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DRAFT REPORT

Risk Analysis, Communication, Evaluation, and Reduction at LANL

Overview of Groundwater Issues at Los Alamos National Laboratory

August 18, 2003

Submitted to Colorado State University
in partial fulfillment of contract no. CSU G-3959-1

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Risk Analysis, Communication, Evaluation, and Reduction at LANL

Overview of Groundwater Issues at Los Alamos National Laboratory

August 18, 2003

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About this Report

This draft report is issued as a work in progress. It provides a discussion of the *RAC* Team's current state of knowledge and approach on groundwater for the project, *Risk Analysis, Communication, Evaluation, and Reduction (RACER) at Los Alamos National Laboratory.* It is being distributed to provoke thought on the topic and solicit specific comments from stakeholders on the information discussed and direction being considered. It also is intended to help identify sources of additional information or other issues that have not been incorporated in this current report.

Comments or suggestions concerning this document should be submitted in writing to *PShanahan@hydroanalysisinc.com,* or mail to Peter Shanahan, HydroAnalysis, Inc., 481 Great Road, Suite 3, Acton, MA, 01720, with *RAC.* All written comments will be considered in subsequent versions of the report.

Executive Summary

Three aspects of the physical setting of the Los Alamos National Laboratory play a major role in determining the fate and transport of chemicals and radionuclides from the Laboratory in the subsurface environment:

1. **The geography and geology of the Los Alamos area dictate the patterns of groundwater flow.** In general, groundwater flows in a regional aquifer from the Jemez Mountains on the west, where precipitation and mountain runoff recharge the aquifer, to the Rio Grande on the east, where groundwater from the aquifer discharges to springs and seeps along and beneath the river. Within the Los Alamos area, the subsurface is a multi-layered sequence of sedimentary and igneous rocks that possess different hydraulic properties. The variable geology creates important local deviations from a simple west-to-east pattern of groundwater flow. These local deviations can be expected also to affect subsurface transport of chemicals and radionuclides.

2. **The geography and climate dictate the patterns of surface-water flow and soil moisture.** The Laboratory is located on a series of flat-topped, finger-like mesas separated by deep west-to-east canyons. The area is semiarid. Mesas tend to be particularly dry, with only scant moisture infiltration to the soil. Most of the canyons, which are the collection points for surface-water drainage, experience only ephemeral natural flows of surface water. Precipitation is limited—only about 18 inches per year—and most originates from convective thunderstorms during the summer. Because of the area's substantial relief and limited groundwater recharge, the regional water table is deep—about 1,200 feet below the mesa tops in the western and central part of the Laboratory and about 600 feet on the eastern side. The thick unsaturated zone between the water table and land surface is an impediment to the movement of water, chemicals, and radionuclides from the surface to the aquifer.

3. **Activities at the Los Alamos National Laboratory and in nearby communities have locally altered the hydrology through the discharge of water and wastewater.** Artificial introductions of moisture have created zones of perched groundwater in the alluvium along some canyon bottoms and in deeper underlying zones between the ground surface and the regional water table. The surface and subsurface zones of artificial moisture may constitute important pathways for water and solute transport to and within the subsurface.

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1.0 Introduction

The Los Alamos National Laboratory (LANL) began as Project Y of the Manhattan Project during World War II. Its primary mission in 1943 was to develop the world's first nuclear weapon. This undertaking drove the Laboratory's operations from its inception in 1943 to August of 1945 when that goal was fulfilled. During these early years, LANL was collocated with the living quarters of the scientists involved in the project and their families. After successful completion of its original mission, the Laboratory moved toward peacetime research and development of nuclear weapons. During this time in LANL history, operations gradually were moved to the adjacent mesas, allowing a more distinct separation between the technical areas of the Laboratory and the residential portions of Los Alamos. The Laboratory was renamed Los Alamos Scientific Laboratory in 1947, which in turn became Los Alamos National Laboratory in 1981. The primary mission of nuclear weapons development has been expanded to include ensuring the safety and reliability of the nation's nuclear deterrent; reducing the global threat of weapons of mass destruction; and addressing national energy, infrastructure, and health security. As research continued at the Laboratory, concerns about the impact of facility operations on the environment increased.

The Laboratory encompasses about 27,500 acres (110 km^2) in northern New Mexico and is situated on the Pajarito Plateau, described as a series of finger-like mesas separated by deep east-to-west oriented canyons cut by intermittent stream flow. The mesas range in elevation from approximately 7,800 ft (2,377 m) on the eastern flanks of the Jemez Mountains to about 6,200 ft (1,890 m) above the Rio Grande Canyon. During its 60-year history, radionuclides and chemicals have been released to the air, soil, and surface water and indirectly to groundwater as a result of routine operations, accidents, and waste disposal practices. Although the Laboratory has substantially reduced radionuclide and chemical releases, the impact and risk associated with current releases and disposal of chemical and radioactive waste continues to be a concern to individuals in nearby communities. The cleanup, removal, and treatment of historical releases of radionuclides and chemicals, referred to as legacy waste, are also concerns.

In 2003, Colorado State University (CSU) undertook an independent and comprehensive risk assessment for public health and the environment for chemicals and radionuclides associated with LANL operations. *Risk Assessment Corporation (RAC)* of Neeses, S.C., was selected to conduct the technical work as the primary, independent sub-contractor. CSU is being supported by the University of California (UC) to conduct this work and to manage the project as an independent entity. CSU also will oversee the technical peer review process and convene a nationally recognized technical peer review panel to evaluate the approach and major deliverables of this project.

The primary objectives of this project are to develop (1) a methodology to estimate contemporary (current) human health risks and ecological impacts from LANL using available data on chemicals and radionuclides measured in environmental media; (2) a methodology to implement a comprehensive risk-informed decision analysis framework, including a prospective risk and ecological impact assessment and other quantitative and qualitative criteria, to guide long-term management of risks and ecological impacts at LANL; (3) a consistent approach for efficiently compiling, using, and updating data to support the risk assessment and decision-making processes; and (4) a process for extensive stakeholder involvement in the risk assessment and decision-making processes for LANL.

The purpose of this report is to provide a general summary of the current understanding of groundwater flow and solute transport in the LANL vicinity at the beginning of the CSU Project. The report is intended to provide the reader with an overview of the geology, surface water hydrology, vadose-zone hydrology, saturated zone hydrology, groundwater modeling studies, and relevant issues. It is not an analysis of risk and is intended to be used only as a summary document that highlights the salient features of groundwater at LANL and their importance in terms of chemical and radionuclide migration to drinking water wells and surface water bodies. This information will be incorporated into subsequent steps of the risk assessment process.

2.0 Geology

This description of the geology of the Los Alamos area is based upon the following references: Chronic (1987), Smith et al. (1970), NMGS (1982), Griggs (1964), and LANL (1998).

The Los Alamos National Laboratory is located on the Pajarito Plateau on the eastern flanks of the Jemez Mountains. The Jemez Mountains are the remnants of a large volcano that was active during the Cenozoic Era. The Cenozoic is the current geologic era, which began 70 million years ago. The Jemez volcano exploded in an enormous final eruption about 1 million years ago and collapsed to form the present-day caldera that contains the Valle Grande. The amount of rock estimated to have been ejected in the final eruption is about 100 times that attributed to the Mt. St. Helens eruption in 1980. The mountain peaks within the caldera are volcanic domes that formed after the collapse of the original volcano.

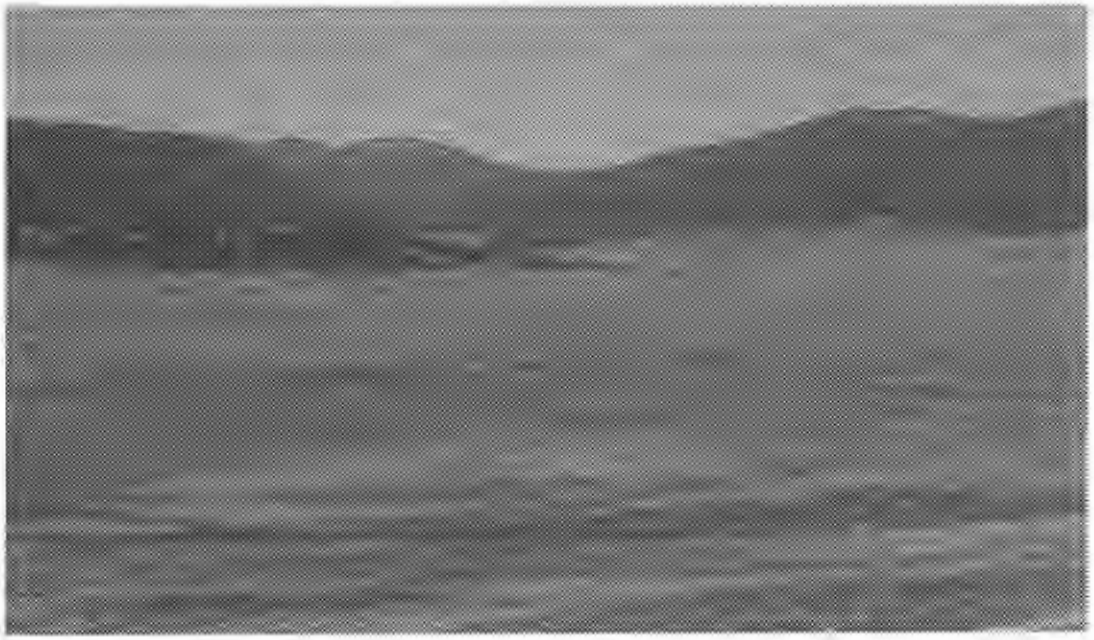

Figure 1. View of Valle Grande caldera west of Los Alamos (photograph by author).

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Figure 2. View of Parajito Plateau above Los Alamos Canyon (photograph by author).

The Pajarito Plateau upon which LANL lies is a sequence of volcanic lava (basalt) and ash built up over millions of years of volcanic eruptions (see **Figure 3**). The layers of rock beneath the plateau (from oldest and deepest, to youngest and shallowest) are:

- Precambrian crystalline bedrock (not shown in **Figure 3**) – very old (>570 million years) and deep rocks that are not a factor in the groundwater flow and solute transport
- The Santa Fe Group (Tsf) – a many-thousand-foot thickness of sedimentary rocks that date from four to 21 million years ago. The sediments that make up the Santa Fe Group are fluvial deposits of mainly sand, silt, clay, and pebbles. In some places, basalt from lava flows and volcanic ash beds lie within these deposits. The regional groundwater aquifer is largely within the Santa Fe Group. The Santa Fe Group is exposed at the ground surface along the Rio Grande and to the east of the river.
- The Puye (pronounced "poo-yay") Formation (Tpt[u], Tpt, Tpt[l]) – a conglomerate of boulders, cobbles, pebbles, and coarse sands that formed in alluvial fans created by runoff from the mountains that lie to the west. The regional aquifer extends upward into the Puye Formation. The formation outcrops northeast of the Laboratory in the San Ildefonso Pueblo. The thickness of the unit varies, from less than 100 feet north of White Rock to as much as 700 feet thick beneath Pueblo Canyon.

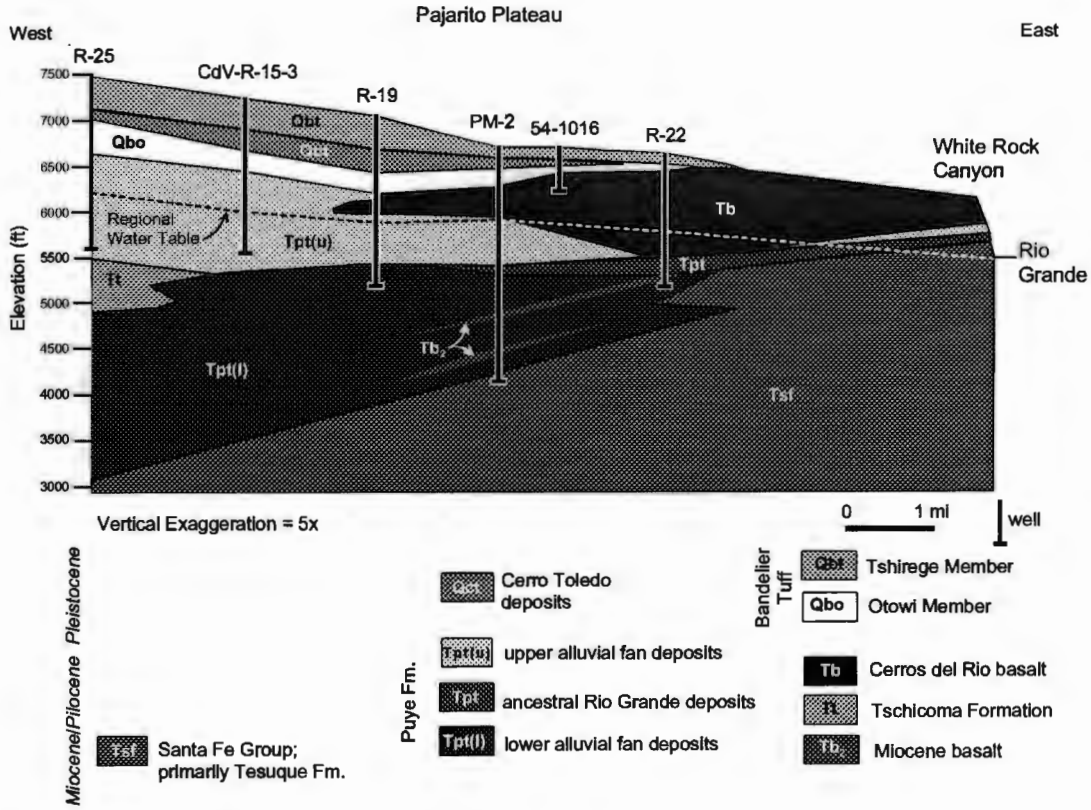

Figure 3. Stratigraphy of the Los Alamos Area (from Nylander et al. 2001).

- The Otowi (pronounced "oh-toe-wee") Member of the Bandelier Tuff (Obo) – a light gray layer of rock deposited from the fall of airborne volcanic ash or the surface flow of ash and gas down the volcano slope. Most of the tuff appears to have originated from hot ash flows. The ash flows carried enough heat that when they finally came to rest, the heat fused the ash particles into a porcelain-like solid known as a welded tuff. The Otowi Member is composed of numerous ash flows and is roughly 200 to 300 feet thick. It generally forms a slope in exposures, as distinct from the more highly welded overlying tuffs that form vertical cliffs. The first, more gently sloped part of the climb on Route 502 to Los Alamos after the turnoff to White Rock crosses this part of the Bandelier Tuff.
- The Cerro Toledo interval (Qct) – a layer of mixed material ejected from volcanoes and weathered from other rocks. The layer is 10 to several tens of feet thick.
- The Tshirege (pronounced "ser-a-gay") Member of the Bandelier Tuff (Obt) – multiple layers of ash-flow tuffs that comprise a total thickness of 300 to 600 feet. The different layers have been defined as separate subunits. Properties vary between and within subunits, reflecting temperature and other differences in the originating ash flows. Some portions of the Tshirege Member are highly welded and form vertical cliffs as well as the cap on the Pajarito Plateau. Most of LANL

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is situated on the Tshirege Member. The nearly vertical buff-colored cliffs seen on the last, steep climb on Route 502 to Los Alamos are Tshirege Member rocks (**Figure 2**).

3.0 Surface-water Hydrology

The Pajarito Plateau is drained by several west-to-east running canyons, which convey surface water to the Rio Grande on the east. The climate of the area, however, creates infrequent surface runoff. Average annual rainfall is 18.3 inches, approximately a third of which comes from convective thunderstorms during July and August (LANL 2001, pp. 102-103). Annual evapotranspiration is approximately equal to annual precipitation (Hollis et al. 1997), allowing for very limited runoff and infiltration of water into the soil.

Reaches (i.e., lengths along the canyon) generally can be classified as *dry*, having only ephemeral flow following intense rainfall, or *wet*, having perennial or relatively frequent flow. The descriptions of the individual canyons below are based on the Hydrogeologic Workplan (LANL 1998). Figure 2-7 of the workplan is copied here as **Figure 4**.

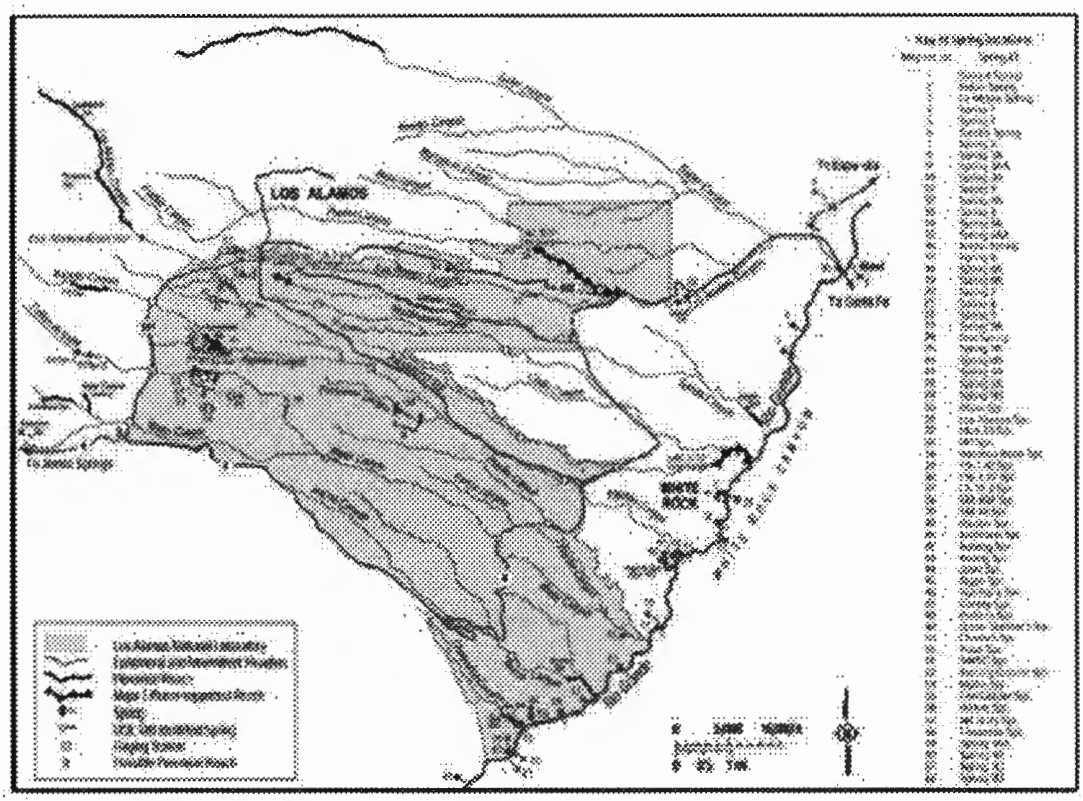

Figure 4. Canyons at Los Alamos National Laboratory (LANL 1998). (Note on this draft: this figure is the clearest available at this time but will be replaced with a clearer image in the final report.)

Moving from north to south, the Laboratory is crossed by the following 15 canyons, which flow from west to east (LANL 1998).

- Pueblo Canyon – Pueblo Canyon extends from west of the Laboratory to its confluence with Los Alamos Canyon. The upper portion of Pueblo Canyon is dry, but there is perennial flow in the lower reaches due to the discharge of treated municipal wastewater from the Los Alamos County Sewage Treatment Plant.
- DP Canyon – This tributary of Los Alamos Canyon is mostly dry. The very lower reach receives flow from DP Spring, a perennial spring.
- Los Alamos Canyon – Los Alamos Canyon originates west of the Laboratory and extends to the Rio Grande on the east. Its upper reaches are impounded by the Los Alamos reservoir. The reaches upstream of the reservoir are perennial and flow tends to be continuous in the reach immediately downstream of the reservoir during spring runoff. Otherwise, the canyon is dry to the confluence with Pueblo Canyon. Flow of treated municipal wastewater from the Los Alamos County Sewage Treatment Plant enters from Pueblo Canyon and maintains flow at the confluence. Approximately a mile downstream of the confluence, the perennial Basalt and Los Alamos Springs provide flow to the channel, but it is not sufficient to maintain perennial flow to the Rio Grande.
- Sandia Canyon – Sandia Canyon originates on the Laboratory and extends eastward to the Rio Grande. It is dry except for a short reach below the treated wastewater discharge from the Laboratory's sanitary wastewater sewage treatment plant. A lower reach, a short distance upstream of the Rio Grande and well away from the Laboratory, is perennial below Sandia Spring, but does not extend all the way to the river.
- Mortandad Canyon – Mortandad Canyon originates on LANL property and is dry, except for an approximately one-mile reach below the treated wastewater and cooling tower discharges at Laboratory Technical Area (TA) 50.
- Cañada del Buey – This canyon originates on LANL property and extends to its confluence with Mortandad Canyon a short distance west of the Rio Grande. It is a dry canyon that carries ephemeral flow only after thunderstorms or snowmelt.
- Twomile Canyon – This tributary of Pajarito Canyon is dry.
- Pajarito Canyon – This canyon extends from several miles west of the Laboratory to the Rio Grande. It is one of the wettest canyons on the Laboratory, with flow roughly eight months out of the year. The canyon is fed by a cluster of springs in TA 9. At least some of these springs appear to be associated with discharges by the Laboratory.
- Threemile Canyon – This tributary of Pajarito Canyon is dry.
- Potrillo Canyon – This is a tributary of Water Canyon. It is a dry canyon with only ephemeral flow. No flow, even ephemerally, appears to occur below an area of infiltration about midway along its length.

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- Fence Canyon – This tributary of Potrillo Canyon is dry.
- Cañon de Valle – This canyon originates several miles west of the Laboratory and extends to its confluence with Water Canyon. It is one of the wetter canyons, being fed by springs west of the Laboratory and in the western part of the Laboratory in TA 16. One reach, below Laboratory outfall TA-16-260, has flowed continuously since at least 1992.
- Water Canyon – At its name implies, Water Canyon is a wet canyon although it very rarely flows as far as the Rio Grande. It originates several miles west of the Laboratory in the Sierra de los Valles. It experiences perennial flow in its upstream reaches, where it is fed by Armistead, American, and other springs. Within the Laboratory, it flows ephemerally upstream of the confluence with Potrillo Canyon, where a spring supports a short perennial reach.
- Ancho Canyon – Ancho Canyon originates on Laboratory land and extends to the Rio Grande. It is dry except for a few thousand feet just above the Rio Grande. This reach is fed by Ancho Spring.
- Chaquehui Canyon – This short canyon extends roughly three miles to its confluence with the Rio Grande. It is dry except for the last half mile, which is fed by the perennial Doe Spring.

4.0 Vadose-Zone Hydrology

The vadose zone encompasses the soils and rock above the regional water table, where a water table is defined as a free-water surface at atmospheric pressure within the subsurface. Below the water table, soils and rock are saturated with water; that is, all of the empty space (known as void space) between solid particles and rock is filled with water. In the vadose zone, the soils and rock are unsaturated; there may be some moisture within the void space, but the voids are not completely filled with water. They contain air as well.

Movement of water through the vadose zone is complicated by climatic factors and the presence and movement of air. In the shallow vadose zone, inflows from precipitation and outflows to evaporation constantly alter the moisture content of the soils. These changes in moisture content in turn cause big changes in the ease with which water moves through the vadose zone. In dry soil, capillary forces hold the water tightly to the solid particles and movement of water is impeded. Also, cracks in the soils and other larger openings (called macropores) can allow faster movement of water than in unfractured soil. An important consideration with respect to the vadose zone is the amount of water that traverses the entirety of the vadose zone and reaches the underlying aquifer. Water that reaches the aquifer is known as *recharge.*

Although vadose-zone hydrology is intrinsically complex, the hydrology of the vadose zone at Los Alamos is further complicated by its great thickness, which is about 1,200 feet below the mesa tops in the western and central part of the Laboratory and about 600 feet on the eastern side. These great thicknesses impede surface water from reaching the water table below the vadose zone, but nevertheless even limited vadose-zone flow has the potential to carry chemicals and radionuclides in recharge to the groundwater. Furthermore, vapor-phase transport (i.e., chemicals

that volatilize and remain in a vapor phase within the vadose zone) also can be an important transport mechanism to the regional aquifer in the vadose zone that may need to be considered in the risk assessment. A broad characterization of recharge at the Laboratory is simple; there is none. For example, for purposes of evaluating the overall water budget of the regional aquifer for regional water supply, the basic model of the aquifer is that there is groundwater recharge from the vadose zone along the mountain front west of the Laboratory, but no recharge of any significance east of that area.

The no-recharge model is clearly inadequate for *RAC*'s risk assessment purposes since relatively minor flow into the vadose zone can carry radionuclides and other chemicals. (However, vadose-zone transport times may by sufficiently long so that impacts to the regional aquifer may be well beyond the time frame of the assessment.) Nonetheless, the no-recharge model is probably a useful working hypothesis for vadose-zone flow and transport from the mesa tops. Recharge from the mesa tops is estimated to be very low, about 1 millimeter per year (Nylander 2003, pg. 5-5). Moreover, detailed studies by the Laboratory have shown that a process of air-drying apparently occurs at middle elevations down the mesas (Hollis et al. 1997). The elevation of drying coincides with a zone of relatively permeable and fractured surge beds deposited by a sudden ground flow of volcanic material at what is now the bottom of the Tshirege Member of the Bandelier Tuff. In essence, the studies show that the mesas "breathe." Atmospheric air enters and exits the mesa rocks due to wind and changes in air pressure. The amount of air is minute, but still enough to evaporate moisture within the rocks. Thus, moisture that enters the mesa tops, which is already limited, is further removed by evaporation from the surge-bed horizon. The idea that the mesas can breathe is not unique. For example, air flow into and out of Yucca Mountain, Nevada, also has been documented (Weeks 1993).

Although there is an absence, or near-absence, of recharge from the mesa tops in general, there may be exceptions that will need to be considered. Specifically, where Laboratory activities create or created continuous sources of water at a mesa top location, there is the potential for the normally dry conditions to have been altered. Examples of these locations include wastewater discharges, drip lines from equipment or cooling systems, or surface impoundments. The Hydrogeologic Workplan (LANL 1998, pg. 2-22), for example, cites annual recharge of 245 cm from surface impoundments at TA 53. These types of potential sources need to be identified and evaluated as a part of *RAC*'s risk assessment study.

The canyon bottoms see more water than the mesa tops and are closer to the regional water table. Thus, these locations have far greater potential to convey recharge to groundwater. Indeed, all of the wet canyons identified above can be presumed to be sources of water to the subsurface. As discussed below under *Groundwater Hydrology*, infiltration beneath the wet canyons has created localized saturated conditions in the shallow subsurface.

5.0 Groundwater Hydrology

Groundwater is found in the Los Alamos area in three distinct horizons in the subsurface: in the deep regional aquifer, in shallow perched zones beneath the wet canyons, and in intermediate perched zones between these two. The following description of these three groundwater units is based largely on the Hydrogeologic Workplan (LANL 1998).

The regional aquifer occurs within the Santa Fe and Puye Formations. It extends from the mountain range west of the Laboratory to the Rio Grande on the east. The regional aquifer forms

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a water table. The water table is 600 to 1,200 feet below the ground surface on the mesa tops. Depth to the water table decreases to the east, and the water table intersects the land surface along the Rio Grande. The elevation of the water table is over 6,200 feet above mean sea level on the west and drops to about 5,500 feet at the river (see **Figure 5**). Groundwater generally flows eastward, from recharge areas along the mountain slopes to discharges at springs along and beneath the Rio Grande. There is also recharge of the aquifer beneath the wet canyons, as discussed above under *Vadose-Zone Hydrology*. The regional aquifer is the only source of groundwater adequate for municipal and similar large-volume water supplies. LANL and the towns of Los Alamos and White Rock are supplied by wells that tap the regional aquifer.

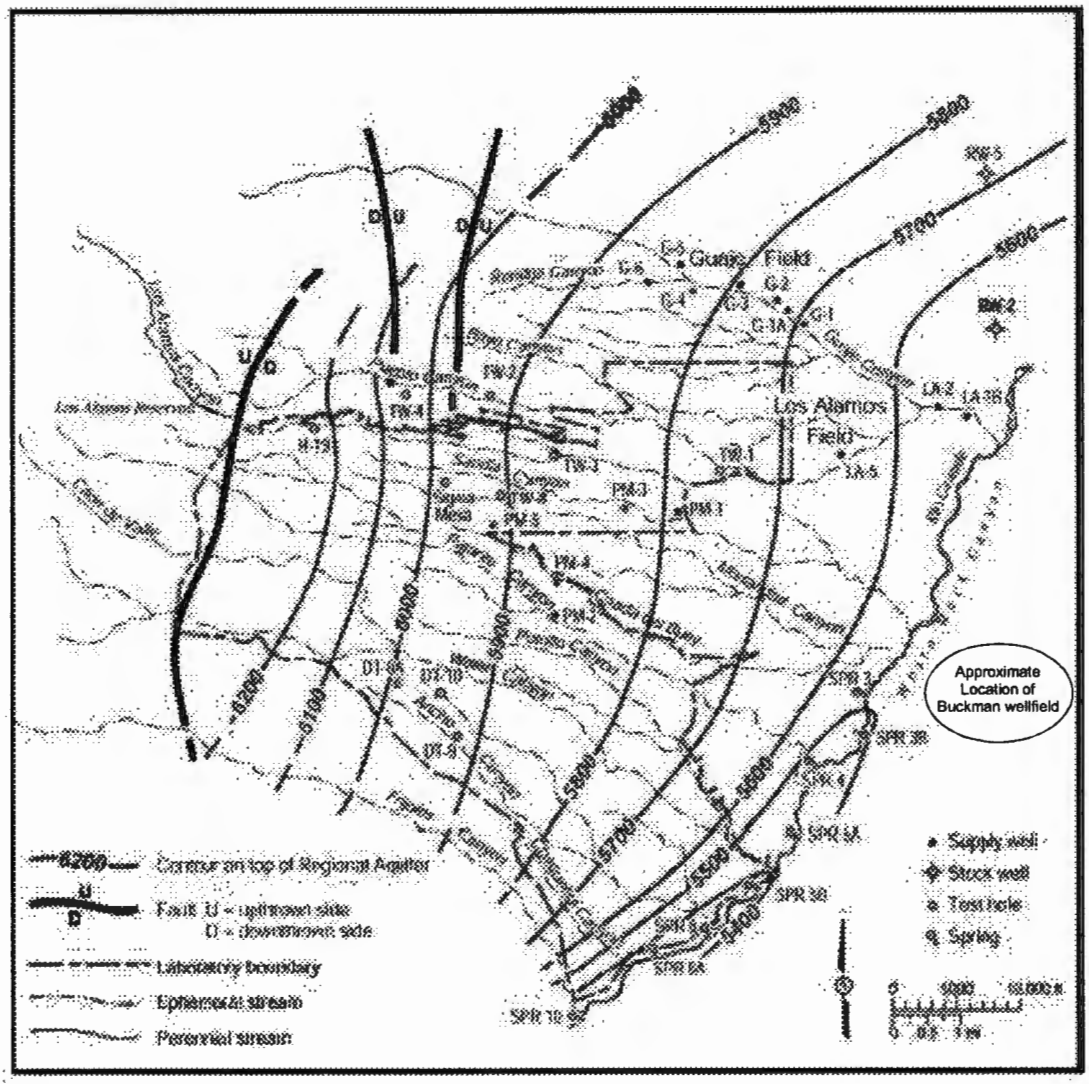

Figure 5. Water-table elevation contours for the regional aquifer (LANL 1998, Figure 2-10). (Note on this draft: this figure is the clearest available at this time but will be replaced with a clearer image in the final report.)

In general, the regional aquifer flows toward the Rio Grande from both the eastern and western sides. An exception is near the Buckman wellfield, a group of public water supply wells used to provide drinking water to the city of Santa Fe. Continuous heavy pumping at the Buckman well field has lowered the water table around the well field substantially, altering the natural flow pattern. In this area, the Rio Grande is a "losing stream"—water in the river is drawn through the river bottom into the aquifer at a rate that exceeds inflows of surface water. Also in this area, groundwater from the western side of the river flows under the river rather than discharging to the river. Instead, this groundwater continues to flow eastward and into the Buckman wells. Roughly one-third of the water withdrawn at the Buckman wellfield is estimated to originate from the western side of the Rio Grande.

The shallowest groundwater occurs within gravel, sand, and finer sediments in the canyon bottoms. These sand and gravel deposits, known as alluvium, have been deposited over geologic times by surface-water flows in the canyons. Alluvium is as much as 100 feet thick in some locations. Alluvium is coarsest in those canyons that originate in the Jemez Mountains west of the Laboratory. Finer deposits, with more silt and clay, are found in the canyons that originate on the mesa tops.

Alluvial deposits are much more permeable than the underlying Bandelier Tuff. Surface water flowing in the canyons infiltrates readily into the alluvium. It is frequently the case that a stream flowing at the upper end of a canyon infiltrates along its course such that no flow ever reaches the lower parts of the canyon. The water that infiltrates the alluvium tends to sit on top of the tighter rock that underlies the alluvium, forming a perched aquifer. The perched aquifers are limited in their geographical extent—they form narrow, ribbon-like aquifers directly beneath the canyons. Groundwater in the perched alluvial aquifers tends to flow in a down-canyon direction, but not laterally. The rate of alluvial groundwater movement is can vary from less than 10 to several tens of feet per day (LANL 1998).

Groundwater from the perched alluvial aquifers also infiltrates into the underlying geologic strata. The downward vertical movement of this water is in some places impeded by low-permeability beds, and the water collects to form intermediate perched water zones. Such zones have been found beneath Pueblo Canyon, Los Alamos Canyon, Sandia Canyon, Mortandad Canyon, Pajarito Canyon, Cañon de Valle, and Ancho Canyon (Nylander et al. 2003, pg. 4-15). Multiple perched zones occur beneath many of these canyons. Depths vary, from less than 100 feet to as much as 900 feet below the canyon bottoms. As with the alluvial aquifers, the perched zones tend to be narrow ribbons that follow the canyons. Some of the perched zones emerge on their eastern end to springs (see **Figure 6**). For example, Basalt Spring, a perennial spring east of the Laboratory on the San Ildefonso Pueblo, is a discharge point from intermediate perched water beneath Pueblo Canyon (Nylander et al 2003, pg. 4-16).

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Figure 6. Spring 3A east of White Rock (photograph by author).

6.0 Radionuclides and Chemicals in Groundwater

Radionuclides and organic and inorganic chemicals associated with LANL operations have been found in groundwater at the Laboratory. Monitoring of groundwater in the LANL area is difficult and expensive because of the rugged terrain, large area of the Laboratory and, particularly, the considerable depth to some groundwater horizons. As a result, there is a limited number of groundwater monitoring wells at which water-quality samples can and have been collected.

Despite the limited number of available sampling points, groundwater contamination problems have been identified and investigated (LANL 1998). The following is a preliminary description of known or suspected source areas within each canyon based on the Hydrogeologic Workplan (LANL 1998). As this project goes forward, the general information provided in this section will be replaced with more complete and precise information developed through a detailed review of groundwater sampling data.

6.1 Pueblo Canyon

The middle reach of Pueblo Canyon formerly received treated wastewater from the Los Alamos County Sewage Treatment Plant and the TA-45 Radioactive Liquid Waste Treatment

Facility discharge to Acid Canyon. Both of these sources are now closed; the TA-45 treatment plant operated from 1943 to 1964 (LANL 2002, pg. 181). Chemicals and radionuclides in the TA-45 effluent included nitrate, tritium, uranium, plutonium, strontium-90, cesium-137, and gross-alpha radiation.

About two miles down-canyon from the former wastewater sources, monitoring well TW-2A intersects a zone of perched water in the Puye Formation at a depth of about 120 feet. Water from this well has elevated concentrations of nitrates and tritium. (Note that the term *elevated* is used in the Hydrogeologic Workplan (LANL, 1998) but is not specifically defined. In this report, *elevated* indicates concentrations that are greater than the levels that would be expected to occur naturally based on observed levels elsewhere on and off LANL. The term does not necessarily indicate concentrations that would be considered problematic.)

Other chemicals and radionuclides also have been detected in the regional aquifer. Strontiurm-90 has been found in Well TW-4 in upper Pueblo Canyon and nitrate in TW-1 in lower Pueblo Canyon near the confluence with Los Alamos Canyon.

6.2 DP Canyon

From 1952 to 1986, DP Canyon received wastewater from the liquid wastewater processing plant associated with the former plutonium processing facility at TA-21 (LANL 2002, pg. 182). Alluvial groundwater in DP Canyon has been found to contain strontium-90 and some organic chemicals.

6.3 Los Alamos Canyon

The upper reaches of Los Alamos Canyon received liquid effluent from TA-1 from 1942 to 1945 during the initial operations of the Laboratory (LANL 2002, pg. 181). It also received inflow from DP Canyon (see above) as well as a sanitary sewage lagoon at the Los Alamos Neutron Science Center, TA-53. Currently, National Pollutant Discharge Elimination System (NPDES) outfalls from TA-53 and TA-21 discharge to the canyon. The alluvial aquifer in upper and middle Los Alamos Canyon has been found to contain tritium and strontium-90. Intermediate perched groundwater at monitoring well LADP-3 has shown concentrations of tritium of about 6,000 pCi/L, which is much higher than groundwater unaffected by anthropogenic sources. Water from the regional aquifer well Otowi-1, located between DP Canyon and Los Alamos Canyon near their confluence, has single-part-per-billion concentrations of perchlorate.

6.4 Sandia Canyon

The Hydrogeologic Workplan (LANL 1998) reports no elevated concentrations of chemicals and radionuclides in groundwater from beneath Sandia Canyon, but indicates that there is little groundwater and few groundwater monitoring wells. The canyon receives cooling water from the TA-3 power plant and treated wastewater from the TA-46 Sanitary Wastewater Systems (LANL 1998, pg. 182).

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6.5 Mortandad Canyon

Investigations of chemicals and radionuclides in alluvial groundwater in Mortandad Canyon date back to the 1960s (Purtymun et al. 1977). The sources of chemicals and radionuclides in this canyon are aqueous discharges from the TA-50 Radioactive Liquid Waste Treatment Facility and cooling water from TA-48. Alluvial groundwater downstream of TA-50 has elevated concentrations of total dissolved solids, nitrates, tritium, strontium-90, plutonium-239/240, americium-241, uranium, and cesium-137.

Samples from well TW-8 in the regional aquifer have shown elevated concentrations of nitrate, tritium, strontium-90, and plutonium-239/240. Springs near the Rio Grande below Mortandad Canyon have shown concentrations of perchlorate of a few µg/L. The springs are presumed to issue from the regional aquifer.

6.6 Cañada del Buey

There is little groundwater, few monitoring wells, and no indication of chemicals or radionuclides in groundwater in Cañada del Buey.

6.7 Pajarito Canyon

Chemicals and radionuclides have been detected in alluvial groundwater in middle and lower Pajarito Canyon. Chemicals and radionuclides in the middle canyon include nitrate, uranium, and the organic solvent 1,2-dichloroethane. In the lower canyon, americium-241, barium, nitrate, total dissolved solids, and chloride occur at elevated concentrations.

Material disposal areas on Mesita del Buey are the source of plumes of tritium, trichloroethylene, and 1,1,1-trichloroethane vapors in the underlying unsaturated zone. The effect of these vapor plumes on groundwater was unknown at the time of the Hydrogeologic Workplan (LANL 1998).

6.8 Potrillo Canyon

This is a dry canyon with no documented source areas.

6.9 Cañon de Valle

There has been little groundwater monitoring in this canyon, although a spring in the upper canyon has shown the presence of tritium.

6.10 Water Canyon

The Hydrogeologic Workplan (LANL 1998) reports no elevated concentrations of chemicals or radionuclides in the groundwater in this canyon. Historically, Water Canyon received wastewater from high explosives operations at TA-16 and TA-9.

6.11 Ancho Canyon

There is, at most, minor alluvial groundwater in Ancho Canyon and no documented concentrations of chemicals or radionuclides. Ancho Spring, at the lower end of Ancho Canyon, exhibits elevated concentrations of high explosives and trace concentrations of depleted uranium.

6.12 Chaquehui Canyon

This is a dry canyon with no documented elevated concentrations of chemicals or radionuclides.

7.0 Groundwater Modeling by LANL

LANL has developed and applied several models to describe groundwater flow and solute transport in the saturated and unsaturated zone on the Pajarito Plateau and surrounding Española basin. Numerical modeling typically involves three major elements: (1) development of a conceptual model, (2) implementation of the conceptual model into a mathematical model that quantitatively describes the behavior of the system, and (3) calibration of the model to observations. Each element of the groundwater modeling effort is summarized in this section. Except where specifically noted, information provided in this summary is taken from the Groundwater Annual Status Report for Fiscal Year 2002 (Nylander et al. 2003). In addition to the groundwater models, LANL has developed a geologic model, a computer representation of the three-dimensional geometry of the various geologic formations beneath LANL and the surrounding area. The geologic model is used to develop input for the groundwater models.

7.1 Conceptual Models

A conceptual model qualitatively describes the processes, mechanisms, and structure that govern the overall behavior of a system. The groundwater conceptual model at LANL provides a concise understanding of the hydrogeologic setting of the Pajarito Plateau and is separated into four hydrogeologic environments: mesas, alluvial groundwater, intermediate perched groundwater, and regional aquifer. A fifth hydrogeologic conceptual model describes geochemical processes, but is not discussed here. Each hydrogeologic environment of the conceptual model is discussed below.

7.1.1 Mesas

Mesas are separated into two types, dry and wet. Dry mesas occur in the eastern parts of the Laboratory. Relatively little infiltration occurs on these mesas (approximately 1 mm yr^{-1}) because of low rainfall, high evaporation, and efficient use of water by vegetation. Water loss deep within the mesas also can occur because of migration of air laterally from the canyon walls. Wet mesas generally occur in the western part of the Laboratory where the topography and rainfall are higher. Water occurs in the Bandelier Tuff under unsaturated conditions. Zones of saturation exist on a transient basis where localized fracturing and lithologic changes result in higher permeability.

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Of particular importance, in terms of water and solute travel times, is the presence of continuous fractures in the unsaturated zone. Matrix-dominated flow (i.e., no fractures or no flow-through fractures) is generally much slower than fracture-dominated flow. The conceptual model considers fracture-dominated flow only in the basalt units, where fractures are large and matrix permeability is low.

7.1.2 Alluvial Groundwater

In some canyons that originate in the Jemez Mountains, infiltration of surface water maintains shallow, unconfined groundwater in the alluvium that is perched on the underlying Bandelier Tuff, Cerros del Rio basalt, or Puye Formation. Alluvial groundwater is depleted through infiltration to underlying strata as it moves down gradient (generally down the canyon). Groundwater levels in canyons that are naturally wet are generally highest in the late spring from snowmelt and in mid- to late summer from thunderstorms. Canyons that form east of the Jemez Mountains are generally dry, with the exception of those canyons that receive anthropogenic (human-made) waters. Percolation losses in alluvial groundwater by unsaturated, and in some cases saturated, flow is an important transport pathway to the regional aquifer. Water travel times by these processes can be decades.

7.1.3 Intermediate Perched Water

Intermediate perched water zones occur on wet mesas in the western part of the Laboratory, beneath wet canyons, or below anthropogenic water sources. Occurrence of perched zones is dictated by sufficient recharge and structural constraints (i.e., permeability variations and geologic structure such as faulting). Intermediate perched water bodies beneath wet canyons generally do not extend laterally below mesas. In general, lateral flow is limited, but does occur when the lithology facilitates it. Lateral flow within the intermediate perched zones could transport chemicals or radionuclides some distance away from their surface source.

7.1.4 Regional Aquifier

The regional aquifer beneath the Pajarito Plateau occurs in the Puye Formations, the Cerros del Rio basalts, the Tschicoma Formation, and the Santa Fe Group. The aquifer properties are heterogeneous. The aquifer is a water-table aquifer in the west and at least partially confined in the east near the Rio Grande. A confined aquifer is one in which layers of low-permeability materials (such as clay) lie above the aquifer and cause the pressure in the aquifer to rise above atmospheric pressure. The average hydraulic conductivity is about 140 m yr^{-1} and typical groundwater velocities are about 10 m yr^{-1}. Hydraulic conductivity is the volume of groundwater that will move over time under a unit gradient (i.e., a vertical fall in water level of 1 foot over 1 foot of horizontal distance) through a unit cross-sectional area that is perpendicular to the direction of flow. Flow is generally west to east, with local deviations occurring because of lithologic heterogeneity and water-supply-well pumping. The Rio Grande is the main discharge area for the regional aquifer. Most recharge occurs from groundwater underflow from the Sierra de los Valles located in the western part of the Pajarito Plateau, although some recharge also occurs from intermediate perched zones within the Laboratory boundaries. Recharge from these sources is important because it provides a pathway for migration of chemicals and radionuclides.

7.2 Mathematical Model

The computational tool used by LANL to solve the governing equations of fluid flow and solute transport is the Finite Element Heat and Mass (FEHM) computer code (Zyvoloski et al. 1997). The FEHM code is a three-dimensional finite-element computer code that can simulate nonisothermal, multiphase, multicomponent flow in saturated and unsaturated porous media. FEHM was originally developed to assist in understanding the flow fields and mass transport in the saturated and unsaturated zones underlying the Yucca Mountain nuclear waste repository. FEHM is capable of describing fracture-dominated flow, including the inherently three-dimensional flow that results from permeation to and from faults and fractures. As noted earlier, fracture flow is an important material property at LANL that can substantially reduce water transit times in the unsaturated zone. The code also can address coupled heat and mass-transfer effects, such as volatilization or vaporization, dry out, and condensation that can occur near the mesa faces, and the natural convection that occurs due to seasonal temperature changes. Reactive and nonreactive solute transport also is performed within the code. The code can address various adsorption mechanisms including simple linear sorption and nonlinear sorption isotherms.

FEHM was developed at LANL for Yucca Mountain and has been applied to LANL presumably because similar processes exist at both LANL and Yucca Mountain. Perhaps more importantly, however, users of the code at LANL have intimate knowledge of the workings of the code and, therefore, are more adept at constructing model input and interpreting output using FEHM than they would be using an alternative code. Code documentation includes a user's manual (Zyvoloski et al. 1997a), model summary (Zyvoloski et al. 1997b), and software requirements, design, and verification and validation document (Dash et al. 1997).

7.3 Vadose-Zone Modeling

Vadose-zone modeling at LANL has been performed on two levels: (1) detailed modeling of small local areas and (2) a regional assessment of water travel times from the surface to the regional aquifer. Detailed modeling of the vadose zone in three-dimensions is computationally intensive and requires characterization data that are not available across the entire Laboratory. Its primary purpose is to understand the processes that control unsaturated flow. The regional assessment of unsaturated water travel times was used to assess the potential for migration of chemicals and radionuclides across the Laboratory. The regional assessment model assumes one-dimensional flow in the unsaturated zone under unit-gradient conditions. Under unit-gradient conditions, the downward movement of water is primarily by gravity-driven flow. Using the geologic model developed for the site, stratigraphic columns from the ground surface to the regional aquifer were extracted at 30,577 grid points across the Laboratory. An alternative simulation considers lateral migration of solute in intermediate and alluvial aquifers. A net infiltration index (NII) is assigned to each grid node based on precipitation, vegetation, evapotranspiration, and surface geology. Two simulations were performed: a base case infiltration scenario, which presumably represents a best-estimate of the infiltration across the site, and an upper-bound estimate of infiltration. The FEHM code performed these calculations and was linked via a geographic information system database that defines hydrologic properties for each lithologic unit defined by the geologic model.

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Results of the simulation indicate that solute travel times in the canyons with NII values of 1 (low infiltration) are less than 1,000 years. On the mesa tops, travel times are predicted to range from 1,000 to 5,000 years on the eastern portion of the Laboratory, and 20,000 to 30,000 years in the western portions (**Figure 7**). The controlling factor in solute transit times appears to be the thickness of Bandelier Tuff, where water flow is controlled by the matrix permeability. Predicted solute transit times are relatively rapid in the wet canyons (i.e., Pajarito Canyon near White Rock, a portion of Cañon de Valle, Mortandad Canyon at the Radioactive Liquid Waste Treatment Facility, middle and lower Los Alamos Canyon, large portions of Pueblo Canyon, and Guaje Canyon). Solute transit times are predicted to be less than 100 years when infiltration estimates are around 30 to 100 cm yr^{-1}. In areas where the Bandelier Tuff is thin (i.e., Los Alamos and Pueblo Canyons), travel times of five to 10 years are estimated. For the case involving an upper-bound estimate of infiltration, solute transit times are shorter and the number of nodes exhibiting solute travel times of less than 100 years is greater.

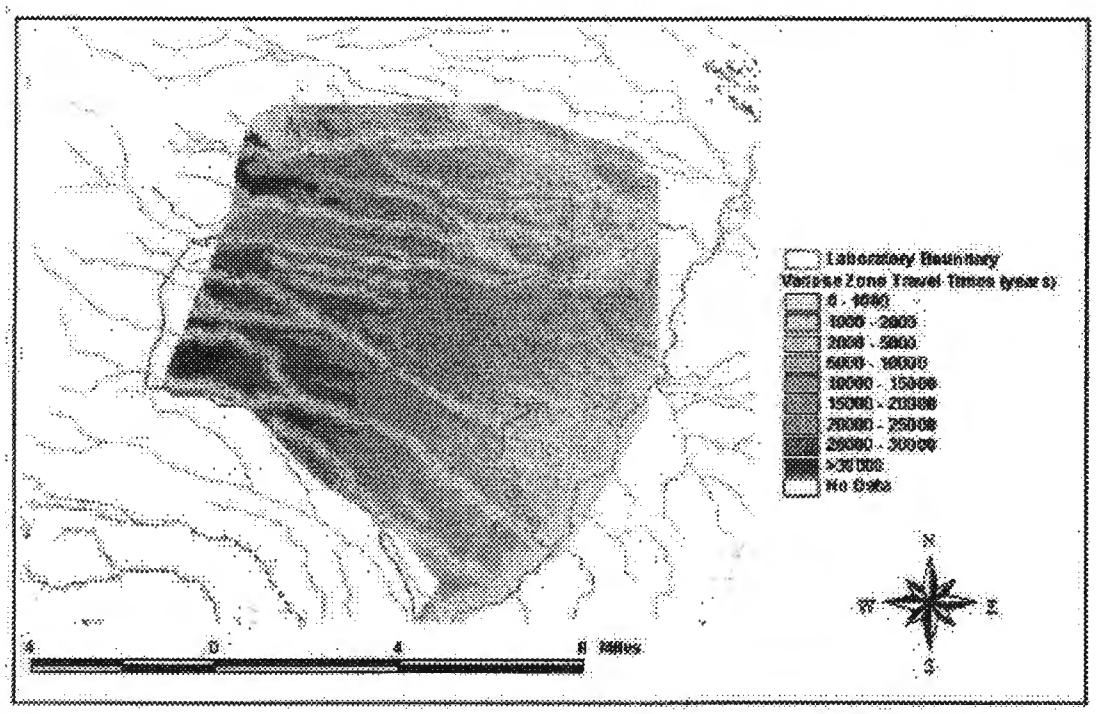

Figure 7. Predicted Vadose-Zone Travel Times (from Nylander et al. 2003). (Note on this draft: this figure is the clearest available at this time but will be replaced with a clearer image in the final report.)

The alternative model for perched water considers lateral migration of solute in perched water bodies. This scenario assumes that there is rapid lateral migration along the top of the perching zone and transit times from the perched water body to the regional aquifer are minimal. When the output from the alternative perched water model is compared to its one-dimensional counterpart, the differences in solute travel times are quite subtle. The regions outlined as having solute travel times <100 years are about the same. Generally, the alternative perched water model

estimated travel times are 15 to 20 years shorter than the base case model. Using the upper-bound infiltration rates, the differences between the one-dimensional model and the alternative perched water model are less noticeable. Despite the apparent insensitivity of water travel times between the one-dimensional and alternative perched water models, the arrival location of the solute in the aquifer is quite different for the two cases. This could be an important factor in estimating solute concentrations in individual wells for the risk assessment process.

7.4 Regional Aquifer Modeling

Regional aquifer modeling was performed on a basin-scale and site-scale resolution. The basin-scale model considers the entire Española basin while the site-scale model considers the area encompassed by the Laboratory. The FEHM code was used as the modeling tool in both cases. The basin model is bounded by topographic and structural features that divide the Española basin from neighboring basins. The northern and southern boundaries are defined according to structural transitions where basin-fill sedimentary rocks are relatively thin. The eastern boundary corresponds to a topographic divide, and the western boundary corresponds to a series of topographic divides and the western margin of Valles Caldera. In general, the boundaries of the basin-scale model are primarily no-flow, except that some inter-basin flow with adjacent basins is allowed through specific head nodes.

The lateral boundaries of the site-scale model (**Figure 8**) are chosen to coincide with the Rio Grande (west), the Santa Clara River (north), the Rio Frijoles (south), and the topographic divide defining the eastern rim of the Valles Caldera (west). Calibration of the basin-scale model is used to determine flux across these boundaries with uncertainty. Analysis of the site-scale model indicated that no-flow is possible across all four boundaries (which was the original working hypothesis); however, limited flow across all four boundaries also is possible.

A three-dimensional computational grid was constructed for basin- and site-scale models. The structure of the two models is identical, except that the site-scale model contains greater vertical resolution. (The grid resolution for the basin-scale model was refined across the Laboratory.) A refined site-scale model is currently being developed with the finest resolution elements having dimensions of 125 m by 125 m horizontally and 12.5 m vertically.

Recharge to the model is formulated as a blend of two distinct recharge models. The first is an elevation-dependent diffuse recharge model that is calculated according to an algebraic function of precipitation (presumably as a function of elevation). Below some given elevation, no diffuse recharge occurs. The second recharge model is canyon-focused, where individual canyons are assigned relative scores reflecting the degree to which they may provide recharge water to the subsurface.

Hydrostratigraphic units are assigned in the groundwater flow model according to a three-dimensional geologic model that LANL also has constructed. Each hydrostratigraphic unit is assumed to have uniform properties (i.e., porosity and hydraulic conductivity). In addition to recharge data, the model also accounts for water withdrawal from pumping wells.

Model calibration used water level and flux data, coupled with the automated calibration software PEST, to determine the set of model parameters (i.e., permeability for each zone and recharge) that provides the best agreement between model-predicted and observed heads and discharge to the Rio Grande. More importantly, PEST provides an estimate of uncertainty in these parameters. Perhaps one of the most significant aspects of parameter estimation using PEST is its

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evaluation of the model complexity. If PEST determines that a large number of parameters are insensitive, then the model may be too complex relative to the available data. In such cases, either more data should be provided to the model or the model should be simplified. Initially, calibration of the basin- and site-scale models involved 38 and 30 parameters, respectively. The total number of calibration parameters was reduced to 21 for the basin-scale model and 12 for site-scale model during the calibration process with PEST.

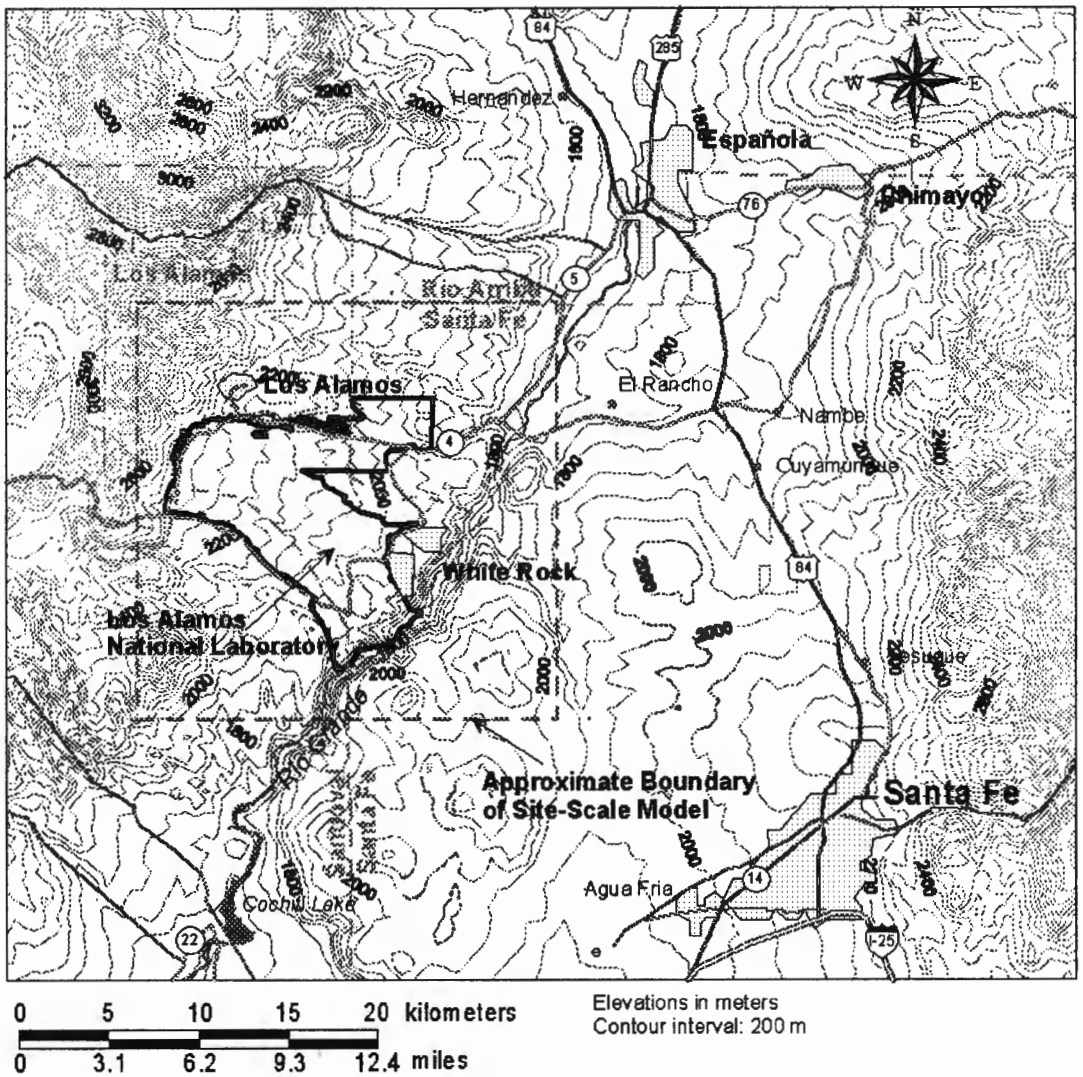

Figure 8. Topographic map of LANL and vicinity showing the approximate boundaries of the site-scale groundwater model domain. ***Note:*** The basin-scale model encompasses most of the area shown and extends off the map to the north by about 45 km and to the northeast by about 20 km.

Results of the calibration indicate model-calibrated permeability values are markedly different than would be obtained by calibration to a single well based on an aquifer test. Because the model attempts to simulate the relatively long-term trend of declining water levels (due to withdrawal) over a relatively large geographic area, the calibration essentially serves as a large-scale test of the regional aquifer. Consequently, the model-calibrated permeability estimates represent the large-scale properties of the hydrostratigraphic units rather than local-scale permeability that may be obtained during a conventional aquifer test analysis. The analysis of water-level data using PEST has led to the conclusion that the large-scale effective permeability of the Santa Fe Group rocks is lower than conventional aquifer test analyses indicate. Three reasons are proposed for this discrepancy, but only one is considered plausible by LANL when considering other data. The explanation for this discrepancy that LANL currently advocates is that a number of north-south trending faults in the Santa Fe Group behave as barriers to flow, and thereby, reduce the large-scale effective permeability of the unit.

The calibrated model exhibits significant over- and under-prediction of water levels in some wells, although the mean difference over all wells is near zero. The most probable reason for this behavior is heterogeneity within each individual hydrostratigraphic unit. Recall that the current model assumes each hydrostratigraphic unit has uniform properties. Stochastic and deterministic approaches to resolve these differences are under development by LANL.

7.5 Implications of Groundwater Modeling in Risk Assessment

Groundwater modeling is not expected to play a significant role in the contemporary risk assessment because the contemporary risk assessment will be based primarily on monitoring data in existing water supply wells, springs, or seeps. However, some numerical techniques may be used to extrapolate radionuclide and chemical concentrations at unmonitored locations where potential exposure might occur. In addition, the groundwater modeling suggests that chemicals and radionuclides from sources on the dry mesas where infiltration is estimated to be less than 1 mm yr^{-1} would not reach the regional aquifer within 1,000 years. LANL currently uses 1,000 years as the time of compliance to prioritize remedial action decisions. Therefore, based on its estimated vadose- zone travel times, LANL does not expect these sources to be important in remedial action decisions. *RAC*, on the other hand, has not yet established a time frame for risk evaluation and plans to reevaluate the LANL vadose-zone travel times. If anthropogenic water sources are present, then vadose-zone travel times could be substantially less and result in chemicals and radionuclides reaching the aquifer in less than 1,000 years. Liquid effluent sources fall into this category and will need to be considered in the risk assessment process. Additionally, chemicals and radionuclides that exist in a vapor phase can travel through the unsaturated zone in substantially less time than those that travel only in the dissolved-liquid phase. Therefore, vapor-phase transport may also be an important process to consider.

Sources in the wet canyons pose an ongoing concern because of their contribution to concentrations of chemicals and radionuclides in groundwater, both underlying the facility and migrating over the long term away from the facility. Using the simple, one-dimensional vadose-zone model described earlier, fluxes to the aquifer from sources in wet canyons could be estimated. Transport in the saturated zone could be more difficult and uncertain if existing wells are used as the point of exposure because local-scale heterogeneity can strongly influence the flow path from source to receptor. LANL groundwater modeling personnel have indicated that

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efforts are being made to quantify this uncertainty. However, the more general question is the deterioration of groundwater as a resource. This relates to the presence of any concentrations of chemicals and radionuclides anywhere in groundwater from anthropogenic sources and, at minimum, is measured by concentrations of materials of concern above some predefined limit (such as a maximum contaminant level [MCL]). The presence of chemicals and radionuclides in groundwater will require, at minimum, evaluation of the fate and transport of chemicals and radionuclides and potential remedial action. On this basis, the major effort of groundwater modeling will be to estimate chemical and radionuclide fluxes to the regional aquifer since concentrations in the aquifer (close to a source) could be modeled using relatively simple analytical or semi-analytical techniques.

8.0 Stakeholder Perception of Groundwater Issues

This section attempts to summarize opinions regarding effects of LANL on groundwater as held by various stakeholders. Stakeholders are individuals or organizations who have a personal, financial, health, or legal interest in policy or recommendations that affect their well-being or that of their environment. Used broadly, this includes any party who has an interest in the issue at hand. The following information is limited to those stakeholders who have a clearly articulated opinion regarding groundwater impacts at LANL.

LANL has articulated a detailed technical position with respect to groundwater, but has been less clear about the implications of those technical findings. The technical position, which has evolved as more information has been gathered, is laid out in detail in LANL's Groundwater Annual Status Reports for 1998, 1999, 2000, 2001, and 2002 (Nylander et al., 1999, 2000, 2001, 2002, 2003). In some cases, the technical position of the Laboratory has changed dramatically. For example, in earlier reports (for 1998, 1999, and 2000), LANL indicates that Laboratory chemicals and radionuclides present in the regional aquifer are diluted below MCLs. In contrast, the reports for 2001 and 2002 become oblique in their discussion of effects on the regional aquifer. The conceptual model for the alluvial aquifer indicates that alluvial groundwater quality is affected by recharge of wastewater from the Laboratory and mentions some radionuclides and chemicals explicitly (e.g., plutonium, tritium, and high explosives), but includes no mention of radionuclide or chemical concentrations. The conceptual models for the intermediate perched groundwater and regional aquifer groundwater also indicate that groundwater quality is affected by the quality of the recharge water, including wastewater effluent, and that chemicals and radionuclides in the perched zone could be transported "some distance away from their surface source." However, the conceptual model does not address the extent to which chemicals and radionuclides could affect the regional aquifer, particularly at important downgradient locations such as Santa Fe's Buckman Wellfield. A discussion of radiocarbon dating of groundwater indicates water discharging from the regional aquifer near the Rio Grande (and, by implication, the Buckman Wellfield) is about 30,000 years old. Thus, LANL implies that any threat of adverse effects on groundwater lies an extremely long time in the future. In the final analysis, the LANL documents on groundwater present a collection of explicit technical details without a synthesis into a clear, coherent position on the implications of those details. Discussions with other stakeholders show that they perceive LANL's position to be that threats to the regional aquifer are remote in both probability and time.

Data presented and interpreted by the New Mexico Environment Department (NMED) present a view that chemicals introduced into the groundwater at LANL already have traveled off the site (McQuillan et al. 2003). McQuillan, et al., construct Stiff Diagrams, a graphical depiction of common groundwater anions and cations, to show the similarities and differences in various groundwaters from wells and springs in Los Alamos County. Several general patterns emerge. For example, groundwater that has apparently spent long periods of time (thousands of years) in the regional aquifer is dominated by sodium, whereas younger groundwater is dominated by calcium. A few wells and springs deviate from these natural background patterns and show increased concentrations of chemicals such as chloride and nitrate that are associated with non-natural sources. In particular, Springs 2B, 3, and 4 below White Rock show these altered ionic signatures and low-part-per-billion concentrations of perchlorate. McQuillan, et al., cite similarities between the chemical signature of the White Rock springs and that of the regional aquifer at Test Well-1 on the LANL site (TW-1; see **Figure 5**) as an indication that the chemicals originate from former operations at LANL. The existence of LANL chemicals and radionuclides at the White Rock springs reveals groundwater travel speeds of about several hundred feet per year, according to McQuillan, et al., considerably faster than indicated in LANL's current groundwater model (see *Section 7.4*), but consistent with earlier LANL estimates. According to McQuillan, et al., LANL disputes the reliability of the perchlorate analyses and has suggested wastewater from the White Rock Sewage Treatment Plant may be the cause of the altered chemical signatures in the White Rock springs. A recent report on perchlorate issues by LANL confirms that LANL takes issue with the perchlorate detections (LANL 2003).

Discussions with Los Alamos County staff responsible for the county's water supply revealed some very specific concerns regarding groundwater quality at LANL. The county is the present owner of the water-supply system originally developed by DOE and LANL. The system provides drinking water to Los Alamos, White Rock, and LANL, drawing from the regional aquifer at several well fields on and near LANL. One of the supply wells, Otowi-1, has shown concentrations of perchlorate, chloride, nitrate, and tritium. While this well is not currently used as part of the drinking-water supply, it is used as a source of non-potable water for the wastewater treatment plant and a transportation garage. The remaining 10 wells currently in use for the drinking-water supply have not shown elevated concentrations of chemicals or radionuclides associated with LANL operations. The county indicates that these wells provide adequate supplies for the current distribution system.

For planning purposes, Los Alamos County assumes that each water supply well can operate productively for a 50-year life and then must be replaced. Several wells are approaching this replacement age. In addition, easements and other issues may force the replacement of several of the wells. For these reasons, the county has investigated possible future supply locations. The most productive portions of the regional aquifer are within the watersheds where the LANL facility is located. As a result, otherwise promising locations for future water supply wells in Water Canyon and Pueblo Canyon have been discounted because of known or potential concentrations of chemicals or radionuclides in groundwater at upgradient locations. Thus, concentrations of chemicals or radionuclides in groundwater at LANL have significantly limited the county's alternatives. The county follows LANL's groundwater investigations closely in order to anticipate areas of present and potential future concentrations of chemicals or radionuclides in groundwater.

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Another concern for the county is the possible role of Test Well 1 (TW-1) in carrying chemicals and radionuclides to the regional aquifer. TW-1 was constructed in 1950 to test feasible water-supply well locations. It is constructed as a metal casing in an otherwise open well bore extending from the shallow subsurface to the regional aquifer. The well annulus (the open hole outside of the well casing and inside the well wall) was not sealed with cement or other sealing material. This open annulus creates a potential conduit for groundwater to flow from the locally saturated alluvium and perched zones down and into the regional aquifer. A local rise in the regional aquifer water table was observed at TW-1 (LANL 1998) and would be consistent with water flowing into the regional aquifer via the well. The county indicated that it has been assured by LANL that any contribution of chemicals or radionuclides in nearby Otowi-1 from such a connection would be negligible and that the well does not need to be sealed. Nevertheless, the county expresses a strong desire to eliminate this potential pathway for chemicals and radionuclides to the regional aquifer.

Local citizen groups also have stated positions with respect to LANL's effects on groundwater. The Concerned Citizens for Nuclear Safety (CCNS) is based in Santa Fe and indicates as its mission "increasing public awareness concerning the issues posed by radioactivity and the nuclear industry" (CCNS 2003). CCNS is not solely an environmental organization, but also is concerned with a broad array of issues related to nuclear weaponry, nuclear power, and nuclear waste disposal. A search of the CCNS internet site (www.nuclearactive.org) located two documents with specific discussions about groundwater issues at LANL. In the earlier of these two CCNS documents, Coghlan and King (1998) present a lengthy review of the Draft Site-Wide Environmental Impact Statement (SWEIS) for LANL prepared by DOE. The SWEIS is intended to analyze the environmental effects of the Laboratory's present and possible future operations. Coghlan's and King's review includes a section entitled "Groundwater Contamination," as well as mentioning groundwater-related issues elsewhere in the document. Their conclusion is that there is insufficient information to determine LANL's impacts on the regional aquifer, but that LANL should have installed wells and completed other work to develop that information long ago. Much of their discussion focuses on LANL's past positions with respect to groundwater. For example, they state, "For years, the lab perpetuated the myth that the volcanic tuff above the deep ground water from which Los Alamos County draws its drinking supply is an impermeable barrier to any potential contaminants." They go on to state that this position has been refuted by field evidence of groundwater contamination. A second CCNS document (Alvarez and Arends 2000) examines the potential effects of the Cerro Grande fire. This document also emphasizes the uncertainties in the hydrogeology, the extent and magnitude of environmental impacts, and the contaminant-transport processes at LANL, as well as the documented instances of groundwater contamination. The document also discusses LANL's past errors in interpreting the groundwater system. In the final analysis, the CCNS documents present the position that LANL has caused groundwater contamination, on-site sources have the potential to cause further groundwater contamination, the eventual effects of that contamination are unknown but potentially dire, and more investigation is needed to evaluate those effects and the hydrogeologic system.

The Los Alamos Study Group (LASG) describes itself as "a non-profit, research-oriented, nuclear disarmament organization based in Albuquerque, New Mexico" (LASG 2000). The group has similar interests to CCNS, but focuses more on LANL. A search of the LASG web site produced one document with a peripheral discussion of groundwater, a critique of the Los Alamos environmental cleanup by Mello (2002). The document identifies groundwater, streams,

and springs to be "seriously contaminated at several locations" at Los Alamos, with chemicals and radionuclides beginning to appear in public drinking water supplies and off-site springs. It states, "While the contaminant concentrations may remain below standards in public wells for decades to come, this desirable outcome is by no means assured." The document otherwise focuses on the cleanup of legacy releases and waste disposal sites at LANL. Mello argues that the requirements for cleanup at LANL have not been rigorous, and he is as critical of NMED for failing to enforce a rigorous cleanup as he is of LANL for delaying meaningful cleanup. Overall, the conclusion with respect to groundwater can be inferred to be that legacy waste disposal and site contamination pose a significant future risk to groundwater and that future risk is being addressed half-heartedly by LANL and the state.

Another Santa Fe organization, Nuclear Watch of New Mexico (NWNM), states its goal is "to provide timely and accurate information to the public on nuclear issues in New Mexico and the Southwest" (NWNM undated). NWNM provides two documents that concern a Corrective Action Order issued under authority of the Federal Resource Conservation and Recovery Act (RCRA) by the NMED Hazardous Waste Bureau (NWNM 2002, 2003). NWNM strongly supports the Corrective Action Order as a means to prompt cleanup action at LANL, something the organization indicates has been accomplished too slowly. With respect to groundwater, NWNM (2003) cites one of the reasons for the order as "Increasing evidence of groundwater contamination, which until six years ago the lab completely dismissed as even being a possibility." Thus, as with the other citizen groups, NWNM reveals a lack of trust based on LANL's past positions and what NWNM views as slow progress in addressing on-site sources of contamination.

This review of stakeholder positions is necessarily incomplete; not all stakeholders have addressed the groundwater issue specifically, have expressed a fully formed view of the issue, or have been accessible to *RAC*. However, *RAC* intends to continue to explore and define stakeholder issues as the *RACER* study progresses. Nonetheless, with this preliminary inquiry, there is some surprising agreement between parties as potentially antagonistic as LANL and citizen activist groups. There seems to be a consensus that the groundwater system is complex and not yet adequately understood, and that more study is needed. There also appears to be some consensus that chemicals and radionuclides in groundwater are not a major current threat, but may be a major threat in the future. Where disagreement seems most intense is on the issue of timing; i.e., whether LANL should have accomplished more investigation and cleanup in the past, how quickly groundwater contamination could emerge as a true threat, and how quickly investigation and cleanup should proceed. With the exception of conflicting interpretations by LANL and NMED of chemical and perchlorate concentrations at springs below White Rock, and disagreement between LANL and Los Alamos County regarding the need to abandon well TW-1, there does not appear to be substantial disagreement regarding technical issues.

9.0 Forthcoming Analysis by *RAC*

The technical analysis of the risk posed by groundwater at the LANL site will proceed in two distinct phases: (1) an assessment of the contemporary risk posed by the current concentrations of chemicals and radionuclides at the LANL facility, and (2) consideration of future solute transport and fate and consequent exposure risk to be incorporated in the risk-informed decision process.

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RAC's immediate task is completion of the contemporary risk assessment. The contemporary risk assessment is proposed to "be based primarily on the most recent, comprehensive data set for which final review and quality assurance have been completed" (*RAC* 2003). For groundwater, *RAC*'s state of knowledge of the groundwater system will necessarily depend upon older data as well, since groundwater travels slowly and groundwater concentrations change slowly over time. Also, groundwater samples tend to be infrequent compared to other media, and are limited by the availability of monitoring wells at which samples can be collected. In order to construct as complete an understanding as possible of groundwater contamination at LANL, *RAC* intends to incorporate other data resulting from previous monitoring efforts to the extent that they can be used quantitatively to supplement the state of knowledge about contemporary groundwater conditions. The intent is to develop a mechanism by which the state of knowledge about groundwater can be readily updated to facilitate a quantitative measure of change in contemporary risk.

The contemporary risk assessment for groundwater will be developed based on observed groundwater chemical and radionuclide concentrations at points of potential exposure. These are limited to wells used for public or private water supply, and springs or seeps that bring groundwater to the surface. Existing groundwater monitoring data will be carefully examined to identify the types and concentrations of chemicals and radionuclides present at these potential points of exposure.

Groundwater or vadose-zone modeling is not anticipated to be required for the contemporary risk assessment. However, numerical techniques may be used to estimate chemical and radionuclide concentrations at unmonitored locations based on available data from adjacent monitoring locations. Later in the project, numerical modeling techniques likely will be used to forecast chemical and radionuclide transport to estimate future chemical and radionuclide exposure associated with groundwater.

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