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David B. Rogers, Alan K. Stoker, Stephen G. McLin, and Bruce M. Gallaher

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RECHARGE TO THE PAJARITO PLATEAU REGIONAL AQUIFER SYSTEM

DAVID B. ROGERS[1], ALAN K. STOKER[2], STEPHEN G. MCLIN[1] and BRUCE M. GALLAHER[1]
[1]Water Quality and Hydrology Group, Los Alamos National Laboratory, Los Alamos, NM 87545;
[2]Science Applications International Corp., 122 Longview Drive, Los Alamos, NM 87545

Abstract—We present a picture of water balance in the Pajarito Plateau regional aquifer system based on a synthesis of geochemical and water level information and prior work. Assuming that water table rather than confined aquifer conditions apply, depletion of the Pajarito Plateau regional aquifer system based on limited water level data appears to equal total pumping for water supply for the period 1950-1993. This suggests that aquifer recharge could be far smaller than withdrawal of water, and that the resource is being mined. Carbon-14 data indicate that the age of aquifer water ranges from about 1000 to more than 35,000 years and that age increases towards the Rio Grande. These data support the possibility that part of the aquifer is recharged from the Sangre de Cristo Mountains, and that a groundwater divide in the aquifer lies west of the Rio Grande. In other cases, tritium detected at trace levels shows the presence of minor recent recharge to the top of the aquifer, particularly beneath canyons on the Pajarito Plateau.

INTRODUCTION

Los Alamos National Laboratory (LANL) is located on the Pajarito Plateau, which lies east of the Valles caldera in the Jemez Mountains (Fig. 1). Groundwater protection activities and resource management at LANL are focused on the main, or regional aquifer system (the aquifer). This aquifer system is the only viable municipal water supply source on the Pajarito Plateau (Purtymun, 1984, 1995). The water table or piezometric surface of the aquifer is projected to lie at depths ranging from 1200 ft along the western margin of the Laboratory to about 600 ft on the eastern plateau, above the Rio Grande (Fig. 2a). The aquifer generally occupies Miocene Santa Fe Group sediments, and rises both in elevation and stratigraphically into the Plio-Pleistocene Puye Conglomerate to the west. The major discharge for the aquifer is along the Rio Grande, the location of numerous cold springs. The portion of the Rio Grande east of the LANL shows a considerable gain in flow due to this aquifer discharge (Purtymun et al., 1980).

The aquifer exhibits artesian or confined conditions along the Rio Grande, but appears to be unconfined or under water table conditions under the rest of the Pajarito Plateau (Purtymun and Johansen, 1974; Purtymun, 1995). Purtymun (1984, 1995) found that the highest-yield water supply wells occur along a relatively narrow north-south zone of coarse-grained, higher permeability sediments within the Santa Fe Group, located near the center of the Pajarito Plateau. He named this zone the Chaquehui Formation (Fig. 2a), and interpreted it as a trough of sediments deposited by the ancestral Rio Grande (Purtymun, 1995). This terminology for the Chaquehui has not been formally adopted by the earth science community.

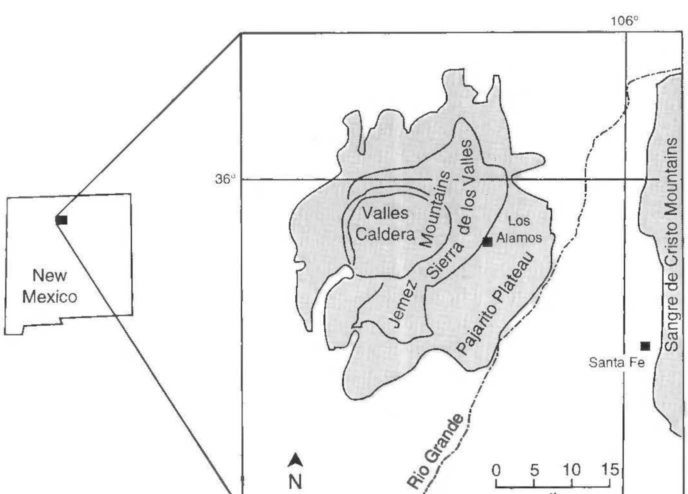

FIGURE 1. Location map for the Pajarito Plateau and Jemez Mountains, after Purtymun (1995).

In this paper we present new geochemical information and aquifer depletion estimates which bear on the question of recharge to the aquifer. Earlier reports attribute aquifer recharge to either stream losses along the lower flanks of the Jemez Mountains at the western margin of the Pajarito Plateau (Griggs, 1964) or to underflow from the Valles caldera (Purtymun and Johansen, 1974). The first explanation initially appears to be unsatisfactory; compared to the relatively large pumpage by water supply wells, losses from the small stream flow in this semiarid region could only be a minor contribution to aquifer recharge.

While the westerly rise of the water table suggests underflow from the Valles caldera as a recharge source, other information appears to rule out this conclusion. Data on stable isotope (deuterium and oxygen-18) geochemistry of waters from the aquifer and the Valles caldera indicate that most aquifer wells were recharged from elevations lower than the

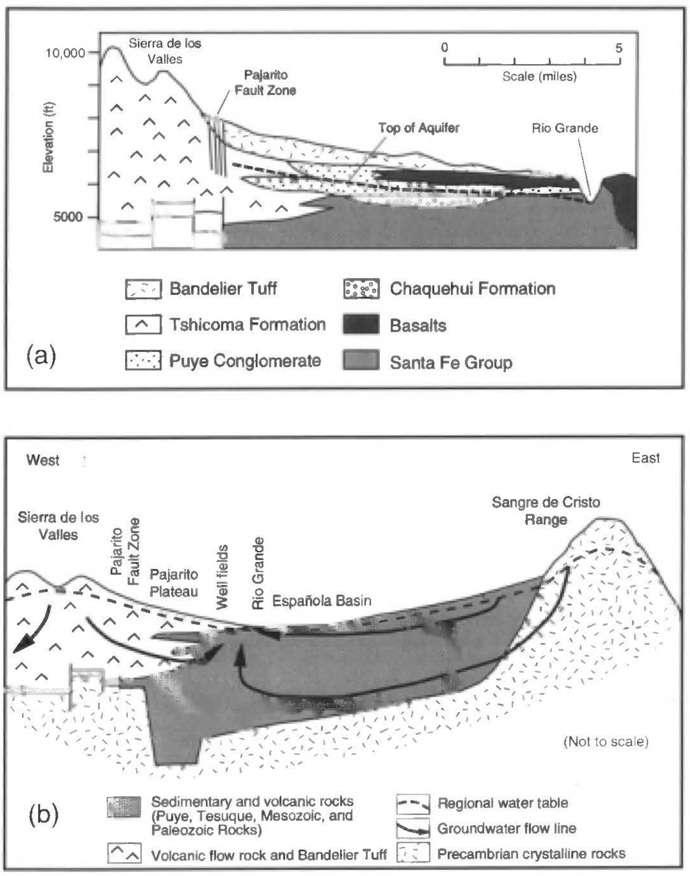

FIGURE 2. (a) Geologic cross section through the Pajarito Plateau, after Purtymun (1995). (b) Conceptual sketch of groundwater flow paths in the Española portion of the northern Rio Grande Basin, after Stephens et al. (1993).

Sierra de los Valles, and do not show the trace elements characteristic of deeper Valles caldera thermal waters (F. Goff, unpub. LANL memo, 1991; Blake et al., 1995). An exception to this pattern of recharge elevations is found at former Los Alamos well field wells LA-6 and LA-1B, located near the Rio Grande in lower Los Alamos Canyon (Fig. 3). These are among the deepest of the wells in this area, and recharge elevations determined from stable isotopes suggest that the recharge area could be the Sangre de Cristo Mountains (Goff and Sayer, 1980; Vuataz and Goff, 1986) as suggested by flow paths in Figure 2b.

The following hypothesis emerges regarding flow directions within, and recharge to the aquifer. On the basis of recharge elevations estimated from stable isotope data, Blake et al. (1995) concluded that most aquifer recharge comes from the Española basin or regions to the north along the Rio Grande, but not from the surrounding mountains. Based on stable isotope and other geochemical evidence, the Pajarito Plateau aquifer system appears to be recharged by a combination of lateral flow parallel to the Rio Grande rift, supplemented by inflow from the Sangre de Cristo Mountains (Goff and Sayer, 1980; Vuataz and Goff, 1986; Blake et al., 1995). There is likely to be a much smaller amount of recharge from infiltration beneath the Pajarito Plateau itself (Rogers and Gallaher, 1996). Note that while Figure 2a suggests that the Rio Grande is a groundwater divide, the groundwater divide actually lies west of the river according to the flow pattern shown in Figure 2b.

AQUIFER DEPLETION

Here, we approximate the total amount of aquifer depletion due to historical pumping for the Los Alamos water supply system, based on water level decline data. We determined water level decline by comparing water level maps from different dates. The preferred procedure for preparing water level maps is to use wells completed in the same hydrogeologic unit, where such data are available. The Los Alamos aquifer system occupies several stratigraphic units having markedly different hydrologic characteristics (Purtymun, 1984). In any case, the validity of using potentiometric maps for interpreting flow directions in an aquifer is extremely limited. Freeze and Cherry (1979, p. 49) stated that this "traditional concept is not particularly sound but... is firmly entrenched in usage... The concept of a potentiometric map is only rigorously valid for horizontal flow in horizontal aquifers."

Water level maps

In keeping with accepted practice in regions with sparse information, prior potentiometric maps of the aquifer were based on data from all wells on the Pajarito Plateau, and water levels from springs along the Rio Grande (Purtymun and Johansen, 1974; Purtymun, 1984; 1995). The well data include both test wells and water supply wells (Fig. 3). The test wells generally penetrate only 10 to 100 ft into the aquifer, although Test wells DT-5A, DT-9 and DT-10 all penetrate about 400 to 600 ft below the water table. On the other hand, the water supply wells are screened over larger intervals of 600 to 3100 ft (Purtymun, 1995) so these water levels represent averages over several hydrogeologic subunits of the aquifer. The water level contours suggest that regional scale flow in the aquifer is generally east or southeast towards the Rio Grande. Local variations in flow resulting from supply well pumping or variations in stratigraphy cannot be resolved with the present information.

Figure 4 shows aquifer water levels using test wells for 1949-50. Although these wells only penetrate the uppermost part of the water table, even these wells do not all sample the same hydrogeologic unit. Timewise, the map is a hybrid, including the 1960 water levels for TW-8, DT-5A, DT-9, and DT-10, because those wells were constructed at that time. The 1949-50 map shows little difference from maps depicting test well water levels in 1960 (not shown). The 1949-50 map includes test well H-19 and the Layne Western well, drilled as a pilot for the Guaje well field (Purtymun, 1995). The geographic location of this latter well greatly improves the quality of the map. The maps based only on the test wells also include the elevations of the Rio Grande at Otowi and Frijoles Canyon, which Purtymun et al. (1980) gave as 5512 and 5315 ft.

Figure 5 shows 1993 aquifer water levels using only the test wells. Test well 1 has been omitted, because it had a 1993 water level 38 ft higher than when it was drilled; this behavior is not understood, and we

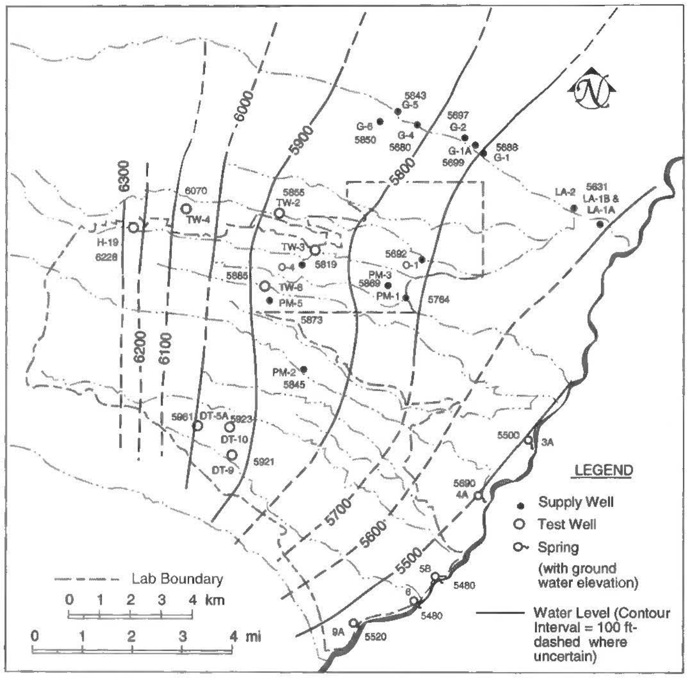

FIGURE 3. Aquifer water levels in 1993 using White Rock Canyon springs, test wells, and water supply wells.

believe that it may not be representative of regional water levels. No other test well has shown this behavior. This map (Fig. 5) differs little from the 1993 map (Fig. 3), which also used the White Rock Canyon springs and water supply wells. The map based only on test wells (Fig. 5) is extremely limited by lack of areal data coverage, particularly in the area of TW-1. The use of the water supply wells appears to increase the extent of reliable map coverage, without giving different results.

Water level decline

Aquifer water level has declined between 1949 to 1993, based on the test wells (Fig. 6). The map (Fig. 6) is obtained by subtracting the 1949-50 and 1993 maps. The water level decline map is highly speculative;

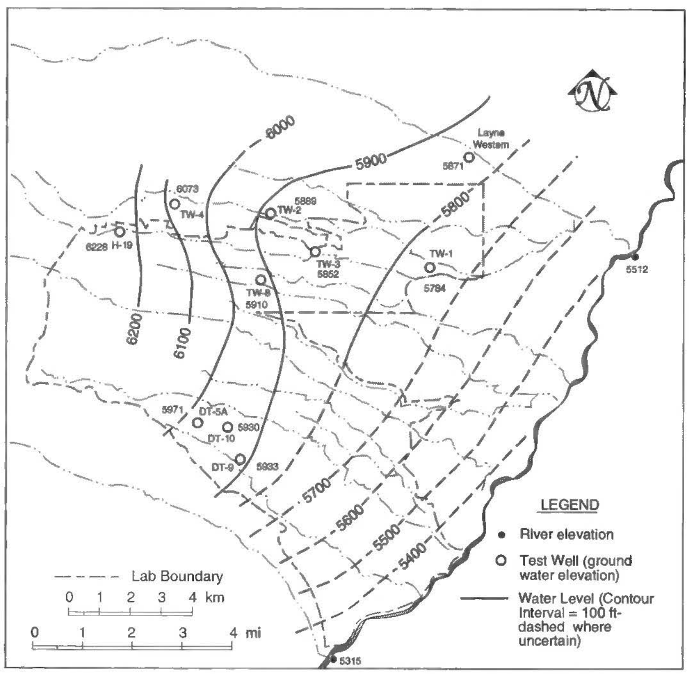

FIGURE 4. Aquifer water levels in 1949-1950 using Rio Grande elevations and test wells. Water levels in 1960 are used for TW-8, DT-5A, DT-9, and DT-10.

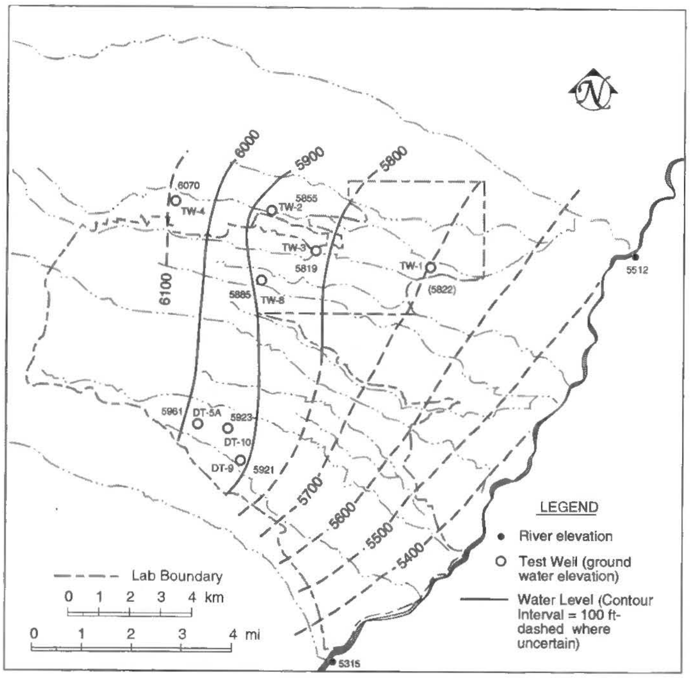

FIGURE 5. Aquifer water levels in 1993 using Rio Grande elevations and test wells.

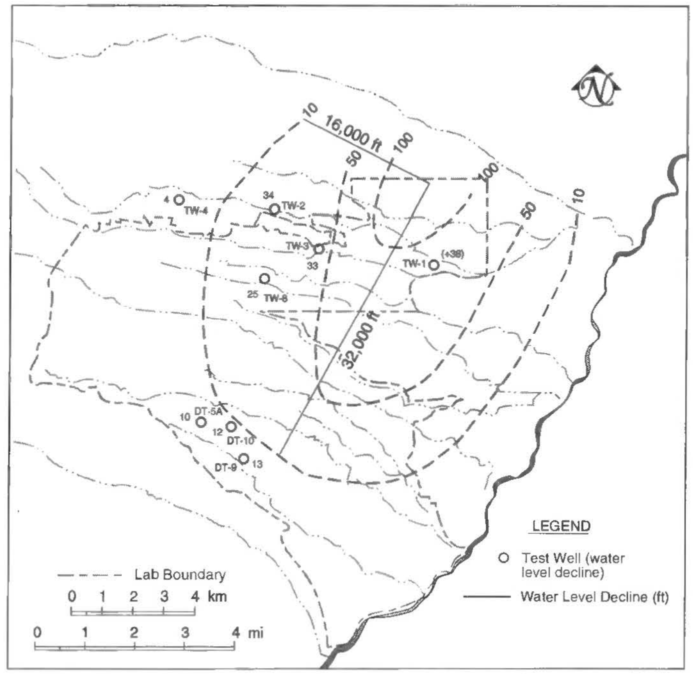

FIGURE 6. Approximate aquifer water level decline from 1949-1950 to 1993 (difference between maps in Figs. 4 and 5) using Rio Grande elevations and test wells. The water level decline from 1960 to 1993 is used for TW-8, DT-5A, DT-9, and DT-10. The area used to estimate aquifer depletion is an ellipse which extends an equal amount north of the area shown.

most of the water level decline has occurred in an area where there is no well control on the 1949-50 and 1993 maps, and where the contours on these maps are poorly constrained. The water level decline depicted on this map is consistent with the observations of water level recovery in the former Los Alamos well field, and with declines noted for the Pajarito and Guaje well fields (Purtymun et al., 1995). Despite a water level decrease of up to 100 ft, the generally east-southeast flow direction suggested by the water level maps has not changed between 1949-1950 (Fig. 4) and 1993 (Fig. 5). The flow directions are speculative, however, due to a lack of well control.

Assuming that the aquifer surface is under water table conditions, we can use the water level decline to estimate the difference in aquifer volume due to pumping. We approximate the volume of aquifer depletion represented by the water level decline map (Fig. 6) as follows. Assuming that the area of decline is an ellipse that continues to the north beyond the location of the Guaje well field (Fig. 3), the semimajor and semiminor axis lengths are about 32,000 ft and 16,000 ft. As the area of an ellipse is π times these semiaxis lengths, a circle with radius 22,600 ft would have the same area. We can approximate the volume of water level decline by formulas for the volume of a cone [$V = (\pi h a^2/3)$] and volume of the segment of the base of a sphere [$V = \pi h\ (3a^2 + h^2)/6$], where a is the radius (22,600 ft) and h is the height (100 ft) (Selby, 1975). Converting to gallons and multiplying by an assumed porosity of 10%, the estimated volumes are 4.0×10^{10} gallons for a cone, and 6.0×10^{10} gallons for a segment of a sphere. Weaknesses in this estimate include uncertainty in aquifer porosity, and limitations of data from which volume of water level changes were estimated.

The total withdrawal of water by Los Alamos for water supply between 1949 and 1993 is 5.7×10^{10} gallons (Purtymun et al., 1995). Thus, our estimate of the total volume of water withdrawn from the aquifer based on water levels approximates the actual pumpage. The implication of this finding is that there has been no significant net recharge to the aquifer since 1949, despite pumping-induced stresses on the aquifer. The best explanation for these observations appears to be that water production by the Los Alamos water system has mined water from the aquifer, but other explanations are possible.

Our assumption that the aquifer is under water table conditions is significant. We have used an estimate for the aquifer porosity (or specific yield, about 0.1) to calculate the depleted volume. For a confined aquifer, the appropriate parameter is the storativity, which gives the relationship between volume of water released per unit area per unit head decrease. For a confined aquifer the primary mechanism of water release is compaction of the aquifer rather than drainage. Storativity values are usually in the range of 0.005 to 0.00005 (Freeze and Cherry, 1979), or one to three orders of magnitude smaller than the specific yield. Application of such a value would reduce our depletion estimate by one to three orders of magnitude, and invalidate the conclusion that water supply pumping is mining the resource. This topic needs to be investigated further, as no storativity values have been determined for wells on the central portion of the Pajarito Plateau. Some evidence, such as for well DT-5A (McLin, 1996) suggests confined aquifer behavior in the southern part of the plateau.

AGE OF WATER IN THE AQUIFER

Age determinations for the aquifer water provide another means of evaluating recharge and flow paths in the aquifer. The Laboratory's hydrology team studied the sources of recharge to the aquifer in 1991 (EPG, 1994, 1995). Samples were collected from test wells and water supply production wells that penetrate the aquifer, and also from springs that issue along the Rio Grande. Measurements of carbon-14 and trace-level tritium measurements permit some preliminary evaluation of recharge pathways and estimates of the age of water in the aquifer. It is important to apply multiple techniques to this problem, in order to overcome the uncertainties in measurement and interpretation that are inherent in these methods.

"Age of water" means the time elapsed since the water, as precipitation, entered the ground to form recharge and became isolated from the atmosphere. Because groundwaters often form by mixing of waters of different ages, another term often used is "mean residence time", which is the apparent age of water at the discharge point. The precipitation at the time of entry into the ground is assumed to have been in equilibrium with atmospheric concentrations of both tritium and carbon.

Carbon 14 dating

Radioactive carbon-14 (or radiocarbon) comes from the interaction of cosmic rays with the atmosphere. Carbon-14, with a half-life of about 5730 years, is useful for estimating ages ranging from a few thousand to several tens of thousands of years. Once water enters the ground as recharge, radioactive decay and/or mixing with other older water or dissolution of older carbon from rocks would result in reduction of the concentration of either isotope in present groundwater samples. Estimates of these latter processes can be made from a knowledge of local geochemistry, including measurement of other carbon isotopes.

Interpretation of the results of carbon-14 analyses by R. R. Spangler (RUST GeoTech, unpubl. report for LANL, 1994) indicates that dissolution of carbonates increases with groundwater age, having a significant affect on radiocarbon content. Spangler estimated the size of this effect from the carbon-13 content of the samples, and determined adjusted radiocarbon ages for the samples (Table 1). These minimum ages for water in the aquifer range from about a thousand years under the western portion of the Pajarito Plateau, increasing eastward to about 30,000 yrs near the Rio Grande (Fig. 7, Table 1). Importantly, samples collected from the water supply wells integrate water drawn from screened intervals of 600 to 3100 ft and are thus composite water ages. These values are consistent with the general understanding of the Los Alamos aquifer, based on physical and geologic conditions. The only major exception to this distribution of ages is LA-1A, the age of which appears quite young for its location. This well has a very young tritium age, indicating an influx of recent water from the surface. The Eastside artesian well, located east of the Rio Grande, may reflect differences in groundwater discharge regime as influenced by the river.

The age values in the range of several thousands of years suggest that much of the water has been in the aquifer for long periods. A corollary is that recent recharge is not a volumetrically significant portion of the aquifer water. It is tempting to conclude that these ages support an easterly flow direction (Fig. 7) with younger water recharged at the western boundary of the plateau, and flowing towards the east. However, another possibility is that two separate water bodies of different ages are represented, as suggested by the flow paths in Figure 2b. The radiocarbon data consist of two geographically isolated sets of data. The older ages near the Rio Grande correspond to the region of waters with higher recharge elevations identified by Goff and Sayer (1980). The much larger ages found here could reflect the longer flow path from the possible Sangre de Cristo recharge area, and confirm the hypothesis that the aquifer groundwater divide lies west of the Rio Grande.

Purtymun (1984) estimated flow velocities for water near the top of the main aquifer from pump tests of water supply and test wells. The rates range from about 250 ft/yr in the Puye Conglomerate near the Otowi-4 well, to about 20 ft/yr in the Tesuque Formation below the Los Alamos well field. For the 5.5 mi distance between wells PM-3 and LA-1B, these flow rates give water travel times between the wells of 115 to 1450 yrs. These travel times are far smaller than the 22,000 to 27,000 yr difference in the carbon-14 ages for these wells. One possible explanation for this inconsistency is that Purtymun's (1984) estimates are based on aquifer tests, which mainly reflect the more permeable portions of the aquifer. A second possibility is that the carbon-14 samples may be influenced by dilution within the entire aquifer. These wells have very large screen intervals and draw water from a large cross section of the aquifer. However, a remaining possibility is that the two sets of wells sample different discharge areas as suggested by the flow paths in Figure 2b.

TABLE 1. Summary of carbon-14 and tritium-based age estimates for wells in the Los Alamos aquifer (R. R. Spangler, RUST GeoTech, unpubl. report for Los Alamos National Laboratory, 1994).

Well	Carbon-14 (% modern)	Carbon-14 Age Estimates: Minimum[b]	Carbon-14 Age Estimates: Maximum[c]	Tritium (pCi/L)	Tritium (T.U.[d])	Tritium Age Estimates[a]: Piston Flow[e]	Tritium Age Estimates[a]: Well-Mixed[f]
PM-5	53.7	1040	5140	0.29	0.09	85	>10000
				1.3	0.39	49	4500
DT-5A	57.6	1810	4560	0.23	0.07	80	>10000
				0.45	0.14	70	>10000
O-4	25.0	3890	11500	1.0	0.32	50	5000
PM-3	23.9	4950	11800	0.75	0.23	60	4500
PM-1	18.5	5620	14000	1.7	0.51	44	3500
				2.2	0.69	39	2500
G-5	26.8	6110	10900	0.26	0.08	80	10000
				1.4	0.43	47	4000
LA-1A	13.9	6250	16300	64	19.7	20	50
E. Artesian	3.8	18200	27000	1.0	0.31	55	5000
LA-1B	<0.9	>27000	>39000	0.58	0.18	60	9000
				0.065	0.02	100	10000
W. Artesian	0.0	>35000	>45000	0.39	0.12	70	>10000
				0.42	0.13	70	>10000

a. Blake et al. (1995).
b. Assumes dilution by dead carbon from dissolution of carbonates, estimated by $\delta^{13}C$.
c. Assumes radioactive decay only, no dissolution of carbonates.
d. Tritium Units, One tritium atom in 10^{18} hydrogen atoms; 1 TU = 3.24 pCi/L.
e. Piston Flow model (Blake et al., 1995) assumes no mixing or dilution with other water.
f. Well Mixed model assumes complete mixing in reservoir, inflow = outflow, no other inputs.

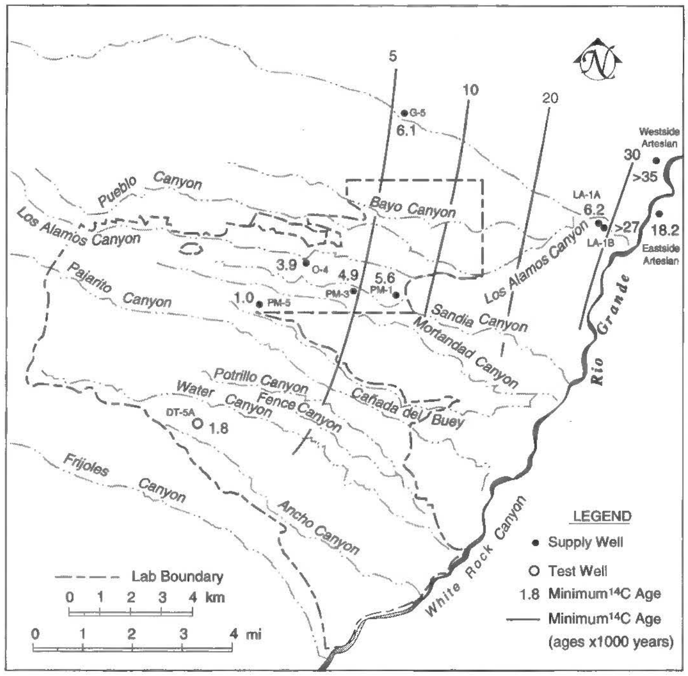

FIGURE 7. Minimum aquifer ^{14}C groundwater ages, adjusted for estimated dissolution of carbonates (thousands of years).

Tritium dating

Tritium, with a half-life of about 12.3 yrs, is useful for estimating ages in the range of decades to hundreds of years. Tritium is a naturally-occurring isotope of hydrogen, produced in the atmosphere by cosmic rays, and by decay of naturally-occurring radioactive elements in rocks. Tritium is also produced by nuclear reactors and as part of the development and testing of nuclear weapons.

Prior to discussing tritium measurements in the Los Alamos area deep wells, it is helpful to give some background on tritium levels. Before atmospheric testing of nuclear weapons began, tritium levels in precipitation were about 20 picocuries per liter of water (pCi/L). By the mid-1960s, tritium in atmospheric water in northern New Mexico reached a peak level of about 6500 pCi/L, the annual average for 1963-1964 (Vuataz and Goff, 1986, fig. 12). Since then, both radioactive decay and dilution by mixing through the global hydrologic cycle have reduced the concentrations of tritium in atmospheric water. Radioactive decay alone would have reduced the peak level of about 6500 pCi/L to a present value of about 650 pCi/L. At present, general atmospheric levels in northern New Mexico are about 30 pCi/L, and those in the Los Alamos vicinity range from 65 to 325 pCi/L (Adams et al., 1995).

As a basis for comparison, the present EPA and New Mexico State drinking water standard is 20,000 pCi/L. Routine evaluation of compliance with the drinking water regulations is determined using the EPA-specified liquid scintillation counting method, with a detection limit of about 300 to 700 pCi/L. The trace-level tritium measurements employed by this study were performed at the University of Miami and have a detection limit of about 1 pCi/L.

The majority of the trace-level tritium measurements show no measurable tritium (i.e., less than about 1 pCi/L). This indicates that the water in the aquifer contains no significant component of "recent" recharge (that is, precipitation from the last several decades, and almost certainly not "post-bomb" precipitation). These results are consistent with the carbon-14 measurements and our general understanding of the hydrogeologic setting of Los Alamos. The general aridity of the climate and the low hydraulic conductivity of unsaturated rocks would lead to little if any recharge through the hundreds of feet of nearly-dry rock separating the land surface and the aquifer. The carbon-14 results indicate that minimum ages of most deep groundwater samples in the Los Alamos area are greater than 1000 years, and should contain no measurable tritium because of its short half life. However, a few samples do show measurable tritium values (Table 2), which are reported here; for a more detailed discussion see EPG (1995).

The tritium concentration in groundwater can be altered by mixing with water already in the aquifer. To account for this possibility, two different age-determination schemes are employed (Table 1). The "piston flow" calculation assumes that the tritium value measured in the groundwater results only from radioactive decay of the original tritium in recharge water, which has moved undiluted through the aquifer. This gives a minimum age. The "well-mixed" model assumes that the recharge has completely mixed with water from the entire groundwater reservoir; this gives a maximum age.

Age determinations from tritium are most reliable for times less than 100 yrs. For ages above 1000 yrs, there is substantial uncertainty (Blake et al., 1995). Confidence in greater ages is increased if ages from carbon-14 or other methods are also available. Groundwaters that contain between 16 and 65 pCi/L of tritium are most likely the result of recent recharge, and are best modeled with the piston flow method (Blake et al., 1995). Waters with tritium concentrations below about 1.6 pCi/L are likely to be old, and can be modeled as well-mixed reservoirs. The ages of these waters are 3000 yrs, but large errors may be associated with small tritium concentrations (Blake et al., 1995). With a tritium concentration below 0.5 pCi/L, modeled ages are 10,000 yrs, but this is at the limit of tritium age determinations. Waters with tritium concentrations 1000 pCi/L and collected after 1990 can not have their ages modeled, and can only be the result of contamination (Blake et al., 1995).

TABLE 2. Los Alamos area trace-level tritium groundwater measurements exceeding about 1 pCi/L.

Location	Date	Tritium Units: Tritium	Tritium Units: ± [a]	pCi/L: Tritium	pCi/L: ±
Aquifer Test Wells					
TW-1	10/8/92	109	4	353	13
	5/19/93	113	3.7	366	12
	6/19/95	87	2.90	277	9
TW-2	10/8/92	0.22	0.09	0.71	0.29
	5/19/93	0.85	0.1	2.8	0.32
	8/1/95	5.27	0.18	16.8	0.57
TW-3	5/20/93	0.89	0.09	2.9	0.29
(max) Initial	7/18/95	-0.03	0.09	-0.10	0.29
(max) Bore 3	7/18/95	16.50	0.50	52.68	1.60
TW-4	5/19/93	3.34	0.11	11	0.36
TW-8	12/6/93	27.6	0.09	89	0.29
(max) Bore 1	7/17/95	4.89	0.16	15.61	0.51
(max) Bore 15	7/18/95	1.64	0.09	5.24	0.29
DT-9	5/20/93	0.14	0.09	0.45	0.29
	5/31/95	0.47	0.09	1.50	0.29
DT-10	5/20/93	0.41	0.09	1.3	0.29
	5/30/95	0.99	0.09	3.16	0.29
Intermediate Perched Zone, Pueblo Canyon (150-250 ft depth)					
TW-1A	10/8/92	41.3	1.4	134	4.5
	5/19/93	45.8	1.5	148	4.9
	6/19/95	24.7	0.8	78.9	2.5
TW-2A	10/8/92	698	23	2262	75
	5/19/93	699	23	2265	75
	8/1/95	566	19	1807	61
Intermediate Perched Zone, Los Alamos Canyon					
Basalt Spring	6/11/91	37.9	1.3	123	4.2
	12/29/92	50.1	1.7	162	5.5
	5/25/95	27.6	0.90	89.4	2.9
LADP-3 [b]	12/17/93	-	-	6000	160
Former Los Alamos Well Field Production Wells					
LA-1B	10/22/91	0.02	0.09	0.06	0.29
	5/12/93	0.18	0.09	0.58	0.29
	5/25/15	0.51	0.09	1.65	0.29
LA-1A	5/12/93	19.7	0.7	64	2.3
	5/25/95	2.74	0.12	8.88	0.39
LA-2	5/12/93	4.04	0.13	13	0.42

a. The ± values represent one standard deviation of the uncertainty of measurement. The University of Miami detection limit is 1 pCi/L (0.3 TU); one TU = 3.24 pCi/L.
b. Broxton et al., 1995.

The tritium groundwater ages (Table 1) are generally consistent with the carbon-14 ages, within the limits just described for this technique. Groundwater ages in the central part of the Pajarito Plateau are in the 5000 yr range. Closer to the Rio Grande, the ages are near or greater than 10,000 yrs. These ages indicate a residence time for groundwater in the aquifer greater than 5000 yrs, and suggest that this water is isolated for the most part from recent surface recharge. The exceptions to this trend are discussed in the following section.

Tritium detection in test wells

Measurements of tritium by extremely low detection limit analytical methods show the presence of some recent recharge (meaning within the last four decades) in water samples from wells into the aquifer at five locations near Los Alamos. The levels measured range from less than 2% to less than 0.01% of current drinking water standards, and are all less than levels that could be detected by the EPA-specified analytical methods normally used to determine compliance with drinking water regulations (EPG, 1995).

The locations (Fig. 3) where tritium measurements clearly indicate the presence of recent surface recharge to the aquifer are (1) test well 1, situated in Pueblo Canyon near the confluence with Los Alamos Canyon; (2) test well 3, in Los Alamos Canyon; (3) in old observation and water supply wells LA-1A and LA-2, located in Los Alamos Canyon near its confluence with the Rio Grande; and (4) at test well 8, in Mortandad Canyon, located about a mile downstream from the outfall of TA-50, the radioactive liquid waste treatment plant for the Laboratory. Additional studies of household wells, surface waters, and springs at San Ildefonso Pueblos are reported elsewhere (EPG, 1995; Blake et al., 1995).

In two other aquifer locations, the trace-level tritium results were questionable and required further investigation. Apparent trace-level detection of tritium occurred in the PM-3 water supply well, but was later discovered to have resulted from laboratory sample contamination. The second of the questionable measurements is at test well 4, on the mesa east of Acid Canyon in the Los Alamos town site. It had been capped and out of service for about 20 yrs until fall 1992, when it was refurbished and equipped with a new pump. This operation included the introduction of some surface water for cleaning and priming the pump. Other data (e.g., temperature) suggest doubt that the well was pumped long enough to completely purge any introduced water, which constitutes a possible source of tritium. Subsequent analysis of both of these wells have shown no detectable tritium.

Results from intermediate perched groundwater give an indication of possible recharge pathways. The four intermediate depth perched groundwater locations having tritium results demonstrating recent recharge include test well 2A in the middle reach of Pueblo Canyon, test well 1A in lower Pueblo Canyon, well LADP-3 in mid-Los Alamos Canyon, and Basalt Spring in lower Los Alamos Canyon. The test wells sample a perched layer 200 to 300 ft beneath the canyon bottom. The results at test wells 1A and 2A and Basalt Spring are consistent with other chemical quality observations extending back into the 1960s, done by the U. S. Geological Survey when it was performing groundwater monitoring for the Laboratory. Well LADP-3 was drilled in Los Alamos Canyon in 1993 as part of the Environmental Restoration Project investigations. Well LADP-3 (Broxton et al., 1995) is down gradient from the Omega Reactor, which was discovered in 1993 to have been leaking tritiated cooling water for some time (EPG 1995).

In some cases of tritium detection, the source of tritium appears to be downward migration from canyon bottom alluvium. Most wells are located downstream of present or former sites of treated radioactive liquid industrial waste discharge into either Acid/Pueblo Canyon (affecting Pueblo Canyon, Los Alamos Canyon, and possibly San Ildefonso Pueblo wells), DP/Los Alamos Canyon (affecting Los Alamos Canyon and possibly San Ildefonso Pueblo wells), or Mortandad Canyon. There are several possible pathways through which tritium might be moving toward the aquifer. For older test wells drilled by the cable tool method, which does not include an annular seal, there could be migration down the well bore outside the steel casing. Additional mechanisms include saturated flow carrying tritium downwards through fractures or faults. There could be unsaturated flow of tritium through the vadose zone beneath the canyon bottom. Finally, tritium could move downwards in the vapor phase through the unsaturated zone.

In order to evaluate the possibility of annular leakage in the test wells, a sequence of samples was collected during continual pumping of test wells 3, 4, and 8 during 1995. No significant tritium was found in test well 4. For test wells 3 and 8, tritium level decreased during pumping. The range of values for these wells is given in Table 2.

CONCLUSIONS

The following picture emerges regarding flow paths and recharge in the Pajarito Plateau aquifer system. Based on aquifer depletion estimates described here, the net aquifer recharge would appear to be much smaller than the pumping rate for municipal water supply. Thus municipal pumping appears to be mining the water from the aquifer. This conclusion is strongly dependent on the assumption that the aquifer is under water table conditions and has a porosity of about 10% .

The carbon-14 data suggest that much older water is found near the Rio Grande, with younger water under the central Pajarito Plateau. The large age values indicate that much of the water has been in the aquifer for long periods, and that recent recharge is not volumetrically significant. It is tempting to conclude that these ages support an easterly flow direction. However, another possibility is that two separate water bodies of different ages are represented, as suggested by the flow paths shown in Figure 2b. The radiocarbon data consist of two geographically isolated sets of data, which together with a large discrepancy between aquifer flow rates and water ages, supports the conclusion that aquifer water near the Rio Grande is recharged from the Sangre de Cristo Mountains, and that a groundwater divide within the aquifer lies west of the Rio Grande.

The tritium data indicate that a small volume of recharge has entered the intermediate groundwater system beneath Pueblo and Los Alamos Canyons during the last four decades. Recent water has also penetrated to the upper portion of the aquifer, as shown by measurements at test wells and some former water supply wells. These tritium values are not of immediate concern to public health. Considering the high tritium levels that were formerly released into Pueblo, Los Alamos and Mortandad Canyons, the low test well tritium levels indicate that only minor recharge has occurred at these locations. The findings do indicate that recharge pathways exist, however, and this will be the subject of further study in an effort to evaluate protection of the aquifer system.

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