TA-00

LOS ALAMOS CANYON WATERSHED EVALUATION

by Robert Gray

for CRP-570

Watershed Management

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6845

Los Alamos Canyon Watershed Evaluation

Table of Contents

page

Acknowledgements....iii
Abstract....iv
Introduction....1

Watershed Description:
- Location, Geographical Setting, and Topography....1
- Climate....5
- Geology....5
- Soils....7
- Vegetation....13
- Hydrology....17
- Water Budget....18
- Social/Economic Components....27

Resource Evaluation....27
- Economic Resources....28
- Water Resources:
  - Surface Water....28
  - Groundwater....30
- Soils and Erosion....31
- Riparian Zone Evaluation....32
- Wildland Resources:
  - Forest Resources....35
  - Wildlife....35

Anthropogenic Impacts on the Watershed:
- Prehistoric Impacts....36
- Historical Impacts....39
- Current Land Uses....41
- Major Development/Urbanization Impacts:
  - Flood Hazard Mitigation....45
  - Water Quality....46
  - Induced Soil Erosion....57
  - Contaminated Sediment Migration....58
  - Biodiversity....61
  - Fire Suppression Impacts....62

Proposed Management, Research, and Rehabilitation Activities....63
- Water Quality Issues....64
- Contaminated Sediment Issues....65
- Biodiversity Issues....66
- Fire Hazard Issues....67

Conclusions....68

References....70

Los Alamos Canyon Watershed Evaluation

Table of Contents (continued)

List of Figures

page

Figure 1: Los Alamos Canyon Regional Location....2
Figure 2: Detailed Location....3
Figure 3: Topography....4
Figure 4: Normal Climatic Data....6
Figure 5: Bedrock Geology....8
Figure 6: Locations of Major Faults....9
Figure 7: Soils....10
Figure 8: Vegetation....15
Figure 9: Main Aquifer Piezometric Surface....19
Figure 10: Precipitation and Streamflow Gage Locations....20
Figure 11: Los Alamos Canyon Elevation vs Precipitation....22
Figure 12: ET vs Precipitation (TA-6)....23
Figure 13: Los Alamos Canyon Watershed Water Budget....26
Figure 14: Los Alamos Canyon Oct 1, 1994 to Sept. 30, 1995 Streamflow....29
Figure 15: Birds Seen in Upper Los Alamos Canyon....37
Figure 16: Birds Seen in Lower Los Alamos Canyon....38
Figure 17: Comparative Aerial Photographs of the Los Alamos Area....42
Figure 18: Land Use....43
Figure 19: Monitor Well Locations....48
Figure 20: Water Quality Data for Los Alamos Reservoir, Alluvial, Guaje Pumice Bed, and Santa Fe Group Waters, Los Alamos Canyon....49
Figure 21: Total Dissolved Solids in Alluvial Groundwater....50
Figure 22: Tritium in Los Alamos Canyon Aquifer....54
Figure 23: Strontium-90 in Los Alamos Canyon Alluvial Aquifer....55
Figure 24: Strontium-90 Activities in Alluvial groundwater....56
Figure 25: Sediment Sampling Locations....59

List of Tables

page

Table 1: Los Alamos Canyon Watershed Soil Types....11
Table 2: Los Alamos Canyon Watershed Soil Properties....13
Table 3: TA-6 ET vs Precipitation....24
Table 4: Los Alamos Canyon Water Budget....25
Table 5: Current Land Use....44
Table 6: DOE Calculated Derived Concentration Guides for Public Dose from Water....51
Table 7: Annual Avg. Macroinvertebrate Biodiversity....62

Los Alamos Canyon Watershed Evaluation

Table of Contents (continued)

Appendices: page

Appendix A: Vegetation, Insect, and Animal Listings:
Table A-1: Vegetation Species in Los Alamos Canyon....A-1
Table A-2: Terrestrial Arthropod Species....A-5
Table A-3: Reptile and Amphibian species in Los Alamos Canyon....A-8
Table A-4: Bird Species in Los Alamos Canyon....A-9
Table A-5: Mammal Species in Los Alamos Canyon....A-11

Appendix B: Chemical Data for Surface Water, Ground Water, and Sediments:
Table B-1: Background Water Quality Data from Los Alamos Reservoir....B-1
Table B-2: Radiochemical Analyses of Surface Water and Groundwater Samples from Los Alamos Canyon in 1993....B-2
Table B-3: Radiochemical Quality of Surface Water in DP Canyon, Upper Los Alamos Canyon....B-3
Table B-4: Radiochemical Quality of Water in Alluvium, Los Alamos Canyon....A-9
Table B-5: Summary of Radiochemical Analyses of Sediments in Los Alamos Canyon and DP Canyon, 1980-1992....B-5
Table B-6: Water, Sediment, and Plutonium Data for Los Alamos Canyon....B-6

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Abstract:

An evaluation of the Los Alamos Canyon watershed was conducted through an extensive literature review and analysis of meteorological and streamflow data. Basemap, topography, soils, vegetation, and land use data were digitized using FASTCAD™ (Evolution Computing, Inc.) software and an ACECAD™ model A-1212 digitizer. Resources of value include physical and economic infrastructure, groundwater, surface water, soils, forests, grasslands, wildlife, recreational opportunity, and landscapes of exceptional visual quality. Anthropogenic impacts on the watershed are diverse and pervasive, and range from altered species associations and increased forest fuel loads to radionuclide contamination of soils and waters. The most seriously impacted aquifers are perched shallow and intermediate zones that are not utilized for water supply. Erosion processes play an important role in transporting radionuclide contaminated sediments beyond the watershed, but streambed levels are generally low and likely represent minimal risks to downstream water users. Watershed management issues were analyzed and the critical issues identified are:

- Water quality.
- Contaminated sediment migration.
- Wildfire hazards.

Supplementary issues are:

- Biodiversity maintenance.
- Implementation of contaminanted water and soil remediation efforts.
- Community involvement in watershed planning.

INTRODUCTION:

This report comprises an evaluation of the Los Alamos Canyon watershed, located in Los Alamos, Santa Fe, and Sandoval counties of northern New Mexico. The objectives of this report are to characterize the watershed with regards to its unique aspects and features including its geographical setting and physical or cultural characteristics such as topography, climate, geology, vegetation, wildlife, hydrology, land uses, and social and economic components; to identify resources of value within the watershed; to analyze the current conditions and problem areas relevant to land use impacts upon the watershed and identify critical issues; and to propose methods for improving the condition of the watershed and to insure its long-term health and the sustainability of its resources and singular characteristics.

WATERSHED DESCRIPTION:

Location , Geographical Setting, and Topography:

Los Alamos Canyon is located primarily within the Pajarito Plateau geomorphic province of north-central New Mexico, just south of the town of Los Alamos and about 25 miles northwest of Santa Fe, and runs nearly west to east, largely within the boundaries of Los Alamos National Laboratory (LANL) (Figures 1 and 2). Its headwaters form in the Sierra de Los Valles of the Jemez Mountains and its runoff drains to the Rio Grande. Elevations of the Los Alamos Canyon watershed range from 10,441 feet atop Pajarito Mountain near the western edge of the watershed to about 6,300 feet at its confluence with Pueblo Canyon near State Road 4 (Figure 3). Below this confluence, the Los Alamos Canyon drainage carries the runoff from several other major canyons including Pueblo Canyon, Guaje Canyon, Rendija Canyon, Bayo Canyon and Barrancas Canyon. Since the purpose of this report is to evaluate the watershed area specific to Los Alamos Canyon, the downstream limit evaluated has thus been restricted to the point where it crosses State Road 4, immediately above its confluence with Pueblo Canyon, rather than also include the contributions of the significantly larger area drained by the other canyons. The study area as shown in Figures 2 and 3 comprises an area of approximately 6,483 acres or 10.13 square miles.

The channel length within the evaluated watershed drainage is ~12.3 miles and the canyon is deeply incised throughout this length, its depth ranging from ~600 feet in the upper watershed to

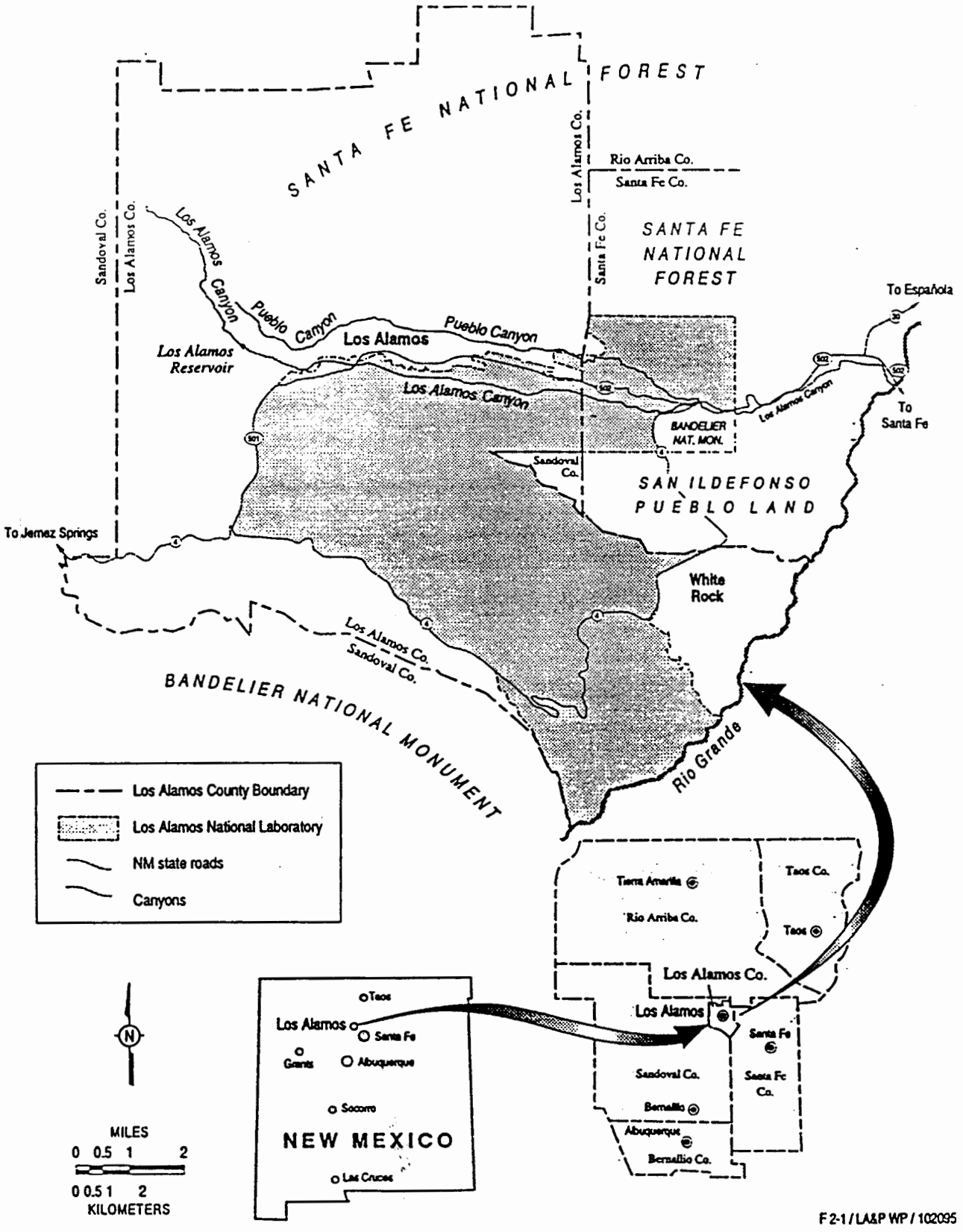


Figure 1: Los Alamos Canyon Regional Location

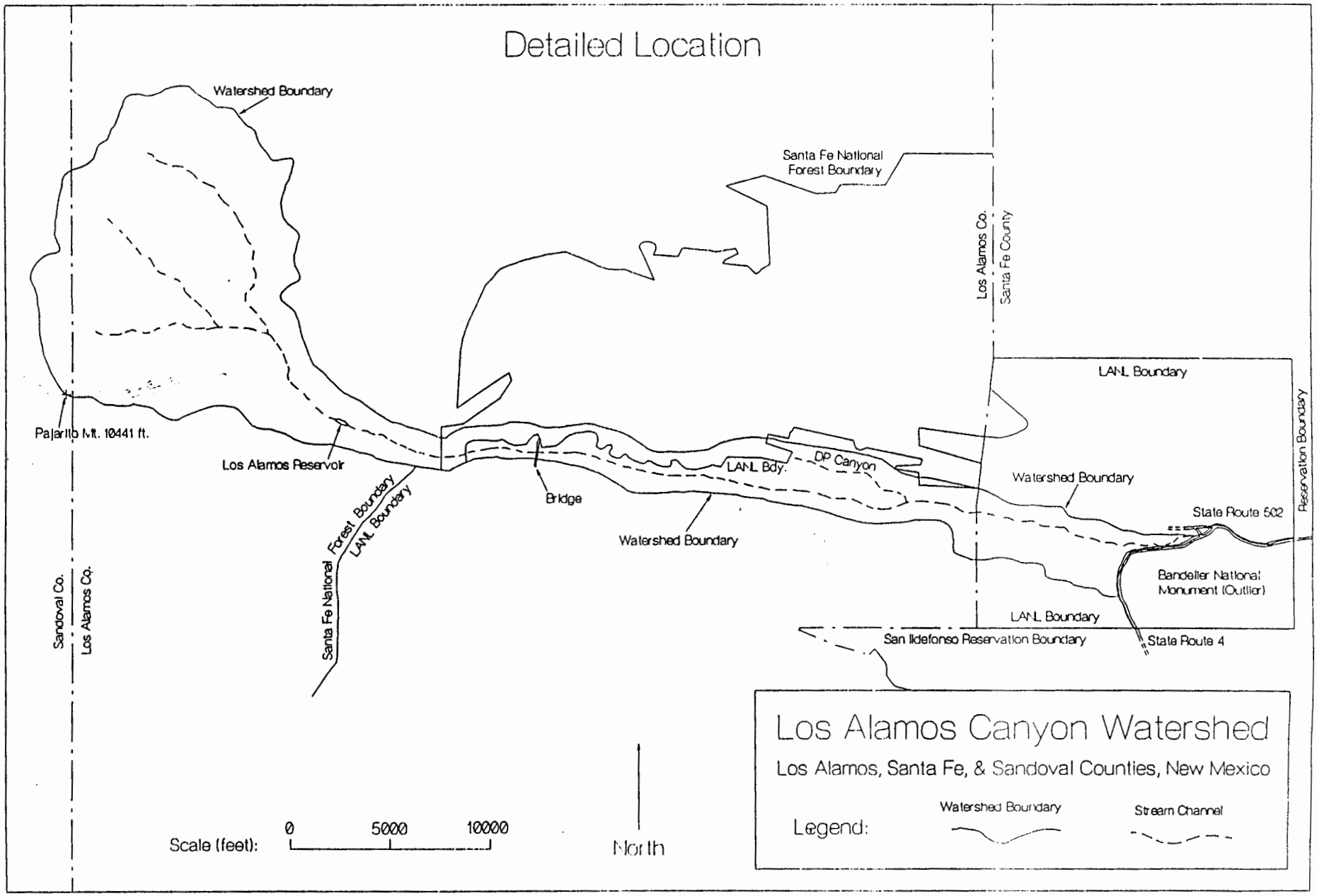

Detailed Location
Watershed Boundary
Santa Fe National Forest Boundary
Los Alamos Co.
Santa Fe County
LANL Boundary
Pajarito Mt. 10441 ft.
Los Alamos Reservoir
Santa Fe National Forest Boundary
LANL Boundary
Bridge
LANL Bdy.
DP Canyon
Watershed Boundary
Watershed Boundary
State Route 502
Reservation Boundary
Bandelier National Monument (Outlier)
LANL Boundary
San Ildefonso Reservation Boundary
State Route 4
Sandoval Co.
Los Alamos Co.
Los Alamos Canyon Watershed
Los Alamos, Santa Fe, & Sandoval Counties, New Mexico
Legend:
Watershed Boundary
Stream Channel
Scale (feet):
0
5000
10000
North

Figure 2

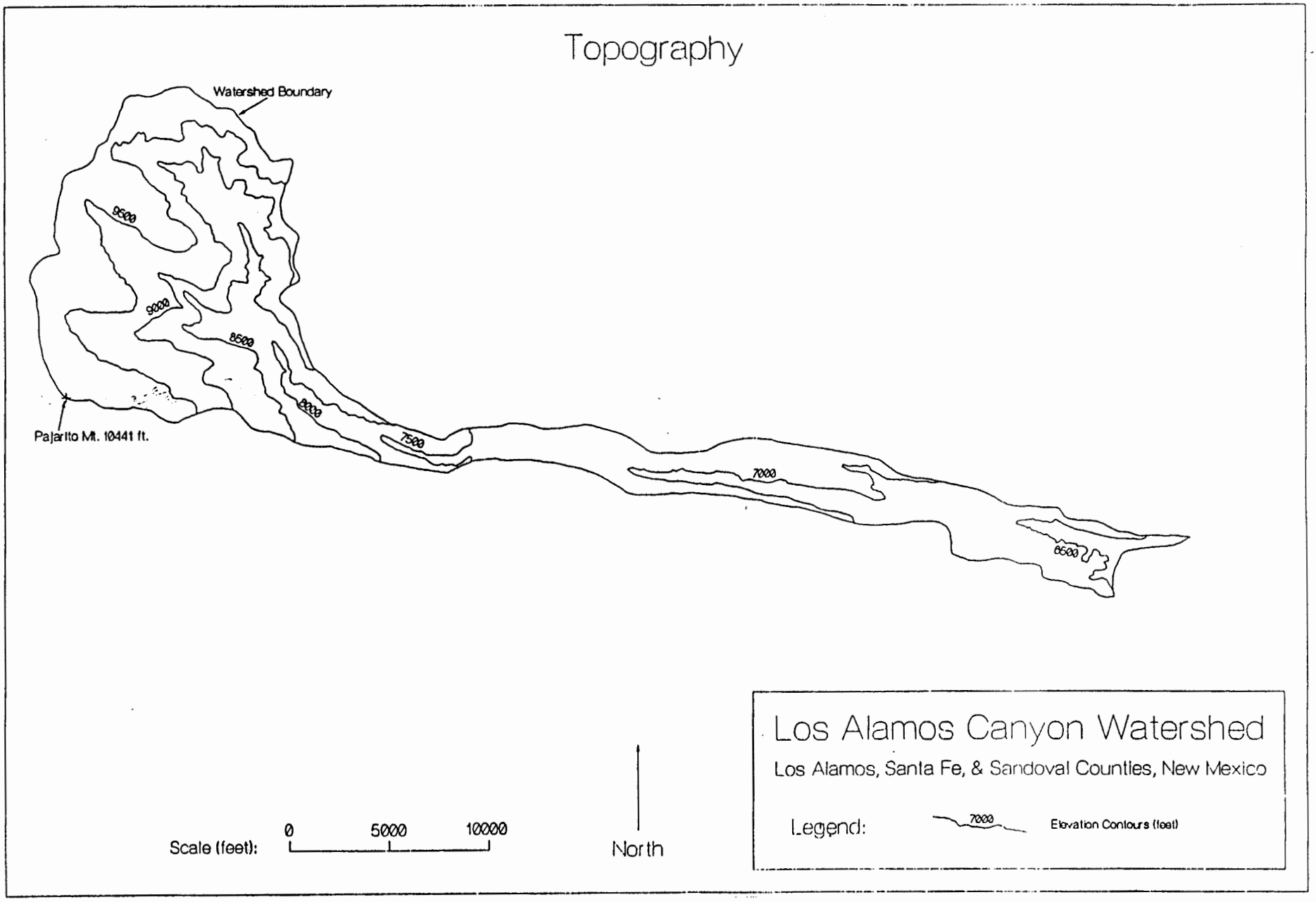

Topography
Watershed Boundary
9500
9000
8500
8000
7500
7000
6500
Pajarito Mt. 10441 ft.
Los Alamos Canyon Watershed
Los Alamos, Santa Fe, & Sandoval Counties, New Mexico
Legend:
7000
Elevation Contours (feet)
Scale (feet):
0
5000
10000
North

Figure 3

~300-400 feet in the middle and lower reaches. The channel gradient ranges from ~20% in the upper watershed to ~2% in the lower reach. The canyon is generally narrow, with a floor ranging from ~100 feet or less in width in the upper watershed to ~250 feet in width throughout most of the middle reach. In the lower 2 miles of the watershed, the floor widens to ~600-1000 feet.

Steep slopes are typical of the canyon walls, on the order of ~60-80% throughout most of the main drainage. The portions of the watershed that extend onto the adjacent mesa tops have slopes on the order of 1-2%. In the uppermost portion of the watershed, slopes on the order of 30-40% are typical.

Climate:

The Los Alamos area has a semi-arid, temperate, mountain climate with average normal monthly temperatures ranging from a low of ~20-40°F in January to a high of ~55-80°F in July. Normal monthly precipitation ranges from <1 inch in the winter months to nearly 4 inches in August. Normal monthly snowfall depths are on the order of 5-12 inches in the winter months, generally between November and March (Figure 4) (Bowen, 1990). Average annual snowfall totals ~50 inches. Mean annual precipitation totals 19.3 inches in the vicinity of LANL, but varies significantly with elevation, with lower totals toward the Rio Grande valley to the east and higher totals in the Sierra de Los Valles highlands to the west. Summer rains provide ~75% of the total annual precipitation (LANL Site Development Plan, 1990). Los Alamos area precipitation is characteristic of a semi-arid climate in that variations from year to year are large, with annual precipitation amounts ranging from 6.80 to 30.34 inches between 1910 and 1989. The rainfall pattern during the summer months is monsoonal, with 40% of the annual precipitation falling in July and August (Bowen, 1990).

Geology:

The Jemez Mountains and Pajarito Plateau are composed of various volcanic rocks ranging from basalt, andesite and rhyolite to lithified volcanic ash (ignimbrite), or tuff. The upper watershed area is characterized by outcrops of the Tschicoma Formation, a volcanic complex consisting of andesites, dacites, rhyodacites and quartz latites of middle Pliocene to late Miocene age (~3-7 million years B.P.). The middle and lower reaches of the watershed are characterized by outcrops of the

Fig. 4 (a)–(c). Los Alamos (elevation 7380 ft [2249 m]) normal weather (1950–1980). The figure shows normal (a) temperature, (b) precipitation, and (c) snowfall for each month.

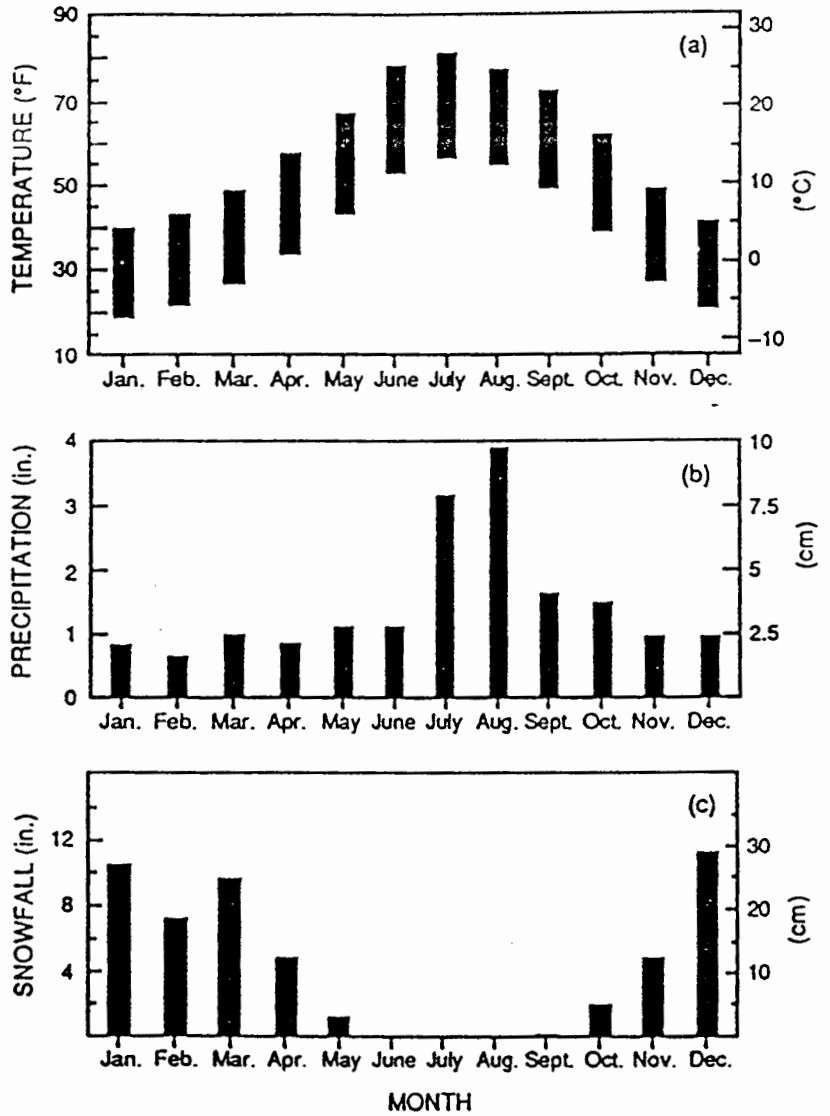


Figure 4: Normal Climatic Data

(Bowen, 1990)

Bandelier Tuff of Pleistocene age (~1.1-1.5 million years ago) which form the bulk of the Pajarito Plateau and are exposed in the walls of the canyon (Gardner, et al., 1986). The basic bedrock geology for the area is shown in Figure 5. Intermittent streamflow has deposited alluvium in the canyon consisting of sand, gravel, pebbles, cobbles and boulders derived from the Tschicoma Formation in the upper watershed and clay, silt, sand and gravel derived from the Bandelier Tuff in the lower watershed (Purtyman, 1995).

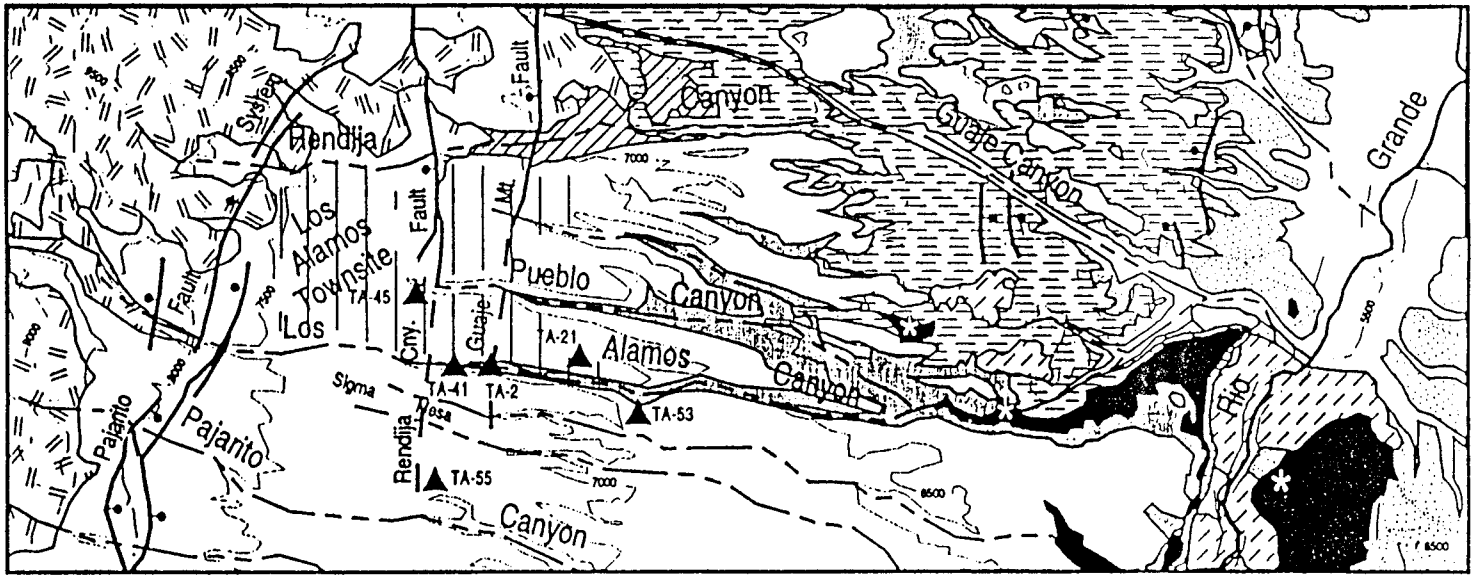
Numerous faults associated with the Pajarito Fault system cut across the canyon (Figure 6). These structural features may facilitate significant amounts of infiltration of precipitation and runoff over the course of the watershed drainage and may provide pathways for contaminant migration from surface and alluvial waters to lower aquifers,

Soils:

The soils in the watershed exhibit a large range of variability, depending on the parent material, landscape setting, and localized vegetation predominance. In the upper watershed, the parent materials are the andesites, dacites, rhyodacites and quartz latites of the Tschicoma Formation, while in the middle and lower reaches, soils are derived from weathered Bandelier Tuff.

An extensive soil survey of Los Alamos County was conducted by LANL and U.S. Forest Service scientists in the mid 1970's and encompassed about 90% of the Los Alamos Canyon watershed area (Nyhan, et al., 1978). Nyhan et al. mapped the soil areas on aerial photographs. The area specific to the Los Alamos Canyon watershed area was digitized by the author using computer aided design (CAD) software (FASTCAD™, Evolution Computing, Inc.) (Figure 7). A listing of soil types and descriptions specific to the watershed was also compiled and is provided in Table 1.

Nyhan et al. also determined soil erodibility factors (K), soil loss tolerance values (T), and Soil Conservation Service (SCS) hydrologic soil groups for selected soil series occurring within the county. The K factor is a unitless constant utilized in the universal soil loss equation. Its determination is based on the texture, structure, permeability, and organic matter content of a soil. K values range between 0.02 and 0.69, with greater values for more readily erodible soils (Nyhan, et al., 1978). T values represent the maximum annual soil loss rate by erosion that can be sustained without adversely impacting the soil's productivity or integrity (Brooks, et al., 1991).



Modified from Smith et al., 1970

Quaternary
- Landslide Deposits
- Alluvium
- Tshirege Member, Bandelier Tuff
- Otowi Member, Bandelier Tuff

Pliocene
- Puye Formation

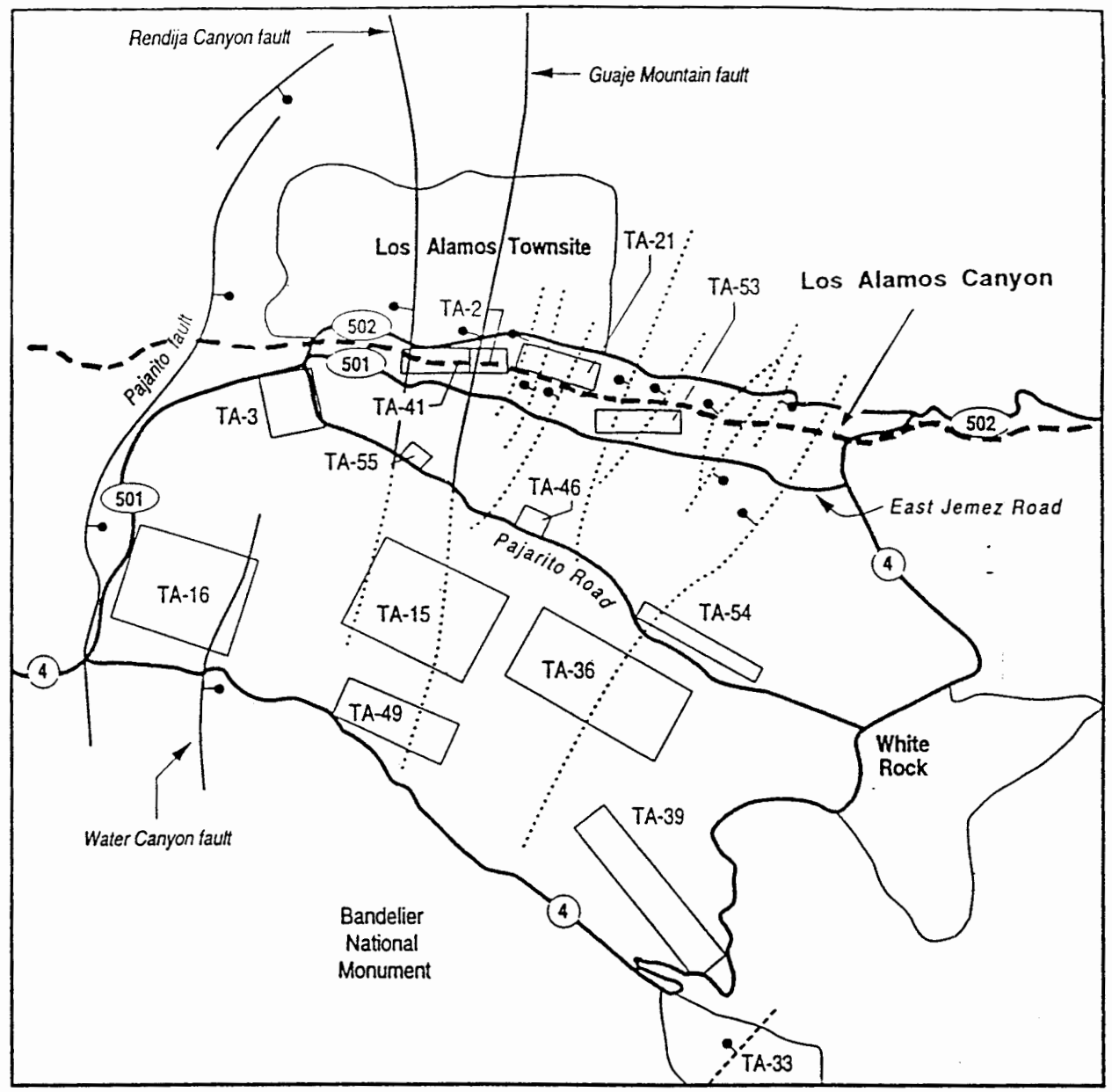
Miocene
- Santa Fe Group

- Cerro Toledo Rhyolite
- Basalts of Cerros del Rio
- Tschicoma Formation

1 0 1 2 3 4
MILES

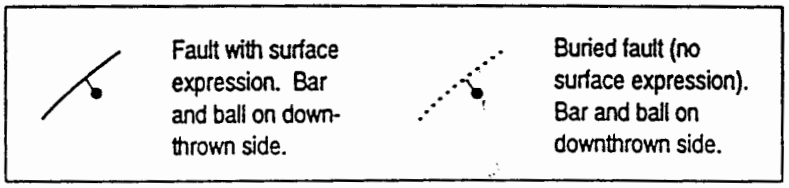
- Contact
- Fault, dashed where inferred
- Volanic Vent
- Technical Area

Figure 5: Bedrock Geology



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

F 3-14 / LA&P WP / 110295



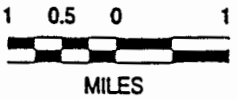


Figure 6: Locations of Major Faults

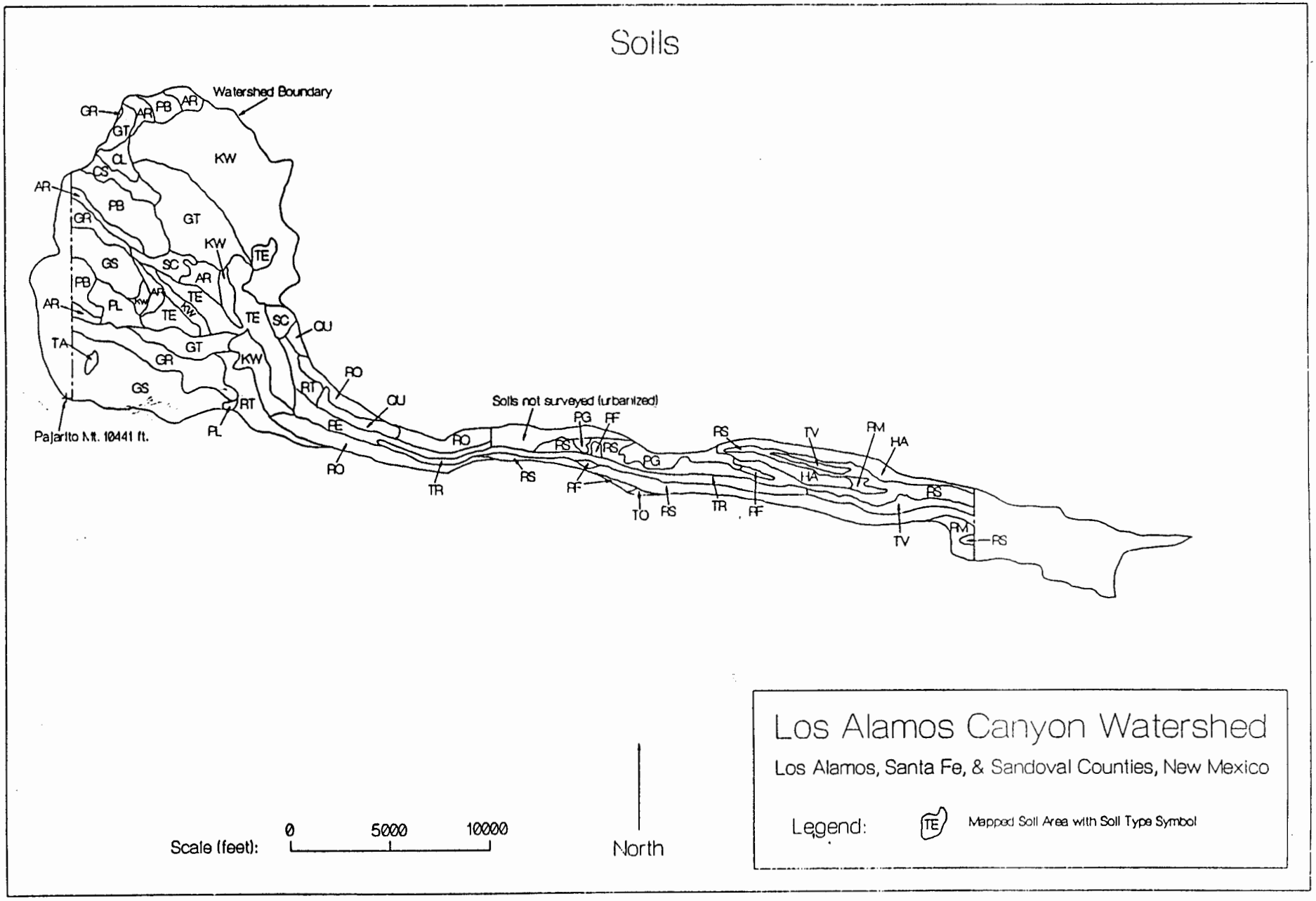

Soils
Watershed Boundary
Pajarito Mt. 10441 ft.
Soils not surveyed (urbanized)
Los Alamos Canyon Watershed
Los Alamos, Santa Fe, & Sandoval Counties, New Mexico
Legend:
Mapped Soil Area with Soil Type Symbol
Scale (feet):
0
5000
10000
North
GR
AR
PB
GT
CL
CS
KW
GS
SC
TE
PL
TA
RT
RO
OU
PE
TR
PG
PF
FS
TO
TV
PM
HA

Figure 7

Table 1: Los Alamos Canyon Watershed Soil Types

Symbol Code	Soil Type Name	Description	Notes
AR	Armstead Loam	Deep, well-drained soils formed from weathered Tschicoma Fmtn. on level to mod. sloping mt. sideslopes; Veg.: Douglas fir, ponderosa pine.	Slow to mod. permeability; mod. avail. water capacity; mod. erodibility; low erosion hazard rating.
CL/CS	Cuervo Gravelly Loam	Mod. deep soils formed on mt. sideslopes from weathered tuff.; CL=0-15% slopes; CS=16-40% slopes; Veg.: Engelmann spruce, Douglas fir.	Mod. to mod. rapid permeability; v. low avail. water capacity; mod. erodibility; low erosion hazard rating.
GR/GS/GT	Griegos Cobbly Loam/Griegos Rock Outcrop Complex	Deep, well-drained soils formed from weathered Tschicoma Fmtn. on mt. slopes; GR=16-40% slopes; GS=41-80% slopes; GT~70% rock outcrops; Veg.: Engelmann spruce, Douglas fir.	Mod. to mod. rapid permeability; mod. avail. water capacity; mod. erodibility; GR=mod. erosion hazard rating; GS/GT=high erosion hazard rating.
HA/HR	Hackroy sandy loam/ Hackroy Rock Outcrop Complex	Very shallow to shallow, well-drained soils formed from weathered tuff on mesa-tops; Veg.: piñon pine, juniper, scattered ponderosa pine, blue grama. HR~70% rock outcrops.	Slow permeability, low avail. water capacity, HA=mod. erosion hazard rating; HR= mod. to severe erosion hazard rating.
KW	Kwage-Pelado Rock Outcrop Complex (sandy loam/loamy sand)	Deep, well-drained soils formed on very steep mt. slopes from weathered Tschicoma Formation; Veg.: Douglas fir, ponderosa pine.	Mod. to v. rapid permeability; low avail. water capacity; mod. erodibility; mod. erosion hazard rating.
NJ	Nyjack Series (loam/ sandy loam/ v. fine sandy loam)	Mod. deep, well-drained soils formed from weathered tuff on nearly level to gently sloping mesa-tops; incl. ~20% rock outcrops; Veg.: piñon, juniper, blue grama.	Mod. permeability; mod. avail. water capacity; slow runoff; slight erosion hazard rating.
PG	Pogna Fine Sandy Loam	Shallow, well-drained soils formed from weathered tuff on gently to strongly sloping mesa tops; Veg.: ponderosa pine, mountain mahogany, Kentucky bluegrass.	Low permeability; mod. avail. water capacity; mod. rapid runoff; mod. erosion hazard rating.
QU	Quemazon-Arriba Rock Outcrop Complex (very stony sandy loam)	Shallow (Quemazon series) to deep (Arriba series), well-drained soils formed from weathered tuff on level to very steep mesa tops; Veg.: ponderosa pine.	Mod. rapid permeability; very low available water capacity; moderate erodibility; low erosion hazard rating.
RE	Rock Outcrop: Pines-Tentrock Complex (gravelly, cobbly sandy loam)	Deep (Pines series) to mod. deep (Tentrock series), well-drained soils formed from weathered welded tuff on very steep to extremely steep (41-80%) mt. sideslopes; ~20% rock outcrops; Veg.: ponderosa pine.	Mod. slow (Pines series) to mod. rapid (Tentrock series) permeability; Mod. (Pines series) to very low (Tentrock series) available water capacity.
RF	Rock Outcrop, Frigid	Mod. sloping to steep (5-30% slope) mesa tops and edges with ~65% tuff outcrop; Veg.: Kentucky bluegrass, ponderosa pine, spruce, fir, and oak.	Mapping unit includes ~5% shallow, undeveloped soils on bedrock, ~5% Tocal soils, and ~25% narrow escarpments.

(Nyhan, et al, 1978)

Symbol Code	Soil Type Name	Description	Notes
RM	Rock Outcrop, Mesic	Mod. sloping to steep (5-30% slope) mesa tops and edges with ~65% tuff outcrop; Veg.: blue grama, piñon pine, one-seed juniper.	Mapping unit includes ~5% very shallow, undeveloped soils on bedrock, ~5% Hackroy soils, and ~25% narrow escarpments.
RO	Rock Outcrop- Colle-Painted Cave Complex (sandy /gravelly-sandy/ sandy-clay loam)	Mod. deep, well-drained soils formed from weathered welded tuff on very steep to extremely steep (41-80%) mt. sideslopes; Veg.: Douglas fir, ponderosa pine.	Colle soils have mod. rapid permeability; mod. available water capacity.
RS	Rock Outcrop, steep	Steep to very steep (>30% slope) mesa breaks and canyon walls; ~90% rock outcrop (Mainly tuff & some basalt); Veg.: ponderosa pine, spruce, fir.	Mapping unit includes very shallow, undeveloped soils on tuff, mesic rock outcrop and frigid outcrop (5-30% slope).
RT	Rabbit-Tsankawi Rock Outcrop Complex (stony-sandy/stoney-clay loam)	Mod. deep (Rabbit series) to very shallow (Tsankawi series) well-drained soils formed from weathered tuff on level to very steep mesa tops; Veg.: Douglas fir, ponderosa pine.	Rabbit soils have mod. rapid permeability; very low available water capacity; mod. erodibility; low erosion hazard rating.
SC	Santa Klara-Armstead Complex (very stoney/gravelly/ gravelly-silty-clay loam)	Mod. deep (Santa Klara series) to deep (Armstead series) well-drained soils formed from weathered Tschicoma Formation on mod. to very steep mt. sideslopes; Veg.: Douglas fir, ponderosa pine.	Mod. to mod. slow permeability; mod. available water capacity; mod. erodibility; mod. erosion hazard rating.
TE	Turkey-Cabra Rock Outcrop Complex (stoney/clay/ stoney-sandy-clay loam)	Very shallow (Turkey series) to deep (Cabra series) well-drained soils formed from weathered Tschicoma Fmtn. on very steep to extremely steep (41-80%) mt. sideslopes; Veg.: ponderosa pine.	Mod. to mod. slow permeability; very low available water capacity; mod. erodibility; high erosion hazard rating.
TO	Tocal Very Fine Sandy Loam	Very shallow to shallow soils formed from weathered tuff on gently to mod. sloping mesa tops; Veg.: ponderosa pine, mountain mahogany, Kentucky bluegrass.	Mod. slow permeability; low available water capacity; mod. runoff; mod. erosion hazard rating.
TR	Typic Ustorthents -Rock Outcrop Complex (stoney/gravelly-sandy loam)	Deep, well-drained soils formed from weathered welded tuff on very steep to extremely steep (41-80%) canyon sideslopes; Veg.: piñon-juniper woodland.	Mod. rapid to very rapid permeability; very low available water capacity.
TV	Totavi Gravelly Loamy Sand	Deep, well-drained soils formed from alluvium in canyon bottom; Veg.: blue grama, piñon pine, one-seed juniper, annual grasses and forbs.	Very rapid permeability; very slow runoff; low available water capacity; low erosion hazard rating.
PB	Pueblo Stoney Loam	Deep, well-drained soils formed from weathered welded tuff on mod. steep to very steep sideslopes; Veg.: Douglas fir, ponderosa pine.	Mod. permeability; mod. avail. water capacity; mod. runoff; mod. erosion hazard rating.
PL	Pelado Cobbly Loam	Deep, well-drained soils formed from weathered Tschicoma Formation on very steep to extremely steep (41-80%) mt. slopes; Veg.: Douglas fir, pond. pine.	Mod. to mod. slow permeability; high avail. water capacity; mod. erodibility; mod. erosion hazard rating.

(Nyhan, et al, 1978)

SCS hydrologic soil groups are used to estimate precipitation runoff and either indicate low runoff potential (group A; transmission rate >0.30 in/hr), moderately low runoff potential (group B; transmission rate = 0.15-0.30 in/hr), moderately high runoff potential (group C; transmission rate = 0.05-0.15 in/hr), or high runoff potential (group D; transmission rate <0.05 in/hr). Thus, group A soils exhibit the highest infiltration capacities while group D soils exhibit low infiltration capacities and high shrink-swell potentials (Nyhan, et al., 1978; McLin, 1992). These data specific to the watershed are provided in Table 2.

Table 2: Los Alamos Canyon Watershed Soil Properties

Soil Series	Texture	K	T (tons/acre/yr)	SCS Hydrologic Group
Hackroy	sandy loam	0.20	1	C
	v. fine sandy loam	0.28	1	
	clay loam	0.32		
Nyjack	sandy loam	0.20		
	v. fine sandy loam	0.28		
	clay loam	0.32		
	sandy loam/gravelly-sandy loam	0.20		
Pogna	fine sandy loam/sandy loam	0.24	1	C
Tocal	sandy loam	0.20	1	C
	v. fine sandy loam	0.28	1	
	clay loam	0.32		
	silt loam	0.28		
Totavi	gravelly, loamy sand	0.17	2	A

(Nyhan, et al., 1978)

Vegetation:

The Los Alamos Canyon watershed supports a rich and diverse collection of vegetation species. Five major vegetation community types are present within the ~4100 foot elevation gradient that exists in the watershed. These are the piñon-juniper, ponderosa pine, mixed conifer, spruce-fir, and subalpine grassland communities. The piñon-juniper community primarily occurs on the mesa tops bordering the canyon from the base of the watershed study area up to about 6,900 feet elevation. The ponderosa pine community exists at elevations between about 6,900 and 7,500 feet, and there is some commingling of these communities in the transitional elevations. The mixed conifer community lies between about 7,500 and 9,500 feet elevation and overlaps the ponderosa pine

community in the canyon bottom and on the north slope, but primarily occurs on high mesas extending into the upper mountain slopes of the Sierra de Los Valles. The subalpine grassland community is mixed with the spruce-fir community from about 9,500 elevation extending to the top of the watershed at about 10,400 feet (DOE, 1979). Aspen is also widely prevalent in many areas of the upper elevations of the watershed.

General vegetation distribution patterns were digitized using CAD software (FASTCAD™, Evolution Computing, Inc.) from USFS and LANL mapping. Aerial photography was used to delineate the grassland areas (Figure 8).

During the summers of 1993 and 1994 the Biological Resource Evaluations Team of the LANL Environmental Protection Group conducted baseline studies within the Los Alamos Canyon watershed to provide background and baseline information for ecological risk models (Foxx, 1995). In the canyon bottom, vegetation transects utilizing circular plots were placed in the upper, middle, and lower portions of the canyon to measure the overstory components of the forest, woodland, and riparian communities, while understory components were measured using Daubenmeier plots. Separate surveys using circular plots, belt transects, and Daubenmeier plots were conducted on the north and south facing slopes.

Twelve overstory species were identified in upper Los Alamos Canyon. In order of relative abundance (individual plant frequency), the tree species include aspen, white fir, Gambel oak, Engelmann spruce, limber pine, Rocky Mountain maple, willow, New Mexico locust, and Douglas fir. In terms of relative cover however, aspen and Douglas fir dominate the canyon bottom and riparian areas (30.6% and 19.1% respectively). The absolute tree cover on north-facing slopes in the upper canyon is ~73%, dominated by Douglas fir, white fir and Rocky Mountain maple (29.5%, 29.8%, and 6.3% relative cover respectively). On the south facing slopes, the absolute tree cover is ~35%, dominated by white fir, Douglas fir, and ponderosa pine (83.5%, 11.3%, and 1.6% relative cover respectively). Shrub species are dominated by cliffbush. A total of 28 understory species were identified in the upper canyon, dominated by cutleaf coneflower, wild strawberry, and James geranium (Foxx, 1995).

High elevation montane grasslands (*Festuca thuberi, Danthonia parryi*) occur in the uppermost portion of the watershed as broad breaks in the mixed conifer forests on the south facing

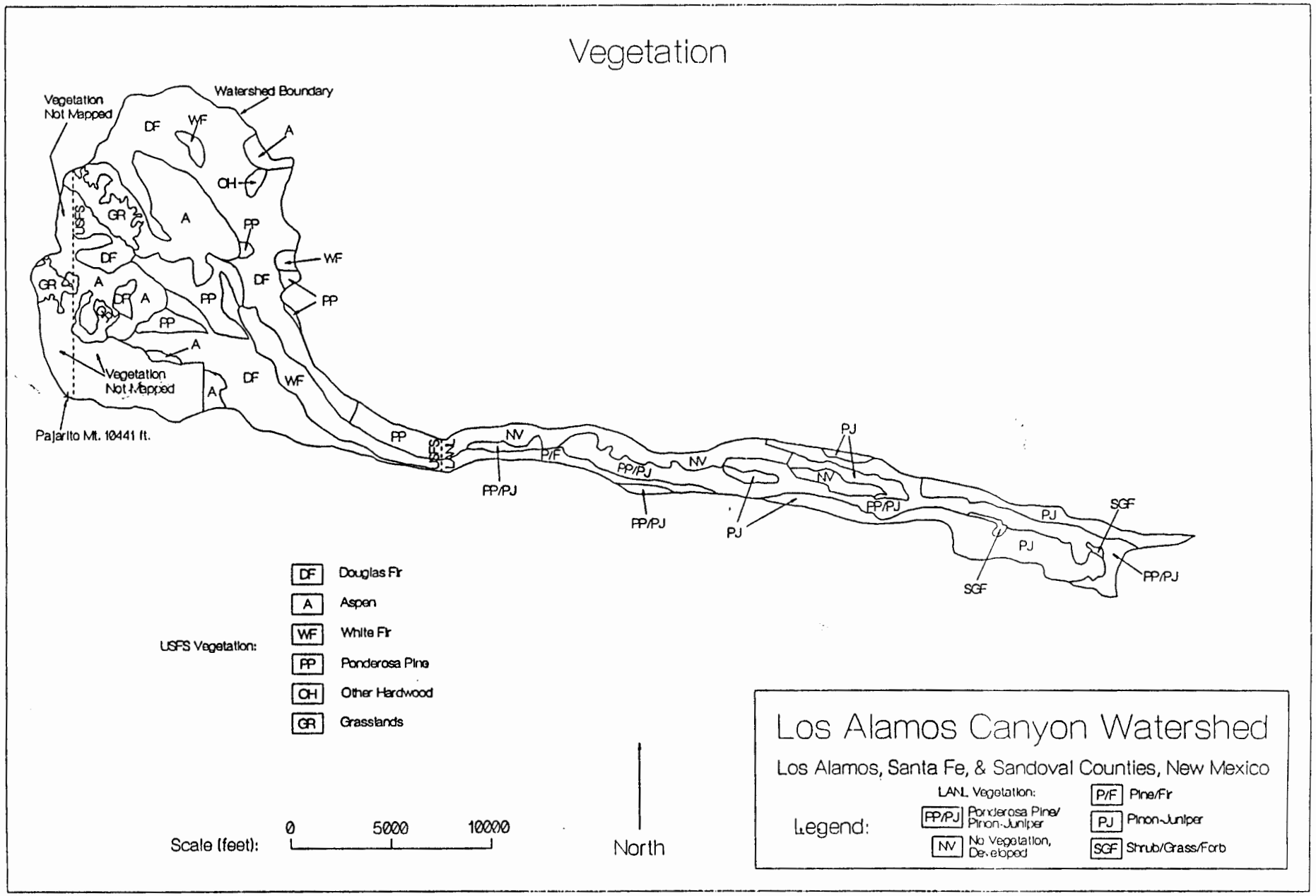

Vegetation
Vegetation Not Mapped
Watershed Boundary
DF
WF
A
OH
GR
PP
USFS
Vegetation Not Mapped
Pajarito Mt. 10441 ft.
NV
P/F
PP/PJ
PJ
SGF
USFS Vegetation:
DF Douglas Fir
A Aspen
WF White Fir
PP Ponderosa Pine
OH Other Hardwood
GR Grasslands
Scale (feet):
0
5000
10000
North
Los Alamos Canyon Watershed
Los Alamos, Santa Fe, & Sandoval Counties, New Mexico
Legend:
LANL Vegetation:
PP/PJ Ponderosa Pine/ Pinon-Juniper
NV No Vegetation, Developed
P/F Pine/Fir
PJ Pinon-Juniper
SGF Shrub/Grass/Forb

Figure 8

slopes. These grasslands exhibit tremendous vigor and constitute a virtually 100% ground cover where present. Well-developed Mollisols with an average A horizon depth of 31 cm indicate that these grasslands have existed for thousands of years (Allen, 1989). One large meadow in the Cañada Bonito area covers an area measured in excess of 123 acres. These grasslands, along with similar occurrences in other nearby upper watersheds of the Sierra de Los Valles, are the most productive grasslands in the state of New Mexico (Craig Allen, personal communication, 1996). The north facing slopes of Pajarito Peak accommodate a variety of exotic grass species planted on the runs of the Pajarito Mountain Ski area. Generally abundant natural moisture supports dense stands of non-native grass with an average cover percentage estimated at ~90% from personal observation.

In the middle reach of the watershed, 13 overstory and 34 understory species were identified. In the canyon bottom, Engelmann spruce and Douglas fir had the highest overstory relative cover values (24.1% and 22.2% respectively) while Douglas fir, white fir, and thin leaf alder had the highest relative frequency (23.1% each). The absolute tree cover on north-facing slopes in the middle canyon is ~68%, dominated by Douglas fir, Gambel oak, and ponderosa pine (50.3%, 13.0%, and 4.5% relative cover respectively). On the south facing slopes, the absolute tree cover is ~41%, dominated by ponderosa pine, oak (*Quercus spp*), and piñon pine (55.5%, 33.2%, and 10.7% relative cover respectively). Gambel oak, cliffbush, and chokecherry are the dominant shrub species while redtop and raspberry are the dominant understory species. Grass species present are muttongrass, bromegrass, and little bluestem (Foxx, 1995).

In lower Los Alamos Canyon 17 overstory and 16 understory species were identified. In the canyon bottom, Gambel oak and water birch had the highest overstory relative cover values (27.5% and 26.7% respectively) while one-seed juniper, and ponderosa pine had the highest relative frequency (23.1% each). The absolute tree cover on north-facing slopes in the lower canyon is ~41%, dominated by ponderosa pine, oak (*Quercus spp*), and piñon pine (55.5%, 33.2%, and 10.7% relative cover respectively). On the south facing slopes, the absolute tree cover is ~22%, dominated by ponderosa pine, piñon pine, and one-seed juniper (65.4%, 24.2%, and 10.4% relative cover respectively). Willow is the dominant shrub species while redtop and smooth brome are the dominant understory species (Foxx, 1995). A complete listing of identified watershed vegetation species is provided in Table A-1 (Appendix A).

Hydrology:

Perennial streamflow only occurs in the upper watershed above Los Alamos Reservoir (Figure 2). Below the reservoir dam, streamflow is intermittent and ephemeral and only occurs during spring snowmelt and during periods of heavy rainfall. During dry periods and when winter precipitation is maintained in a frozen state as snowpack, the streambed dries up completely. Flow from spring snowmelt only occasionally extends to the confluence with the Rio Grande (approximately 4 miles east of the study area). Between 1975 and 1986, snowmelt runoff reached the Rio Grande a total of 205 days during only 5 of those years, averaging 41 days per year but only 4.7% of the days in the total 12-year period (LANL, 1995).

Los Alamos Reservoir has a surface area of approximately 2.5 acres and has a maximum depth of approximately 25 to 30 feet, holding an estimated water volume of approximately 41 acre-feet (LANL, 1987). The reservoir provided part of the LANL water supply through the late 1950's, but since then the only water usage has been approximately 5 million gal/yr for irrigating the high school football field during the summer months. No data on sedimentation within the reservoir have been collected, although it is somewhat silted (personal communication, Dave Sneesby, LANL Utilities and Infrastructure group).

The alluvium in the canyon bottom varies from a few feet to approximately 25 feet in thickness (LANL Environmental Protection Group, 1992). Infiltration of surface water creates a variably saturated zone in the alluvium that is highly sensitive to varying recharge, with observed saturation levels known to fluctuate up to about 10 feet on a seasonal basis. The highest saturation levels occur during the spring snowmelt when active streamflow occurs. During dry periods, the alluvium dries out completely in about the lower third of the watershed study area.

There is a local, intermediate perched aquifer in the Guaje Pumice bed at the base of the Bandelier Tuff, occurring at about 300 feet depth beneath the canyon floor. The zone of saturation is at least about 5 to 22 feet or more thick and may extend into the underlying Puye Formation fanglomerate (LANL, 1995). Chemical data suggests a direct connection between the alluvial aquifer and the intermediate perched aquifer (Broxten, et al., 1995). The perched aquifers in the alluvium and Guaje Pumice bed are minor in volume and localized in extent and are currently not utilized for water supply.

The water supply for both LANL and the community of Los Alamos comes from the so-called "main aquifer" which occurs within the sediments of the Miocene to early Pliocene Santa Fe Group about 800 feet beneath the canyon floor. Figure 9 shows the piezometric surface of the main aquifer mapped from deep well data.

Water Budget:

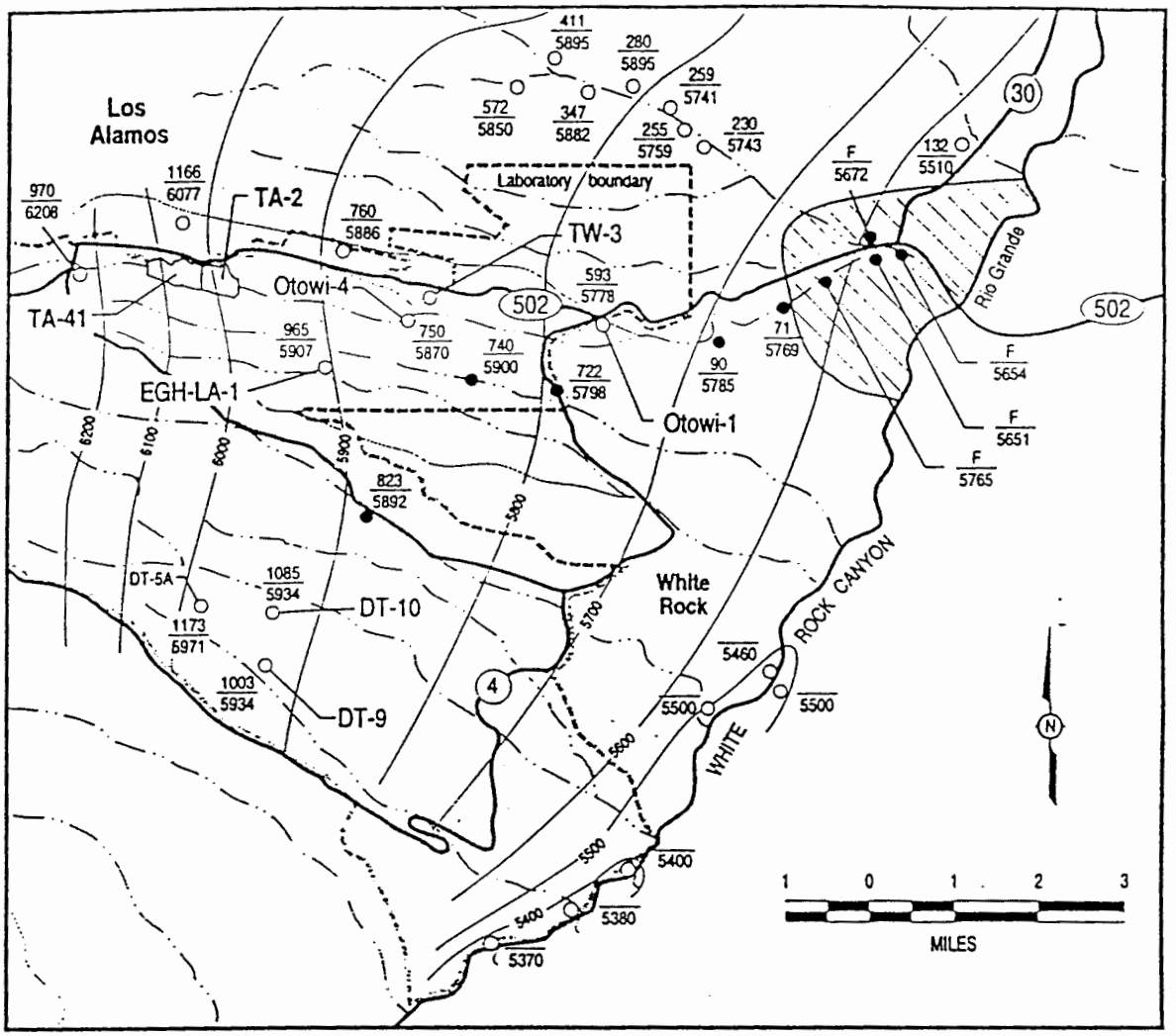
A water budget was prepared for the watershed covering the 1993, 1994, and 1995 water years (October 1-September 30). The conceptual model that was employed to evaluate the water budget is the basic hydrologic equation (mod. after Viessman, Jr., et al., 1989):

$$P - R - I - ET = \Delta S \qquad (1)$$

where P = precipitation, R = runoff, I = infiltration, ET = evapotranspiration, and ΔS = change in storage. For this evaluation it was assumed that $\Delta S = 0$. Data was available to assess the P, R, and ET parameters and I was thus determined as the residual from equation 1.

Data from 5 precipitation measurement stations and 1 streamflow gage were utilized in the water budget calculations (Figure 10). The TA-6, TA-53, TA-74 and North Community stations are operated by the LANL meteorology group while the Quemazon station is operated by the U.S. Department of Agriculture, Bureau of Natural Resources Conservation. There are 3 streamflow gages located in the watershed previously operated by the U.S. Geological Survey (USGS), but currently operated by the LANL Environmental Surveillance group since mid-1995. The upper two stations were put into place just shortly before the 1995 water year began, and thus previous years' data are only available for the lower station. For the purpose of determining the volume of runoff which leaves the watershed study area as streamflow, data from only the lower streamflow gage is necessary. The upper gages provide information relevant to determining varying streamflow character along the channel course within the watershed.

At the TA-6 station, data is also collected on latent heat energy loss. This data is obtained through application of the eddy correlation method which is a standard method employed in micrometeorology (personal communication, Greg Stone, LANL meteorology group). Fluctuations



Source: Purtymun and Johanson 1974, 11835

F 3-16 / LA&P WP / 110295

- ● Well completed into aquifer under artesian pressure
- ○ Depth to water (ft); F, flowing / Altitude of water surface (ft) (well completed into aquifer under water table or near water table conditions)
- Spring — Altitude of water surface (ft)
- 5600 — Water-level contour on aquifer under water table or near water table conditions; in feet above mean sea level; contour interval approximately 100 ft
- ▭ Area of deep wells completed in aquifer under artesian pressures

Figure 9: Main Aquifer Piezometric Surface

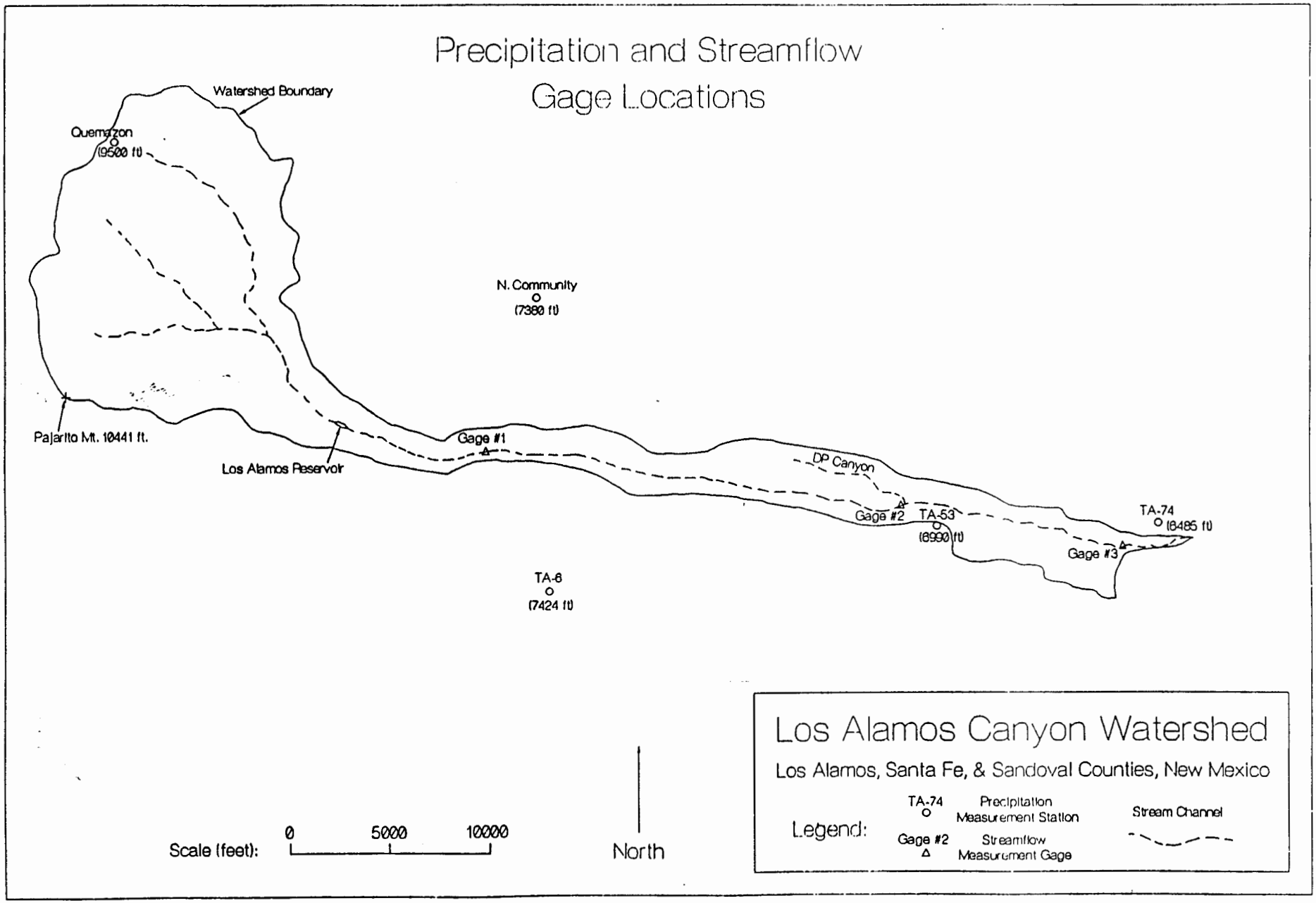

Precipitation and Streamflow
Gage Locations
Watershed Boundary
Quemazon
(9500 ft)
N. Community
(7380 ft)
Pajarito Mt. 10441 ft.
Los Alamos Reservoir
Gage #1
DP Canyon
Gage #2
TA-53
(6990 ft)
TA-74
(6485 ft)
Gage #3
TA-6
(7424 ft)
Los Alamos Canyon Watershed
Los Alamos, Santa Fe, & Sandoval Counties, New Mexico
Legend:
TA-74
Precipitation Measurement Station
Gage #2
Streamflow Measurement Gage
Stream Channel
Scale (feet):
0
5000
10000
North

Figure 10

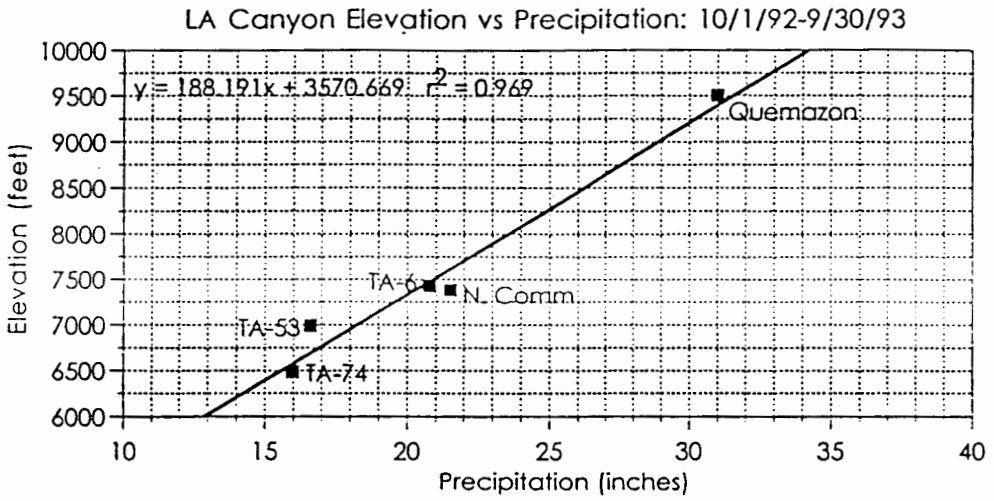
in the vertical direction in wind velocity and absolute humidity are measured and a covariance is performed on the two signals at an amplitude of 2 Hz. The resulting data is reported in units of Mega Joules per square meter. ET amounts can be determined by dividing by the latent heat of evaporation, yielding units of length. The following conversion factor was determined to transform the latent heat energy data to mm of ET, which was then converted to inches to conform with the precipitation data:

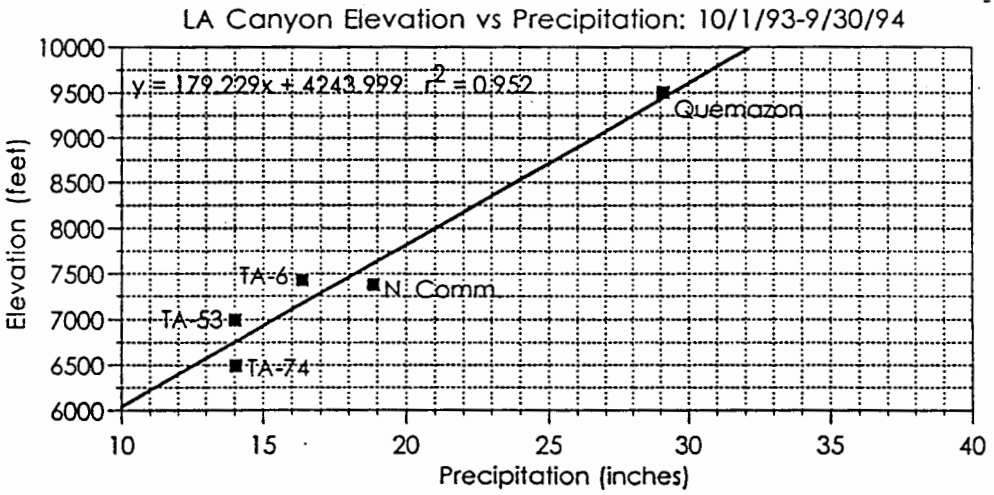
$$\frac{1\,MJ}{m^2} \Rightarrow \frac{\left(\frac{238,845.9\,cal}{m^2}\right)}{\left(\frac{581.6\,cal}{10^{-6}\,m^3}\right)} = 4.1\times10^{-4}\,m\left(\frac{1000\,mm}{m}\right) = 0.41\,mm\,ET \qquad (2)$$

Testing of the wind velocity meter by the LANL meteorology group indicated that the propeller was not fast enough to accurately sense all the fluctuations and that the instrument was underestimating moisture flux by ~10%, so the ET amounts determined from equation 2 were increased by this amount.

Because of the large variation in elevation within the watershed, the distribution of precipitation is highly dependent on elevation. Regression analyses were thus performed on the annual precipitation amounts for each station plotted by station elevation to extrapolate the precipitation data to intervening elevations not representative of the limited data available (Figure 11). Extrapolated annual precipitation depths were then determined for the midpoint values between the elevation contours shown in Figure 3, the exception being for the highest topographic interval. Elevations greater than the 9500 feet elevation of the uppermost measurement station were assigned the same precipitation depth as was measured at that station. The areas between the elevation contours were determined through the use of the CAD software (FASTCAD™, Evolution Computing, Inc.) used to digitize the elevation data.

The ET data were compiled from the TA-6 station data and compared to the precipitation data from that site (Figure 12). As can be seen, the relation between ET and precipitation varies considerably on a seasonal basis. ET amounts vary fairly regularly on an annual cycle, but precipitation variation is more erratic. ET:precipitation ratio percentages were determined on a monthly and annual basis. These data are provided in Table 3. As can be seen, though the ratios also


LA Canyon Elevation vs Precipitation: 10/1/92-9/30/93
y = 188.191x + 3570.669; r2 = 0.969
Quemazon
TA-6
N. Comm
TA-53
TA-74
Elevation (feet)
Precipitation (inches)


LA Canyon Elevation vs Precipitation: 10/1/93-9/30/94
y = 179.229x + 4243.999; r2 = 0.952
Quemazon
TA-6
N. Comm
TA-53
TA-74
Elevation (feet)
Precipitation (inches)

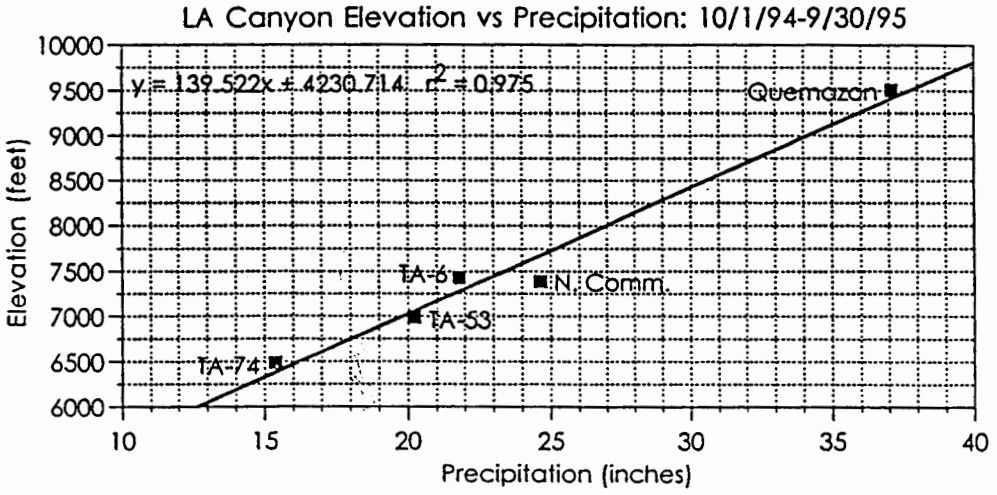

LA Canyon Elevation vs Precipitation: 10/1/94-9/30/95
y = 139.522x + 4230.714; r2 = 0.975
Quemazon
TA-6
N. Comm
TA-53
TA-74
Elevation (feet)
Precipitation (inches)

Figure 11

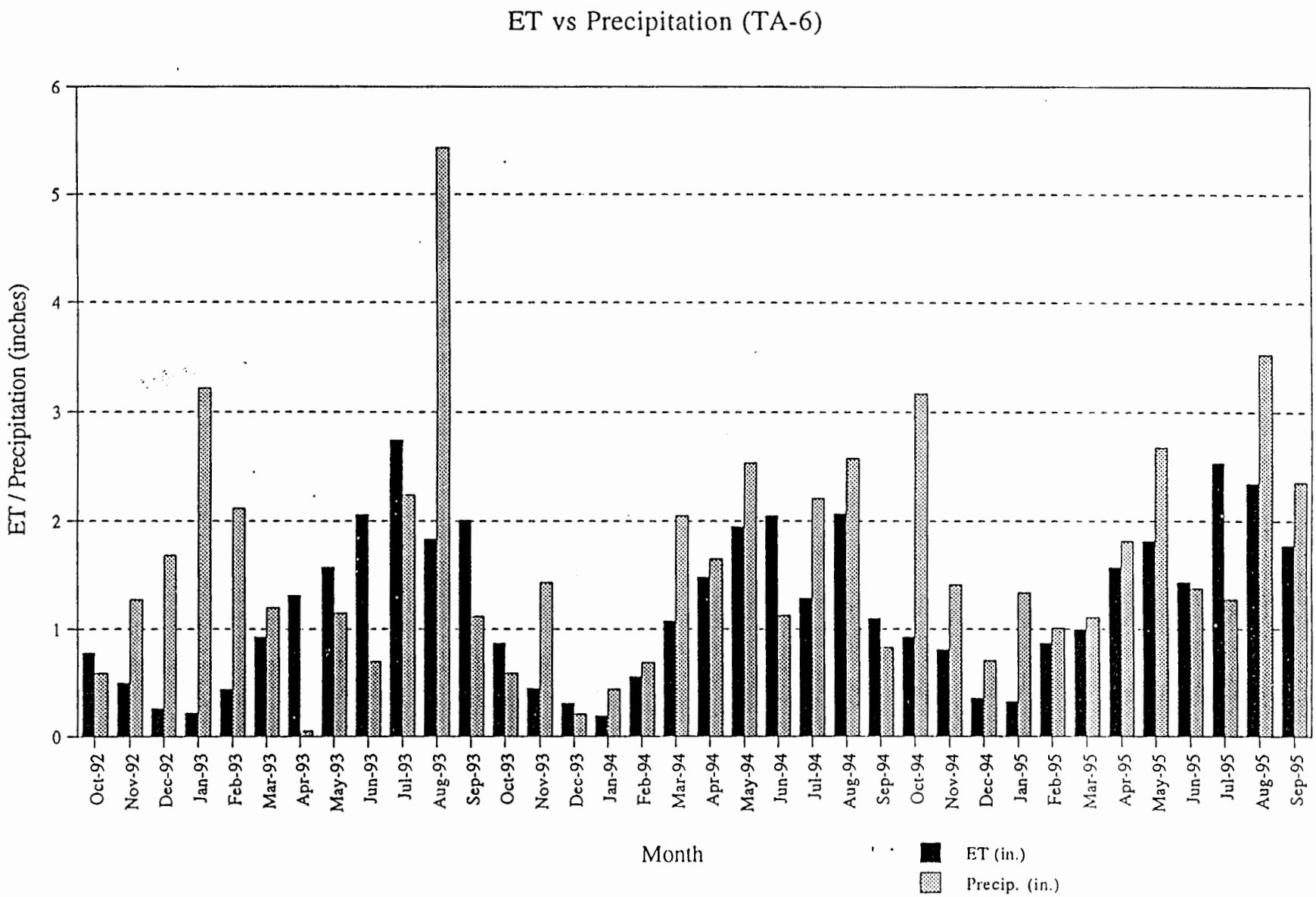

ET vs Precipitation (TA-6)
ET / Precipitation (inches)
0
1
2
3
4
5
6
Oct-92
Nov-92
Dec-92
Jan-93
Feb-93
Mar-93
Apr-93
May-93
Jun-93
Jul-93
Aug-93
Sep-93
Oct-93
Nov-93
Dec-93
Jan-94
Feb-94
Mar-94
Apr-94
May-94
Jun-94
Jul-94
Aug-94
Sep-94
Oct-94
Nov-94
Dec-94
Jan-95
Feb-95
Mar-95
Apr-95
May-95
Jun-95
Jul-95
Aug-95
Sep-95
Month
ET (in.)
Precip. (in.)

Figure 12

varied considerably from month to month, the annual average ratios determined by water year are much less irregular. These annual percentages were then utilized to estimate varying ET throughout the watershed from the extrapolated precipitation data.

Table 3: TA-6 ET vs Precipitation

Month	ET (in.)	Precip. (in.)	ET % of Precip.	Month	ET (in.)	Precip. (in.)	ET % of Precip.	Month	ET (in.)	Precip. (in.)	ET % of Precip.
Oct-92	0.78	0.59	132.7	Oct-93	0.87	0.59	147.9	Oct-94	0.93	3.17	29.4
Nov-92	0.50	1.28	39.1	Nov-93	0.45	1.44	31.6	Nov-94	0.81	1.42	57.2
Dec-92	0.26	1.69	15.4	Dec-93	0.32	0.21	150.9	Dec-94	0.37	0.71	51.7
Jan-93	0.22	3.22	6.8	Jan-94	0.19	0.44	42.8	Jan-95	0.34	1.34	25.2
Feb-93	0.45	2.12	21.1	Feb-94	0.56	0.69	81.7	Feb-95	0.88	1.01	87.0
Mar-93	0.93	1.20	77.7	Mar-94	1.09	2.05	53.1	Mar-95	1.01	1.11	90.9
Apr-93	1.33	0.05	2656.2	Apr-94	1.50	1.66	90.4	Apr-95	1.60	1.82	87.7
May-93	1.59	1.15	138.5	May-94	1.97	2.54	77.4	May-95	1.83	2.68	68.4
Jun-93	2.08	0.70	296.7	Jun-94	2.06	1.13	182.7	Jun-95	1.45	1.38	104.8
Jul-93	2.77	2.24	123.7	Jul-94	1.30	2.21	59.0	Jul-95	2.56	1.28	200.2
Aug-93	1.86	5.43	34.2	Aug-94	2.09	2.58	80.8	Aug-95	2.37	3.53	67.1
Sep-93	2.03	1.12	180.9	Sep-94	1.10	0.83	133.1	Sep-95	1.79	2.36	75.8
Totals:	14.80	20.79	71.17	Totals:	13.51	16.37	82.54	Totals:	15.93	21.81	73.06

The water budget was calculated in a spreadsheet using Microsoft Excel™. The extrapolated precipitation depths for each subarea were multiplied by the ET/precipitation fractions to determine ET amounts per subarea, from which remaining excess precipitation depths were determined. Excess precipitation volumes were then calculated by multiplying these depths by the measured areas between elevation contours, and the volumes were summed by water year. Streamflow discharge data from the lower measurement gage were compiled from USGS and LANL records and annual total discharge volumes were determined by water year. The annual discharge volumes were then subtracted from the annual excess precipitation volumes to determine calculated annual infiltration. The spreadsheet calculations and water balance summaries are provided in Table 4.

As can be seen, by far the major water output pathway for the watershed is through evapotranspiration, which varied between ~71% and ~83% of total precipitation over the 3-year period analyzed. The next largest pathway for water output is by infiltration, which varied between ~17% and ~26% of total precipitation. Very little water left the watershed as streamflow, as evidenced

Table 4: LA Canyon Water Budget

1993 Water Year (10/1/92-9/30/93):

Elevation (ft.) From	To	Avg.	Area (ft^2)	Extrapolated Precip. (in.)	ET/Precip fraction	ET (in.)	Excess Precip. (in.)	Excess Precip. (ft.)	Excess Precip. Volume (ft^3)
6300	6500	6400	6619154	15.0	0.7117	10.7	4.3	0.36	2385378
6500	7000	6750	39591346	16.8	0.7117	12.0	4.8	0.40	15979859
7000	7500	7250	42441134	19.5	0.7117	13.9	5.6	0.47	19883141
7500	8000	7750	12713578	22.1	0.7117	15.7	6.4	0.53	6750306
8000	8500	8250	23578636	25.0	0.7117	17.8	7.2	0.60	14161918
8500	9000	8750	39283348	27.5	0.7117	19.6	7.9	0.66	25954017
9000	9500	9250	52578984	30.1	0.7117	21.4	8.7	0.72	38022624
9500	>9500		65579616	31.0	0.7117	22.1	8.9	0.74	48842059
		Total:	282385796						

Total Excess Precipitation Volume (ft^3): 171979301
Total Lower Station Streamflow Discharge (ft^3): 18601920
Calculated Total Infiltration Volume (ft^3): 153377381

1993 Water Year Summary:	ft^3	acre-ft	inches	% of total precip.
Total Precipitation Volume:	596528966	13694.4	25.35	
Total ET Volume:	424549665	9746.3	18.04	71.17
Total Runoff Volume:	18601920	427.0	0.79	3.12
Total Infiltration Volume:	153377381	3521.1	6.52	25.71
Balance:	0.00	0.0	0.00	100.00

1994 Water Year (10/1/93-9/30/94):

Elevation (ft.) From	To	Avg.	Area (ft^2)	Extrapolated Precip. (in.)	ET/Precip fraction	ET (in.)	Excess Precip. (in.)	Excess Precip. (ft.)	Excess Precip. Volume (ft^3)
6300	6500	6400	6619154	12.0	0.8254	9.9	2.1	0.17	1155704
6500	7000	6750	39591346	14.0	0.8254	11.6	2.4	0.20	8064757
7000	7500	7250	42441134	16.7	0.8254	13.8	2.9	0.24	10312559
7500	8000	7750	12713578	19.5	0.8254	16.1	3.4	0.28	3607160
8000	8500	8250	23578636	22.3	0.8254	18.4	3.9	0.32	7650442
8500	9000	8750	39283348	25.2	0.8254	20.8	4.4	0.37	14403632
9000	9500	9250	52578984	28.0	0.8254	23.1	4.9	0.41	21420678
9500	>9500		65579616	29.1	0.8254	24.0	5.1	0.42	27766737
		Total:	282385796						

Total Excess Precipitation Volume (ft^3): 94381670
Total Lower Station Streamflow Discharge (ft^3): 133920
Calculated Total Infiltration Volume (ft^3): 94247750

1994 Water Year Summary:	ft^3	acre-ft	inches	% of total precip.
Total Precipitation Volume:	540559394	12409.5	22.97	
Total ET Volume:	446177724	10242.8	18.96	82.54
Total Runoff Volume:	133920	3.1	0.01	0.02
Total Infiltration Volume:	94247750	2163.6	4.01	17.44
Balance:	0.00	0.0	0.00	100.00

1995 Water Year (10/1/94-9/30/95):

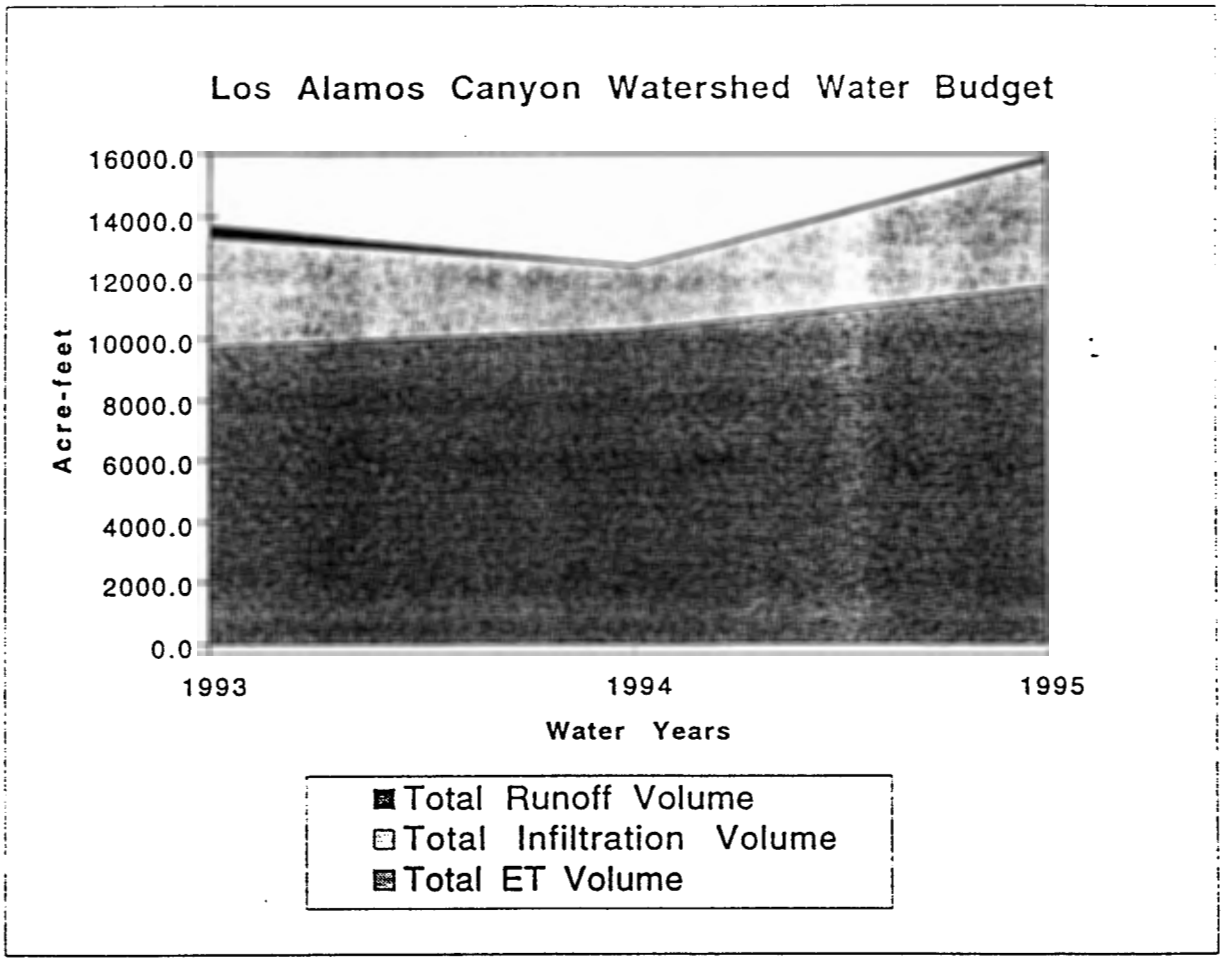
Elevation (ft.) From	To	Avg.	Area (ft^2)	Extrapolated Precip. (in.)	ET/Precip fraction	ET (in.)	Excess Precip. (in.)	Excess Precip. (ft.)	Excess Precip. Volume (ft^3)
6300	6500	6400	6619154	15.4	0.7306	11.3	4.1	0.35	2288440
6500	7000	6750	39591346	18.0	0.7306	13.2	4.8	0.40	15998863
7000	7500	7250	42441134	21.5	0.7306	15.7	5.8	0.48	20485274
7500	8000	7750	12713578	25.1	0.7306	18.3	6.8	0.56	7164038
8000	8500	8250	23578636	28.7	0.7306	21.0	7.7	0.64	15192069
8500	9000	8750	39283348	32.3	0.7306	23.6	8.7	0.73	28485731
9000	9500	9250	52578984	36.0	0.7306	26.3	9.7	0.81	42494335
9500	>9500		65579616	37.1	0.7306	27.1	10.0	0.83	54620934
		Total:	282385796						

Total Excess Precipitation Volume (ft^3): 186729684
Total Lower Station Streamflow Discharge (ft^3): 8984736
Calculated Total Infiltration Volume (ft^3): 177744948

1995 Water Year Summary:	ft^3	acre-ft	inches	% of total precip.
Total Precipitation Volume:	693131713	15912.1	29.45	
Total ET Volume:	506402030	11625.4	21.52	73.06
Total Runoff Volume:	8984736	206.3	0.38	1.30
Total Infiltration Volume:	177744948	4080.5	7.55	25.64
Balance:	0.00	0.0	0.00	100.00

by the proportionally small runoff volumes measured, ranging from <0.1% to ~3% of the total precipitation volume over the evaluated time period. These data are shown graphically in Figure 13.

Figure 13



Mean annual precipitation estimates for Los Alamos range from 17.8 inches (1911-1988) to 19.3 inches (Bowen, 1990; LANL Site Development Plan, 1990). Mean annual precipitation at the TA-6 station over the evaluated period is 19.7 inches while the annual totals ranged from 16.37 to 21.81 inches. Although the analyzed time period is limited to only 3 years, and though normal climatic fluctuations will certainly cause greater variations in the proportions determined, the calculated water budget for the watershed should represent a reasonable approximation of the range of parameter values for an average water year.

Social/Economic Components:

The main source of economic impact in the watershed area is the presence of the LANL facilities. The Laboratory directly or indirectly provides 38% of the jobs in the Northern New Mexico region. In 1984, The Lab's economic impact on the surrounding area was estimated to be at least $1.4 billion (LANL Site Development Plan, 1990).

A small portion of downtown Los Alamos is located within the watershed, and substantial commerce, though of unknown value, thus occurs there. Visual observation of this area suggests that this is primarily a commercial area, and thus does not have a permanent resident population. Also, a small portion of a residential neighborhood lies within the watershed boundary. About 150 homes in this neighborhood lie within the watershed, estimated from the USGS Guaje Mountain 7½' quadrangle topographic map. Assuming an average of 4 residents per home, there is an estimated population of about 600 persons thus residing within the watershed. During working hours, the temporary population of the watershed likely rises to a couple of thousand people.

RESOURCE EVALUATION:

The resources of value in the watershed are varied and many. The economic resources are substantial with several LANL facilities and part of downtown Los Alamos' commercial sector located there. Thus, an infrastructure likely valued in hundreds of millions of dollars exists in the watershed, though only occupying about 12% of its total area.

Natural resources are abundant within the watershed as well. These include surface water, groundwater, riparian habitat, soils, wildland resources such as forests, grasslands, and wildlife, and a generally high degree of biological richness and diversity in both the flora and fauna. The forested mountain slopes occupying the upper watershed offer recreational opportunities such as hiking and skiing. The entire watershed has high aesthetic values associated with a visually spectacular natural setting.

The following section evaluates the current status of these resources and attempts to identify the critical issues of concern with regard to maintaining the integrity of the resource base in the watershed.

Economic Resources:

A substantial economic infrastructure exists within the watershed including LANL research facilities and numerous commercial enterprises located in the downtown Los Alamos community. Other natural resources that might have economic value (such as timber, rock, sand and gravel, etc.) are intentionally unutilized because their exploitation would be incompatible with the current uses of the watershed. With 38% of the region's jobs related to LANL activities, the primary issue of concern relevant to the economic resource base in the watershed is maintaining the integrity and efficiency of LANL facility operations to insure continued stability of regional employment. Also, since part of the townsite area occurs within the watershed boundaries, as well as the Pajarito Mountain Ski Area in the upper watershed, maintaining an attractive environmental setting would be beneficial to promoting commercial prosperity in the community.

Water Resources:

Surface Water:

Surface water is present year-round only in the upper watershed above the Los Alamos Reservoir dam. Besides providing a small amount of irrigation water and the recreational and aesthetic values of the reservoir, a primary function of this dam is to provide flood protection for research facilities located downstream on the canyon floor. The dam impounds surface flow discharged from springs which supply perennial baseflow in the upper watershed (DOE, 1979).

The middle and lower reaches of the canyon support streamflow when the reservoir crests over the dam spillway. In most years, snowmelt released from the reservoir supports a low rate of nearly continuous surface flow in the canyon down to the vicinity of TA-2 (Figure 18) for a period of several weeks to months (LANL, 1995). Except during peak flows, streamflow in the middle and lower reaches of the canyon tends to be intermittent, generally decreasing downstream. Surface water use below the reservoir is limited to that utilized by wildlife or by riparian vegetation which access soil moisture derived from infiltrated snowmelt or rainfall. Lack of water in the stream is partly responsible for marginal riparian conditions in the lower watershed.

A composite stream hydrograph was plotted for the 1995 water year (Figure 14) with data from the three streamflow gages located in the canyon (Figure 10). The 1995 water year precipitation

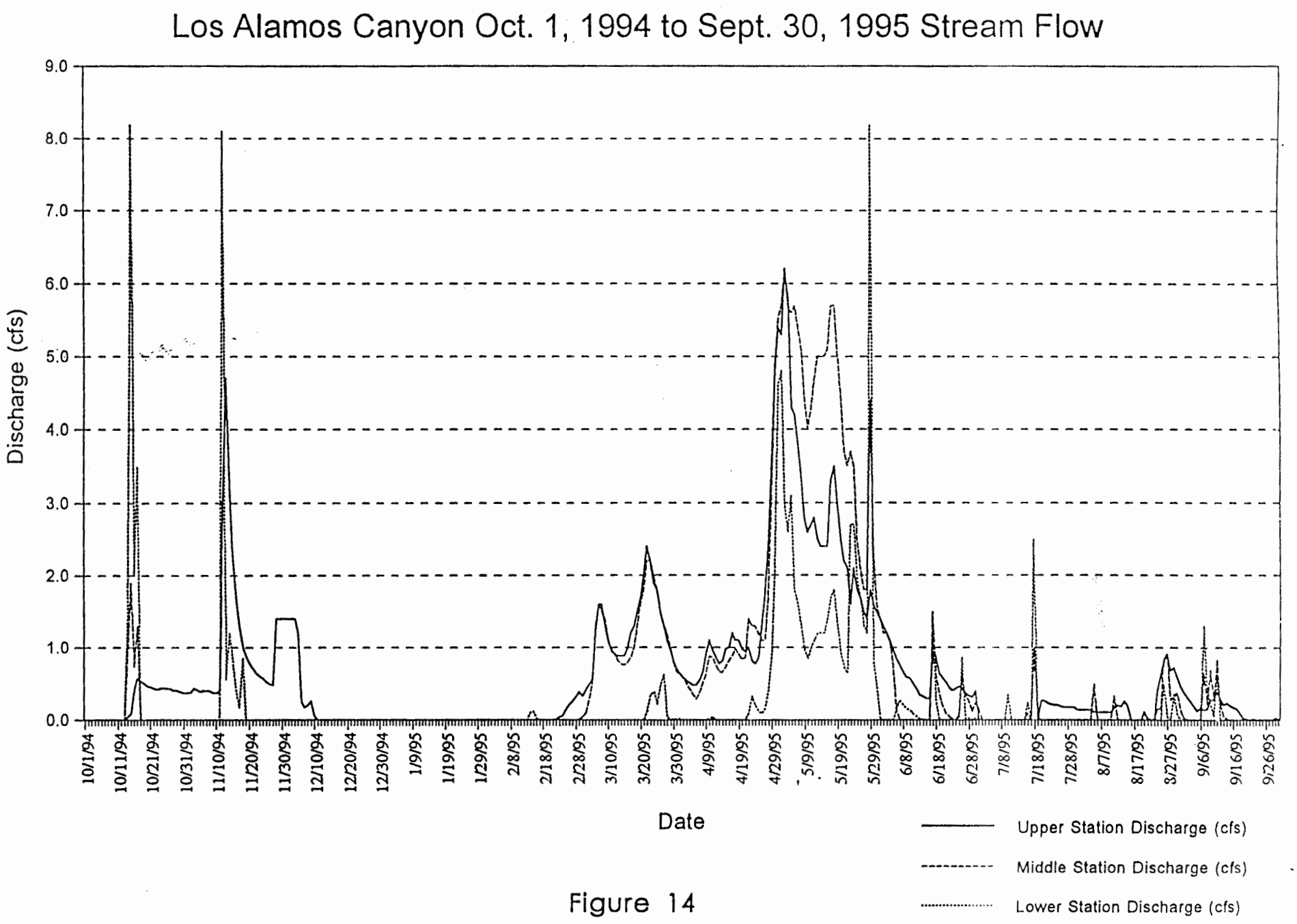

Los Alamos Canyon Oct. 1, 1994 to Sept. 30, 1995 Stream Flow
Discharge (cfs)
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
10/1/94
10/11/94
10/21/94
10/31/94
11/10/94
11/20/94
11/30/94
12/10/94
12/20/94
12/30/94
1/9/95
1/19/95
1/29/95
2/8/95
2/18/95
2/28/95
3/10/95
3/20/95
3/30/95
4/9/95
4/19/95
4/29/95
5/9/95
5/19/95
5/29/95
6/8/95
6/18/95
6/28/95
7/8/95
7/18/95
7/28/95
8/7/95
8/17/95
8/27/95
9/6/95
9/16/95
9/26/95
Date
Upper Station Discharge (cfs)
Middle Station Discharge (cfs)
Lower Station Discharge (cfs)

Figure 14

total (TA-6 station) was ~13% above average, so the streamflow conditions plotted are not representative of expected average conditions. The hydrograph shows the intermittent flow character in the canyon with the major flows occurring during the snowmelt period from late February through June. At other times, streamflow attributable to rainfall is minimal, except for a few short duration events. The stream behavior is generally the normal pattern of a losing stream, except during the snowmelt in May when the middle station flow exceeded the upper station, and during extreme precipitation events (e.g. Oct.-Nov., 1994) when the lower station recorded the highest flows. Apparently, the stream reach between the upper and middle gages shows gains from baseflow during snowmelt because of enhanced recharge. Wilcox, et al. (unpublished draft report), suggest that the cause for elevated responses to precipitation events in the lower gage data is enhanced runoff from nearby urban development in DP Canyon. During the 1995 water year, total discharge volume at the upper gage was 478.9 acre-feet, while discharge volumes at the middle and lower gages were 91.9% and 43.1% of the upper gage total respectively.

Available streamflow data prior to the 1995 water year is limited to the lower gage. During the 1994 water year, the precipitation total measured at TA-6 was 15.2% below normal and the lower gage recorded measurable flow on only 2 days (May 14th and May 25th), for a total discharge volume of only 3.1 acre-feet (USGS, 1995). It is thus apparent that a relatively small precipitation deficit can result in drastically reduced flow conditions in the lower canyon, negatively impacting aquatic biota and the riparian health of the watershed in this region.

The main issue of concern relative to the surface water resources in the watershed is thus lack of streamflow in the middle and lower reaches of the canyon which is at least partly a result of the impoundment of surface waters from the upper watershed in Los Alamos Reservoir.

Groundwater:

The extent of groundwater saturation in the alluvium varies with the availability of recharge from the streambed. During periods lacking active streamflow, saturation levels drop dramatically and have been observed to dry up completely in the lower canyon. The only identified usage of this groundwater is for sustenance of the vegetation growing on the canyon floor. Aside from this utilization by the native flora, none of the perched waters occurring in the alluvium or in the Guaje

Pumice bed are utilized as a source of water supply. The alluvial groundwater resource is thus primarily relevant to the implications of possible water quality impacts on the lower main aquifer or on possible downstream interceptors.

Soils and Erosion:

As previously described, a wide range of soil types exist in the watershed. Maintaining the soil resource base requires minimizing erosional processes in the watershed. Personal observations throughout the watershed area indicate that soil erosion is generally not a major concern except for the mass wasting processes that remain active on the steep canyon slopes and immediately adjacent mesa-tops. Mechanical disturbance of natural and/or stable soil conditions in most of the upper watershed (outside of the ski area) is minimal, aside from the few roads and trails (Figure 18). Also, because of usually abundant precipitation at the higher elevations typical of most recent years, generally dense ground cover prevails in most of the watershed. Areas of the watershed where active erosion occurs are in the canyon bottom and along the steep canyon slopes in the middle and lower watershed, and on the edges of the mesa-tops bounding the lower watershed where a piñon-juniper woodland community dominates and soil conditions were observed to be poor.

The mesa-top areas adjacent to the canyon walls in the lower watershed are clearly susceptible to sheet erosion, and this process has stripped much of the soil there to bedrock. The canyon walls and colluvium slopes are areas of currently active erosion as evidenced by debris lobes below shallow canyon-wall channels observed during summer thunderstorms (Reneau, et al., 1996). Recent research determined ^{14}C ages of ≤ 3 ka for buried soils in a colluvial apron at the base of a steep north-facing slope in Los Alamos Canyon (Longmire, et al., in press). Active erosion and sediment transport are demonstrated in DP Canyon, a tributary to Los Alamos Canyon located within the watershed (Figure 2). Local deposition of up to 6 feet of sediment there since 1943 has been documented followed by renewed channel incision which has partially excavated these sediments (Reneau, 1995).

In the canyon bottom, active erosional processes generally associated with intense summer thunderstorm events cause remobilization of the alluvial sediments, gradually transporting them further downstream on the canyon floor. Burial of the bases of young trees by up to a foot or more of post-1943 sediments is commonly observed in many of the canyons in the Pajarito Plateau,

including Los Alamos Canyon. Erosion of these deposits is likely from lateral stream cutting during flood conditions (LANL, 1995). Reneau, et al., (1996) document aggradation rates of 0.5 to >1.5 mm/yr during the Holocene in some canyons. Other canyons show repeated episodes of alternating aggradation, stability, and incision. They suggest that climatic change since the early Holocene triggered accelerated erosion rates and increased sediment supplies to the drainage channels and basins of the Plateau. Other possible causes of locally varying channel stability are increased sedimentation from adjacent urbanized areas leading to aggradation, and increased flood peaks due to increased runoff from impermeable surfaces, leading to incision (Reneau, et al., 1996).

The major issue of concern relevant to erosion in the watershed is the transport of contaminated sediments down the canyon drainage onto adjacent National Park Service lands (Bandelier National Monument detached Tsankawi unit located east of State Route 4) and San Ildefonso Pueblo lands, and eventually into the Rio Grande.

Riparian Zone Evaluation:

The Forest Service Guide for riparian evaluation indicates that for a Level 1 evaluation, the riparian area should be divided into subareas based on variability among parameters such as stream type, vegetation, geology, geomorphology, soils, topography, and wildlife. Factors addressed in a Level 1 riparian evaluation include streambank stability and potential erosivity, recreation potential and wildlife habitat potential (USFS, 1990).

The evaluated portion of the Los Alamos Canyon watershed can be divided into three reaches based upon variations in elevation and topography, vegetation, geology, and general streamflow characteristics. The upper reach is defined as that part of the watershed that has streamflow west of and above Los Alamos Reservoir (~7600 feet elevation). This reach is ~2.7 miles in length and is the only portion of the canyon that has perennial streamflow, fed by baseflow from springs emanating from the Tschicoma Formation (DOE, 1979). Streamflow begins at an uppermost elevation of ~9300 feet and the gradients are fairly steep, ranging from about 8% to 20%, with a very narrow canyon bottom (generally <100 feet in width). Overstory vegetation is very dense and is characterized by mixed conifers (White fir, Douglas fir, Engelmann spruce, Limber pine) and aspen. Understory species are dominated by cutleaf coneflower, wild strawberry, and James geranium. The National

Wetlands Inventory (NWI) classification is riverine, upper perennial, unconsolidated bottom, and permanently flooded (Foxx, 1995).

The middle reach extends ~4 miles downstream from the reservoir. The canyon bottom in this reach averages a moderately narrow ~250 feet width. Elevations vary from ~7600 feet to ~6800 feet. Streamflow is intermittent in this reach, only occurring during snowmelt and heavy rains when overflows from the reservoir take place. Gradients are moderate, ranging from 2% to 6%. The geology of this section of the canyon is characterized by steep cliffs and colluvium slopes of the Bandelier Tuff Formation, the detritus of which forms the alluvial streambed material. Overstory vegetation is dense and characterized primarily by ponderosa pine with mixed conifer (Douglas fir, White fir) with some aspen on the north slope. Understory species are characterized by redtop and raspberry, with various grass species dominant. The NWI classification is alustrine, scrub-shrub, broad-leaved deciduous, and temporarily flooded (Foxx, 1995).

The lower reach is ~4.1 miles in length, extending to the point where the canyon crosses State Route 4, and the canyon bottom broadens from ~250 to ~600-800 feet width. Elevations range from ~6800 feet to ~6300 feet. Streamflow is intermittent and usually flows only during the rainy season and only for short periods of time. The gradient averages ~2%. Steep cliffs and slopes of the Bandelier Tuff line the canyon, and the overstory vegetation is more open than the higher sections, consisting of open stands of ponderosa pine and piñon-juniper. Understory species are characterized by redtop and smooth brome, with various grass species dominant. The NWI classifies this area as riverine, intermittent, stream bed, and temporarily flooded (Foxx, 1995).

Streambank stability and potential erosivity are not viewed as dominant parameters in the watershed since streamside vegetation is observed to be generally dense, likely due to plentiful moisture for several recent years, and the exclusion of grazing from the watershed since 1943. Local deposition of up to 6 feet of stream sediments followed by renewed incision since 1943 has been documented in DP Canyon (Reneau, 1995). The intermittent flow conditions of the middle and lower reaches of the watershed generally appear to limit this magnitude of instability and erosivity to a few extreme precipitation events and to localized areas, however. The streambed is quite narrow, generally averaging only 3 to 6 feet in width, with a channel depth on the order of 2 to 3 feet, limiting channel erosion to only a minor portion of the canyon floor except during extreme runoff events.

The recreation potential factor is pertinent mainly to the Forest Service lands in the upper reach, where the visual quality is high and opportunities for hiking and wildlife observation are quite good. Public access is still restricted within much of the middle reach and all of the lower reach. Because of vigorous and dense streamside vegetation present within the upper reach, its riparian health is judged to be very good to excellent for this parameter.

Because the reservoir dam restricts the movement of fish downstream, fish habitat is only favorable in the upper reach. Overall wildlife habitat potential is considered to be quite high for the upper reach, and thus its riparian health is excellent based on this parameter. Wildlife habitat potential is considered good for non-aquatic species in the middle and lower reaches. However, ecological baseline studies conducted in Los Alamos Canyon during 1993 and 1994 determined biodiversity index values at three sites in the middle and lower reaches for aquatic macroinvertebrates indicative of progressively greater impairment downstream (Foxx, 1995) (see Anthropogenic Impacts on the Watershed: Biodiversity section). Restriction of streamflow below the reservoir likely aggravates this impairment, and thus the riparian health for the middle and lower reaches is considered to be marginal based on this parameter.

Water quality is another parameter which can be used as an indicator of riparian health. Both surface water and ground water in Los Alamos Canyon have been impacted by point source and non-point source contaminants, and these issues are thoroughly discussed in a later section (see Major Development/Urbanization Impacts: *Water Quality*). Though contaminant levels are generally below both EPA and DOE drinking water limits, their widespread presence can be considered as indicative of likely impaired riparian health.

Thus, while the riparian health is excellent for the upper reach of Los Alamos Canyon, based upon the vigor of the streamside vegetation and high potential for recreational and wildlife values, the riparian health of the middle and lower reaches is considered marginal because of restricted streamflow and chemical contamination of surface water and groundwater. Lack of perennial streamflow limits aquatic wildlife and biodiversity, and the streamside vegetation is more characteristic of a dry land environment than a riparian system as a result. Degraded water quality may also adversely impact aquatic wildlife in these reaches.

Wildland Resources:

Forest Resources:

As described earlier, most of the watershed is undeveloped and its vegetation is dominated by forests and woodlands containing over a dozen different species of trees with total of 42 overstory species and 78 understory species present (Foxx, 1995). Timber harvesting in the area was discontinued in 1943 when the U.S. government restricted access to the area to provide security for the Manhattan Project (Allen, 1989). High elevation grasslands have thrived after the elimination of domestic stock grazing in the watershed at the same time. The grasslands in the Cañada Bonito area of the upper watershed are in a proposed 300 acre research natural area for the Thurber fescue ecosystem. (USFS, 1994). LANL has classified the undeveloped portions of the lower watershed as Environmental Research/Buffer for future land use (LANL Site Development Plan, 1990). The USFS continues to prohibit logging and grazing in the upper watershed area and these restrictions are certain to remain in place in the DOE portion, so the main functions of the forest resources as currently utilized are as habitat for wildlife, as research natural areas, and to provide visual quality and aesthetic value as a setting for human recreation and quality of life enhancement. The USFS lands in the watershed are currently managed for either Recreation-Visual-Wildlife emphasis or Threatened and Endangered Species Habitat (USFS, 1994).

The most critical issue relevant to the watershed forests is thus management for the maintenance and preservation of the forest ecosystems to protect their integrity, biodiversity, and sustainability for continuing the current uses.

Wildlife:

Wildlife inhabiting the watershed is diverse and identified species range from large mammals to aquatic macroinvertebrates and terrestrial arthropods. Rocky Mountain mule deer and Rocky Mountain elk are the most prevalent large mammal species present, with mule deer wintering grounds identified in the middle to lower portions of the watershed, while both mule deer and elk utilize the upper watershed during summer months (DOE, 1979). Medium size mammal species identified in the LANL area include coyote, red fox, porcupine, mountain lion, and bobcat (LANL, 1995). Twenty-nine small mammal species have been identified within LANL properties and are likely present in the

watershed. These include among others, various species of voles and mice, pocket gophers, rabbits, weasels, badgers, chipmunks, squirrels, shrews, and bats (LANL, 1995).

More than 200 bird species have been identified in Los Alamos County, with at least 112 species known to breed in the area (Travis, 1992). Ecological baseline studies conducted in Los Alamos Canyon during the summers of 1993 and 1994 identified 44 bird species present in the watershed. The predominant species identified in the upper and lower canyon areas are shown in Figures 15 and 16 (Foxx, 1995). These data show that species distributions varied significantly between the upper and lower canyon areas and also from year to year.

Eight reptile species have been identified in the canyon (Bogart, 1978). These include various toads, frogs, snakes, and lizards. Other species identified within the canyon include 63 aquatic invertebrate taxa, 13 snail species, and 25 species of terrestrial arthropods. Listings of species of terrestrial arthropods, reptiles and amphibians, birds, and mammals identified in Los Alamos Canyon are provided in Tables A-2, A-3, A-4, and A-5 (Appendix A).

Potential habitat for several threatened or endangered species exists in the watershed. Species with moderate to high potential for occurrence include the Mexican spotted owl, peregrin falcon, Jemez Mountains salamander, spotted bat, meadow jumping mouse, and northern goshawk. Of these, only one species has been officially reported as present; a Jemez Mountains salamander specimen was observed on the north-facing slope in the middle reach of the canyon in 1986 (LANL, 1995).

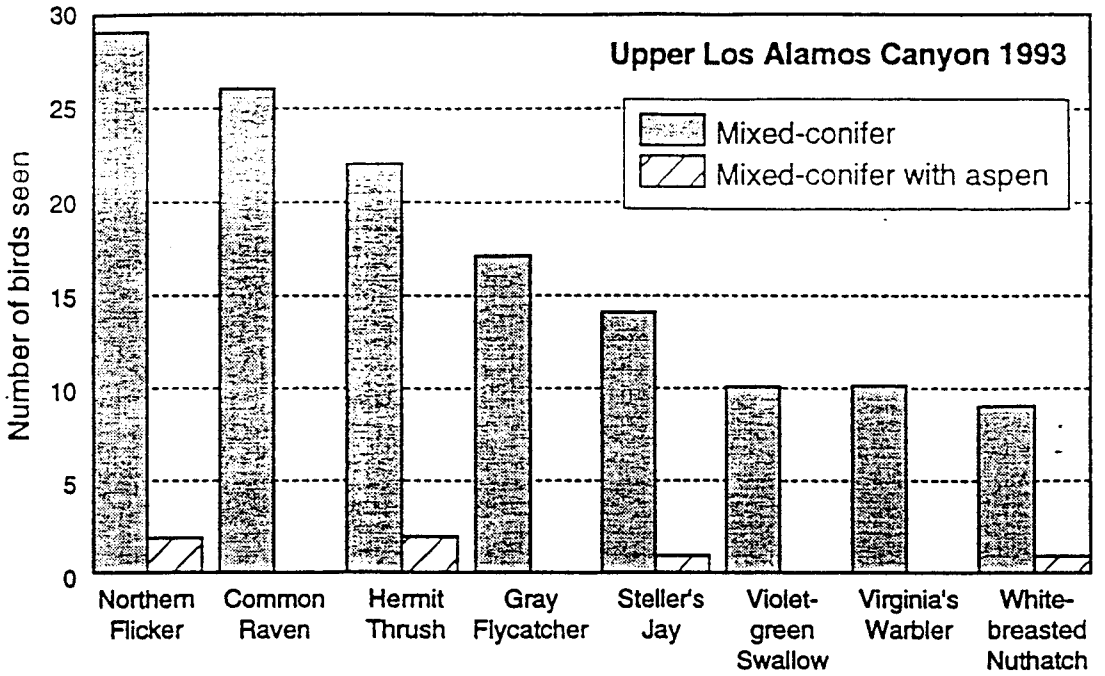
Since there is obviously a high degree of wildlife biodiversity currently present in the watershed, the most important issue relevant to the watershed wildlife resources is the maintenance and preservation of their habitat ecosystems in order to protect their integrity, biodiversity, and sustainability.

ANTHROPOGENIC IMPACTS ON THE WATERSHED:

Prehistoric Impacts:

While the presence of humans in New Mexico has been documented back as far as 11,000 years B.P., minor impacts from early Indian agriculture probably began about 7,500 years B.P. in the Archaic period. Local Puebloan ancestors developed communities with permanent dwellings in the Jemez Mountains around 1100 A.D. The extensive Anasazi settlements of the Pajarito Plateau (such

Figure 15: Birds Seen in Upper Los Alamos Canyon (Foxx, 1995)



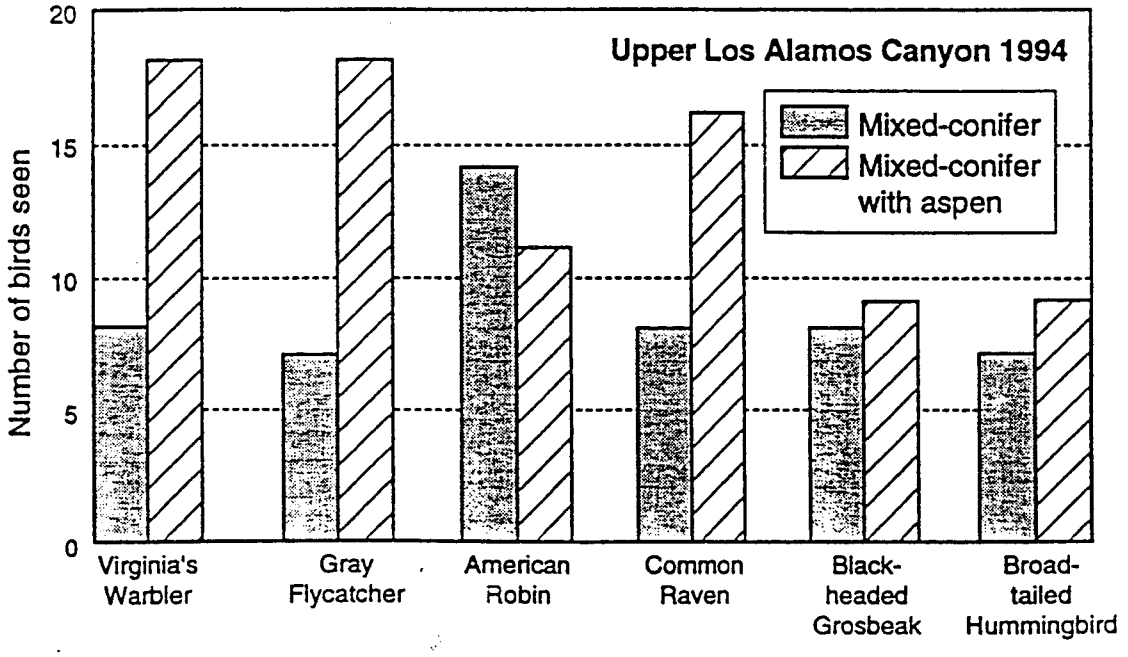
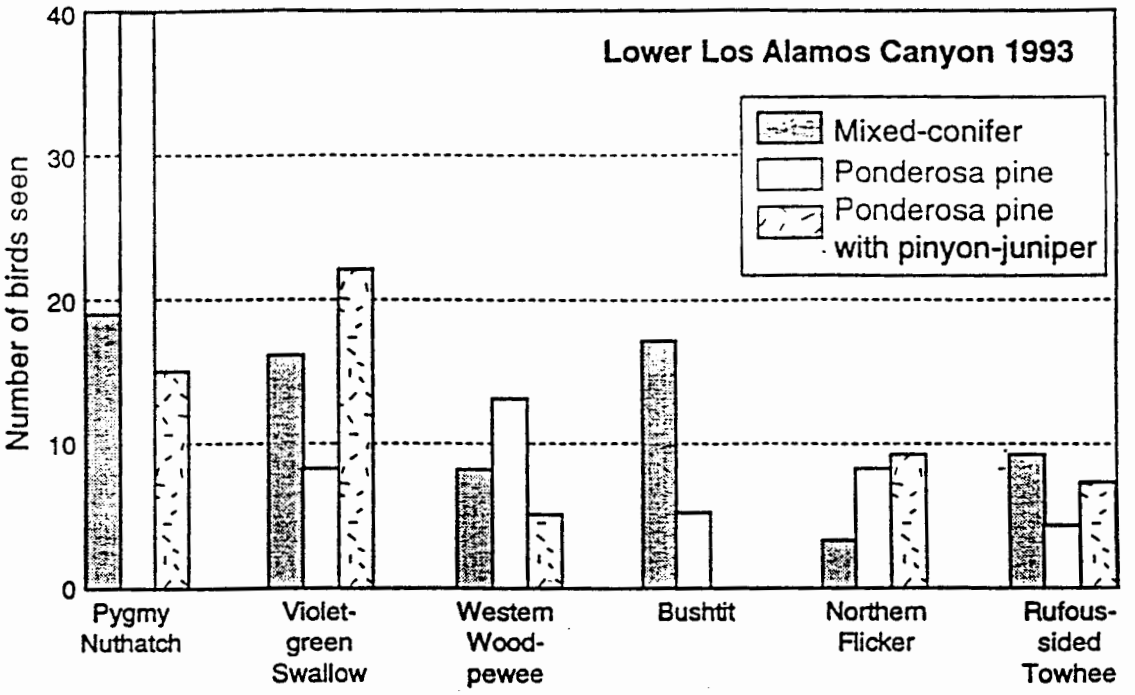
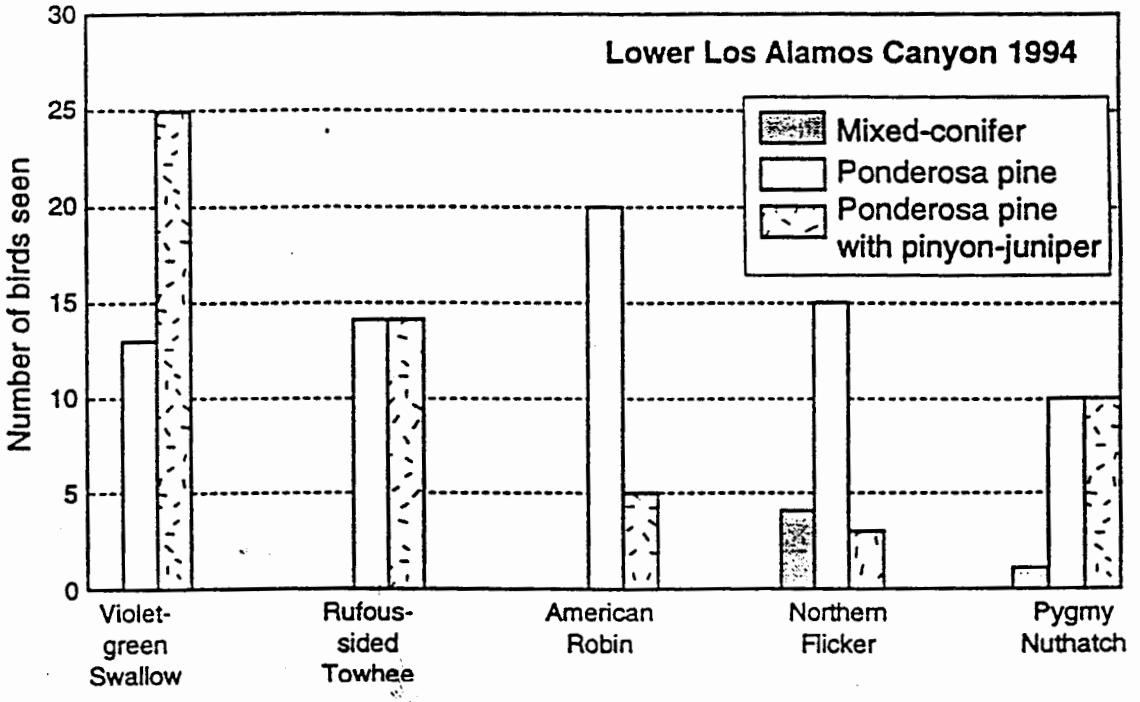


Figure 16: Birds Seen in Lower Los Alamos Canyon (Foxx, 1995)





as those found in Frijoles Canyon in Bandelier National Monument bordering DOE lands to the south) were developed in the 1400's and early 1500's A.D. (Allen, 1989). By 1600 A.D. the Pajarito Plateau was abandoned by the Pajaritans and Puebloan legends say they moved to the Tewa village of San Ildefonso (DOE, 1979).

Prior to about 1200 A.D. Native American impacts on the Pajarito Plateau woodlands were minor or localized. However, archaeological evidence from Bandelier suggests that significant Anasazi impacts on woodland resources probably occurred during their principal period of occupation on the plateau (ca. 1200-1500 A.D.). The result of cutting down trees for firewood and construction along with shifting agricultural activities was probably a significant level of deforestation of the piñon-juniper woodlands on the upland mesas (Allen, 1995, unpublished draft). Estimated agricultural acreage requirements for the peak Bandelier population of over 3,000 people are that over 3,900 acres could have been under cultivation at any one time. Thus a likely impact of the Anasazi occupation was to favor herbaceous vegetation at the expense of the woodlands and forests, which may explain the lack of well developed old-growth piñon-juniper woodlands in the Los Alamos area (Allen, 1995, unpublished draft).

Historical Impacts:

The first Spanish settlement in the Upper Rio Grande Valley was established in 1598 at the confluence of the Rio Chama and the Rio Grande, near the base of the Jemez Mountains (DOE, 1979). The Spanish introduced cattle and sheep to the area, but early livestock grazing was limited by Navajo and Apache raiders which frequented the area until their subjugation in the 1860's. With the suppression of Indian hostilities and the introduction of railroads to the region, large numbers of sheep and cattle were being grazed in the area by the 1880's (Allen, 1995, unpublished draft). In the late 1880's, an estimated 5 million sheep and 1 million cattle were grazed statewide. Extensive grazing continued into the 20th century, with a general shift away from sheep toward cattle since 1920 (Allen, 1989).

One impact of such heavy grazing pressure on the landscape was a significant disturbance to the herbaceous vegetation component which served to favor woodland and forest expansion at the expense of the over-stressed grasslands and caused significant alterations in the species composition

of local vegetation associations. Allen (1989) documents the initiation of conifer invasion of grasslands in Cañada Bonito beginning around 1920, about the same time as significant reductions in area sheep herds occurred. Air photo analysis indicated that open montane grassland area decreased by 55% between 1935 and 1981 in the southeast portion of the Jemez Mountains, from approximately 1,370 to about 620 acres. Heavy sheep grazing likely prevented tree invasion due to browsing and trampling effects. The changeover from high sheep numbers to lower levels of cattle stocking in the 1920's and 1930's is thought to have provided the trigger for the onset of tree invasion. In the Cañada Bonito area, the rate of tree establishnent has continuously declined to a low level after the initial peak tailed off in the 1940's (Allen, 1989). This may be because the grasses are so vigorous that they can effectively outcompete the trees for seedling space (Craig Allen, personal communication, 1996).

A second major impact of the grazing disturbance was the initiation of soil erosion problems in the piñon-juniper woodland areas of the plateau due to the severe reduction of ground cover which lowered infiltration capacities and increased runoff. Though this is a serious problem in some parts of the plateau, such as at nearby Bandelier National Monument, it appears to affect only a minor portion of the lower watershed area, mainly on the bounding mesa-tops immediately adjacent to the canyon wall escarpments.

A third significant impact from overgrazing was the suppression of previous surface fire regimes typified by low intensity and frequent recurrence intervals of generally 5 to 15 years in the ponderosa pine forests. By the early 1900's, government sponsored fire suppression efforts had begun and allowed woody fuel loads to build up in the forests and woodlands. The previous fire regime in the higher elevation mixed conifer forests was typified by a combination of surface fires and patchy crown fires with mean fire intervals of 15 to 30 years. The combined effect of overgrazing and active fire suppression has resulted in the transformation of the former high-frequency, low-intensity fire regime to a low-frequency, high-intensity fire regime which persists to the present day (Allen, 1989; Allen, et al., 1995).

The primary historical land uses in the Los Alamos Canyon watershed during the 1900's prior to 1943 were grazing, logging, and farming. Approximately 3,600 acres of current DOE lands were previously used for agriculture (DOE, 1979). Aerial photos from 1935 clearly show large farm fields

in the areas of the watershed now occupied by downtown Los Alamos and the adjacent residential neighborhood (Figure 17). The U.S. government acquired all of the lands within Los Alamos County in 1942 and established LANL in January of 1943. At this time all grazing and logging was prohibited from the watershed, allowing general recovery from the adverse impacts of these land uses. Most of the townsite and Lab facilities were constructed in the areas previously cleared for agriculture, beginning the impact of urbanization in the watershed. In the mid-1960's, the federal government either sold or transferred title to the areas beyond the current DOE boundaries to various private interests, Los Alamos County, and the USFS.

Continuation of management policies by the USFS preventing grazing and logging has allowed the carrying capacity for wildlife in the upper watershed to improve to a high level. However, continuation of fire suppression policies has allowed the excess woody fuel load in the forests to persist and accumulate. The USFS has recently begun to address this problem by proposing a program of selected control burns in the area. In fact, a firebreak was burned just above the townsite in the fall of 1995 (personal observation; personal communication, Robert Remallard, USFS, 1996).

Current Land Uses:

Because of the large tracts of land within the watershed controlled by either the U.S. Forest Service (USFS) or by the U.S. Department of Energy (DOE), the range of current land uses within the watershed is fairly limited (Figure 18). Within the DOE controlled portion, the major land use is defined by LANL as Environmental Research/Buffer (the undeveloped areas), encompassing ~1,646 acres or ~25% of the total watershed area, while small areas are devoted to Experimental Science (Technical Areas 2, 21, 41 and 43) (LANL Site Development Plan, 1990). These areas encompass ~89 acres, or ~1% of the total watershed area, all located in the central part of the watershed.

Approximately 242 acres of the watershed is occupied by the Los Alamos townsite, of which ~203 acres is urban (downtown Los Alamos) representing ~3% of the total watershed area, and ~39 acres is a residential area, representing <1% of the total watershed area.

Approximately 428 acres is occupied by the Pajarito Mountain Ski Area in the uppermost part of the watershed. The Los Alamos ice skating rink (estimated 1 acre) site is located in upper Los Alamos Canyon. These recreational use areas represent ~7% of the total watershed area.

1974

Comparative aerial photographs of the Los Alamos area.

1935

These two aerial photos of the Los Los Alamos area were taken about 40 years apart. They cover almost identical areas and show the transitions in land use. (Orientation is with north at the top.) The darker horizontal line running across the middle of each is Los Alamos Canyon. Near the right edge, north of the canyon, Ashley Pond shows as a dark oval shape. In the upper middle is an area now forming a residential area that used to be cleared for farming. In the middle, just south of the canyon, is the South Mesa technical area. At the lower left is an irregular area that was cleared for farming and is now partly occupied as a technical site. Somewhat more land is now used for laboratory activities than previously used for farming and the character of present use is urban rather than agricultural. It is interesting to note the clear evidence of agriculture use even after 30 years of different use.

(DOE, 1979)

Figure 17

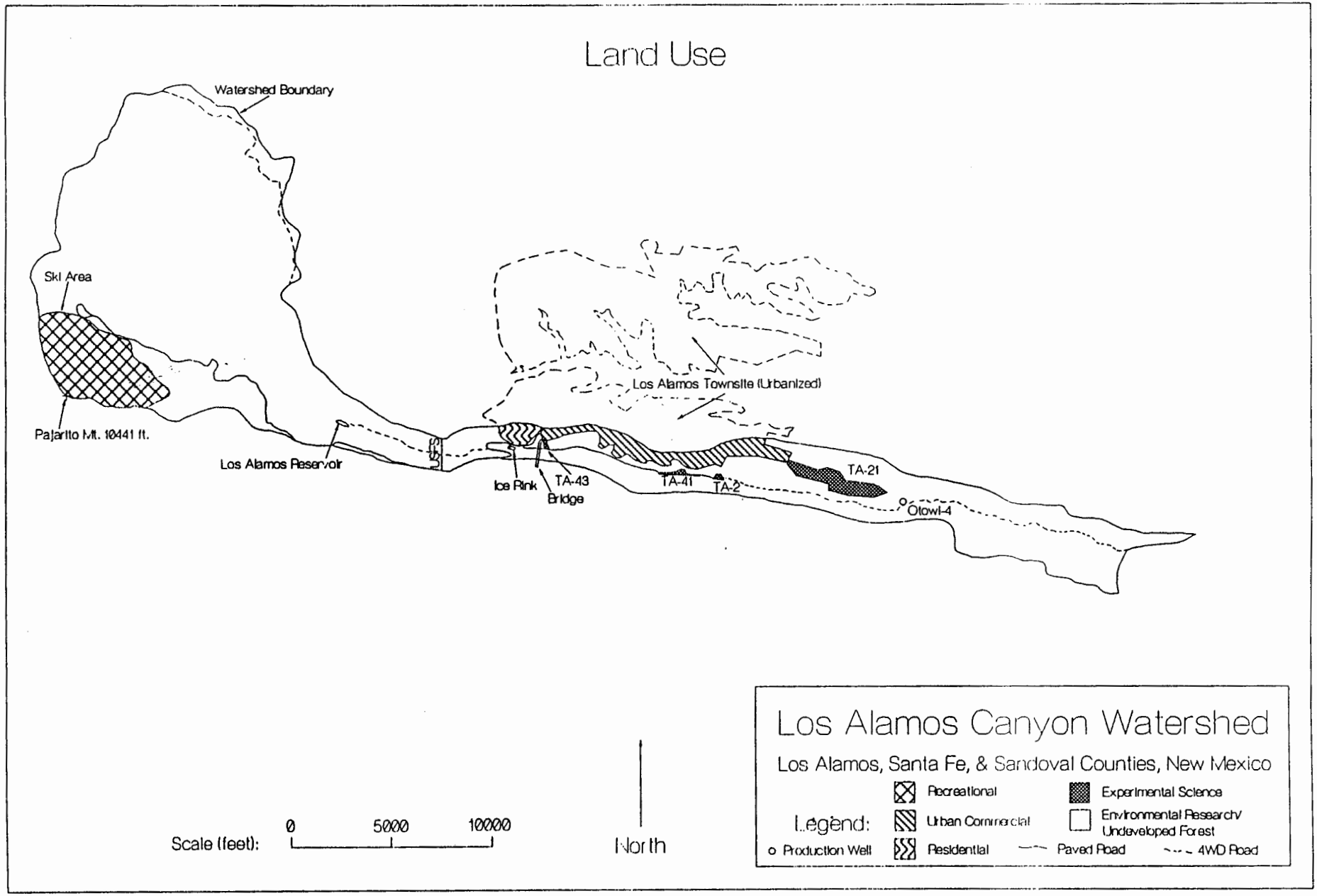

Land Use
Watershed Boundary
Ski Area
Pajarito Mt. 10441 ft.
Los Alamos Reservoir
Los Alamos Townsite (Urbanized)
Ice Rink
TA-43
Bridge
TA-41
TA-2
TA-21
Otowi-4
Los Alamos Canyon Watershed
Los Alamos, Santa Fe, & Sandoval Counties, New Mexico
Legend:
Recreational
Urban Commercial
Residential
Experimental Science
Environmental Research/ Undeveloped Forest
Production Well
Paved Road
4WD Road
Scale (feet):
0
5000
10000
North

Figure 18

A small area (~83 acres) of General Services Administration undeveloped land is located west of the LANL boundary and east of the USFS boundary, representing ~1% of the watershed. The remaining ~3,993 acres or ~62% of the watershed is controlled by the USFS. This area is primarily an undeveloped forest used primarily by hikers and wildlife.

Approximately 760 acres representing ~12% of the total watershed area is occupied by developed lands while ~5,723 acres representing ~88% of the total watershed area is undeveloped. These data are summarized in Table 5.

The remaining major land use in the watershed is for roads. Approximately 3 miles of paved roads and about 8.5 miles of unimproved roads exist within the areas of the watershed classified above as undeveloped (Figure 18). A natural gas pipeline parallels the unimproved road in the northern part of the upper watershed. Also, a small site in the lower canyon is the location of the Otowi-4 production well which is developed in the Santa Fe Group and is a component of the LANL water supply system (Figure 18).

Table 5: Current Land Use

Land Use	Area (ft^2)	Area (acres)	% of Total Area
Ski Area	18650928	428.17	6.60
Ice Rink	43560	1.00	0.02
Recreational Total:	18694488	429.17	6.62
TA-43	100535	2.31	0.04
TA-41	295410	6.78	0.10
TA-2	114651	2.63	0.04
TA-21	3359364	77.12	1.19
Exp. Science Total:	3869960	88.84	1.37
Residential	1710306	39.26	0.61
Urban Commercial	8827708	202.66	3.13
Townsite Total:	10538014	241.92	3.73
Total Developed:	33102462	759.93	11.72
Env. Res./Buffer	71717453	1646.41	25.40
Gen. Serv. Adm.	3614489	82.98	1.28
USFS	173951392	3993.37	61.60
Total Undeveloped:	249283334	5722.76	88.28
Grand Total:	282385796	6482.69	100.00

Major Development/Urbanization Impacts:

Flood Hazard Mitigation:

The presence of the Los Alamos Reservoir dam, constructed between 1937 and 1943, has had a major impact on the watershed. Foremost is the restriction of streamflow below the dam, which not only adversely affects aquatic biota in the lower watershed, but also limits groundwater recharge and the availability of subsurface moisture accessible to riparian vegetation. The flood protection afforded by the dam is of particular concern since the dam is located ~3.6 miles upstream of the site of the Omega West Reactor facility at Technical Area (TA)-2 (Figure 18). Though the reactor has not been operated since 1993, the facilities nevertheless constitute infrastructure of significant economic value. Besides this facility, the research facilities at TA-41 and the ice rink are afforded flood protection by the dam.

The U.S. Army Corps of Engineers (COE) conducted a study to determine the impact of a probable maximum flood (PMF) event in combination with a dam breach on potential flooding at the reactor facility (COE, 1991). A PMF event is defined as, "the flood that may be expected from the most severe combination of critical meteorologic and hydrologic conditions that are reasonably possible in the region; i.e. the flood that should have virtually no chance of being exceeded" (COE, 1991). The PMF event was modeled based on a probable maximum precipitation of 10.4 inches for a 6-hour storm. The study concluded that the combined PMF event and dam breach would result in a peak water surface elevation nearly 11 feet above the first floor elevation of the facility. The report notes, however, that a dam breach was not a main contributor to the flooding, and essentially offered no increased risk to the facility. Thus, the dam is inadequate to provide flood protection during a PMF event. The COE analysis also concluded that the dam would be overtopped at only 2% of the PMF, suggesting that even a moderate storm could overtop and possibly breach the dam, and that there is a "very high potential that the dam will be overtopped" (COE, 1991). A flood at 2% of the PMF was modeled without a dam breach and produced a maximum water level only 3 feet below the reactor facility elevation. Thus, there appears to be only a minimal level of flood protection afforded to the facility by the dam.

A recent study utilized the COE's HEC-1 and HEC-2 numerical hydrologic models to determine 100-year floodplains within LANL (McLin, 1992). Utilizing a 100-year 6-hour storm

event of 2.4 inches, a hydrograph peak of 589 cfs was determined for Los Alamos Canyon above State Route 4, resulting in a 24-hour runoff volume of 240 acre-feet. Considering that recent peak flows recorded in the canyon are under 10 cfs (Figure 14), these results support the conclusion that the dam will not provide adequate flood protection for a 100-year event.

Water Quality:

Water quality is an issue of importance in the Los Alamos Canyon watershed because of contamination of both surface water and groundwater from both point source and non-point source origins associated with LANL research facilities and urbanization influences within the watershed. Though water contamination levels have been quite high in the past, the levels seen in recent years are generally small and for the most part, identified contaminants occur at concentrations below drinking water standards.

Surface water from Los Alamos Reservoir is regularly sampled to measure upstream background levels of potential contaminants in the watershed (Table B-1, Appendix B) (LANL Environmental Protection Group, 1994). These data indicate that radionuclide activities there are near regional fallout levels, and that concentrations of major ions (calcium, sodium, magnesium, potassium, chloride, sulfate, flouride and bicarbonate) are typically less than 20 mg/L. Downstream from the reservoir, concentrations of the major ions, particularly sodium (Na^+) and chloride (Cl^-), increase in the surface water as a result of road salt dissolution and treated wastewater discharges from LANL research facilities located within or adjacent to the canyon. Background concentrations of Na^+ and Cl^- are 6 mg/L, while downstream levels of Na^+ range between 12.9 and 85.0 mg/L and Cl^- levels range from 18.5 to 135 mg/L (LANL, 1995).

Since the establishment of the Laboratory in 1943, LANL research facilities have discharged effluent byproducts into the canyon over lengthy time periods. Of particular concern are a number of radionuclides present in both surface water and groundwater. From 1952 until 1986, an industrial liquid waste treatment plant at TA-21 (Figure 18) discharged effluent containing radionuclides into DP Canyon (Figure 2), a tributary to Los Alamos Canyon within the watershed (LANL Environmental Protection Group, 1995). Though the original source has been eliminated, residual levels of contamination remain in both the surface water and groundwater systems.

In 1993, ^{239}Pu concentrations in surface water in Los Alamos Canyon (at the lower streamflow gage) were measured at levels ranging from 0.029 to 0.040 picoCuries per liter (pCi/L) while ^{238}Pu concentrations ranged from 0.004 to 0.017 pCi/L. Other radionuclides present in surface waters in the canyon include ^{137}Cs at 0.4 to 2.9 pCi/L and ^{3}H at 500 to 1,100 pCi/L (LANL Environmental Protection Group, 1995).

Alluvial groundwater quality is monitored in several shallow observation wells located in the middle and lower portions of the watershed (Figure 19). Well LAO-B serves as a background alluvial well for upper Los Alamos Canyon and the alluvial groundwater there is a sodium-calcium-bicarbonate type with an average total dissolved solids (TDS) content of about 125 mg/L and a Cl^- concentration similar to that observed in the reservoir. (LANL, 1995). Concentrations of Na^+ and Cl^- increase downstream, along with TDS (Figures 20 and 21) (Longmire, et al., 1996a). The TDS concentrations in the alluvial groundwater generally increase by a factor of three downgradient from well LAO-C to well LAO-3 while Na^+, Cl^-, HCO_3^- (bicarbonate), and other major ions also increase in downgradient concentrations (LANL, 1995). Though elevated above background levels, these concentrations fall well below the brackish water threshold of ~1000 mg/L TDS (Drever, 1988).

Figure 20 also shows water chemistry for the intermediate perched aquifer (wells LAOI-1.1 and LADP-3) and for the main aquifer (wells TW-3 and Otowi-4). It is instructive to note the similarity in composition between the alluvial groundwater in well LAO-1 and the intermediate aquifer groundwater in well LADP-3 located ~3600 feet downgradient from LAO-1. Both wells had similarly elevated concentrations of Na^+ and Cl^- while the other intermediate well (LAOI-1.1) is markedly different, with Cl^- concentrations below that of the background surface water. This suggests that the intermediate perched aquifer waters sampled in wells LADP-3 and LAOI-1.1 are not hydrologically connected, but the alluvial water from LAO-1 seems to have a strong hydrologic connection with the intermediate aquifer in well LADP-3. Since chloride is a conservative solute that travels at the same rate as the groundwater, the apparent hydrologic connection between the alluvial and intermediate perched aquifers has important implications relative to the possibility of contaminants from the shallow alluvial system migrating downward and eventually impacting the main aquifer.

Groundwater also shows elevated radionuclide concentrations, with ^{238}Pu measured at 0.0 to 0.356 pCi/L, $^{239,240}Pu$ at 0.015 to 1.584 pCi/L, ^{137}Cs at 0.1 to 3.0 pCi/L, ^{241}Am at 0.019 pCi/L, ^{3}H at 200

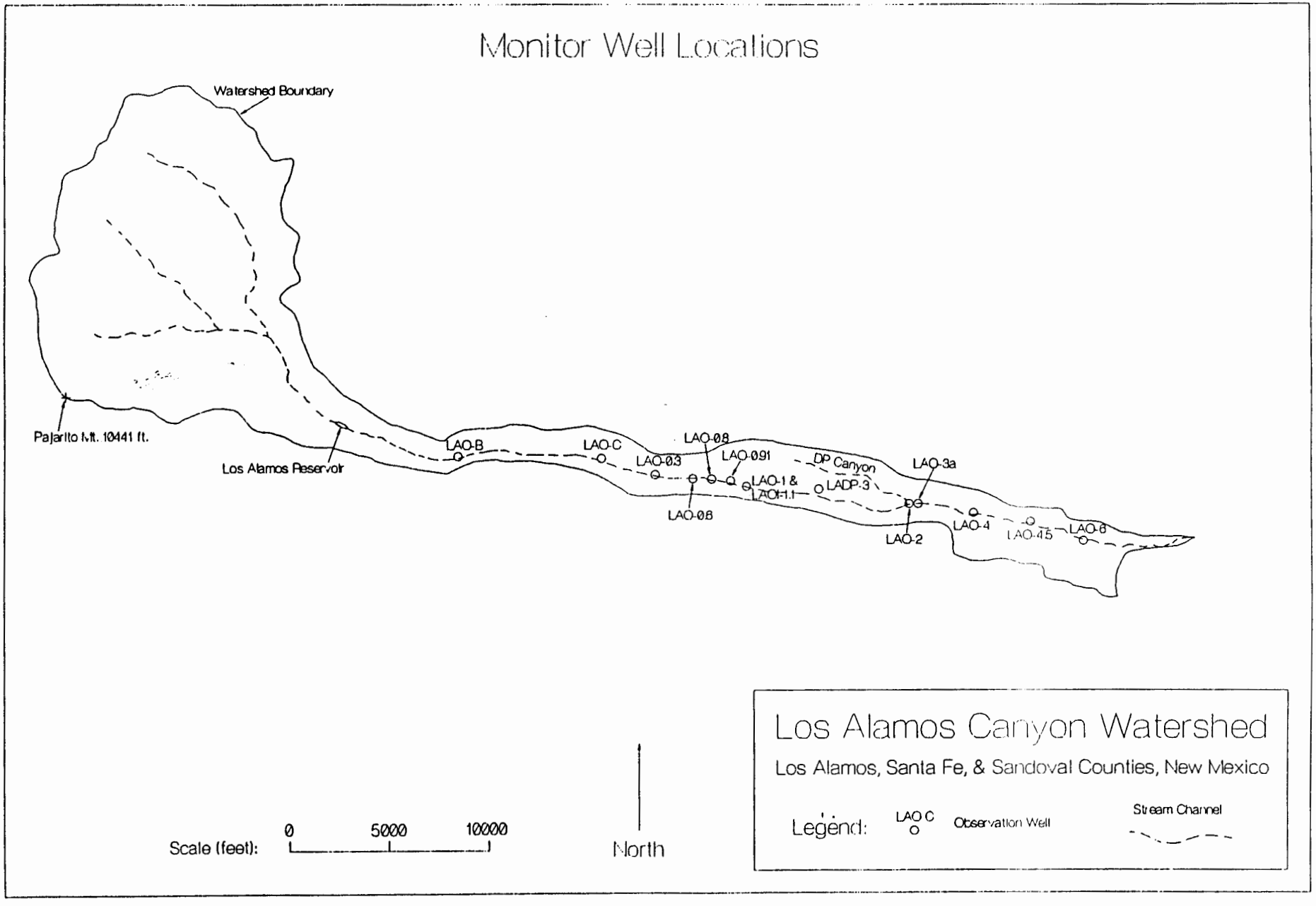
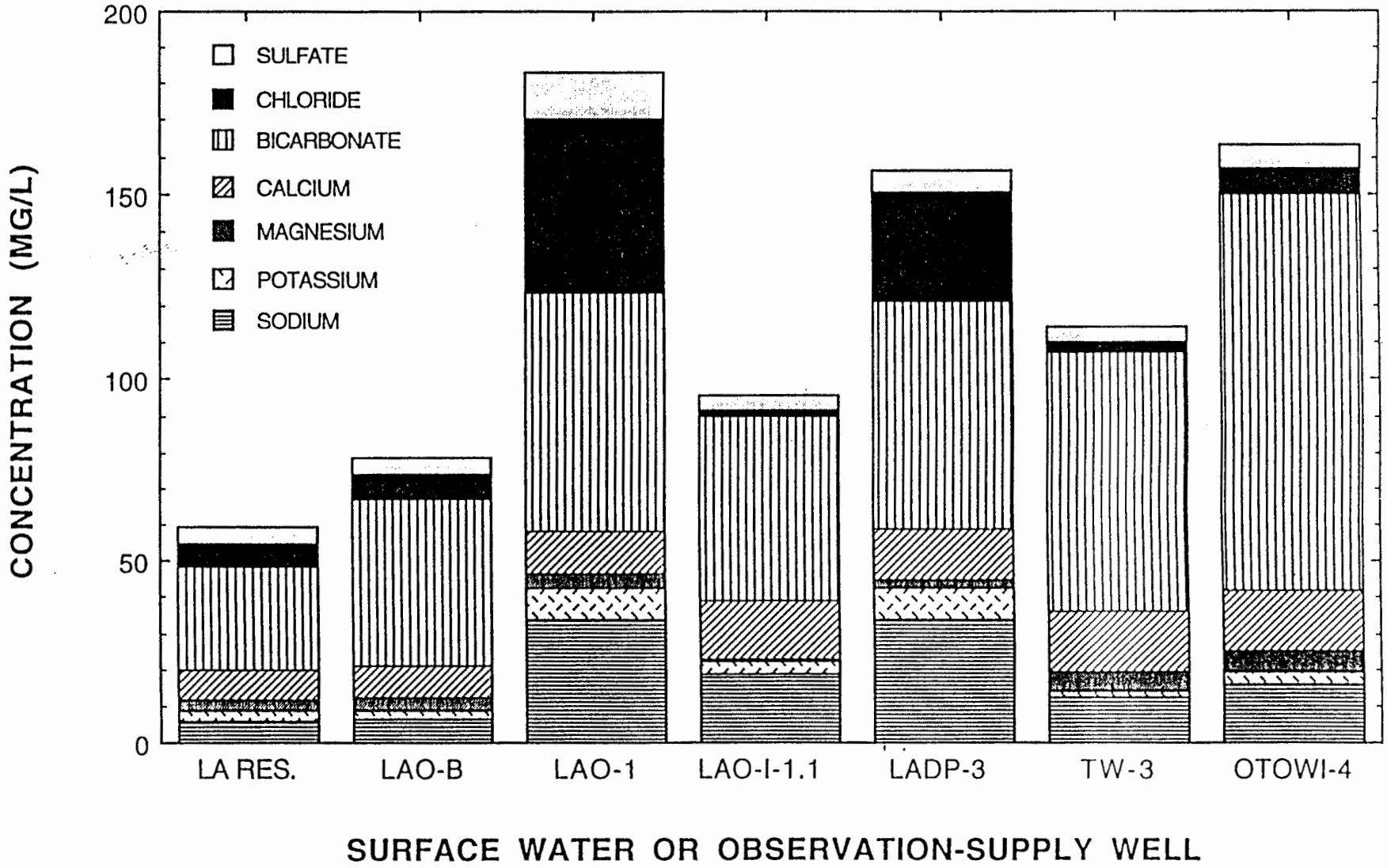

Monitor Well Locations
Watershed Boundary
Pajarito Mt. 10441 ft.
Los Alamos Reservoir
LAO-B
LAO-C
LAO-03
LAO-08
LAO-091
LAO-1 &
LAO-1.1
LAO-06
DP Canyon
LADP-3
LAO-3a
LAO-2
LAO-4
LAO-4.5
LAO-6
Los Alamos Canyon Watershed
Los Alamos, Santa Fe, & Sandoval Counties, New Mexico
Legend:
LAO C
Observation Well
Stream Channel
Scale (feet):
0
5000
10000
North

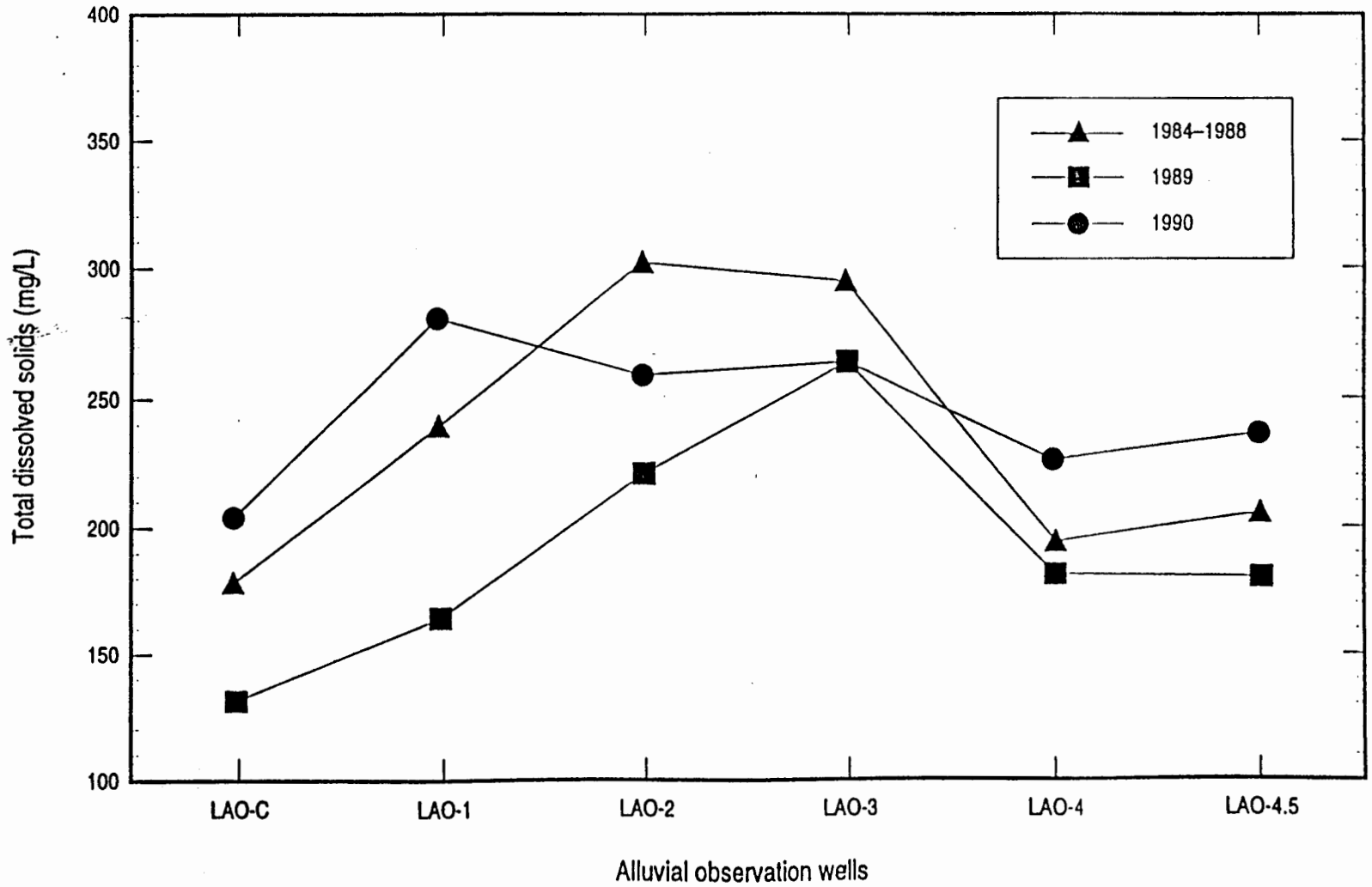
Figure 19

FIGURE 20: WATER QUALITY DATA FOR LOS ALAMOS RESERVOIR, ALLUVIAL, GUAJE PUMICE BED, AND SANTA FE GROUP GROUND WATERS, LOS ALAMOS CANYON.



(Longmire, et al., 1996)

Figure 21: Total Dissolved Solids in Alluvial Groundwater



Sources: ESG 1985, 6610; ESG 1986, 6626; ESG 1987, _____; ESG 1988, 6877; ESG 1989, 6894; Environmental Protection Group 1990, 6995; Environmental Protection Group 1992, 7004

F 3-24 / LA&P / 110295

(OU-1049 Work Plan, 1995)

to 1,300 pCi/L and total uranium at 50.4 µg/L. The radiochemical analyses for environmental surveillance samples collected within the Los Alamos Canyon watershed in 1993 are summarized in Table B-2 (Appendix B) (LANL Environmental Protection Group, 1995). Tables B-3 and B-4 provide historical radiochemical quality data from the watershed for surface water and ground-water respectively (LANL, 1995). Radionuclide levels measured in 1993 represent residual contamination for both the surface water and groundwater and most are below both DOE derived concentration guide (DCG) and EPA maximum concentration level (MCL) drinking water standards for these contaminants (Table 6).

Table 6: DOE Calculated Derived Concentration Guides for Public Dose from Water

Radionuclide	DCG for Drinking Water (pCi/L)
^{3}H	20,000
^{90}Sr	8
^{137}Cs	120
^{234}U	20
^{235}U	24
^{238}U	24
^{238}Pu	1.6
^{239}Pu	1.2
^{240}Pu	1.2
^{241}Am	1.2
Natural Uranium	0.020 (mg/L)

The 1.584 pCi/L activity of $^{239,240}Pu$ measured in well LAO-2 is slightly above the DOE DCG and EPA MCL for drinking water of 1.2 pCi/L $^{239,240}Pu$, but below the DOE DCG for water in uncontrolled areas of 30 pCi/L $^{239,240}Pu$ (LANL Environmental Protection Group, 1995). Of greater concern is the detection of high ^{90}Sr activity in the alluvial groundwater within the canyon, which was measured in 1993 at 367.7 pCi/L in alluvial observation well LAO-2, located at the confluence of DP Canyon with Los Alamos Canyon, a level significantly in excess of the DOE DCG and EPA MCL for drinking water of 8 pCi/L, but below the DOE DCG for water in uncontrolled areas of 1000 pCi/L ^{90}Sr. Guides for uncontrolled areas are based on DOE's radiation exposure public dose limits for the

general public which limits the effective dose equivalent that a member of the public can receive from DOE operations to 100 mrem/yr (LANL Environmental Protection Group, 1995). The highest levels measured for most of the other radionuclides were also found in well LAO-2 indicating that the major source of this contamination is from the TA-21 facility.

It should be noted that well LAO-2 had unusually high levels of ^{90}Sr, uranium, ^{238}Pu, $^{239,240}Pu$, and ^{241}Am in 1993 compared to recent prior years, at concentrations not seen since the late 1970's. These higher levels are possibly the result of a suspected large suspended sediment content in the water sample, reflecting the highly sorptive behavior of radionuclides which tend to bind to sediments rather than dissolve in water. Preliminary 1994 sample results for well LAO-2 are said to show much lower values (LANL Environmental Protection Group, 1995).

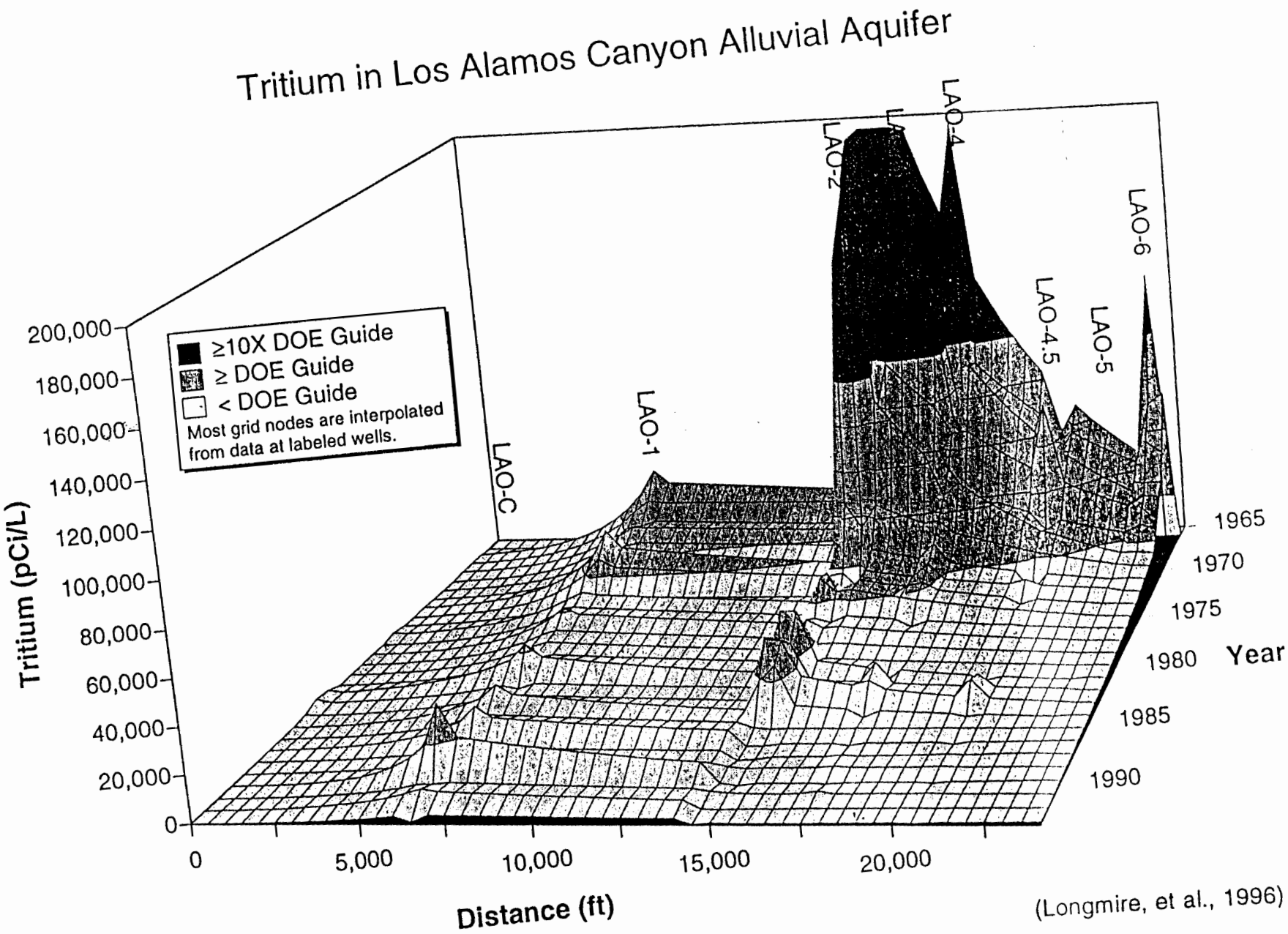
In January of 1993, a leak of ~3 gal/hr was discovered in the cooling system delay line at the Omega West Reactor (OWR) facility at TA-2 (Figure 18), resulting in an extended release of ^{3}H (tritium) into the shallow subsurface. The reactor coolant water contains high tritium activity because the water absorbs neutrons during its passage through the reactor core (LANL Environmental Protection Group, 1995). After discovery of the leak, the fuel rods were removed and the reactor was shut down.

The reactor first began operation in 1956 and elevated concentrations of tritium have been measured in Los Alamos Canyon alluvial wells since the beginning of surveillance measurements in the mid-1960's (LANL Environmental Protection Group, 1995). It has been estimated that over the years of its operation, the reactor facility may have leaked as much as a million gallons of tritiated water into the alluvial groundwater system in Los Alamos Canyon (Pat Longmire, personal communication). Also, discharges of tritium from TA-21 into DP Canyon have likely occurred from a leaking tritiated water tank at the tritium facility (LANL, 1981).

Tritium occurs in the alluvial aquifer in the form of tritiated water, and is a conservative species which migrates at the same rate as the groundwater. In Los Alamos Canyon, the alluvial groundwater flow rate is estimated to be about 900 feet per year (Gallaher, 1995). It also has a half-life of only 12.4 years. As such, its residence time in the groundwater is expected to be less than that for other radionuclides that exhibit greater adsorption tendencies and longer half-lives.

Figure 22 shows varying tritium activities measured in several alluvial observation wells in the canyon from 1965 through 1993 (Longmire, et al., 1996a). This plot shows the distribution of concentrations extending downstream from background well LAO-C located about 2.7 miles downstream from Los Alamos Reservoir (Figure 19). In the late 1960's, tritium activities in DP Canyon surface water ranged from 1.7×10^5 to 4.9×10^6 pCi/L, while alluvial groundwater tritium activities in Los Alamos Canyon ranged up to 8.6×10^5 pCi/L (Purtyman, 1973). Since then, tritium levels in the groundwater have decreased by about 2 orders of magnitude in the wells downstream of DP Canyon to $\sim 10^3$ pCi/L while the tritium activities measured in observation well LAO-2 at the mouth of DP Canyon have remained approximately constant at about 10^4 pCi/L since 1970 (LANL Environmental Protection Group, 1995). The trends apparent in Figure 22 clearly show the separate tritium sources from the OWR site (apparent from elevated activities in well LAO-1, located a short distance downstream from OWR) and TA-21 (DP Canyon) site, and their attenuation over time to recently observed levels below the 20,000 pCi/L MCL. Since the waste treatment facility effluent discharges at TA-21 were stopped in 1986, tritium activities in the alluvial groundwater downstream from well LAO-2 have dissipated substantially through a combination of dilution, migration, and radioactive decay processes. Also, since the leak at OWR was stopped in 1993, the tritium activities observed in well LAO-1 have begun to decrease as well. These trends indicate that tritium activities in the alluvial groundwater should continue to decline from natural attenuation processes.

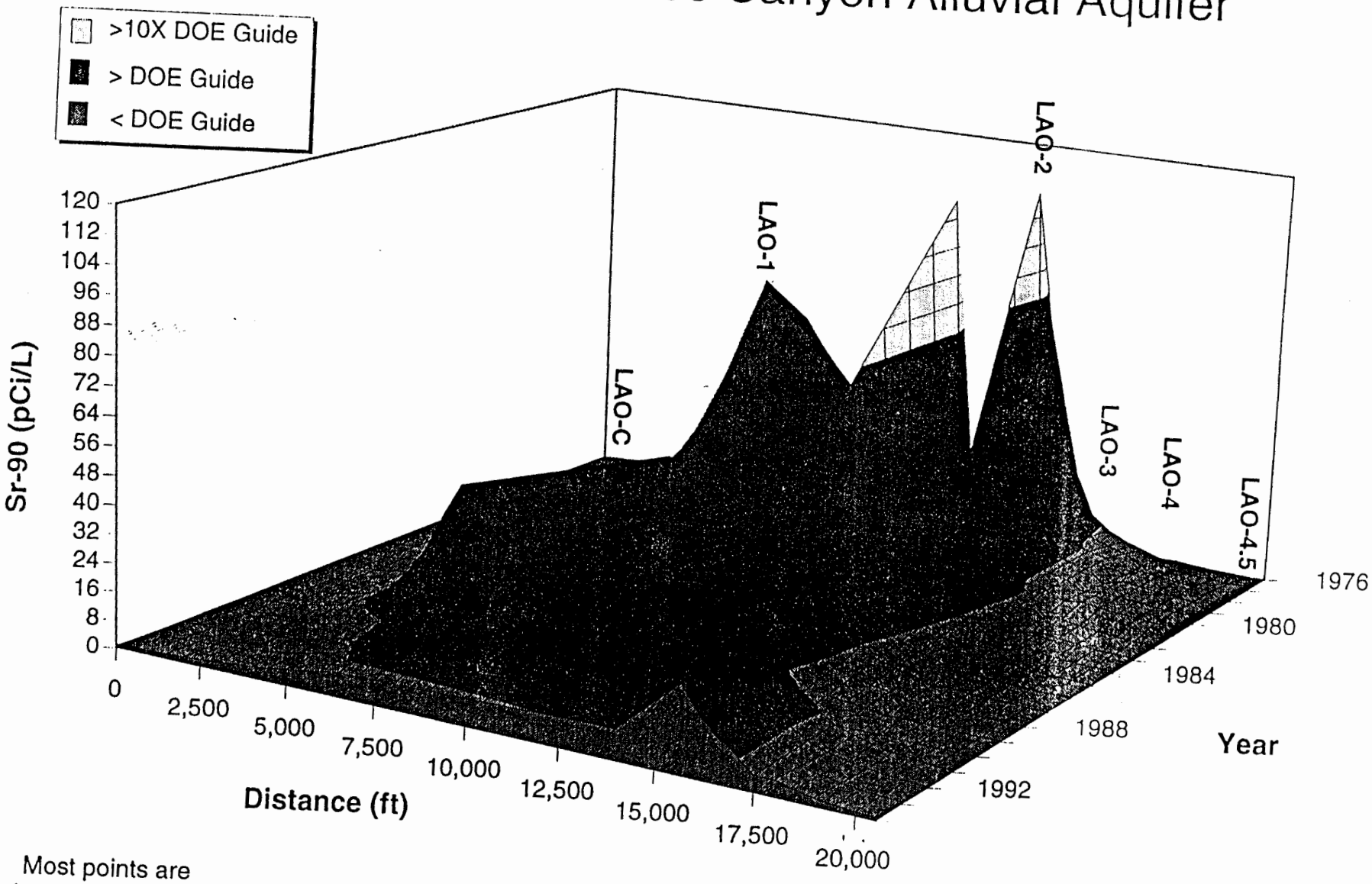
Figure 23 shows ^{90}Sr activities measured in Los Alamos Canyon alluvial observation wells from 1976 through 1994 (Longmire, et al., 1996a). Again the data suggests two sources, near well LAO-1 and near wells LAO-2 and LAO-3 at the mouth of DP Canyon (Figure 19). The high ^{90}Sr activity measured in well LAO-2 in 1993 is not reflected in this plot. In the early 1990's, previously high ^{90}Sr activities found in well LAO-1 diminished to levels near the MCL of 8 pCi/L, suggesting elimination of the source in this region of the canyon. The data from well LAO-2 also showed a decline in ^{90}Sr activities during this same time period (aside from the 1993 results), presumably reflective of the cessation of wastewater effluent discharges at TA-21 since 1986. The elevated concentration levels seen in well LAO-3 since 1992 and in well LAO-2 in 1993 could be a result of remobilized sediments from contaminated soils in DP Canyon and the use of unfiltered water samples for analysis. Alternatively, the data suggests downgradient plume migration. Figure 24 shows ^{90}Sr



(Longmire, et al., 1996)

Figure 22

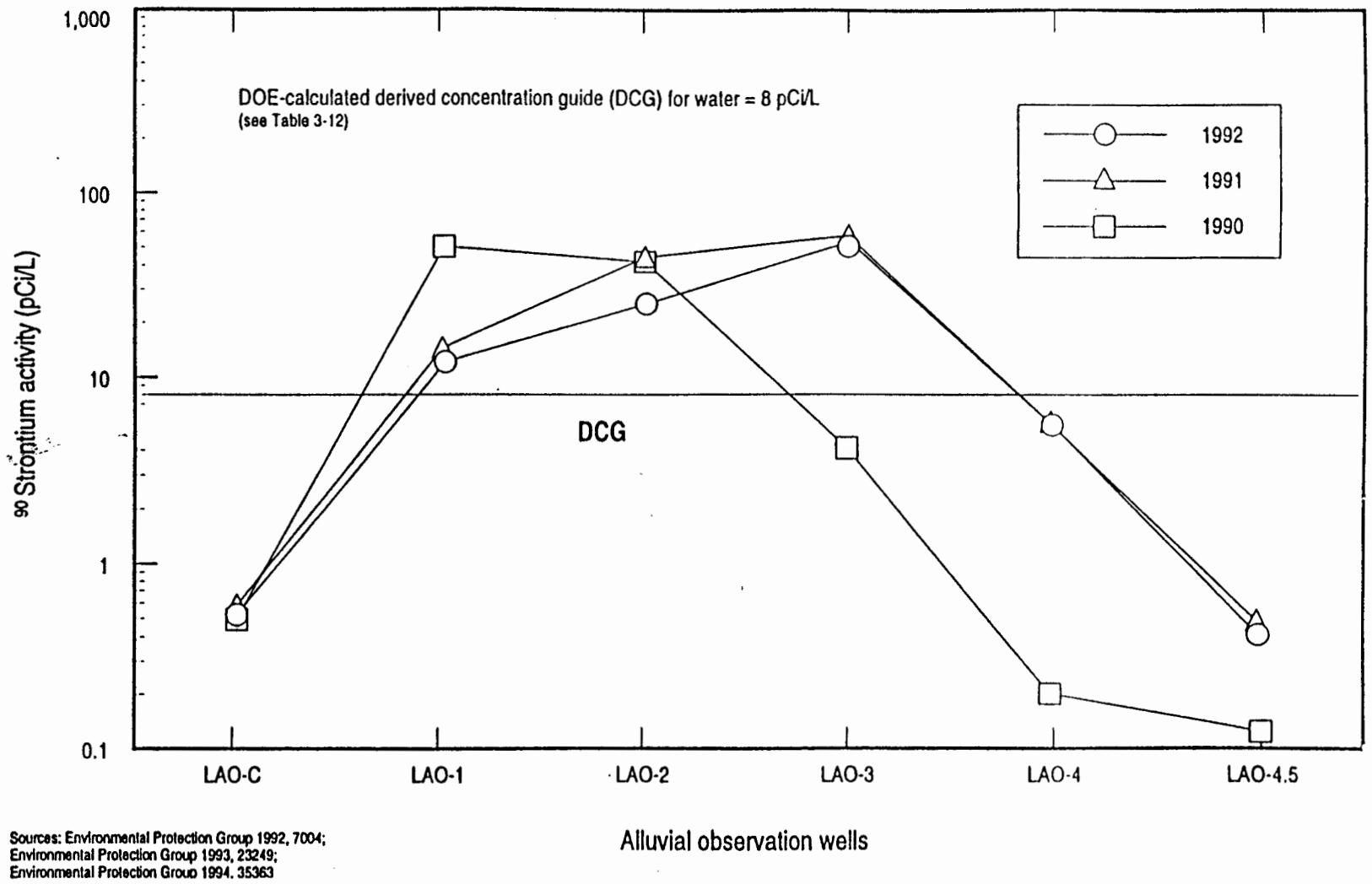
Strontium-90 in Los Alamos Canyon Alluvial Aquifer



Most points are interpolated from limited well data

(Longmire, et al., 1996)

Figure 23



Sources: Environmental Protection Group 1992, 7004;
Environmental Protection Group 1993, 23249;
Environmental Protection Group 1994, 35363

Figure 24: ^{90}Sr Activities in Alluvial groundwater

(OU-1049 Workplan, 1995)

activities measured in the alluvial observation wells from 1990 through 1992 (Longmire, et al., 1996a). This plot illustrates the downstream migration of the ^{90}Sr plume with activities decreasing over time in wells LAO-1 and LAO-2, but increasing in the wells located further downstream.

The main aquifer has shown some minor contaminant levels for chloride, nitrate, and tritium which may be a result of migration along improperly sealed boreholes of wells completed in the 1940's. Recent radiochemical analyses of main aquifer samples generally indicate no contamination based on reported analysis precision (LANL, 1995).

Induced Soil Erosion:

In the lower watershed areas, disturbances to the surface vegetation have been extensive only in the townsite portion and within the grounds of LANL research facilities. Most of these areas have been replaced by impermeable coverings such as paved roads and parking lots, buildings, and homes. Most of the increased surface runoff from these areas is diverted away from the canyon through the community storm sewer system. As previously mentioned, much of the current townsite and LANL development has occurred in areas that were already cleared for agriculture. LANL has minimized vegetation clearing during facility construction, and areas around buildings have been left to natural vegetation wherever possible (DOE, 1979). Because of the relatively abundant moisture at the elevations impacted by urbanization and LANL facility development, generally good vegetative ground cover prevails, and human induced erosion thus does not appear to be a significant problem in the watershed. In the upper watershed, even the steep (~40%) slopes of the ski area do not exhibit erosion problems because of the excellent ground coverage (est. > 90%) of the reseeded grasses. The only exception is perhaps in the degraded piñon-juniper woodland areas on the mesa-tops immediately adjacent to the canyon in the lower couple of miles of the watershed where observed poor soil conditions and lack of herbaceous ground cover is likely a result of overgrazing stresses prior to 1943. The active erosion that does continue to occur along the canyon slopes represents natural geomorphic processes that have shaped the current landscape over millennia.

A cursory erosion rate determination for the degraded piñon-juniper woodland mesa-top areas was performed using the modified universal soil loss equation (MUSLE):

$$A = R\,K\,(LS)\,(VM) \tag{3}$$

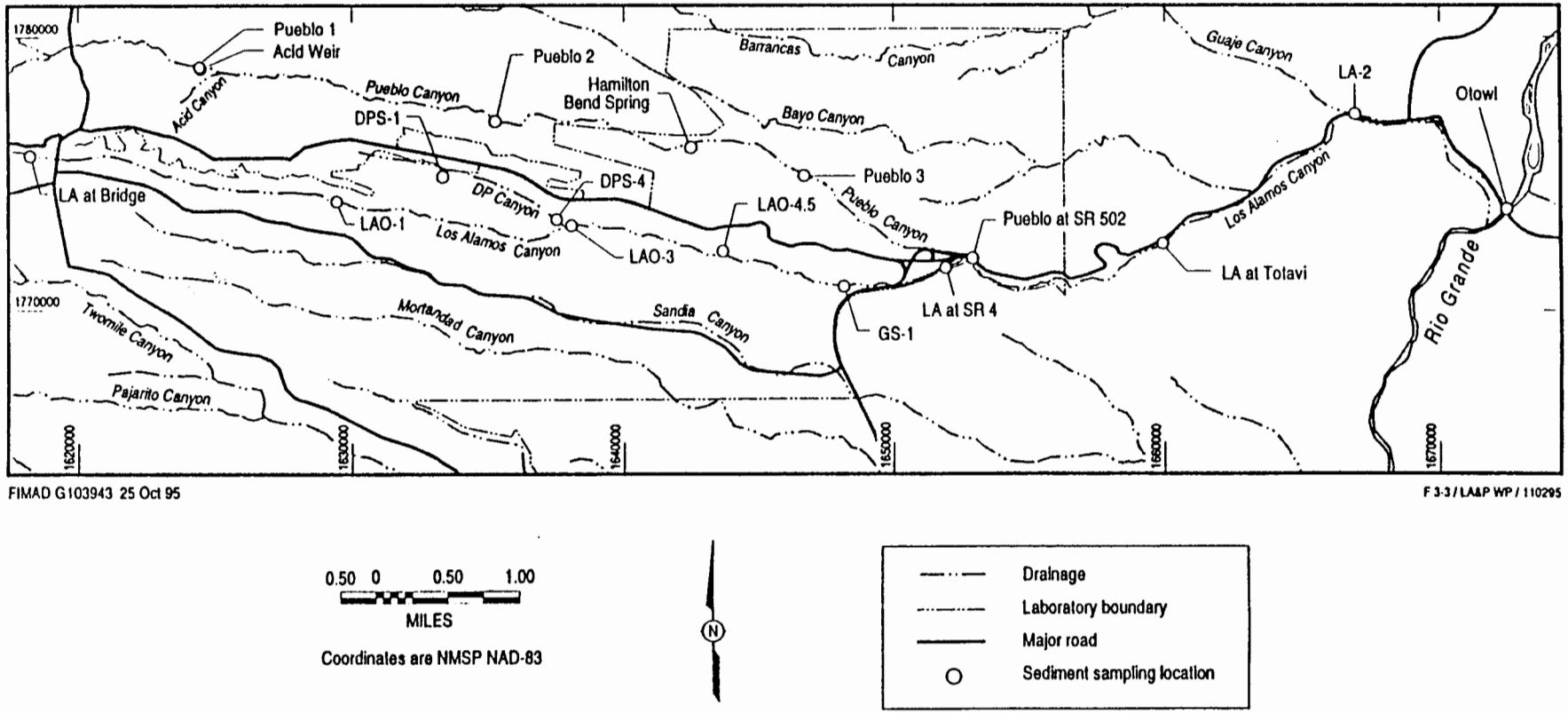
where A is the rate of soil loss (tons/ha/yr), R is the rainfall erosivity factor, K is the soil erodibility factor, LS is the topographic factor combining slope length and gradient, and VM is the vegetation management factor (Brooks, et al., 1991). Although much of the area of interest lies beyond the eastern mapped soils boundary (Figure 7), it is clear from personal observation and by extrapolating adjacent mapped soil trends that the soil type is combined Hackroy sandy loam/ Hackroy rock outcrop complex (Table 1). Parameter values were determined as follows: R = 60 (SCS, 1981), K = 0.20 (Table 2), LS = 0.22 (Brooks, et al., 1991, Eqn. 7.9; assuming avg. 5% slope, L=0.5), VM = 0.32 (Brooks, et al., 1991, Table 7.4; assuming a 50% 2 m brush canopy with 2% grass cover). The resultant determined erosion rate is 0.84 tons/ha/yr, equivalent to 2.1 tons/acre/yr. This is over twice the sustainable soil loss tolerance rate for this soil type (Table 2), indicating a moderate erosion problem in this area.

Contaminated Sediment Migration:

The LANL Environmental Protection Group (EPG) has collected and published environmental data on soils in the watershed since 1971. Soil sample locations are shown in Figure 25. Table B-5 (Appendix B) lists radionuclide contaminant levels in sediments collected from Los Alamos Canyon and DP Canyon between 1980 and 1982 (LANL, 1995). EPG reported that plutonium activity in the active channel west of State Route 4 varied seasonally by location and that ^{90}Sr levels in sediments are above background levels measured at the Otowi Bridge (Figure 2) but below regional background levels (Environmental Protection Group, 1985, 1986, 1987, 1988, 1989).

Purtyman, et al., (1990) reported that between 1975 and 1986, 57% of the plutonium that reached the Rio Grande was associated with suspended sediments, and that 40% was associated with bedload sediments, while 3% was in solution. Five of seven runoff events during the study resulted in transporting an estimated total of 600 μCi of plutonium to the Rio Grande.

Recent efforts to assemble a detailed regional plutonium budget for the Northern Rio Grande system documented the presence of plutonium from LANL sources at low concentrations in Rio Grande sediments (Graf, 1995). The mean plutonium concentration in Rio Grande bedload sediments



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0.50 0 0.50 1.00

MILES

Coordinates are NMSP NAD-83

N

Drainage

Laboratory boundary

Major road

Sediment sampling location

Figure 25: Sediment Sampling Locations

near Otowi where Los Alamos Creek discharges into the Rio Grande was reported at 0.011 pCi/g, while active bedload samples from Los Alamos Canyon stream sediments near Otowi had a mean level of 0.127 pCi/g. LANL contributions accounted for ~15% of the total plutonium budget in the Otowi vicinity, but only ~9% for the entire river system above Elephant Reservoir, the rest being derived from fallout contaminated sediments eroded from the general landscape. Graf (1995) found that most of the LANL contributions remain in storage along the river between Otowi and Peña Blanca, about 3 miles below Cochiti Reservoir. In as much as plutonium migration has only occurred since 1943 and the Cochiti Dam began impounding the sediments in 1973, an rough approximation of maximum travel time from the Los Alamos vicinity is thus ~35 miles over 30 years, or ~6100 ft/yr. The water, sediment, and total plutonium budget for Los Alamos Canyon from 1943 till 1986 is provided in Table B-6 (Appendix B).

A recent study by the LANL Environmental Restoration Group documented highly contaminated soils at TA-21 within the watershed (Figure 18) (Lu, et al., 1996). Radiological surveys in 1992 and 1993 showed levels of ^{241}Am, ^{137}Cs, ^{239,240}Pu, and ^{90}Sr exceeded soil Screening Action Levels (SAL), with ^{137}Cs activities ranging from 42.6 up to 3,226 pCi/g at a hot spot, up to 632 times greater than its SAL of 5.1 pCi/g. Samples collected in the drainage channel and near the confluence of DP Canyon with Los Alamos Canyon confirmed the migration of contaminated sediments downstream from the source area. The affected soils have clay and silt fractions primarily composed of montmorillonite and illite, which are weathering products of tuff. A laboratory column experiment demonstrated the strong, interlayer sorption of ^{137}Cs by the fine sediments with no observed leaching by synthetic groundwater or synthetic acid rainwater (Lu, et al., 1996).

Longmire et al., (1996a) conducted batch sorption and desorption experiments on soil and channel sediment samples from Los Alamos Canyon (TA-2, TA-21, TA-41; Figure 18). Sorption coefficients (Kd) for ^{90}Sr averaged 35.7 ml/g for soils and 21.4 ml/g for channel sediments. ^{90}Sr adsorption was found to vary dependently with organic matter content, whereas surface coatings of organic matter on soil and sediment particles restrict the availability of cation exchange sites in the clay minerals. Desorption experiments showed that approximately 30% of sorbed ^{90}Sr was desorbed from channel sediments, suggesting semireversible cation exchange as the dominant adsorption process (Kung, 1995). Using the average Kd for channel sediments, a retardation factor (Rf) of 102.3

for ^{90}Sr and a predicted migration rate of 2.7 m/yr was determined (Longmire, et al., 1996a). The currently observed widespread distribution of ^{90}Sr in alluvial sediments in Los Alamos Canyon thus suggests significant transport by sediment mobilization. The high peak flows, attributable to urban runoff, shown by the lower gage stream hydrograph (Figure 14) imply that the potential for surface contaminant redistribution is greatest in the lower watershed (Wilcox, et al., unpublished draft report).

Because of the high adsorption affinities the radionuclides have towards the fine grained sediments, most of the radiochemical contamination remains bound to the sediments and likely represents minimal risks to downstream receptors, especially at the low observed concentrations. In the case of plutonium, riverbed sediment concentrations are three orders of magnitude greater than in river water (Graf, 1995). However, the indication of semireversible cation exchange as a primary mechanism for ^{90}Sr sorption suggests that this may not be true for all radionuclides.

Nonetheless, it is clear that erosional processes are transporting radiochemical contamination, mainly as suspended sediment and bedload sediment, through the Los Alamos Canyon watershed and into the Rio Grande and have been for some time.

Biodiversity:

Recent ecological baseline studies by the LANL Biological Resources Evaluation Team of the Environmental Protection Group included the determination of biodiversity index values in the canyon utilizing aquatic macroinvertebrate census data (Foxx, 1995). Three sampling stations (each a 150 m stream reach) were monitored for aquatic macroinvertebrates monthly and assigned a biodiversity index (Wilhm, 1967):

$$D = \frac{S-1}{\ln N} \qquad (D = \text{diversity index; } S = \text{number of taxa; } N = \text{number of individuals}) \qquad (4)$$

A diversity index value of less than 1 indicates heavy pollution; a value between 1 and 3 indicates moderate pollution; and a value exceeding 3 is indicative of clean water (Foxx, 1995). Table 7 lists the average annual diversity index value for each of the three stations during the study period (station LA1 is furthest upstream, located in the upper canyon, while LA3 is furthest downstream, located in the middle canyon).

Table 7: Annual Avg. Macroinvertebrate Biodiversity

Year / Station	*LA1*	*LA2*	*LA3*
1993	3.66	1.64	1.81
1994	3.92	1.64	1.30

(Foxx, 1995)

The clear implication of these data is that the level of biodiversity decreases downstream. This could reflect the effects of increased stream pollutants associated with the urban/industrial setting of the Laboratory facilities on the macroinvertebrate community. Alternatively, the lower index values could result from the generally drier conditions of the streambed that progressively occur as one moves downstream. The streambed in the middle part of the canyon is dry much of the year, at least partly due to the effects of the Los Alamos Reservoir dam. Otherwise, while the average diversity index values for the upper stations were fairly to highly consistent over the two years, the lower station saw a relatively sharp 28% drop between 1993 and 1994. This was likely due to a drier climate in 1994, but is also indicative of the fragile state of aquatic biodiversity in the lower part of the watershed study area where anthropogenic influences are highest. In addition, station LA2 had a preponderance of Dipteran flies, rapid colonizers indicative of previous disturbance, while LA1 contained a variety of aquatic macroinvertebrate groups indicative of a healthy community (Foxx, 1995).

Fire Suppression Impacts:

As previously described, the forests in the watershed have accumulated increased fuel loads through the elimination of the previously prevalent high-frequency, low intensity fire regime. With greater tree density and smaller trunk size now prevalent, along with extensive dead forest litter, the current tendency is for low-frequency, high-intensity fires that result in severe adverse impacts to the forest ecosystem (Allen, 1989). This type of fire regime favors more severe crown fires over less damaging surface fires. For example, the 1977 La Mesa fire which burned over 15,000 acres in the Santa Fe National Forest and nearby Bandelier National Monument killed 80% of all the mature trees in its path (Albuquerque Journal, April 30, 1996). Studies of vegetation succession after the fire

showed many areas with 100% tree mortality rates (Foxx, 1995b). A result of a severe crown fire in the Los Alamos Canyon watershed would be to radically disrupt and exacerbate fragmentation of the forest ecosystem, placing severe stresses on its currently high carrying capacity and inherent biodiversity. This is perhaps the greatest threat to maintaining the health and integrity of the natural watershed ecosystems for continued beneficial use by wildlife, native biota, and humans.

The most significant threat to the watershed's economic base is that an uncontrollable crown fire in the watershed could sweep through the Los Alamos townsite and LANL facilities, damaging or destroying commercial, residential, and research infrastructure that currently exists mainly as patches of development in the forest matrix. The economic impact would be enormous, not to mention the threat to human life. Clearly such a scenario should be avoided, and management goals should seriously address this issue.

PROPOSED MANAGEMENT, RESEARCH, AND REHABILITATION ACTIVITIES:

Management of the watershed resources requires an integrated approach and should address all relevant components, including general ecosystem health, carrying capacity, sustainability and biodiversity, as well as economic viability, anthropogenic impacts, aesthetic and recreational values, and a rehabilitation program. The Los Alamos Canyon watershed has already been the subject of significant planning and management initiatives by both the DOE and USFS. Many commendable efforts by both entities have involved extensive characterization of natural systems and adverse anthropogenic impacts within the watershed, plus remedial actions addressing the most serious problems. Problem identification should be addressed with the input of the stakeholders in the watershed who currently benefit from its use; i.e. LANL management, USFS officials, and concerned public. Incorporating as many of the affected parties as possible in the planning process at the start will promote community involvement and acceptance of rehabilitation initiatives.

This section assesses the current problem areas that are relavent to the most urgent management issues for the watershed and focuses on proposed ideas for further research and rehabilitation efforts that would promote the improvement and maintenance of overall watershed health and viability.

Water Quality Issues:

Probably the foremost issue that management plans need to address is that of improving impaired water quality in the surface waters and alluvial groundwater in the watershed. This is because of the possibility that continued downward migration of radiochemical contaminants could eventually impact the main aquifer, the primary water supply source for both LANL and the community of Los Alamos. Also, downstream users such as the San Ildefonso Pueblo have a vested interest in seeing improved water quality from surface water discharges and groundwater flux from the watershed. Much of the background characterization research required to address the water quality issues has already been initiated by the LANL environmental restoration (ER) program. However, it appears that investigation of impacts in the upper watershed, outside of the LANL boundaries, has been negligible.

An integrated research plan for the watershed should incorporate water quality analyses from the streams above the reservoir, and especially near the ski area, to better assess conditions in the upper watershed area. Integration of this data with that collected by the LANL ER program will allow for a more complete quantification of contamination levels in the lower canyon.

Remediation of the water quality problems will be problematic, with the foremost solution being source elimination. This has already been enacted to a large degree with regards to the more serious contaminants, such as the radionuclides. Alleviating the NaCl input is more problematic, as runoff from the roads cannot be easily contained, and the elimination of the use of road salt altogether would likely be considered a public inconvenience. Perhaps the extensive use of berms deflecting direct runoff into the canyon could contain the majority of the salt on the mesa tops, but routing all runoff away from the canyon would be difficult, if not impossible.

The radionuclide contaminant of greatest concern is ^{90}Sr which exceeds EPA and DOE drinking water standards in the alluvial aquifer. A possible remediation effort could be some sort of pump and treat system. A cation exchange process similar to that used in water softeners could be employed to treat alluvial groundwater before releasing it into the generally dry streambed which would enhance riparian conditions downstream of the reservoir. Longmire, et al. (1996b) estimated that within the reach of the canyon between wells LAO-1 and LAO-4, approximately 5.5×10^{10} gallons (~169,000 acre-feet) equivalent to 481 pore volumes of water would have to be pumped and treated to achieve the MCL for ^{90}Sr. Other possible remediation alternatives are in-situ treatment or the use of

chemical barriers utilizing ion-selective materials such as zeolites to remove strontium from solution. Geochemical modeling suggests that the alluvial groundwater is undersaturated with respect to $SrCO_3$ and $SrSO_4$. Thus, coprecipitation of strontium with $BaSO_4$ using in-situ treatment with $BaCl_2$ could be effective to remove it from solution and immobilize it in the alluvial matrix (Longmire, et al. 1996b).

Chong (1995) provides data on operating costs for pump and treat systems utilized in remediation of leaking underground storage tank sites in New Mexico. A one-well system for the Casey Luna site incurred operating costs of ~$2,400/month. Assuming a pumping rate of 10 gpm from the alluvial aquifer results in a monthly volume of approximately 1.33 acre-feet, and it would take over 125,000 years to treat the necessary water volume within only the restricted reach referred to above. A thousand wells would do the job in a somewhat more reasonable 125 year time-span, but costs would exceed $3 million in current dollars. A cost/benefit analysis for pump and treat was not attempted because of the difficulty of quantifying the economic value of the benefits attained by improving water quality. The alluvial groundwater is not utilized as a water supply, and the value of improving its quality is currently a largely intangible one since uncertainties exist regarding the likelihood of contaminant migration to the lower main aquifer. Besides, the costs for this remediation technique appear excessively prohibitive, at least for ^{90}Sr treatment. Since the primary concern is to prevent possible contamination of the main aquifer, additional research efforts should be directed towards a better understanding of the dynamics of the subsurface hydrology regime to address this issue.

Contaminated Sediment Issues:

As described above, active erosional processes have moved substantial inventories of radionuclides bound to sediments from the watershed into the stream channels of downstream land owners and into the Rio Grande. Since reversible cation exchange reactions have been shown to be possible for ^{90}Sr, water contamination by distributed sediments may be a concern. Thus, elimination of these releases from the watershed should be a management goal. Physical removal of contaminated sediments from the watershed by mechanical excavation does not seem desirable because of the magnitude of the disturbance this would entail. Isolation of contaminated soils on-site may prove to be a viable strategy.

A recent study by the LANL ER Group tested the effectiveness of a multi-layer sand/gravel barrier in removing ^{137}Cs contaminated suspended sediments from solution using a laboratory column experiment (Lu, et al., 1996). The multi-layer barrier, designed to mimic filtration techniques commonly employed for drinking water treatment, was found to be highly effective in removing the contaminated sediments from suspension and immobilizing them in the fine gravel and coarse sand layers. The initial solution of hot spot soil particles in a suspension with 7.6% turbidity had a concentration of 418.2 pCi/g ^{137}Cs while no ^{137}Cs could be detected in the filtered water. Also, testing of zeolite resins showed up to 99% uptake of ^{137}Cs, suggesting that incorporation of such materials in barriers should be highly effective. A third method for preventing ^{137}Cs-contaminated sediment migration could utilize an erosion control web cover material, such as Miramat™, a three-dimensional web of bonded polypropylene or PVC monofilaments that protects soil particles from mobilization by runoff while allowing natural vegetation to establish (Lu, et al., 1996).

Economic analysis of costs and benefits of such remediation strategies was not attempted because of the difficulty of quantifying the economic value of eliminating contaminated sediments from downstream releases from the watershed and uncertainties about the total costs involved to achieve significant results.

Biodiversity Issues:

Management directives should address biodiversity because the results of a no management policy on the biodiversity of the watershed would likely be a general overall decline resulting from non-point source and point source pollutants affecting water quality in both surface water and groundwater, as well natural streamflow restriction in the middle and especially lower watershed areas. As previously discussed, these effects are more pronounced as one moves downstream (Foxx, 1995). A severe drought cycle could intensify these impacts on the already stressed ecosystem in the middle and lower watershed, and a chain reaction adversely impacting higher life forms (birds and small mammals) could be set off as the base of the food chain (insects) becomes overstressed. Opportunistic species would come to dominate the system, and the level of biodiversity would decline. The long-term carrying capacity and sustainability of the watershed ecosystem would be impaired by continued pollution inputs.

A possible management alternative for the watershed that could lessen the severity of some of these negative impacts would be to return natural streamflow to the middle and lower watershed areas. Though non-point source pollutants are difficult to control, water quality in the stream could be improved by allowing releases of water from storage in the reservoir. This would have a negative impact on the recreational value of the reservoir, however, especially in dry years. Thus, a balance must be sought between protecting the canyon ecosystem and allowing recreational enjoyment.

Extensive research already begun by LANL scientists on the distribution and condition of both vegetation and animal species should continue. Extending such research into the upper watershed would enhance the knowledge of background conditions and lead to better understanding of the impacts from the many anthropogenic disturbances prevalent in the lower watershed area. Further verification of adverse impacts on biodiversity in the watershed should initiate more urgent efforts to eliminate continued contaminant discharges into the watershed.

Fire Hazard Issues:

Management policies should address fire hazard issues because a likely result of no management policy is the eventual occurrence of a disastrous wildfire that would negatively impact a large part of the watershed ecosystem, severely constraining its current high level of biodiversity as well as intensifying erosion and contaminant release problems, and damaging or destroying valuable existing infrastructure. The costs of fighting such fires are extremely high. The 1977 La Mesa Fire cost over $4 million to put out in current dollars, a cost of approximately $280/acre (Albuquerque Journal, April 30, 1996). Fire fighting costs can be as high as $10 thousand/acre and if a crown fire develops, it is virtually impossible to control (Craig Allen, personal communication, 1996).

Possible avoidance initiatives include the use of selective thinning and prescribed burns to reduce the fuel load. A recent prescribed burn of ~15,000 acres cost about $100 thousand, a cost of approximately $7/acre (Albuquerque Journal, April 30, 1996). Typical prescribed burn costs are about $50/acre (Craig Allen, personal communication, 1996). Comparing the prescribed burning costs with the alternative fire fighting costs strongly suggests that prescribed burning is a more cost effective fire management strategy. More firebreak buffers may be advisable around significant infrastructure, achievable by clearing the trees away from nearby buildings. This would have the

immediate negative impact of degrading local aesthetic values however, and may likely prove unpopular with the public. A reconnaissance program to evaluate forest and woodland conditions throughout the watershed should be initiated to identify areas appropriate for such actions. A visible public education program could be useful to persuade concerned citizens of the need for such actions.

CONCLUSIONS:

The Los Alamos Canyon watershed has an abundant resource base, with very high values associated with its economic base (LANL and Los Alamos community infrastructure), as well as its predominant (88% of watershed) natural ecosystems. Grazing and logging have been restricted from the watershed for over 50 years now which has resulted in alleviating some previous impacts, but the change in fire regime over the last century has left the forests overburdened with heavy fuel loads that pose an enormous challenge to management of the watershed to maintain high values for ecological health and biodiversity, as well as economic prosperity, recreation opportunities, and aesthetic beauty. Planning for wildfire avoidance policies and infrastructure protection is imperative to insure the future status of these values.

The watershed has unique problems associated with the management of radionuclide contaminant transport by multiple pathways, with groundwater migration and suspended and bedload transport comprising the main processes of concern. These are issues that are currently under intense study by LANL scientists. Though contaminant levels beyond the watershed are low, it is desirable to restrict future releases beyond the watershed. Active research efforts directed towards more detailed characterization of subsurface hydrology and soil erosion/sediment transport dynamics should be priority efforts. Additional laboratory testing plus field scale testing of proposed remediation techniques is needed to assess their effectiveness.

Erosion plays an active role in the watershed landscape because of its deeply dissected canyon setting. Some anthropogenic induced erosion undoubtedly occurs, but relative to the magnitude of the natural erosion processes operating in the canyon, human impacts on erosion in the watershed are not a major issue.

In summation, the major issues for management of the Los Alamos Canyon watershed are:

- Protecting the water quality in the main aquifer from contamination by radionuclide migration from shallow and intermediate perched saturation zones.
- Containment of contaminated sediments in source areas and restricting transport beyond the watershed.
- Minimizing potential wildfire damage.

Supplementary issues include:

- Maintaining ecosystem health, integrity, and biodiversity.
- Implementing remediation efforts to lower contaminant levels in groundwater.
- Incorporating community involvement in watershed planning efforts to facilitate implementation of possibly unpopular policies (such as controlled burns).

Addressing these issues within a comprehensive management plan for the watershed should help to promote the continuation of current high resource values and be beneficial for all its uses, human and wild.

REFERENCES:

Albuquerque Journal North, April 30, 1996, Forest Service Had Proposed Controlled Burn, by Doug McClellan, Peter Eichstaedt, and Mike Taugher, pp. 1, 3.

Allen, Craig D., 1989, Changes in the Landscape of the Jemez Mountains, New Mexico, Ph.D. dissertation, University of California at Berkeley, 346 p.

Allen, Craig D., 1995, Ecological Patterns and Change in the Bandelier Landscape, unpublished draft, 85 p.

Allen, Craig D., Ramzi Touchan, and Thomas W. Swetnam, 1995, Landscape-Scale Fire History Studies Support Fire Management Action at Bandelier, Park Science, v. 15, no. 3, pp. 18-19.

Bogart, C., 1978, The Amphibians and Reptiles of the Los Alamos National Environmental Research Park, Los Alamos National Laboratory unpublished report.

Bowen, Brent R., 1990, Los Alamos Climatology, Los Alamos National Laboratory report LA-11735-MS.

Brooks, Kenneth N., Peter F. Ffolliott, Hans M. Gregersen, and John L. Thomas, 1991, *Hydrology and the Management of Watersheds*, Iowa State University Press, Ames, Iowa, 392 p.

Broxten, David E., P.A. Longmire, P.G. Eller, and D. Flores, 1995, Preliminary Drilling Results for Boreholes LADP-3 and LADP-4, in: D.E. Broxten and P.G. Eller eds., *Earth Science Investigations for Environmental Restoration-Los Alamos National Laboratory Technical Area 21*, pp. 91-109.

Chong, Sharon C., 1995, A Study of Soil and Groundwater Remediation Technologies in New Mexico, M.S. Thesis, University of New Mexico.

COE (Department of the Army, Albuquerque District, Corps of Engineers), 1991, Draft Los Alamos Dam Safety Report, 43 p.

DOE (U.S. Department of Energy), 1979, Final Environmental Impact Statement, Los Alamos Scientific Laboratory Site, Los Alamos, New Mexico.

Drever, J.I., 1988, *The Geochemistry of Natural Waters*, Second Edition, Prentice Hall, Inc., Englewood Cliffs, New Jersey.

Foxx, Teralene S., 1995, Ecological Baseline Studies in Los Alamos and Guaje Canyons, County of Los Alamos, New Mexico, A Two-Year Study, Los Alamos National Laboratory report LA-13065-MS, 283 p.

Foxx, Teralene S., 1995b, Vegetation Succession After the La Mesa Fire at Bandelier National Monument, in: *Proceedings of the 1994 Symposium on the La Mesa Fire*, in press.

Gallaher, B., Sept. 11, 1995, Groundwater Velocities in Los Alamos Canyon, Los Alamos National Laboratory Memorandum ESH-18/WQ&H-95-409.

Gardner, J.N., Fraser Goff, Sammy Garcia, and R.C. Hagan, 1986, Stratigraphic relations and lithologic variations in the Jemez volcanic field, New Mexico, *Journal of Geophysical Research*, v. 91, no. B2, p. 1763-1778.

Graf, William L., 1994, *Plutonium and the Rio Grande-Environmental Change and Contamination in the Nuclear Age*, Oxford University Press, NY, NY, 329 p.

Kung, S., 1995, Sorption and desorption of cesium and strontium on TA-2 and TA-41 soils: Progress Report to Field Unit 4, Environmental Restoration Project, Los Alamos National Laboratory, 164 p.

LANL (Los Alamos National Laboratory), 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, New Mexico, Los Alamos National Laboratory Report LA-8890-ENV.

LANL Environmental Protection Group, 1985, 1986, 1987, 1988, 1989, Environmental Surveillance at Los Alamos annual reports.

LANL (Los Alamos National Laboratory), 1987, Water Supply at Los Alamos During 1986, Los Alamos National Laboratory Report LA-11046.

LANL Environmental Protection Group, 1992, Environmental Surveillance at Los Alamos annual report.

LANL Environmental Protection Group, 1994, Environmental Surveillance at Los Alamos annual report.

LANL Environmental Protection Group, 1995, Environmental Surveillance at Los Alamos during 1993, Los Alamos National Laboratory report LA-12973-ENV.

LANL Work Plan for 1049, 1995, Los Alamos National Laboratory report.

Longmire, Patrick A., Stephen Kung, Jeremy M. Boak, Andrew I. Adams, Florie Caporuscio, and Robert N. Gray, 1996a, Aqueous Geochemistry of upper Los Alamos Canyon, Los Alamos, New Mexico, New Mexico Geological Society Guidebook, in press.

Longmire, Patrick A., Stephen Kung, Jeremy M. Boak, Andrew I. Adams, and Florie Caporuscio, 1996b, Mobility of Strontium-90 in Alluvial Groundwater, Los Alamos Canyon: Implications for Pathway Analysis, unpublished presentation.

Lu, Ningping, Caroline F.V. Mason, and William R.J.R. Turney, 1996, Characterization and Immobilization of Cesium-137 in Soil at Los Alamos National Laboratory, Los Alamos National Laboratory report LA-UR-96-1322, 13 p.

McLin, Stephen G., 1992, Determination of 100-Year Flood Plain Elevations at Los Alamos National Laboratory, Los Alamos National Laboratory report LA-12195-MS, 83 p.

Purtyman, W.D., 1973, Regional Survey of Tritium in Surface and Ground Water in the Los Alamos Area, New Mexico, August, 1966 through May, 1969, Los Alamos National Laboratory report LA-5234-MS, 8 p.

Purtyman, W. D., 1995, Geologic and hydrologic records of observation wells, test holes, test wells, supply wells, springs, and surface water stations in the Los Alamos area, Los Alamos National Laboratory report LA-12883-MS, 339 p.

Purtyman, William D., Richard Peters, and Max N. Maes, 1990, Transport of Plutonium in Snowmelt Run-Off, Los Alamos National Laboratory report LA-11795-MS, 339 p.

Reneau, S.L., 1995, Geomorphic Studies at DP Mesa and Vicinity, in: *Earth Science Investigation for Environmental restoration-Los Alamos National Laboratory Technical Area 21*, Los Alamos National Laboratory report LA-12934-MS, pp. 65-92.

Reneau, Steven L., Eric V. McDonald, Jamie N. Gardner, Thomas R. Kolbe, John S. Carney, Paula M. Watt, and Patrick A. Longmire, Erosion and Deposition on the Pajarito Plateau, New Mexico, and Implications for Geomorphic Responses to Late Quaternary Climatic Changes, New Mexico Geological Society Guidebook, in press.

SCS (U.S. Dept. of Agriculture Soil Conservation Service), 1981, R Factor Values for the Universal Soil Loss Equation, National Oceanic and Atmospheric Administration Atlas 2, Vol. IV.

Travis, J.R., 1992, Atlas of the Breeding Birds of Los Alamos County, New Mexico, Los Alamos National Laboratory report LA-112206.

USFS (U.S. Forest Service), 1990, Integrated Riparian Evaluation Guide, Intermountain Region, Ogden, Utah, selected pages.

USFS (U.S. Forest Service), 1994, Five Year Review of the Santa Fe National Forest Plan: 1988-1992 Monitoring Results and Timber Program Reanalysis, 157 p.

USGS (U.S. Geological Survey), 1995, Water Resources Data, New Mexico, Water Year 1994, U.S. Geological Survey Water Data Report NM-94-1, p. 133.

Viessman, Jr., Warren, Gary L. Lewis and John W. Knapp, 1989, *Introduction to Hydrology*, 3rd ed., Harper Collins, NY, NY, 779 p.

Wilcox, Bradford P., David W. Davenport, Shannon Smith, and John Ferris, Investigations of Surface Hydrology in Los Alamos Canyon, unpublished draft report, 12 p.

Wilhm, J.L., 1967, Comparison of Some Diversity Indices Applied to Populations of Benthic Macro-invertebrates in a Stream Receiving Organic Waste, Journal WPCF, no. 39, pp. 1673-1683.

Appendix A

Vegetation, Insect and Animal Species Listings

Table A-1

Vegetation Species in Los Alamos Canyon

Family	Scientific Name	Common Name	Indicator Status[a]
Aceraceae	*Acer glabrum neomexicanum*	New Mexico maple	Facultative[b]
Amaranthaceae	*Amaranthus retroflexus*	Pigweed	
Anacardiaceae	*Rhus radicans*	Poison ivy	
	R. trilobata	Shunkbush sumac	
Berberidaceae	*Berberis fendleri*	Colorado barberry	
Betulaceae	*Betula occidentalis*	Birch	Faculatative wetland[c]
Boraginaceae	*Cryptantha jamesii*	James hiddenflower	
	Lithospermum multiflorum	Puccoon	
Cactaceae	*Coryphantha vivipara*	Pincushion cactus	
	Opuntia spp.	Prickly pear cactus	
Capparidacieae	*Polanisia trachysperma*	Clammyweed	
Caryophyllaceae	*Arenaria fendleri*	Fendler's sandwort	
Celestraceae	*Pachystima myrsinites*	Myrtle boxleaf	Facultative
Ceratophyllaceae	*Clematis pseudoalpina*	Rocky Mountain clematis	
Chenopodiaceae	*Atriplex canescens*	Four-wing saltbush	Facultative
	Chenopodium album	Lamb's quarters	
	C. fremontii	Fremont goosefoot	
	C. graveolens	Chenopodium	
	Kochia scoparia	Summer cypress	
	Salsola iberica	Russian thistle	
Compositae	*Achillea lanulosa*	Yarrow	
	Ambrosia coronopifolia	Ragweed	
	Antennaria parvifolia	Pussytoes	
	Artemisia carruthii	Wormwood	
	A. dracunculus	False tarragon	
	A. franserioides	Ragweed sagebrush	
	A. frigida	Estafiata	
	A. ludoviciana	Wormwood	
	A. tridentata	Big sagebrush	
	Bahia dissecta	Wild chrysanthemum	
	Brickellia spp.	Bricklebush	
	Chrysopsis foliosa	Golden aster	
	Chrysothamnus nauseosus	Rubber rabbitbrush	
	Cirsium sp.	Thistle	
	Conyza canadensis	Horseweed	Facultative upland[d]
	Erigeron flagellaris	Fleabane	
	E. divergens	Fleabane daisy	
	Eupatorium herbaceum	Throughwort	
	Franseria confertifolia	Bursage	

a. Status of whether species occurs wholly or partially in a wetland or nonwetland area is given, if available.

b. Facultative means equally likely to occur in wetlands or nonwetlands (estimated probability 34–66%).

c. Facultative wetland means usually occurs in wetlands (estimated probability 67–99%) but occasionally found in nonwetlands.

d. Facultative upland means usually occurs in nonwetlands (estimated probability 67–99%) but occasionally found in wetlands (estimated probability 1–33%).

Table A-1 (continued)

Vegetation Species in Los Alamos Canyon

Family	Scientific Name	Common Name	Indicator Status[a]
Compositae (continued)	*Gaillardia pulchella*	Firewheel	
	Grindelia aphanactis	Gumweed	
	Gutierrezia sarothrae	Snakeweed	
	Haplopappus spinulosus	Spiny goldenweed	
	Helianthus annuus	Sunflower	Facultative[b]
	Hymenopappus filifolius	Yellow cut-leaf	
	H. argentea	Perky sue	
	H. richardsonii	Bitterweed	
	Iva spp.	Marsh-elder	Facultative
	Senecio sp.	Groundsel	
	Solidago spp.	Goldenrod	
	Taraxacum officinale	Dandelion	Facultative upland[c]
	T. trifidum	Greenthread	
	Townsendia exscapa	Easter daisy	
	Tragopogon dubius	Salisfy, Goatsbeard	
	Verbesina encelioides	Crownbeard	Facultative
	Viguiera multiflora	Showy goldeneye	
	Xanthium strumarium	Cocklebur	Facultative
Convolvulaceae	*Ipomoea coccinea*	Star glory	Facultative
Cornaceae	*Cornus stolonifera*	Dogwood	Facultative wetland[d]
Cruciferae	*Descurainia* sp.	Mustard	
	Erysimum capitatum	Western wallflower	
	Lesquerella intermedia	Bladderpod	
Cupressaceae	*Juniperus monosperma*	One-seeded Juniper	
	J. scopulorum	Rocky Mountain juniper	
Cyperaceae	*Carex* spp.	Sedge	
Eleagnaceae	*Eleagnus angustifolia*	Russian olive	Facultative wetland
Ericaceae	*Arctostaphylus uva-ursi*	Bearberry	
Euphorbiaceae	*Croton texensis*	Doveweed	
	Euphorbia dentata	Spurge	
Fagaceae	*Quercus gambelii*	Gambel oak	
Geraniaceae	*Erodium cicutarium*	Filaree	
	Geranium caespitosum	James geranium	
Gramineae	*Agropyron smithii*	Western wheatgrass	Facultative
	Andropogon scoparius	Little bluestem	
	Aristida spp.	Three-awn	
	Blepharoneuron tricholepsis	Pine dropseed	
	Bouteloua eriopoda	Black grama	
	Bouteloua gracilis	Blue grama	

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c. Facultative upland means usually occurs in nonwetlands (estimated probability 67–99%) but occasionally found in wetlands (estimated probability 1–33%).

d. Facultative wetland means usually occurs in wetlands (estimated probability 67–99%) but occasionally found in nonwetlands.

Table A-1 (continued)

Vegetation Species in Los Alamos Canyon

Family	Scientific Name	Common Name	Indicator Status[a]
Gramineae (continued)	*Bromus anomalus*	Nodding brome	
	B. inermis	Smooth brome	
	B. marginatus	Mountian brome	
	B. tectorum	Downy chess	
	Dactylis glomerata	Orchard grass	
	Elymus canadensis	Wild rye	Facultative[b]
	Festuca octoflora	Six-weeks fescue	
	Hilaria jamesii	Galleta	
	Hordeum sp.	Barley	Facultative
	Muhlenbergia montana	Mountain muhly	
	M. torreyi	Ring muhly	
	Oryzopsis asperifolia		
	Oryzopsis hymenoides	Indian ricegrass	Facultative upland[c]
	Phleum pratense	Common timothy	Facultative upland
	Poa fendleriana	Mutton grass	
	Poa spp.	Bluegrass	
	Sitanion hystrix	Bottlebrush squirreltail	
	Sporobolus cryptandrus	Sand dropseed	Facultative upland
	Stipa spp.	Needle and thread	
Labiateae	*Monarda pectinata*	Ponymint	
Leguminosae	*Lupinus caudatus*	Lupine	
	Melilotus albus	White sweet clover	Facultative upland
	Melilotus officinalis	Yellow sweet clover	Facultative upland
	Petalostemum spp.	Clover	
	Robinia neomexicana	New Mexico locust	
	Thermopsis pinetorum	Big golden-pea	
	Vicia americana	American vetch	
Liliaceae	*Allium cernuum*	Nodding onion	
	Yucca baccata	Banana yucca	
Linaceae	*Linum neomexicana*	New Mexico yellow flax	
Loasaceae	*Mentzelia pumila*	Stickleaf	
Nyctaginaceae	*Mirabalis multiflora*	Wild four o'clock	
	M. oxybaphoides	Vining four o'clock	
Oleaceae	*Forestiera neomexicana*	New Mexico olive	Facultative upland
Onagraceae	*Oenothera* spp.	Evening primrose	
Pinaceae	*Abies concolor*	White fir	
	Picea pungens	Blue spruce	Facultative
	Pinus edulis	Pinon pine	
	P. flexilis	Limber pine	
	P. ponderosa	Ponderosa pine	Facultative upland
	Pseudotsuga menziesii	Douglas fir	

a. Status of whether species occurs wholly or partially in a wetland or nonwetland area is given, if available.

b. Facultative means equally likely to occur in wetlands or nonwetlands (estimated probability 34–66%).

c. Facultative upland means usually occurs in nonwetlands (estimated probability 67–99%) but occasionally found in wetlands (estimated probability 1–33%).

Table A-1 (continued)

Vegetation Species in Los Alamos Canyon

Family	Scientific Name	Common Name	Indicator Status
Plantaginaceae	*Plantago* sp.	Plantain	
Polemoniaceae	*Ipomopsis aggregata*	Skyrocket	
	Ipomopsis longiflora	Blue skyrocket	
Polygonaceae	*Eriogonum jamesii*	Antelope sage	
	E. leptophyllum	Wild buckwheat	
	Rumex spp.	Dock	
Polypodiaceae		Fern	
Portulacaceae	*Portulaca* sp.	Purslane	
Ranunculaceae	*Clematis ligusticifolia*	Western's virgin bower	Facultative[b]
	Clematis pseudoalpina	Rocky Mountain clematis	
	Delphinium sp.	Larkspur	
	Thalictrum fendleri	Fendler meadowrue	Facultative upland[c]
Rosaceae	*Cercocarpus montanus*	Mountain mahogany	
	Fallugia paradoxa	Apache plume	
	Fragaria americana	Wild strawberry	
	Potentilla pulcherrima	Cinquefoil	
	Rosa woodsii	Wild rose	Facultative upland
	Rubus strigosus	Wild raspberry	Facultative
Rutaceae	*Ptelea trifoliata*	Narrowleaf hoptree	Facultative upland
Salicaceae	*Populus tremuloides*	Aspen	Facultative upland
	P. angustifolia	Narrowleaf cottonwood	Facultative wetland[d]
	Salix spp.	Willow	
Saxifragaceae	*Jamesia americana*	Cliffbush	Facultative upland
	Philadelphus microphyllus	Mockorange	
	Ribes cereum	Wax current	
Scrophulariaceae	*Castilleja integra*	Foothills paintbrush	
	Penstemon barbatus	Scarlet bugler	
	P. secundiflorus	Beardtongue	
	P. virgatus	Variegated penstemon	Facultative upland
	Verbascum thapsus	Mullein	
Solanaceae	*Solanum nigrum*	Black nightshade	
	Physalis foetens	Groundcherry	
Ulmaceae	*Ulmus* sp.	Elm	
Umbelliferae	*Pseudocymopterus montanus*	Yellow mountain parsley	
Valerianaceae	*Valeriana acutiloba*	Valeriana	
Vitaceae	*Parthenocissus inserta*	Virginian creeper	

a. Status of whether species occurs wholly or partially in a wetland or nonwetland area is given, if available.

b. Facultative means equally likely to occur in wetlands or nonwetlands (estimated probability 34–66%).

c. Facultative upland means usually occurs in nonwetlands (estimated probability 67–99%) but occasionally found in wetlands (estimated probability 1–33%).

d. Facultative wetland means usually occurs in wetlands (estimated probability 67–99%) but occasionally found in nonwetlands

(Foxx and Hoard 1984, 50041; Martin and Hutchins 1980, 50040

Table A-2:

Terrestrial Arthropod Species

Terrestrial Insects Found on Laboratory Property as of December 1994		
Order	**Family**	**Common Name**
Thysanura (bristletails)	Lepismatidae	Silverfish
	Machilidae	Jumping bristletail
Collembola (springtails)	Sminthuridae	Globular springtail
	Entomobryidae	Slender springtail
	Isotomidae	Smooth springtail
	Hypogastruridae	Elongate-bodied springtail
Odonata (dragonflies and damselflies)	Aeshnidae	Darner
	Libellulidae	Common skimmer
	Coenagrionidae	Narrow-winged damselfly
	Gomphidae	Clubtail
Phasmida (walkingsticks)	Heteronemiidae	Common walkingstick
Orthoptera (grasshoppers and crickets)	Acrididae	Short-horned grasshopper
	Gryllacrididae	Camel cricket
	Gryllidae	True cricket
Plecoptera (stoneflies)	Perlidae	Common stonefly
Dermaptera (earwigs)	Forficulidae	Common earwig
Thysanoptera (thrips)	Thripidae	Common thrip
Hemiptera (true bugs)	Belostomatidae	Giant water bug
	Miridae	Plant bug
	Reduviidae	Assassin bug
	Phymatidae	Ambush bug
	Lygaeidae	Seed bug
	Cydnidae	Burrower bug
	Scutelleridae	Shield-backed bug
	Pentatomidae	Stink bug
	Anthocoridae	Minute pirate bug
	Coreidae	Squash bug
	Nabidae	Damsel bug
Homoptera (cicadas and kin)	Cicadidae	Cicada
	Aphididae	Aphids
	Cercopidae	Spittlebugs
	Cicadellidae	Leafhoppers
	Coccidaea	Soft scales
	Delphacidae	Planthoppers
	Eriosomatidae	Gall-making aphids
	Psyllidae	Jumping plantlice
Neuroptera (net-veined insects)	Myrmeleontidae	Antlion
	Hemerobiidae	Brown lacewings
	Raphidiidae	Snakefly

Table A-2: (continued)

Terrestrial Arthropod Species

Terrestrial Insects Found on Laboratory Property as of December 1994		
Order	**Family**	**Common Name**
Coleoptera (beetles)	Cicindelidae	Tiger beetle
	Carabidae	Ground beetle
	Silphidae	Carrion beetle
	Lampyridae	Firefly
	Cantharidae	Soldier beetle
	Lycidae	Net-winged beetle
	Buprestidae	Metallic wood-boring beetle
	Staphylinidae	Rove beetle
	Erotylidae	Pleasing fungus beetle
	Nitidulidae	Sap beetle
	Coccinellidae	Ladybird beetle
	Tenebrionidae	Darkling beetle
	Meloidae	Blister beetle
	Cerambycidae	Long-horned beetle
	Lucanidae	Stag beetle
	Scarabaeidae	Scarab beetle
	Chrysomelidae	Leaf beetle
	Curulionidae	Weevil
	Dermestidae	Dermestid beetle
Lepidoptera (butterflies and moths)	Papilionidae	Swallowtail
	Lycaenidae	Copper
	Hesperiidae	Skipper
	Pieridae	White, sulphur, and orange
	Nymphalidae	Brush-footed butterfly
	Satyridae	Satyr, nymph, and artic
	Noctuidae	Noctuid moth
	Sphingidae	Sphinx moth
	Saturniidae	Giant silkworm moth
	Gelechiidae	Gelechiid moth
	Geometridae	Measuring worms
	Pterophoridae	Plume moth
Diptera (flies)	Tabanidae	Horseflies and deer flies
	Therevidae	Stiletto fly
	Asilidae	Robber fly
	Bombyliidae	Bee fly
	Syrphidae	Hover fly
	Tachinidae	Tachinid fly
Siphonaptera (fleas)	Pulicidae	Dog fleas
Hymenoptera (bees, ants, and wasps)	Ichneumonidae	Ichneumonid wasp
	Cynipidae	Gall wasp
	Mutillidae	Velvet ant
	Scoliidae	Scoliid wasp
	Formicidae	Ant
	Pompilidae	Spider wasp
	Eumenidae	Euminid wasp
	Vespidae	Vespid wasp
	Sphecidae	Sphecid wasp
	Halictidae	Metallic wasp
	Megachilidae	Leafcutting bee
	Apidae	Honey bees and bumble bees

Table A-2: (continued)

Terrestrial Arthropod Species

Noninsect Terrestrial Arthropods Found on Laboratory Property as of December 1994	
Class/Order	**Family**
Chilopoda (centipedes)	Geophilidae Lithobiidae
Diplopoda (millipedes)	Julidae
Arachnida/Acarina (spiders and mites)	Anystis Bdellidae Ascidae Bryobiidae Calligonellidae Cryptognathidae Cunaxidae Erythraeidae Eupodidae Gymnodamaeidae Laelapidae Nanorchestidae Paratydaeidae Phytoseiidae Rhagidiidae Rhaphignathidae Scutacaridae Stigmaeidae Stigmaeidae Tenuipalpidae Terpnacaridae Trombidiidae Tydeidae Tarsonemidae Zerconidae
Archnida/Araneida	Agelenidae Amaurobiidae Anyphaenidae Araneidae Clubionidae Dictynidae Gnaphosidae Hahniidae Linyphiidae
Archnida/Araneida	Lycosidae Micryphantidae Miryphantidae Oonopidae Pholcidae Tetragnathidae Salticidae Theridiidae Thomisidae
Arachnida/Opiliones	Phalangiidae

Table A-3

Reptile and Amphibian Species in Los Alamos Canyon

Family	Scientific Name	Common Name
Bufonidae	*Bufo woodhousei*	Woodhouse toad
Colubridae	*Hypsiglena torquata*	Night snake
	Masticophis taeniatus	Stripped whipsnake
	M. flagellum	Coachwhip
	Opheodrys vernalis	Smooth green snake
	Pituophis melanoleucus	Gopher snake
	Thamnophis elegans	Western terestrial garter snake
	Thamnophis sirtalis	Common garter snake
Hylidae	*Hyla arenicolor*	Canyon treefrog
Iguanidae	*Crotaphytus collaris*	Common collared lizard
	Phrynosoma douglassi	Short-horned lizard
	Sceloporus undulatus	Eastern fence lizard
	Urosaurus ornatus	Tree lizard
Pelobatidae	*Scaphiopus multiplicatus*	Southern spadefoot
Scinicidae	*Eumeces multivirartus*	Many-lined skink
Teiidae	*Cnemidophorus velox*	Plateau stripped whiptail
Viperidae	*Crotalus atrox*	Western diamonback rattlesnake
	Crotalus viridis	Western rattlesnake

(Bogart circa 1978, 50038)

Table A-4

Bird Species in Los Alamos Canyon

Family	Scientific Name	Common Name
Accipitridae	*Accipiter cooperii*	Cooper's hawk
	Accipiter gentilis	Northern goshawk
	Buteo albonatus	Zone-tailed hawk
	B. jamaicensis	Red-tailed hawk
Aegithalidae	*Psaltriparus minimus*	Bushtit
Apodidae	*Aeronautes saxatalis*	White-throated swift
Caprimulgidae	*Chordeiles minor*	Common nighthawk
	Phalaenoptilus nuttallii	Common poorwill
Carthartidae	*Cathartes aura*	Turkey vulture
Columbidae	*Columba fasciata*	Band-tailed pigeon
	Zenaida macroura	Morning dove
Corvidae	*Agelaius phoeniceus*	Red-winged blackbird
	Amphelocoma coerulescens	Scrub jay
	Corvus corax	Common raven
	Cyanocitta stelleri	Steller's jay
	Euphagus cyanocephalus	Brewer's blackbird
	Gymnorhinus cyanocephalus	Pinon jay
	Nucifraga columbiana	Clark's nutcracker
	Pica pica	Black-billed magpie
Emberizidae	*Calamospiza grammacus*	Lark sparrow
	Carduelis pinus	Pine siskin
	Coccothraustes vespertinus	Evening grosbeak
	Dendroica coronata	Yellow-rumped warbler
	D. digrescens	Black-throated gray warbler
	D. gracial	Grace's warbler
	D. petechia	Yellow warbler
	Icterus galbula	Northern oriole
	Icterus spurius	Orchard oriole
	Junco hyemalis	Dark-eyed junco
	Loxia curvirostra	Red crossbill
	Melospiza melodia	Song sparrow
	Molothrus aster	Brown-headed cowbird
	Oporornis tolmiei	MacGillivray's warbler
	Passer domesticus	House sparrow
	Passerina cyanea	Indigo bunting
	P. amoena	Lazuli bunting
	Pheucticus melanocephalus	Black-headed grosbeak
	Pipilo chlorurus	Green-tailed towhee
	P. fuscus	Canyon towhee
	P. erythrophthalmus	Rufous-sided towhee
	Piranga flava	Hepatic tanager
	P. ludoviciana	Western tanager
	Pooecetes gramineus	Vesper sparrow
	Spizella passerina	Chipping sparrow
	Sturnella neglecta	Western meadowlark
	Vermivora celata	Orange-crowned warbler
	Vermivora virginiae	Virginia's warbler
Falconidae	*Falco sparverius*	American kestrel

Table A-4 (continued)

Bird Species in Los Alamos Canyon

Family	Scientific Name	Common Name
Fringillidae	*C. psaltria*	Lesser goldfinch
	Carpodacus cassinii	Cassin's finch
	C. mexicanus	House finch
	Guiraco caeulea	Blue grosbeak
	Hesperiphona vespertina	Evening grosbeak
	Loxia curvirostra	Red crossbill
Hirundinidae	*Hirundo pyrrhonota*	Cliff swallow
	Tachycineta thalassina	Violet-green swallow
Muscicapidae	*Catharus guttatus*	Hermit thrush
	Myadestes townsendii	Townsend's solitaire
	Polioptila caerulea	Blue-gray gnatcatcher
	Sialis currucoides	Mountain bluebird
	S. mexicana	Western bluebird
	Turdus migratorius	American robin
Paridae	*Parus gambeli*	Mountain chickadee
	P. inornatus	Plain titmouse
Picidae	*Colaptes auratus*	Northern flicker
	Melanerpes formicivorus	Acorn woodpecker
	M. lewis	Lewis' woodpecker
	Picoides villosus	Hairy woodpecker
	P. pubescens	Downy woodpecker
	P. tridactylus	Northern three-toed woodpec
	Sphyrapicus thyroideus	Williamson's sapsucker
Rallidae	*Rallus limicola*	Virginia rail
Sittidae	*Certhia americana*	Brown creeper
	Sitta carolinensis	White-breasted nuthatch
	S. pygmaea	Pygmy nuthatch
Sturnidae Trochilidae	*Sturnus vulgaris*	European starling
	Archilocus alexandri	Black-chinned hummingbird
	Selasphorus platycercus	Broad-tailed hummingbird
	S. rufus	Rufous hummingbird
Troglodytidae	*Catherkes mexicanus*	Canyon wren
	Salpinctes obsoleuts	Rock wren
	Thromanes bewickii	Bewick's wren
	Troglodytes aedon	House wren
Tyrannidae	*Contopus borealis*	Olive-sided flycatcher
	Contopus sordidulus	Western wood-pewee
	Western wood-pewee	Hammond's flycatcher
	E. oberholseri	Dusky flycatcher
	E. occidentalis	Cordilleran flycatcher
	Empidonax wrightii	Gray flycatcher
	Myiarchus cinerascens	Ash-throated flycatcher
	Sayornis saya	Say's Phoebe
	Tyrannus vociferans	Cassin's kingbird
Tytonidae	*Buto virginianus*	Great horned owl
	Glaucidium gnoma	Northern pygmy owl
Vireonidae	*Vireo gilvus*	Warbling vireo
	V. solitarius	Solitary vireo

(Travis 1992, 12015; Bird surveys of Los Alamos National Laboratory 1986, 1987, and 1988; Foxx et al.

Table A-5

Mammal Species in Los Alamos Canyon

Family	Scientific Name	Common Name	Source
Canidae	*Canis latrans*	Coyote	b
	Vulpus vulpus	Red fox	b
Cervidae	*Cervus elaphus*	Elk	b
	Odocoileus hemionus	Mule deer	b
Cricetidae	*Clethrionomys gapperi*	Boreal redback vole	d
	Neotoma mexicana	Mexican woodrat	a,b,d,e,f,g
	Microtus longicaudus	Long-tailed vole	f,g
	M. montanus	Montane vole	d
	M. pennsylvanicus	Meadow vole	a,e
	Peromyscus boylii	Brush mouse	d
	P. difficilis	Rock mouse	
	P. leucopus	White-footed mouse	d,f
	P. maniculatus	Deer mouse	a,d,e,f,g
	P. trueii	Pinon mouse	a,e,f
	Reithrodontomys megalotis	Western harvest mouse	a,d,e,f
	Sigmodon hispidus	Cotton rat	a
Erethizontidae	*Erethizon dorsatum*	Porcupine	b
Felidae	*Felis concolor*	Mountain lion	b
	Lynx rufus	Bobcat	b
Geomyidae	*Thomomys bottae*	Bottae's pocket gopher	a,e
Heteromyidae	*Perognathus flavus*	Silky pocket mouse	f
	Perognathus intermedius	Rock pocket mouse	f
Leporidae	*Sylvilagus audubonii*	Desert cottontail	b
	Sylvilagus nuttallii	Nuttall's cottontail	e
	Sylvilagus spp.	Cottontail rabbit	a
Muridae	*Mus musculus*	House mouse	a
Mustelidae	*Mustela frenata*	Long-tailed weasel	b
	Taxidae taxus	Badger	b
Sciuridae	*Eutamius minimus*	Least chipmunk	a,d,e,g
	E. quadrivittatus	Colorado chipmunk	d,f,g
	Sciurus aberti	Abert's squirrel	a,d,e
	Spermophilus lateralis	Golden-mantled sqirrel	a
	Spermophilus variegatus	Rock squirrel	a,d,f
	Tamiasciurus hudsonicus	Red squirrel	d
Soricidae	*Sorex vagrans*	Vagrant shrew	e
	S. nanus	Dwarf shrew	a,e
	S. palustris	Northern water shrew	d
Ursidae	*Ursus americanus*	Black bear	b
Verspertilionidae	*Eptesicus fuscus*	Big brown bat	c
	Lasionycteris noctivagans	Silver-haired bat	c
	Lasiurus cinereus	Hoary bat	c
	Myotis evotis	Long-eared myotis	c
	M. volans	Long-legged myotis	c

a. Ferenbaugh et.al. 1982, 6393
b. Biological Resource Evaluation Team database
c. Biological Resource Evaluation Team mist netting 1991
d. Bird surveys of Los Alamos National Laboratory 1986, 1988, and 1989
e. Hakonson 1974
f. Kent 1986, 04-0322
g. Martin et. al. 1971, 04-0323

Appendix B

Chemical Data for Surface Water, Ground Water, and Sediments

Table B-1

BACKGROUND WATER QUALITY DATA FROM LOS ALAMOS RESERVOIR

Element/Parameter	Value
pH (field)	8.1
Total dissolved solids (mg/L)	181
Radiochemical (pCi/L)	
^{3}H[a]	300 (300)[b]
^{90}Sr	N/A[c]
^{137}Cs	2.9 (1.1)
^{238}Pu	0.004 (0.016)
$^{239,240}Pu$	0.018 (0.014)
^{241}Am	N/A
Gross-alpha	1 (0)
Gross-beta	4 (1)
Gross-gamma	110 (90)
Major Constituents (mg/L)	
SiO_2	39
Ca	8
Mg	2.6
K	3
Na	6
Cl	6
F	0.2
CO_3	<5
HCO_3	29
PO_4-P	0.0
SO_4	5
NO_3-N	<0.04
CN	<0.01
Trace Metals (mg/L)	
Ag	<0.0006
Al	0.14
As	<0.0020
B	<0.020
Ba	0.0158
Be	<0.0010
Cd	<0.0020
Cr	<0.0050
Co	<0.0020
Cu	<0.002
Fe	0.14
Hg	<0.0001
Total uranium (µg/L)	<0.6

a. Tritium as tritiated water in moisture distilled from sample
b. Radioactivity counting uncertainties (+/– 1 standard deviation) are shown in parentheses.
c. N/A means analysis not performed, lost, or not completed.

(Environmental Protection Group 1994, 35363)

Table B-2: Radiochemical Analyses of Surface Water and Groundwater Samples from Los Alamos Canyon in 1993

Surface Water Samples:

Location	^{3}H (nCi/L)[a]	^{90}Sr (pCi/L)	^{137}Cs (pCi/L)	Total Uranium (µg/L)	^{238}Pu (pCi/L)	$^{239,240}Pu$ (pCi/L)	^{241}Am (pCi/L)	Gross Alpha (pCi/L)	Gross Beta (pCi/L)	Gross Gamma (pCi/L)
Los Alamos Canyon at Gaging Station 1	1.1[a] (1.3)	N/A	2.9[a] (2.2)	N/A	0.011[a] (0.052)	0.035[a] (0.035)	N/A	1[a] (1)	11[a] (2)	40[a] (173)
Los Alamos Canyon at SR 4	0.9[a] (0.4)	N/A	0.4[a] (1.7)	N/A	0.008[a] (0.042)	0.037[a] (0.028)	N/A	1[a] (1)	8[a] (1)	25[a] (141)
Los Alamos Canyon at Western Boundary	0.5 (0.3)	N/A	2.0 (1.2)	N/A	0.000 (0.030)	0.005 (0.020)	N/A	1 (1)	3 (1)	50 (100)

Groundwater Samples:

Location	^{3}H (nCi/L)	^{90}Sr (pCi/L)	^{137}Cs (pCi/L)	Total Uranium KPA[a] (µg/L)	Total Uranium ICPES[b] (µg/L)	^{238}Pu (pCi/L)	$^{239,240}Pu$ (pCi/L)	^{241}Am (pCi/L)	Gross Alpha (pCi/L)	Gross Beta (pCi/L)	Gross Gamma (pCi/L)
CANYON ALLUVIUM GROUNDWATERS											
DP-Los Alamos Canyons											
LAO-C	0.2 (0.3)	N/A	2.9 (1.3)	N/A	<1.0 (0.0)	-0.010 (0.030)	0.032 (0.020)	N/A	2 (1)	6 (1)	0 (100)
LAO-0.7	0.6 (0.3)	N/A	2.9 (1.3)	N/A	8.0 (1.0)	0.013 (0.030)	0.242 (0.045)	N/A	60 (10)	22 (2)	210 (100)
LAO-1	1.3 (0.3)	N/A	2.9 (1.3)	N/A	<1.0 (0.0)	0.016 (0.030)	0.080 (0.021)	N/A	0 (1)	26 (3)	100 (100)
LAO-2	0.4 (0.3)	367.7 (23.4)	N/A	50.4 (2.7)	N/A	0.356 (0.041)	1.584 (0.095)	0.019 (0.001)	N/A	N/A	N/A
LAO-3	1.1 (0.3)	N/A	3.0 (1.3)	N/A	4.8 (0.4)	0.005 (0.030)	0.015 (0.020)	N/A	1 (1)	92 (9)	300 (100)
LAO-4	0.9 (0.3)	N/A	0.1 (1.3)	N/A	<1.0 (0.0)	0.000 (0.030)	0.088 (0.023)	N/A	1 (1)	16 (2)	10 (100)
LAO-4.5	0.8 (0.3)	N/A	2.3 (1.2)	N/A	1.0 (0.2)	0.019 (0.030)	0.039 (0.021)	N/A	-1 (1)	10 (1)	100 (100)

(LANL Environmental Protection Group, 1995)

[a]Mean of multiple samples.
[b]Counting uncertainties (±1 standard deviation) are shown in parentheses.
[c]N/A means analysis not performed, lost in analysis, or not completed.
[d]Less than symbol (<) means measurement was below the specified detection limit of the analytical method.

Table B-3

RADIOCHEMICAL QUALITY OF SURFACE WATER IN DP CANYON, UPPER LOS ALAMOS CANYON

Element/Parameter	1967	1968	1969	1970	1971	1972	1973	1974
DPS[a]-1								
^{3}H (pCi/L)	540000	20000	430000	402222	356000	396100	310000	11000
^{90}Sr (pCi/L)	28600	11360	800	568	716	—[b]	—	—
^{137}Cs (pCi/L)	34000	13400	3490	692	1200	<350	260	48
Total uranium (µg/L)	—	—	—	—	2.3	7.1	0.1	3.1
^{238}Pu (pCi/L)	3.87	4.25	5.55	0.81	1.16	0.32	2.91	0.17
^{239}Pu (pCi/L)	76.1	28.8	9.1	2.2	2.07	5.68	10.1	0.27
^{241}Am (pCi/L)	1.29	4.52	3.58	1.19	0.6	0.33	—	—
Gross-alpha (pCi/L)	63	34	14	7	22	13	12	10
Gross-beta (pCi/L)	51700	14300	2060	1200	1390	2470	460	670
	1975	**1977**	**1986**	**1988**	**1989**	**1991**	**1992**	
^{3}H (pCi/L)	19000	130000	900	700	1200	Dry	800	
^{90}Sr (pCi/L)	—	—	—	—	—	Dry	19.6	
^{137}Cs (pCi/L)	12	0[d]	35.5	43	0	Dry	44.8	
Total uranium (µg/L)	6.9	108	0.75	1	1	Dry	2.2	
^{238}Pu (pCi/L)	0.27	0.69	0.035	0	0	Dry	0	
^{239}Pu (pCi/L)	0.57	1.67	—	—	—	Dry	0.182	
^{241}Am (pCi/L)	—	—	—	—	—	Dry	0.3	
Gross-alpha (pCi/L)	25	106	—	—	—	Dry	1	
Gross-beta (pCi/L)	500	3870	—	—	—	Dry	40	

Element/Parameter	1967	1968	1969	1970	1971	1972	1973	1974
DPS-4								
^{3}H (pCi/L)	410000	476000	346000	162000	103000	172000	51000	23000
^{90}Sr (pCi/L)	632	435	380	233	315	—	—	—
^{137}Cs (pCi/L)	<240	<240	<240	<240	<300	<50	<350	<50
Total uranium (µg/L)	—	—	—	—	0.6	3.3	0.4	0.9
^{238}Pu (pCi/L)	0.13	0.09	0.44	0.13	0.11	0.11	0.04	0.94
^{239}Pu (pCi/L)	0.14	0.08	0.52	0.21	0.13	0.27	0.11	0.39
^{241}Am (pCi/L)	<0.05	0.08	0.35	0.2	0.08	0.25	—	—
Gross-alpha (pCi/L)	2	6	2	1	3	2	2	5
Gross-beta (pCi/L)	1800	625	418	457	370	609	215	500
	1975	**1977**	**1986**	**1988**	**1989**	**1991**		
^{3}H (pCi/L)	46000	43000	3300	1100	Dry	Dry		
^{90}Sr (pCi/L)	—	—	—	—	Dry	Dry		
^{137}Cs (pCi/L)	<50	93	0	0	Dry	Dry		
Total uranium (µg/L)	1.3	6.8	1	1	Dry	Dry		
^{238}Pu (pCi/L)	0.02	0.03	0.012	0	Dry	Dry		
^{239}Pu (pCi/L)	<0.05	0.15	—	—	Dry	Dry		
^{241}Am (pCi/L)	—	—	—	—	Dry	Dry		
Gross-alpha (pCi/L)	3	0	—	—	Dry	Dry		
Gross-beta (pCi/L)	—	763	—	—	Dry	Dry		

a. DPS means DP Canyon surface water station.
b. — means not analyzed.

Table B-4

RADIOCHEMICAL QUALITY OF WATER IN ALLUVIUM FROM LOS ALAMOS CANYON 1967 THROUGH 1975[a]

Location	Year	No. of Anal.	Gross-Alpha	Gross-Beta	^{238}Pu	^{239}Pu	^{137}Cs	^{3}H	Total U (µg/L)
LAO[b]-C	1970	1	<1	4	<0.05	<0.05	—[c]	<1000	0.4
	1971	2	<1	3	<0.05	<0.05	<350	<1000	1.0
	1972	4	<1	5	0.06	0.07	<350	<1000	1.0
	1973	4	<1	3	<0.05	<0.05	<40	1150	<0.4
	1974	4	1	8	<0.05	<0.05	<40	650	0.5
	1975	3	3	5	<0.05	<0.05	<40	1000	0.5
LAO-1	1967	1	<1	50	<0.05	<0.05	—	41000	1.3
	1968	3	3	37	<0.05	0.08	<250	30000	<0.4
	1969	3	<1	36	<0.05	0.06	—	22000	0.4
	1970	4	<1	76	0.05	0.05	—	—	<0.4
	1971	4	1	94	0.05	0.27	<350	20750	0.6
	1972	4	1	127	0.17	0.18	<350	19600	<0.4
	1973	5	2	140	<0.05	0.06	<40	36000	<0.4
	1974	4	2	147	<0.05	<0.05	40	27000	<0.4
	1975	3	1	56	<0.05	<0.05	<20	7000	<0.4
LAO-2	1967	1	<1	91	<0.05	<0.05	—	475000	2.0
	1968	3	3	59	<0.05	0.06	<250	273000	1.5
	1969	2	1	77	0.10	0.60	—	337000	1.6
	1970	3	<1	80	<0.05	0.14	<250	184000	0.6
	1971	2	1	101	0.15	0.33	<350	52000	0.9
	1972	3	2	188	0.09	0.19	<350	153000	2.6
	1973	4	22	294	<0.05	0.11	<40	46000	<0.4
	1974	3	2	247	<0.05	0.10	<40	18000	<0.4
	1975	3	4	157	<0.05	0.05	<20	72000	0.7
LAO-3	1967	1	<1	45	<0.05	0.05	—	214000	<0.4
	1968	3	2	61	0.07	0.08	<250	126000	0.8
	1969	2	2	49	<0.05	0.06	—	350000	1.3
	1970	4	2	56	<0.05	0.08	<250	73000	0.8
	1971	3	3	95	0.07	0.08	<350	38000	1.2
	1972	4	3	92	0.10	0.15	<350	187000	3.0
	1973	5	3	47	0.06	0.05	50	35000	<0.4
	1974	3	2	75	0.35	0.08	50	11000	0.9
	1975	3	6	81	<0.05	<0.05	—	11000	3.1
LAO-4	1967	1	<1	9	<0.05	0.06	—	222000	0.8
	1968	3	5	16	0.05	0.05	250	61000	1.2
	1969	2	<1	9	<0.05	<0.05	—	55500	<0.4
	1970	1	<1	10	<0.05	<0.05	—	66000	<0.4
LAO-4.5	1969	3	<1	5	<0.05	<0.05	—	43000	0.7
	1970	5	1	26	0.06	0.07	—	78000	<0.4
	1971	3	1	5	0.07	0.08	—	24000	0.4
	1972	4	2	10	0.09	0.06	<350	28000	1.1
	1973	4	1	8	<0.05	<0.05	<40	22000	<0.4
	1974	3	1	107	<0.05	<0.05	<20	8000	<0.4
	1975	3	2	47	<0.05	0.06	—	18000	0.8
LAO-5	1967	1	<1	4	<0.05	<0.05	—	126000	<0.4
	1968	2	1	8	<0.05	0.09	<250	70000	1.2
	1969	2	<1	5	<0.05	<0.05	—	56000	0.7
LAO-6	1968	1	2	18	0.17	0.25	<250	75000	0.4
	1969	1	<1	7	<0.05	<0.05	<250	51000	<0.4

a. Average of a number of analyses in pCi/L, except as noted
b. LAO means observation well in Los Alamos Canyon.
c. — means not analyzed.

Table B-5

SUMMARY OF RADIOCHEMICAL ANALYSES OF SEDIMENTS IN LOS ALAMOS CANYON AND DP CANYON 1980–1992[a]

Location	^{90}Sr (pCi/g)	^{137}Cs (pCi/g)	Total U (µg/g)	^{238}Pu (pCi/g)	$^{239,240}Pu$ (pCi/g)	^{241}Am (pCi/g)[b]
DPS[c]-1	4.4 ± 5.7	7.5 ± 9.2	8.6 ± 18	0.75 ± 1.0	2.0 ± 2.7	6.3 ± 11
DPS-4	1.3 ± 0.8	8.6 ± 7.1	2.5 ± 1.0	0.092 ± 0.059	0.31 ± 0.15	1.1 ± 1.4
Los Alamos @ Bridge	0.13 ± 0.19	0.16 ± 0.11	2.4 ± 0.75	0.029 ± 0.10	0.0051 ± 0.0092	–0.11 ± 0.44
Los Alamos @ LAO-1	0.42 ± 0.38	3.0 ± 4.3	2.9 ± 1.3	0.068 ± 0.089	0.38 ± 0.29	0.37 ± 0.65
Los Alamos @ GS-1	0.16 ± 0.17	0.39 ± 0.59	2.8 ± 0.94	0.0054 ± 0.0065	0.69 ± 1.1	0.20 ± 0.51
Los Alamos @ LAO-3	0.40 ± 0.32	2.4 ± 2.6	3.1 ± 2.9	0.031 ± 0.026	0.22 ± 0.14	0.33 ± 0.46
Los Alamos @ LAO-4.5	0.53 ± 0.42	5.1 ± 7.6	3.6 ± 1.1	0.091 ± 0.092	0.45 ± 0.44	0.41 ± 1.3
Los Alamos @ SR 4	0.43 ± 0.37	2.9 ± 2.2	2.8 ± 1.1	0.047 ± 0.037	0.24 ± 0.21	0.62 ± 0.73
Los Alamos @ Totavi	0.23 ± 0.22	1.3 ± 2.2	3.1 ± 1.0	0.015 ± 0.018	0.25 ± 0.27	–0.24 ± 1.0
Los Alamos @ LA-2	0.46 ± 0.88	0.46 ± 0.43	2.4 ± 0.78	0.0067 ± 0.0074	0.22 ± 0.27	0.28 ± 0.76
Los Alamos @ Otowi	0.18 ± 0.19	0.39 ± 0.38	2.2 ± 0.66	0.0081 ± 0.011	0.14 ± 0.15	–0.25 ± 0.82

a. Values reported are mean ± one standard deviation.
b. Most values for ^{241}Am are strongly skewed by data from 1987.
c. DPS means DP Canyon surface water station.

(ESG 1981–1994)

Table B-6

Water, sediment, and plutonium data for Los Alamos Canyon

Year	Water (ac ft)	Flood (cfs)	Sediment (tons)	Σ Pu (mCi)	Pu (yr) (mCi)
1943	22	66	466	0.00	0
1944	198	631	8,393	2.80	2.798
1945	0	0	61	2.83	0.03
1946	28	80	611	3.15	0.32
1947	1	2	65	3.20	0.05
1948	0	0	61	3.24	0.04
1949	0	0	61	3.29	0.05
1950	6	20	77	3.35	0.06
1951	236	687	9,814	20.25	16.9
1952	209	386	6,316	37.86	17.61
1953	2	4	12	37.89	0.03
1954	40	129	1,006	40.75	2.86
1955	91	283	2,783	49.58	8.83
1956	0	0	0	49.58	0
1957	433	649	16,470	93.53	43.95
1958	63	203	2,062	100.89	7.36
1959	33	59	532	102.63	1.74
1960	0	0	154	103.38	0.75
1961	18	53	443	105.78	2.4
1962	0	1	138	106.66	0.88
1963	88	283	2,772	116.73	10.07
1964	0	0	0	116.73	0
1965	124	233	3,163	126.61	9.88
1966	10	32	165	127.14	0.53
1967	129	361	4,197	137.38	10.24
1968	287	924	14,120	159.20	21.82
1969	124	149	2,899	164.16	4.96
1970	0	0	0	164.16	0
1971	16	42	247	164.58	0.42
1972	0	0	0	164.58	0
1973	109	349	3,955	172.79	8.2099
1974	6	20	129	173.12	0.3301
1975	4	6	99	173.42	0.3
1976	6	20	77	173.65	0.23
1977	1	4	8	173.68	0.0299
1978	108	293	3,198	179.69	6.0101
1979	10	312	426	181.18	1.4899
1980	0	0	183	181.98	0.8001
1981	0	–	0	181.98	0
1982	0	–	0	181.98	0
1983	43	–	24,357	184.76	2.7800
1984	0	–	0	184.76	0
1985	43	–	41,461	186.84	2.0800
1986	3	–	2,460	188.43	1.5900

Sources: 1943–1980 data from calculations by L. J. Lane in support of L. J. Lane, W. D. Purtymun, and N. M. Becker, *New Estimating Procedures for Surface Runoff, Sediment Yield, and Contaminant Transport in Los Alamos County, New Mexico*, Los Alamos National Laboratory Report LA-10335-MS, UC-11 (Los Alamos, N.M.: Los Alamos National Laboratory, 1985); 1981–1986 data from W. D. Purtymun, P. Peters, and M. N. Maes, *Transport of Plutonium in Snowmelt Runoff*, Los Alamos National Laboratory Report LA-11795-MS, UC-902 (Los Alamos, N.M.: Los Alamos National Laboratory, 1990) using different techniques. The compatibility of the two data sets is questionable.

(Graf, 1995)