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Hydrology of waste disposal systems, Los Alamos, New Mexico, 1949 through 1961

By

William D. Purtymun, John H. Abrahams, Jr.
and James R. Avrett

HYDROLOGY OF WASTE DISPOSAL SYSTEMS, LOS ALAMOS, NEW MEXICO,

1949 THROUGH 1961

GEOLOGICAL SURVEY WATER-SUPPLY PAPER

Prepared in cooperation with the

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Hydrology of waste disposal systems, Los Alamos, New Mexico, 1949 through 1961

By

William D. Purtymun, John H. Abrahams, Jr.,
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Prepared in cooperation with the
Atomic Energy Commission
November 1965

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Hydrology of waste disposal systems,

Los Alamos, New Mexico, 1949 through 1961

By

William D. Purtymun, John H. Abrahams, Jr.,

and James R. Avrett

Abstract

Los Alamos County in north-central New Mexico has only one industry, research and development associated with nuclear energy. These activities are directed by the University of California, Los Alamos Scientific Laboratory, under contract to the U.S. Atomic Energy Commission. The town of Los Alamos and laboratories for the Los Alamos Scientific Laboratory and the Atomic Energy Commission are on the Pajarito Pleateau.

Liquid and solid wastes containing radioactivity and undesirable chemical constituents produced as by-products of research and development of nuclear energy are treated and discharged as liquids into canyons or buried as solids in pits on the Pajarito Plateau. The U.S. Geological Survey, the Los Alamos Scientific Laboratory, and the U.S. Atomic Energy Commission jointly studied the movement of the industrial effluents because of possible contamination of the regional water supply.

The Pajarito Plateau, part of the Rio Grande depression, is capped by the Bandelier Tuff of Pleistocene age, which is a rhyolite tuff composed of ash falls, ash flows, and pumice. The western edge of the Pajarito Plateau laps onto the Sierra de los Valles, which is composed of latite and quartz latite of the Tschicoma Formation of Pliocene to Pleistocene(?) age. Rocks of the Santa Fe Group of Middle(?) Miocene to Pleistocene(?) age are exposed along the Puye escarpment, White Rock Canyon, the eastern edge of the plateau, and in the subsurface beneath the plateau. The Santa Fe Group consists of beds of siltstone, sandstone, and conglomerate interbedded with basalt. Deposition of sediments from the west and emplacement of basalt from the east have filled a small basin beneath the central and western parts of the plateau.

The Rio Grande, the master stream of north-central New Mexico, flows along the eastern edge of the plateau. The only perennial stream to cross the plateau and discharge into the Rio Grande is in Frijoles Canyon; however, a stream is perennial in upper Los Alamos Canyon, which is tributary to the river. Treated sewage and industrial effluents flow in the upper and mid-reach of Pueblo Canyon.

The main zone of ground-water saturation is at a depth of about 1,000 feet along the western edge of the Pajarito Plateau. Ground water moves eastward toward the Rio Grande where part is discharged through a series of springs. Small bodies of ground water are perched in the alluvium and in underlying volcanic rocks and sediments in some of the canyons of the plateau.

Radioactive wastes disposed to the ground at Los Alamos consist of liquids, sludges, and solids. Liquid wastes are treated to remove radioactive contaminants at technical areas TA-2, TA-21, TA-35, and TA-45. Treatment consists of chemical pretreatment to remove alpha activity and/or passage through ion exchange columns to remove beta and gamma activity. The radioactivity of industrial effluent is reduced to about one-tenth MPC (maximum permissible concentration in drinking water), and the effluent is discharged into adjacent canyons. The major disposal areas for industrial effluents during the period covered by this study (1949 to 1961) were Acid and Pueblo Canyons, which received discharge from the industrial treatment plant at TA-45. Large quantities of treated sewage effluent from two treatment plants also discharge into Pueblo Canyon.

The sludge resulting from the chemical pretreatment of liquids is mixed with cement or vermiculite and buried in Area "C" or Area "G", areas used for solid-radioactive-waste disposal. Solid wastes are buried in pits dug into the Bandelier Tuff on the Pajarito Plateau. The pits are filled with radioactive waste and are then covered with a sealing layer of crushed tuff.

The chemicals in the effluent from the radioactivity-reduction treatment plant form an unstable combination of ions which tends to stabilize downgradient from the disposal plants. The chemical characteristics (mainly high pH) of the effluent near points of discharge cause most of the radioactive contaminants in the effluent to exchange with ions in the clay minerals or to attach to the clay particles.

Chemical and radiochemical contents of surface and ground water were monitored downgradient from waste-disposal points, industrial-waste treatment plants, and disposal pits to determine if wastes from the laboratories become a source of contamination to surface and ground water. Analyses of water and/or alluvium downgradient from the industrial-waste treatment plants at TA-2, TA-21, TA-35, and TA-45 indicate that most of the contamination is near points of effluent discharge. Dilution of waste effluent and transport of alluvial materials by storm runoff and by treated sewage effluent have dispersed long-half-life contaminants throughout the disposal area; therefore, radioactivity does not accumulate excessively near points of effluent discharge.

Analyses of water from 12 supply wells, four deep test wells, springs, Rito de los Frijoles, and the Rio Grande indicate neither chemical nor radiochemical contamination from industrial or sewage effluents discharged from the laboratories or from the town of Los Alamos during the period 1949 through 1961.

Introduction

Los Alamos County is in north-central New Mexico about 25 miles northwest of Santa Fe, the State capitol. The county has only one industry, the scientific research and development associated with nuclear energy. These activities are directed by the University of California, Los Alamos Scientific Laboratory, under contract to the U.S. Atomic Energy Commission.

The town of Los Alamos and laboratories of the Los Alamos Scientific Laboratory and of the Atomic Energy Commission are on Pajarito Plateau which is a part of the Jemez Mountains (fig. 1).

Figure 1 (caption on next page) belongs near here.

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

The plateau slopes gently eastward from an altitude of about 7,800 feet along its western edge to an altitude of about 6,200 feet where it is terminated by the Puye escarpment and White Rock Canyon. The land surface of the Pajarito Plateau along the Puye escarpment and White Rock Canyon is from 300 to 1,000 feet above the Rio Grande. The river drops from an altitude of 5,510 feet at Otowi to 5,360 feet at the mouth of Frijoles Canyon.

Pajarito Plateau is a shelf along the eastern foot of Sierra de los Valles, which is the eastern rim of Jemez Caldera and reaches an elevation of nearly 12,000 feet. The lower slopes of the mountains and the Pajarito Plateau are dissected by deep canyons that drain southeastward to the Rio Grande. Deep canyons cut into the volcanic rocks have left many finger-like mesas of the plateau.

The town of Los Alamos is near the western edge of Pajarito Plateau. The laboratories and test areas, designated as technical areas, are on the mesas and in the canyons south and east of the town. The technical areas produce liquid and solid wastes containing radiochemical and chemical constituents that if not properly treated and disposed of could create a hazard to the public.

In 1949, the U.S. Geological Survey, Los Alamos Scientific Laboratory, and the Atomic Energy Commission began cooperative study of the movement of industrial solid and liquid wastes discharged to the ground. The study was to assure that contamination would not result from waste-management practice.

The study was initiated by construction of six test wells to define the geology and hydrology of the plateau. A systematic water sampling program began to monitor the chemical and radiochemical quality of the surface and ground water downgradient from the disposal areas.

This report describes the geology and hydrology of areas that are important to the disposal of industrial effluent and methods of disposal of sludge and solids that are contaminated by radioactivity. It also describes the chemical and radiochemical quality of water in the Los Alamos area in the 1949-61 period.

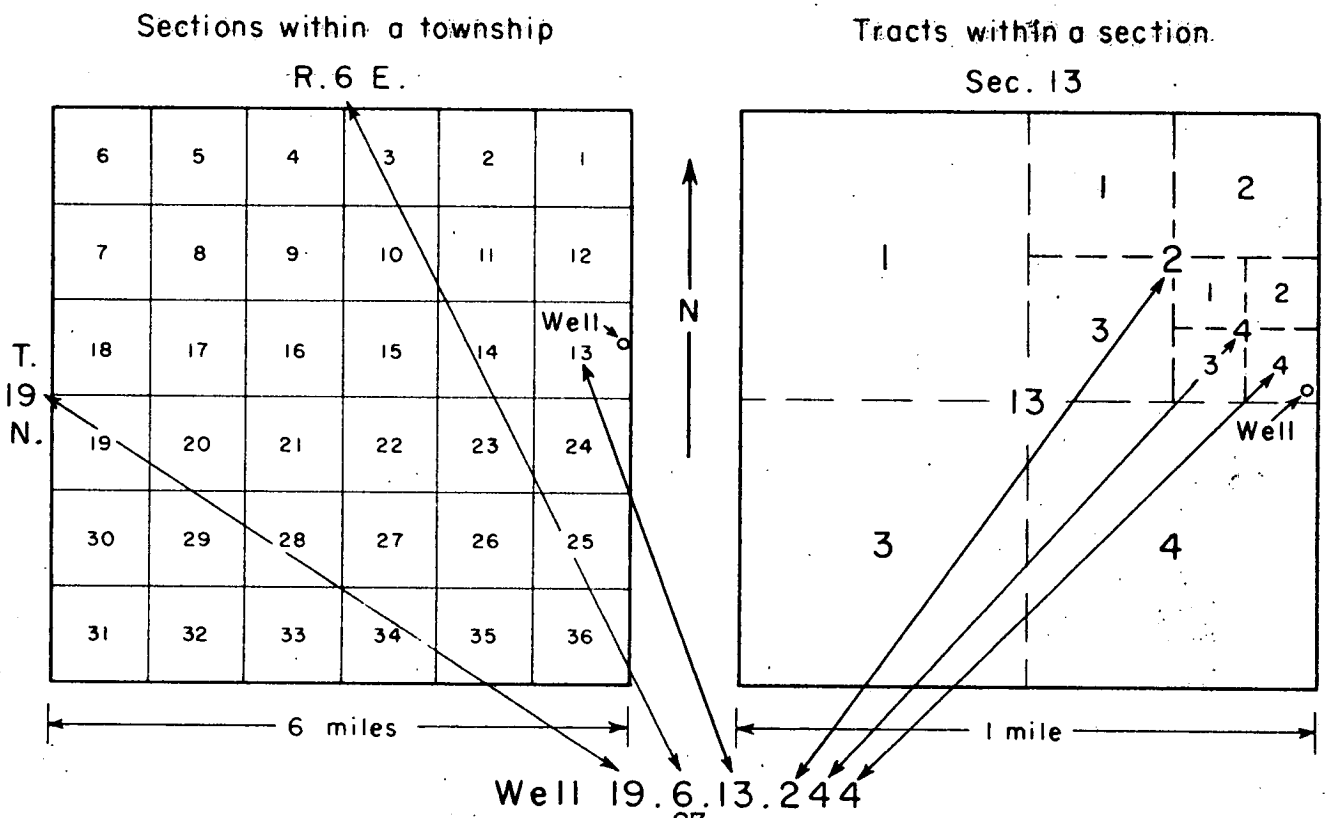
The cooperation of the numerous personnel of the U.S. Atomic Energy Commission and the Los Alamos Scientific Laboratory is appreciated. Especial thanks is expressed to William Kennedy, H-6, LASL, and C. W. Christenson, H-7, LASL, who provided technical advice, personnel, and laboratory facilities to make radiochemical analyses of soil and water.

Previous investigations

R. L. Griggs of the Geological Survey mapped and described the geology and hydrology of the Los Alamos area in a report (1964) prepared for the Atomic Energy Commission. Much of the geologic information used in this report is drawn from Grigg's report. C. V. Theis and C. S. Conover (1962) of the Geological Survey prepared a report on the aquifer conditions in the Los Alamos municipal well field in Los Alamos Canyon. C. W. Christenson (1959) of the Los Alamos Scientific Laboratory described methods of treatment of industrial wastes at Los Alamos. Description of waste-treatment methods and waste-disposal areas is drawn largely from Christenson's report. Christenson and other (1958 and 1962) described the results of experiments dealing with ion exchange between certain radionuclides found in the industrial effluents and the rhyolite tuff of the Pajarito Plateau. Staritzky (1949) of the Los Alamos Scientific Laboratory made a study of available soils at Los Alamos for scavenging plutonium-waste solutions.

System of numbering wells and well designation

All wells referred to in this report are identified by a location number used by the Geological Survey and the State Engineer of New Mexico for numbering water wells in New Mexico. The location number is a description of the geographic location of the well, based on the system of public land surveys. It indicates the location of the well to the nearest 10-acre tract, when the well can be located that accurately. A second well located in a 10-acre tract is denoted by letter "a" following the location number. The location number consists of a series of numbers corresponding to the township, range, section, and tract within a section, in that order, as illustrated below. If a well has not been located closely enough to be placed within a particular section or tract, a zero is used for that part of the number. All wells in the report area are north of the New Mexico base line and are east of the New Mexico principal meridian. Springs and surface water samplying stations are identified by the letter S preceeding the township number.



Wells are referred to also by local designation. Test wells ("T" series) were drilled into the Puye Conglomerate in 1949 and 1950. Drive-point and dug wells were constructed in the alluvium at Acid and Pueblo Canyons ("AC" and "PC" series) in 1954. Additional wells were drilled into the fanglomerate member of the Puye Conglomerate beneath the alluvium Pueblo Canyon in ("PO" series) in 1956. The numbers that follow the series designation denote the relative position of the well downgradient in the canyon from west to east. Supply wells are prefixed by "G" series in the Guaje Canyon well field and "L" series in the Los Alamos Canyon well field. Springs are referred to by name.

Geology

The Pajarito Plateau is capped by the Bandelier Tuff of Pleistocene age. The western edge of the plateau laps onto Sierra de los Valles, composed of rocks of the Tschicoma Formation of Pliocene to Pleistocene(?) age. Rocks of the Santa Fe Group of Middle(?) Miocene to Pleistocene(?) age are exposed along the eastern edge of Pajarito Plateau, the Puye escarpment, and in White Rock Canyon (fig. 2).

Figure 2 (caption on next page) belongs near here.

Figure 2.--Generalized geologic map of the Los Alamos area, New Mexico.

The Santa Fe Group comprises, in ascending order, Tesuque Formation, the Puye Conglomerate, and the basaltic rocks of Chino Mesa. The Tesuque Formation consists of flood-plain sediment deposited in a broad valley or plain. The Puye Conglomerate consists of two members; the lower member is a poorly consolidated channel-fill deposit called the Totavi Lentil; the upper fanglomerate member is composed of volcanic debris derived, in part, from the Tschicoma Formation. Basaltic rocks of Chino Mesa are interbedded with the fanglomerate member in the subsurface of the eastern half of the Pajarito Plateau. The fanglomerate member is interbedded with latite and quartz-latite flow rocks of the Tschicoma Formation in the western half of the plateau (fig. 3).

Figure 3 (caption on next page) belongs near here.

Figure 3.--Diagammatic cross section showing generalized stratigraphic relations of the Santa Fe Group, Tschicoma Formation, and Bandelier Tuff in the Los Alamos area, New Mexico.

The Bandelier Tuff overlies the fanglomerate member of the Puye Conglomerate on the Pajarito Plateau. The Bandelier rests on the basaltic rocks of Chino Mesa along White Rock Canyon, but to the west the Bandelier laps onto the Tschicoma Formation.

The Bandelier Tuff consists of ash-fall and ash-flow rocks that drape over the older rocks, fill the lows, and smooth out the topography of the older rocks. The Bandelier Tuff consists of three members which are, in ascending order: the Guaje Member, an ash-fall pumice; the Otowi Member, a friable ash-flow tuff; the Tshirege Member, a series of ash-flow tuff. The Tshirege Member forms most of the finger-like mesas of the Pajarito Plateau. The Tshirege and the Otowi Members are the most important geohydrologic units in relation to waste disposal, in the Los Alamos area, because the canyons cut into the Tshirege and Otowi Members receive the initial discharge of industrial effluents. Hydrologic characteristics are included with physical descriptions of these units.

Stratigraphy

Santa Fe Group

Tesuque Formation

The Tesuque Formation of the Santa Fe Group is composed of light-pinkish-gray to light-brown siltstone, sandstone, and some conglomerate and clay lenses. Bedding generally is poorly developed except for localized horizontal bedding in the fine-grained material. The sand-size detritus consists dominantly of quartz and feldspar, with minor amounts of chalcedony, biotite, muscovite, and magnetite. Rock fragments consist of rhyolite, latite, gneiss, schist, limestone, and quartzite. A supply well in lower Los Alamos Canyon penetrated more than 2,250 feet of Tesuque Formation, but the maximum thickness of the Tesuque is unknown.

Puye Conglomerate

The Puye Conglomerate of the Santa Fe Group consists of the Totavi Lentil overlain by the fanglomerate member.

The Totavi Lentil is a gray, poorly consolidated conglomerate of fragments of quartzite, schist, gneiss, and granite. It consists mainly of subrounded to well-rounded quartzite and quartz. Although sorting generally is poor, there are occasional well-sorted lenses of silt and sand. Sand-size particles consist of quartz, feldspar, microcline, biotite, magnetite, tourmaline, and chalcedony and are partly subrounded to well rounded. The Totavi Lentil is a channel deposit and in thickness ranges from 0 to 90 feet in the area.

The fanglomerate member of the Puye Conglomerate is a gray conglomerate composed of pebbles, cobbles, and boulders of rhyolite, latite, quartz latite, and pumice in a matrix of silt and sand. Sorting is poor, but tongues and lenses of fairly well-sorted pumiceous siltstone and water-deposited pumice are present in the fanglomerate. The degree of cementation varies from friable to well cemented. Outcrops of the fanglomerate in canyons near Sierra de los Valles contain large, angular boulders to the west and grade to fine, rounded material to the east. The thickness of the fanglomerate member ranges from about 200 feet in lower Guaje Canyon to 640 feet near the center of the plateau.

Basaltic rocks of Chino Mesa

The basaltic rocks of Chino Mesa belong to the Santa Fe Group and consist of basalt flows and interflow breccias. The flows are reddish-brown to black, dense to vesicular basalt. The interflow breccia zones include strata of silt, of clay, and of gravel consisting of basalt fragments and debris from the fanglomerate member of the Puye Conglomerate. The thickness of individual flows varies, but probably no single flow exceeds 50 feet in thickness; however, a series of flows may appear to be a single thick unit.

Volcanic rocks of the Jemez Mountains

Volcanic rocks of the Jemez Mountains, along the eastern flanks of the Sierra de los Valles and on the Pajarito Plateau are latite and quartz latite flow rocks of Tschicoma Formation of Pliocene and Pleistocene(?) age and ash fall and ash flow rocks of the Bandelier Tuff of Pleistocene age.

Tschicoma Formation

Tschicoma Formation flows have a fine-grained matrix of latite and quartz latite. Large phenocrysts are plagioclase and smaller phenocrysts are quartz, biotite, hornblende, and augite. Interflow zones contain greenish-gray siltstone; clay; and rock fragments of tuff, rhyolite, and latite. The latite and quartz latite were deposited as viscous lava flows and generally are highly jointed and fractured by flow deformation and by shrinkage on cooling. Normally, these rocks have two or more joint or fracture systems that intersect. Flows of Tschicoma Formation up to 120 feet thick were penetrated in test holes on the western margin of Pajarito Plateau; however, the maximum thickness of the formation is unknown.

Bandelier Tuff

The Bandelier Tuff is divided into three members--Guaje, Otowi, and Tshirege, from oldest to youngest.

The Guaje Member, the lowest member of the Bandelier Tuff, consists of ash-fall pumice with waterlaid pumiceous tuff and some rounded, pebble-size fragments of light-red rhyolite near the top. Gray lump-pumice fragments as much as 2 inches in length are near the base. Fragments of glass shards and quartz and sanidine crystals are found in a cellular or partly devitrified pumice. The porosity is about 60 percent with a field permeability of from 2 to 12 gpd per sq ft. (field coefficient of permeability is the number of gallons of water per day that flow through a cross section of 1 square foot under a unit hydraulic gradient, or through a section 1 foot high and 1 mile wide under a gradient of 1 foot per mile at prevailing conditions of water temperature). The thickness of the Guaje Member varies because it was unconformably deposited on an eroded surface of the fanglomerate member, basaltic rocks of Chino Mesa, and the Tschicoma Formation. The maximum thickness is about 50 feet.

The Otowi Member of the Bandelier Tuff is a light-gray, pumiceous rhyolite tuff that is nonwelded and friable. Quartz crystals, glass shards, and minor amounts of mafic minerals and rhyolite, latite, and pumice fragments are included in a fine-grained ash. The Otowi Member weathers to a gentle slope. Joints and fractures near the land surface are filled with brown clay. The porosity of the Otowi Member averages about 50 percent by volume. Figures are not available for coefficient of permeability; however, the coefficient of permeability of the nonwelded tuff probably ranges from 5 to 10 gpd per sq ft (gallons per day per square foot). The Otowi Member is about 400 feet thick near the center of the Plateau and thins slightly to the east and west.

The Tshirege Member of the Bandelier Tuff forms the finger-like mesas of the Pajarito Plateau. The Tshirege is composed of a series of ash flow of rhyolitic tuff. The rhyolitic tuff is composed of quartz and sanidine crystals and fragments, some mafic minerals, and xenoliths of gray rhyolite and latite in a fine ash. The flows of rhyolitic tuff are nonwelded to densely welded.

The degree of welding affects porosity and permeability. Porosity ranges from 19 percent by volume in the densely welded flows to as much as 55 percent by volume in the nonwelded flows. The coefficient of permeability of the tuff ranges from 0.04 gpd per sq ft for the densely welded units to 22 gpd per sq ft for nonwelded units.

The ion exchange capacity of the Tshirege ranges from about 2 milliequivalents per 100 grams near the surface to about 0.5 milliequivalents per 100 grams at a depth of 100 feet in a moderately welded tuff. The difference is due to the formation of clay near the surface, which increases the ion exchange capacity of the tuff.

Christenson and others (1958) made a series of experiments on infiltration of liquids, containing radionuclides, through cores of tuff to determine the capacity of the tuff to retain certain nuclides. Plutonium 239, cesium 137, strontium 90, and a solution containing all three were used in the experiment. The cores containing the nuclides were leached by several chemical solutions containing various amounts of calcium chloride, sodium chloride, and magnesium chloride to test the retention of the nuclides on the tuff.

The results of the experiments indicated that cesium 137 was bound tightly to the tuff in the upper part of the core and resisted leaching by any of the common agents. Plutonium 239, likewise, was readily retained by the tuff; however, it is possible that it could be released from the rock at some future time by inadvertent discharge of certain solutions, for example, versene, citric acid or soap. Strontium 90 was not retained by the tuff as well as cesium 137 and plutonium 239 and it is more easily released.

Open joints are common in the densely welded flow units of the Tshirege Member. Infiltration studies made in the tuff at Technical Area 21 indicated that open joints transmit liquid wastes rapidly with very little change in the radiochemical quality of the liquid (Christenson and others, 1962).

The Tshirege Member ranges in thickness from less than 50 feet along the Rio Grande to about 800 feet along the western edge of the Pajarito Plateau.

Recent alluvium and soil

Alluvium in the canyons consists of material eroded from Sierra de los Valles and from sides of the canyons on Pajarito Plateau. Alluvium is thin at the heads of these canyons; bedrock commonly is exposed. Deposits of alluvium may be several hundred feet wide and as much as 80 feet thick in the lower parts of the canyons. Most of the alluvium is silty, sandy, and contains cobbles and boulders, and is considerably more permeable than the Bandelier Tuff.

The finger-like mesas are covered with soil derived from weathering of the underlying tuff. The soil is usually thickest (as much as 9 feet) along the axis of the mesa and thinnest toward the edge of canyons where the tuff is exposed.

Staritzky (1949) of the Los Alamos Scientific Laboratory made petrographic examinations of the soil derived from the Tshirege Member of the Bandelier Tuff. The principal mineralogic constituents of the soil are quartz and feldspar, and the most important secondary constituents are the clay minerals, montmorillonite and illite. Montmorillonite has the highest base exchange capacity (85 to 100 milliequivalents per 100 grams) and illite the next highest (25 to 30 milliequivalents per 100 grams) among the clay minerals in the soils examined by Staritzky. Alluvium along the canyon bottoms is derived mainly from the Tshirege Member of the Bandelier Tuff and contains a large amount of the clay minerals montmorillonite and illite. These minerals would be available to bind and exchange with certain radioactive elements.

Structure

The Rio Grande depression is structurally and physiographically a low area that constitutes the valley through which the Rio Grande flows (Kelley, 1952). Near Los Alamos, the Rio Grande depression contains "basin fill" sediments and interbedded and intruded basalts of the Tesuque Formation. East of the Rio Grande, 5 to 6 miles, the beds of the Tesuque dip 10 to 15 degrees westward; the dip becomes lower to the west, near the river. West of the river, from Guaje Canyon along the river south to Canada Ancha, the beds dip gently at 1 to 2 degrees westward. Below Canada Ancha, the general attitude of the Tesuque Formation is obscured by talus slopes, but where outcrops are exposed there seems to be a reversal of dip. The axis of the depression seems to be parallel to the present river channel.

Pajarito Plateau structurally is part of the Rio Grande depression. The Totavi Lentil, an arkosic conglomerate of river gravels, dips gently westward in the vicinity of Los Alamos Canyon and, to the south near Ancho Canyon, wedges out between the basaltic rocks of Chino Mesa and the underlying Tesuque Formation (fig. 2).

The fanglomerate member of the Puye Conglomerate is composed of volcanic debris that was derived from the Jemez volcanic pile west of the Pajarito Plateau and was deposited eastward toward the Rio Grande. The fanglomerate member thickens westward from the river to the central part of the Pajarito Plateau and thins by interfingering with the Tschicoma Formation, in the subsurface along the eastern fringe of Sierra de los Valles (fig. 3). The upper surface of the fanglomerate member dips gently eastward. It overlies the Totavi Lentil in the vicinity of Los Alamos Canyon and southward from Otowi until it wedges out between the underlying Totavi Lentil and overlying basaltic rock of Chino Mesa near Sandia Canyon.

The basaltic rocks of Chino Mesa consist of basalt flows and interflow breccias. The basalt flows originated from a center at Cerros del Rio, flowed northward, northwestward, and westward, and filled channels that were cut into the older sediments. Basalt flowed westward across the present position of the Rio Grande south of Sandia Canyon to Frijoles Canyon. These flows form the eastern edge of a small north-south trending basin which lies beneath the Pajarito Plateau (fig. 3). The eastern edge of the basin lies from 2 to 4 miles west of the river. The basin is filled with the fanglomerate member interbedding westwardly with the Tschicoma Formation and eastwardly with the basaltic rocks of Chino Mesa.

The source of the Bandelier Tuff was in the area of Jemez Mountains. It is thickest along the western edge of the Pajarito Plateau and thins eastward toward the Rio Grande. The upper beds of the Bandelier dip gently eastward at 1 to 3 degrees toward the river; however, north and west of the town of Los Alamos there is reversal of dip of the Bandelier Tuff to the west.

The Tesuque Formation, in lower Los Alamos Canyon, was faulted before deposition of the Puye Conglomerate. Faults in the Puye Conglomerate are mostly obscured by the Bandelier Tuff. The Pajarito fault zone, which trends north-south along the flanks of the Sierra de los Valles and along the western edge of the Pajarito Plateau, contains broken rock of the Tschicoma Formation and the Bandelier Tuff. The Pajarito fault zone, consisting of several echelon normal faults, is downthrown to the east. The graben northeast of the town of Los Alamos was formed as the result of normal faults which are downthrown to the west. The movement along these faults generally is pre-Bandelier but has continued in some areas into post-Bandelier time (fig. 2).

Hydrology

The master stream of north-central New Mexico, Rio Grande, flows southwestward along the eastern edge of Pajarito Plateau and ultimately receives all runoff from the eastern slopes of Sierra de los Valles and Pajarito Plateau.

Rito de los Frijoles is the only perennial stream in the Los Alamos area that discharges into the Rio Grande. Los Alamos Canyon contains a stream perennial in its upper reaches. Intermittent streams that cross the Pajarito Plateau flow into the Rio Grande only during periods of excess precipitation. Flow from the discharge of treated sewage and industrial effluent is perennial in the upper and middle reaches of Pueblo Canyon.

The water table is at a depth of about 1,200 feet along the western edge of the Pajarito Plateau at about 600 feet along the eastern edge of the Plateau. Ground water in the main zone of saturation moves eastward to the Rio Grande where part is discharged through a series of springs along White Rock Canyon.

Small bodies of perched ground water accumulate seasonally in the thin alluvium in the upper parts of some of the canyons and are perennial in the lower parts of some of the canyons.

Surface water

The Rio Grande has a drainage area in southern Colorado and northern New Mexico, upstream from the gaging station at Otowi, of about 14,300 square miles. The flow in the Rio Grande at Otowi in 1961 ranged from 245 cfs (cubic feet per second) on October 7 to 8,700 cfs on August 23.

Rito de los Frijoles, fed by springs in canyons cut into the flanks of the Sierra de los Valles, flows southeastward to the Rio Grande. Seepage runs made in late 1958, 1959, and 1960 indicate that Rito de los Frijoles is a gaining stream (receives ground water discharge) above the upper crossing (fig. 2) and a losing stream (by seepage) below the upper crossing. Tschicoma Formation which is at shallow depth beneath the stream west of the upper crossing (upthrown side of the Pajarito Fault) retards the movement of water out of the alluvium while east of the fault zone the stream loses water to the alluvium, to the Bandelier Tuff underlying the stream, and by evapotranspiration. The average discharge in 1958 was about 1.5 cfs at the upper crossing and about 1 cfs at Frijoles (fig. 4).

Figure 4 (caption on next page) belongs near here.

Figure 4.--Map showing locations of technical areas, sewage-treatment plants, solid-disposal areas, wells, and springs in the Los Alamos area, New Mexico.

The stream in Los Alamos Canyon also is fed by springs in canyons cut into the flanks of the Sierra de los Valles. The average discharge in Los Alamos Canyon above Los Alamos Reservoir is less than 0.5 cfs. Snowmelt in the spring occasionally maintains flow in Los Alamos Canyon across the Pajarito Plateau; however, about 90 percent of the flow infiltrates the alluvium and underlying Bandelier Tuff or evaporates between Los Alamos Reservoir and New Mexico State Highway 4.

Streamflow in Pueblo Canyon consists chiefly of treated effluents from two sewage plants and an industrial treatment plant near Acid Canyon, a tributary canyon. Precipitation and snowmelt occasionally add to the volume of flow. The average discharge from 1957 to 1961 in Pueblo Canyon, just below the confluence of Acid Canyon, was about 2 cfs from September through April and about 0.7 cfs from May through August. Near well 19.6.14.221 (T-2), the average discharge was 1.6 cfs from September through April and 0.5 cfs from May through August. Decrease in streamflow during the summer reflects decreased discharge from the sewage-treatment plants because most of the effluent was used for irrigation and for cooling water at the power plant. Streamflow during the summer usually ends near well 19.6.14.222 (PC-2) (fig. 4), but during fall, winter, and spring the streamflow extends to well 19.7.17.322 (PC-4) or beyond. Discharge decreases downstream where the alluvium overlies the Bandelier Tuff but gains slightly where Tschicoma Formation crops out in the southern half of sec. 10, T. 19 N., R. 6 E. (fig. 2). This gain in discharge indicates that the Tschicoma prevents downward movement of the underflow.

The soil cover on the surface of the plateau forms a seal which allows little, if any, water from precipitation to reach the underlying tuff, let alone infiltrate the 600 to 1,200 feet of unsaturated volcanic rocks and sediments that overly the main ground water body. Most of the water which infiltrates the soil or reaches the top of the tuff is returned to the atmosphere by evapotranspiration (Abrahams and others, 1961).

Ground water

The main aquifer in the Los Alamos area is the saturated zone of the Santa Fe Group. The Tesuque Formation lies partly within the main aquifer along the Rio Grande and entirely within the main aquifer beneath the Pajarito Plateau. The piezometric surface rises into the Puye Conglomerate along the eastern third of the Pajarito Plateau. Along the western edge of the plateau, the main aquifer occurs partly within the Puye Conglomerate which interfingers with the Tschicoma Formation. Brecciated zones of the Tschicoma Formation also may contain water within the zone of saturation. Changes in gradient of the piezometric surface indicate differences in permeability of the different units within the main aquifer. The hydraulic gradient of water in the Puye Conglomerate beneath the central part of the Pajarito Plateau ranges from 40 to 60 feet per mile, and the gradient in the Tesuque Formation along the eastern edge of the plateau ranges from 80 to 100 feet per mile. The lower gradient denotes greater permeability.

The coefficient of permeability of the Tesuque Formation is estimated to be low, around 2.5 gpd per sq ft. With the prevailing gradient ground water has a velocity of about 360 feet per year (Theis and Conover, 1962).

Wells 19.7.20.221 (T-1), 19.6.14.221 (T-2), 19.6.13.344 (T-3), and 19.6.9.443 (T-4) are completed in the main aquifer and serve as monitoring wells for detecting possible contamination by radioactive-waste effluent. The coefficients of permeability that were determined by tests in wells 19.7.20.221 (T-1), 19.6.14.221 (T-2), and 19.6.13.344 (T-3) all completed in the Totavi Lentil are 10 gpd per sq ft; 290 gpd per sq ft; and 310 gpd per sq ft, respectively. A test in well 19.6.9.443 (T-4), finished in a brecciated zone in the Tschicoma Formation, indicates a coefficient of permeability of 36 gpd per sq ft.

Well 19.7.20.221a (T-1A) taps water that is perched within an interflow zone in the basaltic rocks of Chino Mesa. The coefficient of permeability of the zone at this site is 2,800 gpd per sq ft. Well 19.6.14.221a (T-2A) is completed within the fanglomerate member of the Puye Conglomerate. The coefficient of permeability of the fanglomerate at this site is about 10 gpd per sq ft.

The three Pueblo observation wells /19.6.13.244 (PO-1), 19.6.13.242 (PO-2), and 19.7.18.141 (PO-3)/ are finished in the upper 50 feet of the fanglomerate member of the Puye Conglomerate in perched aquifers of limited areal extent. The wells can be bailed dry, and recovery is slow indicating low permeability of the aquifers. Other bodies of perched water probably occur in the Puye Conglomerate beneath the Pajarito Plateau; however, most of the test drilling has been limited to Pueblo Canyon which until 1963 was the main disposal area for treated sewage and industrial effluents. Small bodies of perched ground water occur in the Puye Conglomerate and the Bandelier Tuff beneath Pueblo Canyon and probably beneath other canyons that receive snowmelt runoff from the Sierra de los Valles.

Waste disposal

Radioactive wastes disposed to the ground at Los Alamos consist of solids, liquids, and sludges. The types and quantities of wastes have changed with time, and the techniques of disposal have evolved from crude, uncontrolled dumping to controlled burial or discharge in water.

Untreated liquid wastes formerly were discharged into dry canyons, into underground storage tanks, or into seepage pits filled with gravel. The Atomic Energy Commission began research on methods of treating liquid radioactive wastes in 1948. A result of the research was construction of the first industrial-waste-treatment plant at technical area 45, which began operations in 1951. Since that time, the liquid wastes have been treated to MPC of radioactivity, the undesirable chemical constituents neutralized, and the effluents discharged into nearby canyons. Radioactive sludges that remain after treatment are placed in barrels, mixed with cement or vermiculite, and buried in the solid-waste disposal pits.

Laboratory or experimental equipment, ranging from glassware and gloves to entire buildings have been buried in pits dug into the surface of the mesas. Small articles are sealed in plastic bags or cardboard cartons and large items, such as buildings, commonly are burned before burial.

Plutonium is the major radioactive contaminant in wastes produced at Los Alamos. Other radioactive contaminants are uranium, radioactive barium-lanthanum, iodine 131, cesium 137, strontium 89 and 90, and other elements not identified. Radiochemical analyses of water were made for plutonium, uranium, and beta-gamma activity. The maximum permissible concentrations are 3×10^5 disintegrations per minute per liter for plutonium and 670 disintegrations per minute per liter for beta-gamma activity (Dummer, 1958). The maximum permissible concentration for uranium is 40,000 micrograms per liter (U.S. Dept. of Commerce Handbook 69).

Liquid wastes are treated at technical areas TA-2, TA-21, TA-35, and TA-45 to remove radioactive contaminants. The largest industrial-waste-treatment plant is at TA-45; therefore, the study has been centered in the disposal area of this plant (Acid and Pueblo Canyons).

Most of the solid wastes containing radioactive material are buried in pits at area "C" near TA-35 and in area "G" at Mesita del Buey.

Technical area TA-45

The industrial-waste-treatment plant at TA-45 has been in operation since January 1951, before which time all waste effluents were discharged into dry canyons. Plutonium, the major waste contaminant, is removed from liquid waste by chemical pretreatment with ferric sulfate and lime, which form a floculent precipitate that sinks to the bottom of settling tanks. The precipitate (ferric hydroxide) carries nearly all of the plutonium with it. The sludge is removed from the bottom of the tank, packaged, and buried in pits (Christenson, 1958).

Treated-industrial-waste effluent is discharged from TA-45 into Acid Canyon, tributary to Pueblo Canyon. Acid Canyon is cut deep into the Tshirege Member of the Bandelier Tuff which is exposed along the canyon floor. Pueblo Canyon is cut into the Tshirege Member and through succeeding older Otowi and Guaje Members eastward from the flanks of the Sierra de los Valles to near the confluence with Los Alamos Canyon where the Puye Conglomerate is exposed. Alluvium in the stream channel is thin in the upper reaches of the canyon but becomes progressively thicker eastward to about 30 feet near the mouth. Pueblo Canyon carries treated-sewage effluent from two plants (fig. 4). Industrial effluents in Acid Canyon are diluted with sewage effluents below the confluence of Pueblo and Acid Canyons. Precipitation and snowmelt runoff add to the volume of flow.

An average of about 2.5 million gallons of industrial effluent per year was discharged into Acid Canyon between 1946 and 1951. The volume of discharge has increased from 4.01 million gallons in 1951, when records were started, to about 13.9 million gallons in 1961. The industrial effluents are released from the treatment plant in slugs of 15,000 to 20,000 gallons rather than by continuous flow. The radioactivity of the treated effluent is usually about one-tenth of the MPC (Christenson, 1958).

The discharge of sewage effluent into Pueblo Canyon has increased from a low of about 70 million gallons in 1956 (start of records) to about 230 million gallons in 1961. The largest amount is discharged from September through April, when demand on the effluent for purposes of cooling and irrigation is low.

The chemical and radiochemical quality of water found in the disposal system of Acid and Pueblo Canyons is discussed under the section of monitoring of chemical quality of water.

Technical area TA-21

The industrial-waste-treatment plant at TA-21 has been in operation since 1952. Prior to 1952, raw effluent was discharged into seepage pits dug into the tuff. However, with an increase in wastes, the pits were not able to absorb all of the liquids. A treatment plant similar to the one at TA-45 was put into operation in 1952. Treatment is virtually the same, and plutonium is the major contaminant. There are many wastes from this area that contain high concentrations of inert salts that would interfere with the usual treatment for plutonium. These wastes are treated separately. Chemical wastes, such as hydrofluoric acid used in processing plutonium, are neutralized and discharged with other effluent from the treatment plant into DP Canyon. The annual discharge of effluent ranges from 2 to 4 million gallons and the radioactivity is usually about one-tenth of the MPC (Christenson, 1958).

Technical area TA-35

Treatment at TA-35 (10-site) consists of chemical pretreatment and passage through an ion-exchange column. The liquid wastes produced at this site are from process water and cleanup operations in the "hot" cell used for producing large sources of radioactive barium-lanthanum. The wastes contain relatively high concentrations of short-life beta- and gamma-emitting isotopes and some strontium 89 and 90. The chemical pretreatment is necessary to remove strontium 89 and 90 and plutonium; the ion-exchange column removes the other nuclides.

In the early 1950's, radioactive wastes were stored in four 50,000-gallon tanks for several months and then discharged into a small flat-bottomed canyon tributary to 10-Site Canyon. Ion-exchange columns were installed in January 1956, and a pilot plant study involving chemical pretreatment for the removal of strontium 89 and 90 began in February 1957. Both processes were used in the plant after June 1960.

The quantity of water discharged into the canyon is small (averaged 102,000 gallons per month from June 1960 to January 1961). The average level of radioactivity in the effluent is about one-tenth of the MPC (Christenson, 1958).

Technical area TA-2

The industrial waste at TA-2 is coolant water from the operation of two reactors. Coolant water from one reactor carries induced activity of short half-life and coolant water from the ion-exchange column of the other reactor contains several curies of short-half-life chromium, zinc, and antimony. The coolant water is discharged periodically into the stream channel of Los Alamos Canyon. Waste materials, containing an average of about 12 microcuries of cesium 137 and iodine 131, cleaned quarterly from the trap of a nearby stack were dumped on the alluvium of the canyon floor until early 1961. Stack wastes are now packaged and buried in the solid-waste disposal pits at Mesita del Buey.

Area "C" solid-waste disposal pits

The solid-waste disposal pits at area "C" consist of two rectangular pits that are each 100 feet by 600 feet by 20 feet deep and four smaller rectangular pits each 40 feet by 600 feet by 20 feet deep. The pits are dug into the Tshirege Member of the Bandelier Tuff. Two prominent, nearly-vertical joint systems in the tuff intersect at about 60 degrees; the soil covering the tuff is 3 to 5 feet thick, and most of the major joints are filled with sediments or altered material to a depth of about 10 feet.

Radioactive wastes placed in the pits have been recorded since 1954; however, records prior to 1954 are incomplete, thus the total radioactivity of solid wastes buried here cannot be estimated. About 10,000 cubic yards of wastes were buried in one of the larger pits between February 1956 and the end of 1959. The pits were mostly filled with wastes by 1960 and were backfilled with a cover of tuff. This cover and the surrounding soil cover should allow little, if any, water from precipitation to infiltrate the waste materials, because of the high retention value of the tuff cover coupled with high evapotranspiration rate (Abrahams and others, 1961).

Area "G" solid-waste disposal pits

The solid-waste disposal pits at area "G" consist of two rectangular pits 100 feet by 600 feet by 30 feet deep. The pits are dug into the Tshirege Member of the Bandelier Tuff. The walls of one of the pits indicated three, nearly-vertical joint systems. All joints that were seen to terminate at the base of the soil zone were filled with a light brown clay; at 3 to 4 feet below the base of the soil zone most of the joint openings are filled or the joint faces are plated with a light gray clay. Among the first items placed in these pits were buildings containing unknown quantities of plutonium, uranium, and mixed fission products. These buildings were burned, and the ashes were buried. One pit was filled and the other was about 40 percent filled by the middle of 1961. Pits that are filled with waste are sealed and compacted with tuff.

Monitoring of chemical quality of water

The U.S. Geological Survey in cooperation with the U.S. Atomic Energy Commission and the Los Alamos Scientific Laboratory began a program in 1949 to monitor the chemical and radiochemical contents of water. Radiochemical analyses considered are of the period July 1957 to 1961, when a reliable technique to analyze the water samples was used. Water samples for chemical and radiochemical analyses were collected downgradient from waste-disposal points, industrial-waste-treatment plants, and disposal pits. The purpose of obtaining this information was to determine whether radioactive waste from the operation of the Los Alamos Scientific Laboratory may be a source of contamination to the natural water system.

Technical area TA-45 disposal system

The disposal area for liquid waste from the industrial-waste treatment plant at TA-45 is Acid and Pueblo Canyons. Samples of water were obtained from shallow wells ("AC", "PC", and "PO" series) to determine the chemical and radiochemical changes in the effluent that moves at shallow depths in the alluvium and in the fanglomerate.

Surface water sampling stations are at 19.6.9.441 (Acid Weir) in Acid Canyon near the confluence with Pueblo Canyon and near wells 19.6.9.442 (PC-1), 19.6.14.222 (PC-2), and 19.7.18.242 (PC-3).

The chemical qualities of surface and ground water in the alluvium of Acid and Pueblo Canyons are interrelated and are discussed together. Trends or significant changes in the chemical quality of effluent from the plant at TA-45 were partly obscured by the dilution effect of effluent from the two sewage-treatment plants, snowmelt and stormflow runoff, and slug type of release of industrial effluents. Analyses of the industrial effluents indicate that they are very basic, high in fluoride and nitrate content, and contain no phosphates. In comparison, the sewage effluents are neutral with respect to hydrogen ion concentration (pH), low in fluoride content, and high in nitrate and phosphate contents (table 1).

Table 1.--Selected chemical and radiochemical analyses of water in the disposal system for technical area TA-45, Acid and Pueblo Canyons. (Chemical quality analyses by U.S. Geological Survey; radiochemical analyses by the Los Alamos Scientific Laboratory. Chemical constituents are in parts per million.)

Explanation: Location numbers: See page 27 of text.

Geologic source: Qal, Recent alluvium; QTsp, Puye Conglomerate, undifferentiated; QTb, Basaltic rocks of Chino Mesa, undifferentiated.

Location number	Atomic Energy Commission and Los Alamos Scientific Laboratory designation	Depth of well (feet)	Geologic source	Date of collection	Chemical														Radiochemical		
												Hardness as $CaCO_3$							Plutonium (disintegrations per minute per liter)	Uranium (micrograms per liter)	Beta-gamma emitters (disintegrations per minute per liter; Bg, background)
					Sodium (Na)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Phosphate (PO_4)	Calcium magnesium	Noncarbonate	Percent sodium	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25°C)	pH	Temperature (°F)			
S19. 6. 9.400	Pueblo plant sewage effluent	-	-	5-24-61	94	121	0	34	4.6	30	35	49	0	75	5.8	613	7.0	-	-	-	-
9.434	Well AC-2	2	Qal	7-14-59	88	47	81	32	3.5	8.6	-	80	0	71	4.3	558	9.7	-	8	< 10	6,000
S 9.441	Surface flow at Acid Weir	-	-	7-14-59	105	186	7	32	3.9	30	-	93	0	71	4.7	629	8.5	-	7	< 10	1,200
9.442	Well PC-1	2	Qal	7-14-59	73	244	0	29	1.9	.4	-	80	0	62	3.6	530	7.7	--	0	< 10	background
S 9.442	Surface flow near Well PC-1	-	-	7-14-59	90	214	0	29	2.8	.5	-	73	0	73	4.6	619	7.5	-	0	< 10	5,800
13.242	Well PO-2	35	QTsp	6- 8-61	58	200	0	33	.6	.1	.13	99	0	56	2.5	483	7.0	53	0	< 10	background
13.244	Well PO-1	21	QTsp	6- 8-61	67	172	0	32	1.1	4.5	14	68	0	68	3.5	482	7.4	51	0	< 10	Do.
14.221a	Well T-2a	133	QTsp	5-11-61	14	52	0	15	.3	12	.26	50	8	38	.9	185	7.0	55	0	< 10	Do.
14.222	Well PC-2	2	Qal	7-14-59	88	272	0	33	1.5	1.0	-	92	0	68	4.0	577	7.8	-	0	< 10	Do.
S 14.222	Surface flow near well PC-2	-	-	7-14-59	90	160	0	36	3.2	19	-	46	0	81	5.8	506	7.6	-	0	< 10	Do.
16.200	TA-45 industrial effluent	-	-	5-24-61	117	a/	191	98	14	12	0.0	248	0	50	3.2	1,320	11.2	-	0	< 3	1,300
16.211	Well AC-1	1	Qal	7-14-59	105	b/	77	39	6.2	7.8	-	97	0	70	4.6	696	10.6	-	10	36	1,500
21.200	Central-plant sewage effluent	-	-	5-24-61	114	158	0	46	2.6	43	22	37	0	83	8.2	618	7.1	-	-	-	-
19. 7.17.322	Well PC-4	14	Qal	7-14-59	77	124	0	32	3.1	16	-	46	0	78	4.9	405	7.2	-	0	< 10	900
S 17.322	Surface flow near Well PC-4	-	-	5-20-59	71	143	0	33	1.4	.3	-	56	0	73	4.1	458	7.6	-	0	< 10	background
S 18.124	Hamilton Bend Spring	-	Qal	7- 7-59	66	116	0	31	.7	10	-	46	0	76	4.2	365	7.0	-	0	< 10	Do.
18.141	Well PO-3	59	QTsp	6- 8-61	12	52	0	15	.3	8.3	2.3	54	12	32	.7	191	6.8	55	0	< 10	Do.
18.242	Well PC-3	2	Qal	7-14-59	70	148	0	32	1.6	.2	-	47	0	76	4.4	422	7.5	-	0	< 10	Do.

See footnotes at end of table.

Table 1.--Selected chemical and radiochemical analyses of water in the disposal system for technical area TA-45, Acid and Pueblo Canyons - Concluded

Location number	Atomic Energy Commission and Los Alamos Scientific Laboratory designation	Depth of well (feet)	Geologic source	Date of collection	Chemical														Radiochemical		
												Hardness as $CaCO_3$							Plutonium (disintegrations per minute per liter)	Uranium (micrograms per liter)	Beta-gamma emitters (disintegrations per minute per liter; Bg, background)
					Sodium (Na)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Phosphate (PO_4)	Calcium magnesium	Noncarbonate	Percent sodium	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25°C)	pH	Temperature (°F)			
S19. 7.18.242	Surface flow near well PC-3	-	-	7-14-59	83	174	0	34	4.8	.2	-	62	0	74	4.6	465	7.6	-	0	10	background
20.221a	Well T-1A	225	QTb	4-22-61	34	126	0	29	.5	45	3.6	127	24	37	1.3	430	7.2	54	0	10	Do.

a/ Hydroxide (OH) = 30 ppm.
b/ Hydroxide (HO) = 18 ppm.

The quality of water from surface flow and selected wells in Acid and Pueblo Canyons is also shown on table 1. The quality of surface and ground water in the alluvium in Acid Canyon varied markedly between sampling periods, but the water generally was highly mineralized. The pH, fluoride, and specific conductance were very high, and the alkalinity was in the form of hydroxide near the point of effluent discharge. The pH was lower and there was no hydroxide alkalinity at the confluence of Acid and Pueblo Canyons.

The chemical quality of water in the alluvium in Pueblo Canyon gradually improves downgradient from Acid Canyon. The phosphate content of water in Pueblo Canyon is high probably because of sewage effluent. Fluoride content is much lower than observed in Acid Canyon and the specific conductance decreases below the confluence of the two streams, whereas the nitrate content generally is high.

The quality of water in the alluvium of Acid and Pueblo Canyons is best during the winter and early spring when streamflow is at a maximum due to increased discharge of sewage effluents and snowmelt runoff. This additional runoff dilutes the industrial effluents. The quality of the water is poorest during the late spring and early summer when the discharge of sewage effluents and storm runoff is at a minimum (less than 1 cfs, cubic feet per second). Streamflow, which may range as high as 40 cfs for short periods, from summer thunder showers may flush some of the industrial effluents from the alluvium to the Rio Grande; however, these effluents are diluted with the increased volume of water.

Within the study period the water quality did not change to any great extent; however, rapid fluctuation of the chemical quality did occur within a short interval of time due to the method of releasing industrial effluents and to varying amounts of dilution with sewage effluent.

The chemical quality of water from S19.7.18.124 (Hamilton Bend Spring) is uniform, except for the nitrate content which tends to fluctuate, and is similar to water in the alluvium above the spring area, although less mineralized (table 1). Water from the stream in Pueblo Canyon recharges the spring area. Water perched on a silt layer in the upper part of the Puye Conglomerate moves eastward into the spring area where it is discharged.

The chemical quality of water from wells 19.6.13.244 (PO-1) and 19.6.13.242 (PO-2) is similar to the chemical quality of water from other shallow wells in Pueblo Canyon. The water level in well 19.6.13.244 (PO-1), less than 50 feet south of the stream, responded directly to changes in flow in the stream. Absence of phosphates in water from well 19.6.13.242 (PO-2) contrasted with relatively high phosphates in water from well 19.6.13.244 (PO-1) may be explained by the greater distance that the water must move from the stream to well 19.6.13.242 (PO-2).

The quality of water from well 19.7.18.141 (PO-3) is substantially different from that in the alluvium and from S19.7.18.124 (Hamilton Bend Spring) but similar to that in well 19.6.14.221a (T-2A). Water from the wells has comparatively low mineral content; however, the chloride content almost doubled within a period of about $3\frac{1}{2}$ years. The water level in well 19.7.18.141 (PO-3) fluctuates only slightly and is about 20 feet below the level of the stream channel and about 25 feet beneath the level of S19.7.18.124 (Hamilton Bend Spring). The chloride content of water from both wells increased, which suggests that recharge probably is from the stream in Pueblo Canyon. Water-level fluctuations correlated with streamflow fluctuations indicates a period of from 4 to 6 months for recharge to reach well 19.6.14.221a (T-2A).

The quality of water from well 19.7.20.221a (T-1A) indicates that the source of recharge is a mixture of water infiltrating the stream channel in the general area of Otowi Seep and further downstream in Pueblo Canyon. The chemical quality of water from well 19.7.20.221a (T-1A) varied slightly from sample to sample, except for nitrate and phosphate concentrations which were often in excess of quantities found in natural water. The water moves through the alluvium, into the underlying fanglomerate member of the Puye Conglomerate, and along the basalt interflow into the well. Water-level changes in the well correlate with the flow at Otowi Seep with a lag of from 1 to 2 months.

Water samples also were analyzed for plutonium, uranium, and gross beta-gamma activity. The radiochemical quality of water from surface flow and wells in Acid and Pueblo Canyons is shown on table 1.

During the period of investigation, the radioactivity in water in the alluvium of Acid Canyon was considerably higher than in the alluvium in Pueblo Canyon due to the direct discharge of industrial effluent into Acid Canyon and lack of dilution. The highest reported activity in surface water in the alluvium in Acid Canyon was plutonium, 400 dml (disintegrations per minute per liter) in May 1959; uranium, 38.5 μgl (micrograms per liter) in May and July 1958; and gross beta-gamma activity, 6,500 dml in July 1960. Relatively high gross beta-gamma activity in water occurred in Acid and Pueblo Canyons during July 1959. The activity decreased from 6,000 dml in Acid Canyon to 5,800 dml at S19.6.9.442 (surface flow near well PC-1). Water from well 19.7.17.322 (PC-4) contained gross beta-gamma activity of 900 dml during the same period indicating that the contamination was carried from Acid Canyon into Pueblo Canyon where dilution and ion-exchange reduced the amount of activity.

Radioactivity in water from wells 19.7.20.221a (T-1A), 19.6.14.221a (T-2A), 19.6.13.244 (PO-1), 19.6.13.242 (PO-2), 19.7.18.141 (PO-3), and S19.7.18.124 (Hamilton Bend Spring) was low; generally no more than the normal background activity.

Samples of alluvium were collected in Acid and Pueblo Canyons to determine the amount of adsorption of nuclides on silts and clays. Radioactivity generally decreased with distance below the points of discharge of industrial effluents. Table 2 shows the radiochemical analyses of the surface alluvium in Acid and Pueblo Canyons from 1954 to 1961. Gross alpha and gross beta activity increased in the alluvium in Acid Canyon in October 1958 due to a release of untreated industrial effluents.

The average gross alpha and gross beta activity was considerably lower in Pueblo Canyon than in Acid Canyon (table 2); however, a pattern of decreasing activity downstream in monitored reach of Pueblo Canyon was not apparent. The nuclides that have a tendency to attach themselves to silt and clay particles are dispersed throughout Acid and Pueblo Canyons due to the slug type of release of industrial effluents, large quantities of sewage effluents discharged into Pueblo Canyon, and periodic storm runoff.

Table 2.--Radiochemical analyses of surface alluvium in Acid and Pueblo Canyons, 1954 to 1961. (Analyses by the Los Alamos Scientific Laboratory.)

Location	Sampling Point (distance, in miles, below point of discharge of industrial effluents)	Gross alpha[1/] Date of collection								Gross beta[2/] Date of collection					
		1954	1955	1956	1957	1958	1959	1960	1961	1956	1957	1958	1959	1960	1961
Acid Canyon	0.06	$1.6x10^{-3}$	$2.6x10^{-3}$	$3.4x10^{-5}$	$3.9x10^{-4}$	$2.9x10^{-3}$	$3.6x10^{-4}$	$1.2x10^{-4}$	$1.3x10^{-4}$	360	370	11,320	990	1,500	70
Do.	.15	$3.2x10^{-4}$	$5.0x10^{-4}$	$1.4x10^{-4}$	$1.7x10^{-4}$	$1.6x10^{-3}$	$2.2x10^{-4}$	$6.7x10^{-5}$	$4.0x10^{-5}$	142	70	10,440	290	730	60
Do.	.3	$1.9x10^{-4}$	-	$1.2x10^{-4}$	$6.4x10^{-5}$	$5.2x10^{-5}$	$1.0x10^{-4}$	$5.7x10^{-5}$	$3.7x10^{-5}$	11	90	440	155	480	120
Do.	.4	-	-	-	-	$3.4x10^{-5}$	$5.0x10^{-5}$	$4.8x10^{-5}$	$2.2x10^{-4}$	-	-	830	107	340	3,650
Pueblo Canyon	.6	$3.5x10^{-5}$	-	$1.8x10^{-6}$	-	$1.1x10^{-5}$	$5.5x10^{-6}$	$2.7x10^{-6}$	$5.7x10^{-5}$	0	-	120	50	0	120
Do.	.7	$1.6x10^{-5}$	-	$2.7x10^{-6}$	-	$5.5x10^{-6}$	$9.0x10^{-6}$	$2.7x10^{-6}$	$2.0x10^{-5}$	17	-	120	7	40	20
Do.	1.2	$5.2x10^{-5}$	-	-	-	$2.7x10^{-6}$	-	$4.1x10^{-5}$	$1.0x10^{-5}$	-	-	370	-	90	0
Do.	1.5	$9.0x10^{-6}$	-	-	-	-	$3.6x10^{-6}$	$1.1x10^{-5}$	$1.1x10^{-5}$	-	-	-	-	0	0
Do.	2.2	$3.6x10^{-6}$	-	-	-	-	$3.6x10^{-6}$	$9.1x10^{-6}$	$1.0x10^{-5}$	-	-	-	60	20	10
Do.	2.7	$5.4x10^{-5}$	-	-	-	-	$1.8x10^{-6}$	$4.6x10^{-6}$	$1.2x10^{-4}$	-	-	-	10	40	190
Do.	3.7	-	-	-	-	-	$3.6x10^{-6}$	$1.8x10^{-6}$	$3.3x10^{-5}$	-	-	-	20	70	0

1/ Microcuries per dry gram

2/ Counts per minute per dry gram showing relative values, isotopes in samples not identified.

Technical areas TA-2, TA-21, and TA-35 disposal systems

The disposal area for TA-21 is DP Canyon which heads on the Pajarito Plateau and has a small drainage area. The chemical quality of surface water collected a short distance from the point of effluent discharge is of poor quality [dissolved-solids, content from 1,300 to 1,800 ppm (parts per million)]. The highest concentration of gross alpha activity in samples of alluvium collected a short distance downgradient from the point of discharge into DP Canyon was 184 cmdg (counts per minute per dry gram).

DP Canyon is tributary to Los Alamos Canyon. Samples of surface water from DP Canyon near the confluence have indicated some beta-gamma activity; however, it has been below the MPC. Beta-gamma activity was reported at 100 cml (counts per minute per liter) and uranium at 4.2 μgl on May 12, 1961.

Samples of alluvium were collected from DP Canyon near the confluence with Los Alamos Canyon in 1959 to 1961. They indicated only small amounts of gross alpha-beta activity.

The disposal area for TA-35 is a dry canyon that has a very small drainage area. No water samples were collected; however, samples of alluvium have been collected since 1956 for radiochemical analyses (table 3).

Table 3.--Radiochemical analyses of surface alluvium in a small canyon that receives treated industrial effluents from technical area TA-35. (Analyses by the Los Alamos Scientific Laboratory.)

Sampling point (distance, in miles, below point of discharge of industrial effluents)	Gross beta 1/						Gross gamma 1/			Strontium 2/					
	Date of collection						Date of collection			Date of collection					
	1956	1957	1958	1959	1960	1961	1956	1957	1958	1956	1957	1958	1959	1960	1961
0.00	824,000	23,480	87,420	2,801	830	2,130	171,510	4,416	61,198	3.2×10^{-1}	3.8×10^{-3}	2.5×10^{-3}	6.1×10^{-5}	1.3×10^{-4}	3.0×10^{-5}
.04	885,000	3,270	1,910	237	370	590	207,810	314	2,002	2.1×10^{-1}	1.4×10^{-3}	7.5×10^{-4}	3.9×10^{-5}	7.6×10^{-5}	2.2×10^{-5}
.25	29,600	2,510	2,440	294	1,470	1,530	1,840	48	852	5.6×10^{-2}	8.7×10^{-5}	1.4×10^{-3}	1.1×10^{-4}	8.9×10^{-5}	2.0×10^{-5}
.42	2,000	750	130	33	260	1,440	290	30	0	4.2×10^{-2}	3.5×10^{-4}	6.9×10^{-5}	3.4×10^{-5}	7.6×10^{-5}	2.0×10^{-5}
.58	1,200	20	-	0	0	850	90	1	-	2.0×10^{-3}	1.4×10^{-5}	1.0×10^{-5}	-	-	-
.67	-	60	340	11	20	50	-	1	0	-	1.5×10^{-5}	2.7×10^{-5}	-	-	-

1/ Counts per minute per dry gram showing relative values, isotopes in samples not identified.

2/ Microcuries per dry gram.

The activity in samples of alluvium collected in the bed of the narrow channel indicates that gross beta, gross gamma, and strontium decreased both downstream and with time (table 3). The activity generally decreased with depth in the alluvium; however, activity in some samples of alluvium collected at a depth of about 6 inches was greater than in the surface material because of a greater percentage of clay in the alluvium.

Untreated radioactive waste was discharged into the canyon in February 1956. Activity from this discharge apparently was gone from the surface and from alluvium at depth before February 1958. Barium and lanthanum cause a large percentage of the beta-gamma activity. They have a combined half-life of 12.8 days so decay accounts for much of the decrease of activity with time. High gross alpha and gross beta activity in the alluvium since February 1958 is the result of subsequent discharges of treated-waste effluents.

The disposal area for TA-2 is Los Alamos Canyon, which has a large drainage area. The few surface-water samples collected downgradient from the point of discharge contained water of good quality, low mineralization, and showed no radioactive contamination.

The radioactivity in samples of alluvium collected downgradient from technical area TA-2 in Los Alamos Canyon was low. Samples of the upper 1 foot of alluvium were collected at intervals of 0.1 to 0.2 mile in Los Alamos Canyon between technical area TA-2 and well T-3. The general range and highest levels of activity are shown below, in counts per minute per dry gram.

Type of activity	General range	Highest Value	Period
Gross alpha	0 to 16	84	1959-61 (5 samples)
Gross beta	0 to 49	73	1959-61 (5 samples)
Gross gamma	0 to 37	45	1958 (4 samples)

Supply wells and test wells

The chemical quality of water from the supply wells in Guaje and Los Alamos Canyons was good. No increasing or decreasing trends of the chemical quality were noted during the investigation. A comparison of the analyses of water collected during June and December of each year indicates a small seasonal change in the quality of the water from wells 19.7.14.312 (L-6) and 19.7.15.434 (L-5), whereas the quality of the water from the remaining wells was constant. The seasonal change in the quality of water from the two wells can be attributed to seasonal variations in pumping rates. Pumpage from the wells is considerabley greater in June than in December. Water that is pumped during the summer has a slightly higher temperature than water pumped during the winter. This may be the result of water-bearing beds at greater depth contributing more of the discharge when the wells are heavily pumped during the summer than during the lighter winter pumping. Selected chemical and radiochemical analyses are shown on table 4.

Table 4.--Selected chemical and radiochemical analyses of water from supply wells, test wells, and springs in the Los Alamos area. (Chemical analyses by the U.S. Geological Survey; radiochemical analyses by Los Alamos Scientific Laboratory. Chemical constituents are in parts per million.)

Explanation: Location numbers: See page 27 of text.

Geologic source: QTsp, Puye Conglomerate, undifferentiated; QTb, Basaltic rock of Chino Mesa, undifferentiated; Tst, Tesuque Formation; QTt, Tschicoma Formation

Location number	Atomic Energy Commission and Los Alamos Scientific Laboratory designation	Depth of well (feet)	Geologic source	Date of collection	Chemical														Radiochemical		
												Hardness as $CaCO_3$							Plutonium (disintegrations per minute per liter)	Uranium (micrograms per liter)	Beta-gamma emitters (disintegrations per minute per liter; Bg, background)
					Sodium (Na)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Phosphate (PO_4)	Calcium magnesium	Noncarbonate	Percent sodium	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25°C)	pH	Temperature (°F)			
S18. 6.23.214	Rito de los Frijoles	-	-	6- 6-61	8.5	56	0	1.8	0.2	0.1	-	31	0	37	0.7	101	7.3	-	0	< 5	background
S18. 7.20.312	Ancho Spring	-	QTsp	6- 5-61	10	73	0	2.8	.4	.2	.14	42	0	33	.7	131	7.8	67	0	<5	Do.
S 30.123	Doe Spring	-	Tst	6- 6-61	11	76	0	1.2	.5	.1	.02	40	0	36	.8	128	7.7	56	0	<5	Do.
19. 6. 9.443	Test well T-4	1,205	QTt	4-19-61	11	80	0	4.2	.3	.1	.03	44	0	33	.7	145	7.8	-	0	<5	Do.
13.344	Test well T-3	815	QTsp	5-12-61	12	117	0	5.4	.4	.5	.02	77	0	25	.6	208	7.6	72	0	<5	Do.
14.221	Test well T-2	789	QTsp	5-21-61	8.7	80	0	2.2	.4	.2	.02	50	0	28	.5	140	7.7	69	0	<5	Do.
19. 7. 4.133	Supply well G-3	1,792	Tst	6- 7-61	25	100	0	2.4	.4	.1	-	33	0	62	1.9	171	7.5	84	0	<10	Do.
4.411	Supply well G-2	1,970	Tst	6- 7-61	35	123	0	3.2	.9	.6	.07	32	0	68	2.7	212	7.8	86	0	<10	Do.
4.441	Supply well G-1A	1,519	Tst	6- 7-61	22	94	0	2.8	.4	.2	-	33	0	59	1.7	165	8.0	81	0	<10	Do.
4.444	Supply well G-1	2,000	Tst	6- 7-61	23	95	0	2.6	.5	.5	.04	31	0	59	1.8	165	7.9	80	0	<10	Do.
5.112	Supply well G-5	1,840	Tst	6- 7-61	12	93	0	3.8	.5	.9	.03	58	0	30	.7	170	7.9	79	0	<10	Do.
5.231	Supply well G-4	1,930	Tst	6- 7-61	12	94	0	3.0	.3	1.0	-	58	0	31	.7	168	7.5	76	0	<10	Do.
S 12.233	Sacred Spring	-	Tst	4-26-61	21	115	0	3.0	.5	.9	-	54	0	46	1.2	203	7.8	55	0	< 5	Do.
S 13.112	Indian Spring	-	Tst	4-22-61	19	113	3	3.0	.5	.1	-	60	0	41	1.1	199	8.4	52	0	< 5	Do.
13.114	Supply well L-1	870	Tst	9-17-58	86	178	6	18	1.4	2.0	-	14	0	93	10	401	8.4	72	0	<5	Do.
13.114b	Supply well L-1b	1,750	Tst	2- 8-61	180	428	0	15	2.7	.9	-	24	0	94	16	775	7.9	87	0	6.5	Do.
14.221	Supply well L-3	870	Tst	2-25-60	43	128	0	6.6	.8	1.7	-	32	0	75	3.3	237	8.2	74	0	< 5	Do.
14.222	Supply well L-2	870	Tst	2- 8-61	68	156	0	16	1.4	1.2	-	17	0	90	7.2	329	7.6	74	0	<5	Do.
14.312	Supply well L-6	1,790	Tst	2-25-60	117	273	7	7.2	2.6	1.8	-	8	0	97	18	486	8.5	83	0	19	Do.

Table 4.--Selected chemical and radiochemical analyses of water from supply wells, test wells, and springs in the Los Alamos area - Concluded

Location number	Atomic Energy Commission and Los Alamos Scientific Laboratory designation	Depth of well (feet)	Geologic source	Date of collection	Chemical														Radiochemical		
												Hardness as $CaCO_3$							Plutonium (disintegrations per minute per liter)	Uranium (micrograms per liter)	Beta-gamma emitters (disintegrations per minute per liter; Bg, background)
					Sodium (Na)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Phosphate (PO_4)	Calcium magnesium	Noncarbonate	Percent sodium	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25°C)	pH	Temperature (°F)			
19. 7.15.434	Supply well L-5	1,750	Tst	2- 8-61	22	83	4	2.2	0.4	1.1	-	27	0	64	1.8	156	8.4	70	0	<5	background
20.221	Test well T-1	642	QTsp	5-12-61	15	90	0	4.4	1.0	7.8	.03	52	0	38	.9	185	7.8	69	0	<5	Do.
22.114	Supply well L-4	1,965	Tst	2- 8-61	18	84	0	2.8	.4	1.0	-	32	0	55	1.4	147	8.2	78	0	<5	Do.
S 22.114	Los Alamos Spring	-	QTb	3-22-61	18	105	0	23	1.1	9.5	-	120	34	25	.7	341	7.9	-	0	<5	Do.
S 22.131	Basalt Spring	-	QTb	6- 9-61	14	96	0	1.4	.5	7.7	.23	99	20	23	.6	270	7.6	61	0	<5	Do.
S 35.121	Sandia Spring	-	Tst	6- 6-61	14	142	0	4.8	.6	.1	.16	99	0	23	.6	256	7.3	67	0	<5	Do.

The concentration of ions in water from wells in the Los Alamos Canyon well field was slightly higher than that in water from the Guaje Canyon well field. The concentration of sodium, bicarbonate, chloride and fluoride was about twice that in water from the Guaje Canyon well field, but the calcium and magnesium content was only about half.

Progressive changes in the quality of water are evident downgradient in the Los Alamos Canyon well field, excluding well 19.7.14.312 (L-6). More notable changes are noted when the three shallow wells are considered separately from the four deeper wells (table 4).

Samples of water were collected from well 19.7.14.312 (L-6) 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 sample after about 15 to 45 minutes of pumping and the other sample after about 350 to 500 minutes of pumping. With few exceptions, the concentrations of sodium, bicarbonate, fluoride and chloride and the temperature and specific conductance increased with pumping, but the pH decreased.

The water from well 19.7.13.114b (L-1B), a new well that is 1,750 feet deep and is in the lower part of the well field, was more highly mineralized than water from any other sampling source in the Los Alamos area, except from Acid Canyon. The sodium content was as much as 210 ppm, specific conductance reached 876 micromhos, and the temperature reached 90°F; however, the average pH was the lowest in the well field. The high concentration of fluoride (range 1.6 to 2.8 ppm) and the high temperature of water from wells 19.7.13.114b (L-1B) and 19.7.14.312 (L-6) (table 4) indicate pumpage of water from aquifers that are not tapped by the other wells.

Water from the supply wells contained no plutonium and the beta-gamma activity was no greater than normal background activity. Uranium content ususally ranged from 0 to 10 μgl in most of the wells. Water from wells 19.7.14.312 (L-6) and 19.7.13.114b(L-1B) was of the poorest chemical quality (highest mineralization) and also contained the largest concentration of uranium. Uranium content ranged from 15 to 25 μgl with a maximum of 130 μgl in water from well 19.7.14.312 (L-6). This amount of uranium occurs naturally in the aquifer. Water from the supply wells is not contaminated by industrial wastes.

The changes in chemical and radiochemical quality of water from the four deep test wells 19.7.20.221 (T-1), 19.6.14.221 (T-2), 19.6.13.344 (T-3), and 19.6.9.443 (T-4) are useful to determine whether surface flow in the disposal systems in Acid, Pueblo, and DP Canyons is hydraulically connected to the aquifers yielding water to the wells. The chemical quality of water from the wells was constant throughout the period of record. Specific conductance of water from each source did not vary more than 18 micromhos. Water-level fluctuations have been slight. Well 19.6.13.344 (T-3) in Los Alamos Canyon yielded water with the highest mineral content. During the period of record, the average mineral content of water from the other test wells increased downgradient toward the Rio Grande. Data pertaining to chemical and radiochemical quality changes and water-level fluctuations indicate that surface flow is not hydrologically connected with the aquifers in the deep test wells.

Water from deep test wells contained no plutonium. Beta-gamma activity in water from the deep test wells was near or below normal background activity, and uranium content ranged from 0 to 12 μgl. This amount of uranium occurs naturally in the aquifers. Water from test wells is not contaminated by industrial effluents.

Springs and Rito de los Frijoles

Water in the main aquifer moves eastward beneath the Pajarito Plateau toward the Rio Grande where part is discharged into the river through springs. Springs S19.7.13.112 (Indian Spring), S19.7.12.233 (Sacred Spring), S19.7.35.121 (Sandia Spring), and S18.7.30.123 (Doe Spring) discharge from the Tesuque Formation. Spring S18.7.20.312 (Ancho Spring) discharges from the Totavi Lentil.

Springs S19.7.22.131 (Basalt Spring) and S19.7.22.114 (Los Alamos Spring) discharge from perched aquifers in the basaltic rocks of Chino Mesa. The water from the springs that discharge from perched aquifers was more mineralized than water from the springs that discharge from the main aquifer (table 4). The quality of water from the springs was relatively constant during the period of the study; however, very slight seasonal differences did occur.

Surface flow at Rito de los Frijoles is used as a water supply for Frijoles. The surface water at Rito de los Frijoles is from springs discharging from the Tschicoma Formation on the flanks of the Sierra de los Valles and from storm runoff. The quality of the water varies slightly due to seasonal changes; however, the water has a very low mineral content (table 4).

Water from springs and Rito de los Frijoles contained no plutonium. Beta-gamma activity above background has been reported in water from several of the springs but additional samples and analysis fail to confirm contamination. Beta-gamma activity above background may have been due to man-caused fallout as most samples are collected from an open source. The uranium content in water from springs ranged from 0 to 20μgl. This amount of uranium occurs naturally in the aquifers. Water from the springs was not contaminated by industrial wastes.

Rio Chama and Rio Grande

Water samples are collected periodically from the Rio Chama at Chamita and from the Rio Grande at Embudo, Otowi, and Cochiti (fig. 1). Water at Otowi, east of Los Alamos, is a mixture of water from the Rio Chama and Rio Grande. Most of the seasonal fluctuations in chemical quality at Otowi is attributable to water from the Rio Chama. The specific conductance varies from an average of 620 micromhos during high discharge in March to an average of 270 micromhos during low discharge in June.

Radiochemical analyses of water from the Rio Chama and Rio Grande reported plutonium at Embudo (46 dml in composite samples July, Aug., and Sept. 1958), at Otowi (3 dml in composite samples Jan. 1 through Jan. 31, 1960), and at Chamita (5 dml in composite samples February 1960). Beta-gamma activity ranged from background to 40 dml and uranium content ranged from 0 to 5 μgl.

It is doubtful that the Rio Chama or Rio Grande received contamination by industrial wastes from Los Alamos. Plutonium content and beta-gamma activity reported at Chamita and Embudo is attributed to fallout. Plutonium content at Otowi and beta-gamma activity at Otowi and Cochiti are probably the result of fallout, because the sampling station upgradient from Los Alamos (Chamita and Embudo) also reported contamination. No traces of contamination can be found in canyons of the disposal system from four to five miles above the Rio Grande. The amounts of plutonium, beta-gamma activity, and uranium that probably was naturally occurring, found in samples of river water, were low and below the MPC.

Conclusions

Chemical and radiochemical contamination (usually below MPC) is limited to the canyon disposal areas receiving treated industrial effluent; is greatest near points of effluent discharge and diminishes downgradient in the canyons.

Test and supply wells completed in the main zone of ground water saturation indicate no chemical or radiochemical contamination.

Chemical treatment of liquid wastes and burial of solid wastes as practiced by the Los Alamos Scientific Laboratory reduce likelihood of serious contamination and complement the effectiveness of local geologic and hydrologic conditions for containing chemical wastes within narrow areal and spatial limits.

Practices, conditions and their interrelationships pertinent to the conclusion that it is unlikely that significant contamination could reach the river or the supply wells are summarized as follows:

1. Liquid wastes are treated to one-tenth MPC of radioactivity before discharge into the disposal areas.

2. Storm runoff and treated sewage effluent dilute the already low-level wastes.

3. Chemistry of the liquid wastes, especially their high pH, promotes exchange of radioactive components in the effluent with ions in clay, and attachment of effluent components to clay particles.

4. Clay minerals, montmorillonite and illite are weathering products of the tuff and are in large quantity in the canyons. They effectively bind radioactive ions or molecules. Clay particles, with attached radioactive material, are dispersed downgradient and laterally in the canyon disposal areas by sudden strong flows of effluent or storm runoff. Seepage also disperses radioactive material by carrying some of it to buried clays. With high flows the seepage reaches further laterally. These factors combine to decrease the likelihood of occurrence of a larger anomalous concentration.

5. Sludge produced in chemical treatment of liquid wastes is mixed with vermiculite or cement and put in barrels to prevent leakage or leaching.

6. Soil around the solids disposal pits and the compacted tuff used to cover the pits when they are filled allow an inconsequential amount of water from precipitation to infiltrate to the waste.

7. The tuff of the plateau can retain certain nuclides by ion and base exchange.

8. The large volume of unsaturated volcanic rock and sediment under the plateau is a potential reservoir for storage of any contaminated water introduced from the surface.

9. The slow movement of ground water (about 360 feet per year) would allow an interval of probably years for chemical reaction and for radioactive decay of contaminants between the time that they might enter the ground water and the time that water would reach the river or the zone from which water is being pumped.

Monitoring of ground water at the supply wells and of surface water in the Rio Grande and at springs emptying to the river confirms that no detectable contamination has reached these waters.

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