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The hydrology and chemical and radiochemical quality of surface and ground water at Los Alamos, New Mexico, July 1957 through June 1961

By

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Abstract

Low-flow measurements of perennial streams in Santa Clara, Guaje, Los Alamos, and Frijoles Canyons indicated gains in flow in the upper third reach of the streams and losses in flow downstream. Streamflow in Acid and Pueblo Canyons is maintained principally by effluent discharged from the waste treatment plant in Acid Canyon and sewage treatment plants in Pueblo Canyon. Effluent from the waste treatment plant has a low level (below off-site tolerance) of radioactivity; effluent from the sewage plant has only background radioactivity. Water from the sewage plants mixes with and dilutes the radioactive waste from the waste treatment plant.

Total dissolved solids in the water from sewage plants generally is low; the specific conductance normally is less than 600 micromhos at 25°C. The water is of the sodium bicarbonate type.

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Changes in the chemical quality of water from shallow wells in the alluvium of Pueblo Canyon suggest that the stream recharges the alluvium. The chemical quality of the water from deep test wells in Pueblo Canyon, which are open to and bottom in tuff and basalt, show no indication that recharge from the stream has carried plant effluents to hundreds of feet below the land surface. There was no significant change in the chemical quality of water from the springs and from the supply wells in Los Alamos and Guaje Canyons. Small quantities of radioactivity in water from the Rio Grande and Rio Chama may be due to fallout; apparently little or no contamination was added to the Rio Grande from waste and sewage disposal at Los Alamos, except possibly that transported in summer flood flows in the tributaries crossing the Los Alamos area.

Radioactivity in the alluvium decreases with distance from the waste treatment plant in Acid Canyon and most activity is retained in Acid Canyon before reaching Pueblo Canyon. Radioactivity in the alluvium in Los Alamos Canyon is small and is confined chiefly near areas of waste discharge. Radioactivity in the alluvial material near Ten Site decreased with time and distance.

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Introduction

This report presents streamflow data and chemical and radiochemical data obtained by analyzing samples of surface and ground water and soils in the Los Alamos area from July 1957 through June 1961. It is the fourth of a series of reports monitoring the waste-disposal program at Los Alamos and is prepared in cooperation with the Atomic Energy Commission and the University of California Los Alamos Scientific Laboratory. The first report describes the radioactive-waste disposal sites (Abrahams, 196[illegible]) and the second and third present a summary of the chemical and radiochemical analyses for the periods 1949 through December 1955 (Weir and others, 1962), and January 1956 through June 1957 (Abrahams, 1965).

The physiographic features of the Los Alamos area are shown on figure 1. The general geology and hydrology of the Los Alamos area

Figure 1.--Generalized map of the physiographic features of the Jemez Mountain region, New Mexico, and sampling stations on the Rio Grande and Rio Chama.

are described by Griggs (1964) and a generalized stratigraphic section describing the geology along the eastern slopes of the Sierra de los Valles, the Pajarito Plateau, and along the Rio Grande is shown in table 1. The stratigraphic relations of the rocks in the Los Alamos area are shown on figure 2.

Figure 2.--Diagrammatic cross section showing generalized stratigraphic relations of the Bandelier Tuff to older rocks in the Los Alamos area.

The radiochemical analyses of water sampled were made by the H-6 Group of the Health Division of the Los Alamos Scientific Laboratory under the direction of William Kennedy, Group Leader, who also furnished personnel to assist in sample collection. The radiochemical analyses of soil samples were made by the H-7 Group under the direction of C. W. Christensen, Group Leader.

Discharge measurements, in Santa Clara, Guaje, Los Alamos, and Frijoles Canyons were made by the Surface Water Branch of the U.S. Geological Survey. The Surface Water Branch also collected water samples from the Rio Grande at gaging stations at Embudo and Cochiti.

The Quality of Water Branch of the U.S. Geological Survey made chemical analyses of all water samples and collected the water samples from the Rio Chama at Chamita and the Rio Grande at Otowi.

Well numbering

Wells from which water samples were collected for chemical and radiochemical analyses in Acid and Pueblo Canyons are numbered according to well-series designations. Wells finished in the alluvium are constructed of drivepoint or corrugated culvert pipe and are in the "AC" and "PC" numbered series. AC designates the series of wells in Acid Canyon; PC designates a similar series in Pueblo Canyon. Wells penetrating the alluvium and finished in the upper 50 feet of the fanglomerate member of the Puye Conglomerate and cased either with 2-inch plastic pipe or 1½-inch to 3-inch diameter galvanized pipe are in the "PO" series. This well series was constructed along lines across the streamway in Pueblo Canyon. The complete well number PO-1A designates well-line 1 and well A in that line. Deep wells finished in the Puye Conglomerate and cased with 6-inch diameter steel pipe are in the "TW" series and are numbered with or without a suffix letter "A" to designate two sub-series. Wells TW-1, TW-2, and TW-3 (the latter is in Los Alamos Canyon) are finished in the Totavi Lentil of the Puye Conglomerate. Wells TW-1A and TW-2A are adjacent to TW-1 and TW-2, respectively, and are finished in basaltic rocks above the Totavi Lentil and within the fanglomerate member of the Puye Conglomerate.

Wells supplying [illegible] are finished in the Tesuque Formation. Supply wells of the Los Alamos Canyon well field are designated with the prefix "LA"; wells in the Guaje Canyon well field are designated with a "G" prefix. Supply-well LA-1B is a replacement well for well LA-1, however, well G-1A is not a replacement well for G-1.

Stream discharge

Streams in Santa Clara, Guaje, Los Alamos, and Frijoles Canyons head on the eastern slopes of the Sierra de los Valles and flow eastward on the Pajarito Plateau toward the Rio Grande (fig. 1). Streams in Santa Clara and Frijoles Canyons have perennial flow to the Rio Grande. Streams in Guaje and Los Alamos Canyons are perennial only above reservoirs built in those canyons (fig. 5). Springs maintain low (base) flow in upper Guaje and Los Alamos Canyons. Stream flow in Pueblo Canyon is maintained from discharge from an industrial waste treatment plant and two sewage treatment plants. Runoff from precipitation and snowmelt increases the discharge at times. Afternoon thunderstorms during July and August cause floods that last only a few hours; snowmelt in the spring causes small discharges that may continue for weeks and months. Some of the surface water in Guaje and Los Alamos Canyons (Pueblo Canyon is a tributary to Los Alamos Canyon) reaches the Rio Grande during periods of large discharge.

Current-meter measurements were made periodically of the discharge in each stream at selected stations in downstream order and spaced throughout the perennial reach. Measurements were made only during periods of low (base) flow to determine more accurately the gain in flow from ground-water discharge through seeps and springs and any loss in flow that might go to ground water in each of the reaches between consecutive stations.

Estimates were made of the discharge in the non-perennial reach of Guaje, Los Alamos, and Pueblo Canyons caused by runoff of precipitation and snowmelt. Flows were estimated at selected points by timing the travel of a wood chip floating along a measured reach. Small flows in Pueblo Canyon were measured with weirs.

Pueblo Canyon

Periodic, generally monthly, streamflow measurements were made in Pueblo Canyon to determine the amount of seepage into streambed materials in Acid and Pueblo Canyons. Streamflow in Pueblo Canyon from sec. 9, T. 19 N., R. 6 E., to sec. 29, T. 19 N., R. 7 E. (fig. 4) consists chiefly of treated effluent from two sewage plants in the

Figure 4.--Map showing [illegible] stations for discharge measurements, Acid and Pueblo Canyons, waste and sewage disposal sites, and sampling points, Los Alamos and Santa Fe Counties, [illegible]

canyon and an industrial waste treatment plant in Acid Canyon, a tributary canyon. Precipitation and snowmelt occasionally add water to the volume of flow.

About 165 million gallons of effluent sewage and industrial wastes are discharged annually to Acid and Pueblo Canyons. All of the effluent from the sewage plants, except for a small amount used for cooling at the power plant, is discharged in Pueblo Canyon from October through April. During May through September as much as 90 percent of the daily effluent is used for cooling and for lawn irrigation, except when summer rains reduce the irrigation demand. Effluent from the industrial waste treatment plant is discharged to Acid Canyon in slugs rather than a continuous flow.

Most of the snowpack in the Pueblo Canyon drainage area generally melts before the end of April. Flow during the winter at Hamilton Bend Spring generally was 50 percent of that at PC-2, and flow reached downstream as far as PC-9 and PC-10. The largest flow of combined effluent and snowmelt observed was 10.4 cfs (cubic feet per second) near well PC-6 in April 1958 (table 2) and, at this time, flow in the lower part of the canyon at Hamilton Bend Spring (fig. 4) was 85 to 95 percent of the flow at PC-2.

Streamflow during the summers reflected the decreased discharge of effluent from the sewage treatment plant. The flow generally ended a short distance downstream from PC-7. The impermeable latite and quartz latite bed of the Tschicoma Formation, that crops out between PC-3 and a short distance upstream from the outfall of the Central Sewage plant, may cause water to remain in the streambed through this reach of the canyon (fig. 4).

Figure 5.--Generalized geologic map of the Sierra de los Valles and the western part of the Pajarito Plateau, showing springs sampled outside the area shown on figure 4, and altitude of initial point of discharge measurements of streams in Santa Clara, Cañada, Los Alamos, and Frijoles Canyons.

Small seeps near Hamilton Bend Spring and Otowi Seep occur in the upper part of the Puye Conglomerate. The stream cuts through the base of the Bandelier Tuff, starting a short distance upstream from Hamilton Bend Spring, and thus exposing a compacted layer of silt in the Puye upon which water is perched and emerges as a spring and seep.

Santa Clara, Guaje, Los Alamos, and Frijoles Canyons

Low flows in Santa Clara, Guaje, Los Alamos, and Frijoles Canyons are fed by springs emerging near the contact between the Bandelier Tuff and the underlying Tschicoma Formation (figs. 2 and 5). Springs or seeps emerge also from the alluvium in the floors of the canyons where the contact between the Bandelier and Tschicoma is covered at only a shallow depth. Some seeps and springs represent the discharge of water stored in the thin soil on the watershed.

The first streamflow measurements, October 14-16, 1958, were made at stations spaced 0.1 to 0.5 mile apart along the perennial reach of streams in the four canyons. Hydrographs showing discharge are shown on figure 6. The number of stations measured and sampled was

Figure 6.-- Hydrograph showing discharge of streams and altitudes of stream channels in Santa Clara, Guaje, Los Alamos, and Frijoles Canyons.

reduced during the study as patterns or lack of patterns became apparent. The stations shown on figure 6 are, in general, those where measurements were made periodically from October 1958 through September 1960. All measurements were adjusted to discharge on one day of the period through use of overlapping measurements. Duplicate measurements at the same station were made when there was a delay of one or more hours between measurements. The discharge figures are reported in U.S. Geological Survey Water-Supply Papers 1632 and 1712.

Low flow through most of the middle part of the perennial reach of Santa Clara Creek (fig. [illegible]) was 4 to 6 cfs. The higher discharge on May 16-17, 196[illegible], probably included appreciable snowmelt. The largest gains in flow in Santa Clara Creek occurred in the 0- to 2-mile reach; flow was relatively steady in the 2- to 12-mile reach, and losses exceeded gains downstream from the 12-mile point as flow infiltrated the rocks of the Santa Fe Group.

Low flow in Guaje Canyon (fig. [illegible]) generally was less than about 1 cfs except for the measurements which included runoff of precipitation in late August 1955 and snowmelt in May 1960. A slight decreasing trend in the 2- to 5-mile reach on several dates appears to coincide with the area where the streambed changes from the relatively impermeable Tschicoma Formation to the permeable Puye Conglomerate; a slight trend toward increasing discharge at about the 5½-mile point may be due to a damming effect on underflow by the impermeable Tschicoma Formation at shallow depth. Water was being diverted at a constant rate at Guaje Reservoir for municipal use on most measuring dates.

The average low flow in Los Alamos Canyon (fig. 6) was less than 0.5 cfs, and was the smallest in the four canyons measured. The discharge on the three dates of measurement did not seem to be affected by snowmelt nor local precipitation. The losses at 0.5 mile and gains at 0.6 mile may have been caused by changes in the amount of underflow in the alluvium.

Measurements of the discharge in the non-perennial portion of Los Alamos Canyon below the reservoir (fig. 4) are presented in table 3. Streamflow, maintained by snowmelt in April and May of 1958 and 1961, in the middle and lower part of Los Alamos Canyon decreased rapidly during late May and was gone by early June. Water content of the snowpack in March 1958 was the highest on record. The flow decreased about 40 percent between the stations 2.1 miles below the dam (sec. 17, T. 19 N., R. 6 E.) and bridge at Highway 4 (sec. 21, T. 19 N., R. 7 E.) during measurements on May 23, 1958, but decreased almost 90 percent during measurements on April 27, 1961, as the alluvium became saturated. On April 27, 1961, the flow remained unchanged in the 3.1-mile reach below the dam where alluvium overlies the Tshicoma Formation and Tshirege Member of the Bandelier Tuff, but decreased about 50 percent before reaching test well 3, where the alluvium overlies the Otowi Member.

Low-flow measurements of Frijoles Canyon showed a consistent pattern (fig. 6). Discharge was greater during spring than during fall. Except for measurements made on April 29, 1959, the maximum measured low-flow discharge was 1 to 2 cfs near the Upper Crossing (fig. 5), which coincides with the position of the Pajarito fault zone. The discharge decreased irregularly downstream from the Upper Crossing. The Tschicoma Formation underlying the tuff at a shallow depth above the Upper Crossing possibly "perches" the stream. Below the Upper Crossing the stream loses water to the downthrown Bandelier Tuff.

A gauge recorded the daily-high discharge at about the 9.4-mile point of Frijoles Canyon, from October 1958 through September 1959. The record shows that high discharges occurred from early March through early May, and peaked at about 12 cfs in April. Low flow generally ranged from 0.9 to 1.1 cfs and correlates with the periodic measurements taken in other years as shown on figure 6.

In summary, the low flow in perennial streams crossing the Pajarito Plateau in the Los Alamos area ranged from about 0.3 cfs in Los Alamos Canyon to about 6 cfs in Santa Clara Creek. The largest low-flow discharge occurred in Santa Clara Canyon north of Los Alamos and much of this flow infiltrated the rocks of the Santa Fe Group in the lower 6 miles of the canyon. Flow in Guaje Canyon west of the well field apparently infiltrates the Santa Fe Group but not the Tschicoma Formation. Infiltration to the Bandelier Tuff in Los Alamos and Frijoles Canyons is relatively small. Seepage losses from the plateau streams increase downstream principally because the alluvium broadens and thickens downgradient, and can store and transmit more water.

Chemical quality of water

The water-sampling network in the Los Alamos area is shown on figures 4 and 5. Samples were collected bimonthly for a period of two years from wells of the AC, PC, and PO numbered series in Acid and Pueblo Canyons. Wells TW-1A and 2A usually were sampled monthly. Wells TW-1 and 2 and supply wells in Los Alamos and Guaje Canyons generally were sampled semiannually. Springs were sampled monthly, bimonthly, quarterly, or annually depending upon their location relative to areas of waste and sewage disposal. Samples from the Rio Grande and Rio Chama were collected weekly, and composited to make a monthly sample for analysis. Samples were collected from selected sites in Santa Clara, Guaje, Los Alamos, and Frijoles Canyons during several low-flow measurements.

The results of the analyses are given in tables 5 through 63, and are shown as equivalent parts per million to facilitate describing types of water by possible chemical combinations in it.

Acid and Pueblo Canyons

Trends or significant changes in the chemical quality of water from the waste treatment plant as the water moved downgradient through alluvium in Acid and Pueblo Canyons were partly obscured by the dilution effect of snowmelt and stormflow, changes in quality and quantity of effluent discharged from the two sewage treatment plants, and slug-type releases of water from the waste treatment plant.

A summary of the chemical quality of water over several years from sampling points in the Acid and Pueblo Canyons disposal system is given on table 5. The analysis of wastes discharged from the waste treatment plant into Acid Canyon and from the sewage plants into Pueblo Canyon also is shown in table 5. Chemical analyses of all samples analyzed from sample points are presented in their respective tables and discussed there.

The chemical quality of the ground water, as indicated in many samples analyzed from Acid Canyon wells, probably was unstable because of the high pH of 10 or above (tables 6, 7, and 8). The pH of ground water in the canyon decreased abruptly downgradient to an average of about 7.5 at well PC-2 in Pueblo Canyon (table 11). The concentration of the carbonate ion commonly was high at AC-3 and 4 and decreased downstream, whereas the concentration of the bicarbonate ion was correspondingly low at AC-3 and 4 and increased downstream. The hydroxyl ion was present when the water had a pH of about 11. The decrease in specific conductance downstream indicated precipitation of some constituents and ion exchange within the alluvium. The concentration of the potassium ion was high in samples from AC-3 and 4, but decreased downstream. Definite statements about the quality of water in AC-5 are not made because the number of samples collected at AC-5 was too small to be considered representative.

There were no radical changes in the chemical quality of water from Pueblo Canyon wells (tables 5, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, and 20), although there were some trends. The pH of samples collected from Pueblo Canyon wells ranged from an average pH of 7.6 at the confluence with Acid Canyon to an average pH of 7.3 in the lower reaches of the stream, a decrease in pH with distance. Specific conductance below the confluence of Acid and Pueblo Canyons also decreased. Concentrations of the calcium, magnesium, sodium, and bicarbonate ions were higher in Acid Canyon wells than in Pueblo Canyon wells (table 5).

The quality of the surface water, at sampling stations Pueblo 1, 2, and 3 (Pueblo 3 is at end of surface flow generally between Otowi seep and well PC-10), generally was similar to the quality of that in adjacent wells PC-2, 6, and 10, respectively (table 5), although concentrations of calcium-magnesium, sodium, bicarbonate, chloride, and sodium ions were higher in samples from the wells (tables 21, 22, 23). This is shown in the table [illegible], which was taken from table 5.

Concentrations of ions, in equivalents per million

	Pueblo 1	PC-2	Pueblo 2	PC-6	Pueblo 3	PC-10
Calcium-magnesium	1.20	1.43	1.03	1.45	1.07	1.37
Sodium	2.57	2.57	2.62	2.90	2.58	2.61
Bicarbonate	2.15	3.15	2.19	2.90	1.88	1.91
Chloride	.69	.79	.77	.79	.74	.78

Water collected from Pueblo Canyon wells from July 1957 through June 1961 was predominantly of the sodium bicarbonate type (table 5); the average percent sodium (ratio of sodium ions to sum of cations) in samples ranged between 66 and 75. The quality of water was relatively stable in all the wells; however, the concentration of the bicarbonate ions decreased slightly downstream and the concentration of nitrate ions increased slightly.

Seasonal changes in the chemical quality of water from wells in Pueblo Canyon (table 23) are shown by the average concentration of most ions being highest during July and lowest during March. Seasonal changes in ion concentration in samples of streamflow were not detected, probably because of the changing quality of effluent discharged from the sewage and waste treatment plants and dilution from varying amounts of flow from precipitation.

Water from Hamilton Dam Spring (table 25) was predominantly a sodium bicarbonate water and generally comparable to water from Pueblo Canyon wells 6 and 7 (tables 15 and 16). Seasonal variations of the concentration of chloride ions may correlate with seasonal changes of quality of water from Pueblo Canyon wells (table 24). A decrease of the concentration of the calcium-magnesium ion and the specific conductance from July 1957 to June 1961 is not evident in Pueblo Canyon wells.

Water samples from wells PO-4A, 4B, and 1A were predominately a sodium bicarbonate water (table 29) and similar to water from other shallow wells in Pueblo Canyon. The quality of the water from well PO-4C (table 27), less than 50 feet south of the stream, responded directly to changes in the quantity and quality of water in the stream. Monthly changes in the quality of water from PO-4C correlated also with changes in the quality of water from well PO-6 over a mile upstream, whereas the quality of water from adjacent PO-4D, more than 300 feet north of the stream (fig.), did not correlate with these changes. The absence of phosphates in water from PO-4D (table 28), as opposed to the relatively high phosphates in water from PO-4C, may be due to the greater distance that the water must move from the stream to PO-4D. Water quality in well PO-1A (table 29) varied directly to chemical quality changes in the stream.

The quality of water from PO-3B (table 30) appears to be substantially different from that in the stream and from Hamilton Bend Spring. Water from the well was a calcium-magnesium bicarbonate water and had a comparatively low specific conductance. However, the concentration of the chloride ion increased and almost doubled within a period of about 3 years indicating that some influence was taking place from stream recharge.

The water from deep well TW-2A was predominantly calcium-magnesium bicarbonate (tables 31 and 32), except for a period of 1958 when it was predominantly calcium-magnesium chloride. The presence of the chloride ions may reflect recharge from surface water in the canyon that had high concentrations of the chloride ion from the industrial effluent during late 1957 and early 1958. The quality of water after November 1959 was similar to that in well PO-3B (table 30), and the increase in the concentration of the chloride ion was of the same magnitude in both wells.

Concentrations of calcium-magnesium, sodium, and bicarbonate ions, and specific conductance in water from deep well TW-1A were markedly less when samples were collected with a bailer before pumping the well (tables 31 and 3) than when they were collected after the well had been pumped for several days. Samples collected with a bailer are probably not representative of water in the aquifer. The water was predominantly sodium bicarbonate water when the samples were collected after pumping, which is similar to the surface water in the lower part of the canyon. The quality of water in samples collected when the pump was in operation varied from sample to sample within a relatively small range. Residual effects from the spike of sodium chloride injected into the well in May 1956 account for the high concentrations in samples collected before November 1957. The abrupt decrease in late 1957 in the concentration of the calcium-magnesium, sodium, and chloride ions is due to dilution by increase in recharge during the wet fall and winter of 1957.

There were no significant trends of changes in the quality of water in samples from the deeper test wells. Concentrations of ions were nearly constant in water from wells TW-1 (table 34) and TW-2 (table 35), but some variations were noted in samples from well TW-3 (table 36). The water from all three wells was a calcium-magnesium bicarbonate water. The higher percentage of sodium in water from well TW-1 and the higher specific conductance in water from well TW-3 may reflect a more circuitous hydraulic connection with surface water than that of TW-2.

The quality of water in a sample collected in well TW-2, on July 17, 1958, with a bailer probably was not representative of the quality of water in the aquifer. There was no notable change in quality of water pumped in 1957-61 from that pumped in 1955.

Water from the Layne-Western well in Guaje Canyon is of the calcium-magnesium bicarbonate type (table 37). The water probably is from a water-bearing bed recharged by the stream in Guaje Canyon.

Los Alamos Supply Wells

The concentration of ions in water from wells in the Guaje Canyon well field (31,4) was relatively low (table 38) and approximately comparable to that of water from wells LA-1, 4, and 5. No increasing or decreasing trends with time were evident although some periodic changes in the quality of water did occur.

Water from wells G-1 (table 39), 1A (table 40), 2 (table 41), and 3 (table 42) was predominantly sodium bicarbonate, whereas the water from wells G-4 (table 43) and 5 (table 44) to the west (upgradient) was predominantly calcium-magnesium bicarbonate. Also, the concentration of ions in the water from wells G-2 and 3, near the middle of the well field, was slightly higher than that in other Guaje Canyon wells. The decrease in concentration of the chloride ion from well G-5 to well G-3 and from well G-2 to G-1 is slight but persistent. The reason for the relatively high concentrations of the fluoride and chloride ions in water collected on June 6, 1956 from all the wells may be analytical error.

A comparison of the analyses of water for June and December of each year from all the supply wells indicates a small seasonal change in the quality of water that may be attributed to seasonal variations in pumping rates. Pumpage from the wells is considerably more in June than in December. The higher temperature of the water during the heavy summer pumping may be the result of water-bearing beds at greater depth entering the mouth of the discharge when the wells are heavily pumped than during the lighter December pumping. The concentration of the calcium-magnesium ion was higher in samples collected during December in the six supply wells in Guaje Canyon whereas the concentrations of the sodium and chloride ions, along with the percent sodium, were highest in samples collected in June (table 30). In general, the change in the quality of water with continuous pumping was not significant and there was no apparent contamination from wastes discharged at Los Alamos.

The concentration of iron in water from wells in the Los Alamos well field (fig. 4) generally is slightly higher than that from the Guaje well field. The concentrations of sodium, bicarbonate, chloride, and fluoride ions (table [illegible]) are about twice that of water from the Guaje well field, but the concentration of the calcium-magnesium ion was only about half. Water in the Los Alamos well field was predominantly sodium bicarbonate and similar to that from the wells in the lower part of the Guaje well field. The average percent sodium in the Los Alamos well field ranged between 6[illegible] and 77, compared to the average percent sodium ranging between 25 and 62 in the Guaje well field. There is some evidence of minor seasonal trends in the quality of water from the individual wells and of changes with time, such as the increase in the concentration of the chloride ion and the decrease in the pH in water from well LA-2.

Progressive changes in the quality of water down canyon, excluding well LA-6, are evident, with more notable changes when the three shallower wells are considered separately from the three deeper wells. The three shallower wells, LA-1 (table 46), 2 (table 47), and 3 (table 48) in the lower part of the canyon, are 470 feet deep, whereas the three wells farther up the Los Alamos Canyon are about 1,700 feet deep. The concentration of the sodium, bicarbonate, chloride, and fluoride ions, and the specific conductance and pH increases between wells LA-3 and LA-4; LA-1 and LA-[illegible] (table 49); and LA-3 (table 50) and LA-4 (table 51).

Samples of water were collected from well LA-6 (table 51) monthly from July 1957 through August 1959 to determine the quality-of-water changes between consecutive samples. Most samples were collected in pairs during a pumping period, one after about 15 to 45 minutes of pumping and the other after about 350 to 500 minutes of pumping. With few exceptions, the concentration of the sodium, bicarbonate, and chloride ions and the temperature and specific conductance increased with pumping, but the pH decreased. This indicates a zone of high permeability with a slightly different chemical quality of water that yields a larger amount of water to the well when pumped.

The quality of water from well LA-1B (table 52), a new well 1,750 feet deep in the lower part of the canyon, was highly mineralized. Concentrations of the sodium ion were as much as 8.18 milliequivalents, specific conductance reached 790 micromhos, and the temperature was a few degrees higher, but the average pH was the lowest in the well field.

The higher concentration of the fluoride ion in water from wells LA-1B and LA-6 possibly is related to the pumping water from deep aquifers not reached by the other wells.

Springs

Waters from springs in the Los Alamos area is predominantly of the calcium-magnesium bicarbonate type and they contains low percent sodium (table 53 and 54). This is common in water-bearing beds above the main aquifer in the Los Alamos area. The percent sodium in water from the springs ranged from about 16 percent at American Spring (table 54) to 48 percent at Sacred Spring (table 55).

The concentration of sulfate ions in the water from Basalt (table 58), Los Alamos (table 57), Indian (table 56), and Spared Springs along Los Alamos Canyon (fig. 4), downgradient from the Acid and Pueblo Canyons disposal system, is somewhat higher than from the other area springs. The concentration of calcium-magnesium and bicarbonate ions in three of the four water samples collected from Basalt and Los Alamos Springs in May and June was slightly lower than other samples collected from these springs. This suggests seasonal differences, although the quality of water from both springs was relatively constant through the period of this report. The concentration of calcium-magnesium and bicarbonate ions in water from Sandia Spring in the lower part of Sandia Canyon (fig. 4) varied somewhat but was comparable to that from Basalt and Los Alamos Springs. The quality of the water from Armstead Spring west of Los Alamos also varied slightly. Water from Doe (table 59) and Ancho Springs (table 60) is of the calcium-magnesium bicarbonate type, and similar to that from American and Sawyer Springs (table 54). Water from Chaval Seep (table 61) is of the sodium-bicarbonate type and reflects the quality of water in Pueblo Canyon.

Rio Grande and Rio Chama

Water in the Rio Grande east of Los Alamos (Fig. 2) is a composite of waters from the Rio Chama and the Rio Grande (table 62). Most of the relatively small seasonal fluctuations in chemical quality seemed to be in water from the Rio Chama, in which the specific conductance varied from an average of 116 micromhos, for samples collected during March when water in the watershed was held as snow, to an average of 268 micromhos for samples collected in June. The 4-year averages (table 5) indicate a downstream decrease in the concentrations of ions between the stations at Otowi Bridge and Cochiti.

Santa Clara, Guaje, Los Alamos, and Frijoles Canyons

Chemical analyses of water samples from Frijoles, Los Alamos, Guaje, and Bayo Canyons are shown in table 67. Changes in quality are principally seasonal.

Samples of water for chemical analyses were collected at all stations in Santa Clara, Guaje, Los Alamos, and Frijoles Canyons during the first series of low-flow measurements of streamflow. These samples were analyzed for calcium carbonate, sodium, and chloride content and specific conductance. Analysis of these four properties was adequate to studying changes in the quality of water with respect to gains and losses in flow. Chemical analyses of the water samples collected during low-flow measurements were reported in U. S. Geological Survey Water Supply Papers 1744 and 1814. Complete analyses of water samples collected at other times are shown in table 68.

The chemical quality of water from the streams was good and changed only slightly downstream. The specific conductance and the concentrations of the calcium carbonate and sodium ions not only increased between upper and lower canyon stations but also increased at each station from April through September. The concentration of the chloride ion increased irregularly. The average values of samples from Frijoles Canyon, as shown in the following table, are used because of the large number of samples collected.

Months	Calcium carbonate (parts per million)		Sodium (parts per million)		Specific conductance (micromhos at 25°C)	
	upper canyon	lower canyon	upper canyon	lower canyon	upper canyon	lower canyon
April	25.4	27.6	5.7	6.0	81	93
May	27.7	30.0	6.0	8.2	90	102
June	26.4	32.5	7.0	9.0	95	106
September	31.4	35.0	5.7	10.0	105	116
October	31.0	34.1	6.5	9.7	105	112

The sampling dates correspond with those shown on figure 6.

Water from springs in the upper parts of these four canyons had specific conductances of 65 to 75 micromhos, concentrations of calcium carbonate of 10 to 30 ppm (parts per million), concentrations of sodium of 5 to 10 ppm, and concentrations of chloride of 1 to 2 ppm. At the downstream end of flow in these canyons, the specific conductance ranged from 125 to 155 micromhos, the calcium carbonate from 35 to 40 ppm, the sodium from 10 to 12 ppm, and the chloride from 1 to 3 ppm.

The specific conductance of the streamflow in Guaje Canyon increased between station [illegible] and [illegible] miles according to analyses of samples for October 19[illegible] and September 19[illegible]. This is the reach where the stream flows over the contact from the Tesuque Formation to the Puye Conglomerate (Fig. [illegible]). Some changes in trends of the chemical quality and temperature of the water also occurred at the Upper Crossing (4.97 mi.) in Frijoles Canyon, which is the reported position of the Pajarito fault zone. However, this quality change may have been due to the interval of several days that sometimes elapsed between sampling upstream and downstream from the fault zone.

Radiochemical quality of water

Water samples for radiochemical analysis were collected generally at the same time that samples were collected for chemical analysis. About 86[illegible] samples were [illegible] during the 4 years covered by this report and include: 284 from Acid and Pueblo Canyons disposal system; 195 from wells other than supply wells; 135 from supply wells; 74 from springs; [illegible] from pueblo streams; and 144 from Rio Chama and Rio Grande. The analyses were made by and are on file with the Los Alamos Scientific Laboratory.

The water samples were analyzed generally for plutonium, gross beta-gamma activity, and uranium. Tap water in the laboratory was used for comparison, and the activity in this water was considered background for the analyses made on that particular day. The background activity in the tap water varied according to the chief source of water for that day. Tap water from supply well LA-6 commonly contained about 15 to 25 μg/l (micrograms per liter) of uranium. Background activity in the tap water from Los Alamos Canyon reservoir ranged from 0 to 4.05 μg/l for uranium, 9 to 117 dpm (disintegrations per minute per liter) for gross beta-gamma activity, and averaged about 10 dpm for plutonium.

Radioactivity in water samples from stations in Acid Canyon averaged considerably higher than from other stations (table 65), although the level of activity was below on-site tolerances. The highest activity reported in samples from Acid Canyon were: gross beta-gamma activity, 6,500 dml in July 1960; plutonium, 400 dml in May 1959; uranium, 50.5 µgl in May and July 1959.

The gross beta-gamma activity was relatively high in water samples collected in different parts of the plateau during early 1958. The gross beta-gamma activity was 3,300 dml in samples of surface water in Pueblo Canyon; 2,850 dml in samples from observation well PC-1A; and 660 dml in a sample from the stream in Frijoles Canyon. The gross beta-gamma activity in samples from ~~well~~ well TW-1A from December 1957 through March 1958 might be attributed to recharge of the shallow aquifer with water discharged from the waste-treatment plant to Acid and Pueblo Canyons. The activity in Frijoles Canyon probably can be attributed to fallout. However, gross beta-gamma activity of 1,890 dml in samples from TW-1 in March 1958; 1,800 dml in samples from Los Alamos Spring in April 1958; and possibly the 2,820 dml in samples from well PC-5B in March probably are not related to recent fallout. The gross beta-gamma activity slightly above background, as well as the uranium and plutonium activity, were recovered in flood-flow samples from Pueblo and Los Alamos Canyons in August 1958.

In another period of relatively high gross beta-gamma activity in Acid and Pueblo Canyons, the activity decreased from 6,000 dml at well AC-4 in Acid Canyon and 3,200 dml at surface station Pueblo 1 on July 14, 1959, to 200 dml at well PC-11 on July 15, 1959, indicating that activity probably was carried from Acid Canyon into Pueblo Canyon decreasing downstream. Activity above background also occurred in samples from Pueblo 3 in April 1961 and PC-10 and PC-11 in May 1961. A water sample collected in May 1961 from LP Canyon above its confluence with Los Alamos Canyon contained gross beta-gamma activity of 100 dml. The only source of contamination for this station, except for fallout, is discharge from the treatment plant at DP West.

Uranium activity above background occurred chiefly in water samples collected in Acid Canyon, Pueblo Canyon, and supply well LA-6. The activity in Pueblo Canyon decreased down the canyon. The highest activity in the samples from Hamilton Bend, Los Alamos, and Basalt Springs was 55, 50, and 14 μgl respectively, whereas activity in samples from the other springs ranged as high as 10 μgl in isolated samples. One sample from DP Canyon contained 4.4 μgl. Activity in samples from wells other than supply wells was as much as 8 μgl, and from supply wells as much as 7.5 μgl. No seasonal nor long term trends were evident.

The average uranium activity in samples from supply well LA-6 had a general range between 15 and 25 μgl with a maximum of 150 μgl. The possibility of a hydraulic connection between well LA-6's deep aquifer and Acid Canyon is remote. The maximum uranium activity was 52 μgl in well LA-1.

The plutonium activity above background was mainly in samples from Acid Canyon, and activity decreased approximately to background samples from Pueblo Canyon. The concentration of plutonium in samples collected at stations outside of Acid and Pueblo Canyons was negligible except for isolated cases which may have been due to contamination of the samples after collection..

Activity in composites of water samples from the Rio Chama and the Rio Grande was less than background during most of the 4-year period, and only slightly above background part of the time. The maximum gross beta-gamma activity of 90 dml in samples collected in September 1960 from the Rio Grande at Cochiti could have been due to either runoff from Los Alamos or from fallout. However, the plutonium activity of 4.5 dml in October-December 1957 and 5 dml in December 1960, in samples collected from theRio Chama, which could not have been due to runoff from Los Alamos, indicate that fallout is the more likely cause for the gross beta-gamma and plutonium activity.

The maximum uranium activity of 4.8 and 4. μgl in the river waters occurred in samples collected during September 1960 and the first quarter of 1961 from the Rio Chama and Rio Grande above Los Alamos. This indicates that the uranium was added from sources in the headwaters of these rivers or from fallout as in the case of plutonium and gross beta-gamma activity.

Radioactivity of the alluvium

Samples of soil and alluvium were collected downgradient from disposal sites to determine the amount of uptake of nuclides on the particles, and the change of concentration of radionuclides with time. The analyses were made by and are on file with the Los Alamos Scientific Laboratory.

Radioactivity of the alluvium in Acid Canyon generally decreased with depth and with distance downgradient below the treatment plant (table 66). Activity at the 12-inch depth commonly was slightly higher than in samples above and below, probably because the water level normally fluctuated at about the 12-inch depth and may have caused a small concentration of ions at that air-water interface.

Radioactivity of samples collected in Acid Canyon during and after November 1956 contained relatively high gross alpha and gross beta activity because of accidental release of wastes above off-site tolerance in November 1958 (table 67). High gross beta and gross alpha activity also occurred in June and July 1959. Prior to November 1958, some samples contained little or no activity, particularly at depths of 18 inches and below. The gross beta activities of surface samples collected in Acid Canyon during November and December 1956 are given below:

Gross beta activity (counts per minute per dry gram)

Water station	November [illegible], 1958	[illegible] [illegible], 1958	December [illegible], 1958
AC-3	11,[illegible]	11,370	[illegible]
AC-4	450	10,440	2,[illegible]
Bottom of pool at AC-4	-	-	2,430
AC-5	200	-	80
Acid Weir	850	-	80

Wastes were being discharged on November [illegible], 1958, at the time samples were being collected, and activity in the upper foot of alluvium in the canyon averaged only about 435 cmdg (counts per minute per dry gram). By November [illegible], 1958, however, the activity had moved downgradient and deeper into the alluvium and the average gross beta activity in the upper foot of alluvium in the canyon was about [illegible],660 cmdg; by December 1[illegible],1958, most of the activity had been washed or leached out of Acid Canyon and the average count in the upper foot was about [illegible] cmdg near AC-[illegible] to about [illegible] cmdg near Acid Weir. The highest activity on December [illegible], 1958, was on samples collected on the bottom of a small pool near well AC-4, where some of the sludge apparently had [illegible]. The [illegible] [illegible] into Pueblo Canyon, or [illegible] in the [illegible] underlying the alluvium in Acid Canyon, is [illegible].

The average gross alpha and gross beta activity in the alluvium in Pueblo Canyon [illegible] was considerably lower than in Acid Canyon. [illegible] activity downstream in Pueblo Canyon was apparent, although some general trends seem probable. Relatively high activity on samples collected on November 1[illegible], 19[illegible], reflects the much higher levels in samples collected in Acid Canyon on that date; some activity probably reached the lower part of Pueblo Canyon because the flow in the canyon during November was continuous to the Otowi Deep area and below. The relatively high activity on samples collected near Pueblo Canyon wells PC-6 and 7 on March 27, 19[illegible], may be residual from a slug of waste which infiltrated the alluvium in this reach in early March before the spring snowmelt.

The radioactivity on samples of alluvium collected in Los Alamos Canyon was relatively low. It was comparable to or slightly less than the average level of activity on samples collected in Pueblo Canyon. Samples of the upper foot of alluvium were collected at intervals of [illegible] to [illegible] [illegible] between an area of minor quantities of low-level radioactive waste at Omega site in Los Alamos Canyon and well TW-3 (Fig. [illegible]). The general range of the highest level of activity are [illegible]

Type of activity	[illegible]	[illegible]	Period
Gross alpha	[illegible]	[illegible]	19[illegible]-19[illegible] ([illegible] dates)
Gross beta	[illegible] to [illegible]	[illegible]	1959-19[illegible] (5 dates)
Gross gamma	[illegible] to [illegible]	[illegible]	19[illegible] ([illegible] dates)

A slight decreasing trend downstream on some of the sampling dates is apparent. The activity probably moved down the canyon in periodic waves. The [illegible] gross alpha and beta activity in DP Canyon, which receives discharge of low-level radioactive wastes from the [illegible] station, [illegible] the same as that upstream in Los Alamos Canyon.

Most of the activity in the small canyon tributary to Ten-Site Canyon (fig. [illegible]) was due to a major spill of radioactive material in mid-February 1956. Activity on samples of alluvium collected in the bed of the narrow channel indicated that the gross beta, gross gamma, and strontium decreased downstream and with time (table [illegible]). The alluvium downgradient from station 4 apparently was not affected by the spill. A large percentage of beta-gamma emitters probably was barium and lanthanum, which have a combined half-life of 12.8 days and account for much of the decrease with time. Activity from the February 1956 spill apparently was gone from the surface and alluvium before February 1956; high gross alpha and gross beta activity since February 1956 is the result of subsequent discharges.

The infiltrability generally decreased with depth in the alluvium, although conductivity on samples collected at a depth of about 6 inches commonly was higher than on the underlying material. This occurred at station 3 (table 70) more frequently than at other stations because the material at 6 inches or below at station 3 is composed of weathered shale and contains a relatively high percentage of clay. The average depth of the alluvium at other stations is about 6 to 12 inches at stations [illegible] station 3, and 6 to 18 inches at the stations downgradient.

References

Abrahams, John H., Jr., 1964, Geologic and hydrologic environment of radioactive waste disposal sites at Los Alamos, New Mexico: U.S. Geol. Survey Admin. Rept., 35 p., 3 figs. 4 tables.

_____, 1965 The hydrology and the chemical and radiochemical quality of surface and ground water at Los Alamos, New Mexico, January 1956 through June 1957: U.S. Geol. Survey Admin. Rept., 6 figs, 9 tbls.

Griggs, R. L., 1964 Geology and ground-water resources of the Los Alamos area, New Mexico: U.S. Geol. Survey Water-Supply Paper 1753, 107 p. 1 pl., 20 figs.

U.S. Geological Survey, 1959, Surface water supply of the United States, Part 8, Western Gulf of Mexico Basins: U.S. Geol. Survey Water-Supply Paper 1652, p. 507-510.

_____, 1960, Surface water supply of the United States, Part 8, Western Gulf of Mexico Basins: U.S. Geol. Survey Water-Supply Paper 1712, p. 481.

_____, 1959, Quality of surface water of the United States, Parts 7 and 8, Lower Mississippi River Basin and Western Gulf of Mexico Basins: U.S. Geol. Survey Water-Supply Paper 17[illegible]: (In preparation).

_____, 1960, Quality of surface water of the United States, Parts 7 and 8, Lower Mississippi River Basin and Western Gulf of Mexico Basins: U.S. Geol. Survey Water-Supply Paper 1814: (In preparation).

Weir, J. E., Jr., Abrahams, J. H., Jr., [illegible], J. F., and Purtyman, W. D., 1962, The hydrology and the chemical and radiochemical quality of surface and ground water at Los Alamos, New Mexico, 1949-55: U.S. Geol. Survey Admin. Rept., 40 p. 1[illegible] figs., 15 tables.

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References

Abrahams, John H., Jr., 1964, Geologic and hydrologic environment of radioactive waste disposal sites at Los Alamos, New Mexico: U.S. Geol. Survey Admin. Rept., 35 p., 3 figs. 4 tables.

_____, 1965 The hydrology and the chemical and radiochemical quality of surface and ground water at Los Alamos, New Mexico, January 1956 through June 1957: U.S. Geol. Survey Admin. Rept., 6 figs.

Griggs, R. L., 1964 Geology and ground-water resources of the Los Alamos area, New Mexico: U.S. Geol. Survey Water-Supply Paper 1753, 107 p. 1 pl., 20 figs.

U.S. Geological Survey, 1959, Surface water supply of the United States, Part 8, Western Gulf of Mexico Basins: U.S. Geol. Survey Water-Supply Paper 1652, p. 507-510.

_____, 1960, Surface water supply of the United States, Part 8, Western Gulf of Mexico Basins: U.S. Geol. Survey Water-Supply Paper 1712, p. 481.

_____, 1959, Quality of surface water of the United States, Parts 7 : Lower Mississippi River Basin and Western Gulf of Mexico Basins: U.S. Geol. Survey Water-Supply Paper 17[illegible]: (In preparation).

_____, 1960, Quality of surface water of the United States, Parts 7, and 8, Lower Mississippi River Basin and Western Gulf of Mexico Basins: U.S. Geol. Survey Water-Supply Paper 1814: (In preparation).

Wear, J. F., Jr., Abrahams, J. H., Jr., [illegible], [illegible], and Purtyman, [illegible] 1962, The hydrology and the chemical and radiochemical quality of surface and ground water at Los Alamos, New Mexico, 1949-55: U.S. Geol. Survey Admin. Rept., 40 p. 1[illegible] figs., 15 tables.