New Mexico Decision-Makers Field Guide No. 1

Water, Watersheds, and Land Use in New Mexico

Impacts of Population Growth on Natural Resources

Santa Fe Region 2001

Peggy S. Johnson, Editor

New Mexico Bureau of Mines and Mineral Resources

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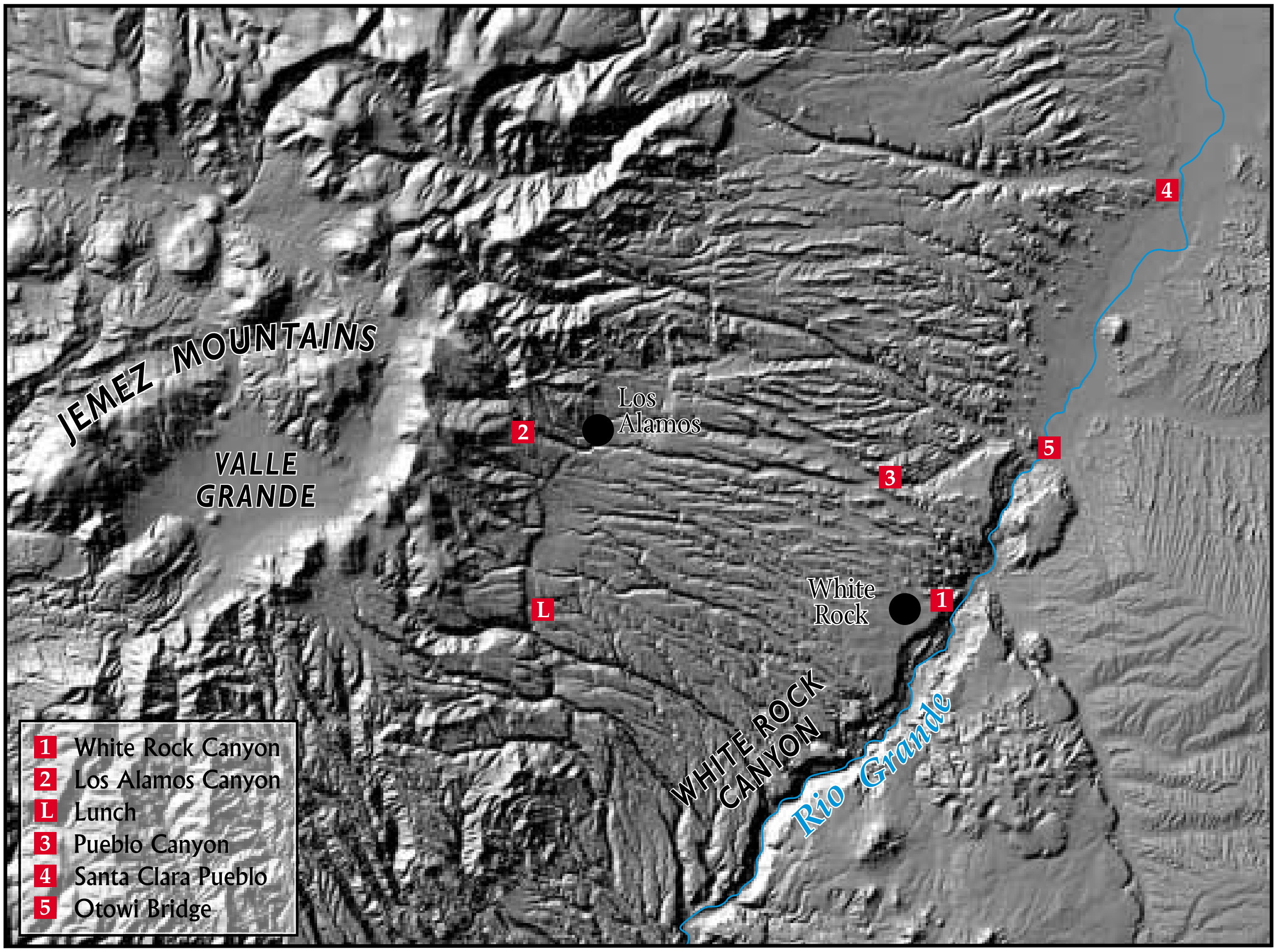
Socorro 2001

Day One, May 9, 2001

The Pajarito Plateau—Earth, Water, and Fire



Wednesday, May 9, 2001

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Why Study Geology?

by *Paul W. Bauer*, New Mexico Bureau of Mines and Mineral Resources

The Earth is the basis for all human economic activity. The Earth provides us with the most basic resources for survival: clean water, fertile soils for agriculture, and the raw materials for adobe, concrete, steel, and glass for constructing shelters. We also extract many of our raw industrial products (iron, copper, aluminum, sand and gravel, and many others) and our most important fuels (oil, gas, and coal) from the Earth. The geologic environment is also the disposal site for all of our industrial by-products, hazardous materials, household trash, and human waste. One of our greatest immediate challenges is to balance our thirst for these finite Earth resources with our duty to protect and preserve the environment in order to sustain future generations of humans, animals, and plants.

Geology is the study of planet Earth. Studying the Earth means studying the **materials** that compose the planet, the **processes** that act on these materials, the **structures** formed by those processes, and the **history** of Earth and its life forms since planet formation.

Earth Materials

Whether we realize it or not, geology plays an important role in our everyday lives. Although we are continually in contact with Earth-derived materials, we typically do not think about their origins or the consequences of their consumption. But the mining of any commodity comes with costs—some are tangible costs (such as the market price), whereas other costs are intangible (such as societal costs due to the consumptive loss of non-renewable resources, pollution, political unrest, worker exploitation, international conflict, human health problems, habitat loss, and other environmental consequences). As supplies of some raw materials dwindle, the costs of exploration and mining increase, and as the true environmental costs of extraction and consumption are incorporated into the marketplace, prices of finished goods rise.

Geologic Processes

A great variety of geologic processes affect our lives, sometimes in unforeseen and catastrophic ways. Some processes produce instantaneous, dramatic impacts, including large costs to society, and sometimes a loss of life. Examples are floods, landslides, earthquakes, and volcanic eruptions—all of which are facts of life in New Mexico. Volcanoes have erupted in New Mexico in recent geologic time, and undoubtedly more will erupt in the future. Other processes operate at slower rates, although their societal costs can still be substantial. Examples include erosion, land subsidence, siltation of waterways, drought, corrosion, and the slow flow of ground water through an aquifer. As the planet has become industrialized, human activities have profoundly affected the rates and severities of many of these natural processes. Additionally, for the first time in human history, we now possess the capability to initiate dramatic and devastating global environmental modifications, such as climate change, nuclear winter, and ozone depletion.

Geologic Structures

Geologic processes are capable of producing a wide variety of structures in rocks and sediments, and some of these structures, such as faults and fractures, have far-reaching impacts on our lives. For example, seismic faults like the San Andreas fault have enormous destructive potential. In New Mexico, seismic faults are a less significant hazard, although moderate quakes have damaged buildings in Albuquerque, Socorro, and elsewhere. A more subtle, but profound, consequence of faults in New Mexico is that they can have an impressive effect on the distribution of ground water in areas such as the Albuquerque Basin and the Sandia Mountains. In places where water is pumped from bedrock, fractures in the rock actually control the productivity of wells.

Geologic History

The rocks and minerals that we depend on for raw materials, and the landscapes that shape our communities and activities, have evolved over millions, even billions, of years. Through careful study, we can use our knowledge of Earth materials, structures, and processes to construct a framework that relates all of the data and their interpretation in space and time. This approach allows us to infer past geologic events and to forecast future geologic scenarios. We can look at any New Mexico landscape and determine why and when it formed, and we can predict its environmental response to some human-induced stimuli. For instance, we can evaluate how a river responds to damming. We can also estimate the volume and value of geologic commodities, such as aggregate, coal, or copper, and we can gauge the environmental impacts of extracting those commodities.

Geologists study the Earth for a variety of reasons (exploration for natural resources, environmental protection and rehabilitation, prediction of natural hazards, pure science, and an appreciation of nature), but fundamental to all is a desire to gain a better understanding of our physical environment. We have only one Earth; to live on it wisely, we must understand it well.

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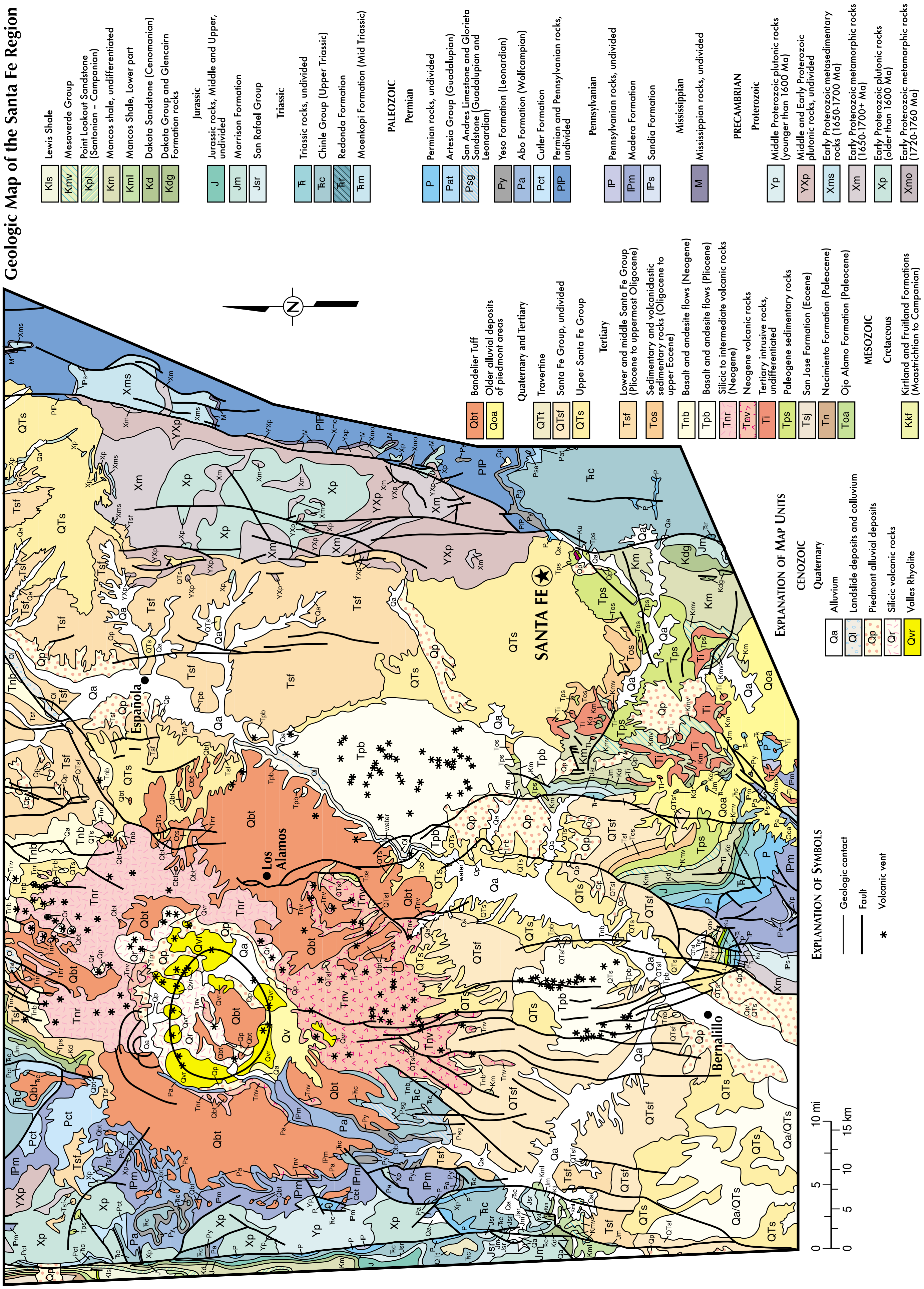
Most of Bauer’s geologic research in New Mexico has been involved in field mapping and structural analysis designed to unravel the ancient geologic history of the state. Recently, he has been investigating the stratigraphy and structure of the Taos area, in order to support ongoing hydrologic studies. He is also very interested in promoting an appreciation of the state's landscapes and natural resources to the non-geologic public and has authored several non-technical books on New Mexican geology.



Geologic Map of the Santa Fe Region
EXPLANATION OF MAP UNITS
CENOZOIC
Quaternary
Qa Alluvium
Ql Landslide deposits and colluvium
Qp Piedmont alluvial deposits
Qr Silicic volcanic rocks
Qvr Valles Rhyolite
Qbt Bandelier Tuff
Qoa Older alluvial deposits of piedmont areas
Quaternary and Tertiary
QTt Travertine
QTsf Santa Fe Group, undivided
QTs Upper Santa Fe Group
Tertiary
Tsf Lower and middle Santa Fe Group (Pliocene to uppermost Oligocene)
Tos Sedimentary and volcaniclastic sedimentary rocks (Oligocene to upper Eocene)
Tnb Basalt and andesite flows (Neogene)
Tpb Basalt and andesite flows (Pliocene)
Tnr Silicic to intermediate volcanic rocks (Neogene)
Tnv Neogene volcanic rocks
Ti Tertiary intrusive rocks, undifferentiated
Tps Paleogene sedimentary rocks
Tsj San Jose Formation (Eocene)
Tn Nacimiento Formation (Paleocene)
Toa Ojo Alamo Formation (Paleocene)
MESOZOIC
Cretaceous
Kkf Kirtland and Fruitland Formations (Maastrichtian to Campanian)
Kls Lewis Shale
Kmv Mesaverde Group
Kpl Point Lookout Sandstone (Santonian – Campanian)
Km Mancos shale, undifferentiated
Kml Mancos Shale, Lower part
Kd Dakota Sandstone (Cenomanian)
Kdg Dakota Group and Glencairn Formation rocks
Jurassic
J Jurassic rocks, Middle and Upper, undivided
Jm Morrison Formation
Jsr San Rafael Group
Triassic
T̄R Triassic rocks, undivided
T̄Rc Chinle Group (Upper Triassic)
T̄Rr Redonda Formation
T̄Rm Moenkopi Formation (Mid Triassic)
PALEOZOIC
Permian
P Permian rocks, undivided
Pat Artesia Group (Guadalupian)
Psg San Andres Limestone and Glorieta Sandstone (Guadalupian and Leonardian)
Py Yeso Formation (Leonardian)
Pa Abo Formation (Wolfcampian)
Pct Cutler Formation
PIP Permian and Pennsylvanian rocks, undivided
Pennsylvanian
IP Pennsylvanian rocks, undivided
IPm Madera Formation
IPs Sandia Formation
Mississippian
M Mississippian rocks, undivided
PRECAMBRIAN
Proterozoic
Yp Middle Proterozoic plutonic rocks (younger than 1600 Ma)
YXp Middle and Early Proterozoic plutonic rocks, undivided
Xms Early Proterozoic metasedimentary rocks (1650-1700 Ma)
Xm Early Proterozoic metamorphic rocks (1650-1700+ Ma)
Xp Early Proterozoic plutonic rocks (older than 1600 Ma)
Xmo Early Proterozoic metamorphic rocks (1720-1760 Ma)
EXPLANATION OF SYMBOLS
Geologic contact
Fault
Volcanic vent
SANTA FE
Española
Los Alamos
Bernalillo
N
0 5 10 mi
0 5 10 15 km

The Value of Geologic Mapping to Decision Makers in New Mexico

by *Paul W. Bauer*, New Mexico Bureau of Mines and Mineral Resources

Of the 121,667 mi² of land in New Mexico, less than 20% has been geologically mapped at the standard scale of 1:24,000 (1 inch = 2,000 ft). Why is this a concern? Decision makers at the local, state, tribal, and federal levels increasingly need specific kinds of scientific information to make informed choices concerning land, water, and resource use. For example, deciding to preserve certain pieces of land may limit economic opportunities and alter nearby land values; alternatively, failing to limit inappropriate development of land may provide short-term benefits, but cause hugely expensive and divisive long-term problems. Detailed, publicly available earth-science information is essential for making informed decisions that encourage sustainable economic development and prosperity. Modern geologic maps are the fundamental tool used to display the information that decision makers require to identify and protect valuable resources and make wise use of our land.

Geologic maps combine descriptive information (such as materials and structures) and interpretations (about process) into a conceptual framework that relates all of the geologic elements through time. This is a powerful tool, as it both describes the geologic environment and permits us to predict how natural systems are likely to behave in the future. For example, we might predict how pumping an aquifer may cause land subsidence and accompanying damage to foundations and buildings.

Geologic maps provide immediate economic benefits. In New Mexico, those benefits add up to many millions of dollars saved. For example, without geologic maps, project costs can be greater, exploration efforts have lower success rates, costly engineering errors can be made, and project completions can be delayed. In addition, high-quality maps made by objective scientists also have very important intangible values. In particular, users of geologic maps find that the quality of their work is enhanced and the credibility of their findings is increased.

Surveys have shown that geologic information is important to government and private industry for a variety of environmental and economic applications, with the following being the most common applications:

(1) Exploration and development (ground water, industrial minerals, metallic minerals, oil and gas, and coal);
(2) Environmental consulting (pollution prevention, site cleanup, and industrial issues);
(3) Hazard prevention and protection (landslides, earthquakes, soil stability, mine subsidence, sinkholes, volcanic eruptions, and floods);
(4) Engineering applications (buildings and foundations, roads, pipelines, dams, utilities, railroads);
(5) City planning (zoning decisions, landscape planning, and building codes);
(6) Regional planning (regional water plans, waste disposal, industrial permits, and planning transportation corridors); and
(7) Property valuation (land acquisition, property tax assessment, and cost-benefit analysis).

In this state, new geological quadrangle maps by the New Mexico Bureau of Mines and Mineral Resources (NMBMMR) are being used to support a great variety of environmental and hydrologic work along the Rio Grande. A few of these recent projects are a hydrogeologic investigation of the Albuquerque Basin aquifer—in cooperation with the United States Geological Survey (USGS), a hydrogeologic study and water resource assessment for Sandoval County in the Placitas development area, a hydrogeologic study of the Taos Valley, and subsidence and aquifer consolidation modeling in the Albuquerque area. Geologic maps are also the primary source of information on the state's aggregate resources (sand, gravel, crushed stone). Aggregates are especially pertinent to geologic map making, as they are needed everywhere that construction occurs (including road-building projects), and their transportation costs must be minimized in order for their use to be economically feasible.

Only by understanding the distribution of geologic materials and structures, and by understanding past, current, and future work of geologic processes, can we minimize societal costs and maximize societal benefits in our dynamic New Mexican geologic environment. The only way to obtain such information is through the production of detailed, field-based geologic maps and derivative research.

New Mexico's Geologic Mapping Program

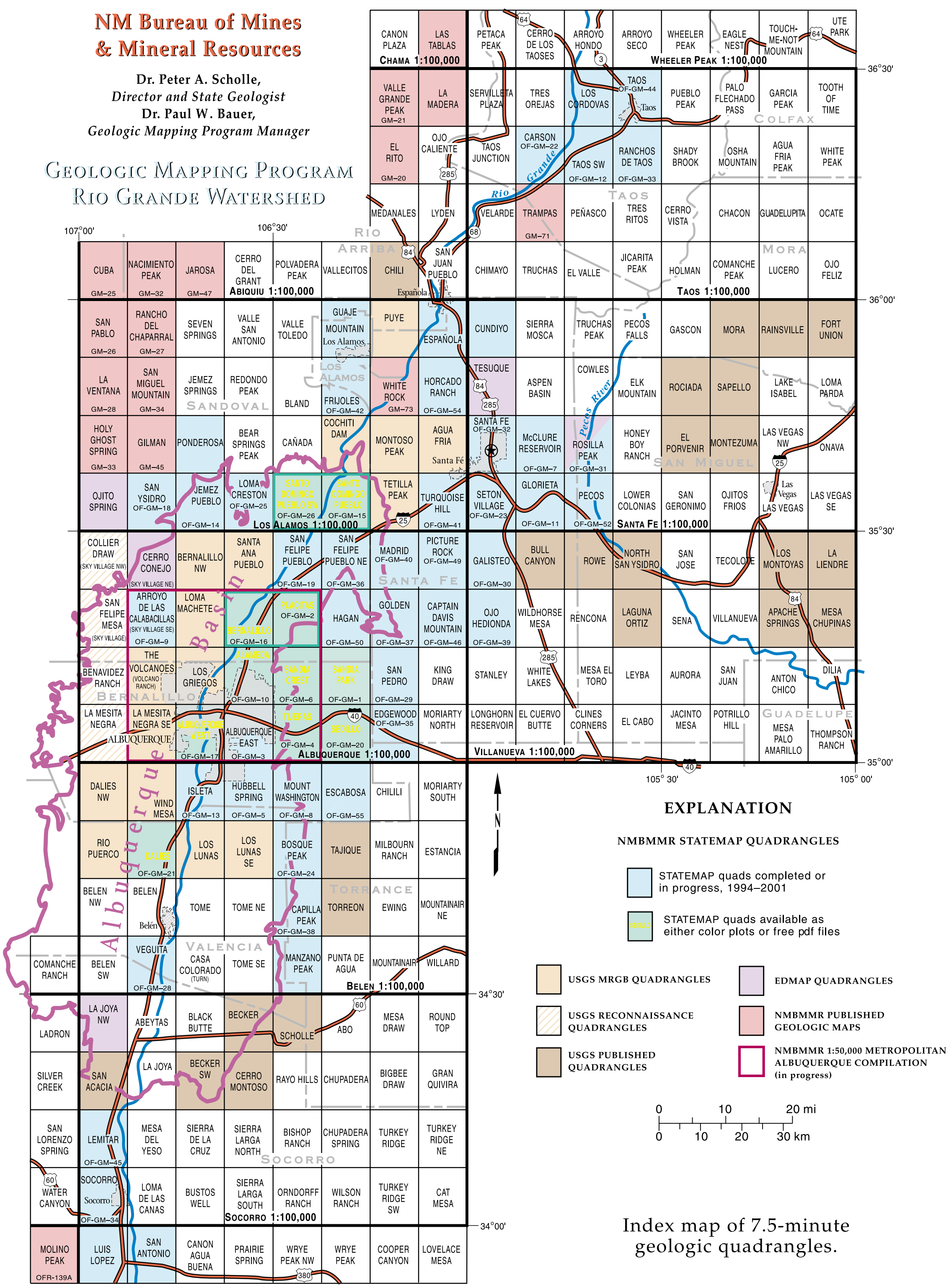
The New Mexico Bureau of Mines and Mineral Resources Geologic Mapping Program (STATEMAP) is partly funded by the National Cooperative Geologic Mapping Program, a federal program administered through the USGS. We are in the 8th year of a project designed to rapidly produce and distribute state-of-the-art, detailed geologic quadrangle maps of select areas of the state. New Mexico is one of the most successful state surveys in the country competing for STATEMAP funds. By June 2002, we will have mapped 60 quadrangles (approximately 2,800 mi²), mostly along the Rio Grande watershed from Taos to Socorro (Fig. 1). As of July 2000, the NMBMMR had received a total of $1,164,893 from the USGS, the best total in the nation. The program is a matching-funds program; NMBMMR matches all federal monies dollar-for-dollar. Our mapping program is especially important to New Mexico because of the approximately 2,000 7.5-min quadrangles in the state, less than 20% have been mapped at the standard scale of 1:24,000. The most critical unmapped areas are along the population centers of the Rio Grande corridor. Most of the corridor is of vital economic, agricultural, social, and scientific importance to the state. The most pressing challenge to cities along the corridor relates to water. A combination of rapid population growth, permeable alluvial aquifers, large topographic relief, and the alternating scarcity and abundance of precipitation gives rise to a host of hydrogeologic and engineering geologic problems.

Our program is cooperative in the broadest sense. Mapping priorities are set annually by a 35-member State Geologic Mapping Advisory Board composed of hydrologists, geologists, and planners from state, local, federal, pueblo, and private agencies and entities. The quadrangles are selected based on their potential to provide essential earth-science data to planners, engineers, geologists, and hydrologists. The program also represents a cooperative effort between NMBMMR geologists, university faculty and students, private-sector consultants, and the Geologic Division of the USGS. The mapping produces mutually beneficial interactions with a great variety of New Mexican entities (e.g., pueblos, Kirtland Air Force Base, the national laboratories, the cities of Albuquerque, Santa Fe, and Taos, county governments, ranchers, state water agencies, federal land management agencies, etc.).

From the beginning, our project objective has been to characterize the geology of each area in sufficient detail to allow use of the information in matters of practical economic and environmental concern to governments, communities, and planners, as well as to satisfy the fundamental goals of basic science. Based on results of the mapping and the ever-increasing demand for our maps, we have achieved and surpassed this goal.

Congress increased the total funds available to STATEMAP from $4,033,821 in 2000, to $6,660,550 for 2001, an increase of 60%. Much of the success of STATEMAP is due to the requirement that maps be designed to address critical societal and/or scientific problems. In New Mexico, recent concerns about water quality, water availability, geologic hazards (earthquakes, floods, and unstable soils), mineral resources, transportation, and environmental problems throughout the Rio Grande corridor have illustrated the importance of modern, detailed geologic data. Our program has received widespread support and acclaim from political leaders, government agency scientists, university professors, professional hydrologists and engineers, water planners, and others. One of the most visible applications of our maps has been by the USGS to produce a hydrogeologic model of the Albuquerque region.

One of the basic conclusions of scientists involved in the production and use of geologic maps is that the value of geologic maps endures—in addition to their immediate value, there will always be unexpected future benefits from investing in good science now.



Index map of 7.5-minute geologic quadrangles.

Geography and Land Use Status of the Los Alamos Area—A Brief Overview

by *Dennis Erickson*, LA-UR-01-2053, Environment, Health, and Safety Division Director, Los Alamos National Laboratory

Los Alamos National Laboratory is located on 43 mi^2 of land in northern New Mexico, about 25 mi northwest of Santa Fe. The surrounding area is largely undeveloped, and large tracts of land north, west, and south of the laboratory are held by the Santa Fe National Forest, Bureau of Land Management, Bandelier National Monument, General Services Administration, and Los Alamos County. The Pueblo of San Ildefonso borders the laboratory to the east.

The University of California administers the laboratory for the Department of Energy. Since its inception in 1943, the principal mission of the laboratory has been the design, development, and testing of weapons for the nation's nuclear arsenal. Research programs in nuclear physics, hydrodynamics, conventional explosives, chemistry, metallurgy, radiochemistry, and biology support this effort. The laboratory's original mission to design, develop, and test nuclear weapons has broadened and evolved as technologies, United States priorities, and the world community have changed. Today, we use the core technical expertise developed for defense and civilian programs to carry out both our national security responsibilities and our broadly based programs in energy, nuclear safeguards, biomedical science, environmental protection and cleanup, computational science, materials science, and other basic sciences. As the largest institution and the largest employer in the area, the laboratory has approximately 6,800 University of California employees plus approximately 2,800 contractor personnel. Our annual budget is approximately $1.2 billion.

The laboratory is located on the Pajarito Plateau, which forms the eastern flank of the Jemez Mountains. The Pajarito Plateau consists of a series of finger-like mesas separated by deep canyons containing ephemeral and intermittent streams that run from west to east. Mesa tops range in elevation from approximately 7,800 ft on the flank of the Jemez Mountains to about 6,200 ft at their eastern termination above the Rio Grande valley. The eastern margin of the plateau stands 300–900 ft above the Rio Grande. Underlying the plateau is the Bandelier Tuff, a thick sequence of volcanic rock that emanated from the Jemez Mountains.

Most laboratory and community residential areas, Los Alamos and White Rock, are confined to the mesa tops. Laboratory research and development facilities are located in 33 active technical areas across the laboratory site. However, these developed areas account for only a small part of the land area. Most of the land provides buffer areas for security and safety and is held in reserve for future use.

The Pajarito Plateau is a biologically diverse and archaeologically rich area. The laboratory spans the ponderosa and piñon-juniper vegetation zones. Within those vegetation zones, approximately 500 plant species, 29 mammal species, 200 bird species, and 27 reptile and amphibian species are living. About 20 of those species have special status, either threatened, endangered, or species of concern at a federal or state level. About 1,400 archaeological sites on laboratory land document the prehistoric human occupation of the Pajarito Plateau, most from the 14th and 15th centuries.

A Geologic Overview of the Pajarito Plateau and Vicinity

by *David E. Broxton*, LA-UR-01-2055, Los Alamos National Laboratory

The Pajarito Plateau is a high, east-tilted tableland eroded into a series of narrow mesas separated by deep canyons. Mesa-top elevations range from approximately 7,800 ft on the west to 6,200 ft on the east. This field trip stop is at the White Rock overlook, where the Rio Grande has cut a 900-ft-deep gorge that marks the eastern margin of the plateau. From this vantage point, you can see the Jemez Mountains rising above the Pajarito Plateau on the skyline to the west, the Española Valley in the foreground to the east and northeast, White Rock Canyon and the Rio Grande below, the Cerros del Rio (hills by the river) across the Rio Grande, and the Sangre de Cristo Mountains on the eastern skyline (Fig. 1).

The geology of this region reflects the interplay of faulting, sedimentation, volcanism, and erosion over the past 25 million years. The Jemez Mountains are a broad highland built up by volcanic eruptions over the last 13 million years. During the latter stages of eruption (approximately 1.5 million years ago), cataclysmic explosions from a volcanic center in the central part of the Jemez Mountains deposited thick blankets of volcanic rock and ash (tuff) over the area that is now the Pajarito Plateau (Fig. 2). These eruptions incinerated all life in their paths and covered all existing valleys and hills. Ash layers

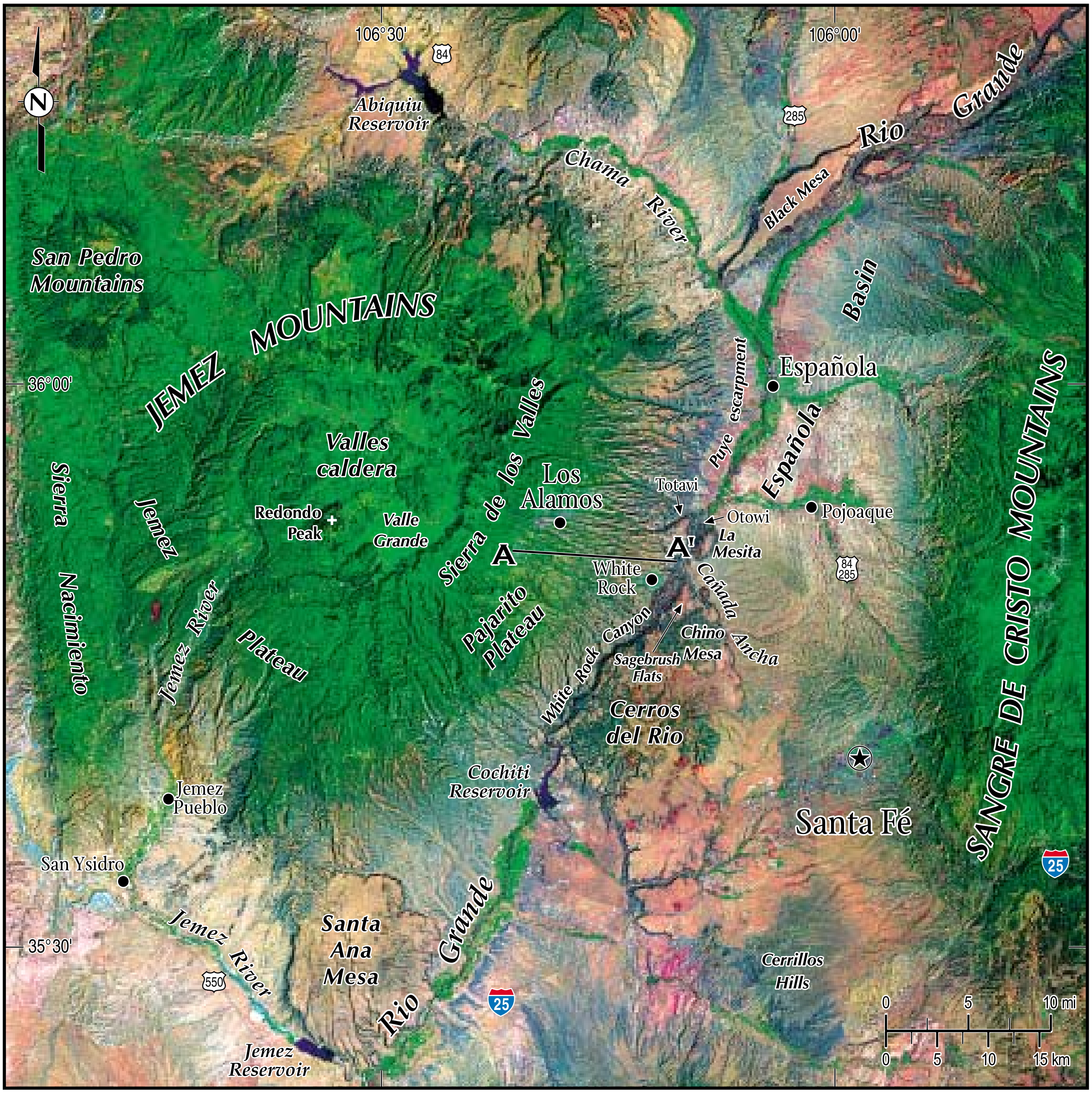


FIGURE 1—General geologic and geographic features of the Pajarito Plateau and surrounding areas.

from the eruptions can be found 150 mi south in Socorro. As they accumulated, intense heat and hot volcanic gases welded the tuffs into hard, resistant deposits (known as the Bandelier Tuff) that make up the upper surface of the plateau. As the tuff layers cooled, they developed a complex system of pervasive cooling cracks (known as joints). These joints now provide pathways for movement of ground water. Creeks flowing eastward across the plateau from the Jemez Mountains to the Rio Grande have cut canyons deep into the tuff, forming the scenic mesas and canyons that characterize the present landscape. The Jemez Mountains are not extinct; volcanoes have erupted here many times in the past and will surely continue to do so in the future.

The Española Valley is a basin that began to subside about 25 million years ago. This basin is part of the Rio Grande rift, a major geologic feature of the Rocky Mountain region that consists of north-trending, fault-bounded basins extending from central Colorado to northern Mexico. The Española Basin is a west-tilted trough that is filled with sediments (termed the Santa Fe Group) derived from erosion of the Jemez volcanic highlands, the Sangre de Cristo Mountains, and other highlands to the north. The deepest part of the basin lies just east of the Pajarito fault system, which forms the eastern front of the Jemez Mountains. In general, the rift basins contain major aquifers that are made up of thick wedges of sand and gravel deposited by the ancestral Rio Grande and that can produce large quantities of high-quality water. Sedimentary deposits in the basin also include important fossil localities that contain a variety of late Tertiary (less than 20 million years old) mammals, including species of early horses and camels that went extinct in North America. The Rio Grande became a major river flowing through the Española Basin at least about 5 million years ago. Some time after establishment of the through-flowing Rio Grande, the river stripped much sediment from the valley and transported it downstream toward the Gulf of Mexico. At present, the river seems to be fairly stable; that is, it is neither eroding nor depositing large amounts of sediment.

The present-day White Rock Canyon is a relatively young geologic feature. It was cut by the Rio Grande during the past 2.4 million years. The lower part of the canyon cuts into tan

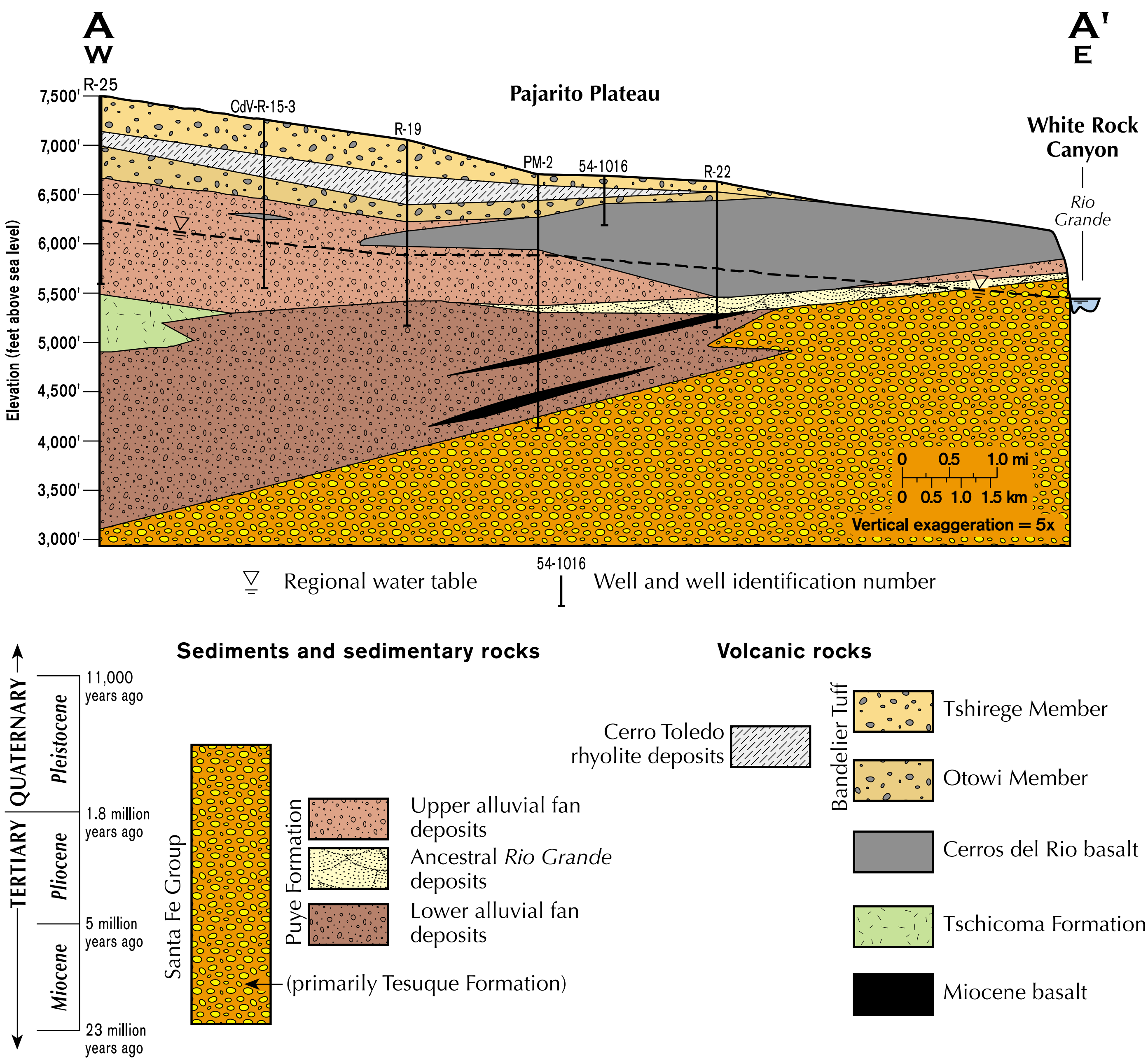


FIGURE 2—East-west cross section showing stratigraphic relations of geologic units making up the Pajarita Plateau. See Figure 1 for location of cross section.

Santa Fe Group deposits that sit beneath the Bandelier Tuff. White Rock Canyon is capped by thick, hard, dark-colored basalt flows derived from cinder cones and small shield volcanoes that make up the Cerros del Rio volcanic field. An excellent example of one of these volcanoes is exposed in cross section at Buckman Mesa, across the river from the White Rock overlook. Numerous landslides have moved large, intact blocks of basalt from the canyon rim to the lower canyon slopes. In the past, such landslides periodically dammed the Rio Grande, causing the formation of temporary lakes that extended as far upstream as Española.

The Sangre de Cristo Mountains are the southernmost range of the Southern Rocky Mountains. This north-trending mountain range contains the highest peaks in New Mexico (for example, the South Truchas Peaks, visible on the skyline to the northeast, are 13,103 ft high). Rocks in the Sangre de Cristo Mountains are considerably older than most other rocks in the area. Granite and metamorphic rocks in the core of the range are as much as 1.6 b.y. old. Sedimentary rocks exposed on the mountain flanks and in parts of the mountain interior range in age from 225 to 290 million years. The present-day form of the Sangre de Cristo Mountains represents two episodes of tectonic uplift. An earlier west- to northwest-trending mountain range formed about 70 million years ago during Laramide deformation of the Rocky Mountain region. This older range was deeply eroded before parts of it were reactivated along north-trending faults 15–20 million years ago during development of the Rio Grande rift. The latest sculpting of the high peaks occurred during the Pleistocene (from 1.6 million to 10,000 years ago) when glaciers and their melt-water rivers carved cirques and steep-walled valleys.

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David Broxton has been involved in a number of projects since joining the laboratory in 1977 including: exploration for uranium resources in Alaska and the Rocky Mountains region, exploration for precious and base-metal deposits in St. Lucia and in Costa Rica, geologic studies of silicic volcanic rocks erupted from the Timber Mountain–Oasis Valley caldera complex in southern Nevada, geologic studies of volcanic rocks as a potential nuclear waste repository in southern Nevada, and hydrogeologic studies of the Pajarito Plateau for the Environmental Restoration Program. His professional interests include the mineralogic and geochemical evolution of volcanic rocks and integrated geologic and hydrologic studies of complex natural systems.

Conceptual Hydrogeologic Model of the Los Alamos Area—A Brief Overview

by *William J. Stone*, LA-UR-01-15, Hydrology, Geochemistry, and Geology Group, Los Alamos National Laboratory

Los Alamos National Laboratory (LANL) is located on the Pajarito Plateau, a deeply dissected expanse of volcanic and sedimentary rocks situated between the Jemez Mountains and the Rio Grande. A sound conceptual hydrogeologic model (a simple, plausible description of the occurrence, movement, and quality of ground water and its relationship to the geologic framework) is essential for effective ground-water protection and environmental restoration. A conceptual model of the region's hydrogeology should address questions such as: Where is the ground water? Where does it come from? Where does it go? and What is its chemistry (or quality)? Despite much previous geologic and hydrologic work, the conceptual hydrogeologic model for LANL is incomplete (Stone, 1996). However, a program to install 32 deep wells under LANL's ground-water protection program (LANL, 1998) is contributing much needed additional information.

Ground-Water Occurrence

The location and extent of ground-water zones at LANL must be known in order to protect, monitor, and remediate them. Ground water exists under three situations at LANL: (1) perched primarily in volcanic tuff or canyon alluvium at shallow depth, (2) perched mainly in basalt at intermediate depth, and (3) in various geologic units beneath the regional water table at greater depth (Fig. 1). Perched ground water originates from the downward percolation of surface runoff through the alluvium in wet reaches of canyons cut into the plateau. This downward movement of water is hindered at fairly shallow depth by the presence of the Bandelier Tuff, which is less permeable than alluvium. Ground water builds up above the tuff, and a perched zone of saturation develops in the alluvium. In some places, downward moving ground water is also perched

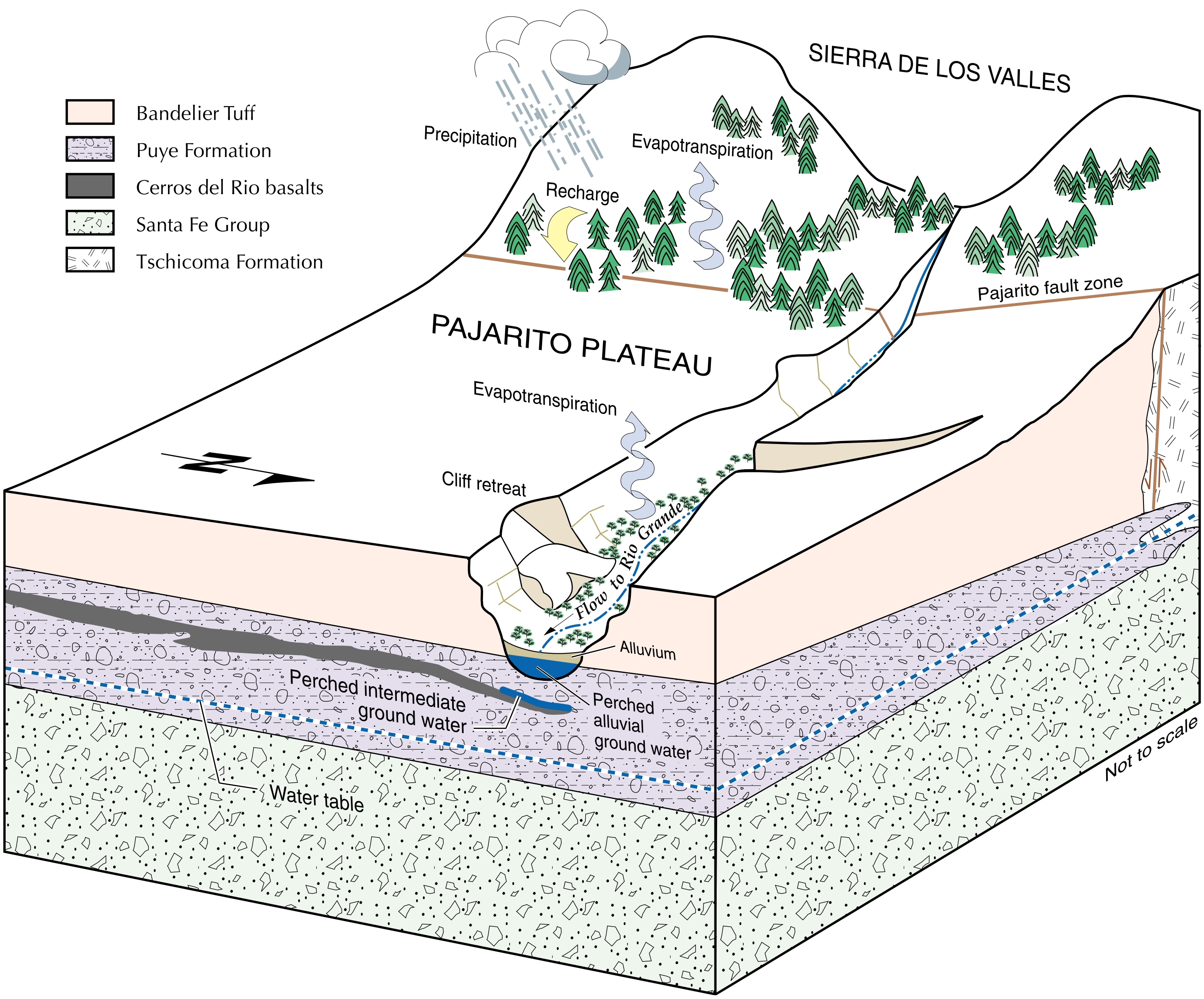

FIGURE 1—Conceptual hydrogeologic model for the Pajarito Plateau (LANL, 1998).

at intermediate depths within the Cerro Toledo interval, the Guaje Pumice Bed, or the Cerros del Rio basalt by underlying materials of lower permeability.

The regional water table lies at depths of less than (<) 100 ft to greater than (>) 1,200 ft below the ground surface, depending on location. Ground water beneath the water table in the deep zone of saturation occurs in various combinations of rock units making up the regional aquifer, including the Tschicoma Formation, Puye Formation, Cerros del Rio basalt, and the Santa Fe Group. This deep ground water is the main source of supply for the communities of Los Alamos and White Rock. Most ground water beneath the Pajarito Plateau is unconfined (not under pressure) and in direct contact with the atmosphere. However, in places near the Rio Grande, ground water in the deep system is confined (under pressure) and rises not only above the level at which it is encountered in wells, but even above the ground surface.

Ground-Water Movement

Understanding ground-water movement is also essential to environmental activities at LANL. The movement of ground water involves three basic elements: (1) recharge or addition of water to a saturated zone, (2) flow of ground water through a saturated zone, and (3) discharge or outflow of ground water from a saturated zone. Recharge and discharge each involve an area, a process, and a rate. Recharge occurs over areas of high elevation (mountains, for example), and discharge occurs at lower elevations (commonly along rivers). Ground-water flow is generally from recharge areas to discharge areas and involves both a direction and a rate.

On regional water-table maps for LANL (Fig. 2), water-level elevation contours have higher values in the west than in the east, indicating that recharge occurs in the mountains west of the laboratory, probably in response to greater precipitation. Recharge processes include infiltration of rainfall, snowmelt, or runoff, followed by deep percolation of any moisture that escapes evapotranspiration. Recharge is especially effective along the ephemeral stream channels in canyons (McLin, 1996), where large volumes of water are periodically concentrated. Rates of recharge of the shallow, intermediate, and deep ground-water systems are not known but probably differ dramatically.

Ground-water flow is generally perpendicular to water-level contours. Water-level maps for the deep regional system show ground-water-flow direction is easterly (Fig. 2). The flow direction for water in the shallow and intermediate systems is uncertain. However, in canyons where there are sufficient wells to make observations, such as Mortandad Canyon, the water table for shallow ground water perched in the alluvium slopes toward the east, like the canyon floor (Stone, 1995). Intermediate-depth perched ground water, monitored in wells R-9 and R-12 in the Cerros del Rio basalt, occurs at a higher elevation than Basalt Spring (Broxton et al., 2000a, b), which discharges from the same unit farther east in lower Los Alamos Canyon. These data suggest that flow in the intermediate system also has an eastward component.

The rate of ground-water flow beneath the Pajarito Plateau varies with the hydraulic properties (hydraulic conductivity and transmissivity) of the various saturated materials. Field tests at the new deep wells are providing much needed data. Slug-injection or pumping tests at wells R-9i, R-15, R-19, R-31, and CdV-R-15-3 have yielded preliminary hydraulic conductivity values ranging from <1 to 37 feet per day (ft/d) for the Cerros del Rio basalt, from <1 to 2 ft/d for the Puye Formation, and from 17 to 20 ft/d for the Santa Fe Group. These values may be revised after test data have been more thoroughly analyzed, but give a general idea of at least the relative potential rates of ground-water movement. Laboratory analysis of selected core samples provides additional data. Such analyses of samples from a wide range of geologic units encountered in wells R-9, R-12, and R-25 have yielded saturated hydraulic conductivity values of up to 0.5 ft/d (Stone, 2000).

The shallow, intermediate, and deep ground waters discharge in different ways in different settings. Shallow ground water in the alluvium is either forced to the surface by bedrock highs to support streamflow downstream, or seeps into the underlying geologic unit, presumably to continue downward or lateral percolation. Ground water in the intermediate-depth perched zones either discharges at down-gradient springs along canyon walls or continues to percolate downward toward the regional water table. The Rio Grande is the discharge point for both the easterly flowing deep ground water beneath the Pajarito Plateau and the ground water flowing west through the Española Basin.

Ground-Water Quality

An understanding of natural and impacted ground-water chemistry is essential to interpreting ground-water monitoring

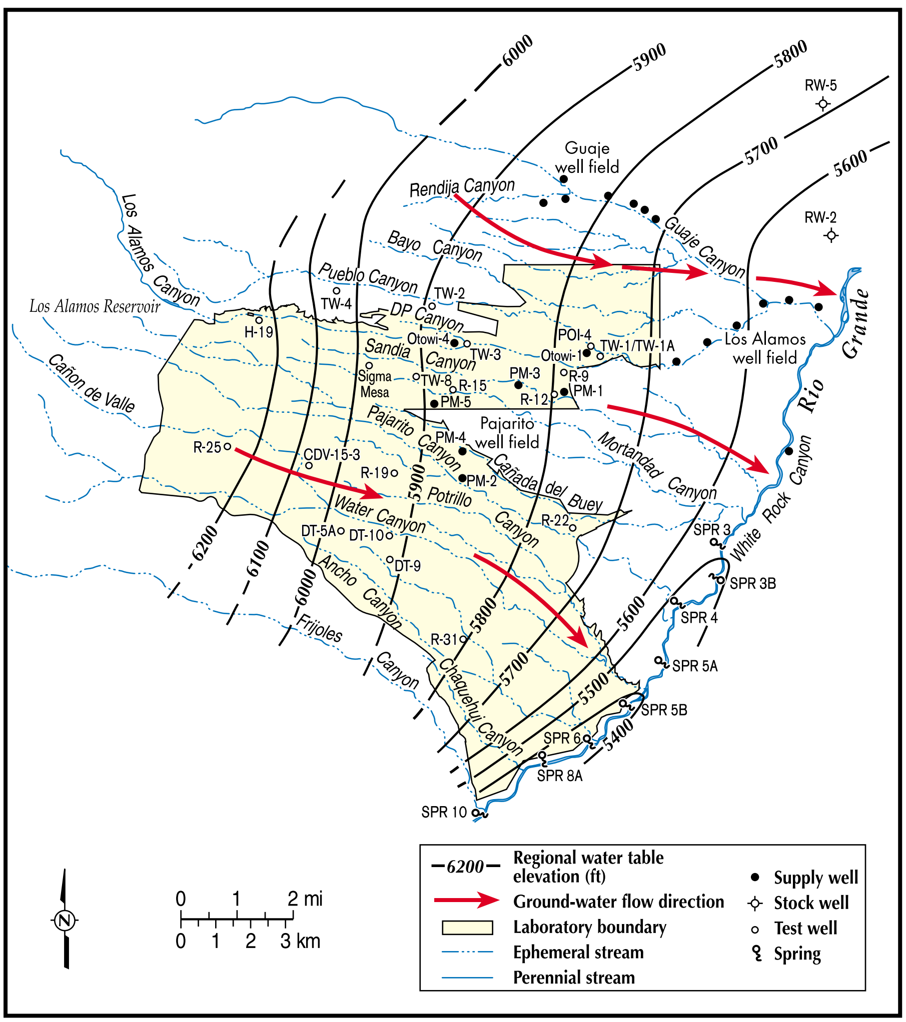

FIGURE 2—Regional water-level map for the Los Alamos area (Purtymun, 1984).

results and determining clean-up levels. The natural quality of ground water is a result of the chemistry of the recharging water(s), the mineralogic composition of the geologic materials through which it has flowed, and the length of time it has been in contact with that material. Although concentrations of major ions and trace metals have been observed to increase along flow paths and with depth in the regional aquifer, the water is classified as a calcium-bicarbonate type in both its recharge and discharge areas (Longmire et al., 2000). The distance the water travels and the variation in aquifer material between these points is not great enough to produce a change in major-ion chemistry.

The natural or background water quality is locally modified by the addition of contaminants from historical human activities at the laboratory. Ground-water quality is monitored at LANL by means of a surveillance network that targets each of the three aquifer systems. This network consists of wells in the shallow perched systems in the canyon alluvium (sampled when they contain water), two wells and one spring representing the intermediate-depth perched system, and 21 wells and numerous springs associated with the deep regional system. Samples are analyzed for a wide range of constituents (major ions, metals, radionuclides, and organics) and various chemical parameters. Results are reported annually in the laboratory's environmental surveillance reports (for example, Rogers and Turney, 1999). Some, if not all, of the new deep wells will eventually supplement this network and become a part of the surveillance program.

Conceptually, contaminants should show up first in the shallow and intermediate-depth perched ground waters, whereas their detection in the regional ground-water system should be less common because of its great depth. Monitoring has generally confirmed this. The occurrence of contaminants in the perched waters, sometimes at levels exceeding standards, is a serious concern as they could eventually migrate to the deep regional water supply. Deep percolation of contaminants is evidenced by their detection in the regional ground-water system. Ground-water flow and transport modeling (for example, Keating et al., 1999; Longmire and Counce, 2000) is providing insight as to the current and probable future extents of contaminant plumes at LANL. Recent improvements in waste-disposal practices and continuing contaminant-source-removal efforts, as well as the deep drilling program, are positive ground-water protection steps at the laboratory.

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Runoff, Erosion, and Restoration Studies in Piñon-Juniper Woodlands of the Pajarito Plateau

by *Craig D. Allen*, U.S. Geological Survey, Jemez Mountains Field Station, Midcontinent Ecological Science Center, Los Alamos

Piñon-juniper woodlands are one of the most extensive vegetation types in New Mexico, including large portions of the Pajarito Plateau. The woodland soils on local mesas largely formed under different vegetation during cooler, moister conditions of the late Pleistocene; in other words, they are over 10,000 years old, and many are over 100,000 years old (McFadden et al., 1996). Changes in climate and vegetation in the early Holocene (8,500–6,000 years ago) led to at least localized episodes of soil erosion on adjoining uplands (Reneau and McDonald, 1996; Reneau et al., 1996). During this time, the dominant climatic and associated vegetation patterns of the modern southwestern United States developed, including grasslands, piñon-juniper woodlands, and ponderosa pine savannas (Allen et al., 1998). On the basis of local fire history, the young ages of most piñon-juniper trees here, and soils data, we believe that many upland mesa areas now occupied by dense piñon-juniper woodlands were formerly more open, with fewer trees and well-developed herbaceous understories that: (1) protected the soil from excessive erosion during intense summer thunderstorm events, and (2) provided a largely continuous fuel matrix, which allowed surface fires to spread and maintain these vegetation types (Fig. 1). In contrast, rocky canyon walls have probably changed relatively little through the centuries, as grazing and fire suppression had fewer effects on such sites.

Native American effects on local woodlands are thought to have been insignificant or highly localized until the late 12th century, when the Ancestral Puebloan population began to intensively occupy and utilize the Bandelier area (Powers and Orcutt, 1999). Piñon-juniper woodlands were the core area of occupation by these prehistoric agriculturalists—most of the more than 2,500 archaeological sites recorded in the part (~50%) of the park surveyed to date are found in piñon-juniper woodland settings. Cutting and burning of piñon-juniper trees for cooking, heating, building, and agricultural activities likely led to significant deforestation of upland mesas from about 1150 to 1550 A.D. Thus, Ancestral Puebloan land use practices favored herbaceous vegetation. Intensive soil disturbance certainly occurred in farmed areas and around habitations, but there was probably little net change in landscape-wide erosion rates due to the small size and dispersed locations of fields and villages.

FIGURE 1—Grassy ground cover and surface fires once maintained more open conditions in many piñon-juniper woodland settings.

Euro-American settlement of the adjoining Rio Grande valley and the introduction of domestic livestock grazing began in 1598. It is unlikely, however, that significant livestock grazing (that is, with substantial widespread effects on the herbaceous understory, fire regime, or erosion rates) took place in much of Bandelier until railroads linked the Southwest to commercial markets in the 1880s. Millions of sheep and cattle were placed in the New Mexico landscape at that time, with unrestricted grazing on public lands. Livestock grazing continued in Bandelier until 1932, and feral burros were similarly allowed to cause grazing impacts until about 1980 (Allen, 1989). Sharp reductions in the herbaceous ground cover and associated organic litter resulted (Fig. 2), effectively suppressing previously widespread surface fires (in concert with institutionalized fire suppression initiated by the federal government after 1910). Severe drought during the 1950s contributed to declines in ground cover (Allen and Breshears, 1998). Fire-sensitive piñon and juniper trees became established in densities unprecedented for at least the past 800 years. As these trees grew, they became increasingly effective competitors for water and nutrients. Thus, a positive feedback cycle was initiated that favors tree invasion and decreased herbaceous ground cover on mesa top.

This land use history has caused the degraded and unsustainable ecosystem conditions observed in many piñon-juniper woodlands today. Intensive watershed research over the past decade, involving collaborations among Los Alamos National Laboratory, U.S. Geological Survey, Colorado State University, U.S. Forest Service, and Bandelier National Monument, shows that the intercanopy soils of Bandelier's woodlands are apparently eroding at net rates of about one centimeter per decade (Wilcox et al., 1996a,b; Davenport et al., 1998; unpublished data). Given soil depths averaging only 1–2 ft in many areas, entire soil bodies across extensive areas will soon be lost (Fig. 3). Also, this accelerated runoff and erosion is damaging thousands of archaeological sites at Bandelier; over 90% of inventoried archaeological sites are being damaged by soil erosion (Powers and Orcutt, 1999; unpublished data). For example, we have found as many as 1,040 cultural artifacts (mostly potsherds) moved by a single thunderstorm into a sediment trap draining only ¼ acre of gentle hillslope (Fig. 4). To a significant degree, the park's biological productivity and cultural resources are literally washing away, posing major management challenges (Sydoriak et al., 2000). Similar histories and high erosion rates likely characterize many piñon-juniper woodlands in New Mexico (Gottfried et al., 1995; Bogan et al., 1998), resulting in considerable transport of sediment through watersheds, with associated impacts on water quality.

Ecological thresholds have apparently been crossed (Fig. 2) such that harsh physical processes are now dominant across Bandelier's degraded piñon-juniper woodlands (Gottfried et al., 1995; Davenport et al., 1998). The loss of organic-rich topsoils, impeded plant-available water (Breshears and Barnes, 1999), extreme soil surface temperatures, and freeze-thaw activity severely impede herbaceous vegetation establishment and productivity (Davenport et al., 1998). Reductions in ground cover cause increased runoff from summer thunderstorms (Reid et al., 1999), with associated increases in erosion (Wilcox et al., 1996a,b). Re-establishment of herbaceous ground cover under today's desertified mesa-top conditions may also be difficult due to depleted soil seed banks, highly efficient seed predators (particularly harvester ants; Snyderman and Jacobs, 1995), and an unnaturally large elk

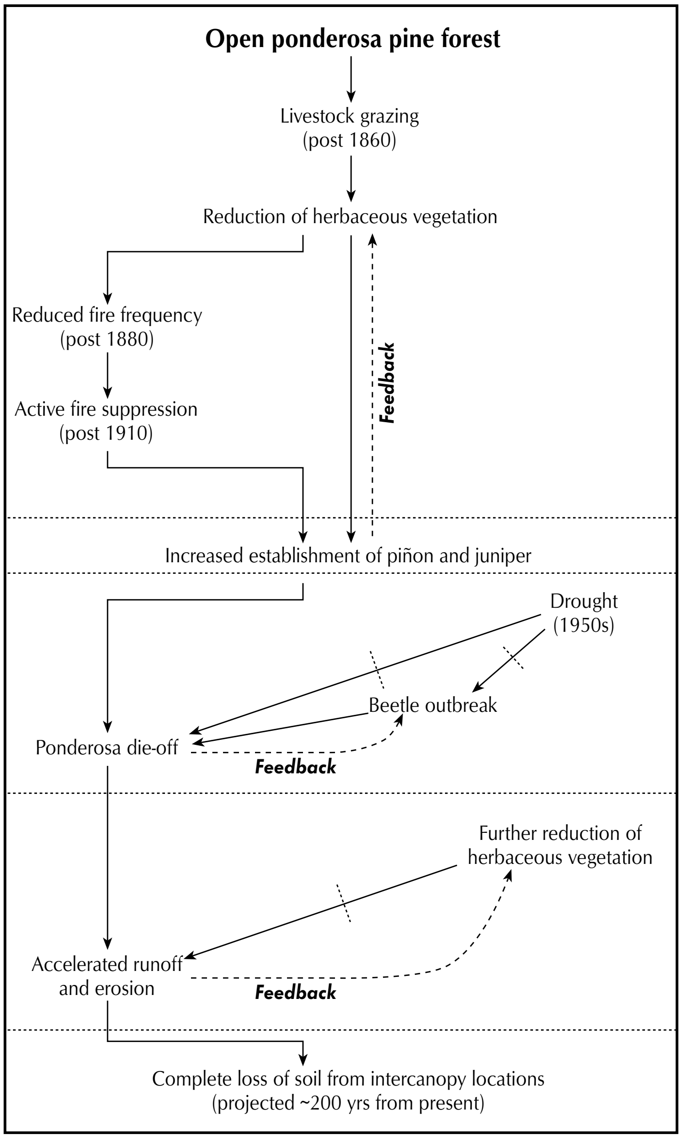

FIGURE 2—Historic changes in forest/woodland border (ecotone) areas on Frijolito Mesa, Bandelier National Monument (Davenport et al., 1998; Allen and Breshears, 1998). Short-dotted lines represent ecological thresholds.

population. Herbivore exclosures established in 1975 show that protection from grazing, by itself, fails to promote vegetative recovery in Bandelier's piñon-juniper ecosystems (Chong, 1992; Potter, 1985). Without management intervention, this human-induced episode of accelerated soil erosion appears to be highly persistent and irreversible (Davenport et al., 1998).

Happily, experimentation over the past decade shows that a simple, though labor-intensive, treatment can restore more stable ecological conditions (Chong, 1994; Jacobs and Gatewood, 1999; Loftin, 1999; Jacobs et al., 2000). By cutting many smaller piñon-juniper trees, and lopping and scattering the branches across the barren interspaces between trees, herbaceous ground cover and soil stability increase markedly (Figs. 5 and 6). It is likely that application of similar methods would restore more sustainable conditions to degraded piñon-juniper woodlands throughout the Southwest.

FIGURE 3—Bare soil and high erosion rates characterize the desertified interspaces between piñon-juniper trees across large areas of the Pajarito Plateau. Note the exposed roots.

FIGURE 4—Immense numbers of ceramic and lithic artifacts are being transported by accelerated runoff and erosion at Bandelier, degrading the cultural resources for which the park was established. These artifacts were collected from a sediment trap after a single storm.

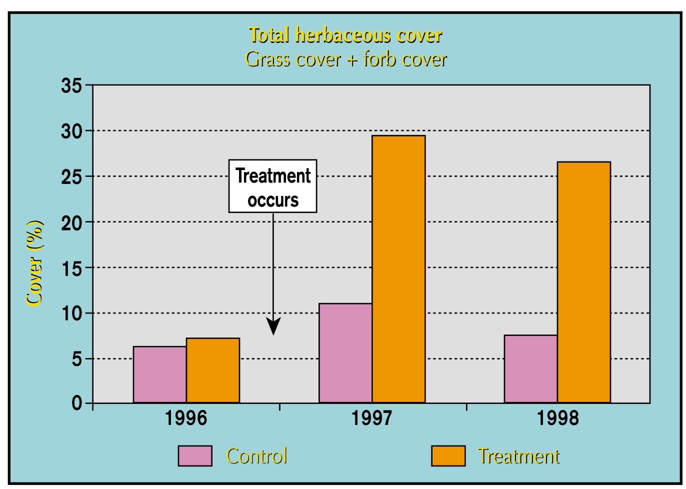

FIGURE 5—Herbaceous cover response to restoration treatment on Frijolito Mesa (Jacobs et al., 2000).

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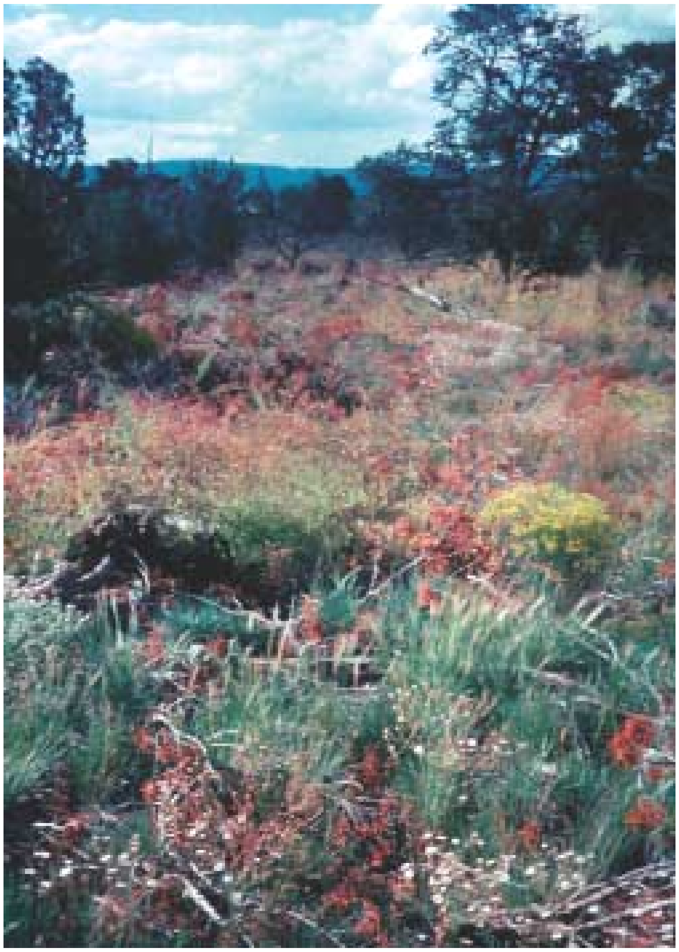

FIGURE 6—View of herbaceous cover response to restoration treatment after first growing season.

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Craig Allen is a research ecologist with the U.S. Geological Survey. He received degrees in geography from the University of Wisconsin (Madison), and a PhD focused on forest and landscape ecology from the University of California (Berkeley). He has worked as an ecologist with the Department of Interior since 1989, beginning with the National Park Service through his current post with USGS. Allen conducts research on the ecology and environmental history of southwestern landscapes, oversees the USGS Jemez Mountains Field Station at Bandelier National Monument (New Mexico), and provides technical support to land management agencies in the region. Ongoing research activities with multiple collaborators include: development of vegetation and fire histories in the Southwest; fire effects on Mexican spotted owls, Jemez Mountains salamanders, and nitrogen cycling; responses of semiarid forests and woodlands to drought (and links to global change issues); development of long-term ecological monitoring networks across landscape gradients at Bandelier; dynamics of runoff, erosion, and restoration of piñon-juniper watersheds; and determining elk movements and habitat effects in the Jemez Mountains. Allen lives with his wife, Sharon, and children Kiyana, Benjamin, and Nikolas in Los Alamos.

The Buckman Well Field

by *Amy C. Lewis*, Sangre de Cristo Water Division, City of Santa Fe

The Buckman well field, located along the east side of the Rio Grande about 15 mi northwest of Santa Fe, was developed by Public Service Company of New Mexico and put into operation in July 1972 to supply the city of Santa Fe (Fig. 1). During the 1990s, the well field provided 40% of the city of Santa Fe's water, or 4,900 acre-ft/yr. The field consists of eight wells drilled to depths of 1,000 to 1,400 ft below land surface. Water is pumped through a pipeline and conveyed about 15 mi into town for a total lift of nearly 1,400 ft. The capacity of the well field is about 7,130 acre-ft/yr (6.36 million gal per day), much less than the originally anticipated yield of 10,000 acre-ft/yr. The yield of the wells has declined substantially in the last decade due to calcification of the well screen, declining water levels, and possibly formation damage (Fig. 2). Water levels have dropped as much as 700 ft in the last 28 years in production wells and about 90 ft in the shallow, unconfined aquifer. However, the estimated sustainable yield from the well field is about 5,000 acre-ft/yr, even less than the capacity of the wells, due to the relatively low transmissivity of the aquifer and insufficient recharge. The Buckman wells draw water from a confined aquifer that is not replenished at a rate equal to the amount pumped, and the hydrologic connection between the wells and the river is much less than originally conceived.

The Buckman wells are associated with several water rights. They are operated under a permit that allows a maximum pumping rate of 10,000 acre-ft/yr. Impacts to the Rio Grande, the Rio Tesuque, and the Rio Pojoaque from pumping the Buckman wells must be offset with existing water rights. Presently, the city uses San Juan-Chama (SJC) water to offset impacts to the Rio Grande. The city of Santa Fe and Santa Fe County together have SJC contract rights of 5,605 acre-ft/yr through December 31, 2016, with an option to renew. Irrigation rights have been obtained in the Rio Pojoaque and Rio Tesuque drainage basins to offset depletions of tributary streams.

The State Engineer Office uses a numerical model of the stream-aquifer system to calculate the annual depletions to the Rio Grande and tributaries. At this time the city of Santa Fe (and Las Campanas who have contracted for a percentage of the Buckman yield) have sufficient water rights to meet the offsets for about eight more years on the Nambe-Pojoaque tributary. Continued production of the well field at the historic rate will require purchase or lease of additional water rights on this tributary.

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Lewis has worked as a hydrologist in New Mexico for 17 years, on both quantity and quality related water resource issues. She is presently the hydrologist for the Santa Fe Water Division and is coordinating the Jemez y Sangre Water Planning Council. Ms. Lewis is interested in being a sound technical voice as the community struggles to make difficult decisions.

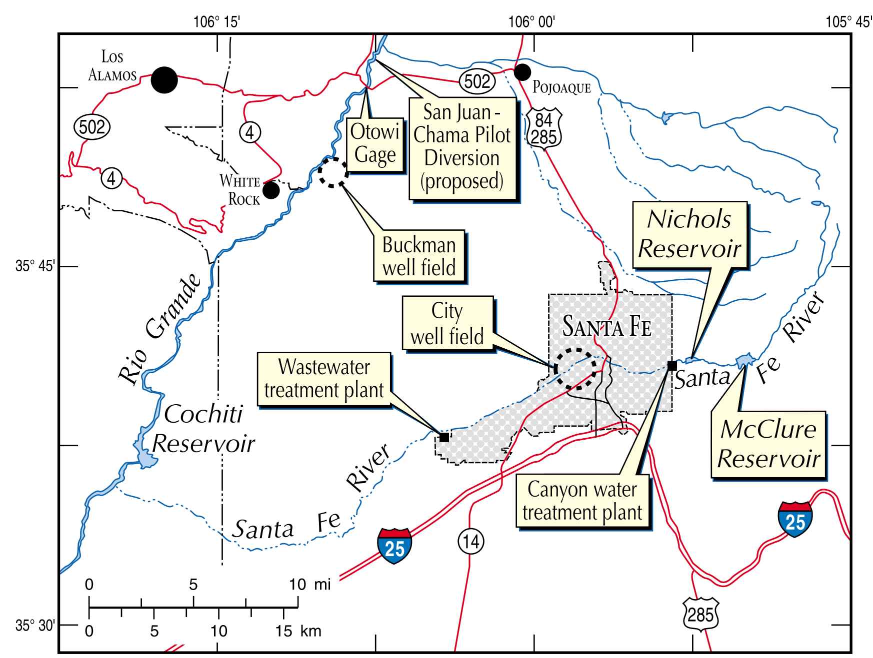

FIGURE 1—City of Santa Fe water supply.

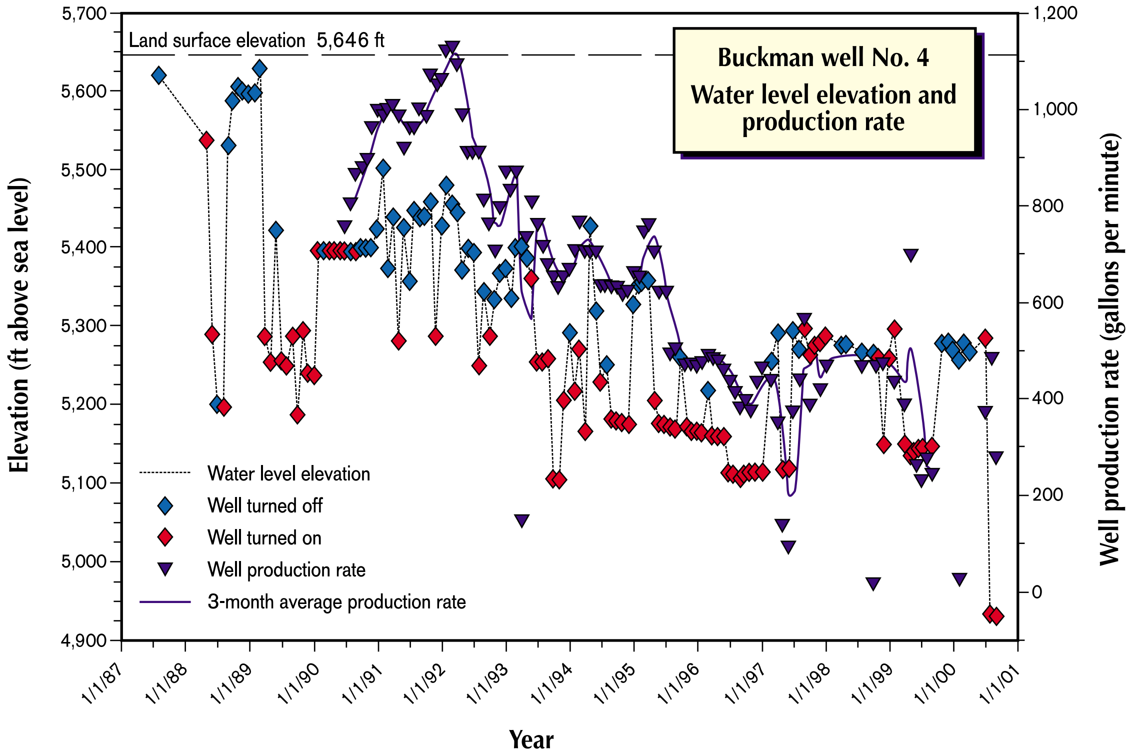

FIGURE 2—Buckman well no. 4 water-level elevation and production rate.

Fire and Vegetation History of the Jemez Mountains

by *Craig D. Allen*, U.S. Geological Survey, Jemez Mountains Field Station,
Midcontinent Ecological Science Center, Los Alamos

Historic patterns of fire occurrence and vegetation change in the Jemez Mountains of northern New Mexico have been described in detail by using multiple lines of evidence. Data sources include old aerial and ground-based photographs, historic records, charcoal deposits from bogs, fire-scarred trees (Fig. 1), tree-ring reconstructions of precipitation, and field sampling of vegetation and soils. The forests and woodlands that cloak the southwestern uplands provide the most extensive and detailed regional-scale network of fire history data available in the world (Swetnam and Baisan, 1996; Swetnam et al., 1999; Allen, in press).

Modern climate/vegetation patterns basically developed in the Southwest about 11,000–8,000 years before present. Substantial fire activity apparently emerged in the Southwest during that time, as evidenced by the contemporaneous and rapid spread of fire-adapted ponderosa pine forests across the region (Anderson, 1989), and by the abundant charcoal deposits found in lake and bog sediments (Brunner-Jass, 1999; Weng and Jackson, 1999). Charcoal sediments from Alamo Bog in the central Jemez Mountains indicate essentially continuous fire activity extending back almost 9,000 years (Brunner-Jass, 1999).

About 5,200 historic fires have been mapped in the Jemez Mountains for the period 1909–1996 from administrative records of local land-management agencies (Fig. 2). Lightning caused fully 75% of the recorded fires, with acreage burned

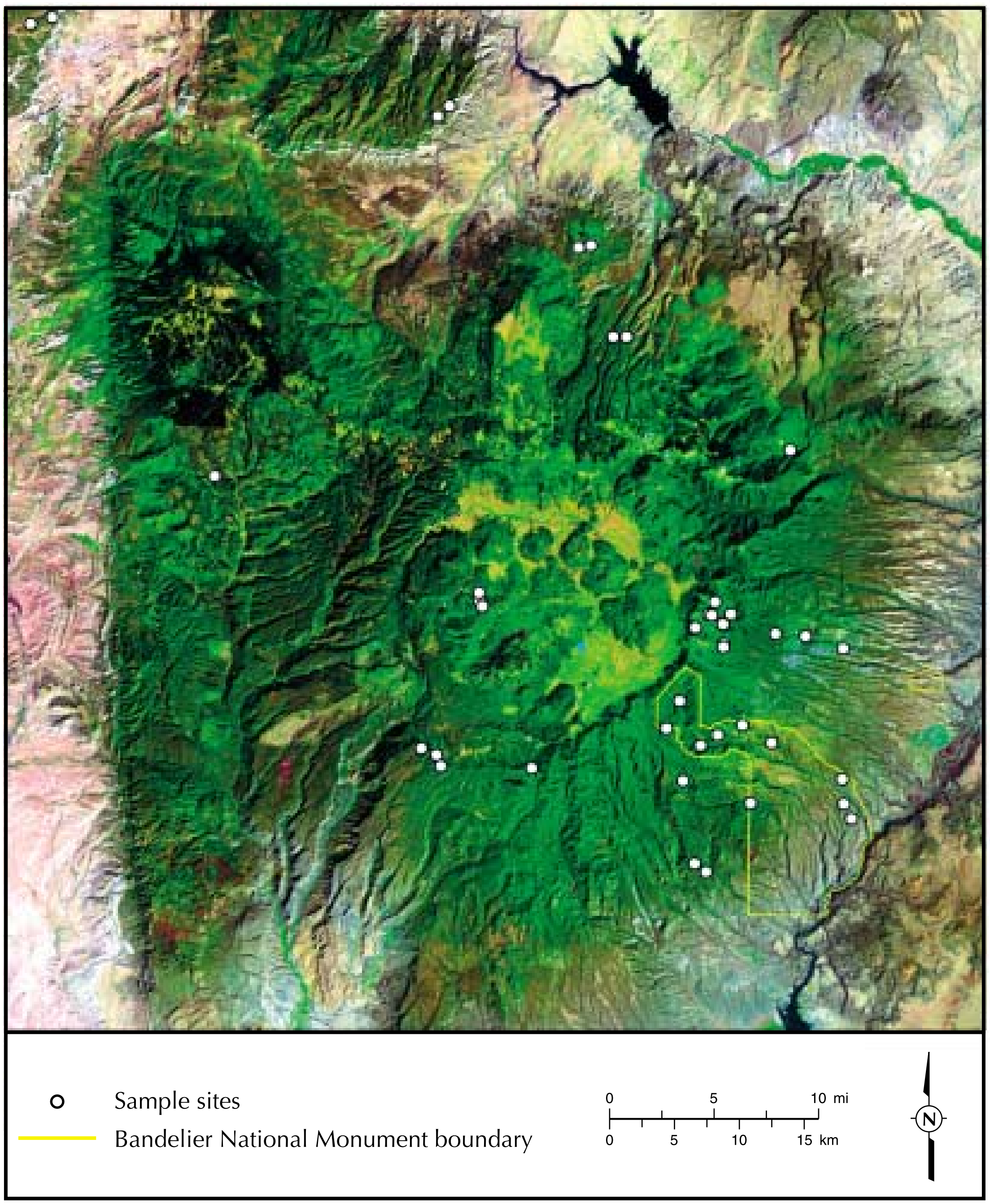

FIGURE 1—Map of fire scar sample site locations in the Jemez Mountains.

Day One

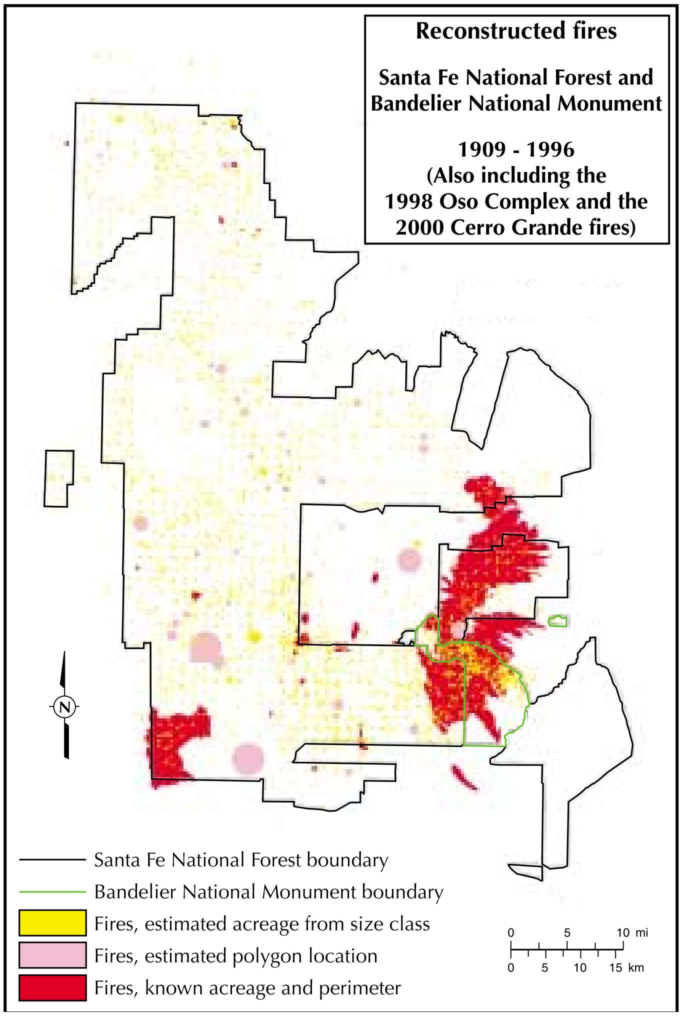

FIGURE 2—Point locations of more than 5,000 historic wildfires in the Jemez Mountains, 1909–1996, compiled from the administrative records of land-management agencies (Snyderman and Allen, 1997). Person-caused fires cluster near major roadways, campgrounds, habitations, and other human use areas.

peaking in the dry months of May and June before the onset of summer monsoon rains. High levels of lightning activity naturally foster fire ignitions here. For example, 62 thunderstorm-days/year are observed at Los Alamos, generating large numbers of lightning strikes. An automated lightning detection system recorded 165,117 cloud-to-ground lightning strikes over a 2,994 mi^2 area centered on the Jemez Mountains during the period 1985–1994 (Fig. 3). The annual number of recorded lightning strikes varied between 9,410 and 23,317. Particularly important for fire ignitions is the substantial lightning activity during the warm, dry, foresummer months of April through June. Lightning strikes during this period are the most significant sources of fire ignition because lightning is much more likely to start a spreading fire if it strikes dry fuels. Because lightning ignitions are so frequent and ubiquitous in the Southwest, climate and fuel conditions are the main drivers of fire regime dynamics in this region.

Fire scars were sampled from over 600 trees, snags, and logs at 42 sites around the Jemez Mountains in northern New Mexico (Fig. 1), resulting in over 4,000 dendrochronologically dated fire scars. Fire scar dates extend back to 1422 A.D. These data have been used to develop fire histories at multiple spatial scales, from individual trees to watersheds and finally the entire mountain range. Fire histories were reconstructed for vegetation types ranging from piñon-juniper woodlands up through ponderosa pine forests and mixed conifer forests into high-elevation spruce-fir forests (Touchan et al., 1996; Allen et al., 1996). These fire histories show that frequent, low-intensity surface fires naturally characterized most southwestern forests. These fires spread widely through grassy understory fuels, maintaining relatively open forest conditions (Fig. 4).

Pre-1900 mean fire intervals ranged from 5 to 25 years across the Jemez Mountains (Fig. 5). Significant spatial variation in past fire regimes is evident, depending upon such local factors as vegetation/fuel type, topography, and land-use history. Fire frequencies and area burned have been greatest in mid-elevation ponderosa pine forests. Fire activity commonly occurred over extensive areas (Allen et al., 1998); for example, watershed-wide fires occurred about every 16 years across the 9-mi-long Frijoles watershed in Bandelier before 1900 (Allen, 1989). In some years fires apparently burned across most of the Jemez Mountains (Allen et al., 1998), and indeed even across the Southwest (Swetnam et al., 1999; see graphics at: http://biology.usgs.gov/luhna/chap9.html).

Climate variability acted to regionally synchronize prehistoric fire activity, as major fire years were clearly associated with drought conditions, while wet periods recorded little fire activity (Touchan et al., 1996; Swetnam and Baisan, 1996; Swetnam and Betancourt, 1998). The most extensive fire activity in ponderosa pine forests occurred in dry years that followed within 1–3 years of wet conditions. This pattern of major fire years suggests the importance of both fuel production and fuel moisture in these fire regimes, with antecedent wet conditions stimulating the buildup of continuous fuels and subsequent drought conditions enabling the fuels to burn widely (Swetnam and Baisan, 1996). The common occurrence of persistent drought conditions in the Southwest likely allowed some fires to burn for months.

In most cases the seasonality of fire occurrence can be inferred by the relative position of a fire scar within the annual growth rings. The patterns of fire seasonality developed from prehistoric fire scars and modern fire records are generally

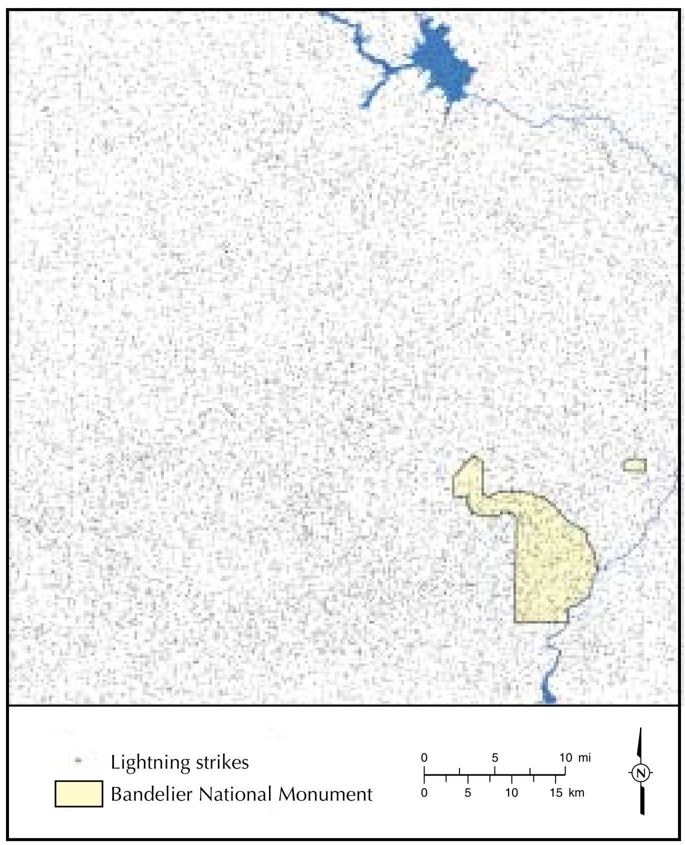

FIGURE 3—Map of 23,317 lightning strikes recorded across 2,994 mi^2 in the Jemez Mountains area during 1986 by the national automated lightning detection system. The nominal resolution of the locational data is ~± 2 km.

FIGURE 4—Open ponderosa pine forest representing "typical" pre-1900 conditions, with grassy understory and surface fire activity.

indistinguishable, indicating that prehistoric fires occurred during the same seasons as modern lightning-ignited fires—predominantly in the spring and summer. Fall fires were rare.

Spatial patterns of consecutive-year fire events indicate the importance of herbaceous fuels in supporting fire spread in pre-settlement forests. Railroads linked northern New Mexico to external markets by about 1880, leading to a local boom in livestock numbers. Abrupt declines in fire frequency throughout the Jemez Mountains in the late 1800s (Fig. 5), decades before active fire suppression, support the hypothesis that overgrazing induced suppression of surface fires as livestock (particularly sheep in mountain forests) literally ate the grassy fuels through which fires previously had spread. Fires would have repeatedly burned across widespread parts of the Southwest during the 20th century if the many natural and human-caused fires had not been vigorously suppressed after 1910 (Swetnam et al., 1999).

This history of livestock grazing and fire suppression in the Jemez Mountains has driven such landscape-wide vegetation changes as: increased density of woody species and accelerated erosion rates in piñon-juniper woodlands; conversion of ponderosa pine forests into thickets (or crown-fire-created grasslands and shrublands); changes in species composition and structure in mixed conifer forests (Fig. 6); and invasion of grasslands and meadows by trees and shrubs (Allen, 1989). Similar changes have occurred throughout the Southwest (Bogan et al., 1998; see graphics at http://biology.usgs.gov/s+t/SNT/noframe/sw152.htm). The increased densities of forests over the past century (often 10-fold increases) have markedly changed many ecosystem processes, including patterns of runoff and water yield from regional watersheds. For example, increased forest densities lead to decreases in total streamflow, peak flow, and base flow (Ffolliott et al., 1989), important concerns in the water-limited Southwest.

Fire behavior has also greatly changed due to the landscape-wide build ups of woody fuels associated with a century of fire suppression. As a result the frequency and severity of wildfire activity (including lightning-ignited fires) has been escalating despite increasing human suppression efforts, as the mean number of lightning fires/year in the Southwest grew by over 50% from 1940 to 1975 (Barrows, 1978) and the mean annual acreage burned has increased continuously since about 1960 (Swetnam and Betancourt, 1998). Unnatural stand-replacing conflagrations like the 1977 La Mesa fire (Allen, 1996), the 1996 Dome fire (Fig. 7), and the 2000 Cerro Grande fire are occurring more often in over-dense ponderosa pine forests

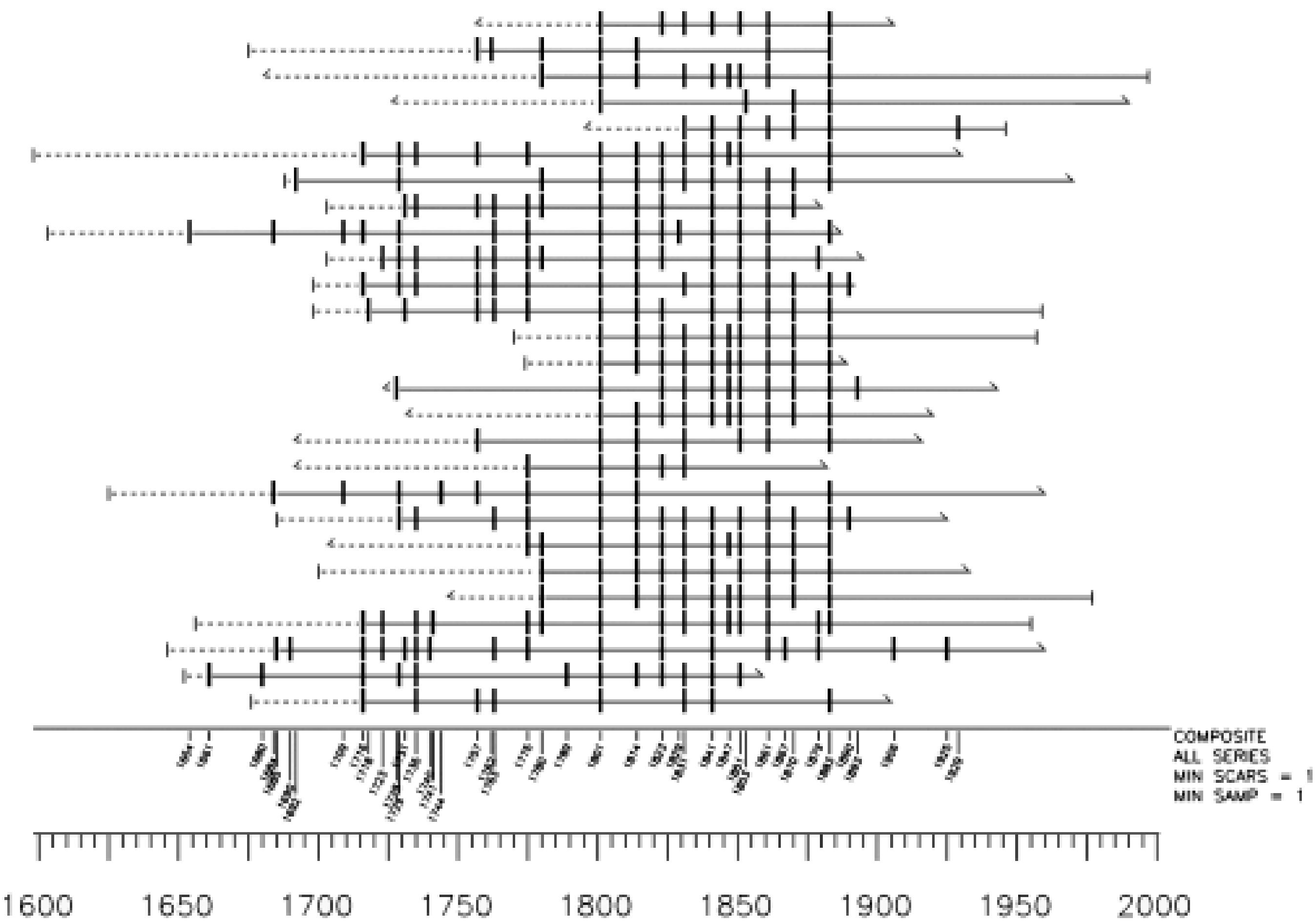

FIGURE 5—Fire scar chronology for Quemazon locality, western edge of Los Alamos townsite. Horizontal lines represent the life spans of individual trees, while fire scar events are shown by short vertical bars. Fire years are listed along the lower axis.

FIGURE 6—Altered ponderosa pine stand in need of restoration, showing changes in both stand structure and species composition. The dense midstory of mixed conifer trees provides ladder fuels that favor crown-fire development.

FIGURE 7—Dome fire, Day 2, April 26, 1996, near headwaters of Capulin Canyon.

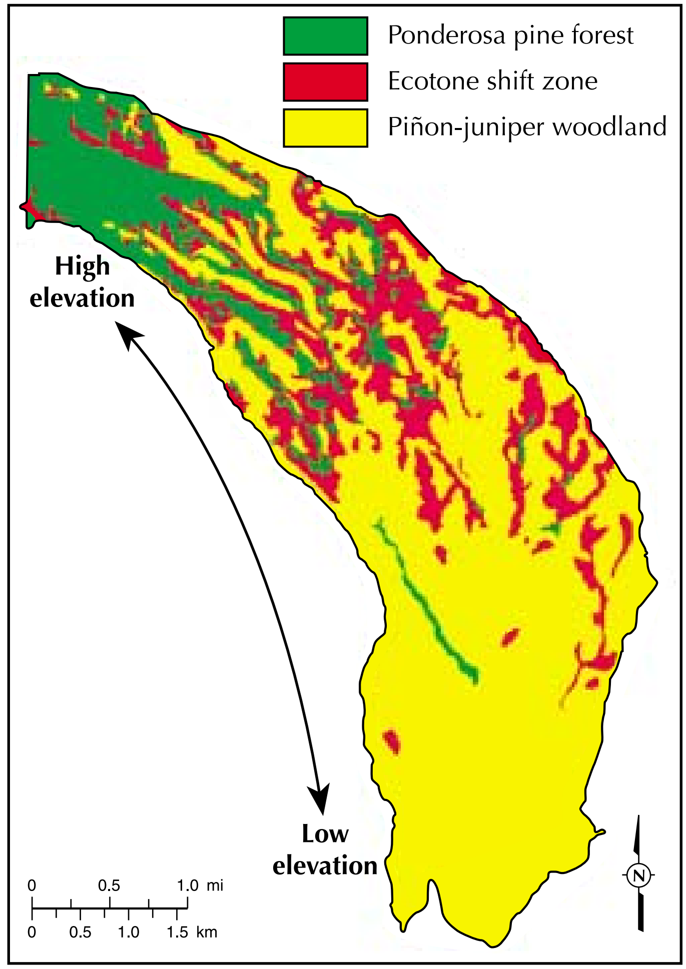

FIGURE 8—Changes in vegetation cover between 1954 and 1963 on Frijolito Mesa in Bandelier National Monument, showing persistent ponderosa pine forest (1.4 mi^2), persistent piñon-juniper woodland (5.9 mi^2), and the ecotone shift zone (1.9 mi^2) where forest changed to woodland due to the death of the overstory ponderosa pine trees.

(Covington and Moore, 1994). Extensive (>0.5 mi^2) stand-replacing fires rarely (if ever) occurred in pure, southwestern ponderosa pine forests before the middle of the 20th century. Severe crown fires typically cause major watershed impacts, including accelerated flooding and erosion. Twentieth century landscape scars created by stand-replacing fires in ponderosa pine and lower elevation mixed conifer are long-lasting legacies of human error in managing these ecosystems. Recovery of forest communities within such burned and eroded landscapes may not occur for centuries. Fire history data and evidence of extreme geomorphic responses following extensive crown fires provide strong justification for management programs aimed at preventing the future occurrence of these ecological and societal disasters (Covington et al., 1997; Allen et al., in revision).

It is interesting to note that droughts can also cause extensive ecosystem changes by rapidly killing vegetation. For example, a severe, regional drought occurred during the 1950s in the Southwest. Associated tree mortality in the Jemez Mountains caused the ecotone between ponderosa pine forests and piñon-juniper woodlands to shift upslope by as much as 1.2 mi in less than 5 years (Fig. 8), while mixed piñon-juniper woodlands were converted to overstories of only juniper at many sites (Allen and Breshears, 1998). The 1950s drought may have also reduced herbaceous ground cover in these ecotone zones, contributing to current high erosion rates (discussed in a separate minipaper). Projected global climate changes may render over-dense southwestern forests increasingly susceptible to rapid decline through drought-induced mortality, associated insect outbreaks, and crown fires (Swetnam and Betancourt, 1998).

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The Cerro Grande Fire, Santa Fe National Forest, May 2000

by *Kevin Joseph*, U.S. Forest Service, Santa Fe National Forest

The Cerro Grande fire began as a prescribed fire in the Bandelier National Monument on May 5, 2000. On the afternoon of May 6, 2000, the prescribed fire was declared a wildfire due to adverse fire behavior and the prescribed-burn parameters exceeding acceptable levels. The fire was torching and crowning in the canopies of the trees resulting in spot fires outside of the control lines and rates of spread and fire intensities that exceeded the capabilities of the suppression forces to control. In the end, the Cerro Grande fire was the most devastating forest fire in the history of New Mexico in terms of acreage burned (47,650; Fig. 1), homes and structures lost (over 235), disruption of the local economy, impacts to the Los Alamos National Laboratory, and impacts and disruption of the lives of the residents of Los Alamos County, which will be felt for years to come. Though there were no fatalities, the Cerro Grande fire was the worst prescribed-fire loss in the history of the United States in terms of size and property losses.

The final cost of the Cerro Grande fire is estimated to amount to over 1 billion dollars in suppression and rehabilitation costs, damage and loss of property, business/economic losses, and preparing for flood damage to roads and communities. Luckily, no human lives were lost. However, no economic price tag can be placed on the personal loss felt by those who were directly affected by the Cerro Grande fire.

The drought conditions in the Southwest for 3 years immediately before the Cerro Grande wildfire and the very dry winter and spring in 2000 caused fuel moistures of both live and dead fuels (trees, chaparral, shrubs, and grasses) to be extremely low. Very dry and drought-stressed-forest fuels contribute to active fire behavior, which includes high fire intensities, long flame lengths, rapid rates of fire spread (including the initiation and sustained spread of crown fires in standing timber), and spot fires up to 1 mi in front of the main fire. This is the type of fire behavior that manifested itself when the fire made a very rapid downhill run toward the city of Los Alamos on Sunday, May 7.

Fire behavior in forest fuels is a result of the dynamics of weather, fuels, and topography. The timbered fuels in the Cerro Grande fire area, and in and near the city of Los Alamos, were very dense as they are throughout much of the Jemez Mountains. The heavy fuel load, made up of very dense stands of ponderosa pine and mixed conifer trees, which were extremely dry due to drought conditions, and the adverse fire weather during the initial escape of the Cerro Grande fire resulted in "blow-up" fire behavior conditions.

On Sunday, May 7, when the fire made its initial run toward Los Alamos and again on Wednesday, May 10, when the fire burned through residential areas in Los Alamos destroying homes, the fire weather conditions forecasted and observed included record high temperatures, low relative humidity of approximately 8% to 12%, a very dry and unstable atmosphere, and very strong southwest to west winds. These were the conditions that existed during the first 12 days of the fire when the fire exhibited extreme fire behavior and made large increases in acreage.

On Sunday, May 7, the Cerro Grande fire made an afternoon run of 4 mi in approximately 5 hrs (Fig. 1). Driven by extremely strong winds, the fire moved off Cerro Grande Mountain and spread downhill at sustained rates of ½–¾ mph and maximum rates of spread as high as 1½ mph. Observed spot fires were up to 1 mi in front of the main fire. Observed flame lengths were up to 200 ft higher than the tops of the trees. This was a sustained, crown-fire run. The direction of spread was northeast, and the fire was moving for the Camp May Road and NM–501 area.

A backfiring operation along the Camp May Road and NM–501 successfully stopped the head of the fast moving fire. This allowed 3 days to begin the evacuation of Los Alamos before Wednesday, May 10, when the fire burned through residential areas of Los Alamos destroying homes and leveling subdivisions. This dramatic fire run spread approximately 8 mi in 12 hrs (Fig. 1).

The Cerro Grande fire spread approximately 13 mi north from its point of origin before slowing down and finally stopping in Santa Clara Canyon in response to more favorable weather and topographic conditions. This allowed suppression forces to begin line construction and burnout operations that were successful in containing the fire spread from continuing to the north.The fire was contained on July 20, 2000, and was declared *out* on September 22, 2000.

The Cerro Grande fire certainly was historical for the state of New Mexico not only in terms of acres burned, structures/homes lost, and economic loss and hardship but also in terms of the severity of the burned area and the subsequent long-term rehabilitation that will occur. The Viveash fire that burned in the Pecos–Las Vegas Ranger District (Santa Fe National Forest) in the summer of 2000 exhibited the same extreme fire behavior, including extremely rapid rates of spread; sustained, high-severity, crown-fire runs; long-range spotting; resulting runoff damage to infrastructure; and the need for long-term, burned-area rehabilitation.

The Cerro Grande fire aftermath resulted in changes to the way we plan and conduct prescribed-fire operations in the federal land-management agencies. More extensive and detailed planning and peer agency review is required. The changes include adding extensive fire-use policies covering implementation planning, personnel certification, fire-use projects, prescribed-fire project assessment, interagency cooperation, contingency planning, prescribed-fire implementation actions, and line officer reviews. In essence, plans are required to be more detailed and thought out with additional plan reviews at several levels.

What we are now experiencing in the state of New Mexico, in terms of fire behavior, fire severity, and large-fire growth, is a mirror of what has occurred nationally for the past 15 years. In the past decade, in the Southwestern Region of the Forest Service, we have seen very large, rapidly spreading crown fires with long-range spotting—these fires threaten communities and lives.

In the past 4 years, the Santa Fe and Carson National Forests and surrounding areas have experienced fires more severe than have been seen here before (Dome fire, 16,774 acres, 1996; Hondo fire, 8,500 acres, 1996; Oso fire, 5,200 acres, 1998; Cerro Grande fire, 47,650 acres, 2000; Viveash fire, 28,500 acres, 2000).

Nationally, since the mid 1980s, we have seen very large, rapidly spreading fires that we were unable to suppress (California, 1987; Yellowstone, Northern Rockies, 1988; Idaho, 1989, 1992; Colorado, Utah, Idaho, 1994; Utah, 1996; Texas, Florida, 1998; Southern, Central, Northern Rockies, 2000). Only late fall or winter rain or snow is successful at stopping these types of fires, which burn for months and occur in all western states. These fires are very destructive and dangerous as well. There has been a dramatic increase in the number of fire shelter deployments and entrapment situations in the past 15 years. Unfortunately, there has also been a dramatic increase in the number of fire line fatalities—there were 34 fatalities in 1994 alone!

This type of fire behavior and the huge increases in acreage burned are a direct result of the buildup of fuels throughout

Cerro Grande fire progression
5 May 2000–18 May 2000

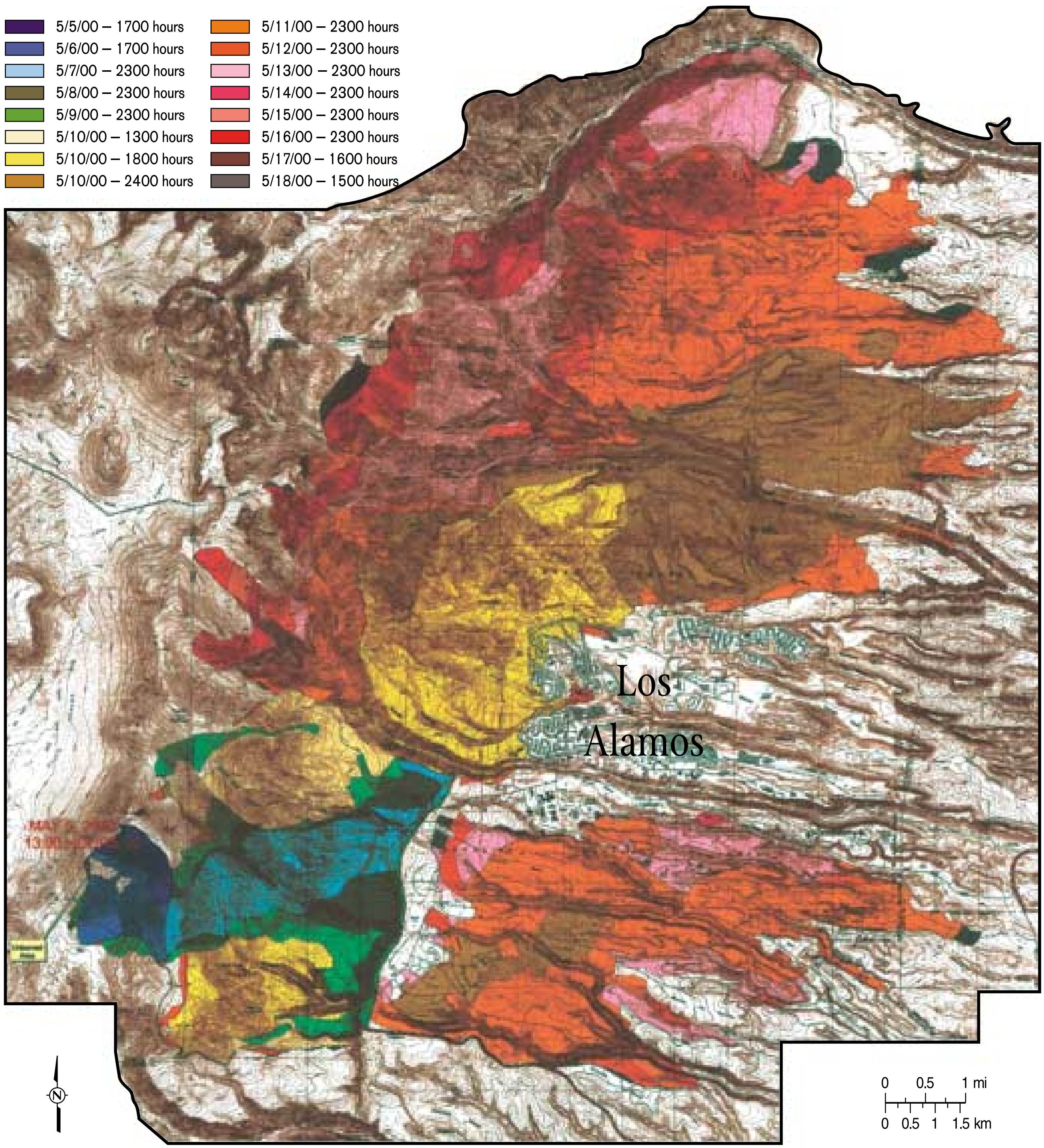

FIGURE 1—Fire progression by time of Cerro Grande fire, May 2000.

the western forests due in large part to forest-fire suppression for the past 100+ years. Drought years that reduce fuel moistures in forest fuels, coupled with heavy fuel loads that have a high dead-fuel component within the fuel bed, are conducive to large, fast-spreading, high-severity wildfires. These are conditions that prevail in New Mexico. Consider the past 10 years. The big fire in the Lincoln National Forest in 1990 was at that time the largest forest fire in New Mexico's history, with 30,000 acres burned. The Cerro Grande fire in 2000 was 47,650 acres burned!

The outlook for the future is dim. Because of dense and deteriorating forest stand conditions throughout the western United States, large, high-severity wildfires that destroy communities and threaten lives are common. Our only defense against these conflagrations is an aggressive fuels-management program where all forest-management tools are at our disposal. These management tools include mechanical treatments such as thinning and prescribed fire. Fire prevention and education programs geared specifically for homeowners and communities in the wild land/urban interface are equally important. Additionally, we must continue to improve and increase our federal fire-suppression forces at all levels.

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Aspen grove burned by the Cerro Grande fire of May 2000, just west of Los Alamos. Photograph by David McCraw.

Impacts of the Cerro Grande Fire on Santa Clara Pueblo

by *Alvin Warren*, Santa Clara Pueblo

Santa Clara Pueblo is a community deeply rooted in the natural environment that encompasses it. A federally recognized Indian tribe with about 2,500 members, Santa Clara is located in northern New Mexico 30 mi north of Santa Fe along U.S. Highway 84/285. Since time immemorial, the Santa Clara people have used and occupied the 25-mi-long Santa Clara Creek and over 100,000 acres of the land surrounding it in the Jemez Mountains, Pajarito Plateau, and Rio Grande valley of northern New Mexico as our ancestral homeland. Currently, the total land area within the exterior boundaries of the Santa Clara Pueblo Reservation is 55,091 acres and comprises two patented Spanish land grants, a reservation created in 1905 by Presidential executive order, and several purchase areas. From traditional potters to Los Alamos National Laboratory technicians, and from tribal officials to construction workers, all Santa Clara people turn to the land as part of our daily lives: to hunt or fish, to gather firewood or building materials, to collect clay or ash for pottery, to conduct cultural activities, to bring water to irrigate our crops, and to graze our livestock. From this perspective it is understandable why the devastation wrought by the Cerro Grande fire on Santa Clara lands was felt deeply and personally by every individual at Santa Clara Pueblo and will profoundly affect the community as a whole for many generations.

The Cerro Grande fire began on May 4, 2000, as a prescribed fire by the U.S. Park Service, raced across the Pajarito Plateau, and burned approximately 13,300 acres of Santa Clara Pueblo's ancestral homeland. This included 6,681 acres of the Santa Clara Indian Reservation, approximately 6,129 acres currently under U.S. Forest Service management, and approximately 490 acres in private ownership. Overall, this represents about 13% of Santa Clara's ancestral lands and 12% of its current reservation. In addition, the fire burned approximately 6,087 acres of the Santa Clara Creek watershed, consuming more than 19% of this critical drainage upon which Santa Clara Pueblo relies. The fire also devastated the Garcia Canyon watershed, ancestral to the Santa Clara people, with 3,771 acres burned or almost 42% of the drainage. In addition, the fire burned almost 18% of the Chupaderos Canyon drainage and about 57% of the Guaje Creek watershed, portions of which are within Santa Clara's ancestral lands. The fire consumed large tracts of sensitive timber and grasslands, which provide critical resources for the Santa Clara Pueblo as well as habitat for wildlife upon which the Santa Clara people depend. This paper will summarize impacts of the Cerro Grande fire upon the Santa Clara people and the lands and resources that sustain them.

Thousands of acres of closed timbered forest were burned in the fire, including ponderosa pine, piñon/juniper, and mixed conifer. A significant portion of this fire burned in spruce-fir mixed conifer forests. These forests have a longer natural fire cycle than that of ponderosa pine, and their regeneration occurs more slowly, taking many decades. In addition, large areas of open ponderosa pine and piñon were also burned. Even where the fire intensity did not cause total mortality, burned trees have become susceptible to infestations of woods imps and wood beetles. These have the potential to build in population and spread to unburned portions of the forest. Finally, mudslides and debris flows in the interior of the Santa Clara Canyon have resulted in repeated closures of the Santa Clara Canyon Road and in pueblo members losing access to large tracts of unburned forested tribal land as well.

The loss of these trees as well as interference with access has hampered the pueblo's customary uses. These forestlands hold a vast number of values for the people of Santa Clara Pueblo. Pueblo members use this forest for personal construction materials, including logs for vigas, small diameter trees for latillas and fence posts, and branches for other purposes. The pueblo issues permits to tribal members to gather fuel wood. Many pueblo members depend upon fuel wood as their source of heating and traditional cooking. The pueblo burns fuel wood in its ceremonial buildings for cultural and religious purposes. Also, pueblo artists use fuel wood to fire their clay pottery. Pueblo members also use these trees for cultural purposes, from the entire tree to parts such as branches and bark. This material is critical to the continuation of the unique and ancient cultural practices of the pueblo. Finally, the pueblo conducts periodic timber harvests to improve the health of the forest and bring important income to the tribe.

A large variety of wildlife existed in the areas burned by the fire, including mule deer, elk, mountain lion, coyote, bobcat, raccoon, deer mouse, and striped skunk. There are also several species of frog, salamander, and lizard constituting the amphibian and reptile population. Bald and golden eagles are found, as well as red-tailed hawk, turkey, grouse, orioles, flickers, and mountain bluebird. Native cutthroat trout, introduced rainbow trout, and hybrid cutbows are present in the Santa Clara Creek. Threatened, endangered, and sensitive species are also present in the area.

This fire has caused both direct and indirect impacts to this wildlife. Certainly some of this wildlife was killed during the fire. A much larger number have been stripped of their habitat for a period of at least 5 to 10 years. The Santa Clara people depend upon this wildlife for subsistence and cultural materials. Again, this is not just for the acreage actually burned, but also for the areas of unburned tribal land that may be inaccessible due to potential floods and debris flows in the Santa Clara Canyon and other areas. Tribal members also depend upon the fish in the Santa Clara Creek for subsistence. The fisheries and water quality necessary to sustain fish have been severely impacted by runoff from the burned areas.

The fire burned thousands of acres of forage, grass, and open timbered lands that Santa Clara livestock owners depend upon to graze their livestock, and may make inaccessible for several years other grazing lands in the Santa Clara Canyon that were not burned. Cattle owners are accustomed to turn out their livestock in the mountainous areas of the reservation from April through October. During these months, the cattle subsist entirely on the native vegetation and water from the natural streams, springs, and constructed dirt stock tanks.

Due to the fire—in combination with the smaller acreage of lands lost on the north side of the canyon to the 1998 Oso fire—the Santa Clara livestock owners have been placed in an expensive and difficult situation. They have had to pen up their livestock in the agricultural fields near the pueblo during the season when such livestock normally are removed to prevent destruction of agricultural fields. This required additional fencing materials and other items such as cattle guards to prevent impacts on farming lands. In addition, livestock owners were forced to pay out of their own pockets for feed and other supplies for their livestock. It will take decades for these forage areas to fully recover, particularly where high fire intensity has caused soil sterility.

The areas within the burn constitute the heart of Santa Clara's ancestral homeland. As such they contain many cultural sites, including the remains of ancient villages and cavate dwellings, agricultural fields and features, field houses, petroglyphs, game pits, and pottery and lithic scatters. Several of these sites were damaged due to exposure to the intense heat and wind conditions of the fire. In addition, the loss of ground cover has exposed many sites making them susceptible to further impacts including wind and water erosion, pot hunting, and damage from falling debris. These sites are touchstones of Santa Clara history and culture and are remembered in the pueblo by names and stories in the Tewa language. The pueblo is particularly concerned with the vulnerability of sites outside the reservation over which it has limited control.

The Cerro Grande wildfire has also severely impacted the integrity and water quality of various watersheds significant to Santa Clara Pueblo. These include the Santa Clara Creek, the Guaje Creek, the Garcia Canyon drainage, and the Chupaderos Canyon drainage. Particularly in the Santa Clara Creek watershed, the fire has caused general dysfunction of the riparian corridor and stream channel. This is due to the accumulation of large dead and down debris from burned areas and increased runoff and soil loss due to destabilized slopes. Over the next decade, large quantities of debris and ash will accumulate in the drainages of the Santa Clara Creek and other watersheds. This debris material forms dams that can wash out and cause erosion downstream. The pueblo is particularly concerned with the Santa Clara Creek watershed as this watershed provides water for the entire community of Santa Clara.

The most significant direct impact of the fire upon the water resources will be in the area of irrigated agriculture. The Santa Clara Canyon irrigation canal, one of the pueblo's primary irrigation canals, draws its water entirely from Santa Clara Creek. Pueblo farmers depend upon this source of water to irrigate orchards as well as various crops, including several varieties of corn, chile, squash, and beans. Flooding of the Santa Clara Creek stream channel has damaged this irrigation canal and caused the ditch to be closed during the irrigation season. Farmers were forced to haul water to their field to keep crops from dying. With the risk for flooding in the creek bed, it is likely that the irrigation ditch will be entirely or periodically unusable for many years until flooding risks have subsided. This may reduce the productivity of planted crops and even prevent farmers from using fields that depend upon this source of water.

In addition, the fire has caused significant increases in runoff and erosion that have on multiple occasions overburdened, filled, realigned, and damaged culverts, catchment basins, irrigation structures, low-water crossings, and the various stream beds. Downstream structures threatened by flooding in the Santa Clara Creek include Santa Clara's senior citizen's center, day school, administrative building, and traditional village and other residences. In particular, large amounts of sediment have accumulated behind Sawyer Dam on the Santa Clara Reservation resulting in a near breach. Several pueblo-owned culverts have been damaged and will need to be replaced.

The fire has also directly and indirectly affected Santa Clara's tourism-dependent economy, both to the tribal members and the tribal government. The Puye Cliff Dwellings, listed on the National Historic Record, is usually open to the public throughout the year. In addition, the Santa Clara Canyon Recreation Area is usually open from March through September annually. Both of these places had to be closed to the public and will remain so for the indefinite future. Both of these attractions allow the pueblo to share portions of its lands with the general public and to bring in critical revenue to the tribe. In addition, individual Santa Clara Pueblo members who sell arts and crafts depend heavily upon this traffic of visitors through the pueblo headed for Puye or the canyon.

While the fire did not burn the historic cliff dwellings and structures at Puye, several direct and indirect impacts have caused Puye to remain closed to the present. These include damage to the parking lot, the natural setting directly south of Puye and around the historic Harvey House buildings, the entrance to Puye that crosses the Sawyer Canyon wash, and the pristine natural appearance of the lands surrounding Puye to the west. The extensive coverage of the fire by the media may also discourage tourist visitation due to misinformation about the ruins themselves being burned or safety concerns. The Cerro Grande fire has burned almost 19% of the Santa Clara Canyon including parts of the recreation area in the bottom of the canyon. It has visually impacted the upper portions of the canyon with large areas of severe burn. These severe burn areas, entirely wiped clean of vegetation with a potential for hydrophobic soil conditions, have led to flooding and debris flows into the canyon. This has impacted half of the constructed fishing ponds in the canyon, causing them to remain drained and unusable. Thus, for safety, quality, and aesthetic reasons it is likely the recreation area will be closed to the public for the indeterminate future.

The Santa Clara Canyon Recreation Area and Puye Cliff Dwellings attract many tourists within and outside the state of New Mexico to Santa Clara Pueblo, many of whom purchase arts and crafts from pueblo members. Tribal members depend upon the revenue from these arts and crafts for their livelihood and for supplemental income. The closure of these two attractions has seriously curtailed the tourist traffic upon which the artists and craftspeople depend. There are currently seven arts and crafts shops and galleries within Santa Clara Pueblo and approximately 450 resident artists and craftspeople who sell from their homes.

In addition, the fire will require a large increase in demands upon the Santa Clara Tribal Government to provide services. The fire has placed the pueblo at increased risk for additional wildfire, flooding, erosion/sedimentation, and ill health through sediment transport of contaminated soils. Overall, these increased risks will require the pueblo to employ additional staff to conduct and coordinate damage assessments and disaster relief, coordinate the Burned Area Rehabilitation Plan (BAER) development and implementation, conduct environmental and health assessments, and provide for law enforcement in areas damaged by the fire (BAER, 2000). Consultants and legal experts will have to be hired to assist the tribe with rehabilitating the damaged lands and resources as well as obtaining adequate compensation. Equipment will also have to be purchased for rehabilitation as well as for future fire response. Repairs to damaged infrastructure will also be needed, including realignment and resurfacing of roads, building of low-water crossings, and installation of erosion-control structures in affected areas.

In conclusion, the Cerro Grande fire will have a lasting and profound impact upon Santa Clara Pueblo's unique and ancient culture. As a land-based culture, the destruction of these resources and potential denial of access to a large part of our land will impose great burdens upon our community. It is not simply a matter of destruction of archaeological and cultural sites; it is a profound alteration of our relationship with areas, plants, and animals upon which our culture depends. No similarly destructive wildfire has occurred in our ancestral homeland in the memory of our oldest living members. Nevertheless, we know that hundreds of generations of our people have lived in this region and survived countless changes and cycles—both natural and human caused. In this spirit, our people intend to persevere through the changes wrought by the Cerro Grande fire and do our part to steward the restoration of our ancestral homeland.

Reference

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Alvin Warren, an enrolled member of Santa Clara Pueblo, assists his and other indigenous communities with identifying, protecting, and recovering traditional lands and resources. Born and raised in northern New Mexico, Alvin received his BA in history with high honors and certification in Native American Studies from Dartmouth College. From 1997 to 2000 he successfully led his pueblo's efforts to regain over 5,000 acres of their ancestral homeland; the largest land reacquisition by the Santa Clara Pueblo in almost a century. He is currently serving his 5th term as a member of the Santa Clara Tribal Council, including one term as the Tribal Treasurer and one term as the Tribal Interpreter, two of the pueblo's six elected officials.

In addition, he served 3 years on the Board of Education for the Santa Clara Day School, including one term as Vice-Chairman. He serves in several capacities with the Trust for Public Land, a national conservation organization, including as a founding member of the New Mexico Advisory Council, a member of the Tribal Lands Program Advisory Council, and a founding member of the National Working Group on Land-and-People Conservation. He also serves on the Board of Directors of the Chamiza Foundation.

Watershed Management on the Pajarito Plateau: Past, Present, and Future

by *Ken Mullen*, LA-UR-01-2056, Water Quality and Hydrology Group, Los Alamos National Laboratory;
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Los Alamos National Laboratory (LANL) developed a draft watershed-management plan that pertains to the 43-mi^2 area within the LANL boundaries. The watershed-management plan was started in 1996 with a number of overall goals: (1) to be a good steward of the natural resources entrusted to the laboratory, (2) to provide long-term evaluation regarding success of the Environmental Restoration Project in acceptably cleaning up sites, (3) compliance with the storm water National Pollution Discharge Elimination System program, and (4) upgrading the LANL environmental surveillance program that has been ongoing since the 1940s.

LANL has an extensive network consisting of 53 surface-water-monitoring stations located in every major canyon, upstream and downstream of LANL, and at most confluences (Fig. 1). Monitoring of the network has been ongoing for about 20 years. The stations are equipped with ultrasonic transducers that trip automated samplers to collect water samples from every flow event. These data have been reported every year in the report series *Environmental Surveillance at Los Alamos*, but have not been used to analyze watershed health. The focus of the LANL watershed-management plan is to use water quality data to monitor watershed health and to implement manage-

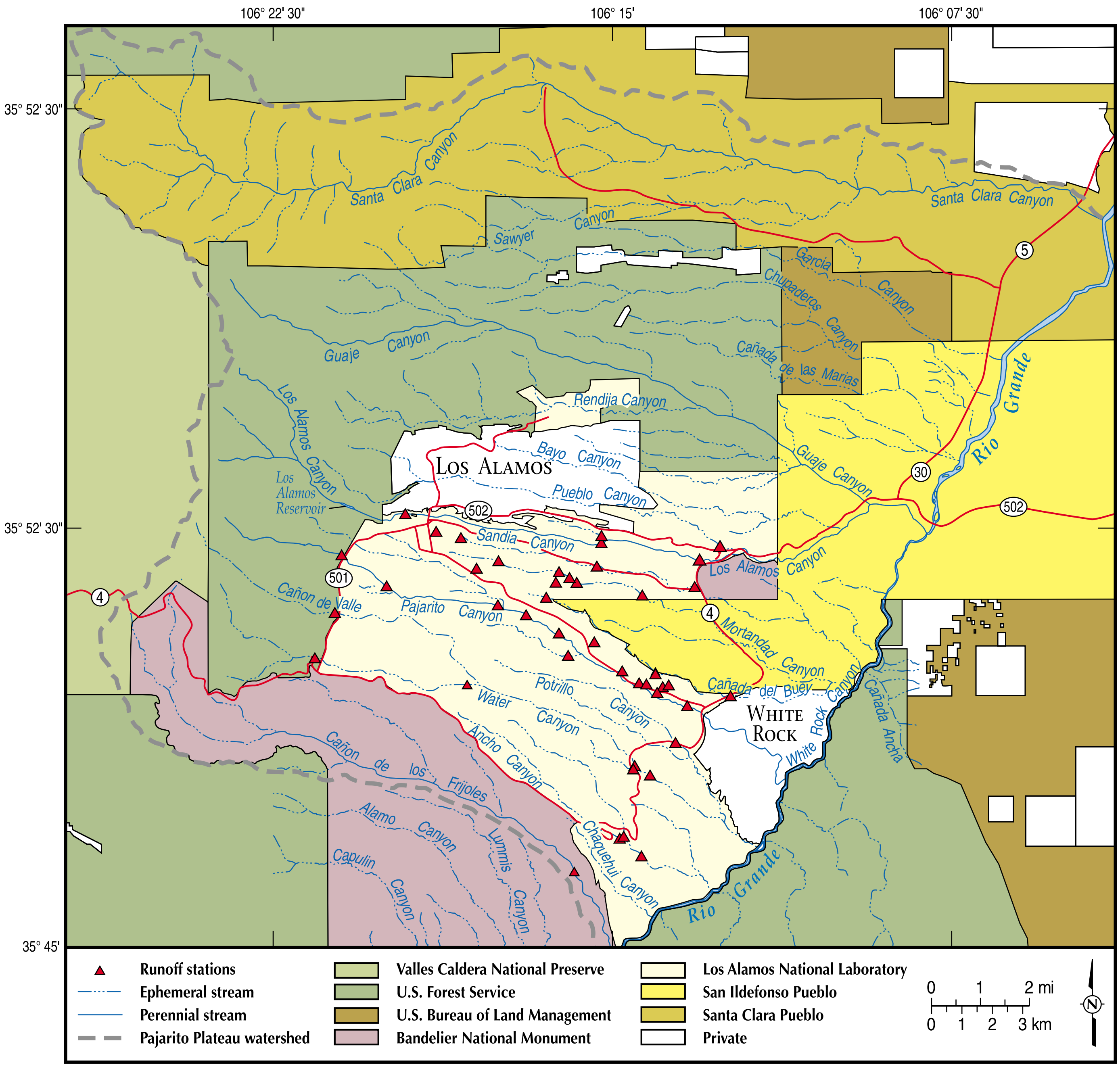

FIGURE 1—Los Alamos National Laboratory surface-water monitoring stations.

ment actions when LANL activities, past or present, adversely impact the health of the watershed.

Comments from stakeholders on the draft watershed-management plan criticized the development of a plan that did not include the entire watershed or the perspectives of the stakeholders that share the watershed: the U.S. Forest Service, National Park Service, Los Alamos County, U.S. Bureau of Land Management, San Ildefonso Pueblo, Cochiti Pueblo, and Santa Clara Pueblo. In response, LANL has sought stakeholder participation in revising the draft plan to include the entire watershed comprising the eastern flank of the Jemez Mountains. At a meeting held on September 16, 1999, most land managers within that watershed and the New Mexico Environment Department committed to participating in the development and implementation of a Pajarito Plateau Watershed Management Plan that covers the entire area.

LANL initiated the formation of the Pajarito Plateau Watershed Partnership, composed of the major stakeholders in the watershed, whose purpose is to plan and implement a program to identify and address the primary issues that affect water quality in all parts of the watershed and are shared by all members of the partnership. One such issue that unifies the partnership and requires a shared-management strategy is erosion. One example of a shared-management strategy to address erosion is vegetation thinning to encourage growth of herbaceous cover. The herbaceous cover holds soil in place, increases surface roughness, and encourages infiltration—all of which decrease erosion by slowing down water. Storm water flow in the aftermath of the Cerro Grande fire has demonstrated how important vegetation is to flood protection.

The Pajarito Plateau Partnership, through grant funding from the NMED or other sources, hopes to implement watershed restoration activities that include reforestation, replanting vegetation in the urban/forest interface, and thinning of ponderosa and piñon-juniper to enhance herbaceous growth in Los Alamos County, Bandelier National Monument, Santa Fe National Forest, and Santa Clara Pueblo.

Other important goals of the Pajarito Plateau Watershed Partnership are outreach and education. These are critical elements of the Pajarito Plateau Watershed Management Plan, and all members of the watershed partnership have agreed to develop and participate in outreach and education activities. Decisions made by the partnership need to be communicated and justified to the public, officials, and other stakeholders. It is anticipated that active participation of partnership members will result in outreach that is effective across all jurisdictional boundaries.

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Kevin Buckley is involved in diverse activities within the Water Quality and Hydrology Group at Los Alamos National Laboratory. He directed watershed rehabilitation on the laboratory after the Cerro Grande fire. He maintains gaging stations on the laboratory and collects surface water and storm water runoff samples. He is also directing outreach activities for the Pajarito Plateau Watershed Partnership. Formerly, Kevin was the hydrologist for the Mescalero Apache in southeastern New Mexico where he developed a watershed management plan for the Mescalero Apache Reservation. Kevin also worked for 6 years as a Biological Technician for the U.S. Forest Service in many western locations.

New Mexico 20 Communities Initiative—Protecting Communities in the Wild Land/Urban Interface

by *New Mexico Energy, Mineral and Natural Resources Department*, presented by Fred Rossbach, Forestry Division

According to a 1999 General Accounting Office (GAO) Report to Congress, "the most extensive and serious problem related to the health of national forests in the interior West is the over accumulation of vegetation, which has caused an increasing number of large, intense, uncontrollable, and catastrophically destructive wildfires."

Scientists believe this increased number of fires is due primarily to the decades-old policy of putting out wildfires on federal lands. The policy has caused the disruption of frequent, low-intensity fires, which had removed accumulated vegetation and prevented fires from becoming larger. Unfortunately, these intense fires now pose a grave threat to human health, safety, property, and infrastructure along boundaries between forests and urban communities. This policy has been costly. Federal Forest Service fire suppression costs rose 150% between 1986 and 1994, and the number of fires in national forests, burning more than 1,000 acres, grew from an average of 25 to 80 per year.

The situation in New Mexico is no different. Costs of suppressing wildfires have escalated to an all time high during the fiscal year 2000, and the number of acres burned almost tripled compared to the 10-year average (Fig. 1). This trend will continue until the threat of large, catastrophic wildfires is diminished.

What is the threat in New Mexico? (1) 15,202,080 acres in New Mexico are considered forested and woodland. (2) 4,800,000 of those forested and woodland acres are under the state's fire suppression jurisdiction. (3) 540,447 of the forested acres administered by the state are located in a wild land/urban interface, estimated using a 2-mi radius around communities with a population greater than 5,000.

A primary goal of New Mexico Energy, Minerals, and Natural Resources Department (EMNRD) Forestry Division is to determine which communities are most vulnerable to fire and provide them with the necessary tools to make needed changes. The Forestry Division's approach will emphasize the importance of protecting homes within these communities; developing fuel breaks, or areas of limited vegetation, from which firefighters can build a line of defense against an approaching fire; and thinning of forested areas to reduce the possibility of catastrophic fires.

In order to evaluate which New Mexico communities are most vulnerable to fire, an objective rating system was developed that assesses a number of factors contributing to a community's fire risk. The criteria include: type of vegetation and proximity to homes, availability of water, effective evacuation route, topography (ridge, valley, slope, and exposure), type of fuels (forest type) and fuel accumulation, number and size of previous fires, direction of prevailing and local winds, and the ability of community or subdivision to protect homes.

Based on an evaluation of these criteria, the 20 New Mexico communities most vulnerable to fire (Fig. 2) are: Angel Fire/Black Lake, Capitan/Lincoln, Catron County, Cloudcroft, East Mountains, Española Bosque, Gallinas watershed, Jemez/La Cueva, Los Alamos, Manzano Mountains, Mayhill/Timberon, middle Rio Grande bosque, Mora County interface, Pecos, Red River, Ruidoso, Santa Fe watershed, Silver City area, Taos Canyon/Shadybrook, and upper Brazos.

In order to proceed with EMNRD Forestry Division's goal to provide at-risk communities with tools to effect needed changes, an implementation plan is being developed. The plan requires cooperation among all stakeholders (federal, state, tribal, and community leaders) and could take from 2 to 5 years to complete. The implementation plan includes two stages: (1) assessment of at-risk communities and (2) development and implementation of damage prevention and restoration projects. Stage I of the plan, assessment, includes the following elements:

- Identify sites that need treatment, immediate and long term, and for each site identify a funding source;
- Ensure that individuals, tribes, municipalities, and counties understand the threat posed by wildfire;
- Establish community-based teams to plan projects and set priorities;

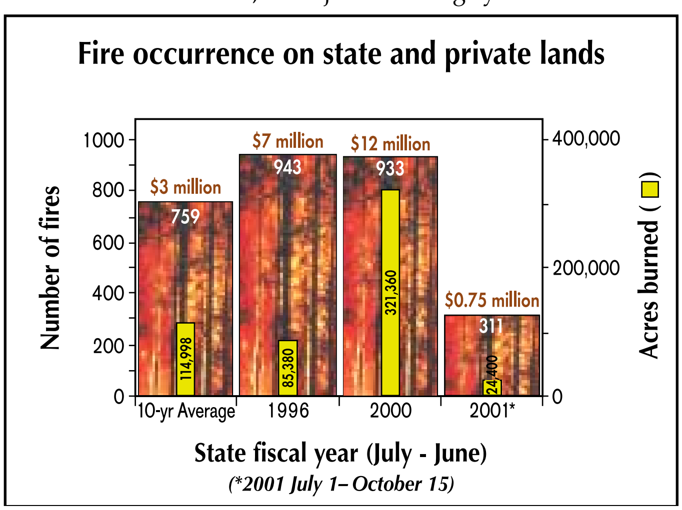

FIGURE 1—Fire occurrence on state and private lands.

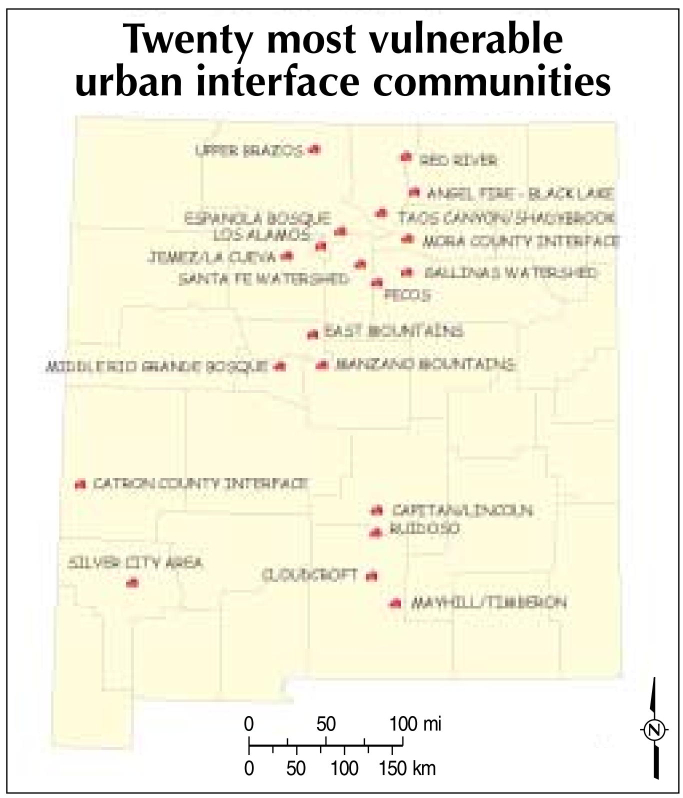

FIGURE 2—The 20 most vulnerable urban-interface communities.

- Involve community leaders in identifying damage prevention and restoration projects;
- Assess suppression infrastructure, fire-fighting capability, and ability to complete projects; and
- Develop information and education programs.

Stage II of the plan, damage prevention and restoration, includes the following elements:

- Identify, define, and complete projects that improve the health of identified sites; for example, estimate that 2,000 acres/community needs an immediate treatment such as thinning, harvesting, prescribed fire, etc.;
- Establish priorities for long-range projects and establish a funding regime;
- Maintain and/or increase local ability to suppress fires while they are small;
- Develop and improve evacuation plans, geographic information system (GIS) mapping, and fire detection;
- Inform landowners and municipalities of specific actions which will help prevent erosion and other after-effects of fires;
- Help individuals understand appropriate treatments to safeguard their homes;
- Work with stakeholders to find commercial markets for material removed during projects;
- Restore burned lands; and
- Enact local ordinances where and when appropriate.

Cooperation among stakeholders is a critical element for success of the assessment, prevention, and restoration plan. First, stakeholders need to be identified and their functions defined. Four stakeholders, or categories of stakeholders, are readily identifiable: (1) federal agencies and tribes, (2) State Forestry Division of EMNRD, (3) local and tribal entities, and (4) individuals. These entities will focus efforts from the backwoods to the urban/wild land interface, and in some cases to individual backyards. Federal agencies and tribes will be required to obtain significant increases in the National Environmental Policy Act (NEPA) and other environmental clearances to complete thinning projects, conduct burning, and create fire breaks, and they will be required to provide education and technical advice. The EMNRD State Forestry Division will provide flow through funding for projects, provide leadership, education and technical advice, and work with landowners on projects to treat their lands according to sound scientific principles. Local and tribal entities will actually implement and complete identified projects, enact relevant ordinances, and enhance fire protection. Individuals can also have a significant impact in protecting their own homes and neighborhoods by making changes to home exteriors to improve fireproofing, clearing vegetation, reducing flammables around homes, and improving access for fire engines.

No one can be excluded from this critical process. According to the GAO (2000), "the window of opportunity for taking corrective action is estimated to be only about 10 to 25 years before widespread, unstoppable wildfires with severe immediate and long-term consequences occur on an unprecedented scale."

Reference

GAO (General Accounting Office), 2000, Western national forests—a cohesive strategy is needed to address catastrophic wildfire threats: Report to Congress, April, 2000.

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The Potential for Rainfall-Triggered Debris Flows Following the Cerro Grande Fire

by *Susan H. Cannon*, Landslide Hazards Program, U.S. Geological Survey

Debris flows generated from recently burned areas can pose a significant hazard to lives and property. The term *debris flow* refers to the rapid downslope movement of a viscous slurry consisting of up to boulder-sized material and mud. Debris flows usually occur during periods of intense rainfall or rapid snowmelt. They can occur with little warning, are capable of transporting large material over relatively gentle slopes, and develop momentum and impact forces that can cause considerable destruction. As a result of these characteristics, mitigation of debris-flow hazards can be more difficult than mitigation of flood hazards. On September 1, 1994, at approximately 10:30 pm, debris flows were generated in response to a torrential rainstorm from the recently burned hillslopes of Storm King Mountain in Colorado. The debris flows poured down onto I–70 from every basin burned by the wildfire. Thirty cars traveling on the highway at the time of the debris flows were engulfed or trapped by the mud, and at least two people were swept into the Colorado River. Although some travelers, including those swept into the river, were seriously injured, fortunately no deaths resulted from this event. I–70 was closed for 3 days to allow crews to remove the tons of rocks, mud, and burned vegetation that inundated the highway.

Factors Controlling Debris-Flow Occurrence in Recently Burned Basins

In a study of 96 recently burned basins in southern California, New Mexico, and Colorado, Cannon (1999) and Cannon and Reneau (2000) compared conditions in basins that produced debris flows with conditions that resulted in sediment-laden streamflow to determine the factors that best indicate a susceptibility specifically to debris flow. This work demonstrated that the factors that best separate debris-flow-producing basins from those that produce primarily streamflow are the basin and the geologic materials that mantle the hillslopes. Although debris flows were produced from basins with a broad range of areas and gradients, a basin area/channel gradient threshold could define debris-flow susceptibility. Cannon (1999) and Cannon and Reneau (2000) also evaluated the effect of the areal extent of the burn and the presence of water-repellent soils on debris-flow generation and found that debris flows can be generated from even partially burned basins and that the presence of a water-repellent soil does not indicate a propensity specifically for debris flow. They also suggested that a spatially extensive burn and the presence of water-repellent soils may affect the magnitude of erosive events following wildfire, but do not distinguish debris-flow-producing basins from those that produced streamflow.

The Cerro Grande Study

In a recent study, I qualitatively evaluated the potential for fire-related debris flows by comparing conditions in eight basins burned by the Cerro Grande fire with the conditions identified by Cannon (1999) and Cannon and Reneau (2000) as likely to produce debris flow (Fig. 1). For each basin, the likelihood of debris-flow activity is assessed upstream from the first point within the channel where debris flows could potentially impact man-made structures. Debris-flow susceptibility of Water Canyon, Cañon de Valle, South Fork of Pajarito Canyon, Pajarito Canyon, and Two Mile Canyon is assessed upstream from where each canyon crosses NM–501/502. Los Alamos Canyon is evaluated for debris-flow susceptibility upstream from Los Alamos Reservoir. Pueblo Canyon is evaluated upstream from the Diamond Drive crossing, and Rendija Canyon is evaluated upstream from the first crossing behind Guaje Pines Cemetery.

Cannon (1999) found debris-flow susceptible basins could be distinguished from streamflow-dominated basins by a basin area/channel gradient threshold (Fig. 2). The basin area and gradients of all the canyons evaluated in this study, with the exception of Los Alamos Canyon, fall above this threshold (Fig. 2). The data suggest that, given sufficient rainfall, the remaining seven basins can potentially produce debris flows. Data from Los Alamos Canyon fall outside the range of conditions known to have produced debris flows; comparison with the threshold is inconclusive in this case.

Cannon (1999) and Cannon and Reneau (2000) found that the geologic materials that mantle the hillslopes could also identify debris-flow susceptible basins. For example, in nearby Bandelier National Monument, fire-related debris flows were generated from colluvium and soil weathered from the dacite-rich Paliza Canyon Formation (a fine-grained volcanic rock). Geologic mapping (Smith et al., 1970) shows that the basins evaluated in this study are primarily underlain by similar dacites of the Tschicoma Formation and in lower reaches by the Bandelier Tuff. This suggests that, based on the type of geologic materials forming the basins' hillslopes, the basins burned by the Cerro Grande fire are also susceptible to debris-flow activity. In addition, the abundance of loose, easily erodible soil and ash mantling steep hillslopes, extensive areas of up to boulder-sized material mantling some steep hillslopes, and the considerable volume of material stored in the channels are all elements that can potentially contribute to debris-flow production from these burned hillslopes.

How long will the debris-flow potential persist? The debris-

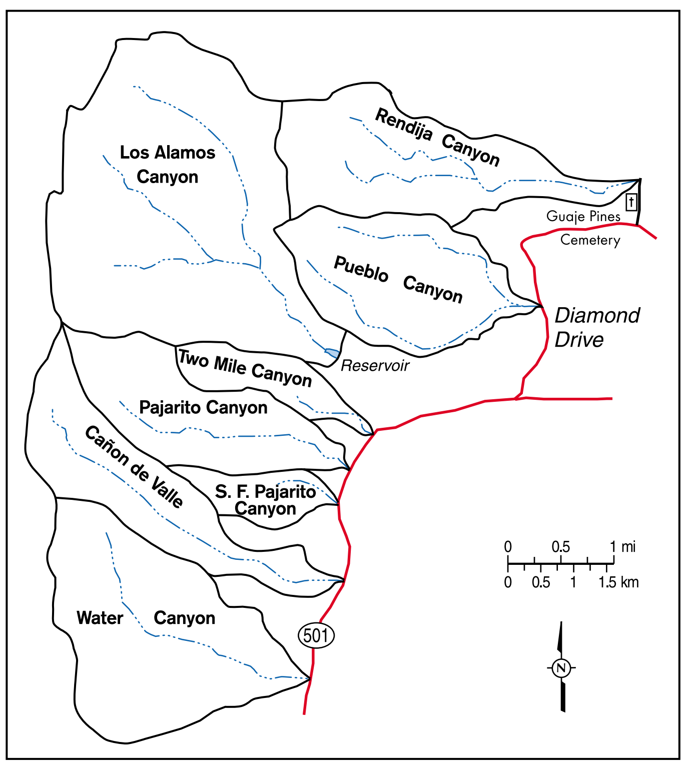

FIGURE 1—Map showing locations and extent of basins burned by Cerro Grande fire that are evaluated in this study.

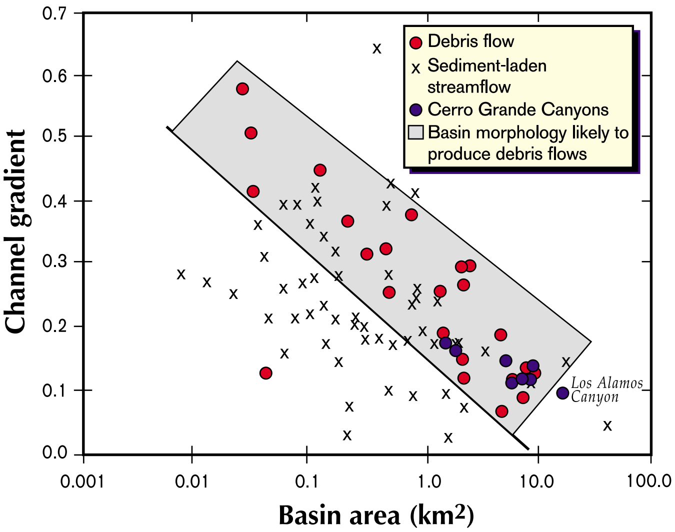

FIGURE 2—Data from Cerro Grande basins compared with basin area/channel gradient threshold for debris-flow-producing basins defined by Cannon (1999). Channel gradient is calculated as the maximum relief from basin mouth to the divide, divided by the length of the longest stream channel extended to the drainage divide. Open circles represent measurements from basins known to have produced debris flows; x's show measurements from basins that produced sediment-laden streamflow. Solid circles show data from the eight basins burned in the Cerro Grande fire evaluated in this study. Shading highlights the field occupied by data from debris-flow producing basins.

flow producing basins studied by Cannon (1999) and Cannon and Reneau (2000) all experienced significant rainfall events within a few months of the wildfires. The evaluation presented here is thus based on the assumption that the burned basins will be exposed to heavy rainfall in the near future. Streamflow measurements following two wildfires in nearby Bandelier National Monument demonstrated that rainfall-triggered runoff events returned to near pre-fire conditions approximately 4 years after the fire (Veenhuis, in press). Based on this work, we conclude that debris-flow hazards will exist in the basins evaluated in this study for approximately 4 years.

Conclusions

This preliminary evaluation suggests that in the next 4 years debris flows can potentially be produced from the basins burned by the Cerro Grande fire, given sufficient but as yet unspecified amounts of rainfall. Hillslope materials are similar to those that produced debris flows following the Dome fire in nearby Bandelier National Monument in 1996, and seven of the eight basins are above the basin area/channel gradient threshold defined by Cannon (1999) for debris-flow susceptibility. Although the materials mantling hillslopes in Los Alamos Canyon can produce debris flows, the basin area and channel gradient of this canyon are beyond the range defined by Cannon (1999).

This method for debris-flow hazard assessment allows for only a qualitative estimation of susceptibility to rainfall-triggered events. Depending on the triggering event, the scale of the debris-flow response from these basins could vary considerably. Extensive areas of high-severity burn and water-repellent soils may also increase the magnitude of potential erosive events following wildfire. Accordingly, the scope and scale of appropriate and effective mitigation approaches must also vary considerably. In addition, although debris flows have been generated from burned areas by snowmelt, this study does not address this issue due to a lack of data.

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Cerro Grande Ash as a Source of Elevated Radionuclides and Metals

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The Cerro Grande fire in 2000 burned a large area in the eastern Jemez Mountains, Los Alamos townsite, and on Los Alamos National Laboratory (LANL) land (BAER, 2000). Because of the potential for large floods generated in the upper portions of burned watersheds to erode and transport contaminated sediments in the canyons, the laboratory is implementing a comprehensive sampling and monitoring effort to characterize the impacts of flooding. The main purpose of the sampling is to obtain data to evaluate the impacts of post-fire floods on sediments, soils, surface and storm water, alluvial ground water, and biota. This information will be used to assess human health and ecological risk for areas that are affected by the floods. Data will also be used to document changes in the spatial distribution of existing contaminant inventories and concentrations (e.g., Reneau et al., 1998; Katzman et al., 1999) as a function of erosion and deposition of sediments and changing hydrology within affected watersheds.

The initial sampling effort focused on the collection of ash and muck (post-fire sediments that are dominated by reworked ash) from locations west of the laboratory. The locations were selected to be representative of background conditions upstream of known laboratory releases and predominantly upwind from airborne releases from stacks at the laboratory facilities. Ash and muck samples were also collected in the Viveash fire area (near Pecos, New Mexico) for comparison. The ash is composed of the concentrated remains of burned vegetation and forest litter (pine, fir, spruce needles, and leaves), and non-flammable, non-volatile constituents like minerals and metals (including radioactive elements). Some researchers have used tree-ring analysis to quantify the timing and magnitude of radionuclide uptake from locations around the world (e.g., Garrec et al., 1995). Thus, it was expected that detectable radionuclide concentrations associated with global fallout from aboveground nuclear testing conducted primarily in the 1950s and 1960s would be present and likely concentrated in the ash. The data from the ash and muck samples are important for interpreting concentrations of radionuclides that may be present in storm runoff and sediment deposits, and are necessary for distinguishing fire-related constituents in storm water and sediments from legacy-contamination in canyons on the laboratory. The ash and muck data provide a necessary post-fire baseline to support the assessment of potential impacts to the laboratory and offsite (e.g., the Rio Grande and Cochiti Reservoirs) from fire-related contaminants found in storm runoff.

An Interagency Flood Risk Assessment Team (IFRAT) consisting primarily of representatives of the New Mexico Environment Department, Los Alamos National Laboratory, the New Mexico Department of Health, the Environmental Protection Agency, the University of New Mexico Center for Population Health, and the Department of Energy are organized to evaluate the data in the context of risk and communicate that information to the public via press releases, the internet, and public meetings.

Expected Hydrologic and Geomorphic Effects

The Cerro Grande fire produced significant hydrologic changes to large portions of several watersheds above the laboratory (BAER, 2000). These hydrologic changes are primarily due to altered soil conditions in the burned areas. Loss of plant cover and forest litter, development of ash covers, and locally extreme water-repellent (hydrophobic) soil conditions have greatly reduced infiltration rates on hillslopes. Under these conditions, reduced infiltration rates produce extremely rapid surface runoff especially during thunderstorms, mobilizing ash, eroding surface soils, and repeatedly generating large floods in the canyons. The 1977 La Mesa fire and the 1996 Dome fire, which burned large parts of the Frijoles Canyon and Capulin Canyon watersheds, respectively, provide examples of expected hydrologic and geomorphic responses of watersheds to the Cerro Grande fire. Peak post-fire flood discharges in these canyons were up to 100 times higher than before the fires, and the most extreme effects occurred in the first 2 years after the fires (Veenhuis, 1999). The effects of flooding can include extensive bank erosion and/or vertical incision, consequently remobilizing large volumes of canyon floor sediment, some containing contamination (Fig. 1). It is expected that contaminants in any remobilized sediment would be mixed with large volumes of uncontaminated sediment derived from the upper watersheds and from downstream reaches, resulting in lower contaminant concentrations than in the original deposits.

FIGURE 1—Photo showing the vertical incision and channel widening in upper South Fork of Pajarito Canyon following several recent, moderate-intensity storms.

Day One

Results

The box plots in Fig. 2 show that concentrations of representative radionuclides in ash and muck are greater than pre-fire background concentrations in soil and sediment determined for the laboratory area (Ryti et al., 1998). The concentrations of cesium-137 and strontium-90 in Viveash area ash and muck are similar to concentrations found in the Cerro Grande fire area, supporting the hypothesis that the source of these elevated constituents is atmospheric fallout. The concentrations of cesium-137 are also comparable to the values reported by Ferber and Hodgdon (1991) for samples of ash from wood collected across the United States. It is worth noting, however, that concentrations of plutonium-239, 240 are greater in the Cerro Grande fire samples. Thus, it is possible that some of the plutonium-239, 240 measured in Cerro Grande ash had its source as stack emissions from laboratory facilities, which would explain a slightly greater concentration near Los Alamos. Data previously reported by the laboratory's Environmental Surveillance Group support this interpretation by showing that laboratory perimeter locations have 3–4 times the regional average for plutonium-239, 240 (Fresquez et al., 1996).

Similar patterns are observed for metals, and the ash and muck samples contain greater concentrations of several metals than measured in pre-fire background soil and sediment samples. The metals most elevated in the ash are those that are readily taken up into plant tissue, including barium, manganese, and calcium. These relationships further confirm that the source for the elevated concentrations of most ash constituents is from the natural process of uptake into plants and concentration of non-flammable, non-volatile constituents during the fire.

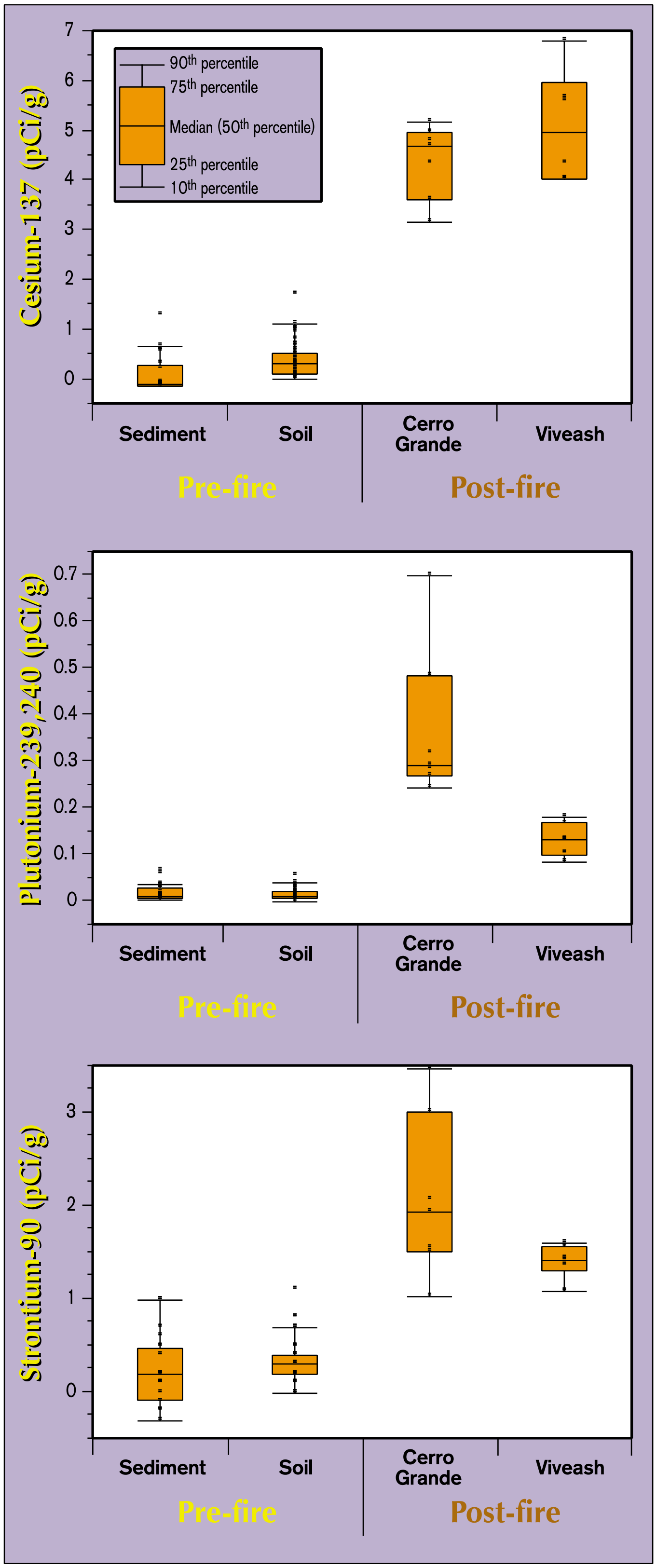

FIGURE 2—Box plot comparison of concentrations of three radionuclides (cesium-137, plutonium-239, 240, and strontium-90). Plots show pre-fire background concentrations in soil and sediment at LANL and post-fire ash and muck samples from the Cerro Grande and Viveash areas.

Conclusions

These findings are important for understanding the effect of large, post-fire floods on the transport and deposition of metals and radionuclides that are present as contaminants in canyons draining the laboratory. Concentrations of fallout radionuclides and metals transported in floods should decrease over time as ash is stripped from the slopes in the upper watersheds. In some canyons, deposition of muck during flooding will leave a radionuclide and metal inventory higher than existed before the fire, and much of the "contamination" transported to the Rio Grande may be unrelated to the laboratory. Risk assessors should not, however, discriminate between sources of contamination in their assessments because the potential effects of exposure to radionuclides and metals are irrespective of their source. Knowledge of the source of contamination primarily guides the nature and location of potential mitigation measures.

Acknowledgments

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Runoff Following the Cerro Grande Fire

by *Bruce Gallaher* LA-UR-01-148, *Ken I. Mullen*, and *Michael Alexander*, Water Quality and Hydrology Group, Los Alamos National Laboratory

The Cerro Grande fire of May 2000 burned almost 48,000 acres of forested land near Los Alamos, New Mexico. The fire burned nearly 7,400 acres on the Los Alamos National Laboratory (LANL) and major portions of watersheds draining onto LANL from adjacent Santa Fe National Forest lands. In these forest service watersheds above the laboratory, from 20% to 80% of acreage burned was considered high-severity burn. On LANL, most of the area burned was considered low-severity burn, but many small structures burned and some inactive waste sites had cover vegetation at least partially burned.

It has been well established through studies around the world that runoff and sediment yields can dramatically increase following wildfires. Accompanying these physical changes are changes in the composition or quality of runoff water. At Los Alamos, these changes may be severe due to the steepness of the burned terrain and the high severity of the burn, creating water-shedding hydrophobic soils (BAER, 2000).

Immediately after the fire, these increases in predicted runoff and sediment yields raised concerns about erosion of contaminants that exist in soils on LANL and about movement of these contaminants to offsite lands and potentially to the Rio Grande.

To understand the possible impact to downstream water bodies, runoff events after the fire were monitored and sampled by the laboratory. An extensive network of automated samplers and stream gages served as the cornerstone of this effort (Fig. 1). By the end of the year 2000 runoff season, over 90 separate runoff samples had been collected and submitted to outside commercial analytical laboratories. Additional complementary monitoring of the Rio Grande by the U.S. Geological Survey during flood events will provide considerable information to scientists about the contaminant risks from the runoff.

Due to a general lack of intense "monsoon" type rainfall during the summer of 2000, severe runoff passing across the laboratory was limited to a single event on June 28. Record peak discharges were recorded for several drainages leading onto LANL during that event. For example, in Water Canyon above NM–501, the estimated peak of 840 cubic ft per second (cfs) dwarfed the pre-fire maximum of 0.3 cfs. Fortunately, downstream property damage from this storm was minimized due to precautionary engineering. It remains to be seen what impacts will be felt during wetter rainy periods in later years.

Based on our review of the early results, the most significant aspects of the chemical quality of the runoff water appears to be in the contaminants being carried by the runoff, as opposed to those that are dissolved in the water. Samples of the sediment and ash being carried onto the laboratory by the runoff contain higher levels of radionuclides and metals than those measured in local background soils and sediments before the fire (Katzman et al., this volume). The radionuclides appear to be from decades of accumulation of radioactive fallout in trees, other plants, and in forest ground litter. The metals include mineral nutrients (like calcium and potassium) and trace concentrations of other metals that are naturally in soils. Several of these materials are 10 times higher than before the fire. Also, approximately one-half of the turbid water samples contained cyanide. Fortunately, we have detected little of the most biologically harmful form of cyanide.

Concentrations of most metals dissolved in storm water are below the Environmental Protection Agency or New Mexico drinking water standards; however, a few (for example, aluminum, barium, and manganese) are above the standards in many samples. Dissolved manganese concentrations increased by about 50 times above pre-fire levels and barium by 20. Concentrations of radionuclides dissolved in storm water are slightly elevated or comparable to pre-fire levels.

Two separate scientific panels are working to formally evaluate the health risks, if any, posed by these contaminants. They hope to have some early results available to the public before the start of the second season of post-fire runoff. This is a considerable challenge. The health experts must not only review the concentrations of the many hundreds of chemicals tested for, but they also must determine the likelihood that some person or organism would come in contact with the chemicals. Then they face a difficult task of communicating the results of their studies to a public that may be very fearful of contacting any chemicals or pollutants at any level.

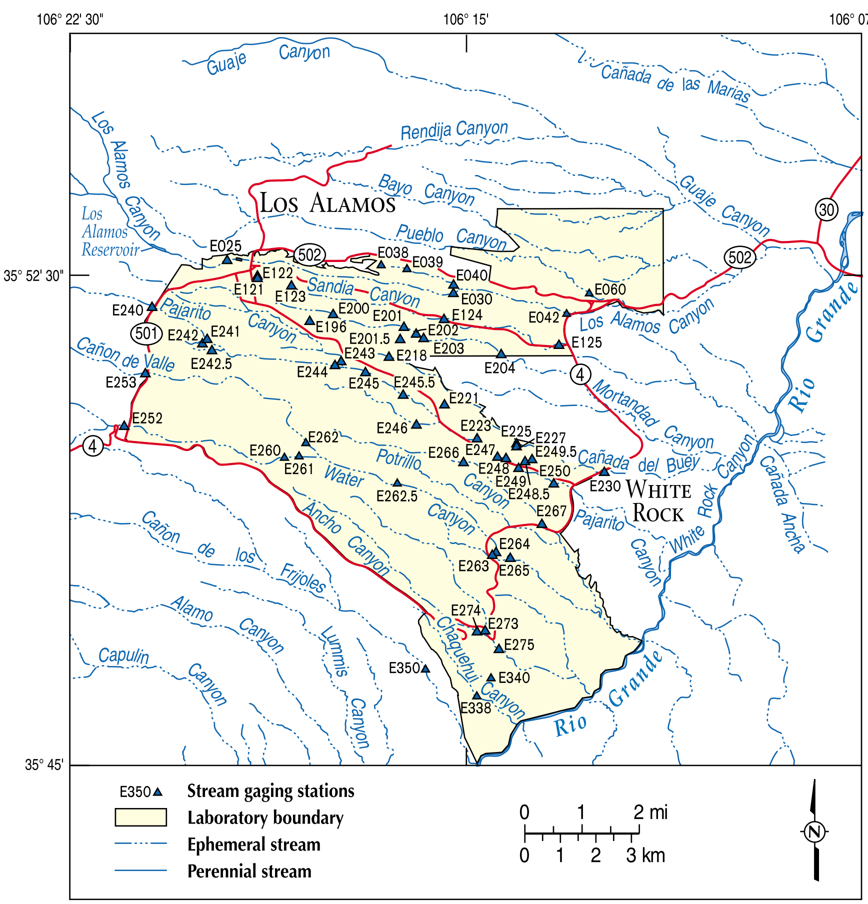

FIGURE 1—Location of Los Alamos National Laboratory automated water quality sampling stations and stream gages.

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Ground-Water Monitoring Program at Los Alamos National Laboratory

by *Charles L. Nylander*, LA-UR-01-2054, Water Quality and Hydrology Group, Los Alamos National Laboratory

Before 1990, Los Alamos National Laboratory (LANL) believed that its facilities and operations could not impact the drinking water in the regional aquifer. This belief was held because its facilities were located 600–1,000 ft above the regional aquifer and were separated from it by dry volcanic rock. Historically, 13 water-supply wells, 8 deep-test wells, and many springs were used to monitor the quality of the ground water in the regional aquifer. However, over the past 10 years of monitoring, the appearance of very low levels of specific contaminants in some of the test wells led laboratory hydrologists to suspect that the dry volcanic rock barrier was not as impervious as originally thought. The laboratory realized that the movement of water from the land surface down to the regional aquifer was not understood well enough to know how contaminants were moving downward. In 1994, the laboratory initiated a project to install additional ground-water monitoring wells.

Because of the laboratory's desire to gain a better understanding of the hydrogeologic setting and the need to satisfy a 1995 request from the New Mexico Environment Department (NMED), the laboratory developed a site-wide hydrogeologic characterization workplan, which was approved by NMED in March 1998. The plan describes data collection, data analysis, and data management activities that are being employed to improve the understanding of the hydrogeologic setting beneath the Pajarito Plateau. Data collection includes the drilling and installation of 32 deep wells into the regional aquifer, installation of 51 shallow alluvial wells, and quarterly sampling of the ground water in those wells. Data are analyzed using numerical modeling tools to synthesize, analyze, and visualize the previously existing and newly collected data. All data collected and used in the hydrogeologic characterization program are managed through a water quality database that will be available to the public via the Internet.

The characterization program described in the workplan represents a 7-year program, estimated in 1996 to cost approximately $50 million, which began with the drilling of the first regional aquifer well in 1998. Through fiscal year 2000, the program has completed 7 wells in the regional aquifer and developed flow and transport models for the unsaturated zone (the dry rock between the ground surface and the regional aquifer) and for the regional aquifer. Wells are prioritized for drilling based on hydrogeologic characterization data needs and on an assessment of which laboratory areas are more likely to have contaminants. Several of the seven wells installed thus far encountered contaminants including nitrate, high explosives, tritium, uranium, and perchlorate, although most contaminants were at levels below health standards. However, well R-25 in the southwest area of the laboratory, where high explosives were manufactured and machined, encountered high explosives in the ground water at concentrations above Environmental Protection Agency (EPA) health advisory limits.

When contaminants are detected in ground water by the hydrogeologic characterization program, the laboratory's Environmental Restoration (ER) Project steps in to further characterize the areas of contamination. To date, the ER Project has installed one deep well in the high explosives area to further delineate the extent of high explosives detected in R-25. The ER Project has also installed one well in the intermediate perched ground-water zone (a zone of saturated rock between the land surface and the regional aquifer) along the northeastern boundary of the laboratory where uranium was detected (at concentrations above a proposed EPA standard) in regional aquifer well R-9.

The data thus far support the conceptual model that ground water is found in three distinct zones beneath the Pajarito Plateau, namely shallow alluvial zones, intermediate perched zones, and the regional aquifer beneath. The characterization wells indicate that the alluvial and intermediate perched zones are typically found beneath the canyons that have large surface-water flows but are typically absent beneath the mesas and dryer canyon bottoms. Deep ground water in the regional aquifer generally moves from west to east-southeast beneath the plateau at velocities estimated to be between 50 and 250 ft/yr. Further characterization and improved mapping of the

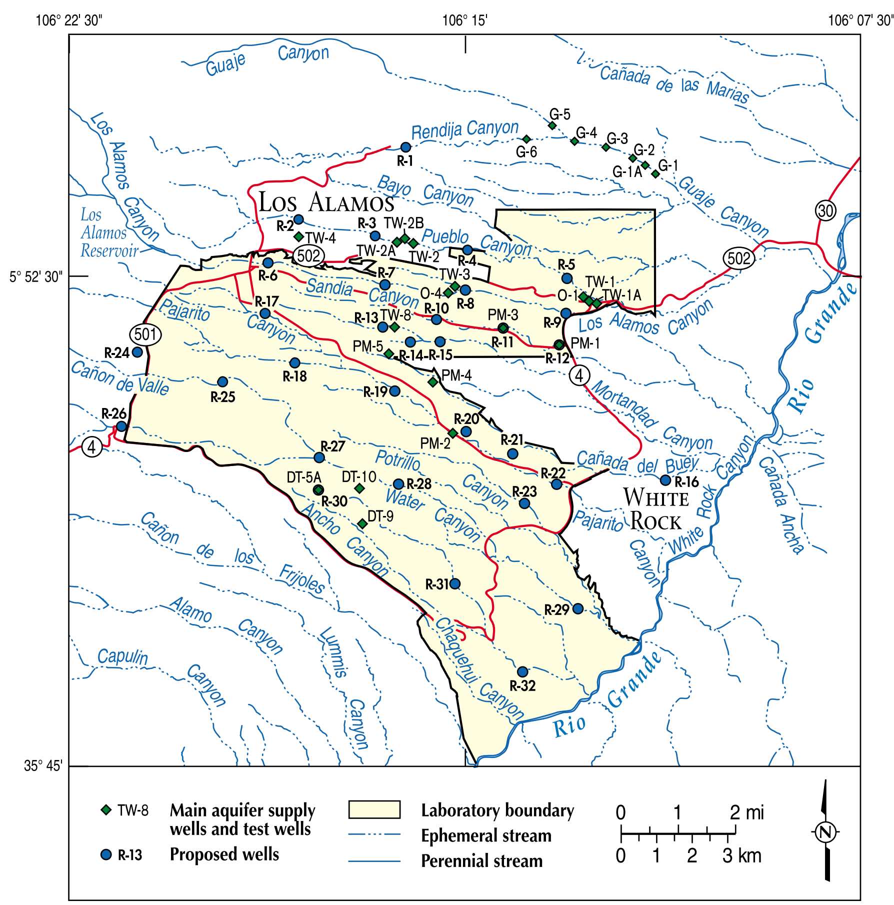

FIGURE 1—Regional aquifer supply and existing test-well locations and locations of proposed characterization and monitoring wells.

ground-water surface(s) will enhance the laboratory's ability to monitor contaminants and locate future monitoring wells as needed.

Due to the complexity of the hydrogeology beneath the Pajarito Plateau, hydrogeologic characterization data quality objectives, laboratory security requirements, data collection, and well installation are costly compared to other regulated facilities nationwide. High costs are primarily attributable to the significant depth to the regional aquifer; the drilling methods required to keep the borehole open while drilling without tainting samples; drilling in areas requiring special site procedures; extensive laboratory health and safety (HS) requirements requiring HS plans and HS personnel at the drill sites; and comprehensive analyses for samples. Although the costs are high, the ultimate value of the characterization data will be worth the costs. The data will assure the laboratory, Department of Energy, NMED stakeholders, and the public that future ground-water monitoring is adequate to protect public health and the environment.

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The Role of Risk Assessment in Ground-Water Protection

by *Diana J. Hollis*, LA-UR-01-2052, University of California/Los Alamos National Laboratory

Studying a hydrogeologic system as complex as the Pajarito Plateau is an earth scientist's dream. Here, water flows from the surface into and through the subsurface geologic units in what reveals itself as a three-dimensional maze of paths, some through-going, others dead-ending; some direct, others circuitous; some fast, and others slow. Because of this complexity, our understanding of the processes governing the hydrologic system is still incomplete, even after decades of productive investigation by hosts of dedicated scientists. While this circumstance is acceptable and even desirable to earth-science researchers, it can frustrate decision makers charged with ensuring that ground-water quality and quantity are adequately preserved and protected for present and future generations. This situation affects both proactive planning to ensure that future activities do not adversely impact surface and/or ground water, and retroactive cleanup to ensure that impacts from past or present activities do not harm the biological systems so integrally dependent on water.

We know with certainty that people's activities have impacted water quality in the Pajarito Plateau watershed. We will likely make decisions about how to minimize that impact before we have the same degree of certainty about exactly how impacted water moves through the geosphere into the biosphere and exactly how living organisms may be affected. We will know absolutely that something must be done only if we find incontrovertible evidence of impacts exceeding a specific regulatory threshold (such as a maximum concentration limit in a drinking-water supply well). However, as responsible stewards of the environment, we would like to be able to control impacts so that they never reach that threshold. Thus, we are compelled to make decisions about ground-water protection (and potential cleanup) in the face of great uncertainties about the detailed hydrogeology that affects, and is affected by, such decisions. One way that we can make those decisions in the face of great uncertainty is through risk assessment.

Risk assessment uses mathematics to describe the physical forces that control the movement of man-made constituents in ground water, and the chemical and biological reactions that such constituents undergo in the environment and in living systems. The solutions to these mathematical equations are used to estimate the risk to living organisms that may come into contact with impacted ground water. By using additional mathematical methods, the uncertainties in the physical, chemical, and biological relationships can be analyzed to understand which uncertainties are most important to the risk estimate. This gives us a way to focus our investigations of the complex hydrogeologic system on the collection of information that is most relevant. Thus, risk assessment and information gathering are iterative (Fig. 1), and the final iteration is that which provides sufficient information to decision makers so that they can make a logical and scientifically sound judgment about the need for and scope of protective measures or cleanup. In a situation where a regulatory threshold is reached, decision makers may need no additional information to know that something must be done to control the situation. However, they may still need additional information to know what would be the most cost-effective solution.

The goal of risk-based decisions is to identify (even in the face of uncertainties) the conditions that pose the highest risk and to focus (limited) corrective-action resources on those highest-risk conditions. Ideally, risk assessment in support of resource protection and cleanup decisions would use exact information about the type, amount, and location of a potential contaminant; the direction and rate of movement of a contaminant; the (eventual) amount of contaminant at a location where living organisms may be exposed; and the biological effect of that amount of contaminant on an exposed organism. Realistically, this information is always uncertain. The objective is to balance the science of information gathering (uncertainty reduction) and interpretation with the risk-management decision at hand. The Los Alamos National Laboratory's investigation of the ground water within the Los Alamos/Pueblo watershed elucidates this process.

The Environmental Restoration Project has identified several sources of potential ground-water contamination in the Los Alamos/Pueblo watershed. These include the decommissioned Omega West research reactor in upper Los Alamos Canyon (a source of radioactive tritium), the decommissioned uranium processing facility on DP Mesa (a source of radioactive uranium isotopes), and the sewage-treatment facility in Pueblo Canyon (a source of nitrates). From the open literature we know certain things about these contaminants needed for risk assessment, including their solubility in water, their physical and biological half-lives, and their regulatory thresholds. This information is supplemented with site-specific information, such as the ground-water travel times and measured contaminant concentrations in alluvial water, in unsaturated rock, in intermediate ground water, and in the regional aquifer. We are in the process of assimilating all of this information by means of a risk assessment to guide our future investigations in a way that reduces the most significant uncertainties in the context of ensuring ground-water (and ground-water receptor) protection. To date, our risk-assessment results indicate very little likelihood of exceeding a regulatory or risk threshold for tritium in a water supply well, now or in the future. We are in the process of calculating the transport of uranium in ground water to support an assessment of risk associated with uranium transport to water-supply wells.

It is the challenge of regulators to make good decisions about ground-water protection and cleanup despite inexact scientific information regarding the current and future impacts of man-made constituents on human health and the environment. We must understand natural ground-water processes to the extent that we can apply the laws of nature to effectively protect and preserve water quality. To this end, risk assessment provides a means of understanding available scientific information and inherent uncertainties. This information can be evaluated by the constituency of affected stakeholders, who

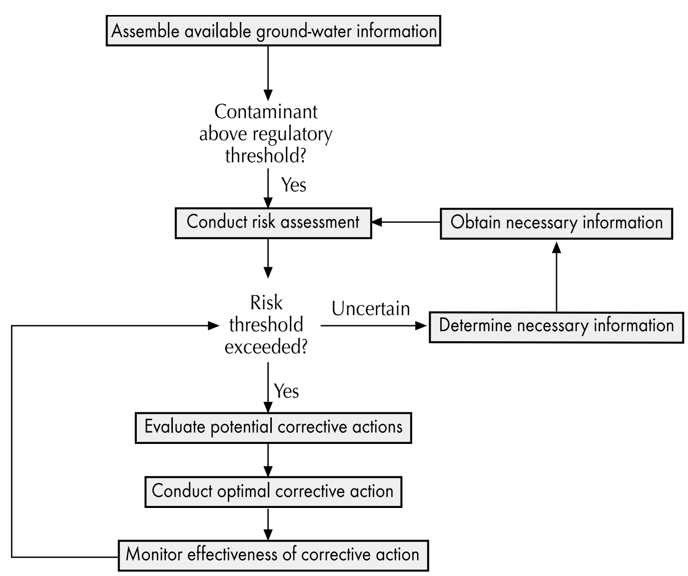

FIGURE 1—Iteration of data collection and decision making.

will provide additional information for decision makers to consider in their task of balancing scientific uncertainty, technological practicability, fiscal accountability, local socioeconomic impacts, and human values.

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Independent Analysis of Exposures and Risks to the Public from the Cerro Grande Fire

by *John Parker*, New Mexico Environment Department

On May 4, 2000, a prescribed burn at Bandelier National Monument grew out of control and was declared a wildfire on the following day. By June 6, when the Cerro Grande fire was finally declared contained, nearly 50,000 acres of forest in and around Los Alamos, New Mexico, were burned, including over 7,000 acres of Los Alamos National Laboratory (LANL). In recognition of the need for an independent assessment of exposures and risks to the public from the fire, the New Mexico Environment Department has contracted with Risk Assessment Corporation[1] (RAC) to evaluate potential health risks to the communities of northern New Mexico.

During the fire, high winds carried huge smoke clouds in a north-northeasterly direction over Los Alamos, Española, and the many small communities north to Taos. The smoke clouds could even be seen from southern Colorado and western Oklahoma. Ash deposits blanketed cars, homes, and the ground surface in these areas. In response to concerns over possible elevated levels of radionuclides and chemicals from LANL, an aggressive air-monitoring program was conducted by LANL, the U.S. Environmental Protection Agency (U.S. EPA), and the New Mexico Environment Department (NMED; Fig. 1). Radionuclide concentrations were found to be elevated above background concentrations—although the elevated readings quickly tailed off when repeated measures were taken, indicating a predominance of short-lived, naturally occurring radionuclides.

In addition to the potential for exposures from the air pathway, another concern from the fire involves the potential for enhanced transport of contaminants via the surface-water pathway. The fire burned along the eastern flank of the Jemez Mountains and portions of the Pajarito Plateau, particularly the heavily forested areas of the western margin and canyons. The loss of vegetation within these watersheds and the reduced infiltration due to the effects of the intense heat on the ground surface are likely to result in much larger-than-normal surface-water flow in the canyons leading to the Rio Grande and the potential for large amounts of surface erosion and flooding.

Whereas the structural damage at LANL from the fire was minimal and major facilities containing chemicals and radioactive materials were not significantly impacted, environmental contamination from over 50 years of operations at LANL was now at increased risk of being transported beyond laboratory boundaries. Historically, facilities at LANL disposed of effluents and debris containing radionuclide and chemical wastes into the many steep-sided canyons traversing the Pajarito Plateau. Areas containing these "legacy wastes" are termed "potential release sites" or PRSs. Over 600 PRSs are located within the fire perimeter[3]. Contaminated materials from these sites could be transported by surface-water runoff, which could impact the water quality and sediments of the Rio Grande.

The independent risk assessment is intended to address public concerns over potential health risks due to the transport of contaminants by air and surface water. The risk assessment will analyze the effects and longer-term impacts of the Cerro Grande fire in terms of increased public exposures to radionuclides and chemical toxins and the corresponding health risks. Specifically, the work will address the following issues:

(1) The magnitude and associated risks of public exposure from the Cerro Grande fire created by the transport of radionuclides and chemicals through the air pathway;
(2) The magnitude and associated risks of public exposure to radionuclides and chemicals resulting from potential surface-water pathways;
(3) The lessons that should be documented with regard to monitoring, analyzing, estimating, and reporting risks to the public from radionuclides and chemicals released during and following the Cerro Grande fire; and
(4) Close interaction with the public to report progress and findings and respond to questions from local communities.

The RAC Team will need to access an extensive amount of information before it can begin to perform any assessment of risk. Much of this information exists at LANL where years of environmental monitoring and an extensive post-fire monitoring effort will provide the primary source of data. In addition, both the U.S. EPA and the NMED have monitoring data on select pathways that will be used in the assessment. Data quality will be assessed to assure that outliers or otherwise questionable results don't influence results of the risk modeling.

The risk-assessment is slated to begin in early 2001 and expected to conclude in approximately a year. Results and conclusions will be presented to the public in a report as well as in public meetings. The assessment is funded under an Agreement-in-Principle[4] between the state of New Mexico and the Department of Energy.

FIGURE 1—New Mexico Environment Department staff collect air samples during the Cerro Grande fire.

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Santa Clara Pueblo and the Cerro Grande Fire—Burned Area Emergency Rehabilitation Projects and Fire Restoration Program

by *Jerome Jenkin*s, Santa Clara Pueblo

Post-fire rehabilitation can reduce hazards such as falling snags and prevent property damage and resource degradation from flooding and erosion. After a major fire, a Burned Area Emergency Rehabilitation (BAER) Team is formed to assess fire damage and to implement a rehabilitation plan. BAER teams include specialists from many disciplines such as biology, archaeology, ecology, and geology.

The Cerro Grande BAER Team, formed in May 2000 following the Cerro Grande fire, was the largest BAER effort in the history of the nation. The team included dozens of representatives from federal and state agencies throughout the West.

On June 17, 2000, a BAER project leader was assigned to Santa Clara Pueblo to assist with the Cerro Grande fire BAER projects and to implement emergency treatments specific to Santa Clara.

On July 7, 2000, a contract was signed between the Department of Interior-Bureau of Indian Affairs and Santa Clara Pueblo. The purpose was to expedite transfer of emergency fire rehabilitation funds for immediate emergency treatment implementation.

The 23 projects below are specific to this contract. A brief narrative follows each line item explaining how these projects affect Santa Clara Pueblo. However, it is not all encompassing and should not be taken as such. Also, it does not apply to implemented or planned rehabilitation work within Santa Clara ancestral lands but outside reservation boundaries.

(1) Rehabilitate roads—This project is for the rehabilitation of roads that may have been damaged during the fire. Santa Clara Pueblo has approximately 20 mi of roads that were affected. Additionally, the maintenance and re-grading of roads within the burned area has been complicated by post-fire soil erosion and flooding, and our crew has responded to many mudslides and debris flows in the canyon (south side area included) following summer rainstorms.

(2) Rehabilitate parking, Puye Cliffs—Fire suppression significantly altered the parking lot at the Puye Cliff Dwellings historical visitor center. Approximately 15 acres were bulldozed flat as part of fire operations during the wind-driven Cerro Grande fire. A landscape designer has been hired to rehabilitate the area through transplanting trees, re-grading the parking lot, and implementing soil erosion treatments.

(3) Protect power poles—Sandbags and large boulders have been strategically placed around streamside power poles for protection from potentially damaging floodwaters.

(4) Protect wellhead—Sandbags were filled and placed around a small concrete building that houses an open well. The sandbags divert water around the structure, thereby protecting the building and preventing floodwater from entering an exposed well hole. Balance of funds remains for anticipated rebuilding of damaged or destroyed barriers.

(5) Monitor water quality—Santa Clara Pueblo Environmental Department obtains water-quality samples from Santa Clara Creek six times a year. Our Office of Environmental Affairs uses an ISCO automated surface-water sampler on loan from the State of New Mexico. The samples, analyzed in Albuquerque, include primary organics and primary inorganics.

(6) Monitor grass-seeding effectiveness—The Santa Clara Pueblo Environmental Department contracted Terry Foxx, an independent contractor, to accomplish this activity. Transects have been placed across Santa Clara Pueblo lands, and these sites will be revisited periodically to determine seeding effectiveness.

(7) Monitor invasive plant species—The Santa Clara Pueblo Environmental Department contracted Terry Foxx, an independent contractor, to accomplish this activity. Transects have been placed across Santa Clara Pueblo lands to determine if any invasive plant species have germinated. If monitoring indicates invasive plant species exist, a recommendation for funding to eradicate these species shall be made.

(8) Install safety-hazard signs—Flood warning and safety signs have been paid for and received. The signs are needed for road-danger areas; several signs also measure the depth of rising waters.

(9) Install range fence—The fence runs from north to south, on the east side of Puye. The purpose of the fence is to keep cows and other livestock away from artificial regeneration or planted seedlings. Funds have been obligated for materials, supplies, and wages associated with this activity.

(10) Repair permanent range and boundary fence—A Santa Clara Pueblo hand crew is in the process of rebuilding this fence. This is a very slow and costly procedure because the area is remote and roadless and the materials must be hand carried. Approximately 1 mi of a 5-mi fence has been completed. Snow has delayed this project.

(11) Inventory trails and trail reconstruction—A majority of trails on the south rim of the canyon have been burned out and are inaccessible due to soil erosion and fallen trees. A short hand crew will dedicate itself to cutting new trails, reopening existing trails, and implementing soil-erosion treatments for cultural and fire-suppression purposes.

(12) Clean and replace culverts—Runoff from rainstorms, slope failure, and mudslides clog culverts, which must be cleaned to prevent added deterioration of the culvert and roadbed. Our crew has responded many times to clean clogged culverts immediately after significant rainfall.

(13) Control tree hazard—Periodically, trees become a public safety threat; they are either cut down or bucked up. Our fire rehabilitation crew completes this as needed.

(14) Assess and protect structures—The Sawyer Dam outlet was constructed in accordance with Corps directions. Clearing for the laying of riprap and tree removal from both dikes has been completed. Jersey barriers from the Corps have not yet been received; they are to be placed in front of streamside trailers by tribal crews.

(15) Armor catchment basins—There are several earth dikes that now function as catchment basins for soils and debris. The earth dikes must be reinforced with rock because the amount of water subsequent to the Cerro Grande fire has the potential to erode the dikes.

(16) Install stream control structures—Rock dams are placed inside drainages where water cuts into the banks. Crews have installed many rock dams as weather permits. Heavy rainstorms and day-to-day operations of stream and culvert cleaning have prevented our crew from concentrating on this very effective flood-control measure. Rock dams within Santa Clara Canyon were destroyed by heavy flooding and were rebuilt. We are currently concentrating on drainages negatively affecting the south side canyon road in the hope of mitigating recurring road damage.

(17) Clear stream debris—Many hours have been spent clearing shrubs, rocks, and downed logs from the stream. This prevents debris from forming dams, which can burst, creat-

ing more damage downstream. Clearing the stream also keeps debris from plugging culverts. Rains push debris into the stream from the burned hillsides above, and the stream must be cleaned again. For example, the rains on September 8, 2000, moved large logs down hill and caused huge culverts at the checking gate to become plugged. The plugged culverts then forced the water to flow over the blacktop and erode the downside road bank. Our crew, using a tribal backhoe, cleaned the culverts after the rain ended.

(18) Re-establish CFI plots—Work has started on the re-establishment of CFI plots. Trees are renumbered, stakes are replanted, and reference trees are re-established. Data sheets are used to assist the crew in plot location, and photo points are established.

(19) Assess cultural-resources damage—We will conduct a cultural-resources field inventory of all places disturbed by the fire-suppression activities to identify cultural-resource sites (cultural, historic, and prehistoric) directly affected by the fire. We will inventory previously documented cultural resources within the burned areas to determine damage and site-stabilization needs.

(20) Stabilize archaeological site LA 12700—Prehistoric archaeological site LA 12700 is listed on the National Register of Historic Places. This site must be protected through erosion-control measures to maintain its integrity. We conduct periodic law-enforcement and site-stewardship patrols to evaluate the effectiveness of treatments and to implement needed changes or additional stabilization measures through plan amendments.

(21) Monitor rehabilitation—We monitor implementation of the cultural-resource prescriptions of the BAER plan, as well as implementation of other ground-disturbing BAER plan treatments to ensure cultural-resource compliance and coordination with other agencies.

(22) Coordinate volunteer workers—We provide a Volunteer Coordinator/Public Affairs Officer to coordinate and oversee volunteer, public involvement, and information exchange for the Cerro Grande Fire Rehabilitation Program in cooperation with other agencies.

(23) Clean catchment—We clean out debris and sediment from catchment basins after each storm-flow event. For seven basins, we estimate four storm-flow events per year for 3 years.

The above treatments, specific to the Pueblo of Santa Clara, were identified in the June 2000 Cerro Grande fire BAER plan prepared by the Interagency BAER Team.

Acequia Communities on the Upper Rio Grande: Acequia de Chamita Case

by *José A. Rivera*, Professor of Public Administration, University of New Mexico

The summer of 1998 marked the cuartocentenario (400th year anniversary) of the first Spanish colony in La Provincia del Nuevo México. On July 11, 1598, Capitán General Juan de Oñate arrived in present-day San Juan Pueblo and established the first European settlement in the northern frontiers of New Spain, calling it San Juan de los Caballeros. This initial headquarters for Oñate and his party was probably located on the east bank of the Rio del Norte (now the Rio Grande), near its confluence with the Rio Chama, all in keeping with the requirement of colonial ordinances that settlements should be located in areas with "good and plentiful water supply for drinking and irrigation."

The Oñate colony was located within lands and dwellings already occupied by Tewa Pueblo Indians. For long term occupation, however, Governor Oñate intended to build a Spanish municipality to be named "San Francisco de los Españoles" somewhere near the vicinity of San Juan Pueblo. On August 11, one month after his arrival, Oñate gathered 1,500 Tewa laborers from the area to construct the first Spanish acequia, presumably to irrigate crops that would be needed to sustain the planned city and permanent capital. In most instances, building of a local ditch was the first public works project for any settlement during the colonial period; construction of a church, government buildings, and other structures all awaited the completion of the critical irrigation system.

The acequia that was initiated for use in the town site of San Francisco appears to have been the first Spanish ditch in the New Mexico province. However, there is no historical record as to its ultimate fate or whether it was ever completed. A more certain development was the fact that Oñate soon abandoned plans to build the new town of San Francisco. Instead, he chose the more practical alternative of relocating his colony across the Rio Grande, on the western bank, at the confluence with the Rio Chama. Here he laid out plans (c. 1599–1600) for the villa of San Gabriel, now Chamita, at the location of a smaller and partially abandoned Tewa Pueblo, Yunque. At this second site for a capital city, Governor Oñate simply had to remodel and expand the existing Tewa structures at Yunque. According to historian Marc Simmons (1991), this location was already advantaged with a plaza and some 400 dwellings, a configuration suitable for expansion into a U-shaped village to also accommodate a new church and an attached convento or friary.

While completing these additions at San Gabriel, the colonists also built an irrigation canal, diverted from the Rio Chama, sufficient to irrigate the fields to be cultivated in the fertile valley between the two rivers. Scholars agree that San Gabriel was located in the area now known as Chamita, and most agree that the San Gabriel ditch is the present-day Acequia de Chamita. This recognition probably establishes the Acequia de Chamita as the oldest, still functioning community ditch of Iberian origin in New Mexico, dating to around 1600. For evidence of its early use, scholars often cite a report by Juan de Torquemada, a Franciscan historian who visited the colony in 1612–13, where he observed the practice of irrigated agriculture:

"San Gabriel…is situated at 37° latitude, and its sides consist of two rivers, one of which has less water than the other. This small one [the Rio Chama] irrigates all the varieties of wheat, barley, and corn, in cultivated fields, and other items that are planted in gardens, because those lands produce cabbage, onions, lettuce and beets, and other small vegetables than in this one: producing many and good melons and watermelons. The other river is very large; they call it [Rio] del Norte, which provides a lot of fish…" (Monarquía Indiana por Fray Juan de Torquemada, published in 1615).

San Gabriel remained the capital city of the fledgling province until 1609–1610 when a subsequent governor moved it to its present location at Santa Fe. In 1968, the archaeological site of San Gabriel del Yunque was declared a National Historic Landmark by the United States Department of the Interior. Today, the Acequia de Chamita runs for 3 or 4 mi, and at its upper and middle sections, the acequia irrigates about 485 acres of farmland, serving 83 Hispanic parciante families, many of them descended from the first Oñate settlers. At its lower end, this ancient canal irrigates hundreds of additional acres farmed by the Pueblo of San Juan. Other large ditch systems on the lower Rio Chama include the Hernández and the Salazar Acequias, themselves of colonial origin and historical significance. The Hernández and the Chamita ditches share the same diversion dam, with their head gates on each bank of the Rio Chama (Baxter, n.d.).

Throughout New Mexico, there exist about 1,000 acequias, the majority of them dating to the colonial or early territorial periods. Many acequias enjoy vested rights, meaning that their historic uses of water predate the New Mexico Water Code of 1907 and are among the oldest non-Indian water rights in the state. Acequia associations have become increasingly expert in gathering and presenting a wide array of evidence to defend the antiquity of their customary irrigation practices, making a case for the protection of the historic acequias in the modern era of population growth and the emergence of active water markets (Rivera, 1998). The contributions and significance of acequia agriculture are many:

(1) Following Spanish and Mexican laws, the acequia appropriators evolved customary rules for the administration and equitable distribution of water resources, traditions that continue in effect but that differ in some respects with the hierarchical system of priority calls;

(2) The technology to construct the irrigation systems was a melding of Iberian–Islamic traditions, transplanted from the Mediterranean provinces of Spain to the Americas, with the irrigation practices observed by early Spanish explorers at many Pueblo Indian villages;

(3) The acequia associations of New Mexico are the oldest European-derived water management institutions in the United States, and their autonomous governance establishes them as the oldest grassroots democracies in the U.S.;

(4) The first water laws of the modern state of New Mexico were in fact the "Acequia Laws" of the territorial period, 1851–1852, a codification of customs and traditions that evolved from the Spanish colonial and Mexican periods;

(5) The acequia associations function as "water democracies" at the local level, and they also enjoy a unique standing as political subdivisions of the state of New Mexico, unlike their counterparts in the other western states;

(6) Located upstream in the major rivers and tributaries, acequias often are the first points of diversion of headwaters' streams, underscoring their stewardship role in protecting forest ecosystems and pristine waters for use by other stakeholders downstream;

(7) As earthen irrigation canals, the acequias extend the riparian zones, preserve hydraulic landscapes, and increase ecological biodiversity for plant and wildlife species (including the willow flycatcher);

(8) After 400 years of successful adaptation, the acequias of the upper Rio Grande are model institutions worthy of further

research as to their historic, cultural, economic, and ecological value to the state as a whole;

(9) The acequia villages perpetuate cultural continuity, a sense of place, and participatory democracy, values that need to be considered when weighing and comparing their contributions against other uses; and

(10) The acequia culture of the region promotes tourism and economic development in the state of New Mexico by way of the quaint village architecture, the greenbelts, and open space that define the landscapes of the river valleys, and the production of renowned arts and crafts marketed worldwide.

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What Decision Makers Should Know About Collapsible Soils in New Mexico

by *David W. Love*, New Mexico Bureau of Mines and Mineral Resources

FIGURE 1—Ground subsidence of 2.2 ft affecting an area of 600 ft^2 after injecting nearly 17,000 gallons of water into the soil at a depth of 10 ft over 16 days (water equivalent to septic tank use by a family of four for 1 month). Collapse was initiated within 1 week.

Collapsible soils are soils that compact and collapse after they get wet. The soil particles are originally loosely packed and barely touch each other before moisture soaks into the ground. As water is added to the soil in quantity and moves downward, the water wets the contacts between soil particles and allows them to slip past each other to become more tightly packed. Water also affects clay between other soil particles so that it first expands, and then collapses like a house of cards. Another term for collapsible soils is "hydrocompactive soils" because they compact after water is added. The amount of collapse depends on how loosely the particles are packed originally and the thickness of the soil that becomes wetted. In one area of El Llano on the east side of Española, one collapse-crater feature was 150 ft across and 5 ft deep in the center. The loose soil originally was more than 50 ft thick. Its collapse literally split and tilted the foundations of two homes and threatened two more. The addition of water to the naturally dry soil was caused by a septic tank, a leaky municipal water line, runoff from roads, and runoff from the roofs of the houses nearby. Several other houses and other facilities in the same neighborhood were affected by addition of water near their foundations.

Collapsible soils are common in New Mexico. They have caused millions of dollars of damage to public facilities such as schools, highway maintenance buildings, jail facilities, water tanks, roads, and other infrastructure. Housing developments from Velarde to Las Cruces and from Alamogordo to Socorro have been subject to collapsible soils. Collapsible soils are likely to continue to plague unsuspecting homeowners. They have damaged some homes to the point of condemnation. Several would-be homeowners have had their houses condemned and have had to continue paying mortgages on houses that they can not live in nor repair. Developers have had to buy houses back from would-be homeowners after foundations were ruined by collapsible soils.

Collapsible soils develop on valley margins where soil particles move from the foothills toward the valleys. They commonly accumulate to tens of feet thick. As New Mexico's population has moved out of the well-watered and irrigated valleys with compact soils to develop the valley margins and foothills, the collapsible soils have made their presence known as the newcomers add water to the drier soils.

What Can Property Owners Do?

In areas that have not been developed, soils should be tested for collapsibility as well as other problems (shrink-swell potential, corrosiveness, and depth to bedrock). If collapsible soils are found, thin amounts may be removed and compacted with heavy machinery. If collapsible soils are thick, large tracts may be settled by prewetting the soils to depth before development takes place. Road right-of-ways may be compacted by repeatedly dropping heavy weights from a large crane along the route.

In areas that have already been developed and then are discovered to have collapsible soils, property owners should try to keep as much water as possible from seeping into the ground. This means xeriscaping rather than watering lawns and shrubbery, particularly near building foundations; installing municipal water and sewer lines rather than individual wells and septic tanks; and installing downspouts and storm-sewer lines to remove rainfall runoff from the area as quickly as possible. New foundations should follow construction guidelines of the Building Research Advisory Board (BRAB), developers of the BRAB slab, a reinforced "waffle-like" foundation that also prevents damage from shrink-swell soils. Pylons not on solid subsurface materials and "slurry jacking" do not work in collapsible soils.

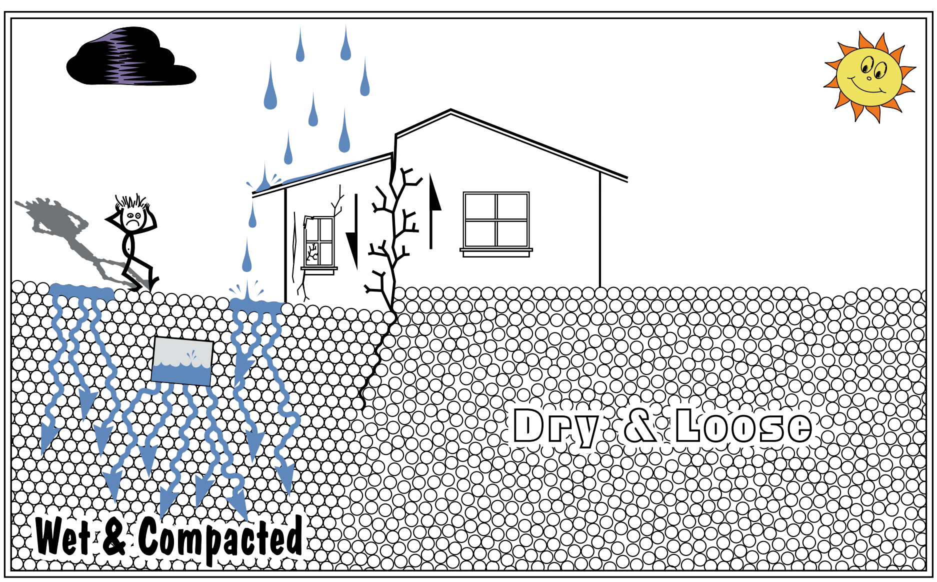

FIGURE 2—Cartoon of loose, dry soil supporting a house versus soil collapse due to the addition of water by runoff, septic tank, and irrigation.

What Can Geologists, Engineers, and Soil Scientists Do?

Collapsible soils may be suspected in undeveloped areas that have young, accumulating sandy and silty soils in dry areas. The soils may be confirmed to be collapsible through engineering testing. These tests include study of seismic waves through the soils, rates of drilling through the soils (blow counts), and testing undisturbed soil samples obtained by careful drilling for compaction after wetting. Unfortunately, these tests are expensive for individual property owners. Scientists need to develop better, less expensive ways of determining the extent of collapsible soils in the subsurface. Developers are required to file soil-engineering reports before development, but often tests for collapsible soils are not performed, and homebuyers rarely look at soil-engineering reports. More publicity about the presence of collapsible soils in New Mexico would help make the public more aware of the problem and make property sellers more apt to test and treat problem soils before they become a problem. It should be noted that collapsible soils are not the sole cause of surface subsidence in New Mexico; several other natural and human-caused processes may also cause the ground to collapse.

What Can Decision Makers Do?

The dilemma for decision makers is how to balance the protection of would-be buyers and users of property from the devastation of problem soils against the undue burden of expensive testing of soils regardless of the property's location. Some municipalities and counties have zoning restrictions that may aid in limiting some uses of some property or in requiring xeriscaping in developed areas that have experienced collapsible soils. All construction of public facilities should have proper subsurface testing and evaluation done before bidding takes place, and supervision of the site during the building phase. Xeriscaping makes sense for foundation safety regardless of the availability of water and rainfall runoff. Decision makers should insist on non-leaky waterlines and better municipal sewer and drainage systems to remove rainfall runoff from problem neighborhoods.

Where Can I Get More Information?

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The Rio Grande Compact in New Mexico and the San Juan–Chama Project

New Mexico Interstate Stream Commission, presented by Rolf Schmidt-Petersen, Hydrologist

The Rio Grande Compact was signed in Santa Fe, New Mexico, in 1938, following more than a decade of negotiations and four decades of controversy over the relative shares of three states (Colorado, New Mexico, and Texas) and two countries to this desert river.

The compact was developed for the purposes described in its introduction: "to remove all causes of present and future controversy among these States and between the citizens of one of these States and citizens of another State with respect to the use of the waters of the Rio Grande above Ft. Quitman, Texas"; "for the purpose of effecting an equitable apportionment of such waters"; "for interstate comity."

The apportionment of water under the Rio Grande Compact reflects uses at the time it was being negotiated. Large-scale irrigation systems were developed in the San Luis Valley in Colorado in the late 1800s. The Rio Grande Project, including Elephant Butte Reservoir, was developed by the Bureau of Reclamation to serve more than 155,000 acres of irrigated land in New Mexico and Texas. Most of this irrigated land (57%) is in New Mexico. In contrast, acequias in the middle Rio Grande in New Mexico were irrigating approximately 40,000 acres, far less than Colorado and the Rio Grande Project. The Rio Grande Compact does not affect the obligations of the United States to Indian Tribes nor impair their rights.

The obligation of New Mexico to deliver water to Texas under the Rio Grande Compact is based on flow conditions measured at the Otowi gage located near Otowi Bridge. New Mexico's maximum annual allocation of the native water that passes Otowi gage is 405,000 acre-ft (Fig. 1). New Mexico is obligated to deliver the remaining portion of the annual Otowi gage inflow to the base of Elephant Butte Dam. Under the compact delivery schedule, the percentage of Otowi flow that must be delivered at Elephant Butte increases with increasing water supply, ranging from 57% in low-water years to 86% in high-supply years. Thus, when the annual flow of the Rio Grande at Otowi gage is very low, New Mexico may consume 43% of that water and must deliver the remaining 57% to below Elephant Butte Dam. When the annual flow of the Rio Grande at Otowi gage is very high, New Mexico may consume only 13% of that water and must deliver the remaining 87% to below Elephant Butte Dam. In an average year, when 1.1 million acre-ft of Rio Grande water flow past the Otowi gage, New Mexico is entitled to consume 393,000 acre-ft of that amount (Fig. 2). If depletion of Rio Grande flows in New Mexico above the Otowi gage changes, the Otowi "index" flow must be adjusted accordingly. However, no adjustments of this nature have been needed.

New Mexico is also allowed to consume all tributary inflows to the Rio Grande between Otowi gage and Elephant Butte Dam. This includes flows from the Rio Jemez, the Rio Salado, the Rio Puerco, Galisteo Creek, and the Santa Fe River. Tributary inflows are highly variable, but in an average year total about 100,000 acre-ft plus an unknown, small amount from minor ungaged tributaries (Fig. 3). Water imported from the Colorado River basin, including the San Juan–Chama Project supply, is not subject to Rio Grande Compact apportionment (Fig. 3).

New Mexico's deliveries are measured as the releases from Elephant Butte Dam plus the change in storage in Elephant Butte Reservoir. Evaporation from Elephant Butte Reservoir is accounted against New Mexico's compact allocation of Rio Grande water.

The compact requires annual water accounting and provides for a system of annual debits and credits. Figure 4 presents New Mexico's historical compliance with its Rio Grande Compact delivery obligations. During the 1990s New Mexico had a net credit and that situation continues today. However, as you can see from the figure, it is not the usual historical situation. New Mexico may accumulate up to 200,000 acre-ft of debits in its deliveries to Elephant Butte Dam. Water must be retained in storage in reservoirs constructed after 1929 to the extent of each state's respective debits and cannot be used. It must be released upon demand by the downstream states under conditions specified in the compact. Reservoirs constructed after 1929 in New Mexico include El Vado Reservoir (owned by the Middle Rio Grande Conservancy District) and Nichols and McClure Reservoirs, which provide a large portion of the Santa Fe municipal water supply. If storage in Elephant Butte Reservoir is less than 400,000 acre-ft, neither Colorado nor New Mexico may increase the amount of water stored in reservoirs constructed after 1929.

Spills from Elephant Butte and Caballo Reservoirs are an important element of the compact. Credit water spills first. Debits are reduced as the reservoirs approach full capacity to the point of elimination when the reservoirs are completely full. Normal total releases from Elephant Butte and Caballo Dams are defined as 790,000 acre-ft/yr. Releases in excess of that amount affect the calculation of spills.

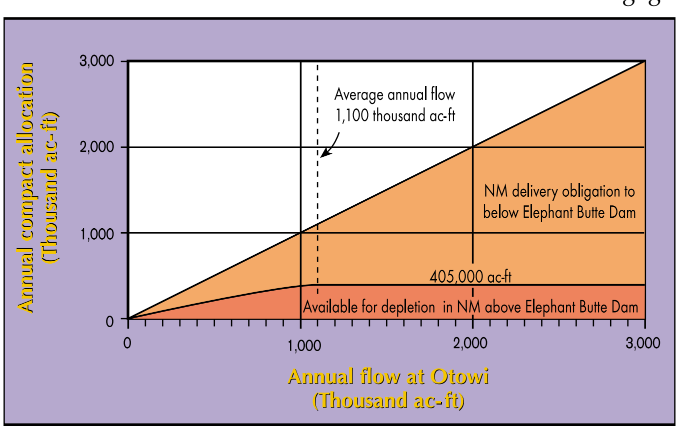

FIGURE 1—The Rio Grande Compact, signed in 1983 in Santa Fe, New Mexico, apportions the Rio Grande water supply between Colorado, New Mexico, and Texas based on flow conditions at Otowi gage.

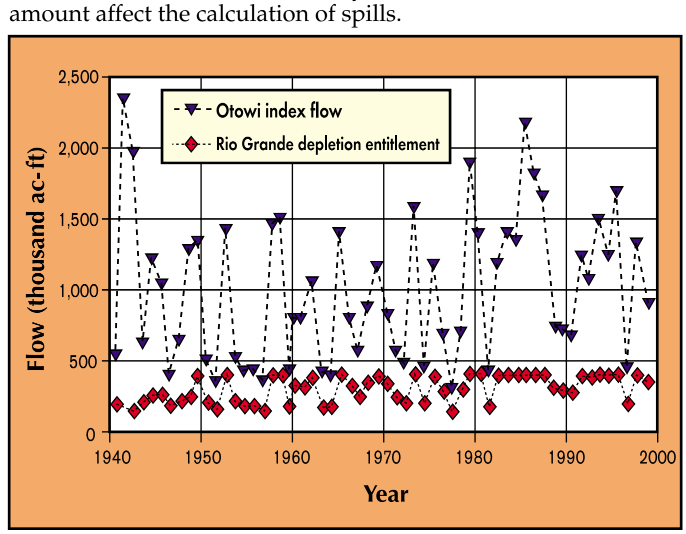

FIGURE 2—New Mexico's share of the native flow of the Rio Grande at Otowi gage.

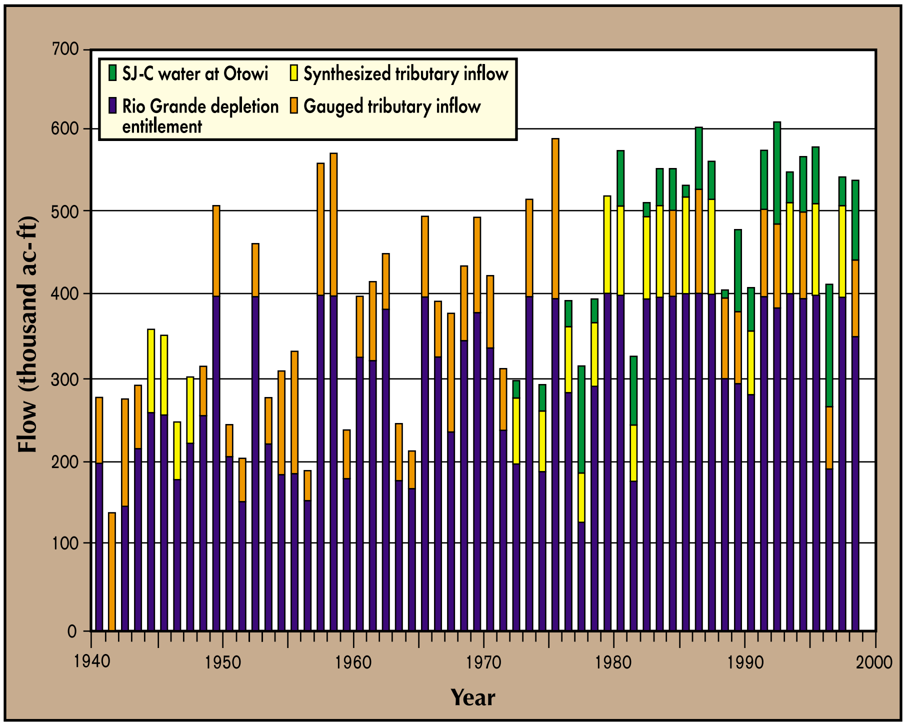

FIGURE 3—New Mexico's total available water supply (1940–1998) from the Rio Grande, tributary inflow, and San Juan–Chama Project supply.

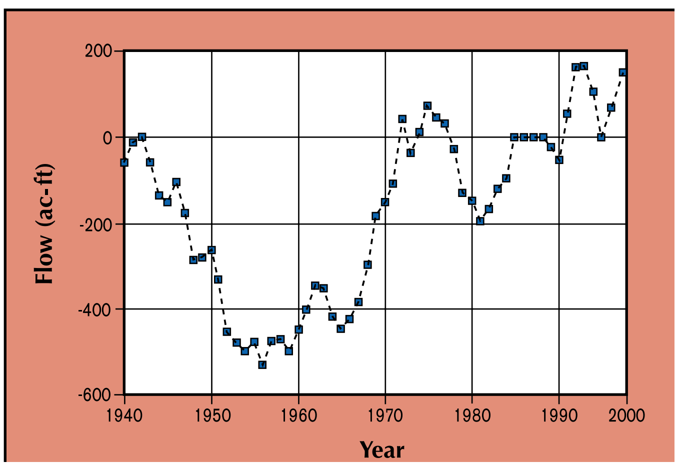

FIGURE 4—New Mexico's Rio Grande cumulative compact delivery (1940–1998).

TABLE 1—Water allocated and contracted by the San Juan–Chama Project.

Entity	Allocation (acre-feet)
City of Albuquerque	48,200
Middle Rio Grande Conservnacy District	20,900
Jicarilla Apache Tribe	6,500
City of Santa Fe	5,605
County of Los Alamos	1,200
Pojoaque Valley Irrigation District	1,030
City of Española	1,000
City of Belen	500
Town of Bernalillo	400
Village of Los Lunas	400
Town of Taos	400
Town of Red River	60
Twining Water and Sanitation District	15

San Juan–Chama Project

The San Juan–Chama Project is a trans-basin diversion that was authorized in 1962 by Public Law 87-483 to divert an annual average of 135,000 acre-ft/yr of Upper Colorado River basin water allocated to New Mexico under the Upper Colorado Basin Compact into the Rio Grande basin for use in New Mexico. The water is diverted from tributaries to the San Juan River and brought through a tunnel across the continental divide to the Rio Chama drainage, where it is stored in Heron Reservoir until it is released to its New Mexico contractors. Further storage of San Juan–Chama Project water in Abiquiu and Elephant Butte Reservoirs was authorized in 1981 by Public Law 97-140.

Diversions from the San Juan River basin by the San Juan–Chama Project in any given year are limited by the available water supply. The project has three diversion points, all in Colorado, one each on the Blanco River, the Little Navajo River, and the Navajo River. The diversions are administered so as not to deplete minimum bypass flows required for the preservation of fish and aquatic life in the Blanco and Navajo Rivers.

San Juan–Chama Project water is contracted by the U.S. Bureau of Reclamation (USBOR) based on allocations recommended by the New Mexico Interstate Stream Commission. San Juan–Chama Project water has been allocated and contracted to the following entities in the amounts shown in Table 1.

In addition, 2,990 acre-ft of water has been reserved for the Taos area for possible settlement of water rights claims of Taos Pueblo and 2,000 acre-ft for San Juan Pueblo. An additional 5,000 acre-ft is used to offset annual evaporative losses to the Cochiti Lake recreational pool, as authorized by Public Law 88-293. These allocations represent the entire firm yield of the San Juan–Chama Project of 96,200 acre-ft.

Each year's allocation of San Juan–Chama Project water must be released from Heron Reservoir within the calendar year unless a waiver is requested from and granted by the USBOR. The project water can only be released from the reservoir upon request of the above contractors, and the water must be beneficially used in New Mexico.

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Rolf Schmidt-Petersen is the Albuquerque Office Manager for the New Mexico Interstate Stream Commission (NMISC), New Mexico's water planning and development agency. His responsibilities on the Rio Grande include investigation, development, conservation, and protection of Rio Grande water resources, interstate stream compact administration and compliance, and resolution of interstate and federal water resource issues affecting Rio Grande water resources. Before joining the NMISC staff, Mr. Schmidt-Petersen worked in New Mexico as a consulting hydrologist on many projects ranging from the investigation and remediation of ground-water contamination, characterization of landfill seepage, and development of mine land closure plans. His current interests include developing a better understanding of surface water/ground-water interactions and riparian and open-water evapotranspiration along the Rio Grande.

The San Ildefonso Pueblo Collector Well Pilot Project

by *Jack Frost*, Santa Fe County Hydrologist, 1996–2000; and
Estevan Lopez, Santa Fe County Land Use Administrator

San Ildefonso Pueblo and the city and county of Santa Fe are partners in an experimental collector well to divert water from the Rio Grande. This is one of two projects to access surface water. The city and the county are also evaluating a surface diversion from the river at Buckman Springs well field, about 4 mi south of Otowi Bridge. The collector well site lies approximately 1,000 ft north of the bridge (NM–502) on the east side of the Rio Grande (Fig. 1). First evaluated in 1984 by Public Service Company of New Mexico (PNM) and the Bureau of Indian Affairs (BIA), collector well feasibility to access the Rio Grande is finally being tested.

Collector wells (also known by the proprietary name "Ranney wells") are large diameter caissons containing horizontal wells beneath the level of and aimed toward the river (Fig. 2). About 25 ft of permeable channel sediment lies beneath the river at the test site. Rio Grande water quality is poor and varies seasonally. Collector wells are an alternative to expensive surface-water diversion and treatment structures. Pumping at the collector well induces flow from the river through the streambed, using the filter function of the sediment to enhance water quality. Well yield is sensitive to stream flow, water temperature, and turbidity. Hopefully, the resulting water quality will be stable and clean enough that only disinfecting will be necessary.

Direct diversion of surface water from the Rio Grande could help relieve part of the demand on local ground water, currently the primary source of water in the region. Available water rights to Rio Grande water include the city and county joint contract for San Juan–Chama water, Native American rights, and potential rights transferred to the wells. Coincidentally, the project lies north of the Otowi stream gage, whose measurements determine New Mexico water deliveries to Texas and Mexico under the Rio Grande Compact. Pre-compact water rights, including pueblo rights, consumed above the gage decrease New Mexico's delivery requirements south of Elephant Butte. The site also lies upstream of watersheds draining Los Alamos and is thus isolated from associated water-quality concerns.

Environmental studies have been completed, and plans for the test project appear acceptable. The environmental, visual, and noise impacts of construction and the resulting structure can be mitigated. All phases of the project are subject to oversight by the San Ildefonso Pueblo Environment Department.

Test drilling on the project was conducted in 1999, and a yield of 1 million gal/day is expected. The next phase will construct a pilot collector well and conduct testing over a variety of conditions for several seasons. Stored city San Juan–Chama water will be used for testing.

The current agreement between the parties only covers the pilot well. The city, county, and pueblo will each retain an ownership interest in the completed pilot well. The pueblo has its own water supply needs, as the shallow valley-aquifer-water quality has degraded over the years. Santa Fe County has expressed an interest in taking a share of water to serve the greater Pojoaque Valley and to address water-quality concerns at several traditional communities and pueblos. This possibility might resolve some of the sticky issues of the Aamodt federal water rights lawsuit, which has clouded water rights and development in the Pojoaque, Nambe, and Tesuque River basins for many years.

If the pilot confirms feasibility, new negotiations with San Ildefonso Pueblo are necessary to develop subsequent collector wells. The city of Santa Fe plans require the ultimate development of multiple collector wells, each producing 1,000+ acre ft/yr. Water would be transported 6 mi to the south to link up with Buckman Springs well field and the existing 16-mi pipeline to the city. If successful, this project, coupled with a return flow pipeline at Buckman Springs, could help satisfy water needs for the greater Santa Fe metropolitan area for 40 years.

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Environmental Assessment, 1984, Proposed Ranney Collector Project at San Ildefonso, New Mexico: BIA.

Feasibility Study for Rio Grande Diversion System, 1997: Boyle Engineering.

Environmental Assessment for the Rio Grande Infiltration Collector Well

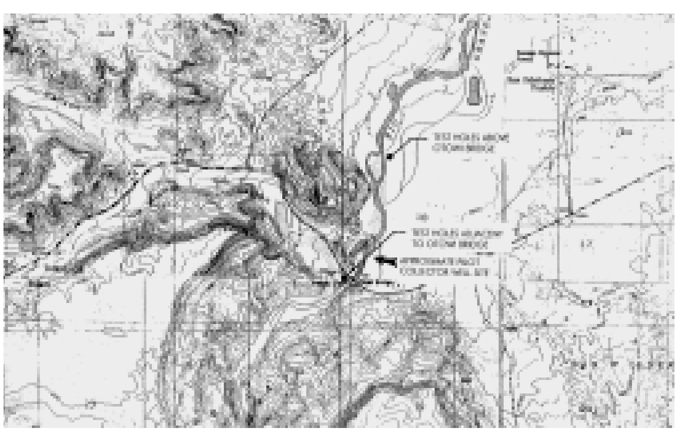

FIGURE 1—Site of San Ildefonso Pueblo collector well pilot project.

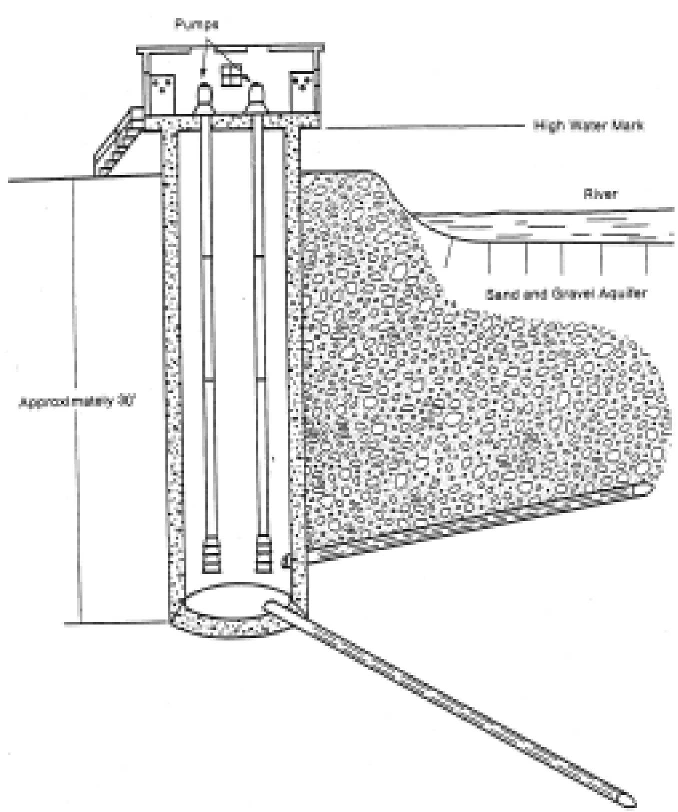

FIGURE 2—Collector well schematic diagram.

Demonstration Project at San Ildefonso Pueblo, 2000: BIA.

Contacts

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