Report 1: Drilling and Logging Activities.

Bohn, R., and Nylander, C., 1988,
"Biomonitoring of the Laboratory's Liquid Effluents", Environmental Surveillance at Los Alamos During 1987.

Bowen, B.M., 1990,
Los Alamos Climatology.

Bowen, B.M., et al., 1982,
Measurements and Modeling of Gamma Absorbed Doses Due to Releases from a Linear Proton Accelerator: Experimental Design and Preliminary Results.

Bowen, B.M., et al., 1987,
Measurement and Modeling of External Radiation During 1985 from LAMPF Emissions.

Bowker, R.G., and Ferenbaugh, R.W., 1983,
"Temperature Regulation and Energetics of Lizards at Los Alamos National Environmental Park", Environmental Surveillance at Los Alamos During 1982.

Bresheers, D.D., et al., 1989,
"Uncertainty in Predictions of Fallout Radionuclides in Food and of Subsequent Ingestion".

Brooks, G.N., 1989,
The Comparative Uptake and Interaction of Several Radionuclides in the Trophic Levels Surrounding the Los Alamos Meson Physics Facility (LAMPF) Waste Water Ponds.

Buhl, T.E., and Hansen, W.R., 1984,
Estimating the Risks of Cancer Mortality and Genetic Defects Resulting from Exposures to Low Levels of Ionizing Radiation.

Carlson, S.R., 1988,
Influence of Western Harvester Ants on Vegetation and Soils in a Semi-Arid Mountain Ecosystem.

Christensen, C.W., and Thomas, R.G., 1962,
"Movement of Plutonium Through Los Alamos Tuff".

Christensen, C.W., et al., 1958,
"Soil Adsorption of Radioactive Wastes at Los Alamos".

Clements, W.E., Barr, S., and Fowler, M.M., 1980,
Effective Transport Velocity and Plume Elongation in Nocturnal Valley Wind Fields.

Cokal, E.J., and Rodgers, J., 1985,
Composition of the E-F Site Ground Water.

Cokal, E.J., and Rodgers, J., 1985,
Data Analysis of the E-F Site Soil Samples.

Cokal, E.J., and Rodgers, J., 1985,
Series of Memos Describing Uranium, Beryllium, and Lead in E-F Site Water Samples Collected 4 March, 1985.

Cokal, E.J., and Rodgers, J., 1985,
Soil Moisture Uranium, 22 March Samples.

Dahlman, R.C., Garten, C.T., and Hakonson, T.E., 1980,
"Comparative Distribution of Plutonium in Contaminated Ecosystems at Oak Ridge, Tennessee, and Los Alamos, New Mexico", Transuranic Elements in the Environment.

Daniels, W.R., 1981,
Laboratory and Field Studies Related to the Radionuclide Migration Project: October 1, 1979 - September 30, 1980.

Daniels, W.R., 1982,
Laboratory and Field Studies Related to the Radionuclide Migration Project: October 1, 1980 - September 30, 1981.

Daniels, W.R., 1983,
Laboratory and Field Studies Related to the Radionuclide Migration Project.

Daniels, W.R., and Thompson, J.L., 1984,
Laboratory and Field Studies Related to the Radionuclide Migration Project: October 1, 1982 - September 30, 1983.

Devaurs, M., 1989,
Modeling of Radionuclide Transport at Inactive Material Disposal Area T, TA-21.

Dodd, A.D., 1956,
A Survey of Some Los Alamos County Canyons for Radioactive Contamination.

Dreesen, D.R., and Cokal, E.J., 1984,
"Plant Uptake Assay to Determine Bioavailability of Inorganic Contaminants".

Dreicer, M., et al., 1984,
"Rainsplash as a Mechanism for Soil Contamination of Plant Surfaces".

Dubois, F.W., and Boyles, J.F., 1972,
Effect of Soil and Weather on the Decomposition of Explosives.

Eberhardt, L.E., and White, G.C., 1979,
Movements of Mule Deer on the Los Alamos National Environmental Research Park.

Environmental Science Group, 1977,
"Radiation Exposures Measured in Rodents Inhabiting a Liquid Radioactive Effluent Receiving Area at Los Alamos", Environmental Surveillance at Los Alamos During 1976.

Environmental Studies Group, 1973,
Environmental Monitoring in the Vincity of the Los Alamos Scientific Laboratory: Calendar Year 1972.

Environmental Studies Group, 1973,
Omnibus Environmental Assessment.

Environmental Studies Group, 1976,
Environmental Surveillance at Los Alamos During 1975.

Environmental Surveillance Group, 1974,
Environmental Surveillance at Los Alamos During 1973.

Environmental Surveillance Group, 1975,
Environmental Surveillance at Los Alamos During 1974.

Environmental Surveillance Group, 1977,
Environmental Surveillance at Los Alamos During 1976.

Environmental Surveillance Group, 1978,
"Radionuclide Uptake by Vegetable Crops in the Mortandad Canyon Garden Plot During 1976", Environmental Surveillance at Los Alamos During 1977.

Environmental Surveillance Group, 1978,
Environmental Surveillance at Los Alamos During 1977.

Environmental Surveillance Group, 1979,
"Archeology", Environmental Surveillance at Los Alamos During 1978.

Environmental Surveillance Group, 1979,
Environmental Surveillance at Los Alamos During 1978.

Environmental Surveillance Group, 1980,
"Archeology", Environmental Surveillance at Los Alamos During 1979.

Environmental Surveillance Group, 1980,
Environmental Surveillance at Los Alamos During 1979.

Environmental Surveillance Group, 1981,
"Archeology", Environmental Surveillance at Los Alamos During 1980.

Environmental Surveillance Group, 1981,
Environmental Surveillance at Los Alamos During 1980.

Environmental Surveillance Group, 1982,
"Archaeological and Historical Protection", Environmental Surveillance at Los Alamos During 1981.

Environmental Surveillance Group, 1982,
Environmental Surveillance at Los Alamos During 1981.

Environmental Surveillance Group, 1983,
"Archaeological and Historical Protection", Environmental Surveillance at Los Alamos During 1982.

Environmental Surveillance Group, 1983,
Environmental Surveillance at Los Alamos During 1982.

Environmental Surveillance Group, 1984,
"Archaeological and Historical Protection", Environmental Surveillance at Los Alamos During 1983.

Environmental Surveillance Group, 1984,
Environmental Surveillance at Los Alamos During 1983.

Environmental Surveillance Group, 1985,
"Archaeological and Historical Protection", Environmental Surveillance at Los Alamos During 1984.

Environmental Surveillance Group, 1985,
Environmental Surveillance at Los Alamos During 1984.

Environmental Surveillance Group, 1986,
"Archaeological and Historical Protection", Environmental Surveillance at Los Alamos During 1985.

Environmental Surveillance Group, 1986,
Environmental Surveillance at Los Alamos During 1985.

Environmental Surveillance Group, 1987,
"Archaeological and Historical Protection", Environmental Surveillance at Los Alamos During 1986.

Environmental Surveillance Group, 1987,
Environmental Surveillance at Los Alamos During 1986.

Environmental Surveillance Group, 1988,
"Archaeological and Historical Protection", Environmental Surveillance at Los Alamos During 1987.

Environmental Surveillance Group, 1988,
Environmental Surveillance at Los Alamos During 1987.

Environmental Surveillance Group, 1989,
Environmental Surveillance at Los Alamos During 1988.

Erdal, B.R., 1979,
Sorption-Desorption Studies on Granite I. Initial Studies of Strontium, Technetium, Cesium, Barium, Cerium, Europium, Uranium, Plutonium, and Americium.

Erdal, B.R., et al., 1979,
Sorption-Desorption Studies on Argillite I. Initial Studies of Strontium, Technetium, Cesium, Barium, Cerium and Europium.

Feltheuser, M., and McInroy, D., 1982,
"Mapping Pocket Gopher Systems with Expanding Polyurethane Foam", Environmental Surveillance at Los Alamos During 1981.

Ferenbaugh, R.W., and Purtymun, W.D., 1980,
"Special Study of Radionuclides from LAMPF Lagoons", Environmental Surveillance at Los Alamos During 1979.

Ferenbaugh, R.W., et al., 1982,
Environmental Analysis of Acid/Middle Pueblo Canyon, Los Alamos, New Mexico.

Ferenbaugh, R.W., et al., 1982,
Environmental Analysis of the Bayo Canyon (TA-10) Site, Los Alamos, New Mexico.

Ferenbaugh, R.W., Spall, W.D., and LaCombe, D.M., 1981,
Detection of Bromacil Herbicide in Ponderosa Pine.

Foster, G.R., and Nakonson, T.Z., 1987,
"Erosional Losses of Fallout Plutonium", Dynamics of Transuranics and Other Radionuclides in Natural Environments.

Foster, G.R., et al., 1983,
Modeling the Effectiveness of On-Site Sediment Controls..

Foster, G.R., Neibling, W.H., and Nutterman, R.A., 1982,
A Programmable Rainfall Simulator.

Fowler, E.B., Gilbert, R.O., and Essington, E.H., 1974,
Sampling of Soils for Radioactivity: Philosophy, Experience, and Results.

Foxx, T., and Tierney, G., 1979,
"Botanical Survey for Critical Habitats in the LA/NERP", Environmental Surveillance During 1978.

Foxx, T.S., 1982,
Use of a Computer Generated Movie to show the Sequence in Fire History Interpretation.

Foxx, T.S., and Tierney, G.D., 1980,
Status of the Flora of the Los Alamos Environmental Research Park.

Foxx, T.S., and Tierney, G.D., 1982,
Vegetational Analysis of a Canyon Ecosystem at Los Alamos.

Foxx, T.S., and Tierney, G.D., 1984,
Status of the Flora of the Los Alamos National Environmental Research Park: A Historical Perspective.

Foxx, T.S., and Tierney, G.D., 1985,
Status of the Flora of the Los Alamos National Environmental Research Park: Checklist of Vascular Plants of the Pajarito Plateau and Jemez Mountains.

Foxx, T.S., Tierney, G.D., and Williams, J.M., 1984,
Rooting Depths of Plants on Low-Level Waste Disposal Sites.

Foxx, T.S., Tierney, G.D., and Williams, J.M., 1984,
Rooting Depths of Plants to Biological and Environmental Factors.

Fuentes, H.R., 1987,
Preliminary Report on Sorption Modeling.

Fuentes, H.R., et al., 1984,
Nonequilibrium Behavior of Cobalt, Cesium, and Strontium in Competitive Sorption on Bandelier Tuff.

Gallegos, A.F., and Wenzel, W.J., 1984,
HUNTER: Documentation and Verification for an ICRP-BASED Age-and Sex-Specific Human Simulation Model for Radionuclide Dose Assessment.

Gallegos, A.F., Garcia, B.J., and Sutton, C.M., 1980,
Documentation of TRU Biological Transport Model.

Gedeylee, T., et al., 1979,
Behavior of a Tall Stack Plume in Flow over a Ridge..

Gedeylee, T., et al., 1979,
Summertime Nocturnal Drainage Flow in the San Mateo and Ambrosia Lake Sheds of the Grants Basin..

Gonzales, G.J., 1984,
The Potential Effects of Hydrogen Sulfide Gas from Geothermal Energy Conversion on Two Plant Species Native to Northern New Mexico.

Graham, E.R., 1963,
Plant as Monitors of Radioactive Contamination of the Environment of Los Alamos, New Mexico.

Graham, E.R., 1964,
Strontium-90, Cesium-137, and Radioactive Rare Earths in Environmental Rain and Air at Los Alamos, New Mexico, 1958-June 1963.

Graham, E.R., 1965,
Strontium-90, Cesium-137, and Radioactive Rare Earths in Environmental Rain and Air at Los Alamos, New Mexico: 1963-1964.

Gunderson, T., et al., 1983,
Radiological Survey Following Decontamination Activities Near the TA-45 Site.

Gunderson, T.C., et al., 1983,
An Environmental Study of Emissions from Testing of Shaped-Charged, Depleted Uranium Munitions.

Guthrie, D.A., and Larpe, N., 1980,
Mammals of Bandelier National Monument, New Mexico.

Gutschick, V.P., 1977,
Long-Term Strategies for Supplying Nitrogen to Crops..

Hakonson, T.E., 1975,
"Environmental Pathways of Plutonium into Terrestrial Plants and Animals".

Hakonson, T.E., 1987,
Environmental Surveillance of Low-Level Radioactive Waste Management Areas at Los Alamos During 1985.

Hakonson, T.E., and Bostick, K.V., 1975,
"Honeybees as Biological Indicators of Radionuclide Contamination", Annual Report of the Biomedical and Environmental Research Program of the LASL Health Division: January through December 1974.

Hakonson, T.E., and Bostick, K.V., 1976,
"Cesium-137 and Plutonium in Liquid Waste Discharge Areas at Los Alamos", Radioecology and Energy Resources.

Hakonson, T.E., and Johnson, L.J., 1973,
"Distribution of Environmental Plutonium in the Trinity Site After 27 Years".

Hakonson, T.E., and Miera, F.R., Jr., 1976,
"Ecological Studies of Non-Nuclear Materials in the Los Alamos Environs", Biomedical and Environmental Research Program of the LASL Health Division: January - December 1975.

Hakonson, T.E., and Nyhan, J.W., 1980,
"Ecological Relationships of Plutonium in Southwest Ecosystem", Transuranic Elements in the Environment.

Nakonson, T.E., and Whicker, F.W., 1969,
"Uptake and Elimination of Cs-134 by Mule Deer", Symposium on Radioecology.

Nakonson, T.E., and Whicker, F.W., 1971,
"The Contribution of Various Tissues and Organs to Total Body Mass in the Mule Deer".

Nakonson, T.E., and White, G.C., 1981,
"Effect of Retilling on the Distribution of Cesium-137 in Trinity Site Soil".

Nakonson, T.E., Cline, J.R., and Rickard, W.H., 1982,
"Disturbance of a Low-Level Waste Burial Site Cover by Pocket Gophers".

Nakonson, T.E., et al., 1973,
Ecological Investigation of Radioactive Materials in Waste Discharge Areas at Los Alamos for the Period July 1,1972 through March 31, 1973.

Nakonson, T.E., et al., 1979,
"The Comparative Distribution of Stable Mercury, Cesium-137 and Plutonium in an Intermittent Stream at Los Alamos", Environmental Surveillance at Los Alamos During 1978.

Nakonson, T.E., et al., 1980,
"The Distribution of Mercury, Cesium-137 and Plutonium in an Intermittent Stream at Los Alamos".

Nakonson, T.E., Johnson, L.L., and Purtymun, W.D., 1972,
The Distribution of Plutonium in Liquid Waste Disposal Areas at Los Alamos.

Nakonson, T.E., Martinez, J.L., and White, G.C., 1982,
"Disturbance of a Low-level Waste Burial Site by Pocket Gophers", Environmental Surveillance at Los Alamos During 1981.

Nakonson, T.E., Nyhan, J.W., and Purtymun, W.D., 1976,
Accumulation and Transport of Soil Plutonium in Liquid Waste Dischare Areas at Los Alamos.

Nakonson, T.E., Watters, R.L., and Hansen, W.C., 1981,
"The Transport of Plutoniumin Terrestrial Ecosystem".

Neiford, D.K., Markham, O.D., and White, G.C., 1983,
"Biological Elimination Rates of Radioisotopes by Mallards Contaminated at a Liquid Radioactive Waste Disposal Area".

Hansen, W.C., and Ponton, D.A., 1978,
"Observations and Activities Related to Peregrine Falcons", Biomedical and Environmental Research Program of the LASL Health Division: January-December, 1977.

Hansen, W.R., Mayfield, D.L., and Walker, L.J., 1980,
Interim Environmental Surveillance Plan for LASL Radioactive Waste Areas.

Hansen, W.C., 1974,
Ecological Considerations of Depleted Uranium Munitions.

Hansen, W.C., 1974,
Particle Size Distribution of Fragments from Depleted Uranium Penetrators Fired Against Armor Plate Targets.

Hansen, W.C., 1975,
"Ecological Considerations of the Behavior of Plutonium in the Environment".

Hansen, W.C., and Miera, F.R., Jr., 1976,
Long-term Ecological Effects of Exposure to Uranium.

Hansen, W.C., and Miera, F.R., Jr., 1977,
Continued Studies of Long-Term Ecological Effects of Exposure to Uranium.

Hansen, W.C., and Miera, F.R., Jr., 1978,
Further Studies of Long-Term Ecological Effects of Exposure to Uranium.

Harper, J.R., and Garde, R., 1981,
The Decommissioning of TA-21-153, A-227 Ac Contaminated Old Filter Building.

Harris, D.R., and Beyer, W.A., 1972,
BIOTA2, a Program for Monte Carlo Simulation of Population Interactions in a Biome.

Health Research Division, 1976,
Status and Plans Report for Former Technical Area One at Los Alamos Scientific Laboratory.

Health, Safety and Environment Division, 1986,
Occupational Health and Environment Research 1984: Health, Safety and Environment Division.

Health, Safety and Environment Division, 1988,
Health, Safety and Environment Division Annual Report 1987.

Healy, J.W., 1971,
"Some Thoughts on Plutonium in Soils", Proceedings of Environmental Plutonium Symposium: Held at LASL, August 4-5, 1971.

Healy, J.W., 1974,
A Proposed Interim Standard for Plutonium in Soils.

Healy, J.W., 1977,
An Examination of the Pathways from Soil to Man for Plutonium.

Healy, J.W., and Rodgers, J.C., 1978,
A Preliminary Study of Radium-Contaminated Soils.

Heaton, R.C., et al., 1985,
Long-Term Exposure of 238-PuO2 to a Terrestrial Environment.

Henderson, R.W., and Larsen, O.W., 1966,
Radiation Measurements of the Effluent from the MEX A-2 and MEX A-3 Reactors.

Herceg, J.E., 1972,
Environmental Monitoring in the Vicinity of the Los Alamos Scientific Laboratory January through June, 1971.

Herceg, J.E., 1972,
Environmental Monitoring in the Vincity of the Los Alamos Scientific Laboratory: July through December 1971.

Heyser, J.W., Warren, R.S., and Fink, N.F., 1985,
Adsorption to NaCl Followed by in vivo MMR.

International Technology Corporation, 1989,
Interim Status Closure Plan, "Technical Area 35 TSL-85 Surface Impoundment Los Alamos National Laboratory Los Alamos, New Mexico".

International Technology Corporation, 1990,
Interim Closure Plan: Technical Area 35 TSL-125 Surface Impoundment Los Alamos National Laboratory, Los Alamos, New Mexico.

John, E.C., Envart, E., and Purtymun, W.D., 1966,
Records of Wells, Test Holes, Springs, and Surface-water Stations in the Los Alamos Area, New Mexico.

Johnson, L.J., 1972,
Los Alamos Land Areas Environmental Radiation Survey; 1972.

Kasunic, C.A., Ferenbaugh, R.W., and Gladney, E.S., 1985,
"Silver Transport in Canon de Valle", Environmental Surveillance at Los Alamos During 1984.

Kaufman, E.L., and Siciliano, C.L.B., 1979,
Environmental Analysis of the Fenton Hill Hot Dry Rock Geothermal Test Site.

Kennedy, W.R., 1960,
Radioactivity in Environmental Air at Los Alamos, New Mexico for the period November 17, 1958 through December 31, 1959.

Kennedy, W.R., 1961,
Beta-Gamma Radioactivity in Environmental Air at Los Alamos, New Mexico, for 1960.

Kennedy, W.R., 1962,
Beta-Gamma Radioactivity in Environmental Air at Los Alamos, New Mexico, for 1961.

Kennedy, W.R., 1970,
Los Alamos Environmental Monitoring Program.

Kennedy, W.R., and Aeby, J., 1971,
Beta Radioactivity in Environmental Air and Precipitation at Los Alamos, New Mexico, for 1970.

Kennedy, W.R., and Aeby, J.W., 1966,
Beta-Gamma Radioactivity in Environmental Air at Los Alamos, New Mexico, for 1965.

Kennedy, W.R., and Aeby, J.W., 1967,
Beta Radioactivity in Environmental Air and Precipitation at Los Alamos, New Mexico, for 1966.

Kennedy, W.R., and Aeby, J.W., 1968,
Beta Radioactivity in Environmental Air and Precipitation at Los Alamos, New Mexico, for 1967.

Kennedy, W.R., and Aeby, J.W., 1970,
Beta Radioactivity in Environmental Air and Precipitation at Los Alamos, New Mexico, for 1969.

Kennedy, W.R., and Purtymun, W.D., 1971,
Plutonium and Strontium in Soil in the Los Alamos, Espanola, and Santa Fe, New Mexico, Areas.

Kennedy, W.R., and Purtymun, W.D., 1971,
Plutonium and Strontium in Soil Near Technical Area 21, Los Alamos Scientific Laboratory, Los Alamos, New Mexico.

Kennedy, W.R., Purtymun, W.D., and Schulte, H.F., 1971,
Los Alamos Environmental Monitoring Program: July through December 1970.

Kingsley, W.H., 1947,
Survey of Los Alamos and Pueblo Canyon for Radioactive Contamination and Radioassay Test Runs on Sewer-Water and Soil Samples Taken from Los Alamos and Pueblo Canyons..

Kovacic, D.A., et al., 1985,
Biomass Estimates in New Mexico Ponderosa Pine Following Wildfire.

Kovacic, D.A., et al., 1986,
"Immediate Effects of Prescribed Burning on Mineral Soil Nitrogen in Ponderosa Pine of New Mexico".

Lane, L., 1981,
Estimated Rainfall Frequencies for Los Alamos.

Langham, W.H., Harris, P.S., and Shipman, T.L., 1953,
Plutonium Hazards Created by Accidental or Experimental Low-Order Detonation of Atomic Weapons.

Langhorst, G.J., 1980,
Preliminary Study of the Potential Concerns Associated with Surface Waters and Geothermal Development of the Valles Caldera..

LANL, 1975,
Summary of Records Search and Discussions with LASL Pioneers Concerning Building and Drain Lines in TA-1 where Radioactive Materials were Processed.

LANL, 1981,
Formerly Utilized MED/AEC Sites-Remedial Action Program: Radiological Survey of the Site of a Former Radioactive Liquid Waste Treatment Plant (TA-45) and Effluent Receiving Areas of Acid, Pueblo, and Los Alamos Canyons, Los Alamos, NM.

Lopez, E.A., 1982,
The Effects of Coal Fly Ash on Rainbow Trout (Salmo gairdneri).

Los Alamos National Laboratory, 1977,
The Los Alamos National Environmental Research Park.

Los Alamos National Laboratory, 1981,
Radiological Survey of the Site of a Former Radioactive Liquid Waste Treatment Plant (TA-45) and the Effluent Receiving Areas of Acid, Pueblo and Los Alamos Canyons, Los Alamos, New Mexico.

Marthen, D.D., et al., 1983,
"Iodine-129 in Mule Deer Thyroids in the Rocky Mountain West".

Mayfield, D., and Hansen, W.R., 1983,
Surface Reconnaissance through 1980 for Radioactivity at Radioactive Waste Disposal Area G at the Los Alamos National Laboratory.

Meadows, S., 1980,
"A Reference Elk Model for Calculating Contaminant Dose to Rocky Mountain Elk", Environmental Surveillance at Los Alamos During 1980.

Meadows, S.D., and Salazar, J.G., 1982,
"An Investigation of Radionuclide Concentrations in Tissues of Elk Utilizing Los Alamos National Laboratory Land".

Miera, F.R., and Nakonson, T.E., 1978,
"Radiation Doses to Rodents Inhabiting a Radioactive Waste Receiving Area".

Miera, F.R., Jr., 1975,
"Small Mammal Studies in Los Alamos Waste Disposal Areas", Annual Report of the Biomedical and Environmental Research Program of the LASL Health Division: January through December 1974.

Miera, F.R., Jr., et al., 1977,
Biotic Survey of Los Alamos Radioactive Liquid Effluent Receiving Areas.

Miera, F.R., Jr., et al., 1979,
"Environmental Monitoring of Hot Dry Rock Development", Summary of Talks, 2nd Annual Hot Dry Rock Geothermal Conference.

Miera, F.R., Jr., Montoya, C.Z., and Schofield, T., 1980,
"Seedling Germination Affected by Chemical Agents Used in Solar Applications",
Biomedical and Environmental Research Program of the LASL Life Sciences and
Health Divisions: January-December 1979.

Meibling, W.H., and Foster, G.R., 1983,
Modeling Shallow-flow Sediment Transport of Naturally Eroded Sediment.

Nyhan, J.W., 1975,
"Decomposition of Carbon-14 Labeled Plant Materials in a Grassland Soil Under
Field Conditions".

Nyhan, J.W., 1975,
"Sampling Mixtures of Soil and Carbon-14-Labeled Plant Materials".

Nyhan, J.W., 1976,
"Influence of Soil Temperature and Water Tension on the Decomposition Rate of
Carbon-14 Labeled Herbage".

Nyhan, J.W., 1981,
Sampling Soils for Cs-137 Using Various Field Sampling Volumes.

Nyhan, J.W., and Nakonson, T.E., 1978,
"Soil Plutonium in the Los Alamos Environs and at the Trinity Site", Proceedings
of an Actinide-Sediment Reactions Working Meeting.

Nyhan, J.W., and Lane, L.J., 1986,
"Rainfall Simulator Studies of Earth Covers Used in Shallow Land Burial at Los
Alamos, New Mexico", Erosion on Rangelands: Emerging Technology and Data Base,
Proc. of the Rainfall Simulator Workshop.

Nyhan, J.W., and Trujillo, G., 1978,
"Soil Plutonium and Cesium in Stream Channels and Banks of Los Alamos Liquid
Effluent-Receiving Areas".

Nyhan, J.W., Beckman, R., and Bowen, B., 1989,
An Analysis of Precipitation Occurrences in Los Alamos, New Mexico, for Long-
Term Predictions of Waste Repository Behavior.

Nyhan, J.W., et al., 1978,
Temporal Changes in the Distribution of Cs-137 in Alluvial Soils at Los Alamos.

Nyhan, J.W., et al., 1983,
"An Evaluation of Soil Sampling for Cs-137 Using Various Field-Sampling
Volumes".

Nyhan, J.W., et al., 1984,
Distribution of Radionuclides and Water in Bandelier Tuff Beneath a Former Los
Alamos Liquid Waste Disposal Site After 33 Years.

Nyhan, J.W., Miera, F.R., Jr., and Weber, R.E., 1976,
"Distribution of Plutonium in Trinity Soils After 25 Years".

Wyhan, J.W., Niera, F.R., Jr., and Peters, R.J., 1976,
"Distribution of Plutonium in Soil Particle Size Fractions of Liquid Effluent-Receiving Areas at Los Alamos".

Wyhan, J.W., Niera, F.R., Jr., and Peters, R.J., 1976,
"The Distribution of Plutonium and Cesium in Alluvial Soils of the Los Alamos Environs", Proceedings of the Fourth National Symposium on Radioecology.

Wyhan, J.W., White, G., and Schofield, T., 1978,
"Sampling Los Alamos and Trinity Site Soils for Cesium-137", Biomedical and Environmental Research Program of the LASL Health Division: January-December 1977.

Wyhan, J.W., White, G.C., and Trujillo, G., 1980,
Soil Plutonium and Cesium in Stream Channels and Banks of Los Alamos Liquid Effluent-Receiving Areas.

Wyhan, J.W., White, G.C., and Trujillo, G., 1982,
"Soil Plutonium and Cesium in Stream Channels and Banks of Los Alamos Liquid Effluent-Receiving Areas".

Owens, J.W., 1976,
Fluorometric Determination of Uranium in Environmental Materials..

Patterson, J.H., Nelson, C.B., and Matlack, E.H., 1974,
The Dissolution of Pu-238 in Environmental and Biological Systems.

Perkins, B.L., and DePoorter, G.L., 1985,
Plants and Their Relationship to Soil Moisture and Tracer Movement.

Pettitt, R.A., 1976,
Environmental Monitoring for the Hot Dry Rock Geothermal Energy Development Project: Annual Report for the Period July 1975-June 1976.

Pippin, W.F., 1977,
Preliminary Check List, Arthropods of Bandelier National Monument, NM.

Polzer, W.L., and Essington, E.H., 1984,
A Modified Adsorption Equation for Modeling of Ion Exchange Reactions in Soils.

Polzer, W.L., et al., 1984,
Equilibrium Adsorption of Cobalt, Cesium, and Strontium on Bandelier Tuff: Analysis of Alternative Mathematical Modeling.

Polzer, W.L., et al., 1986,
Compilation of Field-Scale Caisson Data on Solute Transport in the Unsaturated Zone.

Polzer, W.L., Fowler, E.B., and Essington, E.H., 1979,
Characteristics of Wastes and Soils Which Affect Transport of Radionuclides Through the Soil and Their Relationship to Waste Management.

Pelzer, W.L., Fowler, E.B., and Essington, E.H., 1981,
"The Interactions of Low-Level Liquid Radioactive Wastes With Soils:
3. Interaction of Water Radionuclides With Soil From Horizons of Two Soil Series".

Potter, L.D., and Foxx, T., 1984,
"Postfire Recovery and Mortality of the Ponderosa Pine Forest After La Mesa Fire", La Mesa Fire Symposium; Los Alamos, New Mexico October 6 and 7, 1981.

Potter, L.D., Foxx, T.S., and Barnes, F.J., 1982,
Natural Regeneration of Ponderosa Pine as Related to Land Use and Fire History on the Pajarito Plateau.

Purtymun, W.D., and Adams, A., 1980,
"Changes in Quality of Surface Water Related to La Mesa Fire, 1977",
Environmental Surveillance at Los Alamos During 1979.

Purtymun, W.D., 1971,
Plutonium in Stream Channel Alluvium in the Los Alamos Area, New Mexico.

Purtymun, W.D., and Kennedy, W.R., 1966,
Distribution of Moisture and Radioactivity in the Soil and Tuff at the Contaminated Waste Pit Near Technical Area 21, Los Alamos, New Mexico.

Purtymun, W.D., and Rees, M., 1987,
"Survey of Sediments in Major Stream Channels for Toxic and Hazardous Waste",
Environmental Surveillance at Los Alamos During 1986.

Purtymun, W.D., and Rees, M., 1988,
"Survey of Sediments in Major Stream Channels for Toxic and Hazardous Waste",
Health Safety and Environment Division Annual Report 1987.

Purtymun, W.D., and Rees, M.N., 1988,
Environmental Investigation of the Pueblo of San Ildefonso: Reference to Water, Soil, and Sediments.

Purtymun, W.D., and Stoker, A., 1987,
"Environmental Studies of TA-49", Environmental Surveillance at Los Alamos During 1986.

Purtymun, W.D., and Stoker, A., 1988,
"Environmental Studies of TA-49", Health, Safety and Environment Division Annual Report 1987.

Purtymun, W.D., and Stoker, A.K., 1987,
Environmental Status of Technical Area 49, Los Alamos, New Mexico.

Purtymun, W.D., Buchholz, J.R., and Nakonson, T.E., 1975,
Chemical Quality of Effluents and their Influence on Water Quality in Mortandad Canyon.

Purtymun, W.D., et al., 1983,
"Plutonium in Reservoir Sediments", Environmental Surveillance at Los Alamos During 1982.

Purtymun, W.D., et al., 1983,
"Plutonium in Soil Near Technical Area 21", Environmental Surveillance at Los Alamos During 1982.

Purtymun, W.D., et al., 1983,
"Storm Transport of Radionuclides from Area G, Technical Area 54", Environmental Surveillance at Los Alamos During 1982.

Purtymun, W.D., et al., 1987,
Background Concentrations of Radionuclides in Soils and River Sediments in Northern New Mexico, 1974-1984.

Purtymun, W.D., et al., 1987,
Water Quality in the Vicinity of Fenton Hill Site, 1983 and 1984.

Purtymun, W.D., Ferenbaugh, R.W., and Adams, W.H., 1981,
Water Quality in the Vicinity of Fenton Hill Site, 1980.

Purtymun, W.D., Garde, R., and Peters, R., 1978,
Movement of Fluids and Plutonium from Shafts at Los Alamos, New Mexico.

Purtymun, W.D., Johnson, C.L., and John, E.C., 1966,
Distribution of Radioactivity in the Alluvium of a Disposal Area at Los Alamos, New Mexico..

Purtymun, W.D., Peters, R.J., and Stoker, A.K., 1980,
Radioactivity in Soils and Sediments in and Adjacent to the Los Alamos Area, 1974-1977.

Purtymun, W.D., Rogers, M.A., and Wheeler, M.L., 1980,
Radiochemical Analyses of Samples from Beneath a Solid Radioactive Waste Disposal Pit at Los Alamos, New Mexico.

Ramotnik, C.A., and Scott, N.J., Jr., 1988,
"Habitat Requirements of New Mexico's Endangered Salamanders", Management of Amphibians, Reptiles, and Small Mammals in North America: Proceedings of the Symposium.

Rea, K.H., 1977,
Environmental Investigation Associated with the LASL Hot Dry Rock Geothermal Energy Development Project.

Rich, P.M., 1988,
Video Image Analysis of Hemispherical Canopy Photography.

Richmond, C.R., 1958,
Retention and Excretion of Radionuclides of the Alkali Metals by Five Mammalian Species.

Rodgers, J.C., 1982,
Radiological Hazards of Alpha-Contaminated Waste.

Rogers, M.A., 1977,
History and Environmental Setting of LASL Near-Surface Land Disposal Facilities for Radioactive Wastes (Areas A, B, C, D, E, F, G and T).

Romine, M.J., and Eberhardt, L.E., 1975,
"Understory Vegetation Analysis", Annual Report of the Biomedical and Environmental Research Program of the LASL Health Division: January-December 1974.

Salazar, J.G., 1984,
Produce and Fish Sampling Program of Los Alamos National Laboratory's Environmental Surveillance Group.

Smith, W.J., II, Fowler, E.B., and Stratford, R.G., 1977,
Experience in the Cleanup of Plutonium-Contaminated Land.

Springer, E.P., 1984,
Modeling of Organic Vapor Movement at Area L Disposal Site Los Alamos, New Mexico.

Stahlecker, D.W., et al., 1989,
"Breeding Birds Assemblages in the Rio Grande Wild and Scenic River Recreation Area, New Mexico".

Steen, C.R., 1977,
Pajarito Plateau Archaeological Survey and Excavations.

Steen, C.R., 1979,
The Mortandad Style of Rock Art, Pajarito Plateau, New Mexico.

Steen, C.R., 1982,
Pajarito Plateau Archaeological Surveys and Excavations, II.

Thomas, R.L., and Neely, J.W., 1976,
An Appraisal of Available Information on Uptake by Plants of Transplutonium Elements and Neptunium.

Thompson, J.L., 1985,
Laboratory and Field Studies Related to the Radionuclide Migration Project: October 1, 1983 - September 30, 1984.

Thompson, J.L., 1986,
Laboratory and Field Studies Related to the Radionuclide Migration Project: October 1, 1984 - September 30, 1985.

Thompson, J.L., 1987,
Laboratory and Field Studies Related to the Radionuclide Migration Project: October 1, 1985 - September 30, 1986.

Tierney, G.D., and Foxx, T.S., 1982,
Floristic Composition and Plant Succession on Near-Surface Radioactive Waste Disposal Facilities in the Los Alamos National Laboratory.

Tierney, G.D., and Foxx, T.S., 1987,
Root Lengths of Plants on Los Alamos National Laboratory Lands.

Tribby, J.F., 1945,
Report on the Contamination of Creek Water.

U.S. Department of Energy, 1979,
Final Environmental Impact Statement: Los Alamos Scientific Laboratory, Los Alamos, New Mexico.

Van Etten, D., and Scoggins, W., 1988,
"Development of the Mobile Ranger Radiation Mapping System", Health, Safety and Environment Annual Report 1987.

Voelz, G.L., 1983,
Occupational Health, Waste Management, and Environmental Research Program of the Health Division 1981.

Voelz, G.L., 1984,
Occupational Health and Environmental Research Program of the Health Division 1982.

Voelz, G.L., 1985,
Occupational Health and Environmental Research 1983: Health, Safety, and Environmental Division.

Wellwort-Barber, Ferenbaugh, R., and Gladney, E., 1982,
The Use of Honey Bees as Monitors of Environmental Pollution.

Wellwort-Barber, H., Lyell, K., and Ferenbaugh, R., 1985,
Thallium Movement in a Simple Aquatic Ecosystem.

Wellwort-Barber, H.K., and Nakamson, T.E., 1981,
"Accumulation and Retention of Soil Particles on Plants", Environmental Surveillance at Los Alamos During 1980.

Wangen, L.E., and Jones, H.H., 1984,
The Attenuation of Chemical Leachates from Coal Mineral Wastes by Soils.

Wangen, L.E., and Stallings, E.A., 1984,
Surface Transport of Contaminants from Energy Process Waste Leachates: January 1 - December 31, 1982.

Wangen, L.E., and Turner, F.E., 1980,
"Trace Elements in Vegetation Downwind of a Coal-Fired Power Plant".

Wangen, L.E., Martinez, A.M., and Jones, H.H., 1985,
The Subsurface Transport of Contaminants from Energy Process Waste Leachates: Final Report.

Watson, C.W., and Barr, S., 1976,
Monte Carlo Simulation of the Turbulent Transport of Airborne Contaminants.

Wenzel, W., et al., 1986,
Los Alamos Low-Level Waste Performance Assessment Status.

Wenzel, W.J., and Gallegos, A.F., 1985,
EFFECTS: Documentation and Verification for a BEIR III Cancer Risk Model Based on Age, Sex, and Population Dynamics for BIOTRAN.

Wenzel, W.J., et al., 1987,
Cesium-137, Plutonium-239/240, Total Uranium, and Scandium in Trees and Shrubs Growing in Transuranic Waste at Area B.

Wheeler, W.L., Smith, W.J., and Gallegos, A.F., 1977,
A Preliminary Evaluation of the Potential for Plutonium Release from Burial Grounds at Los Alamos Scientific Laboratory.

Whelan, G., et al., 1982,
Annual Report, October 1980 - September 1981; Multimedia Radionuclide Exposure Assessment Modeling.

Whelan, G., Thompson, F.L., and Yabusaki, S.B., 1983,
Multimedia Contaminant Environmental Exposure Assessment Methodology as Applied to Los Alamos, New Mexico.

White, G.C., 1978,
Estimation of Expected Value and Coefficient of Variation for Lognormal and Gamma Distributions.

White, G.C., 1979,
"Computer Generated Movies to Display Biotelemetry Data".

White, G.C., 1981,
Biotelemetry Studies on Elk.

White, G.C., 1982,
Estimation of Survival Rates from Band Recovery and Biotelemetry Data.

White, G.C., and Waterman, T.E., 1979,
"Statistical Considerations and Survey of Plutonium Concentration Variability in Some Terrestrial Ecosystem Components".

White, G.C., and Lisscomy, J., 1980,
Research Plan for Elk in the Eastern Jemez Mountains.

White, G.C., et al., 1979,
Studies of Long-Term Ecological Effects of Exposure to Uranium IV.

White, G.C., et al., 1982,
Capture-Recapture and Removal Methods for Sampling Closed Populations.

White, E.C., Simmons, J.C., and Bostick, K.V., 1980,
Studies of Long-Term Ecological Effects of Exposure to Uranium V.

Williams, J.M., 1982,
A Study of the Potential Health and Environmental Impacts from the Development of Liquid-Dominated Geothermal Resources..

Williams, J.M., and Wenzel, E.M., 1980,
Worksheets to Rate and Assign Air and Water Issues for Hydrothermal Energy Development.

Worman, F.C., 1959,
"1957 Archeological Salvage Excavations at Los Alamos, New Mexico: A Preliminary Report".

Worman, F.C., 1967,
Archeological Salvage Excavations on the Mesita del Buey, Los Alamos County, New Mexico.

Worman, F.C., and Steen, C.R., 1978,
Excavations on Mesita de Los Alamos.

Appendix I

Comments and Recommendations

Attached are the Tiger Team Assessment, the LANL Self-Assessment, the New Mexico Environment Department (NMED) Initial Assessment, and the Hydrogeologic Review for the Environmental Restoration Program at LANL. Also included are memos to and/or from LANL, DOE, NMED, and EPA addressing specific aspects of the GWPMPP. The documents have been reformatted so that section numbers could be added in the right-hand margin. These section numbers correspond to the GWPMPP sections that address the particular concern mentioned in that paragraph of the document or memo. Some of the comments and recommendations do not necessarily pertain to groundwater protection or to the GWPMPP. The paragraphs where these occur are marked N/A.

Los Alamos National Laboratory ES&H Self-Assessment Report
August 91

3.2.4 Ground Water

Statement addressed in Section:

Ground water occurs in two principal subsurface regimes at Los Alamos: 1) perched water in relatively shallow (10-100 ft) alluvial canyon bottoms across the Laboratory or in basalts in the northeastern portion, and 2) the main aquifer in deep sediments (800-1200 ft below the mesa tops) underlying the more recent volcanic rocks that make up the entire Pajarito Plateau. The deep main aquifer is the source of the municipal and industrial water supply for the entire Laboratory and Los Alamos County.

The several hundred feet of dry volcanic rock provide protection for the main aquifer from surface infiltration or downward migration of moisture from the perched water in canyon alluvium. Extensive monitoring of the main aquifer since the late 1940s has never shown any contamination attributable to Laboratory operations. Not enough is yet known about the fundamental processes controlling movement of water or contaminants through the unsaturated zone to completely understand whether contamination could ever reach the main aquifer.

Several of the canyon-bottom shallow alluvial aquifers contain contamination, both radiological and nonradiological, from discharge of both untreated (during early years) and treated (continuing to present) Laboratory effluents. These situations have been and continue to be monitored by an ongoing routine surveillance program that has evolved from the initial monitoring provided to the U.S. Atomic Energy Commission by the U.S. Geological Survey starting in 1946 and continuing until the early 1970s when taken over by Laboratory staff. The potential for recharge to the main aquifer from such alluvial perched water is not fully studied. Tritium contamination has been found to depths of about 200 ft (the greatest depth of core samples taken to date) in the unsaturated zone below Mortandad Canyon, the canyon that receives effluent from the radioactive liquid waste treatment plant at TA-50. The tritium concentration in moisture extracted from the tuff was less than 10 percent of the DOE's Derived Concentration Guide for Tritium in water. In addition, continued sampling of the water of the deep aquifer, located 950 feet beneath the canyon, has not detected any impact of Laboratory operations on water quality in the aquifer and with no resultant radiation dose to users of this water. New special studies being implemented under auspices of the Environmental Restoration (ER) Program are beginning to contribute significant additional understanding to mechanisms by which the main aquifer may be recharged by alluvial perched water. 5.1.2

In addition to the environmental quality aspects of contaminant migration, the main aquifer is also monitored for resource management as the source of water supply. Water levels, pumping drawdown, total production and pumping rates, and other hydrologic data related to well performance are documented and evaluated routinely. This evaluation provides the basis for determining requirements for well maintenance, sighting of new wells, and planning for the reliability of future water supply. The data also provide the basis for compliance reporting to the New Mexico State Engineer Office in relation to the legal water rights owned by DOE.

The major deficiency related to ground water is that there is not enough basic detailed information available to fully understand the complex hydrogeologic setting of the Pajarito Plateau on which the Laboratory is located. The deficiencies in understanding relate to both the water quality and resource management issues. The available information is inadequate to meet the requirements of DOE Order 5400.1 for the Ground Water Protection Management Program Plan. Fundamental research is necessary in basic geology, unsaturated zone geology and hydrology, and saturated zone geology and hydrology. An independent panel of experts is reviewing the current state of hydrogeologic knowledge to recommend research priorities for the Laboratory. 5.1.2

Ground water monitoring facilities, equipment, and documentation are inadequate and do not satisfy the Ground Water Protection Management Program Plan. No significant numerical modeling capability is in place to routinely model the unsaturated zone or saturated zone of the aquifers at the Laboratory. 5.1.2 5.3.2

The Laboratory has not prepared ground water discharge plans for discharges from existing facilities. A request for such plans is anticipated from NMED. These plans would be required within 120 days after a request by NMED, which is insufficient time for meeting this requirement. In addition, the Laboratory has not prepared a Notice of Intent to Discharge and a Ground Water Discharge Plan for the new SWSC Project, which must be approved before discharge begins in July 1992. 5.7.2

DOE owns the water supply system for the Laboratory and Los Alamos County, including the wells, booster pump stations, transmission lines, and storage tanks. The Laboratory provides oversight of the water supply system. JCI provides the day-to-day operation and maintenance of the system. DOE sells water to Los Alamos County, which operates and maintains the distribution systems at Los Alamos Townsite and White Rock.

The Laboratory is responsible for meeting the monitoring and oversight requirements of the Safe Drinking Water Act (SDWA) for the system. Samples are collected by the Laboratory and tested for chemical quality and radioactivity by the state Laboratory Division (SLD). JCI collects and tests samples for bacteriological quality (coliform bacteria) in their laboratory, which is certified by the SLD. Sampling and test results for bacteriological and chemical quality, and for radioactivity, meet the requirements of the SDWA.

Programs to ensure that the water supply is not contaminated from external sources at the Laboratory are inadequate. A cross-connection control program inside buildings is needed to ensure against contamination of the potable supply from an industrial or waste water source. A survey of all water fountains and potable drinking water outlets for lead is needed to ensure that elevated levels of lead are not originating from lead-lined water fountains or building plumbing. A plan to improve the bacteriological quality of the water supply at the Laboratory along dead-end and stagnant lines is also needed. This plan would include control of noncoliform bacteria, which is recommended to ensure against contamination but is not required under the SDWA. NA

No mechanisms, legal or related to infrastructure, are yet in place to provide for additional water pumpage for reliable future water in conformance with regulations of the New Mexico State Engineer Office. Additional efforts are needed to ensure continuing adequate water supply for the Laboratory and Los Alamos County. 5.4.2

GW.1 Quality Control Regulations

Performance Objective: The Laboratory must comply with New Mexico Water Quality Control Commission Regulations related to ground water and other ground water requirements.

Finding/GW. 1-1: The Laboratory is not in a position to provide a 120 day period response as required by NMED for preparation of a Laboratory-wide Ground Water Discharge Plan. 5.7.2

Discussion: Under the regulations of the New Mexico Water Quality Control Commission, a Ground Water Discharge Plan may be requested at any time for the continued operation of any one or all of the 9 sanitary treatment facilities and over 100 industrial outfalls. A Ground Water Discharge Plan would be required within 120 days after notification from NMED. A Laboratory-wide Ground Water Discharge Plan is needed to meet New Mexico Water Quality Control Commission regulations in a timely manner.

Finding/GW. 1-2: A Notice of Intent to Discharge and a Ground Water Discharge Plan have not been prepared to meet the July 1992 SWSC Project to allow for discharge from the new SWSC Project. 5.7.2

Discussion: The new SWSC sanitary treatment plant is included in the Laboratory's new NPDES permit. A Notice of Intent to Discharge and a Ground Water Discharge Plan are needed as soon as possible to satisfy New Mexico Water Quality Control Commission Regulations. The WQ&T Section of EM-8 has collected ground water discharge information for the plan and a draft Notice of Intent has been prepared. The new SWSC Project will not begin operation until these items are completed.

Finding/GW. 1-3 A Ground Water Discharge plan regarding sanitary sludge disposal has not been initiated for TA-54, Area G in response to a potential request for such a plan by NMED. 5.7.2

Discussion: Under New Mexico Water Quality Control Commission regulation, a Ground Water Discharge Plan may be requested at any time by the NMED for continued disposal of sanitary sludge at TA-54, Area G a Ground Water Discharge Plan would be required within 120 days after notification from NMED. A Ground Water Discharge Plan for TA-54, Area G, relating to sanitary sludge disposal is needed to meet New Mexico Water Quality Control Commission regulations in a timely manner.

Finding/GW. 1-4: A Ground Water Discharge Plan has not been initiated for the TA-3 lagoons in response to a potential request by NMED. 5.7.2

Discussion: Under the New Mexico Water Quality Control Commission regulations, a Ground Water Discharge Plan may be requested at any time by NMED for continued use of these lagoons. Liners do not exist for the two sanitary lagoons. The TA-53 lagoons were included in Part A (Mixed-Waste Section) of the Laboratory's RCRA Permit in January 1991. A Ground Water Discharge Plan for the TA-53 lagoons should be initiated to meet New Mexico Water Quality Control Commission regulations. The 120 day period allowed for preparation of a Ground Water Discharge Plan for the TA-53 lagoons is not adequate for completion of such a plan.

GW.2 Implementation of Ground Water Protection Programs

Performance Objective: The Laboratory should implement all provisions of the Ground Water Protection Management Program Plan (GWPMPP) as required by the DOE Order 5400.1, and its implementation guidance provided by DOE.

Finding/GW. 2-1: Sufficient detailed information is not available on the hydrogeology of the Pajarito Plateau to meet all the requirements of DOE Order 5400.1 and the GWPMPP guidance. Furthermore, a plan to acquire the necessary information does not exist. 5.1.2

Discussion: The large area encompassed by the Laboratory and its location on the very complex geologic setting of the Pajarito Plateau present an extremely challenging setting. A complete

understanding of the sources, occurrence, and movement of water in both saturated and unsaturated conditions is essential to evaluating the present and potential impacts of waste management and water resources for water supply purposes. Fundamental information is not available on the basic geology and hydrology to adequately address the requirements of the DOE GWPMPP guidance or the requirements of RCRA Corrective Action studies

Major deficiencies in information can be found in the following areas taken from the DOE GWPMPP guidance and the DOE ground water check list in Section 11 of the DOE *Environmental Audit Manual:*

- Basic Geology: Basic geology of the Laboratory area includes structural features, stratigraphy, fracture and fault zones (knowledge of both the Pajarito fault zone on the western margin of the plateau and the plateau itself where faults and fractures may control erosional patterns and potential infiltration zones are crucial to understanding ground water recharge), geomorphology, seismic history, and geochemistry. 5.1.2

- Saturated Zone Geology and Hydrology: Information on recharge of the main aquifer and lithology is incomplete; knowledge of the upper surface of the main aquifer, especially toward the west, is incomplete; temporal variation of the ground water surface is not well described; information is lacking on vertical and horizontal permeability variation, horizontal and vertical pore-water velocities, pore-water flow gradients, the extent of phreatic versus confined zones, geologic structure beneath the Bandelier tuff, spatial variations of natural ground water quality, and areal continuity of data. 5.1.2

- Unsaturated or Vadose Zone Geology and Hydrology: The areal variation in lithology is incompletely described; infiltration rate and vertical permeability are known only for a few select locations, the geologic structure and thickness of strata lack detail, unsaturated moisture characteristics have been measured for only two basic locations (TA-54 and Mortandad Canyon) within the Laboratory; unsaturated hydrologic property measurements are lacking for the Otowi and Guaje Members of the Bandelier tuff, the Chino Mesa Basalts, the Puye Conglomerate, and the unsaturated portions of the Santa Fe Group sediments. 5.1.2

Finding/GW. 2-2: Ground water monitoring facilities, equipment, documentation, and procedural improvements needed to satisfy the GWPMPP guidance have not been completed. 5.3.2

Discussion: A large number of improvements need to be made in the Laboratory ground water monitoring for compliance with the recommendations of the DOE GWPMPP guidance. The following paragraphs highlight the most important items:

- Additional ground water monitoring wells to the main aquifer are needed to provide better areal coverage, especially in the western and southeastern portions of the Laboratory. All possible test wells to the main aquifer need to be equipped with access tubes or transducers to provide more extensive capability to measure the piezometric surface. Water-level measurements need to be made at least annually, and in some areas possibly more frequently to establish the appropriate interval for detecting significant changes in gradient. Annual potentiometric surface maps need to be prepared. 5.1.2

- The complete inventory and comprehensive map of all known monitoring and production wells, including all known abandoned holes and "similar holes in the ground," need to be completed. The inventory needs to identify availability of as-built and development records and the existence or availability of geologic and geophysical logs. 5.3.2

- Procedures and methodology need to be more completely documented. Such things as purging methods, water-level measurement protocols, well maintenance, pump tests, well abandonment, well security, details of sampling protocols (frequency, custody records, and analyses for each well), details of interpretation (data base, statistical comparisons, and trends) need to be specified appropriately for specific Laboratory conditions. 5.3.2 5.6.2

- All monitoring wells, test wells, and test holes (in addition to those used as part of the routine monitoring program) need to be equipped with locking security caps, marked with permanent stamped labels, and surveyed to 0.01 ft elevation and 0.5 ft New Mexico State Plane coordinates to permit mapping on the Laboratory graphic information system. 5.6.2

GW. 3 Ground Water Monitoring Program

Performance Objective: The Laboratory should be conducting a comprehensive ground water monitoring program in accordance with the provisions for ground water monitoring as required by DOE Order 5400.1, and the General Environmental Protection Program, including the requirements for procedural documentation. Routine 5.3.1

environmental monitoring of ground water for contamination from Laboratory operations should be implemented to address all issues and requirements of relevant DOE Orders and directives (e.g., DOE Order 5400.1 DOE Order 5820.2A, and DOE Order 5400.5), including the requirements for complete procedural documentation.

Findings/GW. 3-1: The documentation of procedural aspects of the ground water monitoring component of the EMP is not adequate, and the Ground Water Monitoring Plan required by DOE Order 5400.1 is not completed or implemented 5.3.2

Discussion: While the overall ground water sampling component of the routine Environmental Surveillance Program at the Laboratory is considered appropriate and in accordance with DOE guidance (e.g. DOE/EH-0173T, and DOE/EP-0023), documentation of procedural aspects for citing of sampling locations, sampling techniques, data handling (including data basing) and QA are incomplete in relation to the requirements of DOE Order 5400.1 (Chapter IV Sections 4 and 9.A and 9.B). The general Environment Monitoring Plan (EMP) and the separately identifiable Ground Water Monitoring Plan (which becomes a component of both the EMP and the GWPMPP) are required to be in place by November 9, 1991. The existing QA program plans do not completely meet the requirements of the more recent DOE Orders and directives for extent of documentation and do not fully address QA aspects. 5.3.2 5.6.2

Findings/GW. 3-2: No significant numerical modeling capability is in place to routinely model either the unsaturated zone or saturated zone at the Laboratory. 5.1.2

Discussion: Inadequate physical data is available to support a comprehensive modeling effort. Basic physical processes are not fully understood. This includes both basic water movement as well as potential transport of contaminants. 5.1.2

The Laboratory has premier computing capabilities, and the Laboratory staff has developed state of the art general models, specifically TRACR3D, to address such problems under specific funding for other DOE programs, e.g., Yucca Mountain.

GW. 4 Safe Drinking Water Regulations

Performance Objective: The Laboratory must comply with the SDWA and New Mexico regulations governing water supplies.

Finding/GW. 4-1: The cross-connection control program, wellhead inspection program, and program for disinfection of lines after construction are not current and formalized for compliance with the SDWA. 5.3.2 5.6.2

Discussion: Formal procedures and QA for these programs are required to properly document that the work being performed by JCI Health, Safety, and Environment Department, in behalf of the WQ&T Section of EM-8, meets regulatory requirements and environmental standards

Finding/GW. 4-2: Sampling procedures, QA and SOPs including worker protection, are not current for the SDWA Program. 5.6.2

Discussion: Formal procedures for SDWA sampling and QA are required. Formal procedures for SDWA record keeping are also needed to properly document routine SDWA activities. These activities include sampling and testing, as well as programs required to protect the water supply such as cross-connection controls, wellhead inspection, and disinfection of lines. A formalized notification procedure for violations of the SDWA is also needed.

Finding/GW. 4-3: No plan exists for improved microbiological quality of the Los Alamos water supply system. 5.4.2

Discussion: Growths of biofilms of flavobacterium and other noncoliform bacteria have been experienced in the Los Alamos water system. These growths represent a deterioration of microbiological water quality in sections of the system in which flows are limited. Preparation of a plan to improve microbiological water quality at the wellheads and throughout the system is needed to control potential contamination and potential growths of disease-causing organisms.

Finding/GW. 4-4: There has not been a Laboratory-wide survey of plumbing inside buildings to identify cross connections and to ensure against contamination. NA

Discussion: A survey of the potable water supply inside buildings for cross connections is needed to ensure against contamination. The New Mexico regulations governing water supply require the use of backflow prevention devices and stipulate that there shall be no piping arrangement or connection that allows an unsafe substance to enter a public water supply. A Backflow Prevention Device Test Program is in place at the Laboratory, but a formal cross-connection control survey inside buildings also is needed to ensure compliance with state regulations.

Finding/GW. 4-5: A systematic survey to identify potential elevated levels of lead in drinking water from water fountains and other outlets has not been conducted. NA

Discussion: Certain models of water fountains were manufactured using lead solder and tanks. Lead from these sources can leach into the drinking water. A Laboratory-wide survey, which includes sampling, is needed to identify and remove older water fountains and other potable water outlets that could produce elevated levels of lead in drinking water.

Selected water fountains at the Laboratory have been sampled for lead and have been found to exceed proposed new lead limits for drinking water. Levels over the current drinking water standard for lead (0.05 mg/l) have not been found. A Laboratory-wide inventory and sampling of water fountains are needed to ensure against elevated levels of lead and to provide a data base for action when proposed new lead limits are implemented by EPA and NMED.

GW. 5 New Mexico State Engineer Water Rights Regulations

Performance Objective: The Laboratory must operate and manage the water supply system in conformance with the New Mexico State Engineer Office (NMSEO) regulations on water rights.

Findings/GS. 5-1: Under the permit for NMSEO, there are no mechanisms, legal or infrastructure, in place to provide for additional water pumpage when the demand increases above the legal water rights limit. 5.4.2

Discussion: The DOE-owned wellfields that supply water for the Laboratory and the community are being pumped at 95 percent to 98 percent of the annual legal water rights maximum under the permit from the NMSEO. Several possible approaches would permit either greater pumpage or use of the additional San Juan-Chama water that was contracted for by DOE. These include establishing return flow credits for effluents, and devising a method to divert the San Juan-Chama water from the Rio Grande when released from upstream reservoirs. Additionally, replacement wells are needed to ensure current capacity as older wells lose yield or fail. Lead times for providing such mechanisms may well be much longer than the potential demand increase that could result from a hot dry summer, for example. Higher priority efforts to ensure adequate water supply in future years are essential to meet commitments to Los Alamos County and the needs of the Laboratory.

Tiger Team Assessment of the
Los Alamos National Laboratory
November 91

3.5.2.2 Compliance Findings

FINDING GW/CF-1: Groundwater Protection Management Program Plan

Performance Objective

DOE Order 5400.1, "General Environmental Protection Program," Chapter III, Section 4.a. required that a Ground Water Protection Management Program Plan (GWPMPP) be completed by May 1990. Elements of the GWPMPP include documentation of the ground water regime with respect to quantity and quality; design and implementation of a monitoring program; a management program for ground water protection and remediation; a summary of areas that may be contaminated; strategies for controlling sources of these contaminants; a remedial action program that is part of the site Resource Conservation and Recovery Act program; decontamination and decommission programs; and other remedial programs contained in DOE directives.

Finding

The LANL GWPMPP does not fully meet the requirements of DOE 5400.1

Discussion

LANL's GWPMPP (GW-87) does not fully meet the requirements and lacks specific information and reviews as required by DOE Order 5400.1. Information deficiencies include the following:

1.	The GWPMPP does not include an adequate Groundwater Monitoring Plan (GMP) according to the criteria in DOE Order 5400.1 (see Finding GW/CF-2).	5.3
2.	The GWPMPP does not adequately define the relation between the recharge and baseline water quality and quantity of the main aquifer.	5.1.2
3	There is no written, formal relationship between the groups within the Environmental Management Division to implement specific sections within the GWPMPP (e.g., underground storage tank management programs).	6.2
4.	There is no description of training, other than for safety and health that is expected for new and existing employees, to further the goals of the ground water program.	6.7
5.	The GWPMPP lacks documentation of both quality and quantification of the TA-57 (Fenton Hill) perched ground water regime.	4.3.5

LAAO could not provide documentation indicating that they approved or reviewed the GWPMPP initially or annually, as required by DOE Order 5400.1. The Environmental Protection Group (EM-8) indicated that the document was sent to LAAO for review on April 27, 1991; however, EM-8 did not receive any comments from LAAO (I-GW-95).

This finding was partially identified in the LANL Self-Assessment.

FINDING GW/CF-2: Sitewide Hydrogeological Monitoring Well Network

Performance Objective

DOE Order 5400.1 "General Environmental Protection Program." Chapter III, Section 4. a., requires preparation of a GWPMPP by May 1990. Specific elements of the GWPMPP include the "documentation of the ground water regime with respect to quality and quantity, design and implementation of a monitoring program, a management program for ground water protection and remediation, a summary of areas that may be contaminated, and strategies for controlling sources of these contaminants."	4.5 6.0 Appendix D
DOE Order 5400.1, Chapter IV, Section 9 requires that a Ground Water Monitoring Plan (GMP) be developed and implemented as a specific element of the GWPMPP by November 9, 1991. The GMP specifies "Ground Water that is or could be affected by DOE activities shall be monitored to determine and document the effects of operations on ground water quality and quantity." The GMP must address regulations and requirements applicable to ground water protection and monitoring, sampling strategies, sampling and analysis plans, and data management.	5.3.2 Appendix F
DOE Order 5400.1 Chapter II, Section 10, "Ground Water Protection," states "The Ground Water Protection Program," should be summarized, including a review of the monitoring program that describes the number of wells."	4.3

Finding

LANL's sitewide hydrogeological ground water monitoring well network will not be extensive enough to be able to characterize the impact of DOE operations on ground water quality by November 9, 1991, as required by DOE Order 5400.1.

Discussion

The existing ground water monitoring well network at LANL was largely developed by the U.S. Geological Survey prior to 1960 without a GMP. It is not adequate to determine the complex hydrogeologic conditions of the Pajarito Plateau. The LANL GMP, as required by DOE Order 5400.1, is being drafted, but will not be available for review by November 9, 1991.

The well network monitors the main aquifer and perched alluvial aquifers in the Canyons. The following deficiencies regarding the main aquifer monitoring well network on-site have been identified:

1. The 11-well onsite well monitoring network includes no wells on the western perimeter of the site and the western side of the Pajarito fault zone. Site baseline measurements, and the means of detecting migrating contamination from offsite locations, are lacking due to the absence of wells on the western perimeter. The effect of faults on ground water recharge and directional flow, potential infiltration zones, and seismic history on both sides of the fault zone cannot be accurately determined because of the lack of wells. — 5.1.2, 5.3.2

2. Five of the 11 onsite monitoring wells are also potable production wells. When these wells are pumped for drinking water purposes, significant cones of depression are created, giving rise to inaccurate measurements for monitoring purposes both in depth to ground water and generalized ground water flow direction. This results in inaccurate measurement of piezometric surfaces on a major portion of the monitoring network. Accurate piezometric surface measurements are essential for determining generalized ground water flow direction. — 5.1.2

3. All of the potable production wells and only one of the remaining six onsite monitoring wells have access for depth-to-ground water piezometric surface measurements. — 5.3.1

4. Only the 5 potable production wells are sampled for bacteria. Noncoliform (anaerobic) bacteria counts fluctuate randomly at these wells and were observed to increase during some runoff events, especially at Pajarito Well No. PM-2 (I-GW-12). The wells also contain free floating, nontoxic, edible mineral oil, a standard result of lubricating the line shaft turbines. Neither the source of the bacteria nor the environmental consequences of the mineral oil in the well bores is understood by LANL. — 5.4.2

The following deficiencies of the perched hydrogeological monitoring well network located in the shallow alluvium have been identified:

1. There are no monitoring wells located in the perched alluvial water located adjacent to the Los Alamos County Landfill to monitor for potential ground water contamination (I-GW-17). The landfill is located on a zone of intense fracturing (I-GW-73). The possibility exists for contaminant migration to the ground water located in the perched alluvial water. — 5.2, 5.4.2

2. LANL's characterization of surface flow contaminants infiltrating into perched aquifer zones in Los Alamos Canyon, which ultimately outcrop as seeps and springs at the confluence of the Rio Grande, is not complete (I-GW-54). The understanding of contaminant transport pathway mechanisms is essential for understanding canyon-specific perched aquifer systems. — 5.2.2

3. LANL has not adequately characterized the seep-spring recharge mechanism located in the Santa Fe Group (I-GW-54). A thorough understanding of the seep-spring recharge mechanism is required part for adequate comprehension of the sitewide hydrologic regime. — 5.2.2

LANL has no standard operating procedures for borehole drilling, well construction, disposal of borehole cuttings and drilling fluids, well inspection and maintenance, and well abandonment. Further, LANL does not have a monitoring well inventory program that lists inactive or properly abandoned monitoring wells, piezometers, neutron moisture probe access tubes, or boreholes. Best management practice would suggest the need for standard operating procedures and an inventory to track and manage the well network. — 5.2.2, 5.3.2, 5.5.2, 5.6.2, Appendix E

This finding was fully identified in the LANL Self-Assessment.

FINDING GW/CF-3: Groundwater Sampling Procedures

Performance Objective

DOE Order 5400.1, "General Environmental Protection Program," Chapter IV, "Environmental Monitoring Requirements," requires that a Quality Assurance Program (QAP) consistent with DOE Order 5700.6B, "Quality Assurance," be implemented by November 9, 1991. It also states that the QAP shall include chain-of custody procedures. 5.6

DOE Order 5400.1 further states that "Test Method for Evaluating Solid Waste, Physical/Chemical Methods" (SW-846) should be used as a reference for environmental monitoring. Appendix F

OSWER 9950.1, "Ground Water Monitoring Technical Enforcement Guidance Document," discusses specific procedures for sample collection, including Section 4.2.2, "Sample Withdrawal"; Section 4.3.3, "Special Handling Requirements"; and Section 4.4, "Chain-of Custody.".

LANL's Water, Soil, Sediments, and Water Supply Monitoring Quality Assurance Project Plan (QAPP) (revised January 10, 1990) specifies the procedures to be used in conducting ground water sampling and analysis at the monitoring wells, springs, and sediment sampling locations.

Finding

LANL ground water sampling procedures are not consistent with DOE Orders and guidance documents.

Discussion

Sampling procedures outlined in OSWER 9950.1, "Groundwater Monitoring Technical Enforcement Guidance Document," and DOE Order 5400.1 requirements for chain-of-custody are not incorporated into the Environmental Protection Group's (EM-8's) Water, Soil, Sediments, and Water Supply Monitoring QAPP. In addition, EM-8 does not follow required sampling procedures as contained in the QAPP.

The following deficiencies are present in the QAPP:

1. The QAPP does not contain formal chain-of-custody procedures. Section 5.2 of the QAPP states, "The analytical request form serves as an informal chain-of-custody for the samples." This chain-of-custody is prepared in the field. 5.6.2

2. Section 6 of the QAPP specifies "equipment used in routing collection of water, soils, and sediment requires no calibration." Calibration is necessary for standardization and equipment checks. To Be Addressed

3. Section 4.6.1 of the QAPP specifies sample acidification prior to filtration for all chemical analysis, which is opposite of OSWER 9950.1 requirements for metal analysis. However, the procedure was consistent with the requirements for the radiochemistry samples as specified in Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance (DOE/EH-0173T). To Be Addressed

4. Section 4.6.3 of the QAPP does not directly address sample collection techniques to minimize agitation and aeration. To Be Addressed

5. The QAPP manual does not address field decontamination procedures for sampling equipment. To Be Addressed

6. The QAPP manual does not directly address the need for refrigeration for sulfate, nitrate, and semi-volatile organic compounds. Although the information is incorporated by reference in LANL Report No. LA-11738, the requirements should be in a form that is easily accessible during sampling. To Be Addressed

7. The QAPP manual does not adequately address well purging requirements. To Be Addressed

The Environmental Subteam observed three sampling events (October 1, 7-9, and 17, 1991) conducted by LANL. During the sampling events, there was an overall lack of formality, and inadequate field sampling protocols. Sample collection lacked consistency. The following deficiencies in field sampling methods were noted:

1. No environmental chain-of-custody form was used in the field on October 1, 1991 (I-GW-32). No environmental chain-of-custody forms were used in the field during the second sampling

event, but were generated later at the laboratory, according to EM-8 staff (GW-89). Environmental chain-of-custody forms were used in the field on October 17, 1991. However, the forms were not properly completed. The EPA SW-846 document states, "The possession and handling of samples should be traceable from time of collection through analysis and final disposition" (GW-147).

2. The pH, temperature, and specific conductivity meters were field checked for accuracy only at the beginning of the sampling event on October 1, 1991 (I-GW-30). Accuracy should be checked at the beginning and end of each sampling event. The two types of pH paper were not checked for accuracy to a known standard prior to the October 7-9, 1991, sampling event. In response to Tiger Team observations, the pH, temperature, and specific conductivity meters were field checked for accuracy at the beginning and end of the sampling event on October 17, 1991 (I-GW-79).

3. Ground Water samples collected on October 1, 7-9, 17, 1991, were not filtered prior to being preserved with an acidic solution as specified in OSWER 9950.1. However, radiochemistry samples were preserved in accordance with DOE/EH-0173T.

4. Ground Water sample containers for the October 1, 1991, sampling event were acidified (e.g., preserved) in a radiological laboratory prior to field sampling (I-GW-31). Given the possibility for radiological cross-contamination, sample containers should not be acidified in locations that could impact analytical integrity of the sample.

5. During the October 1, 1991, sampling event, the sampling port of the production well emitted an aerated ground water sample which is not acceptable for volatile organic compound analyses or semi-volatile organic compound analyses (I-GW-26).

6. Sample containers for parameters other than volatile organic compound analyses were not preserved on ice for transport to the laboratory during the October 1, 1991, sample event (I-GW-30). No samples were preserved on ice for transport to the laboratory for October 7-9, 1991 sampling event (I-GW-55). However, samples were preserved on ice for transport to the laboratory during the October 17, 1991, sampling event (I-GW-76).

7. Tygon sampling tubes and sediment sampling scoops were not properly decontaminated between sampling stations during the October 7-9, 1991, sampling event (I-GW-55).

8. The purging of ground water monitoring well MCO-5 during the October 17, 1991, sampling event was not based on an appropriate calculation of well-bore volume (I-GW-76). This resulted in analysis of well-bore water rather than ground water.

9. Two of the three temperature probes were broken on the October 7-9, 1991, sampling event (I-GW-53). The lack of functioning thermometers could result in a lack of quality data.

This finding was fully identified in the LANL Self-Assessment.

3.5.3.2 Best Management Practice Findings

FINDING GW/BMPF-1: Closure and Protection of Wells and Boreholes

Performance Objective

DOE Order 5400.1, "General Environmental Protection Program," Section 5.a., "Policy" requires that DOE "minimize risks to the environment or public health, and anticipate and address potential environmental problems before they pose a threat to the quality of the environment or public welfare." 5.2 5.3

The 1986 RCRA Ground Water Monitoring Technical Guidance Document (TEGD) suggests that locking caps should be placed on wells to prevent tampering and ground water contamination. Additionally, the TEGD states that when wells are no longer operable, or give false ground water analytical data, they should be decommissioned and sealed. 5.2.1

The New Mexico Environment Department (NMED) has issued procedures to be used for plugging and abandonment of monitoring wells installed after January 1, 1991. These are best management practices for wells installed before that date. 5.2.1

Finding

Abandoned or inactive monitoring wells, peizometers, neutron moisture probe access tubes, and boreholes are not adequately closed or sealed to protect the environment. 5.2.2

Discussion

LANL has not developed procedures or criteria for determining when wells should be decommissioned or in what manner they will be abandoned. There are several monitoring wells, peizometers, neutron moisture probe access tubes, and boreholes which are not properly secured nor protected. However, best management practices suggest that these should be plugged and sealed as suggested by the NMED; otherwise, they present a potential pathway for ground water contamination. 5.2.2

1. A new monitoring well, MCO-5.1., has no locking cap. The polyvinyl chloride casing is not protected against potential vandalism to the well bore or aquifer (I-GW-23). 5.6.2

2. A monitoring well (TW-2B) that was partially installed in 1947, was observed to be inadequately secured (I-GW-24). Both the production tubing and the annulus between the well casing and the production tubing were open ended. The potential to introduce contaminants to the well bore and perched aquifer exists since it is not plugged and sealed. 5.2.2

3. An older U.S. Geological Survey monitoring well (LAO-5), located in the perched alluvial, was observed to be missing a lock (I-GW-25). 5.6.2

4. At various locations throughout Mortandad Canyon, piezometers and neutron moisture probe access tubes were observed without caps or locks (I-GW-77). 5.6.2

5. LANL has no procedures for placing permanent identification placards on ground water monitoring wells (1/22). 5.6.2

This finding was fully identified in the LANL Self-assessments

FINDING GW/BMPF-3: Groundwater Discharge Plan

Performance Objective

New Mexico Water Quality Regulation (NMWQR), Section 3-104, states that no person shall cause or allow effluent or leachate to discharge so that it may move directly or indirectly into ground water without a Groundwater Discharge Plan approved by the Director of the New Mexico Water Environment Department (NMED).

NMWQR, Section 3-106, requires that for discharges existing prior to March 1977, a Groundwater Discharge Plan shall be submitted within 120 days of receipt of notice from NMED that a plan is required. For discharges initiated subsequent to March 1977, a Notice of Intent must be submitted to NMED, which will determine whether a discharge plan is required.

NMED has not yet notified LANL that Groundwater Discharge Plans are required. However, as a best management practice, LANL should initiate Groundwater Discharge Plans to ensure compliance with anticipated NMWQR requests. 5.7.2

Finding

LANL has not initiated preparation of Groundwater Discharge Plans to ensure compliance with anticipated NMWQR requirements. 5.7.2

Discussion

LANL has indicated that a request is anticipated from NMWQCC for Groundwater Discharge Plans for some or all for the 9 sanitary treatment facilities and approximately 100 industrial outfalls. LANL has also indicated that they would be unable to meet the 120-day schedule for either a sitewide plan or site-specific plans if a request were made at the present time. LANL has currently identified the potential need for plans for continued disposal of sanitary sludge at TA-54, Area G, and for discharges from the unlined sanitary lagoons at TA-53. LANL has also identified the need for a Laboratory-wide Ground Water Discharge Plan to meet potential NMWQCC requests. However, drafting of the plans has not been initiated, and there is currently no program in place to draft the plans. 5.7.2

LANL has also identified the need for a Ground Water Discharge Plan for the new Sanitary Treatment Plant at TA-46 and has initiated drafting of the Notice of Intent, but has not initiated drafting of the Discharge plan so as to ensure compliance with the required schedule. 5.7.2

This finding was fully identified in the LANL Self-Assessment.

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Hydrogeologic Review for the Environmental Restoration Program at Los Alamos National Laboratory

LANL Hydrogeology Panel Final Report

SUMMARY OF COMMENTS ON ISSUES IDENTIFIED BY THE ER PROGRAM

The following is a brief summary of the panel's comments on issues identified by the ER staff. Detailed comments by each reviewer are provided in Section 6.

ISSUE 1: *Do we have enough hydrogeological data at LANL to defensibly answer pertinent hydrogeological questions related to the ER site cleanups (e.g., stabilization in place)* 5.1.2

There is considerable uncertainty in several aspects of hydrogeology which needs to be addressed. However, at a few sites such as Mortandad Canyon and TA-54, sufficient hydrogeological data may already be available to support some ER program decisions. Primary areas of concern include the importance of vapor and liquid transport on mesa tops, characterization of perched aquifers, and radionuclide uptake by vegetation.

ISSUE 2: *Is there adequate flow and transport data to defend calculation of the subsurface pathway?* 5.1.2

Data may be sufficient only at sites that have been characterized, such as TA-54 and Mortandad Canyon. Even at these sites there is uncertainty in the spatial extent of contamination, hydraulic properties, and transport processes such as colloidal mechanisms. Moreover, the quality of the existing water chemistry data base which could be used to evaluate pathways is considered deficient in several aspects (Section 2.3).

ISSUE 3: *Do we know enough about the role of fractures?* 5.2.2

The panel is somewhat divided on this question. On one hand, some geologic evidence suggests that fractures lack connectivity over great depths and fractures may provide capillary barriers to unsaturated flow. On the other, roots and weathering patterns suggest that some fractures on mesa tops may be preferential paths for infiltration. Our primary concern for liquid flow in fractures is in canyon bottoms where fractures in bedrock may intersect perched alluvial aquifers. There are few field data on the role of fractures, but there is also very little one can do to adequately and quantitatively characterize variably saturated fracture flow and transport coefficients. At small site scales, the role of fractures as transport pathways and their connections to regional pathway will likely have to be addressed for each site individually.

ISSUE 4: *Can we defensibly model LANL hydrogeology using a porous continuum model?* To Be Addressed

Much of the experimental and environmental monitoring data suggests that a porous media flow model would be appropriate. However, porous media models should be used to predict observed behavior in order to validate the models and to confirm the validity of the porous media approach.

ISSUE 5: *Are we sufficiently certain of ground water flow direction regionally that we can know ground water flow direction at a specific OU? Additionally, is there any reason to believe that there are local ground water gradients?* 5.1.2

Generally sufficient data exist to establish that regional flow is to the east. Local effects undoubtedly occur near the well fields, and it is possible that small perturbations may occur in the main aquifer beneath perched aquifers or other potential recharge areas. Additional information is required to monitor horizontal and vertical pathways and to confirm sources of recharge. Mapping details of drawdown and "zones of capture" around the well fields would add to the knowledge base.

ISSUE 6: *Can we defensibly state there is no connection between any perched zones and the aquifer?* 5.1.2

Existing data are insufficient to state that no perched water percolates to the main aquifer. In fact, recent work at Montandad Canyon shows that vertical transport has occurred in the Bandelier Tuff to at least 150 ft (46) beneath the perched alluvial aquifer. Little is known of vapor phase transport in these areas.

ISSUE 7: *Do we know enough about gas exchange between the subsurface and atmosphere as a potential contaminant transport pathway?* To Be Addressed

Gas exchange has been observed near open shafts and boreholes. Density driven gas phase transport of chlorinated solvents, for example, may also be important, but has not been documented in the field at LANL. The importance of gas transport and the characterization of gas transport pathways requires additional study.

ISSUE 8:	*Do we know enough that modeling as a homogeneous, steady state system adequately defines the system? Alternatively, do we know enough to model as a nonhomogeneous, transient system?*	To Be Addressed

Except for scoping calculations, field observations and model studies show that some degree of heterogeneity will need to be incorporated into the conceptual models of flow and transport in the vadose zone, in the perched aquifers, and in the main aquifer. Transient effects will need to be considered to simulate transport at lease within perched alluvial aquifers, and in pumping scenarios for the main aquifer.

Available data are scarce, and details of experimental procedures need to be published. A model study using existing sorption data underestimated observed radionuclide transport. Available data do not appear to be sufficient to defend ER objectives.

Initial Assessment of the Ground Water Monitoring Program at Los Alamos National Laboratory, New Mexico

POTENTIAL GROUND WATER POLLUTION SOURCES

DOCUMENTATION

Radioactive and hazardous waste has been generated and disposed of at LANL since the Lab's inception in 1943 (Kelly, 1975). Twenty-three Materials Disposal Areas (A, B, C, D, E, F, G, H, J, K, L, M, N, P, Q, R, S, T, U, V, W, X, and Y: Figure 4) were identified by Rogers (1977). All such sites are considered potential sources of ground water contamination. Some of these disposal sites have been characterized in considerable detail by previous workers. Kelly (1975) summarized burial conditions and environmental monitoring at eight of these Areas (A, B, C, D, E, F, G, and T) in conjunction with an evaluation of monitoring efforts at LANL. Rogers (1977) made an invaluable and exhaustive two-volume compilation of the history and environmental settings of the same Areas covered by Kelly. 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, the Lab's solid Radwaste management policy, the guidelines for disposal pit construction, and records of disposal in Tech Area 54, Area G shafts.

Statement Addressed in Section

Waste disposal sites were identified by LANL (DOE 1987) as part of the Comprehensive Environmental Assessment and Response Program (CEARP), under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA or Superfund). A Resource Conservation and Recovery Act (RCRA) Facility Assessment (RFA), conducted by A. T. Kearney (1987) for the Lab. Provided additional information on Solid Waste Management Units (SWMUs) at LANL. In 1988, draft SWMU report, providing "reasonably available" information, as submitted to the Environmental Protection Agency (EPA), pursuant to Title 40, Code of Federal Regulations, Part 270.14d (40 CFR270.14d). The 1988 draft SWMU report was revised by International Corporation under contract to LANL and includes an update on SWMU's identified at the Lab (IT Corporation, 1990). The 1990 report identifies 537 SWMU's located in 50 active and formal TA's. As of this writing, the number of potentially contaminated sites recognized is approximately 2,000. Many of these are minor and LANL estimates that 90-95 percent of these will be handled under Voluntary Corrective Actions or No Further Action proposals.

An additional possible source of ground water contamination is the historic and current practice of discharging liquid waste (NPDES-permitted) in canyons near the northern boundary of the Lab. According to the latest Surveillance Report (for 1990: Environmental Protection Group, 1992), four areas have received industrial or sanitary effluents: DP-Los Alamos (DP-LA), Sandia, Mortandad, and Acid-Pueblo Canyons.

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 receives radioactive liquid waste from TA-50. This maintains a perched ground water body in the alluvium on the canyon floor. Purtymun (1974) found 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.

CONCERNS/RECOMMENDATIONS

As this is the initial review of the ground water program at LANL, this report primarily addresses basic concerns regarding potential sources of ground water contamination.

1. Regarding location of potential sources of ground water contamination, the 1990 Environmental Surveillance Report contains no map of known disposal areas. Evaluation of monitoring efforts at LANL would be greatly facilitated if the major disposal areas (not individual SWMU's) were generally indicated (along with monitoring sites and water level contours) on a single map in future Environmental Surveillance Reports. This would likely require a larger plate (preferably at a scale of 1:24,000) folded in a pocket at the back of the report. — To Be Addressed

2. A biannual update on disposal activity at all these areas should be prepared. Such reports should cover the same topics addressed by Rogers (1977). To Be Addressed

3. It is a cause for concern that a large number of the potential sources of contamination are located in the vicinity of high fault/fracture density (Wachs and others, 1988), near cliffs, and in canyon bottoms. 5.2.2

Subsequent assessment reports by the NMED will address site-specific concerns.

CONCEPTUAL HYDROGEOLOGIC MODEL

PREVIOUS WORK

Oversight at LANL is facilitated by the existence of a sizable body of reference materials and the availability of most of them in LANL's Environmental Restoration Program Records Processing Facility in Los Alamos. The citations below are not intended to be exhaustive, but rather to indicate representative important works.

Major sources of geologic information on the Pajarito Plateau include reports by Theis and others (1950), Griggs (1964), Purtymun (1966), Smith and others (1970), Crowe and others (1978), and Kelley (1978). Most of these include mapping. The most detailed (1 inch = 400 ft), and only Lab-wide geologic map is unpublished (Rogers 1981).

Numerous published works report on various aspects of the hydrologic system associated with the Pajarito Plateau. Many of these reports treat the system strictly from a water-supply point of view (Theis and Conover, 1962; Griggs, 1964; Cushman, 1965; Cooper and Purtymun, 1965; Purtymun and Cooper, 1965, 1969; Cushman Purtymun, 1975; Purtymun and others, 1980; Purtymun, 1984; Purtymun and Stoker, 1988). The water supply at Los Alamos has been carefully documented in a series of annual reports by Purtymun, and Purtymun and others dating back to 1972 (Purtymun 1984). Modeling of the ground water system near Santa Fe by McAda and Wasiolak (1988) includes the Los Alamos area.

Some reports, however, do focus on hydrogeologic considerations in radwaste disposal or monitoring at the Lab (Weir and others, 1962; Weir and Purtymun, 1962; John and others, 1966; Purtymun, 1966, 1973a, b; Devaurs, 1895; Purtymun and others, 1974, 1989; Anonymous, 1990; Penrose and others, 1990; Stoker and others, 1991). The spread of radioactive contamination in specific canyons or Tech Areas was addressed by Baltz and others (1963), Purtymun (1974), Devaurs and Purtymun (1985), Purtymun and Stoker, and Stoker and others (1991).

LANL's CONCEPTUAL MODEL

As many of the reports listed above were done by or for the Lab, they are the basis for LANL's conceptualization of the regional hydrologic system. The key elements, as summarized in the 1990 Surveillance Report, are as follows.

1. Ground water occurs in three situations:

   a) perched water in alluvium in canyons

   b) perched water in basalts and sedimentary units of the Puye Conglomerate, and,

   c) beneath the regional water table in the main aquifer.

2. The alluvium on canyon floors is recharged by surface water runoff.

3. The main aquifer consists of the Tesuque Formation and the lower parts of the overlying and interfonguing 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).

4. Water in the main aquifer is separated from that in the shallow alluvium and other perched systems by 250 - 620 ft of unsaturated tuff and sediments.

5. There is little or no recharge of the main aquifer from the mesas, the shallow alluvium, or other perched ground water.

6. The main aquifer is recharged in the Valle Caldera, west of the Laboratory.

7. Ground water in the main aquifer flows easterly until discharging to the Rio Grande.

LANL's conceptual hydrogeologic model is shown diagrammatically in Figure 5.

Site specific studies undertaken by the Lab have added to the understanding of the relationship of the complete hydrologic system. For example, the study of Mortandad Canyon by Stoker and others (1991) enhanced the conceptualization of the so-called "shallow alluvium aquifer."

1. Saturation is confined to a relatively thin zone, extending 5 - 20 ft above the contact of the alluvium with the underlying Tshirege Member of the Bandelier Tuff.

2. The area of saturated alluvium extends from the treatment plant (TA-50) outfalls SWMU 50 - 051 to a point approximately 2 miles down canyon.

3. Thickness of the saturated zone decreases towards the canyon margins.

4. Since 1960, the saturated portion of the alluvium aquifer has neither changed significantly in size nor moved down canyon (eastward).

Reportedly, tritium was found at a depth of approximately 200 ft within the Bandelier Tuff. Other radionuclides had 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.

CONCERNS/RECOMMENDATIONS

Again, as this is the initial assessment, the focus is on very basic questions. The adequacy of the monitoring network at LANL depends to a very large extent on the accuracy of the conceptual hydrogeologic model upon which it is based. In his evaluation of environmental monitoring at LANL, Kelly (1975) concluded that further hydrogeologic data were needed to design an effective monitoring system. Although some progress has been made in this area, there are still concerns about LANL's conceptual model, the hydrogeologic data base, and the presentation of surveillance information.

1. 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 intermountain basin of the Valle Caldera in the Jemez Mountains west of Los Alamos" following Purtymun (1974). The water level map published by the lab does suggest 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 elevation higher than available in the Jemez Mountains (Goff and Sayer, 1980). The Sangre de Cristo Mountains have been suggested at the site of these higher elevations. Further work is needed on this manner. 5.1.2

2. Maps published by the Lab 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. 5.2.3

3. Perched water beneath the Bandelier Tuff suggests that there is recharge through the tuff. Various methods of determining recharge (e.g. chloride mass balance, chlorine 36, etc.) may prove useful in answering this question. 5.1.2

4. TW-1 is deep ground water observation well that shows a 50 ft water mound. TW-1A is completed in perched water above the screened interval of TW-1. The perched water from TW-1A and the alluvial water in this area have similar chemistry, different from that in TW-1. This situation raises questions concerning the effectiveness of the Bandelier Tuff as a barrier to vertical migration and needs to be investigated. 5.1.2

5. If ^3H has penetrated at least 200 ft beneath the alluvium aquifer in Mortandad Canyon, it seems possible that it could ultimately reach the main aquifer. 5.2.2

6. As asked by LANL hydrologists, is 200 ft the true maximum depth of ^3H percolation, or is that merely the deepest it can be detected, owing to dilution? Furthermore, did the ^3H move in the liquid or vapor phase, and which phase is most common at the Lab? 5.2.2

7. What is the cause and fate of disappearing streams in canyons (for example, Potrillo Canyon)? A study of hydrogeologic conditions at such sites (water table depth, thickness/character of the alluvium, etc.) would be useful. 5.1.2

8. An alluvial deposit within the Cerro Toledo interval of the Bandelier Tuff, lithologically similar to the Puye Conglomerate, and known informally as the "epiclastic unit", crops out in various places on the plateau LANL has reported that, where unsaturated, this unit may serve as a capillary barrier to vertical migration of contaminants or recharge, but that it has been observed to be as much as 90 percent saturated, locally. Of particular concern is an outcrop of the epiclastic unit in a cliff near the confluence of Pueblo and Acid canyons. In this position it lies down canyon of both the Larry Walkup Center, which discharges approximately 800,000 gallons of chlorinated water annually, and the decommissioned untreated liquid radwaste facility (SWMU 1-00). Thus, the potential role of the "Epiclastic Unit" as a pathway for contaminant transport should be investigated. 5.2.1

9. 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 conducts, barriers, or inconsequential. 5.1.2 5.3

10. Water level maps for the shallow, perched systems should be contoured separately from those for the deep (main) aquifer. 5.1.2

11. An approximate geologic map at the water table should be constructed from available subsurface data, and appropriate hydraulic conductivity's should be assigned to each unit in order to show the contaminant-transport capacity across the area. 5.1.2

12. Once such a map is available, modeling of the ground water flow system should be undertaken. This would be an excellent way of testing the conceptual model, as well as the assumed hydrologic properties of materials underlying the Pajarito Plateau. 5.1.2

13. Eventually, contaminant transport should also be modeled. This could initially be done with hypotheticalleaks or spills, then modified for actual excursions. Such models could show directions, rates, and concentrations that might be expected from a most conservative scenario. Results would be ideal for presentations to the public, the Pueblos, etc. 5.2.2

14. No water-level map is provided with the 1990 surveillance report. Such maps normally accompany monitoring reports and provide essential information on the hydrologic system. In fact, it is difficult to interpret water quality data, let alone evaluate the monitoring network, without such maps. As noted above, page-size versions will probably not suffice; a 1:24,000 map, including major disposal areas and monitoring sites would be ideal (folded in a pocked at the back of the report). If digitized, it should be a simple matter to update such a map for subsequent annual reports. NA

15. Previously published water level maps essentially depict pre-development conditions; no impacts of pumping at production wells (i.e. cones of depression) are indicated (Figure 6). Yet, water level changes (i.e. drawdown values) are regularly given in the annual reports on the water supply at LANL. Modeling by McAda and Wasiolak (1988) predicts significant cones of depression in the future as well. As groundwater flow is toward such depressions, their position and extent are critical to both designing and evaluating the monitoring network. Water level maps for the Lab should include these features. 5.1.2

16. Water-level maps are commonly used for closure plan. RCRA Facility Investigation (RFI) Work Plans, operating permit applications, etc., all include data collected over 10 years ago at TA-40 in wells DT-5A, DT-9 and DT-10. This gives a false impression of the water level in the southwestern part of the Pajarito Plateau. 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. 5.3.2

GROUND WATER MONITORING NETWORK

WELLS/SPRINGS USED

The 1990 Surveillance Report identifies 43 ground water monitoring wells (Figure 7). Of these, 26 are deep and target the main aquifer, whereas, 17 are shallow and monitor perched water in the alluvium. Of the 26 are deep wells, 19 are water supply sells; the remaining 7 are test wells. The supply wells used for monitoring include 7 in the Guaje well field, 6 in the Los Alamos well field, and 6 in the Pajarito well field. None of the shallow wells are water supply wells. In addition to these wells, ground water is also monitored by means of 33 springs that primarily discharge along the eastern edge of the plateau in White Rock Canyon.

PARAMETERS MONITORED

Different sites are analyzed for slightly different lists of parameters. According to Appendix G of the 1990 Surveillance Report, springs in White Rock Canyon are monitored for 16 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), 6 radiochemical parameters (^3H,

^{137}Cs, total U, ^{238}Pu, $^{239,240}Pu$, gross gamma), and trace metals (Ag, Al, As, Ba, Cd, Cr, F, Hg, NO_3-N, Pb, Se, Cl, Cu, Fe, Mn, Ni, P, Sb, Se, Sr, Tl, U, V, Zn). Ground water in supply wells and the water distribution system at LANL is monitored for 6 radiochemical parameters (gross alpha, gross beta, ^{3}H, ^{238}Pu, $^{239,240}Pu$ and total U), 18 EPA primary/secondary standards (Ag, As, Ba, Cd, Cr, F, Hg, NO_3-N, Pb, Se, Cl, Cu, Fe, Mn, SO_4, Zn, TDS, pH), and 20 other parameters (Al, SiO_2, Ca, Mg, K, Na, CO_3, HCO_3, P, SO_4, Cl, F, NO_3-N, TDS, hardness, pH, specific conductance, B, Mo, Sr, V, Be, Ni, Sb, Tl, NO_3-N). Ground waters are also monitored for organic compounds: 68 volatiles, 71 semi-volatiles, 19 pesticides, 2 herbicides, and 4 PCB's.

CONCERNS/RECOMMENDATIONS

1. It is understood that the monitoring plan for the Lab is currently being revised. Inclusion of a table, in both the plan and future surveillance reports, giving sites, parameters monitored and frequency of monitoring, would be most helpful in our oversight effort. — Tables 4-1, 4-2

2. As in all monitoring networks, existing wells are employed where possible because drilling new ones is expensive. 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. By contrast, water-level or water quality wells are usually screened over a narrow interval to provide information for a more discrete portion(s) of the aquifer. Properly constructed monitoring wells should be installed to replace, or at least supplement/verify, data from the supply wells currently used. — 5.3.2

3. There are relatively few monitoring wells/sites in view of the size of the area encompassed by the Lab. This may result from the conceptual notion long held by the Lab that, due to the depth water table, and presumedimpermeability of the volcanic tuff at the surface, the main aquifer is not at risk and need not be monitored, other than at the supply wells. Not only would more wells better cover the area and, if properly constructed, better monitor the aquifers, but they would provide an excellent test of this hydraulic isolation hypothesis. Lower Los Alamos Canyon is one such area that should have a more extensive monitoring system in place. — 5.3.2

4. The density of wells/sites is also unrealistic. There are many wells in some areas and few to none in others. A more uniform spacing of wells is desirable and should be established. New wells should be strategically located with respect to historically contaminated areas of the plateau or to enhance depiction of the water table. A partial solution to this is to not use all wells in the well fields. A representative well should be selected, an alternate designated, and the others ignored, as far as regional surveillance is concerned. This would prevent the misconception that the relatively large of "monitoring wells" actually represents an adequate regional surveillance system. — 5.1.2

5. The wells drilled under the Hazardous Solid Waste Amendment (HSWA) permit requirements are not currently included in the Environmental Surveillance network, but should be. — 5.3.2

6. As noted above, the map of monitoring wells/sites in the surveillance reports should also show the major disposal areas (not every SWMU) that are being monitored, and contours that represent recent water level information. — NA

7. The classification of monitoring sites should be reconsidered and standardized. The designation of springs is not consistent; sometimes they are denoted as surface water and sometimes as ground water. Ground water is preferable inasmuch as springs are outcrops of the water table or the potentiometric surface. — 5.3.2

8. Spring-sampling stations are inadequately marked in the field. They should be identified by as permanent a monument as possible, to avoid major deviation in a sampling point over time. A written description of sampling points should also be on file. — 5.3.2

9. The organization of the surveillance reports is somewhat confusing. The following would be helpful for the oversight effort: — NA

   a) field identification of sites should be the same as maps identification. Site identification numbers, as used on figures and maps, should appear in the first column;

   b) presentation of a summary table with sampling frequency and parameters monitored for each site (water level, major ions, radionuclides, etc., quarterly, annually, etc.);and

   c) listing the standards for all parameters, for easy reference. LANL projects, understood to be underway or planned, will greatly enhance our conceptualization of the hydrogeologic system.

SUMMARY

Current monitoring efforts at LANL go far beyond those of just a few years ago, and surveillance reports regularly present more than was previously know. However, a number of general and specific inadequacies are recognized, based on our initial assessment. The following are largely summarized from the sections entitled "Concerns/Recommendations" above. However this list is not all inclusive and the concerns/recommendations listed above should be consulted for details.

1. Potential Contamination Sources

a)	Biannual reports on waste-disposal activities at all sites should be prepared.	To Be Addressed
b)	General waste-disposal areas (not individual SWMU's) should be shown on maps of monitoring wells/sites, together with the regional water-level contours, so that adequacy of the surveillance network may be better evaluated.	To Be Addressed

2. Conceptual Hydrogeologic Model

a)	Questions concerning recharge, confined/unconfined conditions of the aquifer, and permeability of the Bandelier Tuff should be resolved. Appropriate tests should be designed and conducted (chloride, isotopes, paired piezometers, pumping tests, etc.).	5.1.2
b)	A water-level map, depicting current conditions (drawdown around supply wells), should be included with surveillance reports.	5.1.2
c)	Ground water flow and contaminant-transport modeling should be undertaken to test LANL's conceptual hydrogeologic model.	5.1.2 5.2.2

3. Ground Water Monitoring Network

a)	The monitoring plan should be revised as soon as possible, focusing on clearly stated objectives.	5.3.2
b)	The number and location of monitoring wells should reflect the number and location of major waste disposal areas; this does not mean a well or series of wells is needed at each SWMU, but rather there should be enough wells to intercept any possible contamination.	5.3.2
c)	The location of future monitoring wells should be based on the location of the potential sources of contamination, transport pathways, and the regional flow system as indicated by a current water-level map that includes drawdown due to pumping of production wells. Some additional monitoring wells may be needed merely to better depict the water table.	5.3.2
d)	New wells should be constructed to monitor discrete hydrologic interval(s) (production wells are screened over too large an interval).	5.3.2

We would be glad to clarify or discuss our position/recommendations on any of the issues addressed herein at any time. Inquiries may be directed 827-2434 or 665-7130.

ACKNOWLEDGMENTS -- Cooperation of various LANL and DOE personnel during our investigation, through tours and interviews, is greatly appreciated. Discussions with John Hawley (NM Bureau of Mines and mineral Resources) and Margaret Anne Rogers (MARA, Inc.) were most helpful.

DOE LAAO COMMENTS ON
GROUNDWATER PROTECTION MANAGEMENT PROGRAM PLAN (GWPMPP)
JUNE 21, 1994

Statement Addressed in Section:

SUMMARY: The Draft-Business Plan for Ground Water Protection developed by ESH-8 is the most comprehensive GWPMPP developed by LANL to date. This plan begins to address the management organization, required actions, funding requirements and schedule in significantly greater detail. The following comments are minor and offered to enhance the plan.

A. INTRODUCTION
   1. Purpose of Business Plan
   2. Past Ground Water Programs
   3. Need for Ground Water Protection Management Program (GWPMP)
      Comment: Include DOE as a stakeholder. 6.2

      Include a discussion of HSWA Permit Appendix A

Requirements

B. OBJECTIVES
   1. Establish a Institutional Program
   2. Address Deficiencies and Unfunded Activities

C. STRATEGY AND ACTION REQUIRED
   1. Management Organization
      Comment: The Management Organization discussion needs to provide greater detail as to straight line versus dotted line reporting relationships, such as: 6.2

      1) are stakeholder involvement office, internal and external customer reporting relationships straight line or dotted line, and 6.2

      2) does the ESH-8 Hydrology team report directly to the Program manager, and 6.2

      3) what position does the Program Manager report directly to. 6.2

      Accountabilities need to be addressed. Within each section, define the management position which is ultimately responsible for ensuring that individual or group responsibilities are carried out. 6.2

      As this is an institutional program, a dotted line relationship should be shown either from the division office or program manager to the ES&H Council. 6.2

2. FISCAL ORGANIZATION

Comment: Further definition of "coordination" responsibilities is required, exactly what authority if any does the Program Manager have for coordination of ER or WM program activities or funds. 6.3

Accountabilities need to be addressed. Within each section, define the management position which is ultimately responsible for ensuring that individual or group responsibilities are carried out. 6.2

3. INTERNAL/EXTERNAL SUPPLIERS

4. PRODUCTS

Comment: The sentence, "Replacement of these wells will also be required", should more clearly indicate that this means a plugging and abandonment program. NA

5. INTERNAL/EXTERNAL CUSTOMERS

6. PERFORMANCE MEASURES

Comment: Include in the discussion frequency of performance review, target completion date, who has responsibility and accountability for conducting, and what is the mechanism for reoptimization of the program based on the results of the evaluation. 7.1 7.2 7.3 7.4 7.5

D. PRIORITIZED ACTIVITIES

Comment: Include a section addressing Plugging and Abandonment. 5.2 6.6.2

Initial priorities for the listed action items needs to be included. 6.6.2

E. COST ESTIMATES FOR IMPROVED MONITORING

F. PRELIMINARY SCHEDULE

Comment: Accelerate Additional Testing and Line Item Cost implementation activity by one year. To Be Addressed

Fully define and include the total projected cost associated with Groundwater studies and reporting once the final action item list is jointly developed by LANL, NMED AIP and LAAO. To Be Addressed

G. IMPLEMENTATION OF BUSINESS PLAN

Comment: Include a discussion of primary management responsibilities and accountabilities in meeting the approved GWPMPP Business Plan 6.2

June 23, 1994

Mr. Joseph C. Vozella, Chief
Environment, Safety and Health Branch
Department of Energy
Los Alamos Area Office, A-316
Los Alamos, NM 87544

Comment Addressed in Section:

RE: NMED Review of "Business Plan for Ground Water Protection," dated March 31, 1994

The issue of ground water and the question of its vulnerability from past, current and future operations at Los Alamos National Laboratory (LANL) has been a central concern of the NMED For many years. Those of use who have followed this issue are extremely pleased that the Department of Energy (DOE) has decided to dedicate its energy toward making a determination regarding the status of the main aquifer beneath and surrounding its facility.

Staff of the New Mexico Environment Department's (NMED) Agreement In Principle, Hazardous and Radioactive Materials and Ground water Protection and Remediation bureaus have reviewed the subject document ("Plan") and the collective comments of these programs are presented below.

In Section A3 of the plan the following regulatory drivers should be added to the list of those in this project: 1) Task III of Module 8 of LANL's RCRA permit ("HSWA permit"), 2) possible ground water discharge permit requirements under New Mexico's Water Quality Control Commission, and 3) possible involvement by the Office of the Natural Resources Trustee. 5.7

In Section C5, to the list of primary customers should be added the non-AIP NMED regulators. 6.2

In Section C6, compliance with the HSWA permit should be included among the performance measures 6.9

In Section D, "Priority 1 Items", the non-AIP NMED regulators should be added to those contributing to the list of identified needs. *"Priority 1 items should commence as soon as practical with a goal of completion or significant progress within five years."* We suggest the priority groups be redefined as follows: Priority 1 to be achieved in 18 months; Priority 2 to commence as soon as is practicable with a goal of completion within five years; Priority 3 to commence within the next five years with a goal of completion within eight years; and Priority 4 as the final, clearly stated objectives of the entire project, to be completed in ten years. 6.6.2

The following comments all pertain to Section D.

In general, clarification is needed as to whether this plan pertains to installation of monitor wells off-facility. 5.1.2

It is recommended that sampling frequencies be considered on a bi-annual basis. 5.1.2
5.3.2

Our candidates for Priority 1 are as follows: 6.6.2

- o A comprehensive study of seeps and springs (Spring Inventory) to include water chemistry might lead to a better understanding of recharge of the intermediate and main aquifers and would elucidate the relationship between alluvial aquifers that are coterminous with fracture or fault zones.
- o Evaluate and asses the validity of existing hydrogeologic data. 6.6.2
- o Integrate all hydrogeological information using FIMAD and enable the input of data by outside entities (e.g., NMED, BIA, Pueblo contractors) into specific data bases within FIMAD for general access. 5.6.2 6.6.2
- o Define analytical data turnaround times from sample acquisition of general availability Reduce administrative data review requirements after agreements are formed with State, tribal and public entities specifically defined as participating in this project regarding use and release of 'draft' data. 5.6
- o Form a system within the ES&H program for rapid follow-up response to data indicating presence of contaminants in groundwater, seeps or springs. 5.6
- o Define ground water surveillance roles at LANL. It is apparent that different programs have access to monitor wells. This has led to damage of equipment and possible cross contamination between wells. To Be Addressed
- o Standardize and include dedicated sampling equipment for each well including pumps and transducers. 5.3.2

Candidates for Priorities 2-4 should be determined during the discussion to take place at the next meeting, July 7, 1994

Again, we very much appreciate the fact that DOE and LANL have dedicated themselves to this project and we look forward to working with all affected parties towards its successful completion.

If you have any questions regarding these matters, please contact me at (505) 672-0447.

Sincerely,

Bruce A. Swanton, AIP Point of Contact
Hazardous and Radioactive Materials Bureau
DOE EM Oversight Program Manager

cc: HRM Technical Compliance Program
HRMB Permits Program
NMED LANL AIP Program
ES&H 8 Group
Bob Hull/Sue Johnson, LATA
Ken Zamora, Scientech
Karen Mc Ada, DOE/AL/EPD

State of New Mexico
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BRUCE KING
GOVERNOR

JUDITH M. ESPINOSA
SECRETARY

RON CURRY
DEPUTY SECRETARY

July 7, 1994

Mr. Joseph C. Vozella, Chief
Environmental, Safety, and Health Branch
Department of Energy
Los Alamos Area Office, A-316
Los Alamos, New Mexico 87544

RE: RCRA Technical Compliance Review of the Business Plan for Ground Water Protection Management Program Plan (GWPMPP), dated March 31, 1994

Dear Mr. Vozella:

The New Mexico Environment Department (NMED), Hazardous and Radioactive Materials Bureau (HRMB), RCRA Technical Compliance Program (RTCP) recognizes the importance the subject document has towards establishing LANL's future ground-water monitoring system. Information collected and generated from the GWPMPP will have great implications regarding RCRA ground-water monitoring requirements at LANL. Therefore, the RTCP is submitting comments to DOE with the hopes that hydrogeologic information required under RCRA may be incorporated into the GWPMPP.

The following comments are suggestions and are not to be construed as final decisions regarding RCRA ground-water monitoring at RCRA units. The information obtained from the GWPMPP can facilitate the required understanding of the hydrogeologic environment beneath RCRA regulated units.

Joe Vozella
July 7, 1994
Page 2

HRMB would like to coordinate with DOE on the GWPMPP to ensure that RCRA ground-water monitoring requirements need not be duplicated unnecessarily under other DOE required programs. Should you have any questions concerning this matter please contact myself or Ms. Teri Davis of my staff at 827-4308 or 827-4313.

Sincerely,

Ronald A. Kern Ph.D, Program Manager
RCRA Technical Compliance Program

enclosure

cc: Benito Garcia, HRMB Bureau Chief
Barbara Hoditschek, Permitting Program Manager
Teri Davis, HRMB
Bruce Swanton, AIP Program Manger
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MEMORANDUM

TO: Ronald A. Kern, RCRA Technical Program Manager

FROM: Teri Davis, RCRA Technical Program

THROUGH: Lee Winn, RCRA Technical Program Supervisor

DATE: July 7, 1994

SUBJECT: **Technical Compliance Review of LANL's Business Plan for Ground Water Protection (March 31, 1994)**

General Comment

It is advised that EPA Region 6 be brought into this discussion as soon as possible to avoid any potential differences in approach to this complex subject.

Item	Comment	Statement Addressed in Section
1	(Section 3, pg.2) An additional regulatory requirement to consider under the context of a GWPMP is within the HSWA, Section P., Task III Part (A) (1). The permittee shall conduct a program to evaluate hydrogeologic conditions at the facility. It has been determined by NMED that the existing ground water monitoring system is inadequate to sufficiently address the requirements under the HSWA module.	5.3.1 5.3.2
2	Another regulatory consideration is the requirements under RCRA ground-water monitoring requirements per regulated unit. An understanding of the uppermost aquifer (conceptual model) beneath a regulated unit is required is 40 CFR Parts [264, 265, and 270]. At present, individual zones of saturation beneath LANL have not been delineated and the hydrogeologic connection between these zones is not understood. A GWPMP could incorporate the needs of RCRA ground-water monitoring requirements to assure the required hydrogeologic information is available and adequate.	5.1.2
3	(Section D., pg.12) In general, clarification is needed to understand if this plan pertains only to DOE properties or if this approach will incoordinate all technical concerns regardless of property boundaries.	1.1
4	(Section D., pg. 13,(3)(c). It is recommended that sampling frequencies be considered on a bi-annual basis.	5.3.2

The following comments refer to a recommended phased approach with items representing the order. Additional items from the subject document have been included. Items with the same number represent concurrent tasks to be conducted during that phase. When appropriate, activities list in the Business Plan are prioritized.

PHASE 1 - Develop and Implement Integrated Information and Archiving System

ITEM	Comment	
1	Evaluate and assess the validity of existing hydrogeologic data.	5.5.2 6.6.2
2	(5)(a) Compile validated existing subsurface geologic and hydrogeologic information into common database.	5.5.2 6.6.2

3	(5)(b) Integrate databases with FIMAD	6.6.2
4	Conduct geophysical surveys across known or suspected fault-fracture zones to investigate the role fractures may play in the migration of aqueous fluids.	6.6.2
4	Complete site-wide geologic mapping to facilitate development of hydrogeologic model and to assist in siting of monitoring wells.	6.6.2
4	Identification of all springs on-site and near laboratory boundaries (Spring Inventory)	6.6.2
4	Evaluate water chemistry trends utilizing the validated integrated data within the various zones of saturation (alluvial aquifers, perched-intermediate aquifers, and main aquifer intervals) for indications of potential migration pathways.	6.6.2
5	Evaluate validated aquifer characterization data with respect toward siting initial phase monitoring wells as guided by water chemistry trend analysis.	6.6.2

PHASE II Develop Integrated Ground Water Program for Technical Studies and Reporting

1	Delineation of occurrence and extent of saturated canyon ground water (seasonal saturation). For example, Ancho Canyon by State route 4, Canon de Valle by TA-16 Area P Landfill, etc.)	6.6.2
1	(4)(b). Determine recharge pathways into intermediate depth perched ground water.	
high	o Delineation of occurrence and extent of intermediate depth perched ground waters (perched ground water within Tuff recognized).	6.6.2
high	o Recharge route from saturated canyon ground water.	6.6.2
med	o Recharge from mesa tops surface waters. This topic might be divided into different components: 1) drainage run-off from mesa tops to canyon surface waters and 2) water balance budgets.	6.6.2
1	(4)(a). Determine recharge pathways into main aquifer	
high	o Secondary route from perched-intermediate groundwater	6.6.2
high	o Secondary route from saturated canyon groundwater.	6.6.2
high	o Develop understanding of mechanisms and processes for recharge through unsaturated zone. Agree that fracture transport should be understood as well understanding flux through the Cerro Toledo interval and other "underlying strata such as basalts" and vapor phase transport within the particular intervals within the Tuff. However, additional testing of hydraulic conductivity of nonwelded ignimbrite may not yield as much needed information as it is already fairly known that these units of the Tuff have low hydraulic conductivities values and high matrix potentials.	6.6.2

med	o Secondary route from mesa tops surface waters. This topic might be divided into different components: 1) drainage run-off from mesa tops to canyon surface waters and 2) water balance budgets.	6.6.2
low	o Regional recharge route.	6.6.2
low	o Recharge to main aquifer on regional basis	6.6.2
1	Determine discharge of main aquifer and perched-intermediate aquifers.	6.6.2
1	Determine recharge for springs site-wide.	6.6.2

PHASE III - Develop Hydrogeologic Model

1	Agree with all of these activities. These projects will most likely occur after portions of Phase II are complete or may occur concurrently.	
low	o Regional flow model for main aquifer.	6.6.2

July 12, 1994

Mr. Steve Rae, Section Leader
Environmental Protection Group., ES&H-8
Los Alamos National Laboratory, MS K490
Los Alamos, NM 87545

RE: Ground water Business plan - Concurrence on Priority 1 Items

Dear Mr. Rae:

	Comments Addressed in Section
At the meeting on July 7, 1994, the Ad Hoc Ground Water Protection Committee concurred on a new Priority 1 action item grouping which the committee agreed could and should be achieved within 18 months of the project's inception on June 9, 1994. Following is a listing of the elements of the Priority 1 grouping. Please note that the list is not arranged in order of highest to lowest priority within the grouping.	
1. Complete the spring and seep inventory whose objective is to compile a listing of existing NMED/LANL data regarding springs on lab property or potentially associated with ground water originating under lab property. Include new springs known to exist, e.g. in TA-3, Starmer Gulch, etc. Inventory to include X, Y, Z locations, water quality data determined by the Committee to be pertinent, water temperature, etc.	6.6.2
2. Expand the ground water monitoring plan sufficiently to define schedules and objectives of the ground water monitoring program.	6.6.2
3. Produce an updated peizometric map using existing data.	6.6.2
4. Evaluate hydrogeological data and integrate into FIMAD or an equivalent centralized electronic data storage facility. Provide for input of NMED data for use by LANL in data comparisons. Provide a mechanism for updating sampling schedules of LANL/NMED ES and possibly all ER groups.	6.6.2
5. Include and implement a system for contingency follow-up on environmental surveillance 'hits'.	To be Addressed
6. Define ground water surveillance roles to prevent equipment problems, i.e., cross-contamination of wells.	5.3.2
7. Define and implement lab-wide SOP's on well construction, well logging, geophysics, plug-and-abandonment procedures, etc.	5.6.2
8. Determine within this Priority 1 timeframe what level-of-effort should be assigned to producing a site-wide or area-specific geological map in order for the map to be produced during the Priority 2 timeframe.	To Be Addressed
9. Employ manual trend analysis on a selected set of wells for a defined listing of COC's.	6.6.2
10. By September of this year, achieve consensus on a draft, proposed well location map for presentation to DOE for funding.	Map completed 5.1.1

If you have any questions regarding this matter, please contact me at (505) 672-0447.

Sincerely,

Bruce Swanton, NMED AIP POC
Hazardous and Radioactive Materials Bureau
cc: Karen McAda, DOE/AL/EPO
Steve Zappe, HRMB Permits Program
Suzanne Johnson, LATA/ES&H-8
William Stone, HRMB GWPRB
Teri Davis, HRMB Technical Compliance
Bonnie Koch, Scientech/LAAO
Benito Garcia, HRMB Bureau Chief
Neil Weber, NMED DOE Oversight Bureau Chief
NMED LANL AIP Program file

United States Government

memorandum

Department of Energ
Albuquerque Operations
Los Alamos Area Omc
Los Alamos, New Mexico 8754

DATE: OCT 2 5 1994

REPLY TO ATTN OF: LAAMEP:LJV-048

SUBJECT: Comments on Updated Ground Water Protection Management Program Plan (GWPMPP)

TO: Steve Rae, ESH-18, LANL, MS-K490

LAAO has completed review of the above-referenced GWPMPP and has attached comments. Overall the GWPMPP is a significant enhancement over past efforts. Our comments primarily focus on expanding the detail provided on well rationale, providing associated data quality objectives, vadose zone monitoring objectives, additional cost data for studies, definition of resource requirements, schedules for individual activities and inclusion of authorities and accountabilities for the Project Leader. Many of these comments were previously provided in a DOE memorandum. LAAO requests that the plan be revised to incorporate our comments.

After revision, LAAO will transmit the revised GWPMPP to the NMED Agreement in Principle (AIP) staff. LAAO will request the AIP staff to conduct a technical review of the adequacy of the proposed deep well monitoring network based on the rationale provided in the GWPMPP and their expertise, and provide LAAO and LANL technical comments at a subsequent meeting.

The joint effort between NMED AIP, LAAO, and LANL will take several more months and meetings to complete. Future technical meetings will address plugging and abandonment, shallow alluvium and intermediate zone wells, ongoing and proposed LANL Environmental Management Programs projects, vadose zone studies, environmental surveillance monitoring frequency, prioritization of planned actions and Project Leader accountability/authority prior to finalizing the plan.

Please refer any questions or comments on this matter to Ken Zamora, Scientech, LAAO, at 665-5047.

for Joseph C. Vozella
Acting Asst. Area Manager
Office of Environment and Projects

Attachment

cc:
See page 2

Attachment

LAAO Comments on the Updated Ground Water Protection Management Program (GWPMPP) Plan

Statement Addressed in Section

Executive Summary

Executive Summary Pg. 1, Paragraph 5: The Business Plan should define who has ultimate accountability within the ES&H Division for the Project Leader accomplishing his/her responsibilities under the plan and the authority this position requires and has been granted by the ES&H Council to successfully accomplish the GWPMPP objectives. Include accountability and authority in sentence 1 following roles and responsibilities. — 6.2

Section 1
Introduction
1.1 Purpose and Scope

Pg. 1-1, Paragraph 2: Expand this discussion to list the specific requirements or scope of Chapter III, Section 4a (1-7), of DOE Order 5400.1. — 1.1

1.2 Laboratory Environmental Goals

Pg. 1-1, Paragraph 3: Appendix A should detail the specific requirements of the HSWA Permit, Module 8, Task III relative to ground water monitoring. — Appendix A

1.3 GWPMP Mission and Objectives

Pg. 1-1, Paragraph 1: Include meeting the above specific requirements. — 1.3

Section 5
5.0 Issues and Solutions

Pg. 5-1, Paragraph 1: Expand this section to include Plugging and Abandonment, and Environmental Surveillance Monitoring. — 5.2.1, 5.3.1

5.1.2 Hydrogeological Characterization Solutions

Pg. 5-2, Paragraph 7: Provide a discussion section expanding the rationale for each well supporting the data quality objectives referenced in the following paragraph. In addition, a map showing the proposed location of the 50 shallow alluvium and 14 intermediate zone wells should be provided with a similar discussion of rationale. — 5.1.2

Pg. 5-5, Paragraph 1: A table and associated expanded discussion specifying the specific data quality objectives for each well (shallow, intermediate and deep) should be defined, including core sample analysis, frequency of monitoring, analytical parameters, etc. which ties to table 5-1 Proposed Well Location Rationale. — 5.1.2

Pg. 5-5, Paragraph 2: Include a section in the GWPMPP addressing vadose zone monitoring needs and planned activities. There are a number of ER studies being performed to study vadose zone conditions at or near SWMU locations. For instance, studies are underway at TA-54, Area G (OU-1148). The GWPMPP should integrate and expand these studies as necessary. While the number of studies are increasing, many are conducted over short periods of time. An extended field program, one capable of spanning a time frame as long as a decade, is necessary to understand the unsaturated flow conditions. Small groups doing their own studies need to have their efforts coordinated ultimately leading to a much broader understanding. More importantly, most of these studies do not study below more than 150 ft. Currently there are no vadose zone studies that have gone beyond 200 ft. so there is a data gap that should be filled by coordinating with ER to expand the studies down to the water table. 5.1.2

Section 6.0
Business Plan
6.2.1 Project Leader
Pg. 6-1, Paragraph 2: This section does not adequately address accountability and authority consistent with previous DOE LAAO recommendations. 6.2

6.3.2 Environmental Surveillance Program
Pg. 6.4, Paragraph 4: Based on the quality objectives defined in 5.1.2, budgetary requirements should be defined to support a monitoring program with a minimum sampling frequency of quarterly as previously recommended by EM-8 and DOE LAAO. In addition, previous DOE LAAO memorandum recommended that Additional Testing and Line Item Cost implementation referenced in Figure 6-2 be accelerated by one year. The technical conclusion of the LANL Hydrology Team is that the monitoring well network is inadequate and well installation and additional testing should be implemented as soon as possible. In Progress

6.6.2 Prioritized List of Activities
Pg. 6-9, Paragraph 4: Previous DOE LAAO comments have requested the Laboratory identify the total cost of compliance and how it would be funded which would include resource requirements for all action items in including studies. Modify this paragraph to indicate a commitment by the Laboratory to complete all recommended priority 1 action items within the recommended time frame. Additional resource requirements should be identified and reflected in Table 6-1 GWPMP Funding Sources and Table 6-2 GWPMP Preliminary Cost Estimate. In Progress

Pg. 6-9, Paragraph 5: Again as stated above, DOE LAAO has requested the Laboratory determine funding requirements and source. Also, DOE LAAO has also requested a recommended 6.6.2

implementation schedule. Priority two items need to be completed within the Priority time frame based on program need. Modify this paragraph to indicate recommended projects to meet DOE Order requirements will be funded and completed within the Priority time frame.

Pg. 6-9, Paragraph 7: As discussed in earlier team meetings, DOE LAAO agrees with the need to include a paragraph describing all aspects of each activity in detail to ensure that the reviewer and/or reader clearly understands the objective of the activity. Table 6-4

Pg. 6-10, Table 6-4: Include a section on Plugging and Abandonment as previously recommended by DOE LAAO, and Monitoring, with planned activities. A technical discussion of known well or borehole status and locations including construction data is required to support the plan to plug and abandon only 9 existing monitoring wells. This part of the plan should include the necessary data from the "Record of Observation Wells, Testholes, Test Wells, Supply Wells, Springs and Surface Water Stations at Los Alamos; with Reference to the Geology and Hydrology, William D. Purtyman, 1994" in an appendix. The GWPMPP should address plugging and abandonment of all known potential contaminant pathways, not just active monitoring wells of inadequate construction. 5.2.2 Appendix E

Section 7
Implementation Plan
7.6 Business Plan Schedule In Progress
Pg. 7-1, Paragraph 7: This section needs to be expanded to include a discussion of sequential implementation of prioritized activities shown in Figure 6-2 and listed in Table 6-4. Define th order of the prioritized activities recommended, and the specific initiation/completion schedule over the 10 year period..

Pg. 7-3, Paragraph 3: The DOE LAAO approved business plan targeted a July 1, 1994 hiring date for the Program Manager. Please ensure the Project Leader target hiring date is met. In Progress

MEMORANDUM

To: Mr. Joseph C. Vorella, Chief Environment, Safety & Health, Department of Energy, LAAO

From W. Stone, DOE Oversight Bureau, Technical Support
M. Dale, DOE Oversight Bureau LANL
S. Yanicak, DOE Oversight Bureau, LANL

Date 11 July 1995

Subject Review of Los Alamos National Laboratory's (LANL) Groundwater Protection Management Program Plan (GWPMPP)

The DOE Oversight Bureau (DOE OB) has reviewed the subject document. The following comments are provided for the purpose of communicating the results of the DOE OB review. These comments are not provided or intended for the purpose of representing the regulatory position of the New Mexico Environment Department.

We have reviewed the latest version of the Ground Water Protection Management Program Pan (Issued 6 March 1995) and supplementary material provided by DOE labeled "Attachment 2" (Issue 12 June 1995). This review included not only going through the text, but also evaluating the wells proposed for monitoring the hydrologic systems on the Pajarito Plateau. The purpose of this memo is to convey our general and specific comments.

GENERAL

ESH Response

We have several comments of a general nature on the text/report as a whole:

1. Section 2 (Background) is useful, but it does not seem the appropriate place to include geology. Why not have section on Regional Setting that includes all natural aspects of the facility (geology, climate, hydrology and vegetation). Section 3 could be renamed, the geology material now in Section 2 could be moved there and information on climate and vegetation (not now provided) could be added. — Suggestion considered, original format retained

2. Care should be taken to be correct and consistent in the use of stratigraphic nomenclature. Different terminology is sometimes used in figures than in is given in the text. For example, the correct new term "Puye Formation" is used in the text (p. 2-4), but the old term "Puye Conglomerate" is used in Figure 2-3. Proper usage is important as the reader may wonder how good the hydrology is if the geology is sloppy. — Addressed

3 Although it has been pointed out to LANL hydrologists before, there is still confusion over the use and meaning of the term "aquifer" and "water table". The line on figures, such as 2-3 and 3-2, labeled "top of the main aquifer" is in fact the top of the saturated zone or regional water table. In common usage, an aquifer is a geologic material, the saturated portion of which, yields useful quantities of water (the definition in the report glossary is awkward and misleading — Addressed

(not just rock); (why not replace it with this one?) Thus, the aquifer is the entire unit yielding water, not just the saturated portion. Therefore, the top of the aquifer is much higher than the water table or the line shown. As it is the water table that is of interest in these figures, the labels should be corrected. Confusion on such basic concepts casts a shadow over the rest of the hydrologic work at LANL. It is hoped that this correction will finally be embraced by LANL hydrologists and incorporated in future reports as well.

4. The informal designation of the aquifer or hydrologic systems at LANL is somewhat illogical, mixing genetic ("alluvial"), depth ("intermediate"), and use ("main") connotations. The most parallel set of names would be "shallow perched", "intermediate perched" and "deep regional", focusing on depth and type of aquifer. Aquifers are also often informally named by the stratigraphic or lithologic identity of the material involved: Ogalalla aquifer, limestone aquifer, etc. The are nouns, not adjectives, thus "alluvial" denote genesis or origin of the material. Genesis has not been used for other aquifers at LANL, so why apply it to any? For example, when water is perched in the basalt, it is not called the volcanic aquifer. Although the informal names are fairy entrenched by now, it is useful to reflect on what they mean whether they can be defended an if it is desirable to perpetuate them. Addressed

5. Inclusion in the glossary of the terms "ephemeral", "intermittent" and "interrupted" for stream type suggest they are not intended to be interchangeable. Yet, they are sometimes used that way in the text. For example, compare the first paragraph in section 2.3, p.2-4 and first paragraph in section 3.1, p.3-1. Addressed

6. Figures incorporating blowups of certain areas should be proofed to assure that wells shown on the general map appear on the blowup (for example, Figure 4-2). Addressed

7. There are several problems associated with references. Not all references cited are in the list provided (for example, the Tiger Team Assessment and other reports cited at the top of p5-1). Also, some citations in that list are incomplete (for example, Kelly, 1975, was USGS Open-File Report, but that is not given). Such omissions prohibit the reader from obtaining further information if desired, the ultimate purpose of the list. For future reference, there is no period after "et"; it is Latin for "and", not an abbreviation. Addressed

SPECIFIC

Our review also included an evaluation of the proposed new wells, from the DOE Oversight perspective. Such evaluation involved a comparison of the proposed well locations with perceived hydrogeologic/hydrochemical data gaps or needs. Wells believed to meet these needs were then prioritized in view of the urgency of these needs and the reality or shrinking budgets (Tables 1 & 2).

In many cases, wells were proposed for the shallow and/or intermediate perched water, as well as the seep regional aquifer, at the same location. We agree that this is the best way to investigate the communication between these systems. We suggest that this may be accomplished by adopting the following general policy in installing the new wells. Whenever shallow and/or intermediate perched water is encountered during drilling, the water-producing interval (s) should be screened and isolated before going deeper. In other words, the opportunity for monitoring all water-bearing zones at a site should be provided, regardless of the lists provided in the report. This may involve multiple completions in the same hole or multiple wells the same location. As shown in Table 1, twenty-five sites hold the most interest in the deep aquifer. This includes some proposed by LANL as well as some we suggest adding. Of these twenty-five sites, six are considered as very high to high in priority, two as moderate to high priority, ten as moderate and seven as pertinent and nice-to-have-if-budget-allows, but of low priority.

As shown in Table 2, thirteen sites hold the most interest in the intermediate aquifer. Of these thirteen sites, five are considered as very high to high in priority, two as moderate to high priority, three as moderate and three as pertinent and nice-to-have-if-budget-allows, but of low priority.

Monitoring well location will be modified during the implementation of this plan. That is, well placement decisions will change as new data (i.e., water levels) becomes available. It should be noted that our comments reflect general technical oversight concerns rather than RCRA or other regulatory needs.

XC: N. Weber, NMED, Chief, DOE Oversight Bureau
J. Parker, NMED, DOE Oversight Bureau
R. Kern, NMED Hazardous & Radioactive Materials Bureau
I. Trujillo, DOE LAAO, AIP POC

Table 1 AIP's Recommendations and Prioritization for LANL's Proposed Main Aquifer Well Locations/Figure 6-1 and Table 6-1

Main Proposed Well ID	Map Ref. #	Priority	AIP's Comments and Recommendations	Water Quality and Hydrology Group (ESH 18) Response to Comments	New Well ID
PLATS 1	1	Not Applicable	AIP suggests omitting the well	ESH 18 considers this well an important perimeter off site monitoring point for background water quality, water level data and stratigraphic information	same
PGC-1	2	Low	Appropriate		same
PLAC 1	3	Moderate	Appropriate		same
PPFZ-1	4	Low	AIP suggests locating this well near Pajarito Canyon in order to obtain data which might help determine the relationship(s), recharge between Pajarito Canyon surface water and surrounding ground water.	ESH 18 feels that surface flow would complicate the intended purpose of this well to analyze the fault as either a conduit or barrier to groundwater flow. Surface water issue best addressed separately.	same
PWC-1	5	Moderate to High	Please note that this well is placed in upper Cañon de Valle, not upper Water Canyon as stated in Table 6-1. Also note that a perched zone within the Bandelier Tuff near MDA P contain high explosives, volatile organic compounds and elevated amounts of dissolved barium, therefore, AIP suggests re locating this well topographically downgradient from MDA P.	ESH 18 notes that placement of this well downgradient of MDA P was the original intent. The well label has been corrected to reflect location in Cañon de Valle	PCDV-1
PPC-1	6	Moderate	Appropriate		same
PPC-2	7	Moderate	Appropriate		same
PTBC-1	8	High	Appropriate		same
PPOC-1	9	Moderate	AIP suggests re locating this well approximately 500 ft downgradient from the "discharge sink". This well will assist in monitoring releases from Tech Areas 15 and 36	ESH 18 agrees to place an intermediate depth well downgradient of the "discharge sink". Regional aquifer well # 9 has been relocated in LA Canyon to address other AIP concerns	FLAC-3
PPC 3	10	Moderate	Appropriate		same
PMC-1	11	Very High	AIP suggests placing this well approximately 500 ft southeast of the sediment trace in order to monitor Mortandad Canyon's contribution (i.e., recharge) to deeper zones	ESH 18 notes that this was the original intention of the well	same
PSC 1	12	Moderate	AIP suggests placing this well near PM 1 in order to minimize Los Alamos Canyon's contribution to deeper zones	ESH 18 does not concur as this well is located near the TA-53 lagoons to address RCRA issues and monitor for southward contaminant migration from LA Canyon site	same
PPBC-1	13	Very High	AIP suggests placing this well upgradient of TW 1. Plugging of TW 1 and TW 1A should be performed prior to new well placement, which should help any influence from residual waters from TW 1's possible borehole leakage	ESH 18 agrees to relocate this well upgradient of TW-1. ESH 18 will consider not plugging TW 1 and TW-1A until after emplacement of new well for purposes of hydrogeologic testing	same
PLAC-2	14	High	AIP suggests locating this well upgradient of production well LA 8. This location may give greater hydrologic control and monitoring capabilities	ESH 18 agrees with relocation of this well for greater contaminant detection capabilities	same
PPFZ 2	15	Low	AIP suggests locating well near Pajarito Canyon, and may help determine the relationship(s) between Pajarito Canyon surface water and surrounding ground water.	ESH 18 feels that surface flow would complicate the intended purpose of this well to analyze the fault as either a conduit or barrier to groundwater flow. Surface water issue best addressed separately.	same
PPC 4	16	Moderate	Appropriate		same
PMC-2	17	Low	Appropriate		same
PCDB 1	18	Not Applicable	AIP suggests omitting this well	ESH 18 considers this well an important off site monitoring point but agrees that this well is of low priority	same
PPOC 2 -	19	Low	Appropriate		same
PWC 2	20	Moderate	Appropriate		

PAC-1	21	Moderate to High	This well appears to be located in Ancho Canyon, approximately 1 mile east of Main Site and MDA E which are the primary liquid release sites. AIP suggests relocating this well near MDA E	ESH 18 does not understand AIP rationale for relocation of this well. Lack of access into Cheapside Canyon near MDA E will not permit drilling in this location.	same
PBHQ or PBHQ 1	22	Low	Appropriate. Note that the well identification does not match from Table 5.1 to Figure 5.1.	The discrepancy between the table and the figure has been corrected.	PBHQ 1
PBC-1	23	Low	Appropriate	This well label has been corrected	PPBC-2

Recommendation for additional wells.

AIP suggests placing one or two wells near DT 9A, DT 9 and DT 10. These wells would provide deep aquifer monitoring downgradient from the hydronuclear shafts at Tech Area 49. (High Priority)

ESH 18 does not concur. Shallow well coverage in adjacent canyon is considered sufficient

AIP suggests placing one well near the Los Alamos airstrip in order to monitor releases from Acid and Pueblo Canyon. (Moderate Priority)

ESH 18 considers placement of proposed well # 23 (PBC-1) (new name PPBC-2), as well as proposed ER Project intermediate wells as sufficient for this purpose

AIP suggests placing one well near LANL's proposed intermediate well PLC-3. This well would monitor deep zones downgradient from Los Alamos and DP Canyon. (Moderate Priority)

ESH 18 concurs and proposes moving well #9 (PPOC-1) (new name PLAC-3) to Los Alamos Canyon between existing well TW-3 and State Road 4.

AIP suggests Placing one well between TA 21's MDA A, T, and U, and production well O-4. (High Priority).

ESH 18 feels that the new location well # 9 (PLAC-3) is sufficient to monitor this area and that additional drilling in AIP proposed location would provide possible conduit for contaminant migration.

Table 2 AIP's Recommendations and prioritization for LANL's Proposed Intermediate Aquifer Well Locations (Figure 5 2 and Table 5 2)

Intermediate Proposed Well ID	Map Ref. #	Priority	AIP's Comments and Recommendations	Water Quality and Hydrology Group (ESH 18) Response to Comments	New Well ID
PIBC 1	1	Low	Appropriate		same
PIPBC 1	2	High	Figure 5 3 shows this well near TA 0 and TW 2, not TA 74 or TW 1 as stated in Table 5 2 AIP suggests placing slightly upgradient of TW 2 and TW 2A.	ESH 18 agrees with location of well upgradient of TW-2 and TW-2A. Location designation has been corrected	same
PIPBC-2	3	High	Figure 5 2 shows this well near the Bayo Canyon waste treatment facility, not TW 2A as stated in Table 5 2 AIP suggests coupling this well with LANL's proposed main aquifer well PBC 1.	ESH 18 notes that this was the original intention.	same
PIPBC-3	4	High	This well appears to be a replacement of TW 1A. AIP suggests coupling this well with LANL's proposed well PPBC-1.	ESH 18 notes that this was the original intention	same
PILC-1	5	Low	Figure 5 2 shows this well near test well H 19 (TA 43), not TW 3 or O 4 as stated in Table 5 2 AIP suggests coupling this well with LANL's proposed main aquifer well PLAC 1.	ESH 18 notes that this was the original intention	same
PILC-2	6	High	Figure 5 2 shows this well at TA 73, not TA 43 as stated in Table 5 2 AIP suggests coupling this well with an additional deep aquifer well for monitoring TA 21's MDA A, T, and U	ESH 18 does not concur with the need for an additional deep well at this location ESH 18 has proposed an additional deep well further downgradient in Los Alamos Canyon	same
PILC-3	7	Moderate to High	AIP suggests coupling this well with an additional deep aquifer well for monitoring deeper zones downgradient from Los Alamos and DP Canyon	ESH 18 concurs and has proposed well PLAC-3 in Los Alamos Canyon between TW-3 and state road 4	same
PISC-1	8	Not Applicable	AIP suggests omitting this well	ESH 18 considers this well to be an important monitoring point for the TA-53 lagoons and to monitor possible southward movement from LA Canyon	same
PISC-2	9	Moderate	AIP suggests coupling this well with LANL's proposed main aquifer well PSC-1.	ESH 18 does not concur with relocation of proposed regional aquifer well PSC-1.	same
PIMC-1	10	Very High	AIP suggests coupling this well with LANL's proposed main aquifer well PMC 1.	ESH 18 proposes to relocate this well further west up the canyon where water loss and contamination questions may be better addressed	same
PIPC-1	11	Moderate	AIP suggests coupling this well with LANL's proposed main aquifer well PPC 4	ESH 18 concurs, PPC 4 will be located on Mesita del Buey east of Area G, PIPC-1 will be located nearby in Pajarito Canyon to look for perched water	same
PICDV-1	12	Moderate to High	AIP suggests coupling this well with LANL's proposed main aquifer well PAC 1.	ESH 18 notes that this was the original intention	same
PIWC-1	13	Moderate	AIP suggests coupling this well with LANL's proposed main aquifer well PWC 2	ESH 18 notes that this was the original intention	same
PIPOC-1	14	Low	Figure 5 2 shows this well at TA 33, not TA 36 as stated in Table 5 2 AIP suggests coupling this well with LANL's proposed main aquifer well PPOC 2	ESH 18 proposes to relocate this well 500 ft downgradient from the "discharge sink" to monitor discharges from TA's 35 and 36 per AIP suggestion	same

APPENDIX J

Monitoring Well Design and Completion Matrix

MONITORING WELL DESIGN AND COMPLETION MATRIX

PREPARED BY :
JON C. NEWSOM
EES-4, SUBSURFACE TECHNICAL TEAM
10/27/94

CATEGORY	PROPOSED LANL ER SOP SOP- 5.01, R1	PRESENT LANL ER SOP SOP-5.01, R0	NEW MEXICO MONITORING WELL CONSTRUCTION AND ABANDONMENT WELL STANDARDS	HSWA PERMIT 8/15/92	NATIONAL EPA GUIDELINES
WELL ABANDONMENT	OVER-REAM CASING AND REMOVE IF POSSIBLE. PUMP GROUT WITH TREMIE PIPE BOTTOM TO SURFACE IN ONE MONOLITHIC EFFORT. WHERE A PROPER SURFACE SEAL HAS BEEN SET AND OVER-REAMING IS NOT PRACTICAL : RIP THE SCREEN AND CASING WITH PERFORATOR AND PUMP GROUT FROM BOTTOM TO SURFACE IN ONE EFFORT.	OVER-REAM CASING AND REMOVE IF POSSIBLE. PUMP GROUT WITH TREMIE PIPE BOTTOM TO SURFACE IN ONE MONOLITHIC EFFORT. WHERE A PROPER SURFACE SEAL HAS BEEN SET AND OVER-REAMING IS NOT PRACTICAL : RIP THE SCREEN AND CASING WITH PERFORATOR AND PUMP GROUT FROM BOTTOM TO SURFACE IN ONE EFFORT.	REMOVE CASING WHERE POSSIBLE. CUT CASING AT GROUND SURFACE. USE EXPANDING GROUT OR FILL WITH BENTONITE PELLETS FROM BOTTOM TO SURFACE.	NOT MENTIONED.	
PROTECTIVE SURFACE CASING / SHROUD	STEEL POST, 3' MINIMUM LENGTH, 1.5' TO 3.0' ABOVE GROUND, 8" OD FOR 4" WELLS AND 6" OD FOR 2" WELLS, LOCKING CAPS, LOCK, WHETHER-PROOF	STEEL POST, 3' MINIMUM LENGTH, 1.5' TO 3.0' ABOVE GROUND, 8" OD FOR 4" WELLS AND 6" OD FOR 2" WELLS, LOCKING CAPS, LOCK, WHETHER-PROOF	LOCKING CAP, LARGE ENOUGH TO ALLOW REMOVAL OF PVC CASING CAP		
CASING MATERIALS, CONDITIONS	PVC, STAINLESS STEEL, OR IN SOME CASES NON STAINLESS STEEL WELL CASING, WHERE DESIGN DICTATES	PVC	SCHEDULE 40 OR HEAVIER PVC, MINIMUM 2" ID	INERT MATERIALS, FLUSH JOINT, INTERNAL UPSET OR, THREADED, NO GLUE, SCREWS, OR RIVETS	

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SURFACE PAD AROUND CASING	MINIMUM 24' X 24' X 6" THICK, CEMENT, PLACED AROUND CASING, SLOPED DOWNWARD FROM CASING FOR RUNOFF.	24' X 24' X 4" THICK, CEMENT, PLACED AROUND CASING, SLOPED DOWNWARD FROM CASING FOR RUNOFF.	24' X 24' X 6" THICK, CEMENT, PLACED AROUND CASING, SLOPED DOWNWARD FROM CASING FOR RUNOFF.	NOT MENTIONED	
WELL PROTECTIVE GUARD POSTS	3" OR LARGER STEEL PIPE MINIMUM 4' ABOVE GROUND, 2' BELOW GROUND. 3 POST RADIALLY LOCATED 4' AROUND THE WELL. CEMENTED INSIDE 6" HOLE. MAY NOT BE REQUIRED IN AREAS OF ZERO TRAFFIC.	3" OR LARGER STEEL PIPE OR TEE BAR POST. MINIMUM 4' ABOVE GROUND, 2' BELOW GROUND. 3 POST RADIALLY LOCATED 4' AROUND THE WELL. CEMENTED IN PLACE.	NOT MENTIONED	NOT MENTIONED	
ANNULAR WELL SEAL MINIMUM WIDTH (BETWEEN CASING OD AND WELL BORE)	2" OR LARGER PER SIDE, 4" OR LARGER TOTAL	2" OR LARGER PER SIDE, 4" OR LARGER TOTAL	2" OR LARGER PER SIDE, 4" OR LARGER TOTAL	3" OR LARGER PER SIDE, 6" OR LARGER TOTAL	2" OR LARGER PER SIDE, 4" OR LARGER TOTAL
ANNULAR WELL SEAL SURFACE TO MINIMUM DEPTH.	PORTLAND CEMENT TYPE I II, WITH 2% TO 5% BENTONITE ADDED. MINIMUM DEPTH IF PLACED ABOVE BENTONITE SEAL IS 10'. WAIT 48 HOURS ADD MORE AT SURFACE.	GROUT WITH SMALL % BENTONITE. WAIT 48 HR. ADD MORE AT SURFACE.	CEMENT WITH 2% TO 8% BENTONITE. MINIMUM DEPTH IS 10' FROM SURFACE.	GROUT (PRESUMED TO MEAN CEMENT) PLACED WITH TREMIE IF DEEPER THAN 5'.	

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ANNULAR WELL SEAL MATERIALS (BELOW MINIMUM DEPTH SURFACE SEAL) GENERALLY BETWEEN 10' FROM SURFACE AND 2' ABOVE SCREEN	HIGH SOLIDS CONTENT BENTONITE SLURRY GROUT, DRY GRANULAR BENTONITE CHIPS, OR PORTLAND TYPE II CEMENT WITH 2% TO 5% BENTONITE NOTE* PLACE AND HYDRATE 2' THICK CHIP OR PELLET SEAL ABOVE FILTER PACK BEFORE PLACING GROUT. *NOTE: HEAT AND HIGH HYDROSTATIC PRESSURES CAUSED BY CEMENT CAN COLLAPSE PVC PIPE.	HIGH SOLIDS BENTONITE SLURRY GROUT, PORTLAND CEMENT, OR BENTONITE PELLETS. PLACE A 2' THICK SEAL ABOVE FILTER PACK. HYDRATE FOR 24 HOURS BEFORE ADDING ANY LIQUID GROUT.	CAN USE DRILL CUTTINGS, CLEAN SANDY CLAY, OR TIGHTER SOIL TO WITHIN 10' OF SURFACE.	GROUT (PRESUMED BENTONITE OR CEMENT) IF BENTONITE HYDRATE A MINIMUM TIME OF 12 HOURS BEFORE ADDING SURFACE SEAL. PLACE WITH TREMIE.	
CENTRALIZERS: QUANTITY, SPACING	PLACE ONE AT BOTTOM OF SCREEN, ONE AT TOP OF SCREEN, AND SPACE ADDITIONAL ONES EVERY 50' UNLESS PLACING THROUGH HOLLOW STEM AUGERS OR THROUGH ODEX CASING, WHERE FEWER ARE REQUIRED.	EVERY 20' IF PLACED WITHOUT AUGERS. MAY NOT BE APPLICABLE IF PLACED THROUGH AUGERS. USE MECHANICAL FASTENERS, SPACE AT 90 DEG. AND 120 DEG.	ONE AT TOP OF SCREEN AND ONE AT BOTTOM OF SCREEN.	NOT MENTIONED	

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FILTER PACK, MATERIAL, MINIMUM/MAXIMUM COVERAGE	WASHED WELL ROUNDED COLORADO SILICA SIZED TO PASS 10% OR LESS THROUGH THE SCREEN SLOTS. PLACE 2' ABOVE SCREENED INTERVAL. PLACE 2' BELOW SCREENED INTERVAL IF ABOVE A BENTONITE SEAL.	INERT SILICA, SIZED TO PASS 10% OR LESS THROUGH THE SCREEN SLOTS. PLACE 2' ABOVE THE SCREEN, PLACE 2' BELOW THE SCREEN IF A BENTONITE SEAL HAS BEEN PLACED BELOW THE SCREEN INTERVAL. FILTER PACK TO BE PLACED WITH TREMIE PIPE IF 30' OR DEEPER.	PLACE 2' TO 5' MAXIMUM ABOVE THE THE SCREEN. PLACE 1' OR GREATER BELOW THE SCREENED INTERVAL IF ABOVE A BENTONITE SEAL. PLACE 2' OR GREATER IF ABOVE AN ARTESIAN ZONE.	PLACE 2' ABOVE THE SCREENED INTERVAL. DO NOT PLACE ACROSS CLAY ZONES.	
SCREEN, MATERIAL, MINIMUM/MAXIMUM LENGTH	PVC, STAINLESS STEEL, OTHER INERT MATERIALS. COVERAGE TO BE DETERMINED AS PART OF INDIVIDUAL WELL DESIGN. GENERALLY THE SCREENED INTERVAL WILL BE BETWEEN 5' AND 25'. A BOTTOM CAP IS REQUIRED AND A SHORT BLANK SECTION MAY BE USED.	DETERMINED ON A WELL TO WELL BASIS FOR BETTER WELL DESIGN. SCREEN TO COVER ONLY ONE PRODUCING ZONE.	PVC (ASSUMED), 20' MINIMUM LENGTH TOP OF SCREEN MUST BE 5' ABOVE WATER TABLE. MUST BE MACHINE SLOTTED (NOT DONE WITH A HACKSAW).	(PVC ASSUMED) 10' MAXIMUM LENGTH. DO NOT PLACE ACROSS A CLAY ZONE.	

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DEVELOPMENT	USE A SURGE PLUG TO PURGE FINE SANDS AND DRILLING CONTAMINATES FROM WELL USE A BAILER AND OR SUBMERSIBLE PUMP TO REMOVE SUFFICIENT BOREHOLE FLUIDS TO ACHIEVE TURBIDITY MEASUREMENTS AS REQUIRED BY THE HSWA PERMIT.	NOT MENTIONED	DEVELOP SO THAT WELL WATER FLOWS FREELY AND THAT ALL SEDIMENT HAS BEEN REMOVED.	PURGE THE WELL UNTIL CONTAMINATES INTRODUCED DURING DRILLING CAN BE ASSURED OF BEING REMOVED. DEVELOPMENT SHALL INCLUDE THE USE OF A SURGE PLUG, AND EITHER BAILING OR PUMPING UNTIL NEPHELOMETRIC TURBIDITY UNITS (N.T.U.) CAN BE CONSISTENTLY MEASURED AT FIVE (5) OR LESS, IF POSSIBLE	

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WELLS 300' OR DEEPER	300' OR GREATER AND NOT TO THE MAIN AQUIFER: GROUT IN A SURFACE CASING DEPTH OF THIS CASING SHOULD EXTEND BEYOND SHALLOW AQUIFERS. 300' OR GREATER AND INTO THE MAIN AQUIFER THAT ENCOUNTERS A PERCHED AQUIFER: SET A CONDUCTOR PIPE TO THE TOP OF THE MAIN AQUIFER (FROM SURFACE TO MAIN AQUIFER) TO ISOLATE THE PERCHED AQUIFER FROM THE MAIN AQUIFER.	NOT MENTIONED	NOT MENTIONED	300' OR GREATER AND NOT TO THE MAIN AQUIFER: GROUT IN A SURFACE CASING (DEPTH OF THIS CASING IS NOT SPECIFIED). 300' OR GREATER AND INTO THE MAIN AQUIFER THAT ENCOUNTERS A PERCHED AQUIFER: SET A CONDUCTOR PIPE TO THE TOP OF THE MAIN AQUIFER (FROM SURFACE TO MAIN AQUIFER) TO ISOLATE THE PERCHED AQUIFER FROM THE MAIN AQUIFER.	
SHALLOW ALLUVIUM PERCHED AQUIFER MONITORING HOLES	DESIGN MAY VARY SIGNIFICANTLY IN VERY SHALLOW HOLES WHERE NEAR SURFACE WATERS ARE TO BE MONITORED A 24" MINIMUM CEMENT GROUT SEAL MAY BE USED.	DESIGN MAY VARY SIGNIFICANTLY	NOT MENTIONED	NOT MENTIONED	

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WELL POINTS AND PIEZOMETERS	DESIGN MAY VARY SIGNIFICANTLY. PROVIDE A SURFACE SEAL WHICH PREVENTS SURFACE WATER FROM ENTERING THE WELL.	DESIGN MAY VARY SIGNIFICANTLY.	NOT MENTIONED	NOT MENTIONED.	
DOCUMENTATION				WITHIN 30 DAYS OF INSTALLATION OF WELLS, SUBMIT A MAP TO THE ADMINISTRATIVE AUTHORITY WHICH DELINEATES THE KNOWN EXTENT OF THE PERCHED GROUND WATER AT THE FACILITY. WITHIN 90 DAYS THE PERMITTEE SHALL SAMPLE EACH WELL FOR CERTAIN CONSTITUENTS AND ANALYTICAL RESULTS SENT TO THE AD. AUTHORITY. OTHER ONGOING MONITORING PROGRAM REPORTS.	

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