Appendix 4a - Río Jemez

1. This field guide is included becaus it contains quality information on the geological history of the region, particularly the Río Jemez.

http://www.solutionmining.org/M01F/Rautman%20-%20M01F%20Field%20Trip%20to%20Jemez%20Mountains.pdf

2001 Solution Mining Research Institute Fall Meeting Field Trip
Touring Guide to the Jemez Mountains page 1 October, 2001

A Geologist's Touring Guide to the Jemez Mountains

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prepared for the
Solution Mining Research Institute, 2001 Fall Meeting
Albuquerque, New Mexico
October 10, 2001

This field trip will provide a brief and somewhat informal overview of the volcanic geology of the Jemez Mountains of north-central New Mexico, including the geology and landforms of the Valles Caldera, the Bandolier Tuff, and the underlying volcanic edifice that forms the more expansive Pajarito Plateau and surrounding volcanic highlands. The trip also highlights some of the more obvious features of the geology between the city of Albuquerque and the Jemez Mountains on the way north and between the Jemez Mountains, the city of Santa Fe, and Albuquerque on the return journey.

In addition to providing spectacular, classic northern New Mexican scenery, the Jemez Mountains are interesting in that they provide an example of an accessible, smaller-scale, and less-complex caldera- and outflow-facies pyroclastic-tuff environment similar in many respects to the geologic environment present at Yucca Mountain, Nevada. A remote location at Yucca Mountain, roughly 100 miles northwest of Las Vegas, Nevada, has been proposed as the site of the first high-level nuclear-waste repository in the U.S. Although there are many differences in detail between the two locations, the basic geologic principles revealed in the volcanic rocks are essentially identical.

Geological Overview

The field trip begins in Albuquerque (figure 1) and proceeds northward along the eastern portion of the Rio Grande Valley, which occupies an asymmetrical rift valley extending from the vicinity of El Paso, Texas, to as far north as Leadville and Climax, Colorado. The steep escarpment of the Sandia Mountains is to the east of the rift, whereas to the west, a large number of stairstep-like normal faults forms the opposite side of the rift-graben structure. The trip crosses the Rio Grande at the town of Bernalillo, and proceeds westward across Quaternary to Recent fluvial sediments of the ancestral Rio Grande to the very western structural margin of the rift. Mesozoic sedimentary rocks of the Colorado Plateau geologic province bound the rift to the west at this location.

Near the town of San Ysidro, the trip turns northwards, and follows San Diego Cañon through the Pueblo of Jemez. The Jemez River in this region flows essentially along a major normal fault forming the eastern escarpment of the Nacimiento uplift. The Nacimiento Mountains expose a colorful sequence of Upper Paleozoic sediments, particularly redbeds, overlying Precambrian granitic and metamorphic basement rocks.

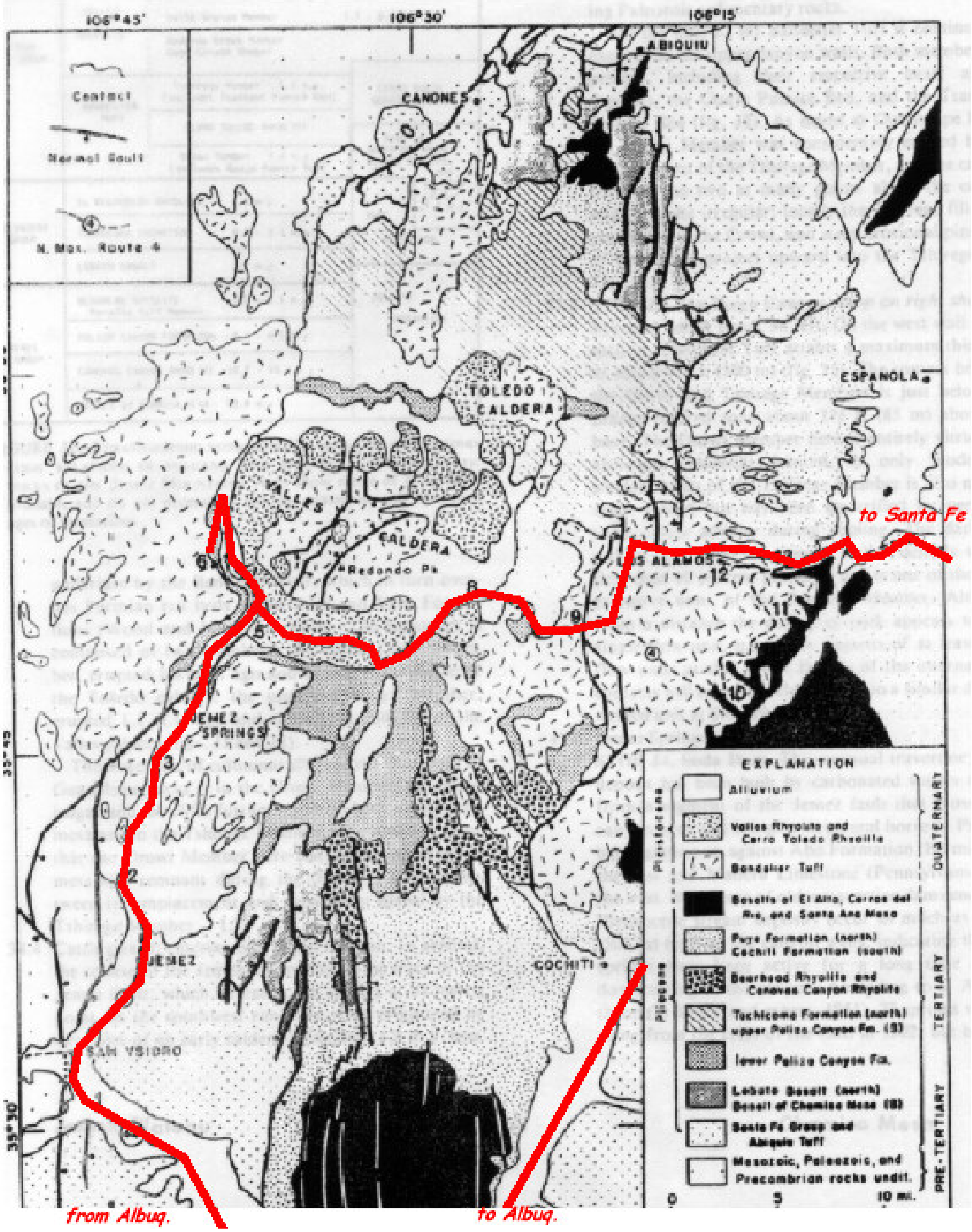


Figure 1. Index/location map showing north-central New Mexico, with general geographic features and the route of the touring guide (heavy line).

Outflow facies of the Quaternary rhyolitic Bandolier Tuff are exposed in the higher parts of the canyon walls in the upper reaches of San Diego Cañon. The unconformable contact between the white tuffaceous rocks and the dark-red underlying sediments is spectacular. The Bandolier Tuff consists of two major pyroclastic flow deposits and ancillary air-fall tuffs and other rocks produced by two major eruption/caldera-collapse sequences that formed the present day Valles Caldera.

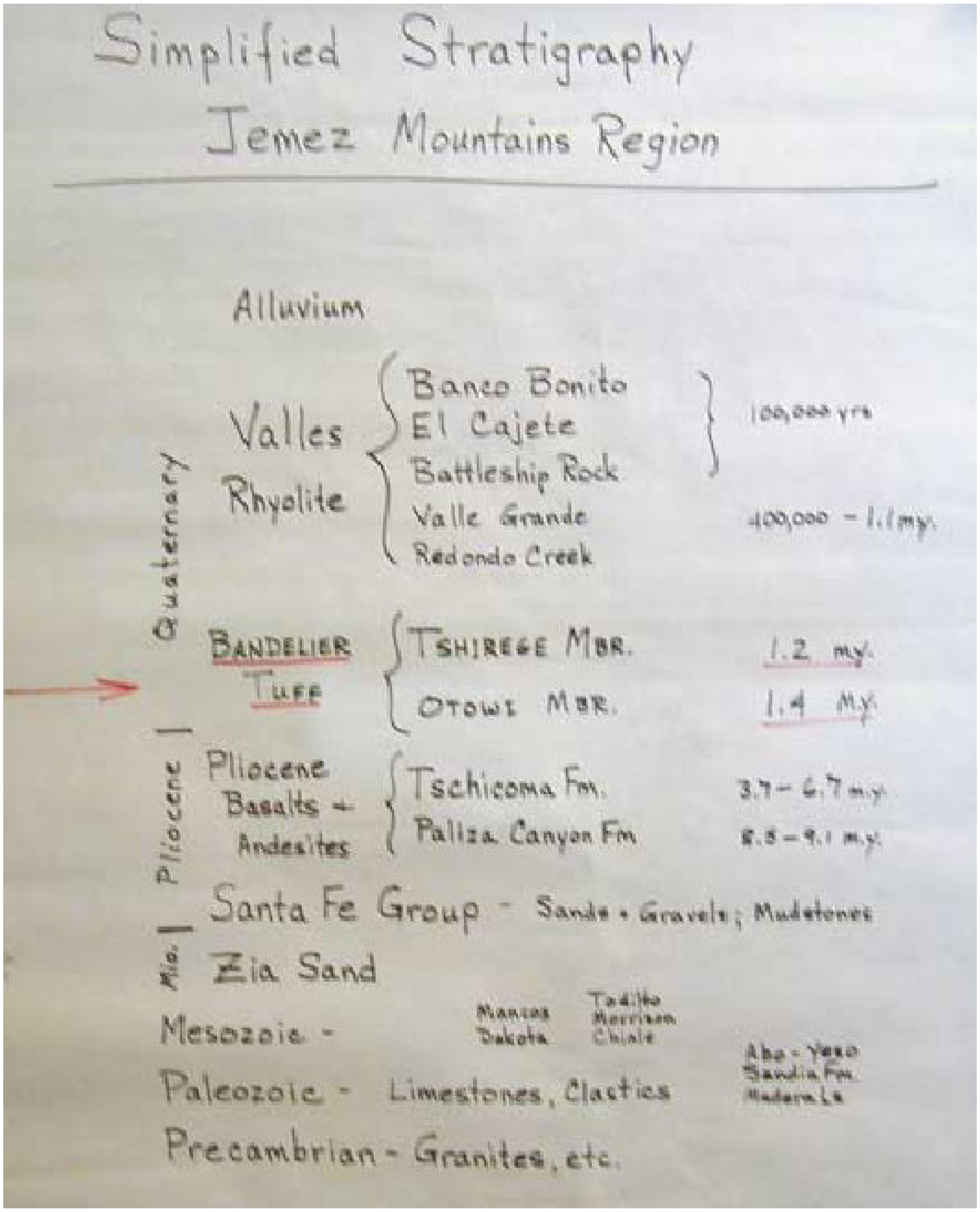
The trip ascends the valley of the Jemez river and reaches the moat of the caldera, which is a more-or-less annular valley surrounding the central portion of the volcanic-collapse structure. The moat is generally excavated along the trace of the ring-fracture zone, along which the majority of the post-eruptive collapse (due to withdrawal of magma) occurred. At locations around the moat, post-main-eruptive rhyolite domes have been extruded, representing degassed remnants of the original magma that formed the pyroclastic deposits of the Bandolier Tuff.

A side trip to the top of the western external wall of the caldera moat provides a spectacular overview of the moat/ring-fracture zone; Redondo Peak, the central resurgent dome of the caldera formed by late-stage re-uplift of the collapsed structural block; and some of the late-stage rhyolite domes. The trip then proceeds eastward essentially along the ring-fracture zone and passes the southern margin of the Valle Grande, a large open meadow region that preserves a large area of the structurally low central collapse region. The trip then climbs out of the caldera proper, traverses older, more mafic volcanic rocks of the pre-caldera eruptive sequence, and descends to the broad-though-deeply-incised Pajarito Plateau, which again is directly underlain by the outflow facies of the Bandolier Tuff. The most abrupt part of the descent crosses the Pajarito Fault, one of the major rift-bounding faults in this region.

The Pajarito Plateau is home to both Bandolier National Monument and Los Alamos National Laboratory. The highway passes through regions that were extensively burned in 2000 by the Cerro Grande Fire, a controlled burn that “got away” due to a combination of drought conditions and unexpected high winds. The Cerro Grande Fire devastated much of the eastern flank of the Jemez Mountains, including portions of the city of Los Alamos.

From Los Alamos, the trip descends through the Bandolier Tuff, basaltic lava and tuffs, volcanic fanglomerates and lithic tuffs, and finally arkosic sands of the ancestral Rio Grande. We cross the Rio Grande at Otowi Bridge, and proceed eastward and southward to Santa Fe, traversing through Quaternary sediments of the Santa Fe Group (broadly defined). The high mountains to the east are the southernmost portion of the Sangre de Cristo Range, and they comprise significant exposures of Precambrian granitic and metamorphic basement rocks and a Paleozoic sedimentary sequence quite different in some respects from the Colorado Plateau sequence to the west of the Rio Grande Rift.

From Santa Fe, the trip follows Interstate Highway 25 across a high basaltic plain. The igneous intrusive centers of the Cerillos Hills (famous for turquoise deposits in Spanish times) and the Ortiz Mountains are to the south of the highway. The trip descends the abrupt, basalt- flow-capped escarpment of La Bajada through Upper Paleozoic redbeds, and then follows the eastern margin of the Rio Grande Rift through various Quaternary sediments back to Albuquerque. A very-much simplified stratigraphic column relevant to this field trip is presented in figure 2


Simplified Stratigraphy
Jemez Mountains Region

	Alluvium		
Quaternary	Valles Rhyolite	Banco Bonito El Cajete Battleship Rock	100,000 yrs
		Valle Grande Redondo Creek	400,000 – 1.1 my.
	Bandelier Tuff	Tshirege Mbr.	1.2 my.
		Otowi Mbr.	1.4 M.y.
Pliocene	Pliocene Basalts + Andesites	Tschicoma Fm.	3.7 – 6.7 m.y.
		Paliza Canyon Fm	8.5 – 9.1 m.y.
	Santa Fe Group – Sands + Gravels; Mudstones		
Mio.	Zia Sand		
	Mesozoic –	Mancos Dakota Todilto Morrison Chinle	
	Paleozoic – Limestones, Clastics		Abo – Yeso Sandia Fm. Madera Ls
	Precambrian – Granites, etc.		

Figure 2. Simplified (very!) stratigraphy of the Jemez Mountains region.

Road Log North of Albuquerque

Leave hotel; access Interstate-25 northbound.

The Sandia ("watermelon") Mountains form the eastern skyline. North Sandia Peak is the location of the numerous radio and television antennae. The north peak is also the location of the "World's Longest Tramway." Bear Canyon forms a reentrant towards the east, and separates North Sandia Peak from South Sandia Peak.

The Albuquerque volcanoes form the close skyline to the west. These are a series of small basaltic cinder cones and spatter vents that are aligned north-south along a fracture zone that forms part of the western margin of the Rio Grande Rift. Mount Taylor, an alkaline, composite stratovolcano, forms the high skyline in the distance.

To the north and slightly to the west of the highway alignment are the Jemez Mountains. Redondo Peak is the prominent peak in the center skyline. The Nacimiento uplift is the somewhat discrete range to the west of the Jemez volcanic highland.

Pass Sandia Pueblo Hotel and Casino to the east.

Indian gaming is now big business in New Mexico. Although there may be valid objections to promotion of widespread, commercialized gambling as a form of entertainment in a society, it is clear that some of the pueblos and other tribes in New Mexico have reaped tremendous economic advantages from this locally controlled source of revenue.

Note on Pueblo Cultures and Relationships

The Pueblo peoples, together with several other native groups, form the one of the bases (the oldest!) of the Three Cultures for which New Mexico is famous and which create our unique State. The others, of course, are the Hispanics (dating back to Spanish Colonial times) and the late-arriving Anglos. With the exception of Zuni Pueblo, which is located near the Arizona border south of Gallup, New Mexico, all of the Pueblo peoples now live along the Rio Grande and its tributaries.

Also with the exception of the Zuni, the Pueblo people speak (originally) one of four principal languages: Tiwa, Tewa, Towa (believe it or not!; collectively derived from a common base known as Tanoan), or Keresan. Although the different language groups are now diversely scattered, all Pueblo peoples were originally primarily agricultural. Indeed, the entire concept of a “pueblo” or town implies a settled lifestyle, in contrast to the more nomadic lifestyle of some of New Mexico’s other native peoples: the Navajo or Apache, for example.

Sandia Pueblo is a remnant of several once-thriving agricultural communities scattered up and down the middle Rio Grande in the vicinity of present-day Albuquerque. The Pueblo has probably been in its current physical location since at least the year 1300. Sandia is one of four Tiwa-speaking (along with Spanish and English) pueblo settlements.

Rincon Ridge, the sharp mid-level ridge closer than the Sandia Mountain skyline, is a resistant mass of Precambrian metamorphic rocks. Note the many cross-cutting aplite and pegmatite dikes. This feature is sometimes known locally as “pegmatite ridge.”

I-25 traverses pinkish sediments of the Santa Fe Group. These are essentially fluvial deposits of the ancestral Rio Grande, and local coarse-sand and gravel deposits are extremely valuable for concrete and aggregate. There are numerous sand-and-gravel quarries along this part of the route; some are still operational.

North Bernalillo Exit; turn west onto U.S. Highway 550, formerly known as New Mexico Highway 44.

The large industrial complex northwest of the interchange is a gypsum wallboard plant, which makes sheetrock from gypsum deposits mined in the Todilto Formation (Jurassic), some distance to the west.

Cross the Rio Grande — Note for gringos: “Rio Grande” is “big (or great) river,” so “Rio Grande River” is “River Big River.” Likewise, “La Fonda” is “the hotel,” so “the La Fonda Hotel” (on the plaza in Santa Fe) is “the hotel The Hotel.”

Note tilted flat topographic surfaces to the north of the highway. These surfaces represent a number of small fault blocks containing Santa Fe Group sediments overlain by thin, resistant basalt flows. From the air, a whole sequence of these minor fault blocks can be distinguished. An interesting basaltic eruptive center is also preserved a few miles to the north and west of the highway interchange

Pass road to Coronado State Monument, home to an Anazazi- or transitional-age well preserved abandoned pueblo and kiva.

Pass Santa Ana Pueblo Hotel and Casino to the north (“Santa Ana Star”).

Santa Ana Mesa to north continues the fault-block geology of Santa Fe Group sediments overlain by thin basalt flows. Sprawl development of Rio Rancho, New Mexico on Santa Fe Group sediments to the south of the highway.

Santa Ana Pueblo is one of the Keresan-speaking language groups. The original location of the pueblo is not known, as all members of the community either left or were killed during the Pueblo Revolt of August 10, 1680, a simultaneous uprising of virtually all the Pueblo people against oppressive Spanish Colonial rule. After the reconquest of New Mexico by the Spanish in 1692-94, the present Santa Ana Pueblo was established in its present location.

Climb out of the Rio Grande Valley to the west. Subsurface geology here is a number of east-dipping normal faults displacing buried Mesozoic and Paleozoic sediments and completely obscured by Quaternary deposits. The vertical displacement along the Sandia Mountain front is distributed over at least 15-20 miles on this side of the rift graben.

Various views of badland topography cut in sediments of the Santa Fe Group.

Pass Zia Pueblo to the north.

The Zia are a people of the Keresan language group, although because of their relative western location, a non-trivial number of members of Zia Pueblo also speak Navajo in addition to Spanish and English. The ancient sun symbol of the

Zia ("tsia") has been "appropriated" as the design for the New Mexico State Flag, and it is the quintessential representation of the Land of Enchantment in many minds.

Note that we are now approaching the western margin of the Rio Grande Rift and of the Quaternary sediments of the Santa Fe Group.

Approaching San Ysidro, New Mexico; highway will curve to the right (north).

White Mesa due west of the major curve in the highway. "White" Mesa is capped by massive gypsum deposits of the Todilto Formation; it is this gypsum that is being mined for wallboard production in Bernalillo. The white gypsum overlies a much thinner dark layer (where not obscured by mining spoil) that is the limestone unit of the Todilto Formation. Much farther to the west, the gypsum portion of the Todilto is absent, and the limestone unit is much thicker. Many of the earliest uranium deposits mined in the Grants Uranium Region during the 1950s were in the Todilto Limestone. The white-and pink Entrada Sandstone (Jurassic) is exposed in the lower portion of White Mesa, and the lowermost slopes are cut on softer shales of the Triassic Chinle Formation of Painted Desert fame in Arizona.

Below and between White Mesa and the highway are variegated shale and sandstone of the Jurassic Morrison Formation overlain by the Cretaceous Dakota Sandstone, a distinctive marker for the lowermost Cretaceous throughout the Rocky Mountain West. Drab colored shales and soft sandstones are part of the marine Mancos Shale (Cretaceous), which is in fault contact here with the Entrada Sandstone (Jurassic) along the San Ysidro (or Sierrita) Fault.

As the road curves to the north, note the major uplift of the Nacimiento Mountains. Paleozoic sediments overlying Precambrian basement rocks dip westward from here into the San Juan Basin. The San Juan Basin is a major structural and depositional basin that occupies essentially the northwestern quadrant of New Mexico.

Road Log into the Jemez Volcanic Complex

Intersection of U.S. Highway 550 (NM-44) and New Mexico Highway 4; turn right (eastward) toward Jemez Springs.

To the west of the road, the Jemez Fault throws Cretaceous Mancos Shale against Triassic Chinle Formation redbeds. Hogback cut on Permian redbeds.

Leave town of San Ysidro; cross bridge over Jemez River

White outcrops along road are of the Zia Sand (Miocene) overlain by Pleistocene terrace gravels.

Enter Jemez Pueblo.

Jemez Pueblo is the only remaining pueblo belonging to the Towa language group; the people are believed related to descendents of the abandoned pueblo at Pecos in northeastern New Mexico.

Leave Jemez Pueblo

Contact between massive, white Zia Sand and the layered redbeds of the Permian Yeso Formation.

Redbeds of the Yeso Formation change upstream (northward) into redbeds (shales and sandstones) of the underlying Permian Abo Formation. Try to pick out the subtle differences in shades of red.

Ahead, note massive white to pinkish cliffs of Bandolier Tuff outflow facies overlying Permian redbeds.

In general here, the course of the Jemez River from here on follows the Jemez Fault up San Diego Cañon. The fault intersects the caldera wall at the topographically lowest point along the southwestern rim. The river originated by (probably catastrophic) overflow of an early caldera lake approximately 1.0 Ma.

For the next 12 miles, Bandolier Tuff is continuously exposed in the upper canyon walls. There are two members of the Bandolier: the lower Otowi Member (1.4 Ma) and the upper Tshirege Member (1.1 Ma). Counted as part of these members but underlying the main pyroclastic flow deposits are the thin, early-stage air-fall eruptive deposits known as the Guaje and Tsankawi Pumice Beds. Eruption of the Otowi Member was associated with collapse of the Toledo Caldera, whereas eruption of the Tshirege Member was associated with collapse of the Valles caldera

Stop No. 1: San Diego Cañon

The Bandolier Tuff on the west wall of San Diego Cañon is approximately 1000 ft thick; the contact between the Otowi and Tshirege Members is just below the orange-colored oxidized zone, roughly one-third of the way up the tuff section (at 275 ft above the base). At this location, the Otowi Member is totally vitric (original chilled volcanic glass shards). Although exhibiting prominent columnar jointing, the unit is only moderately welded (compacted and with some flattening of the original shard structure; see figure 3). The Tshirege Member is also moderately welded at this location, but unlike the Otowi, the Tshirege unit has been devitrified by extensive vapor-phase alteration during cooling. Vapor-phase alteration refers to the corrosion of initial glass shard fragments by hot magmatic gasses exsolving from the cooling glass fragments and the growth of microscopic crystals in place of the glass. Because of the rhyolitic composition of the original magma, these crystals are typically of sanidine (a high-temperature potassium feldspar) and tridymite or crystabolite (high-temperature crystal forms of quartz).

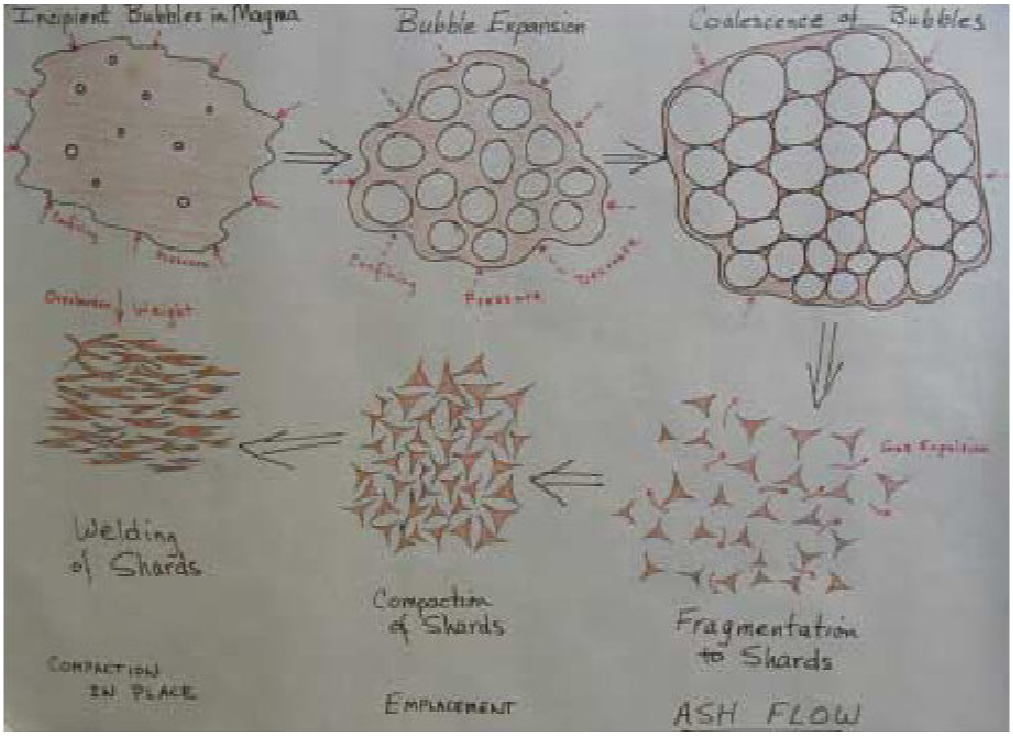


Figure 3. Schematic representation of the formation of a welded tuff. Incipient gas bubbles in magma expand prior to and then violently during eruption, fragmenting the magma to a mass of individual glass shards. This mass of pyroclastic debris flows as a density current of sorts and comes to rest as a hot mass, after which the weight of overlying materials may allow the still plastic glass shards to compact, flatten, and weld.

The dark-grey unit near the top of the canyon wall is densely welded tuff, in which the original shard structure has been essentially completely flattened and virtually all initial porosity compressed out. Although the dark-grey unit appears to be a single unit from this vantage points, it is reported to consist internally of at least three separate flow units.

The intensity of welding is frequently observed to be a function of the thickness of the overlying mass of pyroclastic deposits. However, in this instance, the most densely welded portion of the Tshirege is at or near the top of the deposit, presumably reflecting variations in internal temperature of the magma being erupted (hotter = more fluid = greater flattening).

In contrast to the Bandolier Tuff units, the pyroclastic tuff deposits at Yucca Mountain Nevada are much more voluminous and more extensive areally. The proposed host rock at Yucca Mountain is the Topopah Spring Tuff of the Paintbrush Group (nominally 12 Ma), and the rock is very densely welded essentially throughout its nearly 1,000 ft thickness. There are three other major pyroclastic flow deposits at Yucca Mountain belonging to the Paintbrush Group. Although the middle two are relatively small-volume flow deposits, the uppermost Tiva Canyon Tuff is itself nearly 300 ft thick in the vicinity of the potential repository site, and it, too, is densely welded throughout. Virtually all of both the Topopah Spring and Tiva Canyon Tuffs are intensely devitrified. A graphical comparison of volume and extent of the Bandolier Tuff with the better-preserved Timber Mountain Tuff in the Yucca Mountain region is presented in figure 4.

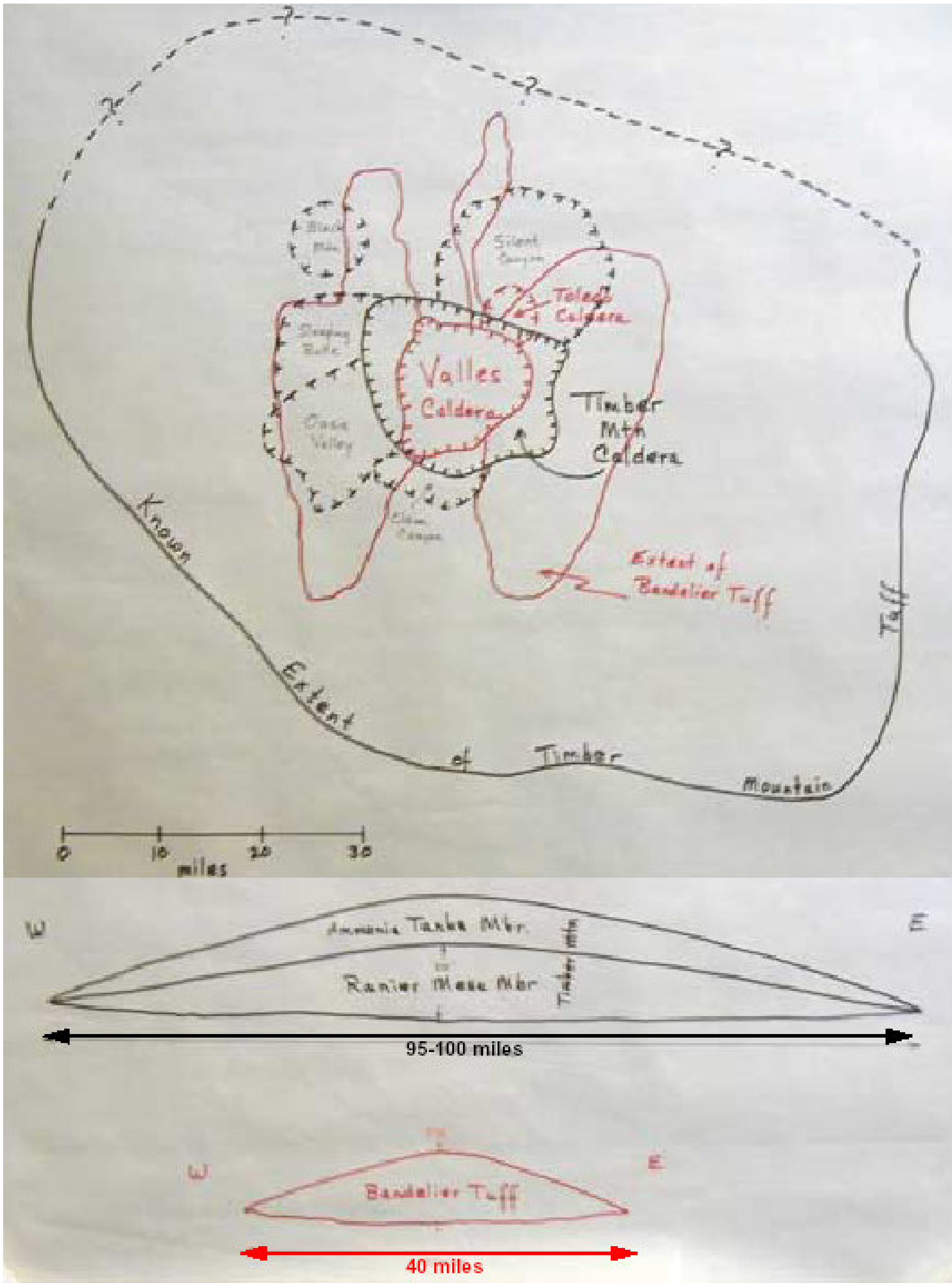


Figure 4. Comparisons of the extents of the Bandolier Tuff of Northern New Mexico with the older Timber Mountain Tuff of the Southern Nevada Volcanic Field.

Interestingly, the Paintbrush Group tuffs (although not true for all of the volcanic sequences near Yucca Mountain) are all nearly aphyric: lacking in phenocrysts (early formed large crystals present in the magma chamber prior to eruption). In contrast, the units of the Bandolier Tuff are quite crystal rich. Erosion of the less welded portions of the Bandolier produces surfaces that sparkle brightly in the sun with literally billions of small (2-3 mm) crystals of sanidine feldspar with well-defined crystal faces that reflect light.

Road Log Climbing into the Caldera

Pass through the town of Jemez Springs
Soda Dam

Soda Dam is an unusual travertine spring deposit that has been build by hydrothermal ground waters issuing from a fissure along the Jemez Fault. The fault places a horst of Precambrian granitic basement rocks against Abo Formation redbeds (Permian) on the east and a block of greyish Madera Limestone (Pennsylvanian) on the west. The Madera limestone is similar to the limestones that cap the Sandia Mountains east of Albuquerque.

Although as many as 22 springs were reported flowing and contributing to Soda Dam in the early years of the twentieth century, only three were noted flowing in the 1950s. Highway reconstruction beginning in the late 1960s cut through the main mass of the dam and destroyed the principal feeders to the “living” dam. However, small flows of hydrothermal and heated meteoric waters still issue from the fault, flow across the road in a culvert, and are continuing to deposit small quantities of travertine on the lower portions of Soda Dam.

Pass Hummingbird Music Camp for school-age band and orchestra students

Immediately past the camp, are a number of small solfataras, located along the Jemez Fault in a similar manner to the hot springs at Soda Dam. You may note a strong odor of hydrogen sulphide (H_2S) if the winds are right and the bus windows are open. The solfatara vents themselves may be identified by white bleaching of the redbeds in small (meter-square) areas (and locally yellowish sulphur encrustations). These features indicate that degassing of the Jemez volcanic/magmatic province is still on-going.

Stop No. 2: Battleship Rock Picnic Grounds

Battleship Rock (think of the “dreadnaughts” of the post WW-I era) is located at the intersection of San Antonio Creek (draining the west and north moat of the Jemez Caldera) and the East Fork of the Jemez River (draining the south moat). The rock is a spectacular outcrop of columnar-jointed, densely welded tuff, exhibiting the prominent “prow” of battleships from the 1920s and 1930s.

The Battleship Rock Member of the Valles Rhyolite is actually very much younger than the Bandolier Tuff: approximately 0.1 Ma in age. Originally these small-volume pyroclastic flow deposits extended from the vicinity of El Cajete Crater still further upstream of the picnic ground a substantial distance down San Diego Canyon and filled the canyon to a depth of more than 300 ft. Battleship Rock itself is the result of the ash flow filling a narrow, steep-walled gorge cut into rocks of the Madera Limestone and Abo Formation. However, subsequent erosion has removed the softer sedimentary rocks leaving the densely welded tuff as a prime example of inverted topography. Distinctly curved cooling joints in the lower part of Battleship Rock indicated cooling into the original near-vertical “cold” sedimentary walls of the former gorge.

Continue up San Antonio Creek toward the caldera wall

The Battleship Rock Member of the Valles Rhyolite is exposed on the right (east) side of the canyon for several miles.

Large float blocks on the left (west) side of the canyon are out-of-place blocks of Paliza Canyon Formation volcanics, part of the more mafic volcanic edifice upon which the main part of the Jemez Mountains was built.

Pass Spence Warm Spring, popular *au naturale* bathing spot

The black cliffs on the right (east) side of the canyon are outcrops of the Banco Bonito Member of the Valles Rhyolite. This unit represents a very thick rhyolite glass (obsidian) flow that is slightly younger (and overlies) the Battleship Rock Member. It probably erupted from the same vent as the Battleship Rock Member. Note the locally very steep flow banding in the glass flow of the Banco Bonito Member.

La Cueva (The Cave)

La Cueva is in cliffs of welded tuff of the Battleship Rock Member. The Anglo recreational settlement of La

Cueva is just around the bend from the geographic feature.

Junction of New Mexico Highway 4 and New Mexico Highway 126; turn left onto NM-126

Travel northward along the lowest part of the moat marking the western margin of the caldera. Weak, highly fractured rocks associated with the ring-fracture zone of the Valles Caldera have been excavated by San Antonio Creek in this location.

Cross San Antonio Creek at a near-hairpin turn back toward the south.

For the next mile or so, the road climbs the west wall of the Valles Caldera. Roadcuts expose in succession from the base: Abo Formation (Permian), Paliza Canyon Formation quartz latites (9.1–8.5 Ma), and Bandolier Tuff (1.4–1.1 Ma). There are several small fault blocks along the climb that repeat various units. Also, there is a moderately large earthflow that cuts the highway and which has caused numerous episodes of road reconstruction over the past several decades. The earthflow typically moves in late winter/early spring when the ground is nearly saturated and yet not frozen.

Stop No. 3: West Caldera Overlook

From this perch, high on the west wall of the Valles Caldera, we can look eastward across the collapsed and later resurgent dome of the inner caldera. The high domical mountain on the skyline is Redondo Peak, elevation 11,205 ft. The lower and closer, more irregular ridge is Redondo Border, which is also structurally part of the resurgent dome. The valley between the two high points represents an apical graben structure that trends southwest-northeast, and which represents late-stage, partial collapse of the resurgent dome (figure 5).

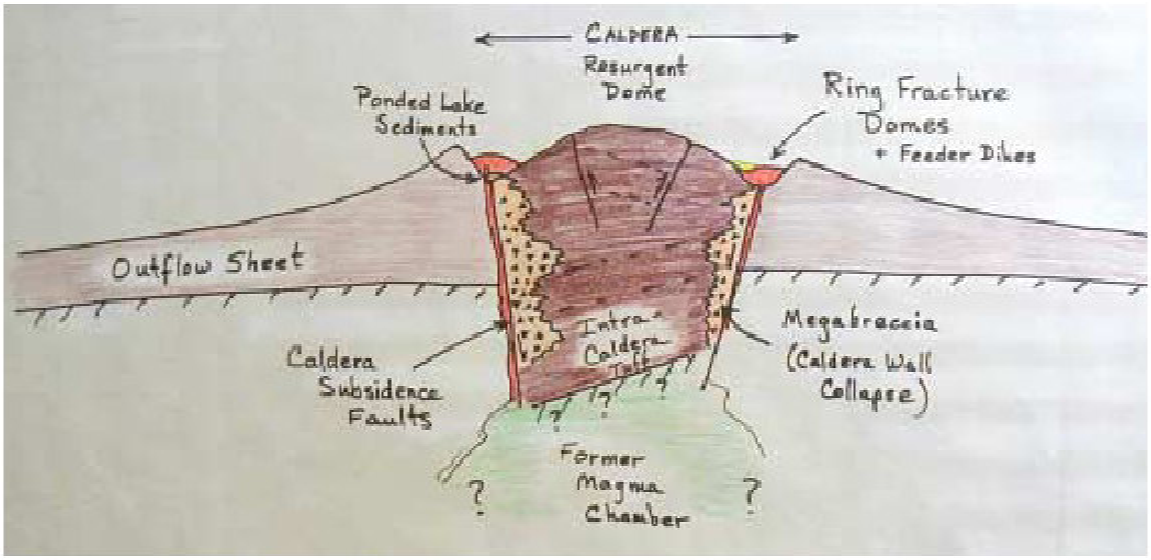


Figure 5. Conceptual geometry of a caldera system.

An ascending magma body ultimately ruptures the earth's crust such that a more-or-less piston-like mass of rock founders into the magma chamber along a quasi-circular annular zone. Magma is erupted principally along these ring faults, and forms an eruption column that ultimately collapses of its own mass, forming a pyroclastic flow.

Much of this erupted material simply falls back into the space previously occupied by the magma chamber itself and forms intra-caldera tuff. Some of the material flows across the surrounding countryside as a density flow, forming outflow-facies tuff.

The over-steepened caldera margin typically collapses in places during and after the eruption forming megabreccia bodies of both preexisting rocks and tuff. Later repressurization of the underlying magma chamber may give rise to a resurgent dome, which may itself fracture and suffer internal subsidence along (generally linear) faults.

Late stage remnant degassed magma may rise along in places along the ring-fracture zone forming small pyroclastic flows, lava flows, extrusive flow-domes and other features. A lake may form within the caldera and/or moat surrounding a resurgent dome, leading to deposition of water-lain reworked volcaniclastic sediments.

Almost without exception, the rocks within the dome consist of densely welded intracaldera facies of the Bandolier Tuff: material that was ejected skyward during the eruption, but which then fell back into the subsiding structural caldera as the preexisting overlying rocks collapsed into the void left by the erupted magma. Post-collapse resurgence of the intra-caldera rocks has resulted in uplift of the welded tuffs on Redondo Peak that probably exceeds 4,500 feet. The uplift has been dated as within about 100 Ka of the last (Tshirege) main eruptive phase, or at about 1.0 Ma. Estimates of the total volume of material involved in the eruption of the Tshirege Member of the Bandolier Tuff are approximately 300 cubic kilometers.

If we look toward the south, west, or north, the major, essentially flat-lying mesa tops are underlain by the outflow facies of the Bandolier Tuff that we observed from the floor of San Antonio Cañon on our way here. As noted earlier, most of the outflow facies tuffs are only moderately welded. the difference between those tuffs and those of the intra-caldera facies is the immensely greater thicknesses of the deposits that accumulated in the two environments. To the northeast of our stop in the middle distance are San Antonio Mountain and Cerro Seco. These peaks are post-resurgent rhyolite domes located within the caldera moat. Age dates on the rhyolites of these two domes are 0.54 Ma and 0.73 Ma, respectively. A similar post-resurgent rhyolite dome is just barely visible to the south of Redondo Peak. South Mountain, dated at 0.49 Ma, is located within the southern portion of the moat. Altogether, there are twelve rhyolite flow-domes at various positions within the caldera moat, all essentially located along the ringfracture zone of principal caldera subsidence. In contrast to the magmas that gave rise to the Bandolier Tuff, which was extremely gas-charged, these later magmas were relatively low in volatiles. Thus, they were erupted as viscous flow-domes of rhyolitic lava instead of as explosive pyroclastic debris (tuff).

Looking downward and eastward of the moat portion through which we ascended to this overlook, we can see the hummocky upper surface of the Banco Bonito glass flow. Recall that this member of the Valles Rhyolite was dated at 0.1 Ma, much later than even the post-resurgent rhyolite flow-domes.

A mile or two to the west of this location along Highway 126 is the site of the Los Alamos National Laboratory "Hot-Dry Rock" experiment. Funded by the Department of Energy during the late 1970s, the concept was to drill a pair of deep boreholes into "hot, dry" volcanic rocks that are unsuitable naturally for geothermal steam production. A set of artificial fractures would then be induced to establish communication between the pair of boreholes, after which water could be pumped down one hole, superheated by contact with hot rock along a large areal surface, and then flashed to steam at the surface after being pumped up the second borehole. Much of the equipment still sits atop Fenton Hill, as the site is named, but the project was abandoned as impractical at present.

Road Log Along and Through the South Moat of the Valles Caldera

Return to La Cueva; turn left (eastward) onto N.Mex. Highway 4

Just before La Cueva, note moat sediments of lacustrine origin in outcrop to east of highway.

Junction of Sulphur Creek and Redondo Creek

The road to the north leads to Sulphur Springs, the most active solfataric area in the caldera. At one time, this was the location of a small hotel that advertised "health cures" by soaking in the bubbling mudpots and hot springs of the region.

Road up Redondo Creek to north

This road leads to the medial graben that separates Redondo Peak from Redondo Border to the west. At one time in the 1960s and 1970s, Union Oil (Unocal) was drilling for geothermal steam production in this region. Although steam was found, the project has been non-economic and no recent development activity has occurred.

Road climbs through pumiceous tuff breccia of the Battleship Rock Member of the Valles Rhyolite.

Cross contact of Battleship Rock Member with the Banco Bonito glass flow Member of the Valles Rhyolite

Note hummocky surface topography of the glass flow, which formed as the low-volatile, viscous molten glass flowed across this portion of the caldera moat. Note also the conchoidal fracture surfaces to some of the surface boulders along the roadside, as well as the reflective, "glassy" surfaces.

Stop No. 4: El Cajete Roadcut

This prominent roadcut exposes three distinctly different members of the Valles Rhyolite (0.1 Ma). At the top are vitrophyric blocks of the basal portion of the Banco Bonito glass flow. Underlying these "black boulders" are well-bedded pumice and ash of the El Cajete Member. Most of the units are well-layered air-fall tuffs ("fallout tephra"), but there are two ash-flow ("pyroclastic-flow") tuffs near the base of the section; these exhibit pink iron coloration resulting from high-temperature oxidation. They are also much less laterally extensive than the more-extensive and more-uniform thickness air-fall deposits. Near the base of the outcrop is part of the South Mountain flow of the Valle Grande Member.

As a general rule, air-fall pyroclastic deposits tend to be well sorted and to exhibit relatively consistent thicknesses laterally. We talk of these as "slope-mantling" deposits, as the fallout debris tends to cover high ground and low ground with similar thicknesses (originally, before any reworking). In contrast, pyroclastic flow deposits tend to exhibit very poor sorting, as a consequence of the simultaneous "capture" of all the materials that are in the eruption column during a collapse event. This includes millimeter-scale ash, centimeter- to decimeter-scale pumice chunks, phenocryst (crystals in the magma preexisting the eruption), and lithic blocks torn from the walls of the magma chamber or rocks through which the magma is erupting. In common with their submarine "equivalents" of turbidites (sedimentary density flow deposits), pyroclastic flow deposits tend to exhibit a "dispersed" fabric with larger clasts "floating" in a finer-grained matrix (or groundmass).

Cross East Fork of the Jemez River — this is an attractive and popular trout-fishing area

Upper valley of the East Fork of the Jemez River

Outcrops to the north of the highway are of the South Mountain rhyolite flow-dome; outcrops contain basaltic fragments of the much older Paliza Canyon Formation (9.1 – 8.5 Ma). These indicate incorporation of older rocks of the underlying volcanic edifice into the magma during its ascent along the highly faulted ringfracture zone.

Stop No. 5: Valle Grande Overlook

We are now located more-or-less at the southeastern margin of the Valles Caldera. Redondo Peak is to the west; recall that this is the summit of the resurgent dome. South Mountain, one of the post-resurgent rhyolite flow domes along the ring-fracture zone is to the south of Redondo Peak. A number of additional post-resurgent domes are also visible from this viewpoint.

The caldera wall is to the south and east of us. Interestingly, part of the caldera rim to the east is, in fact, the margin of the Toledo Caldera. The Toledo Caldera was the source of and collapsed as a result of eruption of the Otowi Member of the Bandolier Tuff. (1.4 Ma). A significant portion of the Toledo Caldera was obliterated by later collapse of the Valles Caldera.

The Valle Grande, as well as most of the terrain that lies to the north and west of here, was originally part of the Baca Location No. 1, owned by the Baca Land and Cattle Company. This tract has recently been purchased by the Federal Government, and is being set aside as the Valles Caldera Natural

Preserve. Debate is ongoing regarding how much of the area will be open to the public and under what conditions. Previously, this area was essentially inaccessible as private property.

Road Log to Los Alamos area and Bandolier National Monument

Continue east/southeast on N.Mex. Highway 4.
Climb southeast margin of the Valles Caldera; road on upper part of outflow facies of Bandolier Tuff.
Hairpin curve at head of Frijoles ("bean") Cañon, which cuts nearly 1,000 ft into the Bandolier Tuff. Outcrops near road are densely welded tuffs of the Tshirege Member.
Cerro Grande Fire

On May 5 of 2000, a controlled burn within Bandolier National Monument went out of control as a result of drought conditions and sudden wind changes. The fire burned out of control for six and a half weeks, spreading to the north and east, and ultimately charring parts of Los Alamos National Laboratory and the city of Los Alamos. Approximately 240 homes in Los Alamos were destroyed. The intensity of the fire increased markedly as it spread to the northeast (figures 6 and 7)

Note the densely overcrowded condition of the forest as we approach the burned region. This condition is the result of decades of fire suppression throughout the mountain west, and it is widely blamed as one of contributing factors to the spread and intensity of the Cerro Grande Fire.

Pajarito Plateau Overlook — A "non stop"

As the land falls away sharply to the east, the highway descends through densely welded Bandolier Tuff and eventually crosses the Pajarito Fault. The Pajarito Fault can be traced for some 30 miles along the east margin of the Jemez Mountains, and it is one of the major bounding faults of the Rio Grande Rift to the east. The fault has been active intermittently throughout the Pleistocene, and has known displacements of up to 1,000 ft. The Bandolier Tuff is displaced approximately 300–500 ft at this location.

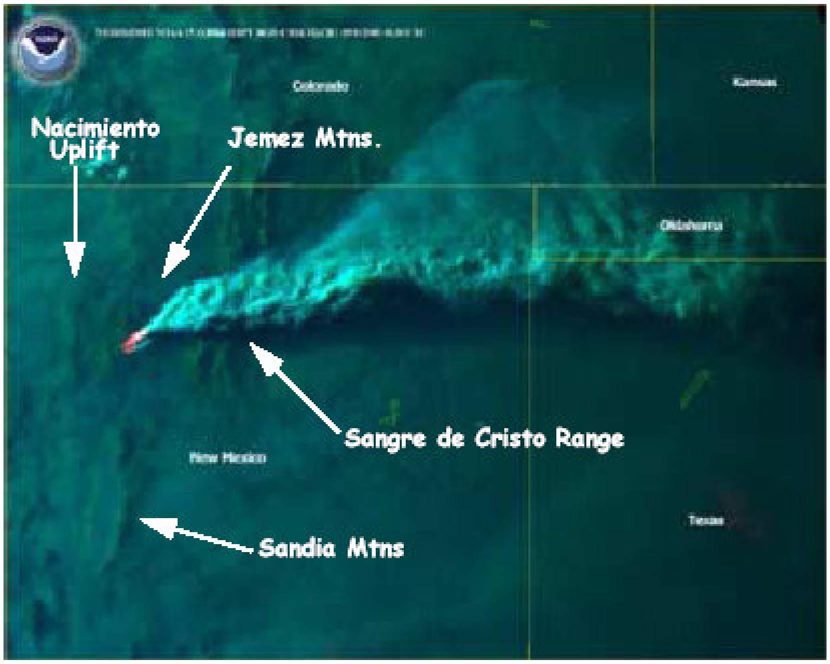


Figure 6. Satellite image of the smoke plume from the Cerro Grande fire, May–June, 2000. The plume originates from the eastern part of the Jemez Mountains and extends across parts of at least four states.

One could consider this smoke plume as a surrogate for dispersal of an eruption plume from the Valles (or Toledo) Caldera, only the extent of such a plume, containing many cubic kilometers of erupted material obviously would be much more extensive.

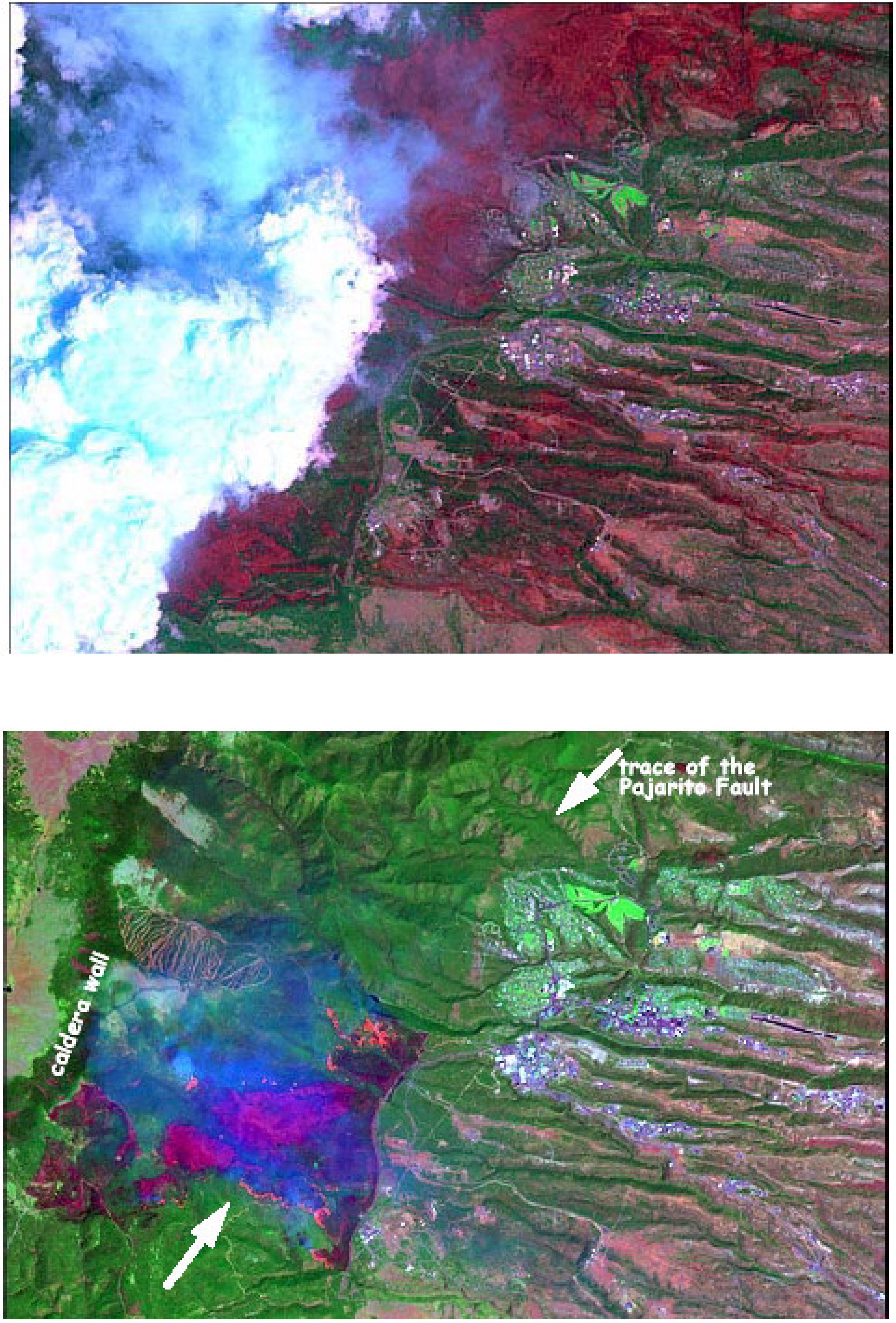


Figure 7. False-color satellite imagery of the vicinity of the Cerro Grande Fire on June 12, 2000, shortly before the fire was controlled. The burned areas are in red; clouds obscure the original starting location of the fire in the southwest portion of the imagery. Compare to the early-burn imagery below taken on May 9. Note caldera wall on the far-left side of the lower image

Although time on this field trip does not permit a stop at this location (the highway is also quite hazardous for large crowds), the outcrops along the road above the hairpin turn reveal an assortment of fascinating volcanic features. The tuffs are densely welded at this location. However, some of the individual flow units (as distinct from the "cooling unit" of the entire Tshirege Member; see figure 8) are separated by thin, sandy partings in which the "sand" is comprised of phenocrysts of sanidine and quartz. Vertical, pipe-like structures representing extinct fumaroles are also present. Some of these pipes also contain loose phenocrysts.

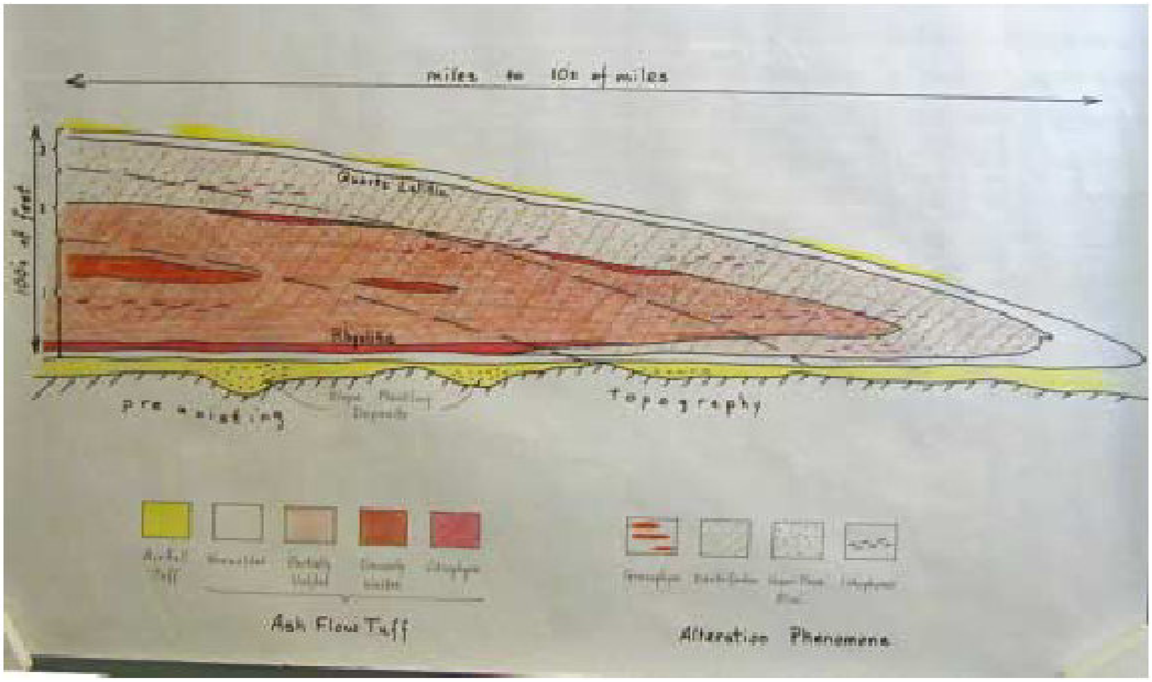


Figure 8. Conceptual representation of the distinction between cooling units (here a single one) and flow units (here three separate units).

Flow units are the result of "separate" eruptions or column-collapse events during a moreor-less continuous eruptive episode. In contrast, a cooling unit is formed as an accumulated pyroclastic flow deposit cools as an entity from magmatic to ambient temperatures.
Time periods separating individual flow units may range from hours to days to months to possibly years. The time period associated with a single cooling unit probably extends from years to hundreds or even thousands of years. Partial reversals of cooling profiles are observed associated with some caldera sequences.

Collectively, these features and others indicate that the emplacement of the major ash-flow units of the Bandolier Tuff took place in stages. Individual pyroclastic flows resulting from collapse of the eruption column were separated in time from one another by periods sufficient for thermal winds, gas blasts, pyroclastic surge, or other processes to winnow the finer ash and leave thin concentrations of heavier crystals as lag deposits. Even fumaroles had time to form and to degas part of the then-accumulated mass to a now-buried topographic surface. Yet the entire eruptive cycle was completed in a sufficiently short time period that the entire accumulated mass remained at high temperatures, so that the pile of debris and glass shards compacted, welded, and cooled essentially as a whole.

The far-distant skyline to the east is formed by the Sangre de Cristo ("Blood of Christ," from the color they turn during sunset) Mountains to the east of the Rio Grande Rift. These peaks are principally Precambrian granitics and metamorphic rocks flanked by a thick accumulation of Pennsylvanian arkosic sandstones, which represent the sedimentary debris from an episode of late Paleozoic uplift and erosion. The particularly jagged mountains are the Truchas Peaks, and the prominent “softer” mountain to the south is Santa Fe Baldy, home to the Santa Fe Ski Area.

When opportunity offers, look south (to the right) over out-flow facies Bandolier Tuff. The large open area extending most of the way into the middle distance is the area burned in 1979 by the La Mesa Fire.

Junction of N.Mex. Highway 4 and Highway 4 Alternate

Bandolier National Monument is to the south on Alternate Highway 4. The Monument is home to a number of spectacularly preserved cliff dwellings built by ancestors of today’s Pueblo cultures. This route forms an excellent alternative trip, as there are several good (and accessible!) exposures of outflow-facies Bandolier Tuff along the winding road.

Turn left (north) onto Highway 4 to Los Alamos

The road wends its way through some of the outlying Technical Areas of Los Alamos National Laboratory, home of the Manhattan Project of World War-II fame. During the 1940s, this region was remote, poorly accessible, and easily secured Note extensive fire damage from the Cerro Grande Fire of 2000, with intensity of the destruction increasing northward.

Pass main entrances to Los Alamos National Laboratory.

Enter City of Los Alamos; turn east to follow N. Mex. Highway 4.

Pass Los Alamos airport to the north. Flights into and out of Los Alamos are “interesting,” to say the least. Leave Los Alamos; note guard tower to the south.

Descend through a virtually complete section of Bandolier Tuff

The road drops steeply along a bench cut into the two members of the Bandolier Tuff: the upper Tshirege Member and the lower Otowi Member. The basal part of each member is marked by a prominent air-fall pumice bed, marking the early stages of the major eruptive cycles. The pumice at the base of the Tshirege Member is known as the Tsankawi Pumice Bed, whereas the lower pumice at the base of the Otowi Member is the Guaje Pumice Bed.

Although again, time (and safety) does not permit an actual stop along these near-perfect exposures, note the distinctive appearance of the pyroclastic flow deposits vs. the air-fall pumice units. Note, too, changes in oxidation character within the only partly to moderately welded tuffs through which we descend. Much of the cliff-forming character of the Bandolier Tuff in this eastern portion of the outflow facies is the consequence of extensive vapor-phase alteration, rather than of compaction and associated welding. Columnar jointing is extremely well developed in some parts of both the Tshirege and Otowi Members (exposed principally to the north of the roadway across the canyon). Note also the “cavernous” weathering phenomenon locally.

Interchange of N.Mex. Highway 4 and Highway 4 Alternate (to Bandolier National Monument and the town of White Rock (a bedroom community for Los Alamos).

Although highway reconstruction during the late 1990s significantly altered the exposures just east of the interchange, a number of features are noteworthy here. These features comprise the transition from the precaldera volcanic edifice upon which the Jemez Mountains rest and the massive pyroclastic deposits associated with collapse of the Toledo and Valles Calderas.

To the north of the highway, outcrops of the Otowi Member of the Bandolier Tuff (1.4 Ma) overlie exposures of the Guaje Pumice Bed. The Guaje Pumice is about 23 ft thick at this location. The Otowi ash flows are essentially nonwelded here, but they are variably vapor-phase altered.

Immediately underlying the Guaje Pumice is 2.4 Ma basalt (part of the basalt of Cerros del Rio); a soil profile was evident at one time on the uppermost portions of the basalt.

The flow rocks of the basalt grade downward into what was (prior to highway reconstruction — or destruction!) an excellent exposure of pillow lavas and pillowed palagonite breccia. Palagonite is *basaltic* glass (in distinct chemical contrast to *rhyolitic* glass, such as the Banco Bonito glass flow). The glassy nature and pillow structures are evidence of eruption of the basalt into water. Indeed, original outcrops to the east (and also still to the south of the highway) indicate that the pillowed materials overlie water-lain, bedded basaltic tuffs and lacustrine clays. The implication is that basaltic volcanic activity at roughly 2.4 Ma had dammed the Rio Grande and resulted in the formation of a lake at one time.

The view to the east reveals flat-topped Black Mesa, capped by essentially horizontal basalt flows, and the more rugged La Mesita basaltic eruptive center.

The residents of San Ildefonso Pueblo, which extends up the Rio Grande valley north of the highway east of here), were besieged by the Spaniards on Black Mesa in 1690. San Ildefonso Pueblo is one of several Tewa-speaking communities, and the pueblo is perhaps most noted for the black-on-black pottery revived in the 1920s by the famed potter, Maria Martinez. Many members of San Ildefonso Pueblo, as well as of other northern New Mexico pueblos, are highly skilled technicians and staff members at Los Alamos National Laboratory.

Continue down N.Mex. Highway 4 to the east

Lacustrine clays overlie coarse boulder beds of the Puye Formation (older than 2.4 Ma). The Puye Formation represents a huge alluvial apron that spread eastward from the Jemez area and which was derived by erosion of pre-caldera quartz latites of the Tschicoma Formation (6.7–3.7 Ma). The unit is a geological grab-bag of volcaniclastic debris, lithic pyroclastic flows (quite unlike the ash flows of the Bandolier), laharic deposits (volcanic mudflows), and reworked fluvial deposits farther east away from the pre-caldera volcanic edifice. Well-rounded boulders of Precambrian granitic and metamorphic rocks near the base of the unit indicated uplifted exposures of these very old rocks somewhere in the vicinity at this time.

Interchange with N. Mex. Highway 30 to Española; continue east on Highway 4

The highway is descending through distal fluvial facies of the Puye Formation and other units of the Ancestral Rio Grande. The Ancestral Rio Grande has a highly complex history in this region, as volcanic activity of the Cerros del Rio volcanic field intermittently dammed and diverted the river in different directions. An entire field trip could be spent on the basaltic magmatism of this small area.

Cross Rio Grande at Otowi Crossing; begin climb up the eastern part of the rift valley

Interchange with U.S. Highway 285 at Pojoaque; turn south on Highway 285 toward Santa Fe. Pass Pojaque Pueblo Cities of Gold Casino

Between here and Santa Fe the road traverses Quaternary sediments of the Santa Fe Group and winds through classical Northern New Mexico piñon-juniper terrain. The main highway skirts a number of small Pueblos.

The pueblos of Pojoaque, Tesuque, and Nambe, all three originally Tewa-speaking peoples, are all located in this same general region along U.S. Highway 285. Tesuque Pueblo, which has been demonstrated to have existed before 1200, was a prominent player in the Pueblo Revolt of 1680, with members acting as inter-tribal messengers coordinating the simultaneous uprising on August 10 that evicted the Spanish from northern New Mexico for more than a decade. The vicinity of Pojoaque Pueblo has been inhabited since roughly the year 500. Perhaps it is fitting that, after the Pojoaque people decimated were during the Pueblo Revolt — and indeed the village was abandoned at the time of the Reconquest, to be resettled in 1706 by a mere five families —, they now reap “gold” in their “Cities of Gold” Casino that the Spaniards so desperately sought (the “seven cities of Cibola”) three-and-a-half centuries ago.

Pass Santa Fe Opera to the west

Note the view of the Jemez Mountains volcanic center to the west. The long east-trending mesas are Bandolier Tuff, behind which is the caldera rim and high country of the resurgent dome. Redondo Peak is the skyline. Closer to the river are the complex of sediments and basaltic materials of the Cerros del Rio volcanic field.

Note also the view of the Sangre de Cristo Mountains to the east.

Enter City of Santa Fe, the "City Different"

Continue south on U.S. 285

Interchange with Interstate Highway 25. Turn south toward Albuquerque

Pass rest area for northbound traffic to the east.

The highest peaks directly ahead of the highway in the distance are the Ortiz Mountains, a Tertiary intrusive center. Gold deposits are associated with some of the intrusive activity, and a low-grade open-pit mine was operated on the eastern flank of the mountains for some years.

The closer conical hills are the Cerillos Hills. These also represent Tertiary intrusive centers. The Cerillos area has been an important source of beautiful turquoise since pre-Colombian times, although the mines are now essentially exhausted.

Crest of La Bajada ("The Ascent")

As the highway turns to the west, the road and surrounding flat plain are underlain by an extensive basalt flow. At La Bajada, the flow has been eroded near its distal portion, and the highway drops sharply through the basal and into Mesozoic and Paleozoic sediments, here, principally redbeds. The road continues descending into Quaternary deposits of the Santa Fe Group and of the Ancestral Rio Grande.

In Spanish Colonial times, "the ascent" of La Bajada was a very difficult and time-consuming process for those traveling from Old Mexico to Santa Fe. Wagons were taken apart and hauled in pieces, together with their contents, up the slope. Willa Cather's *Death Comes for the Archbishop* describes the travails of travelers through this part of New Spain at that time.

Pass Cochiti Pueblo

Cochiti Pueblo is famous both for drums, cut from whole aspen trunks, and for the now-popular "Storyteller" figurines that were revived only as recently as 1964. The U.S. Bureau of Reclamation has constructed a large dam on the Rio Grande for flood control and irrigation of the entire Middle Rio Grande valley, behind which has accumulated Cochiti Lake. The lake also serves a significant recreational community.

Cross Gallisteo Wash, a "major" tributary to the Rio Grande

A good view of the Sandia Mountains to the south reveals the fault-block nature of this major uplifted structural block. A cap of Upper Paleozoic sediments dips gradually to the east, and the main front of the range is an eroded fault scarp along which the Rio Grande rift subsided

Pass Santo Domingo Pueblo

Santo Domingo Pueblo is one of several Keresan-speaking language groups along the upper Middle Rio Grande. Many members of Santo Domingo Pueblo specialize in silver-and-turquoise jewelry, perhaps originally because of their proximity to the Cerillos Hills deposits. Today the pueblo extracts significant revenue from the Anglo-dominated interstate highway traffic via sales of tax-free cigarettes and gasoline.

Pass San Felipe Pueblo's Casino Hollywood

Much of the area to the east of here forms the so-called Hagan Basin. This is a structurally low block that preserves Upper Mesozoic rocks, including coal-bearing units of the Cretaceous. The town of Madrid ("Mad-rid") was a prosperous coal-mining center during the early parts of the twentieth century. Although the town suffered through long hard times following the close of the coal mines shortly after WW-II, the area has recently revived as a significant art colony.

The coal in this area is unique in that thermal metamorphism related to Tertiary intrusive activity has locally elevated the rank of the normally bituminous/subbituminous coal of the western Cretaceous to essentially anthracite grade. These are the only "anthracite" deposits west of the Mississippi River.

San Felipe is also a Keresan-speaking pueblo. Despite its proximity to the Albuquerque metropolitan area and the fact that many members work there, San Felipe Pueblo is known as one of the most culturally conservative groups.

Pass Algodones

The modern school buildings to the north of the highway on San Felipe Pueblo are post-introduction of "Indian Gaming."

Note the number of sand-and-gravel quarries east of the highway. These are big-dollar operations "near" the growing Albuquerque-Rio Ranch population centers.

Pass (do *not* exit) Bernalillo Exit toU.S. Highway 550 (old NM-44)

We have now come full circle on our trip through the Rio Grande Rift of north-central New Mexico and the Jemez volcanic centers.

Precambrian granitics and metamorphic rocks capped by Upper Paleozoic limestones form the Sandia Mountains to the east.

Return to hotel via Interstate Highways 25 and 40

End of Road Log

Acknowledgments

The geology of the Rio Grande valley and of the Jemez Mountains in particular has been described in a large number of field guides, road logs, and other publications. I have borrowed "liberally" from several of these older guides, as well as from personal conversations with other geologists, including members of the Earth Sciences staff at Los Alamos National Laboratory and geological consultants (who have made their living out of the geology of New Mexico). Most of these authors and informal consultants have far more rigorous experience in the local geology than do I, and I must accept any errors or gross simplifications contained in this road log and discussion as my own.

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- anonymous/unknown, 1990, Field trip to the Jemez Volcano Complex, informal field guide dated May 23, 1990, 8 p.
- anonymous/unknown, undated, but post-1978, Field Trip guide to the Jemez Mountains and Pajarito Plateau, informal field guide compiled (to my knowledge) by staff at Los Alamos National Laboratory, 16 p.
- http://www.indianpueblo.org — The Indian Pueblo Cultural Center website For those participants with additional time in Albuquerque, a visit to the Indian Pueblo Cultural Center just north of Old Town at 12th Street and I-40 is highly recommended.

Additional Reading

- Cas, R.A.F., and Wright, J.V., 1987, Volcanic successions, modern and ancient, London: Chapman & Hall, 528 p.
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- Ross, C.S., and Smith, R.L., 1961, Ash-flow tuffs: Their origin, geologic relations, and identification, U.S. Geol. Survey Prof. Paper 366, 81 p.
- Smith, R.L., 1960, Zones and zonal variations in welded ash flows, U.S. Geol. Survey Prof. Paper 354-F, pp. 149– 159.

Note: the above two USGS professional papers are out-of-print, but have been reprinted as New Mexico Geological Society Special Publication 9, 1980.

2. A recent report was issued recently by the Army Corp of Engineers. So much relevant information was included that same as been set out verbatim in this section.

http://www.spa.usace.army.mil/fonsi/Jemez%20Weir%20Final/JemezWeirFinalEA.pdf

FINAL ENVIRONMENTAL ASSESSMENT FOR THE PROPOSED CONSTRUCTION OF A LOW-HEAD WEIR, RIO JEMEZ, THE PUEBLO OF SANTA ANA, NEW MEXICO

U.S. Army Corps of Engineers
Albuquerque District
4101 Jefferson Plaza Northeast
Albuquerque, New Mexico 87109
August 2003

1. INTRODUCTION

1.01 LOCATION AND BACKGROUND

The Rio Jemez originates in the Jemez Mountains of New Mexico, converges with the Rio Grande north of Bernalillo, and is entirely situated in Sandoval County, NM. The proposed project vicinity map is shown on Figure 1 and the project site map is shown on Figure 2. The proposed project site would be located approximately 2.5 miles upstream of Jemez Canyon Dam on land held in trust by the United States for the benefit and use of the American Indian people of the Pueblo of Santa Ana. The Rio Jemez flows in a generally southeasterly direction with a total length of approximately 65 miles. Elevation ranges from over 11,000 ft. at the headwaters of the watershed to 5,075 at the confluence with the Rio Grande. The river is perennial in the upper reach and ephemeral in the lower reach above the Jemez Canyon Reservoir due to irrigation diversion upstream. The Rio Jemez in the project area has an elevation of 5,120 ft. The project site is located on the Santa Ana Pueblo USGS 7.5 minute topographic quadrangle.

The U.S. Army Corps of Engineers (Corps) and the Pueblo signed an MOU in 1952 (amended in 1978 by P.L. 95-498) which established a perpetual right and privilege for the construction, operation, and maintenance of the Jemez Canyon Dam and Reservoir Project. The facility was subsequently built and put into service in 1953 with the intention of regulating Rio Jemez flows for flood damage reduction and sediment retention. The Pueblo of Santa Ana reserved the right to use all associated lands for any purposes not inconsistent with those expressly granted to the government for the facility. Prior to dam construction, aerial photography taken in 1935 showed that the Rio Jemez in the proposed project area was typically a sand-bedded, low gradient channel. The only constraints to active meandering were valley walls and alluvial fan and debris deposits along the valley wall edges. During dam construction, the Corps established sediment and channel aggradation and degradation monitoring transects upstream and downstream of the dam (Figure 3).

Rio Jemez flows have typically passed through Jemez Canyon Dam with little, if any, regulation. Reservoir releases were typically restricted to the maximum non-damaging capacity of the downstream channel of the Rio Grande, as measured at Albuquerque, up to 7,000 cfs (USACE 1994). When the passage of inflow to the reservoir has exceeded the channel capacity of the Rio Grande downstream, flood control storage has been initiated. Flood waters have been stored only for the duration needed to evacuate the water as rapidly as downstream conditions permit. Operation of Jemez Canyon Dam for flood control is coordinated with Cochiti and Galisteo Dams in order to regulate for the maximum safe flow at Albuquerque. Deviations from the existing water control plan which are not deemed an emergency require approval by South Pacific Division of the Corps and (except for San Juan Chama Project water) concurrence by each of the Rio Grande Compact Commissioners.

The Jemez Canyon Reservoir pool area for flood and sediment control is approximately 6 miles long and 1 mile wide and encompasses the proposed project site. Initial capacity allocations were 73,000 acre-feet for flood control and 44,000 acre-feet for sediment deposition. As of June 1998, approximately 19,000 acre feet of sediment had accumulated behind the dam.
1
2
3
Flood storage is normally associated with snowmelt runoff during March through June. Summer flood storage is generally the result of short-term, high intensity thunderstorm events. The maximum storage to date has been 72,254 acre-feet (elevation 5,220.3 feet), occurring in 1987.

In the spring of 1979, the Corps and the New Mexico Interstate Stream Commission (NMISC) established a sediment retention pool of about 2,000 acre-feet at Jemez Canyon Reservoir using water exchanged from the San Juan-Chama Project. In January 1986 the sediment retention pool was expanded to include the entire unused capacity of the allocated sediment space to further improve trap efficiency of the reservoir. The water for this expansion (up to a maximum sediment retention pool capacity of 24,425 acre-feet) was again obtained through exchange for water currently at the San Juan-Chama Project leased from the City of Albuquerque by the NMISC. The pool was created and maintained by capturing native water from the Rio Jemez in the reservoir and replacing that water to the Rio Grande by releasing San Juan-Chama Project water from upstream storage, usually during the spring runoff period. Thus, a pool existed without interruption at Jemez Canyon Reservoir since 1979.

Subsequent to the creation of a sediment pool at the reservoir, the effect of groundwater-surface water interaction in the upstream delta area allowed vegetation growth that narrowed the traversing channel. Vegetation growth just upstream of Rangeline 4 to the Tamaya Bridge provides more bank structure and overbank flow resistance that constrains the channel and causes the channel to divide.
Downstream of Rangeline 4 and the vegetated delta and subsequent to the evacuation of the sediment pool, channel width and meander width has expanded, with the potential meander width covering the entire valley bottom similar to pre-dam, pre-pool conditions (Data Collected by Pueblo Consultants).
The Corps and the NMISC storage agreement expired on December 31, 2000, the MOU's original expiration date. The NMISC decided not to extend the agreement for sediment pool storage, citing significantly increased demands on available water in the region, its increasing cost, and the need for increased sediment loading to the currently degrading Rio Grande channel as factors in this decision. A partial evacuation of the pool began on September 20, 2000. The pool at Jemez Canyon Reservoir was finally evacuated by October 2001. Subsequently, the Corps and the Pueblo of Santa Ana have formulated a mitigation plan with an array of alternatives to address the onset of channel incision of the Rio Jemez resulting from evacuation of the sediment pool at Jemez Canyon Reservoir.

1.02 PURPOSE AND SCOPE OF THE PROPOSED PROJECT

During the fall of 2000, consultants to the Pueblo began monitoring channel incision promulgating as a result of the pool drawdown. By July 2001, knick points on the Rio Jemez channel had progressed approximately 5,200 ft. upstream, and volume of sediment moved as a result of the progressing incision was estimated at 380,000 cubic yards (Data Collected by consultants to the Pueblo 2001). Consultants to the Pueblo attempted to model channel incision following pool evacuation using HEC-6 erosion and sediment transport software. The model predicted an incision of 4-7 ft. in the vicinity of Rangeline R-4, occurring over 1-4 years, depending on Rio Jemez flows. Upstream of R-5, channel incision was predicted to be 2-3 ft. The survival of a bosque of mixed Rio Grande cottonwood, coyote willow, saltcedar, sedges, bulrushes, and rushes above R-4 is threatened by channel incision and the resulting effects of declining or lowered surface and subsurface water, reduced overbank inundation and decreased soil moisture.

Continued channel incision would likely affect approximately 390 acres of riparian bosque of mixed native and exotic species along the Rio Jemez delta on lands owned by the Pueblo of Santa Ana. The effect would be a lowered groundwater table below the uptake capabilities of native riparian obligate tree species. Such a consequence would likely result in further colonization of non-native salt cedar, Russian olive and Siberian elm trees and brush in the delta bosque. Habitat quality and quantity for the federally endangered Southwestern Willow Flycatcher, the warranted but precluded Western Yellowbilled Cuckoo, and other riparian obligate bird, mammal, reptile and amphibian and plant species would be lost as a consequence of future channel degradation. This Environmental Assessment (EA) examines the no-action and remedy alternatives proposed by the Corps and the Pueblo of Santa Ana and recommends a preferred alternative to minimize channel degradation and decline of groundwater elevation.

1.03 RELATIONSHIP TO OTHER ACTIONS

The proposed action is related to mitigation for the evacuation of the Jemez Canyon Reservoir sediment pool and to the future action of draining the Tamaya Pond (inadvertently created from past levee construction), future modification of the Jemez Canyon Dam outlet works, and future adaptive management of the former pool area and adjacent delta lands.

The average annual precipitation over the Rio Jemez Basin, based on National Weather Service stations in and adjacent to the basin, is approximately 17.0 inches based on data from 1914-2001 compiled by Western Regional Climate Center, Desert Research Institute (2002). The Jemez Springs rainfall station recorded a maximum annual precipitation of 28.72 inches in 1957 and a minimum of 6.17 inches in 1956. The maximum recorded 24-hour rainfall was 3.24 inches on October 5, 1911. Since the installation of the weather station at Jemez Canyon Dam in 1954, the maximum annual precipitation was 13.88 inches in 1987 and the minimum was 2.40 inches in 1956. The maximum recorded 24-hour rainfall was 2.75 inches on October 17, 1960. Mean annual precipitation in the Rio Jemez Basin varies from 8.35 inches at Jemez Canyon Dam to more than 30 inches in the high mountainous regions of the basin. About one-third of the annual precipitation occurs during July and August as thunderstorms.

During the winter months, heavy snowfall occurs in the upper mountainous areas of the watershed and snow is light over the lower basin. Snow remains in the mountainous areas above 7,000 ft. elevation from December into April. Below 7,000 feet in elevation, snow seldom stays on the ground more than a few days. The average annual snowfall varies from 10 inches at Jemez Canyon Dam to over 100 inches in the mountains.

Four notable floods have occurred since the Jemez Canyon Dam was completed in 1953 and the project began operation (Table 1). Summer or fall floods of significant magnitude have not occurred during project operation.

Jemez Canyon Reservoir reached a record pool elevation on June 2, 1987. Flood control storage starting on 13 April resulted in a maximum elevation of 5,220.3 feet (72,254 acre-feet).

Table 1. Highest Rio Jemez Inflows Recorded at Jemez Canyon Dam and Reservoir Project, the Pueblo of Santa Ana, NM.

Date	Peak inflow (cfs)
June 8, 1958	3,350
May 27, 1973	2,000
May 2, 1979	1,282
June 2, 1987	1,242

In the Rio Jemez Basin, runoff response to precipitation is very rapid due to steep slopes, resulting in floods with very high peak flows. Flood volumes are usually small due to an interaction between the areal extent of the watershed and the temporal and areal nature of a storm event. The mountain streams are narrow and steep so flow rises very rapidly and falls rapidly after the peak passes. The Rio Salado channel in the lower reaches and the Rio Jemez channel below the Rio Salado confluence are wide and sandy with a shallow, braided flow pattern that results in rapid attenuation of floods with high peaks and small volumes. The mountains, due to the vegetal cover, have relatively high evapotranspiration loss rates of 0.5- to 1.0-inch per hour. This, along with significant depression storage in the valleys, greatly reduces runoff. The mesas have flatter slopes, grass and herbaceous cover, and large playas that reduce runoff. Mesa loss rates vary from 0.2 - to 0.5-inch per hour. The area generally below an elevation of 6,000 feet is covered by semi-arid desert vegetation and has the lowest loss rates (0.1 - to 0.3-inch per hour) due to the scarcity of vegetation and soils with high clay content. Summer thunderstorms with their very high intensity precipitation and short duration often result in 80% or greater runoff from this area. Spring runoff from snowmelt during March through June produces most of the annual runoff volume. Sixty percent of the flow occurs in April and May from the winter snowpack accumulation. Thirty-four percent of annual precipitation occurs as summer thunderstorms in July and August.

The mountain streams are perennial with high flows in the spring or immediately following a storm. Summer, fall, and winter flows are very low and clear. The Rio Jemez is usually dry during the summer at the Rio Salado confluence (south of San Ysidro) due to upstream irrigation diversions and evapo-transpiration. Most streams below 7,000 feet in elevation are intermittent and flow only following precipitation that exceeds infiltration and evapo-transpiration losses.

3.04 GEOMORPHOLOGY

The total area drained by the Rio Jemez is 1,038 square miles, with 1,034 square miles above the dam. The watershed is about 65 miles long with a maximum width of 30 miles. The terrain rises from elevation 5,120 feet at the dam to over 11,000 feet in the mountainous region of the headwaters in the Jemez Mountains. The stream channel in the upper reach is confined within narrow canyons. The stream meanders through a broad sandy valley in the lower reaches and through the reservoir area which is several hundred feet wide without well-defined banks. Below the dam the river enters a narrow canyon, which extends to the confluence with the Rio Grande. Stream slopes vary from 0.3% at the dam to greater than 4.7% in the mountains.

The Rio Jemez at the project impact area can be classified as a Rosgen D5 stream type (Rosgen 1996). A D5 river/stream is characterized by braided streams within a broad alluvial valley and an alluvial fan consisting of deposited sand-sized material. Channel bed materials are predominantly sand with interspersed amounts of silt/clay materials on deltas. The braided channel system is characterized by high bank erosion rates, excessive deposition occurring as both longitudinal and traverse bars, and annual shifts of bed location. Bed morphology is characterized by a closely spaced series of rapids and scour pools formed by convergence/divergence processes that are very unstable. A combination of conditions are responsible for channel braiding, including high sediment supply, high bank erodibility, and very flashy runoff conditions which can vary rapidly from a base flow to an over-bank flow on a frequent basis (Rosgen 1996).

The principal mountain tributary of the Rio Jemez is the Rio Guadalupe, which enters the river about 26 miles upstream from the dam. It originates in the Jemez Mountains and is perennial. Coniferous forest, interspersed with groves of aspen, covers the watershed above 7,000 feet. Vegetal cover in the lower elevations includes pinyon pine, juniper, and oak brush with very sparse grasses and forbs. The upper area is characterized by steep slopes varying from 250 feet per mile to 130 feet per mile, which results in rapid runoff.

The principal tributary in the lower basin is the Rio Salado, an ephemeral stream, which drains the southwest portion of the Rio Jemez Basin. It originates in the lower mountain region and flows through the highly erodible, low-lying plateau area of the watershed. Vegetal cover is sparse and consists of short grass and desert shrubs. Slopes in this area vary from about 2.5% at higher elevations to 0.3% along the Rio Jemez delta. Because of the nature of the soils and plant cover, the lower area is much more conducive to runoff than the upper area. The Rio Salado-Rio Jemez confluence is near San Ysidro about 17 miles upstream from the dam.

3.05 SEDIMENTATION

The Rio Jemez above its confluence with the Rio Salado at San Ysidro has a drainage area of about 600 square miles. From sediment sampling records between February 1937 and June 1941, suspended sediment passing San Ysidro was approximately 400 acre-feet per year and the average concentration for all months of record was 0.46% sediment by weight. Some sediment was diverted into irrigation ditches at San Ysidro. No known sediment samples were secured from this location between 1941 and 1975 (USACE 1975).

The Rio Salado has a drainage area of about 251 square miles, most of which is plateau with rough, broken and hilly terrain, and is easily eroded. For about three miles above San Ysidro, the streambed is wide and sandy. Sediment sampling on this stream showed that the sediment load was about 150 acre-feet per year including 15 acre-feet of bedload. Records of sediment sampling from the Rio Jemez at Zia Pueblo, about five miles below the Jemez-Rio Salado confluence, show an average annual suspended sediment load of about 500 acre-feet per year (USACE 1994).

Below San Ysidro, the characteristics of Rio Jemez suddenly change. The slope becomes flatter and the streambed becomes wider and is plugged with sand and fine material, which is washed into the river from tributaries and aeolian deposition. The 183 square miles of drainage area between Jemez Dam and San Ysidro produces about one-half of the total sediment entering the reservoir area. Most of the sediment comes from the south side of the Rio Jemez where the Santa Fe formation is exposed or is covered with a mantle of wind-blown alluvium. The surrounding area is sparsely vegetated. The terrain consists of rolling hills cut by numerous steep-sided arroyos. Near the river extensive dunes have advanced to the edge of the stream in some places. Runoff from this area discharges large quantities of sediment into the river. The suspended sediment load entering the reservoir area was estimated to be about 910 acre-feet per year and the bed load about 10% of the suspended load for a total of about 1,000 acre-feet per year. Approximately 60% of the total yearly runoff occurs during the spring runoff period and about 70% of the total suspended sediment load occurs during this period (USACE 1994)
The transport and deposition of sediment, which affect the operation of Jemez Canyon Dam and Reservoir Project, are monitored by the measurement of suspended sediment concentrations of reservoir outflow and by periodic ground and hydrographic surveys of the reservoir area. Thirteen transverse sediment ranges were installed in Jemez Canyon Reservoir in 1952 and marked with concrete monuments (Figure 3). Each range was numbered and profiled. Ranges 10 through 13 are located above the maximum water surface of the reservoir for the purpose of determining channel changes and aggradation or degradation of the river channel. Ranges 1 through 9 are used to determine the amount of sediment deposition that has taken place in the reservoir area. Sedimentation resurveys are normally scheduled on a five to seven year basis. Resurveys at Jemez Canyon Reservoir were conducted in August 1959, December 1965, January 1975, December 1983, June 1991, and June 1998.

According to a Corps 1998 longitudinal reservoir profile survey, the apparent extent of upstream influence of sediment deposition on the channel is around Range Line R-9, just upstream of the bridge to the old the Pueblo of Santa Ana. There is reason to believe that this bridge causes deposition to be greater in this immediate area, but deposition has also been affected by the presence of Jemez Canyon Dam (USACE 1975). Deposition also occurs at Rangeline R-5 where a large arroyo enters from the south, and at Rangeline R-4 where the mean pool elevation since 1986 has occurred.

3.06 GROUNDWATER

Groundwater has been monitored along the Rio Jemez delta on lands of the Pueblo since January, 2001 by the Pueblo's Department of Natural Resources staff and consultants. Piezometers were installed at various depths and reveal that groundwater depths tend to be relatively shallow throughout the year; the depths were greatest in late summer, and shallowest during winter and spring. The shallowest groundwater occurs between the old Tamaya Pueblo (equivalent to Rangeline R-8) and R-5. Consultants to the Pueblo determined that during 2001 above Rangeline R-4, the local shallow groundwater flow system is largely controlled by the regional groundwater flow system and the Rio Jemez. Below Rangeline R-4, the local shallow groundwater flow system was largely controlled by the regional groundwater flow system and Jemez Canyon Reservoir. The observed groundwater backwater effect caused by Jemez Canyon Dam did not extend much above Rangeline R-4 but could extend to Rangeline R-5A. The highest groundwater effect between R-8 and R-5A may be sustained by the natural constriction at R-5 more than by the reservoir.

During construction of the Pueblo of Santa Ana levee, about 1.5 miles upstream of the proposed project site, pumps were installed to remove water from the interior of the levee. Since the establishment of the 1986 sediment pool it has been necessary to pump water from the site. During spring runoff season, it has been necessary to pump twice weekly. Four piezometers were installed at the site in May 2000. Although there is limited data at this point, it appears the groundwater at this site (commonly referred to as Tamaya Pond) is mostly influenced by the existing stream flow.

3.07 WATER QUALITY

In the spring of 1999, the Pueblo of Santa Ana, the New Mexico Fisheries Resource Office of the U.S. Fish and Wildlife Service, and the Corps cooperated in a preliminary study of heavy metal concentrations in the reservoir, sediments, and biota at Jemez Canyon Reservoir. Surficial sediment samples showed no contamination of metals, and one water sample was just above the detection limit (0.0002 mg/L) for mercury. (See additional discussion below regarding biota.)

3.09 ECOLOGICAL SETTING

Plant Communities

The Rio Jemez delta is within the Plains-Mesa Sand Scrub biotic community as defined by Dick-Peddie (1993), and vegetation typical of this community dominates the entire area south of the Rio Jemez on Pueblo of Santa Ana lands. The following grasses and forbs occur in sparse to moderately dense stands throughout the area: black grama, New Mexico feathergrass, western wheatgrass, galleta, sand dropseed, and ring muhly. Shrubs commonly found throughout the area include fourwing saltbush, sand sagebrush, rabbitbrush, and bush penstemon. Unconsolidated sand dunes with sparse pioneer vegetation occur in a portion of this community. At slightly higher elevations, and often interspersed with the sand scrub community, are pinyon pine /one-seed juniper woodlands.

Prior to construction of Jemez Canyon Dam in the early 1950s, the Rio Jemez floodplain between the damsite and the old Pueblo of Santa Ana was very sparsely vegetated (USACE 1976). The river occupied a wide, braided channel through the area. Plant community establishment was likely hindered by ephemeral flows, periodic large floods, deposition of sediment, and a shifting channel. Riparian vegetation likely bordered at least a portion of the channel, especially near the western end of the current reservoir, but information on its location and extent is limited.

By the early 1970s, vegetation occupied about 624 acres of the 1,143-acre Jemez Reservoir flood pool below an elevation of 5,197 feet (USACE 1976). Vegetation development was likely enhanced by more frequent (but still periodic) flooding due to flood control operations, which generally increased soil moisture and nutrient availability. The widespread invasion of salt cedar throughout the middle Rio Grande Valley during this period also contributed to plant community development at Jemez Canyon

Reservoir.

In 1976, the upper portion of the reservoir pool space near the proposed project impact area was vegetated by volunteer salt cedar with a modest understory of salt grass and sedges. A salty crust on the soil surface was common (USACE 1976). A dense and varied riparian community bordered the river channel, which wound through the reservoir (USACE 1976). Mixed stands of willow, cottonwood, Russian olive, and saltcedar were interspersed with western wheatgrass, mat muhly, ring muhly, and shadscale. The relatively moist soils along the river channel were able to sustain willow and cottonwood growth, while saltcedar dominated the drier soils throughout the remainder of the basin. Tree ages indicated that flood control storage during 1959 and 1965 was responsible for germination of most of the woody vegetation throughout the reservoir.

Vegetation patterns were not markedly different in 1984. The establishment of the 2,000-acre sediment pool in 1979 inundated up to 100 acres of dense saltcedar in the lower portion of the reservoir (USACE 1984). Plant communities in the upstream portion of the reservoir near the proposed project impact area appear to have been affected only locally where sediment deposition patterns were altered as a result of the pool. A narrow band of riparian vegetation occurs along the former sediment pool margins. In the delta area, large mixed stands of Rio Grande cottonwood, Gooding’s willow, and coyote willow occur, intermixed with non-native Russian olive, salt cedar, and occasional Siberian elm.

Wetlands

A formal delineation survey of the Rio Jemez delta on the Pueblo of Santa Ana has been conducted by consultants to the Pueblo and inspected and confirmed by USACE Albuquerque District Regulatory Branch. The majority of the vegetated delta discussed above is classified as wetland as defined in Section 404(b)(1) of the Clean Water Act. The area is dominated by facultative and facultative-wetland species and is inundated by surface flows for at least 11 contiguous days during the growing season. The Rio Jemez channel and the current sediment pool are regulated “waters of the United States” as defined in Section 404 of the Clean Water Act.

Fish

No comprehensive fish surveys have been conducted in the vicinity of the proposed project area. Prior to the creation of the former sediment pool, the fish community was comprised primarily of native species such as gizzard shad, red shiner, longnose dace, fathead minnow, flathead chub, river carpsucker, smallmouth buffalo, western mosquitofish, and bluegill. These fish were adapted to the ephemeral condition of the lower Rio Jemez (USFWS 2001). No Rio Grande silvery minnows are currently known to occur upstream of the Jemez Canyon Dam, and therefore are not known to occur in the intermittent, sometimes ephemeral reach of the proposed project area.

As referenced in the water quality section, a preliminary study of heavy metal concentrations in the reservoir, sediments, and biota was conducted during 1999 at Jemez Canyon Reservoir. Tissue samples of largemouth bass and channel catfish indicated some bioaccumulation of mercury. Mercury concentrations in several samples were greater than 0.5 parts per million (ppm) wet weight, indicating a low level of risk for consumption. Preliminary comparison to the U.S. Environmental Protection Agency (1977) “reference doses” suggest that there could be a risk to young children and pregnant women consuming fish for as few as 14 days per year. However, due to the pool evacuation and on-going drought, the lower Rio Jemez remained dry from March 2002 until the occurrence of monsoon thunderstorms in July and August, and no live fish are known to be present in the proposed project area.

Wildlife

Riparian areas with moist soil conditions are considered important areas for many life stages of many species of Southwestern U.S. wildlife. The following species have been detected by surveys within the bosque area of the lower Jemez delta on the lands of the Pueblo of Santa Ana (Consultants to the Pueblo, Inc. 2001b; Walker 2001). It should be noted that a reservoir pool existed at the time that the above surveys were conducted. Please see Appendix A for a comprehensive list of birds, mammals, amphibians and reptiles that could potentially occur in Sandoval Co., NM near Jemez Canyon Dam and Reservoir Project.

Birds
Least Bittern Gray Catbird Mockingbird
Great Blue Heron Townsend's Warbler Common Yellowthroat
Black-Crowned Night Heron Yellow-Breasted Chat Song Sparrow
White-Faced Ibis Yellow Warbler Black-Headed Grosbeak
Kildeer Peregrine Falcon Western Scrubjay
Western Wood Pewee Ruby-Crowned Kinglet Evening Grosbeak
Dusky Flycatcher Spotted Towhee Vesper Sparrow
Gray Flycatcher Western Meadowlark Brown-Headed Cowbird
Cordillean Flycatcher Bullock's Oriole Lark Sparrow
Vermillion Flycatcher Blue Grosbeak Pine Siskin
Say's Phoebe House Finch American Crow
Ash-Throated Flycatcher Raven Black Phoebe
Western Kingbird Northern Roughwinged Swallow Yellow-Rumped Warbler
Violet-Green Swallow Black-Chinned Hummingbird Common Nighthawk
Cliff Swallow Mourning Dove Gambel's Quail
Barn Swallow Northern Harrier Red-Tailed Hawk
Bewicks Wren Hairy Woodpecker Northern Flicker
Yellow-Billed Sapsucker Mountain Chickadee Western Yellow-Billed Cuckoo
Southwestern Willow Flycatcher

Bats
Western Small Footed Myotis Little Brown Myotis
Long-Legged Myotis California Myotis
Pallid Bat Pipistrelle
Mexican Free-Tailed Bat Northern Long Eared Myotis
Western Mastiff Bat Fringed Myotis
Big Brown Bat Big Free-Tailed Bat
Hoary Bat

Amphibians and Reptiles
Red Spotted Toad Woodhouse's Toad
Western Chorus Frog Bullfrog
Side-Blotched Lizard Northern Mexican Whiptail
Plateau Striped Whitptail Checkered Whiptail
Leopard Lizard Striped Whipsnake
Slider

Non-volant mammals that use the bosque area of the Rio Jemez delta on lands of The Pueblo of Santa Ana include furbearers, big and small game mammals, and a host of small rodents. Riparian habitat is used at least sporadically by virtually all of these mammals. The New Mexico Ecological Services Field Office of USFWS released a draft Fish and Wildlife Coordination Act Report regarding this proposed project in December 2001. From that report, appendix A lists potentially occurring mammals near Jemez Canyon Dam and Reservoir Project at The Pueblo of Santa Ana, NM.

Federally Threatened and Endangered Species

The Rio Grande silvery minnow (listed as Federally endangered July, 1994) is known to occupy the Rio Grande and may potentially occupy sections of the Rio Jemez downstream from Jemez Canyon Dam, but not above the dam. The silvery minnow likely had a historical presence in the lower Rio Jemez as demonstrated by collections made in 1958 (Hoagstrom 2000). However, as this sampling was conducted after the construction of the Jemez Canyon Dam, it is unknown if the silvery minnow ever occurred above the dam location. In the Proposed Rule (50 CRF Part 17, June, 2002) on Designation of Critical Habitat for the Rio Grande Silvery Minnow, the Rio Jemez is not designated as critical habitat for the species upstream of the Jemez Canyon Dam.

The Southwestern Willow Flycatcher (listed as Federally Endangered February, 1995) may occur in a variety of riparian habitat types along the Rio Jemez during spring or fall migration periods. Vegetation suitable for use during migration occurs at the margins of the Rio Jemez throughout the delta, and along the Rio Jemez downstream from the Dam. A survey to USFWS protocol standards was conducted throughout the Rio Jemez delta on the Pueblo of Santa Ana during the spring and summer of 2001, and no breeding Southwestern Willow Flycatcher pairs were documented (Walker 2001). A second survey was conducted in the spring and summer of 2002 by the Corps and the Pueblo of Santa Ana, and no breeding pairs were documented. A third survey of the proposed project impact area is being conducted from May 15 through July 17, 2003 to determine the presence or absence of breeding southwestern willow flycatchers. No willow flycatchers have been detected as of the date of this EA.

Breeding habitat for the Southwestern Willow Flycatcher includes very dense, tall (>=9ft.) shrubs or trees (willow, boxelder, Russian olive, saltcedar, and/or cottonwood) with a partial overstory, situated in or adjacent to saturated or moist soils or water bodies. Throughout the flycatcher's range, these riparian habitats are now rare, widely separated, and occur in small and/or linear patches. Low gradient streams and rivers are preferred habitat. Flycatchers begin arriving in the Rio Grande Valley of New Mexico as early as the first week of May, but more typically arrive in mid-to-late May. Potentially suitable flycatcher breeding habitat occurs in the delta at the western end of the Jemez Canyon Reservoir. The nearest known breeding flycatchers occur along the Rio Grande near San Juan Pueblo and Isleta Pueblo, 50 miles upstream and 35 miles downstream, respectively, from the confluence of the Rio Jemez.
Bald Eagles (downlisted to Federally Threatened 1995) are known to be present along the Rio Grande and have been present at Jemez Canyon Reservoir during the winter. Both adult and juvenile birds may be present in the area between late November and early March. The Corps conducted aerial surveys for Bald Eagles between 1988 and 1996 during January, the month of highest abundance. During the 8 years of survey, Bald Eagles were observed at Jemez Canyon Reservoir during 4 years and the number of birds observed ranged from 1 to 3. The same frequency and maximum number of eagles were observed along the main stem of the Rio Grande from the confluence of the Rio Jemez downstream to the Interstate 40 bridge at Albuquerque during the same survey period. The number of Bald Eagles observed along the Rio Grande from the Rio Jemez confluence north to and including Cochiti Lake was significantly higher. Collectively, these data indicate that Bald Eagles did not utilize the area around Jemez Canyon Reservoir preferentially when a pool existed. One Bald Eagle was sighted wintering in the vicinity of the evacuated pool of the reservoir during winter, 2001 (Wm. DeRagon, Biologist, Corps, pers. comm., 2002).

The Yellow-billed Cuckoo (Coccyzus americanus), western continental U.S. Distinct Population Segment (DPS) was assigned Candidate Status July 25, 2001 as warranted for listing under ESA but precluded because of higher priority species. While the cuckoo is still relatively common east of the crest of the Rocky Mountains, biologists estimate that more than 90 percent of the bird's riparian habitat in the West has been lost or degraded. These modifications, and the resulting decline in the distribution and abundance of Yellow-billed Cuckoos throughout the western States, is believed to be due to conversion to agriculture; grazing; habitat degradation by competition from nonnative plants, such as tamarisk; river management, including altered flow and sediment regime; and flood control practices, such as channelization and bank protection.

The western race of the yellow-billed cuckoo is associated with lowland deciduous woodlands, willow and alder thickets, second-growth woods, deserted farmlands, and orchards. Caterpillars form the main component of the diet, with cicadas, grasshoppers, beetles, bugs, ants, wasps, frogs, lizards, and small fruit being consumed in smaller amounts. Populations fluctuate substantially in response to fluctuations in caterpillar abundance. Declines resulting from loss or disturbance of riparian habitat have been consistently reported in the West. The greatest factors affecting the yellow-billed cuckoo have been the invasion of exotic woody plants into Southwestern riparian systems, and clearing of riparian woodlands for agriculture, fuel, development, and attempts at water conservation

Walker (2001) estimated at least 10 pairs of Western Yellow-billed Cuckoos inhabited the Jemez Canyon delta on the Pueblo of Santa Ana based on a 2001 survey of the area. A pair of yellowbilled cuckoos was observed off the proposed project impact area in June, 2002 and individuals were heard in June, 2003 (Matt Clark, Pueblo of Santa Ana and Champe Green, USACE, pers. comm., 2003)

State of New Mexico Endangered and Threatened Species

New Mexico has separate provisions from federal law for endangered plants and animals. The New Mexico Department of Game and Fish, through its Conservation Services Division, administers the Wildlife Conservation Act. (NMSA 1978 § 17-2-37 et seq.) The Act requires the listing of any species or subspecies of "wildlife indigenous to the state" as endangered or threatened on the basis of investigations and other scientific and commercial data, and after consultation with wildlife agencies in other states, federal agencies, local and tribal governments, and other interested persons and organizations. It is important to note that federally recognized tribal reservations are sovereign and exempt from compliance with state wildlife laws.

The Peregrine Falcon is listed as Threatened in New Mexico, and individuals were observed in the bosque area of the Rio Jemez delta on Pueblo of Santa Ana land in the fall of 2001 (Consultants to the Pueblo, 2001)

A state threatened species that may occur but is not documented as occurring on the proposed project impact site is the New Mexico meadow jumping mouse. The New Mexico meadow jumping mouse is found in riparian meadows of grass and forbs. In both the Jemez Mountains and the Rio Grande Valley, Morrison (1992) found that preferred habitat for the meadow jumping mouse contained permanent streams, moderate to high soil moisture, and dense and diverse streamside vegetation consisting of grasses, sedges, and forbs. Since the lower Rio Jemez without the sediment pool in the Jemez Canyon Reservoir is intermittent at best (and likely ephemeral when agricultural diversion occurs upstream of the proposed project area), it is unlikely that the meadow jumping mouse occurs within the project area.

The project area might include several Species of Concern, of which those most likely to be present are the big free-tailed bat, long-eared myotis, and Townsend's big-eared bat. Big free-tailed bats prefer coniferous and mixed woodland and depend on rocky cliffs for roosting. However, they have been found in sycamore and cottonwood riparian habitats (BISON-M 2001). The long-eared myotis occurs in coniferous forests at moderate elevations. It is most common in ponderosa pine woodlands and is also found in pinon-juniper woodlands and subalpine forests. The animals use day roosts in tree cavities, under loose bark, and in buildings. These sites as well as caves and mines are used for night roosts. The longeared myotis feeds over water and along the margins of vegetation, and thus may use the project area when the reach is wet (BISON-M 2001). Townsend's big-eared bat occurs widely in the state during summer and can be found over desertscrub, in shelters in desert-mountains, oak-woodland, pinyonjuniper, or coniferous forests. This bat occupies a diversity of habitats, including desert shrublands, pinyon-juniper woodlands, and high-elevation coniferous forests. However, it does forage over water and thus could potentially occur at the proposed project site when the river reach is wet (BISON-M 2001).

The Forestry Division of the Energy, Minerals and Natural Resources Department (EMNRD) administers the Endangered Plant Species Act, passed in 1985 (NMSA 1978 § 75-6-1). This Act acknowledges only one status, "Endangered." The only rare plant potentially occupying the proposed project impact area is Parish's alkali grass, a state endangered grass and categorized as a Species of Concern by USFWS. It requires wet alkaline soils. It occurs at the heads of drainages or on gentle slopes at 800-2,200 m (2,600-7,200 ft) range-wide. The species requires continuously damp soils during its late winter to spring growing period. It frequently grows with salt grass, alkali sacaton, sedges, bulrushes, rushes, spike rushes, and yerba mansa (NMRPTC 1999).

3.10 LAND USE, RECREATION, AND AESTHETICS

All lands associated with the Jemez Canyon Dam and Reservoir Project are held in trust by the United States for the benefit and use of the people of the Pueblo of Santa Ana. The Department of the Army and the Pueblo of Santa Ana signed an MOU in 1952 (augmented in 1978 by P.L. 95-498) which established a perpetual right and privilege for the construction, operation, and maintenance of the Jemez Canyon Dam and Reservoir Project. The Pueblo of Santa Ana reserved the right to use all associated lands for any purposes not inconsistent with those expressly granted to the government for the facility. No livestock are now allowed to graze in the project area; however an occasional breach of fencing may occur with resultant short-term utilization of the area by cattle. Hunting, hiking, fishing, swimming, horseback riding, and ceremonial activities occur near the proposed project impact area.

3.11 CULTURAL RESOURCES

Cultural resources surveys of the project location including the weir construction area, access road, and staging areas, have been completed in consultation and cooperation with the Pueblo of Santa Ana and coordinated through the Pueblo of Santa Ana's Department of Natural Resources. The Corps is the lead review agency and reviewed the cultural resources inventory survey reports and the scope-of-work for limited testing. The Pueblo of Santa Ana contracted with Earth Analytic, Inc. to perform the cultural resources surveys and limited testing.

Prior to the surveys, Earth Analytic and the Corps conducted searches of the New Mexico Historic Preservation Division, Archeological Records Management Section's database that found that numerous archaeological sites occur on Pueblo of Santa Ana lands and several newly recorded sites are located near the project areas (Penner, Duncan, Byszewski, and Dorshow 2003 [EA 66.01]; Penner, Baletti, Byszewski, and Dorshow 2001 [EA 41a]). Searches of the State Register of Cultural Properties and National Register of Historic Places found that there are no known historic properties reported to occur within or immediately adjacent to the project areas other than LA8975, the Pueblo of Tamaya. During project planning, tribal members indicated that no Traditional Cultural Properties would be affected by the projects described below. During construction, work operations may be temporarily suspended for Pueblo ceremonies or special functions. Temporary work suspensions would be coordinated through all appropriate points-of-contact.

In late January and early February 2002, Earth Analytic, Inc. conducted a cultural resources inventory of two survey areas, covering a total of about 13.6 hectares (33.7 acres). The first area, identified as the Delta Neck Area and located at the upstream end of the sediment pool of the evacuated Jemez Reservoir, included the surveying of four alternative weir alignments and the adjacent gravel terraces located along the north bank of the reservoir. This survey covered approximately 12.5 hectares (31.0 acres; Dorshow and Barz 2002 [EA 41b]). The survey resulted in the discovery of one archaeological site, identified as LA135152. Earth Analytic recommended that the site is eligible for inclusion to both the State and National Registers. The Corps agrees that the LA135152 site is eligible. The second survey area was identified as the Southeast Access Road; the survey covered about 1.1 hectares (2.7 acres). The Southeast Access Road is located near and upstream of Jemez Canyon Dam's emergency spillway. No artifacts, cultural resource manifestations, or archaeological sites were observed during the Southeast Access Road survey.

Prior to the surveys of the Delta Neck Area and the Southeast Access Road, Earth Analytic conducted searches of the New Mexico Historic Preservation Division, Archeological Records Management Section's database and of the State Register of Cultural Properties and National Register of Historic Places. The searches found that while numerous archaeological sites occur on Pueblo of Santa Ana lands, there are no archaeological sites or historic properties located in the immediate vicinity of the surveyed areas.

Since the survey of the Delta Neck Area was conducted, the recommended alignment for the proposed weir has been moved a significant distance downstream of LA135152, and none of the four surveyed Delta Neck Area weir alignments are to be used; therefore there is no project in this area and there would be no effect to LA135152. Since there are no cultural resources known to occur near the Southeast Access Road, use of the road would have "No Effect to Historic Properties."

Between July 7 and October 2, 2002, Earth Analytic, Inc. conducted the cultural resources inventory survey of the weir construction site, the access road, and two staging areas located between U.S. Highway 550 and the upstream end of the Jemez Canyon Reservoir's sediment pool. The weir alignment, access road and staging areas survey covered a total of 28.5 hectares (70.46 acres; Penner, Duncan, Byszewski, and Dorshow 2003 [EA 66.01]). The proposed project provides for improvements to the access road that include gravel surfacing, straightening of sharp corners, and surface water drainage features. During the cultural resources survey, four archaeological sites were discovered within the alignment of the existing road (LA137047, LA137048, LA137049, and LA137050) and one archaeological site (LA137046) was discovered near the southern end of the newly proposed weir alignment.

The existing road crosses the four archaeological sites and limited testing was conducted at all four sites to determine their nature and extent. In consultation with the Pueblo of Santa Ana, it was determined that, rather than realigning the road (to bypass the four sites) and risk the possibility of discovering other cultural resources, the most practical solution would be to utilize the existing access road that has been in use for many years, and cover the four sites with 18 to 24 inches of clear earthen fill material to protect the sites in addition to the materials to be used to construct the road's surface. At the request of the Pueblo of Santa Ana, artifacts discovered within the road construction area were collected, analyzed, and were reburied at a known location within the confines on the site but outside of the road right-of-way. Artifacts and cultural manifestations observed at the four sites are similar and include chipped-stone, ceramics, ground-stone, and charcoal stain features.

Subsequent to the discovery of the LA137046 site near the southern end of the proposed weir, Corps' engineers redesigned the proposed weir resulting in a slight realignment; moving the southern one-half of the proposed weir further downstream, away from LA137046. Therefore, the construction of the Weir and Access Road project would have "No Adverse Effect" to the LA137047, LA137048, LA137049, and LA137050 sites located along the road and there would be "No Effect" to the LA137046 site near the southern end of the weir. Monitoring will occur during all earth-moving construction activities. The existing access road, to be used to access the weir construction site, crosses the old, historic 1940s Santa Fe Northwest Railroad grade (EA41.04, LA138836 [LA78691]), at about a right angle. The Corps is of the opinion that use of the rehabilitated road would have "No Adverse Effect" on the old railroad grade.

Earth Analytic recommended that sites LA137046, LA137047, LA137049, and LA137050 are eligible for inclusion to both the State and National Registers and that LA137048 was potentially eligible. The Corps agrees with Earth Analytic's eligibility recommendations for these sites.

During engineering design work on the Jemez Weir Access Road, it was determined that, in several locations, eroding arroyos may threaten the road in the near future and therefore erosion control measures should be planned for. When the proposed locations for erosion control features were determined, Earth Analytic conducted a cultural resources survey of three areas, as well as an area where the road alignment was to be slightly realigned. The survey was conducted on April 16, 2003, covering a total of 20.7 hectares (51 acres), and is reported by Byszewski 2003. During the survey, one archaeological site was discovered; LA139126 is a lithic and ceramic artifact scatter with two thermal stain features.

The site has been significantly affected by surface water erosion with Earth Analytic estimating that only 30 percent of the site remains intact. The proposed erosion control structure for the primary arroyo in this area would be located about ten meters outside of the site boundary as defined by Earth Analytic. Pueblo of Santa Ana Tribal representatives originally had concerns and therefore visited the site; however, they determined that access to and from the location and the proposed installation of the erosion control structure, sheet piling to be driven into place with wire-wrapped, rock filled gabion baskets placed immediately downstream of the sheet piling, would not affect the archaeological site. Earth Analytic recommended that the site was potentially eligible for nomination to the State and National Registers. The Corps agrees that the site is potentially eligible and the Corps is of the opinion that the proposed project would have “No Effect” on the LA139126 site.

Culture history for the Pueblo of Santa Ana and generally for the middle Rio Grande area has been documented in numerous references such as White (1942), Cordell (1979, 1984, 1997), Ortiz (1979), Strong (1979), and Bayer (1994). The Northern Rio Grande Region has been archaeologically defined by Wendorf and Reed (1955). Archaeological surveys conducted in the Santa Ana Pueblo area have been reported by Enloe (1976), Rodgers (1979), Hammack (1981), Harrill (1984), Walt and Marshall (1986a, 1986b), Frizell and Acklen (1987), Condie (1993), Anschuetz *et al.* (1995), Bradley and Brown (1998), and Brown (1999). In recent years, the Pueblo of Santa Ana has been actively working to develop and protect its natural and cultural resources and has sponsored numerous archaeological surveys on Pueblo lands in anticipation of construction and rehabilitation projects and habitat restoration efforts related to Pueblo conservation and development. Some of these recent Pueblo of Santa Ana projects include Acklen *et al.* (1998), Acklen and Railey (1998), Larralde (1999, 2000), Penner *et al.* (2001a), and Everhart (2001, 2002).

The Corps is of the opinion that there would be “No Adverse Effect to Historic Properties” by the proposed project or on the historic and cultural resources of the region. Should previously unknown artifacts or cultural resource manifestations be discovered during construction, work would be stopped in the immediate vicinity of the find, a determination of significance made, and a mitigation plan formulated in consultation with the Pueblo of Santa Ana and the New Mexico State Historic Preservation Officer. All archaeological site recording forms and reports have been submitted to the Pueblo of Santa Ana and the New Mexico State Historic Preservation Officer. Consultation with the Pueblo of Santa Ana and the New Mexico State Historic Preservation Officer is documented in Appendix B.

3.12 SOCIO-ECONOMIC ENVIRONMENT

The Pueblo of Santa Ana Reservation covers approximately 79,000 acres spanning the Rio Grande and lower Rio Jemez. The majority of the population of approximately 850 resides in three communities along the east side of the Rio Grande. The historic pueblo mentioned previously in this document is located along the Rio Jemez.

Principal employment sectors include agriculture, government, and service. Over the past 25 years, the Pueblo of Santa Ana has developed a successful agricultural enterprise centered on the production and processing of organic blue corn products. Other natural resource enterprises include sand and gravel mining and a native plant nursery. Extensive recreational and entertainment attractions include the Santa Ana Star Casino, the Prairie Star Restaurant, two golf courses, a 22-field soccer complex, and the Tamaya Hyatt resort which opened in December 2000.

4. PLAN FORMULATION

Beginning in 2001 and ongoing, the Pueblo of Santa Ana facilitated monthly planning sessions with the Corps, consultants to the Pueblo, and the USFWS to discuss objectives for the mitigation of the evacuation of the Jemez Canyon Reservoir sediment pool. Through these sessions and ensuing coordination and data collection, a set of alternatives was developed. The Corps' HEC-6 modeling software was used to estimate river channel changes that would occur from pool evacuation. As a result of the model runs, four low-head sheetpile weir location alternatives were considered to remedy the predicted channel incision that would jeopardize the mixed native/exotic species bosque above Rangeline four. After analyzing the alternatives with the Corps' incremental analysis software, the following incremental costs per unit (acre) of habitat conserved were considered.

Option	**Cost**	**Ac. Protected**	**Avg. $/Ac.**	**Incremental $**	**Incremental Ac. Protected**	**Incremental $/Ac.**
No Action	$0.00	0	$0.00	$0.00	0	$0.00
Weir Location Option 1	$1,931,700.00	299	$6,460.54	$1,931,700.00	299	$6,460.54
Weir Location Option 2	$2,083,300.00	323	$6,449.85	$151,600.00	24	$6,316.67
Weir Location Option 3	$2,729,100.00	355	$7,687.61	$645,800.00	32	$20,181.25
Weir Location Option 4	$3,451,500.00	390	$8,850.00	$722,400.00	35	$20,640.00

Location option one was dismissed due to the potential visibility of the weir from the old Pueblo upstream. Location option two was dismissed because of its low number of bosque acres protected/conserved. Location option three was dismissed because its location would disturb a cultural site important to the people of the Pueblo of Santa Ana. The site is also eligible for the Registry of National Historic Preservation Cultural Sites. Location option four was the selected alternative because of the following reasons: 1) largest acreage of bosque conserved; 2) not visible from the old Pueblo, and 3) absence of cultural resources within the construction impact area.

6. SUMMARY AND CONCLUSION

The Jemez Canyon Dam and Reservoir Project was authorized by the Flood Control Acts of 1948 (P.L. 80-858) and 1950 (P.L. 81-516) for flood damage reduction and sediment retention. Construction of the dam began May 1950 and the facility was completed and placed into operation in October 1953. All lands associated with Project (approx. 6,711 ac.) are held in trust by the United States for the benefit and use of the Pueblo of Santa Ana.

The reservoir did not include a permanent pool for the first 26 years of operation. In 1979, the Corps and the New Mexico Interstate Stream Commission (NMISC) agreed to establish a 2,000-acre-foot sediment retention pool. To further improve sediment retention, the Corps and NMISC agreed, in a 1986 Memorandum of Understanding (MOU), to store water within the remaining sediment storage space, as much as 29,712 acre-feet at that time. The Corps-NMISC storage agreement expired on December 31, 2000 (the MOU's original expiration date). The existing sediment pool was evacuated by October, 2001 and has not been refilled.

The proposed action evaluated in this EA entails the following: The Corps and the Pueblo of

Santa Ana propose a series of four interlocked polyvinyl chloride (PVC) sheetpile sections. The weir would be oriented roughly perpendicular to the Rio Jemez channel, approximately 2.5 miles upstream of Jemez Canyon Dam. The suggested weir design has a series of 4 vertical drops where the river thalweg will drop a total vertical distance of 14 ft. A 25-ft. long downstream horizontal impact zone of wire-enclosed rock would be placed below the sheetpile weir sections in the invert. The lateral extent of the first vertical drop would be across the entire width of nonvegetated channel, with successive drops increasing uniformly in extents at 45 degrees. Only the second row of sheet piling would be extended to high ground on each side of the river. The top of the second row would increase in incremental one-foot high steps. Stair-stepped configuration of the second row of sheet piling is meant to induce over bank flows towards the center of the weir structure. Two additional sheet-piling rows would extend diagonally from second row to the third and fourth row along created slopes. These diagonal rows of sheet piling are intended to add stability to wire enclosed rock protection set on slope and to divert flow back towards the center of weir structures.

Two wing dikes would be constructed, one on each side of the river channel on the upstream side of the weir to maintain higher peak flows within the existing channel. The wing dikes would be earthen berms, covered in rock armor, with a maximum height of about two ft. above the height of the weir. The dikes would be approximately 450 ft. long, flaring out from each bank in the upstream direction. The Corps has conducted a hydraulic analysis study to justify this design.

The rock for the wire-enclosed aprons and wing dike armor would be removed from an existing basalt quarry located on Pueblo of Santa Ana land in the vicinity of the dam site. Rock would be extracted with explosive charges, then crushed and stockpiled at the quarry site.

A staging area, not to exceed two acres, would be provided for the contractor’s use during the construction phase of the project. Construction limits of 50 ft. upstream of the weir and 200 ft. downstream of the weir would be established around the perimeter of the project to prohibit any unnecessary destruction of habitat. The project site would be accessed via an existing four-mile-long two-track road originating from U.S. Hwy 550 (Figure 2). This access road would be improved with accepted rural road best management practices to accommodate heavy vehicular traffic while minimizing soil erosion and maintaining water quality standards and protecting other natural/cultural resources. Final design of the weir would be accomplished by August, 2003, and construction would be performed during August, 2003 through March, 2004. The staging area (two acres) and construction corridor (18 acres) and any other upland areas disturbed by construction activities would be revegetated with native plant species after construction is completed, as soon as temperature and moisture conditions allow. Howevr, species selection and planting density will be tempered by the potential for fuel accumulation near the weir which, if ignited, could destroy or damage the weir.

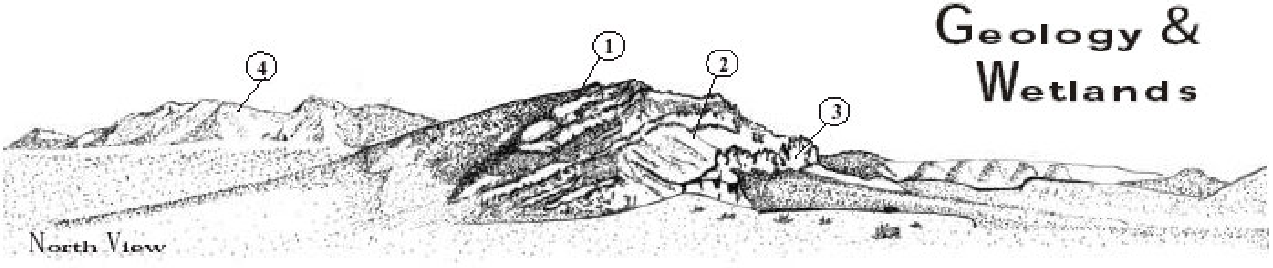
The proposed plan is compared to the method, timing, and potential effects of the no-action alternative. Because there are no proposals for future permanent water storage in Jemez Reservoir, that action was not considered a reasonable alternative for evaluation in this Environmental Assessment. Prior to implementation of construction activity under the proposed plan, an individual permit relative to Section 404 of the Clean Water Act would be obtained from the Albuquerque District Regulatory Branch, and a Section 401 Water Quality Certification Permit would be obtained from the U.S. Environmental Protection Agency, Region 6.

In consideration of the relative effects to the human environment evaluated in this Environmental Assessment, the proposed plan is recommended for implementation.

Geology & Wetlands

Perea Nature Trail

U.S. Department of the Interior
Bureau of Land Management
Albuquerque Field Office



Trail Location:

Located in San Ysidro, New Mexico, just off US 550, at the Rio Salado Bridge.

Geology:

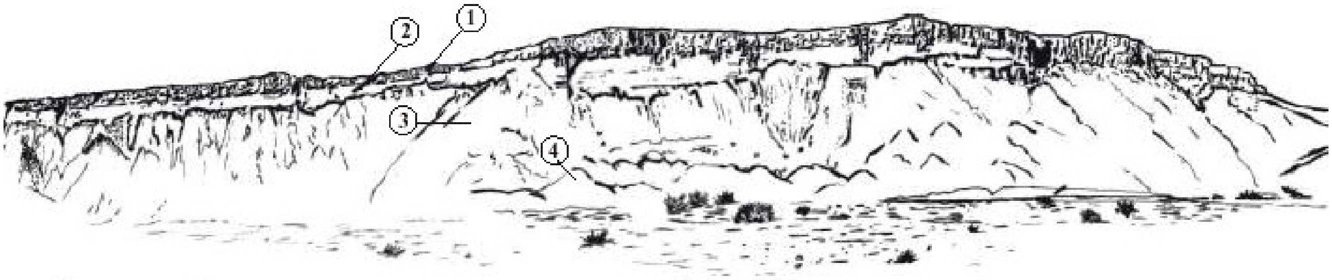
The view to the North, from the Perea Nature Trail, is dominated by a mountain peak, meagerly covered with native juniper and grasses. The mountain highlights the Jemez Mountain range, which is the southern start of the Rocky Mountains that extend northward to Alaska.

1. The western reaches of the mountain peak, and its crest, are composed of a white-to-tan sandstone that forms sharp ridges. It is of the Triassic Age and called the Agua Sarca formation.

2. Lower, on the east side of the peak, an overlay of grey Permian-Age sandstone appears. The sand stone is called the Glorieta formation and is a cliff-forming rock.

3. The slope breaks abruptly, and forms a brilliant red, vertical face at the San Ysidro Fault. Here, the mountain is striped with shades of red. This was developed during the Permian Age and these stripes are out-crops of the Abo and Yeso formations. The Abo formed in river channels and on floodplains, while the Yeso formed in a shallow marine environment with local wind-blown sands.

4. The high rock formations with purple hues seen in the distance are part of the Nacimiento Mountain chain. These are principally granite, gneiss, and schist that formed during the Precambrian Age. The gneiss and schist form the core of the Nacimientos, and are the oldest rocks in the area.



Southwest View

Visitors to the Perea Nature Trail may look to the southwest, over the Rio Salado river bed, to view an outstanding geologic setting.

1. The Todilto layer forms the edge of a large flat mesa known as ‘Blanco Mesa’, for its unusual white surface. The mesa has been used as a creative background for motion picture scenes and photographic productions, and for the mining of gypsum. Gypsum is mined and shipped to Albuquerque and Bernalillo for manufacture of wall-board to be used nationwide in home construction.

2. At the upper reaches of the existing cliffs, layers of near-white rock can be seen. These layers are known as the Todilto Formation, also of the Jurassic Age. The Todilto Formation is composed of brown limestone at the base and is overlain by white gypsum up to 100 feet thick.

3. This layer is composed of light tan-to-yellowish sandstone cliffs, and is part of the Jurassic Age it is called the Entrada formation. The sandstone was formed from ancient sand dunes.

4. Rising from the sparsely vegetated grazing lands are small hills and mounds of landslide deposits, fallen from centuries of decay of the rocky cliffs above. These show an inter-mix of colors from red-to-orange in the lower layer, and grey-to-white material deposited from above. The lower layer was formed during the Triassic Age and is part of a group of rocks called the Chinle formation.

Riparian-Wetland Area

Riparian-wetland areas occupy a unique position in the landscape and life of the western United States. They are a great deal more important than we might expect, given their relatively small acreage (less than 2 percent of the land in New Mexico).

Riparian-wetland ecosystems are areas near rivers, lakes or springs and are important islands of environmental diversity. Lying within much larger, drier and higher ("upland") ecosystems, these small areas attract greater numbers and more use by wildlife and livestock than their size would suggest. In terms of the total volume of plants they support, they are generally more productive than the nearby uplands. They also add to the supply of groundwater, reduce the effects of flooding, and remove pollutants.

Wetlands have a water table at, near or above the land surface. They are waterlogged for a long enough period to support "hydric" soils (with a higher level of the element hydrogen and less oxygen) and "hydrophytic" vegetation (those plants that grow well in very wet soil). Plants in wetlands are especially good at producing oxygen.

Wetlands are so productive because they can catch large amounts of the sun's energy and store it as chemical energy, and they recycle much of the energy they produce on their own. These areas and their plants are nutrient traps that in the future will probably help us with some of our air and water pollution problems.

Geologic Time Scale	
Subdivisions Based on Strata/Time Systems/Age	Radiometric Dates (millions of years ago)
Quaternary	0-2?
Tertiary	2?-63
Cretaceous	63-145
Jurassic	145-210
Triassic	210-255
Permian	255-280
Pennsylvanian	280-320
Mississippian	320-360
Devonian	360-415
Silurian	415-465

For More Information Contact:

Bureau of Land Management
Albuquerque Field Office
Albuquerque, New Mexico 87107
(505) 761-8700
www.nm.blm.gov

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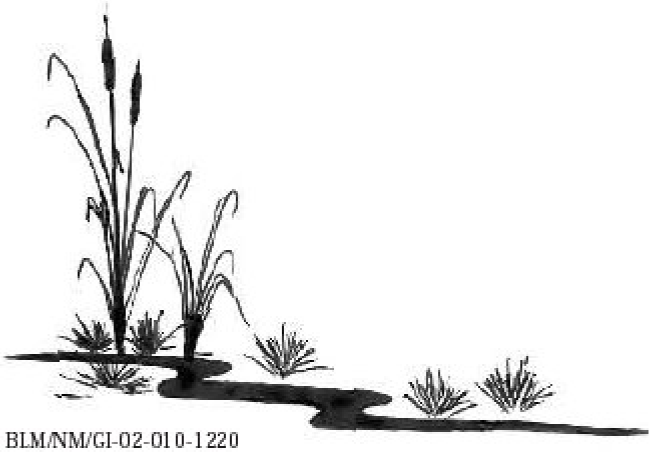

BLM/NM/GI-02-010-1220

News Release

U.S. Department of the Interior
U.S. Geological Survey

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Release
October 28, 2002

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http://www.usgs.gov/public/press/public_affairs/press_releases/pr1669m.html

The Ins and Outs of Ground-Water Flow in the Southwest: Recent population growth and development in the arid Southwest have made it essential for scientists to increase their understanding of ground-water flow responses in hydrologic systems. Studying ground-water removal and alteration ground-water inflow and outflow patterns is important for the effective management of ground-water systems. The principles that ultimately dictate these patterns are simple but not well understood by many water managers and hydrologists. In the past, effects of ground-water withdrawals have been viewed mostly in terms of lowering water tables and removing water from storage. Today water-resource managers must increasingly consider how withdrawals affect the amount of water flowing in and out of aquifers. A primary concern is that ground-water withdrawals over long periods will reduce ground-water outflow, and water availability to streams, wetlands, and riparian areas. To hear more about the principles that determine the ultimate responses of inflow and outflow to ground-water withdrawals in the Southwest, attend "The Ins and Outs of Ground-Water Flow in Basins of the Southwest," from 8:35 to 8:50 a.m. on Monday Oct. 28 in Room A209.

A Sinking Feeling: What happens when agricultural and municipal-industrial demands for ground-water deplete groundwater resources? In the western United States, scientists have documented 100 meters or more of ground-water level declines, and in many places the declining trends continue at rates of 300 mm or more per year. By using satellite-borne radar (InSAR), along with other techniques, USGS scientists and their colleagues are able to detect areas that are more susceptible to aquifer-system compaction, especially in the southwestern United States. Subsidence is an ongoing concern in the San Joaquin Valley, Calif., and numerous other areas in California; the Houston-Galveston area; Las Vegas Valley, Nev., and throughout south-central Arizona. To learn more, attend "Ground-Water Depletion and Spaced-Based Monitoring of Aquifer-System Compaction in the Western USA," 8:50 a.m. to 9:05 a.m. on Monday Oct. 28 in Room A209.

Water Availability for the Western United States---the Challenge for Science: In the American West, ensuring sustainable water supplies for agriculture, industry, and municipal use without adverse effects on the environment has become a Herculean challenge. For example, the rate of U. S. population growth is the greatest in the Southwest – the most arid region of the country. Surface water is fully developed in most cases, and aquifers near population centers are already in various stages of depletion. Many communities in the Southwest are dependent on water withdrawn from ground-water storage, which cannot be sustained in the long-term. Water availability has come to mean water for endangered flora and fauna, in addition to the traditional off-stream uses such as municipal supplies and irrigation. A key challenge for science in this new era will be to quantify the physical habitat requirements of individual species of concern. To hear more about the use of scientific information in the development and management of western water supplies, attend "Science to Support the Management of Western Water," from 9:05 a.m. to 9:20 a.m., Monday Oct. 28 in Room A209.

SIMULATION OF GROUND-WATER FLOW IN THE MIDDLE RIO GRANDE BASIN BETWEEN COCHITI AND SAN ACACIA, NEW MEXICO

Excerpts

By Douglas P. McAda, U.S. Geological Survey, and
Peggy Barroll, New Mexico Office of the State Engineer

Prepared in cooperation with the
NEW MEXICO OFFICE OF THE STATE ENGINEER
and the
CITY OF ALBUQUERQUE PUBLIC WORKS DEPARTMENT
U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 02-4200
Albuquerque, New Mexico
2002

GEOHYDROLOGY OF THE MIDDLE RIO GRANDE BASIN

Geologic Setting

Surface-Water Hydrology

The Jemez River, which is perennial through most of its length within the basin, is the largest tributary to the Rio Grande within the basin and provides an average of about 45,000 acre-feet per year of surface water to the Rio Grande (S.S. Papadopulos and Associates, Inc., 2000; Ortiz and others, 2001, p. 135). The Rio Grande and Jemez River predominantly lose water to the aquifer system, although some reaches gain water.

Jemez Canyon Reservoir was constructed for sediment control and flow detainment when the Rio Grande is in flood stage. Jemez Canyon Reservoir began permanently storing water in about 1979, but stored water on a short-term basis prior to this time. Neither reservoir provides storage for irrigation water; the MRGCD's surface-water storage is in reservoirs considerably upstream from the Middle Rio Grande Basin.

The remaining tributaries to the Rio Grande within the basin are ephemeral where they enter the Rio Grande, but many are perennial or intermittent at the basin margins. The Santa Fe River, Galisteo Creek, Tijeras Arroyo, Abo Arroyo, Rio Puerco, and Rio Salado (in the southern part of the basin) often flow at the basin margins, but only ephemeral flow from storm-water runoff reaches the Rio Grande. Two of those, the Rio Puerco and Rio Salado, have been gaged near their confluence with the Rio Grande. The Rio Puerco contributes an average of about 30,000 acre-feet per year to the Rio Grande (Ortiz and others, 2001, p. 184), and the Rio Salado contributes about 5,900 acre-feet per year (average of 1974-84 flow; Thorn and others, 1993, p. 84). A number of arroyos are also tributary to the Rio Grande.

Ground-Water Hydrology

The aquifer system in the Middle Rio Grande Basin as defined for this report consists of the Santa Fe Group and post-Santa Fe Group alluvial units within the Rio Grande inner valley (and, to a lesser extent, along other tributaries). The most permeable parts of the aquifer system are composed of axial-channel deposits of the ancestral Rio Grande in the upper part of the Santa Fe Group and the post-Santa Fe Group recent river-channel alluvium in the inner Rio Grande Valley. The western boundary of the aquifer system is associated with cemented faults (fig. 3), which restrict ground-water flow within Santa Fe Group sediments in the basin (fig. 5; Kernodle and others, 1995, p. 12). The northern boundary of the aquifer system as defined for this study is the approximate contact of Santa Fe Group sediments with Cenozoic volcanic rocks of the Jemez Mountains. The northeastern boundary is the La Bajada Escarpment, where Santa Fe Group sediments of the Española Basin are uplifted across the La Bajada Fault relative to Santa Fe Group sediments in the Middle Rio Grande Basin (fig. 3). These north and northeast boundaries are similar to the boundaries defined for the ground-water-flow model of the Albuquerque Basin by Kernodle and others (1995).

This boundary is likely not a distinct geohydrologic boundary. It has been suggested that the Middle Rio Grande Basin (Albuquerque Basin) extends beneath the volcanics of the Jemez Mountains and that it has a significant geohydrologic connection with the Española Basin to the northeast (Hawley and Grant, 1997; Grant, 1999). This geohydrologic connection contributes a substantial amount of subsurface groundwater recharge across the northern and northeastern boundary of the aquifer system as defined for this study.

Mountain-Front and Tributary Recharge

Mountain-front recharge results from surface runoff or shallow underflow originating from mountains adjacent to the basin that infiltrates into the upper part of the aquifer system near the mountain fronts. Tributary recharge occurs as seepage from streams and arroyos tributary to the Rio Grande that have surface flows extending into the Middle Rio Grande Basin. Mountain-front recharge comes from the Sandia, Manzanita, Manzano, and Los Pinos Mountains along the east side of the basin; Ladron Peak in the southwestern part of the basin; and the Sierra Nacimiento and Jemez Mountains in the northern part of the basin. Tributary streams that likely contribute substantial recharge to the aquifer system beyond the mountain front include the Santa Fe River, Galisteo Creek, Tijeras Arroyo, Abo Arroyo, Rio Salado, and Rio Puerco

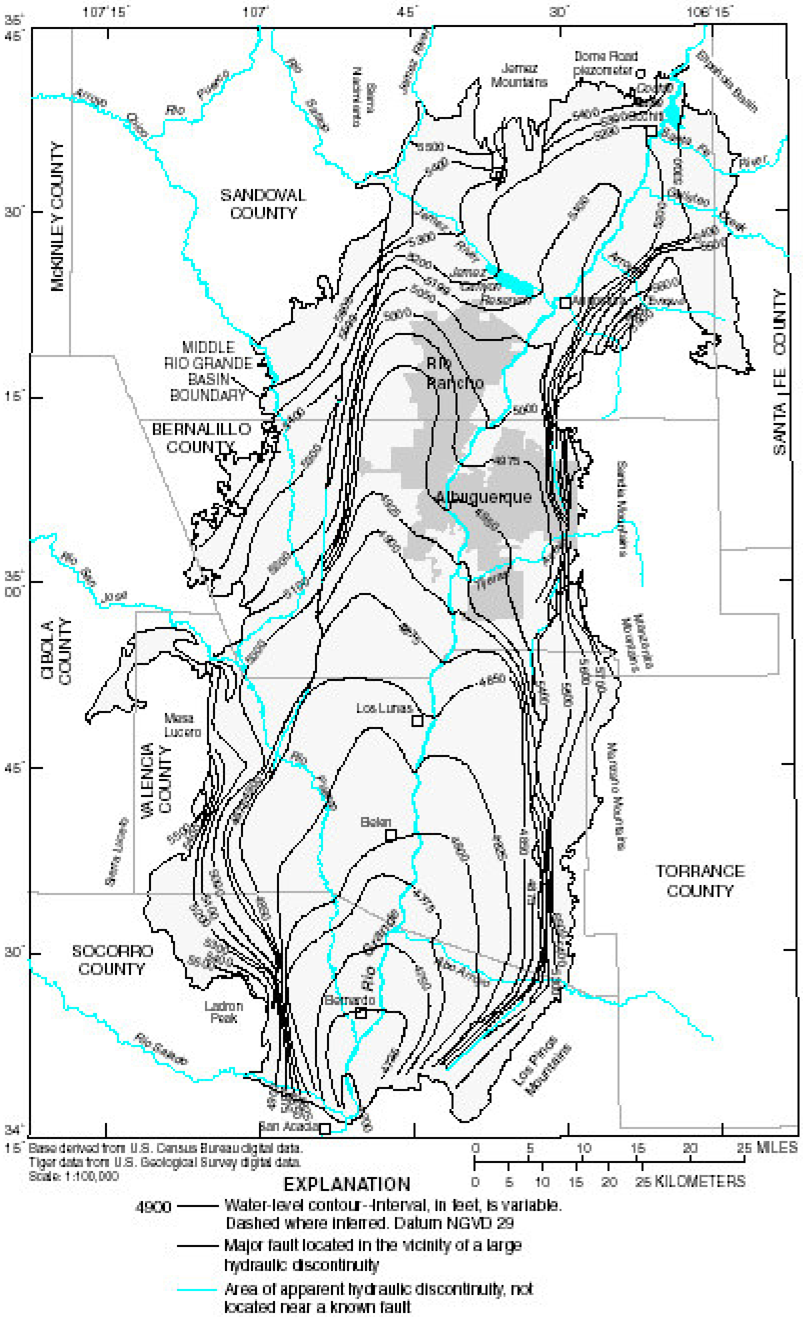

Figure 5. Predevelopment water-level contours in the Middle Rio Grande Basin (modified from Bexfield and Anderholm, 2000).

Subsurface Recharge

page 13

Recharge from the Rio Puerco was estimated by Jack Dewey (U.S. Geological Survey, written commun., 1982; cited in Kernodle and Scott, 1986) to be about 10,400 acre-feet per year. A portion of that recharge was attributed to reaches of the Rio Puerco beyond the boundary of the aquifer system as defined for this report. The portion of that recharge within the aquifer boundary is about 5,600 acre-feet per year. Kernodle and others (1995) applied this portion of recharge in their model along the Rio Puerco and the remainder (about 4,800 acre-feet per year) to the nearby model boundary. Tiedeman and others (1998) estimated values ranging from 1,500 to 3,800 acre-feet per year for the reach within the model boundary using nonlinear-regression modeling techniques. In preliminary nonlinear-regression modeling using water ages, Sanford and others (2001) estimated Rio Puerco recharge within the model to be about 2,000 acre-feet per year.

The Sierra Nacimiento and Jemez Mountains provide mountain-front recharge to the aquifer system in the northern part of the basin. Kernodle and others (1995) did not specifically estimate mountain-front recharge in this area but included recharge in this area as subsurface recharge and recharge along the Jemez River Valley north of the confluence of the Rio Salado and Jemez River. These recharge amounts are discussed in the sections below. The combination of these recharge amounts specified by Kernodle and others (1995) was about 12,800 acre-feet per year.

Mountain-front and tributary recharge to the aquifer system was estimated by Thorn and others (1993, p. 92) to be about 139,000 acre-feet per year. The estimate of Kernodle and others (1995) was about 110,000 acre-feet per year. Tiedeman and others (1998) estimated mountain-front and tributary recharge to be about 90,000 acre-feet per year. Recent work by Anderholm (2001) and Plummer and others (2001) and preliminary estimates made by Sanford and others (2001) indicate that total mountain-front and tributary recharge is likely smaller than the values listed above.

Subsurface Recharge

Subsurface recharge occurs as ground-water inflow from adjacent basins or mountains. Subsurface recharge comes from the vicinity of the Jemez Mountains, Española Basin, and Hagan Embayment in the north-northeastern part of the basin and from Sierra Lucero to the San Juan Basin in the western part of the Middle Rio Grande Basin.

A substantial amount of subsurface recharge enters the basin from the Jemez Mountains and Española Basin areas (Hawley and Grant, 1997; Grant, 1999). Ground-water-flow modeling in the Española Basin resulted in estimated subsurface flow from the Española Basin to the Middle Rio Grande Basin ranging from about 8,800 acre-feet per year (Frenzel, 1995) to about 12,600 acre-feet per year (McAda and Wasiolek, 1988). Kernodle and others (1995) used the latter value (12,600 acre-feet per year) for subsurface recharge from the Española Basin and estimated an additional amount of subsurface recharge of 7,000 acre-feet per year from the Jemez Mountains for a total of 19,600 acre-feet per year along the northern and northeastern aquifer-system boundary. Tiedeman and others (1998) used approximately the same amount. Sanford and others' (2001) preliminary estimates are significantly smaller (a total of 11,000 acre-feet per year for this recharge plus recharge from the Santa Fe River, Galisteo Creek, and Hagan Embayment). Grant (1999, p. 434), referring to the combined Española- Albuquerque aquifer systems west of the Rio Grande, speculated that “there may be large volumes of unaccounted for water that recharge the underground system.”

Subsurface recharge along Sierra Lucero and Mesa Lucero was estimated by Jack Dewey (U.S. Geological Survey, written commun., 1982) to be about 1,100 acre-feet per year. Kernodle and Scott (1986, fig. 5) located about 5,200 acre-feet per year of recharge as underflow along Mesa Lucero. J.M. Kernodle (U.S. Geological Survey, oral commun., 1996) determined that recharge along Mesa Lucero was intended as recharge from the Rio San Jose at its confluence with the Rio Puerco. Tiedeman and others (1998, fig. 5) showed the distribution of recharge in this area as intended by Dewey (U.S. Geological Survey, written commun., 1982).

Estimates of recharge along the entire western aquifer margin (north of the southern Rio Salado to the boundary adjacent to the Sierra Nacimiento) can be compared. These estimates exclude any recharge attributed to the Jemez River along the western aquifer margin. The recharge used by Kernodle and others (1995, fig. 5) along the entire western margin was about 13,600 acre-feet per year. This included about 4,700 acre-feet per year of recharge from the reach of the Rio Puerco that was on or outside their model boundary. Tiedeman and others (1998) estimated 11,200 acre-feet per year of recharge for the entire western margin. The difference from the Kernodle and others (1995) estimate is that Tiedeman and others (1998) estimated half the amount of recharge from the reach of the Rio Puerco on or outside their model boundary. Sanford and others (2001) preliminarily estimated recharge along this boundary to be about 2,000 acre-feet per year using carbon-14 ground-water age dates.

Ground-Water Withdrawal

Ground-Water Flow and Ground-Water/Surface- Water Interaction

page 18

Seepage has been investigated along the Jemez River. Fischer and Borland (1983) reported that the results of seepage investigations conducted in 1981 were inconclusive. Craigg (1992) conducted two seepage investigation in 1984, one in March and one in August. The winter results indicated a gain in flow between Jemez Pueblo and Zia Reservoir of about 18 cubic feet per second, a possible loss of flow between Zia Reservoir and Zia Pueblo of about 5 cubic feet per second, and a gain in flow between Zia and Santa Ana Pueblos of about 8 cubic feet per second. The possible uncertainty of these estimates, based on streamflow measurement errors (Craigg, 1992, table 3), is +/- 6 to 7 cubic feet per second. The summer results indicated that the upper reach of the Jemez River gained flow but that the reach between Zia and Santa Ana Pueblos lost about 11 (+/- 4) cubic feet per second of flow. Craigg (1992) concluded that the loss in the lower reach was likely due to evapotranspiration by phreatophytes.

Data that would allow estimation of seepage from Jemez Canyon Reservoir were not available for this study. Prior to 1979, when the reservoir began permanently storing water, the reservoir operated to desilt flows above 30 cubic feet per second by a 1-day detention and to provide flood protection. Although water would have seeped from the reservoir during temporary-storage periods, the seepage likely was relatively small compared with the amount of seepage that occurred during permanent storage.

Ground-Water Withdrawal

page 36

Jemez River

The Jemez River is in hydraulic connection with the aquifer system over most of its length in the basin, so changes in water-table altitude in the aquifer system adjacent to the river can influence seepage between the river and the aquifer system.

page 38

Riparian Evapotranspiration

Evapotranspiration from the water table in riparian areas along the inner Rio Grande Valley and the Jemez River is simulated in the model using the Evapotranspiration Segments Package of MODFLOW- 2000 (Banta, 2000). Agricultural cropland and urban areas, such as yards, parks, and golf courses, are irrigated. Evapotranspiration on these areas is assumed to come from applied irrigation water; therefore, evapotranspiration from ground water is not simulated in those areas. Riparian areas along the Rio Grande were delineated on the basis of GIS coverages of land use in the inner valley for 1935 (National Biological Service digital data) and for 1955, 1975, and 1992 (Bureau of Reclamation digital data). Areas of evapotranspiration developed on the basis of 1935 land-use data along the Rio Grande were used in the predevelopment steady-state simulation and beginning in the 1900-04 historical stress period.

Evapotranspiration derived from 1955, 1975, and 1992 land-use conditions along the Rio Grande is simulated beginning in the 1945-49, 1965-69, and 1984 stress periods, respectively. Only the 1955 and 1975 land-use coverages showed the riparian areas along the Jemez River. Very little riparian area that could contribute to evapotranspiration from the water table was located where Cochiti Reservoir now exists and therefore is not simulated. Evapotranspiration values derived from 1955 land-use conditions along the Jemez River are simulated in the predevelopment steady-state simulation and beginning in the 1900-04 stress period. Evapotranspiration values derived from 1975 land-use conditions along the Jemez River are simulated beginning in the 1945-69 stress period. Evapotranspiration from the water table is excluded from the area beneath Jemez Canyon Reservoir beginning in 1979, the year during which a permanent reservoir pool was established.

A maximum evapotranspiration rate of 5.0 feet per year applied to the riparian areas was used when the simulated water table is at or above land surface. The evapotranspiration rate linearly decreases from 5.0 feet per year at land surface to 2 feet per year 9 feet below land surface.

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Water Budget

page 59

The simulated annual water budgets for the predevelopment steady-state and the 1999 (average of the two seasonal stress periods ending in March 1999 and October 1999) simulation periods are listed in table 3. The change in the model water budget throughout the simulation period is summarized in figure 22, which is based on the standard water-budget output of MODFLOW-2000. This figure combines the gain 208,000 acre-feet per year (for 1999; table 3) . Thus, the main stem of the Rio Grande and the riverside drains set up a short circuit, in which losses from one appear in the other. The interior drains are simulated to gain volumes of water ranging from 70,000 to 150,000 acre-feet per year over the historical period (fig. 22). Many of these interior-drain gains are actually recapture of part of the 90,000 to 130,000 acre-feet per year of canal and crop-irrigation seepage (the difference between net recharge before and after 1930, fig. 22). For the 1970's and 1980's, some increases in surface-water losses to the aquifer system associated with Cochiti Lake are shown in figure 22. Also, the effects of ground-water development on the surface water system probably influence the trends of net drain and river losses.

During predevelopment (steady-state simulation) before any drains or canals are simulated, the Rio Grande is simulated to have a net loss of about 63,000 acre-feet per year. Simulated predevelopment loss rates are largest in the central reaches, averaging about 1 cubic foot per second (about 724 acre-feet per year) per mile between Bernalillo and Bernardo.

The water budget of the Rio Grande surface water system changes dramatically through the historical simulation as surface-water irrigation begins and riverside and interior drains are added to the model structure (fig. 22). Once drains and canals are installed (simplified in the model to occur in 1930), the model simulates the Rio Grande main stem as losing about 316,000 acre-feet per year, whereas the riverside drains drains make the net gains of this reach greater still. Some of this gain represents recapture of irrigation water diverted from the Rio Grande, and some represents the reappearance of seepage from Cochiti Lake.

Page 63

Table 3. Simulated annual water budgets for the Middle Rio Grande Basin ground-water model, steady state and year ending October 1999
[All values are in acre-feet per year]

Mechanism	Steady state			Year ending October 1999	
	Outflow (to aquifer)	Inflow (from aquifer)		Outflow (to aquifer)	Inflow (from aquifer)

Jemez River and Jemez Canyon Reservoir	15,000	0	17,000	0

p 64

The Jemez River is simulated to gain water in its upper reach (above its confluence with the northern Rio Salado) and to lose water in its reaches below the Rio Salado confluence. Gains in the upper reach generally are consistent with measurements and seepage work by Craigg (1992). Simulated loss in the reach below the confluence is not entirely consistent with Craigg's 1992) seepage data, which indicates that the reach of the Jemez River between Zia and Santa Ana Pueblos gains water in the winter and loses water (presumably to evapotranspiration) in the summer. The model does predict a decrease in loss in this reach in winter, but no actual gain. The inability of the model to simulate this gain may be related to the simulated heads near the Jemez River that are still too low, and there may be considerable subsurface geologic structure not represented in this model. The reach of the Jemez River below Santa Ana Pueblo is simulated to lose water, and once Jemez Canyon Reservoir is added to the model in the lower reach of the Jemez River, the reservoir loses water as well (from 4,000 acre-feet per year in years of low stage to 11,000 acre-feet per year in years of high stage). This finding is consistent with the understanding of that reach from seepage and water budget considerations (Craigg, 1992).

Phreatophyte consumption of ground water by evapotranspiration is the main simulated discharge of the model during predevelopment time. This discharge is simulated to be about 129,000 acre-feet per year in steady state (table 3). The model simulates a decrease in phreatophyte consumption over time to about 84,000 acre-feet per year in 1999, largely in response to a decrease in area covered by native riparian vegetation and wetlands and a lowering of the water table in some areas. These values are consistent with available estimates of phreatophyte consumption (Bureau of Reclamation, 1997d), but such estimates are very poorly constrained.

The net annual water budget simulated by the model for 1999, calculated as the time-weighted average of the two seasonal stress periods ending in March 1999 and October 1999, is listed below (positive numbers are inflow (sources of water) to the aquifer and negative numbers are outflow (discharges of water) from the aquifer).

Jemez River and Jemez Canyon
Reservoir: 17,000 acre-feet

SIMULATION OF GROUND-WATER FLOW IN THE MIDDLE RIO GRANDE BASIN BETWEEN COCHITI AND SAN ACACIA, NEW MEXICO

By Douglas P. McAda, U.S. Geological Survey, and
Peggy Barroll, New Mexico Office of the State Engineer
Prepared in cooperation with the
NEW MEXICO OFFICE OF THE STATE ENGINEER
and the
CITY OF ALBUQUERQUE PUBLIC WORKS DEPARTMENT
U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 02-4200
Albuquerque, New Mexico
2002

SUMMARY AND CONCLUSIONS

The Middle Rio Grande Basin between Cochiti and San Acacia, also called the Albuquerque Basin, has been the focus of investigations by the USGS and other agencies to improve the understanding of the hydrology, geology, and land-surface characteristics in the basin. The Santa Fe Group aquifer system in the Middle Rio Grande Basin consists of a thick sequence (as much as 14,000 feet) of Santa Fe Group and post- Santa Fe Group sediments. Population growth in the basin has increased dramatically since the 1940's.

These population increases have caused dramatic increases in ground-water withdrawals from the aquifer system, resulting in large ground-water level declines. Because the Rio Grande is hydraulically connected to the aquifer system, these ground-water withdrawals have also decreased flow in the Rio Grande.

This report describes a ground-water-flow model of the Middle Rio Grande Basin developed (1) to integrate the components of the ground-water-flow system, including the hydrologic interaction between the surface-water systems in the basin, to better understand the geohydrology of the basin and (2) to provide a tool to help water managers plan for and administer the use of basin water resources. The three dimensional, finite-difference, ground-water-flow model of the Santa Fe Group aquifer system within the Middle Rio Grande Basin was developed using MODFLOW-2000. The aquifer system is represented by nine model layers extending from the water table to the pre-Santa Fe Group basement rocks, as much as 9,000 feet below NGVD 29. The layers are divided into cells by a uniform grid containing 156 rows and 80 columns, each spaced 3,281 feet (1 kilometer) apart.

The model simulates predevelopment steady-state conditions and historical transient conditions from January 1900 to March 2000 in 1 steady-state and 52 historical stress periods. Average annual conditions are simulated prior to 1990, and seasonal (winter and irrigation season) conditions are simulated from 1990 to March 2000. The model simulates mountain-front, tributary, and subsurface recharge; canal, irrigation, and septic-field seepage; and ground-water withdrawal as specified-flow boundaries. The model simulates the Rio Grande, riverside drains, Jemez River, Jemez Canyon Reservoir, Cochiti Lake, riparian evapotranspiration, and interior drains as head dependent flow boundaries.

Hydrologic properties representing the Santa Fe Group aquifer system in the ground-water-flow model are horizontal hydraulic conductivity, vertical hydraulic conductivity, specific storage, and specific yield. Variable horizontal anisotropy is applied to the model to simulate the effect of numerous south trending faults in the basin so that hydraulic conductivity along columns (north-south) is greater than hydraulic conductivity along rows (east-west) over much of the model. Resulting horizontal hydraulic conductivities range from 0.05 to 60 feet per day.

Vertical anisotropy simulates the effect of sedimentary bedding that includes sub layers of low-permeability sediments. Vertical anisotropy is specified in the model as a horizontal to vertical anisotropy ratio (calculated to be 150:1 in the model) multiplied by the horizontal hydraulic conductivity along rows. Specific storage was estimated to be 2 x 10^{-6} per foot in the model. Specific yield was estimated to be 0.2 (dimensionless).

Model sensitivity to changes in simulated hydrologic properties was tested using changes in the sum of squared weighted residuals for the entire simulation period. The ground-water-flow model is most sensitive to lower than calibrated values of hydraulic conductivity, specific yield, and horizontal anisotropy for part of the modeled area (zone 2) but is relatively insensitive for greater than calibrated values of these properties. The model is fairly sensitive to the horizontal to vertical anisotropy ratio. The model is relatively insensitive to changes in specific storage and horizontal anisotropy for zones 1 and 5.

The net annual water budget simulated by the model for 1999, calculated as the time-weighted average of the two seasonal stress periods ending in March 1999 and October 1999, is listed below (positive numbers are inflow (sources of water) to the aquifer and negative numbers are outflow (discharges of water) from the aquifer).

Mountain-front recharge:	12,000 acre-feet
Tributary recharge:	9,000 acre-feet
Subsurface recharge:	31,000 acre-feet
Canal seepage:	90,000 acre-feet
Crop-irrigation seepage:	35,000 acre-feet
Rio Grande and Cochiti Lake:	316,000 acre-feet
Riverside drains:	-208,000 acre-feet
Interior drains:	-133,000 acre-feet
Jemez River and Jemez Canyon Reservoir:	17,000 acre-feet
Ground-water withdrawal:	-150,000 acre-feet
Septic-field seepage:	4,000 acre-feet
Riparian evapotranspiration:	-84,000 acre-feet
Aquifer storage:	60,000 acre-feet

A ground-water-flow model is a tool that can integrate the complex interactions of hydrologic boundary conditions, aquifer materials, aquifer stresses, and aquifer-system response. It can help in the understanding of these complexities and be used to estimate the effects of particular stresses on the aquifer and river system. The ground-water-flow model described in this report provides a reasonable representation of the geohydrologic processes of the basin and simulates many historically measured trends in flow and water levels. By simulating these complex interactions, this ground-water-flow model can provide a tool to help water managers plan for and administer the use of basin water resources. However, a solution using the ground-water-flow modeling technique is not unique because any number of reasonable variations in the representation of the aquifer system used in the model may produce equally acceptable results.

Uncertainties in our knowledge of the ground-water system remain. Some of these uncertainties are reflected in the range of values that have been estimated for various components of the aquifer-system water budget and in the plausible ranges of hydrologic characteristics estimated for various physical components of the aquifer system. These sources of uncertainty need to be considered when applying this model to any specific problem.

The ground-water-flow model described in this report is a culmination of the 6-year effort by the USGS and other agencies (including the New Mexico Bureau of Geology and Mineral Resources, the New Mexico Office of the State Engineer, the City of Albuquerque, and the University of New Mexico) to improve the understanding of the hydrology, geology, and land surface characteristics of the Middle Rio Grande Basin. Although more remains to be learned about the basin, this effort has resulted in an improved understanding of the aquifer system. This increased understanding has been incorporated into this ground-water-flow model.

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USGS Reports

June 5, 2003
WRI 03-4040. NEW MEXICO.

Simulated effects of ground-water management scenarios on the Santa Fe Group aquifer system, Middle Rio Grande Basin, New Mexico, 2001-40. By Laura M. Bexfield Douglas P. McAda, 39 pages.

Available from U.S. Geological Survey Information Services, Box 25286, MS 517, Denver Federal Center, Denver, CO 80225, USGS Water-Resources Investigations Report 03-4040.

Future conditions in the Santa Fe Group aquifer system through 2040 were simulated using the most recent revision of the U.S. Geological Survey ground-water-flow model for the Middle Rio Grande Basin. Three simulations were performed to investigate the likely effects of different scenarios of future ground-water pumping by the City of Albuquerque on the ground-water system. For simulation I, pumping was held constant at known year-2000 rates. For simulation II, pumping was increased to simulate the use of pumping to meet all projected city water demand through 2040. For simulation III, pumping was reduced in accordance with a plan by the City of Albuquerque to use surface water to meet most of the projected water demand. The simulations indicate that for each of the three pumping scenarios, substantial additional water-table declines would occur in some areas of the basin through 2040. However, the reduced pumping scenario of simulation III also results in water-table rise over a broad area of the city. All three scenarios indicate that the contributions of aquifer storage and river leakage to the ground-water system would change between 2000 and 2040.

Comparisons among the results for simulations I, II, and III indicate that the various pumping scenarios have substantially different effects on water-level declines in the Albuquerque area and on the contribution of each water-budget component to the total budget for the ground-water system. Between 2000 and 2040, water-level declines for continued pumping at year-2000 rates are as much as 120 feet greater than for reduced pumping; water-level declines for increased pumping to meet all projected city demand are as much as 160 feet greater. Over the same time period, reduced pumping results in retention in aquifer storage of about 1,536,000 acre-feet of ground water as compared with continued pumping at year-2000 rates and of about 2,257,000 acre-feet as compared with increased pumping. The quantity of water retained in the Rio Grande as a result of reduced pumping and the associated decrease in induced recharge from the river is about 731,000 acre-feet as compared with continued pumping at year-2000 rates and about 872,000 acre-feet as compared with increased pumping. Reduced pumping results in slight increases in the quantity of water lost from the ground-water system to evapotranspiration and agricultural-drain flow compared with the other pumping scenarios.

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May 7, 2003
OFR 03-169. NEW MEXICO.

Rainfall, runoff, and water-quality data for the urban storm-water program in the Albuquerque, New Mexico, metropolitan area, water year 2001. By Todd Kelly and Orlando Romero, 153 pages.

Available from U.S. Geological Survey Information Services, Box 25286, MS 517, Denver Federal Center, Denver, CO 80225, USGS Open-File Report 03-169.

Urbanization has dramatically increased precipitation runoff to the system of drainage channels and natural stream channels in the Albuquerque, New Mexico, metropolitan area. Rainfall and runoff data are important for planning and designing future storm-water conveyance channels in newly developing areas. Storm-water quality also is monitored in accordance with the National Pollutant Discharge Elimination System mandated by the U.S. Environmental Protection Agency. The Albuquerque Metropolitan Arroyo Flood Control Authority, the City of Albuquerque, and the U.S. Geological Survey began a cooperative program to collect hydrologic data to help assess the quality and quantity of surface-water resources in the Albuquerque area. This report presents water-quality, streamflow, and rainfall data collected from October 1, 2000, to September 30, 2001 (water year 2001). Also provided is a station analysis for each of the 20 streamflow-gaging sites and 38 rainfall-gaging sites, which includes a description of monitoring equipment, problems associated with data collection during the year, and other information used to compute streamflow discharges or rainfall records. A hydrographic comparison shows the effects that the largest drainage channel in the metropolitan area, the North Floodway Channel, has on total flow in the Rio Grande.

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February 20, 2003
WRI 02-4200. NEW MEXICO.

Simulation of ground-water flow in the Middle Rio Grande Basin between Cochiti and San Acacia, New Mexico. By Douglas P. McAda and Peggy Barroll, 81 pages.

Available from U.S. Geological Survey Information Services, Box 25286, MS 517, Denver Federal Center, Denver, CO 80225, USGS Water-Resources Investigations Report 02-4200, 81 p. Copies also available from the USGS District Office, 5338 Montgomery Blvd. NE, Suite 400, Albuquerque, NM 87109.

This report describes a three-dimensional, finite-difference, ground-water-flow model of the Santa Fe Group aquifer system within the Middle Rio Grande Basin between Cochiti and San Acacia, New Mexico. The aquifer system is composed of the Santa Fe Group of middle Tertiary to Quaternary age and post-Santa Fe Group valley and basin-fill deposits of Quaternary age.

Population increases in the basin since the 1940's have caused dramatic increases in ground-water withdrawals from the aquifer system, resulting in large ground-water-level declines. Because the Rio Grande is hydraulically connected to the aquifer system, these ground-water withdrawals have also decreased flow in the Rio Grande. Concern about water resources in the basin led to the development of a research plan for the basin focused on the hydrologic interaction of ground water and surface water (McAda, D.P., 1996, Plan of study to quantify the hydrologic relation between the Rio Grande and the Santa Fe Group aquifer system near Albuquerque, central New Mexico: U.S. Geological Survey Water-Resources Investigations Report 96-4006, 58 p.). A multiyear research effort followed, funded and conducted by the U.S. Geological Survey and other agencies (Bartolino, J.R., and Cole, J.C., 2002, Ground-water resources of the Middle Rio Grande Basin, New Mexico: U.S. Geological Survey Circular 1222, 132 p.). The modeling work described in this report incorporates the results of much of this work and is the culmination of this multiyear study.

The purpose of the model is (1) to integrate the components of the ground-water-flow system, including the hydrologic interaction between the surface-water systems in the basin, to better understand the geohy drology of the basin and (2) to provide a tool to help water managers plan for and administer the use of basin water resources. The aquifer system is represented by nine model layers extending from the water table to the pre-Santa Fe Group basement rocks, as much as 9,000 feet below the NGVD 29. The horizontal grid contains 156 rows and 80 columns, each spaced 3,281 feet (1 kilometer) apart. The model simulates predevelopment steady-state conditions and historical transient conditions from 1900 to March 2000 in 1 steady-state and 52 historical stress periods. Average annual conditions are simulated prior to 1990, and seasonal (winter and irrigation season) conditions are simulated from 1990 to March 2000. The model simulates mountain-front, tributary, and subsurface recharge; canal, irrigation, and septic-field seepage; and ground-water withdrawal as specified-flow boundaries. The model simulates the Rio Grande, riverside drains, Jemez River, Jemez Canyon Reservoir, Cochiti Lake, riparian evapotranspiration, and interior drains as head-dependent flow boundaries.

Hydrologic properties representing the Santa Fe Group aquifer system in the ground-water-flow model are horizontal hydraulic conductivity, vertical hydraulic conductivity, specific storage, and specific yield. Variable horizontal anisotropy is applied to the model so that hydraulic conductivity in the north-south direction (along model columns) is greater than hydraulic conductivity in the east-west direction (along model rows) over much of the model. This pattern of horizontal anisotropy was simulated to reflect the generally north-south orientation of faulting over much of the modeled area. With variable horizontal anisotropy, horizontal hydraulic conductivities in the model range from 0.05 to 60 feet per day. Vertical hydraulic conductivity is specified in the model as a horizontal to vertical anisotropy ratio (calculated to be 150:1 in the model) multiplied by the horizontal hydraulic conductivity along rows. Specific storage was estimated to be 2 x 10-6 per foot in the model. Specific yield was estimated to be 0.2 (dimensionless).

A ground-water-flow model is a tool that can integrate the complex interactions of hydrologic boundary conditions, aquifer materials, aquifer stresses, and aquifer-system responses. This ground-water-flow model provides a reasonable representation of the geohydrologic processes of the basin and simulates many historically measured trends in flow and water levels. By simulating these complex interactions, the ground-water-flow model described in this report can provide a tool to help water managers plan for and administer the use of basin water resources. Nevertheless, no ground-water model is unique, and numerous sources of uncertainty remain. When using results from this model for any specific problem, those uncertainties should be taken into consideration.

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January 16, 2003
WRI 02-4233. NEW MEXICO.

Estimated water-level declines in the Santa Fe Group aquifer system in the Albuquerque area, central New Mexico, predevelopment to 2002. By Laura M. Bexfield and Scott K. Anderholm, 1 pages.

Available from U.S. Geological Survey Information Services, Box 25286, MS 517, Denver Federal Center, Denver, CO 80225, USGS Water-Resources Investigations Map Report 02-4233.

This map report presents estimated changes in static water levels in the production zone of the Santa Fe Group aquifer system in the Albuquerque metropolitan area between recent (1999-2002) and predevelopment (pre-1961) conditions. Contours of recent water levels are mapped, along with the ranges of estimated water-level change.

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January 13, 2002
WRI 02-4235. NEW MEXICO.

Ground displacements caused by aquifer-system water-level variations observed using interferometric synthetic aperture radar near Albuquerque, New Mexico. By Charles E. Heywood, Devin L. Galloway, and Sylvia V. Stork, 18 pages.

Available from U.S. Geological Survey Information Services, Box 25286, MS 517, Denver Federal Center, Denver, CO 80225, USGS Water-Resources Investigations Report 02-4235, 18 p., 5 figs.

Six synthetic aperture radar (SAR) images were processed to form five unwrapped interferometric (InSAR) images of the greater metropolitan area in the Albuquerque Basin. Most interference patterns in the images were caused by range displacements resulting from changes in land-surface elevation. Loci of land-surface elevation changes correlate with changes in aquifer-system water levels and largely result from the elastic response of the aquifer-system skeletal material to changes in pore-fluid pressure. The magnitude of the observed land-surface subsidence and rebound suggests that aquifer-system deformation resulting from ground-water withdrawals in the Albuquerque area has probably remained in the elastic (recoverable) range from July 1993 through September 1999. Evidence of inelastic (permanent) land subsidence in the Rio Rancho area exists, but its relation to compaction of the aquifer system is inconclusive because of insufficient water-level data. Patterns of elastic deformation in both Albuquerque and Rio Rancho suggest that intrabasin faults impede ground-water-pressure diffusion at seasonal time scales and that these faults are probably important in controlling patterns of regional ground-water flow.