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Hydrology and general geology of the Pojoaque area, Santa Fe County, New Mexico

by

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Open-file report

Prepared in cooperation with the Bureau of Indian Affairs

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Introduction

This report was prepared in cooperation with, and at the request of, the U.S. Bureau of Indian Affairs as a result of litigation--State of New Mexico and the United States v. Aamodt, et al., Civil No. 6639, U.S. District Court, District for New Mexico,--involving the use of water in the Pojoaque River drainage basin, Santa Fe County, New Mexico.

It is the purpose of this report to provide a general description of the geology and hydrology of the Pojoaque River system.

The report is based upon a reconnaissance that included the examination of geologic rock units in the area and the determination of the specific conductance of some surface waters. A study was made of geologic and hydrologic literature pertaining to the problem.

Common hydrologic terms and basic hydrologic principles used or referred to in the report will not be defined or explained in the interest of brevity. Meinzer (1923, a and b) and the Glossary of Geology and Related Sciences (American Geological Institute, 1960) may be consulted for technical definition and explanation of terms and principles.

Geography

The area examined during the reconnaissance embraces about 400 square miles. It lies in north-central New Mexico mostly between Santa Fe to the southeast and Espanola to the northwest, and between the Rio Grande on the west and the crest of Sangre de Cristo Mountains on the east (fig. 1).

The Pueblos of Tesuque, Nambe, and Pojoaque lie entirely within the area; San Ildefonso Pueblo lies partly within the area. Numerous small communities populated mainly by non-Indians are located along the water courses outside the Pueblos' boundaries as designated on U.S. Geological Survey maps. The principal such community is Tesuque (as distinct from Tesuque Pueblo). Some Indian families live in the Pojoaque area but outside designated reservation boundaries, and some non-Indian families reside within designated reservation boundaries.

Some of the Indians and most of the non-Indian residents make their living away from the area in which they live. Most of them work at Los Alamos, Santa Fe, or Espanola either for the local or Federal governments or for private business. Many, perhaps most, of these suburban residents keep some animals and raise some fruit and vegetables.

However, agriculture, as a means of livelihood, is practiced mainly by the Indians, and only along the principal water courses--primarily the Rio Tesuque, Rio Nambe, Pojoaque Creek, and the Pojoaque River, where water in limited quantities is available locally for irrigation.

The trend in recent years for people to move from, or settle outside, the cities has been pronounced in the area studied. Many new homes have been built and many old places, some nearly in ruins, have been restored. No matter what the style, extent of development of the buildings and grounds, or means of livelihood of the owners, whether Indian or non-Indian, each new family unit means an additional demand for water. The natural supply of water available to the area is controlled by the environment, and that environment probably is not capable of yielding all of the water that eventually could be utilized in the area.

The topography, drainage, and climate are the principal elements of environment affecting the habitability and usability of the area.

The land surface rises from an altitude of about 5,500 feet, where the Pojoaque River enters the Rio Grande, to about 6,100 feet at Nambe Pueblo, a rise of 600 feet in a distance of about 9 miles.

Nambe Pueblo is situated near the head of a comparatively broad alluviated stream valley cut in a piedmont plain that slopes westward toward the Rio Grande. Toward the east the plain abuts the Sangre de Cristo Mountains.

The line of demarcation between plains and mountains is abrupt and marked by a distinct change in gradient. The land surface rises steeply, becomes rugged to precipitous, and within a distance of about 12 miles east from Nambe Pueblo, rises some 6,500 feet. The highest headwaters of the Pojoaque River drainage basin are on Santa Fe Baldy, at an altitude of 12,622 feet, one of the highest points in New Mexico.

The mountainous area is important because it is a principal source of water for the area; however, this report is concerned primarily with the plains that lie between the rugged mountains and the Rio Grande.

Erosion by the Pojoaque River and its tributaries has dissected the piedmont plain to the degree that it appears more like a low-hill country when viewed from the level of the stream valleys. A few remnants of the original surface remain and these are best preserved near the mountains. Only when one stands on a ridge crest and views the evenness and sameness-of-level of other surrounding ridges is it readily apparent that a relatively smooth and gently sloping plain once extended from the foot of the mountains to the Rio Grande.

The Pojoaque River drainage basin is bordered on the north by the Santa Cruz River drainage basin and a few small drainages tributary directly to the Rio Grande. Tributaries of the Pecos River lie across the crest of the Sangre de Cristo Mountains on the northeast. The Santa Fe River drainage basin lies to the south and southeast, and the Canada Ancha drainage lies to the southwest.

The climate of the Pojoaque drainage basin is similar to that of the Santa Fe area as described by Spiegel (in: Spiegel and Baldwin, 1963, p. 14-17) who discussed briefly the climate in relation to hydrology and explains the significance to agriculture of the climatic pattern.

The climate of Santa Fe has been summarized also by Von Eschen (1961, p. 57-58) and a copy of that summary is attached as Appendix A.

Particular note should be made, however, of the distribution of annual rainfall in time, the type of rainfall, and the wide differences in annual precipitation at the lower elevations compared to the higher elevations. The average annual precipitation at Espanola (altitude 5,595 feet) is about 9.5 inches; and it is about 9 inches at Nambe (altitude 6,050 feet). However, at Santa Fe (altitude 7,200 feet) it is about 13.7 inches. In Santa Fe Canyon, at an altitude of about 8,400 feet, the precipitation ranged from about 15.8 to 21.2 inches for the period of record, 1911-1915, (New Mexico State Engineer, 1956, p. 337). At Espanola, during the same period the range was from about 7.7 to 15.4 inches, and at Santa Fe it was from about 10.3 to 17.9 inches.

As to distribution in time, and the type, Von Eschen states that at Santa Fe, "70 percent of the annual precipitation falls during the May-October period, practically all of it brought by brief afternoon and evening thundershowers--." The significance of these three features of the precipitation pattern will be explained in the discussion on hydrology.

Rock units

For the purpose of this report the rocks of the region are divided into two principal categories: (1) the sedimentary rocks of relatively recent age that include alluvium in the stream valleys and units of the Santa Fe Group of Tertiary and Quaternary(?) age, and (2) the older crystalline rocks, mostly granite, gneiss, and schist of Precambrian age and older sedimentary rocks. The sedimentary rocks underlie the plains and valleys between the mountains and the Rio Grande, and the crystalline rocks underlie the mountains. The equivalents of these rocks in the Santa Fe area have been described in detail by Baldwin and Kottlowski (in: Spiegel and Baldwin, 1963, p. 21-67).

This report is not particularly concerned with the crystalline rocks of Precambrian age because they have only a slight, and indirect, effect on the problems involved. The rocks underlying the mountains are almost all densely crystalline, granitic to gneissic and schistose. They do not store water in any large quantities. They affect the hydrology of the plains area in that runoff is high and rapid during the spring snowmelt and the frequent summer thunderstorms. Otherwise they have almost no effect and they may be omitted from further consideration in this report.

Not all of the units of the sedimentary sequence described by Baldwin in the Santa Fe area are present in the Pojoaque drainage basin. In particular, the volcanic flows and tuffs are absent and the Ancha Formation (of late Pliocene or Pleistocene age), which in the Santa Fe area is thick, below the water table, and a principal aquifer, is restricted in the Pojoaque drainage basin to small isolated outcrops that cap ridges and hills. These outcrops are thin, disconnected, and not water bearing because of their position high above the regional water table. In essence, except for alluvium in the valleys, and a few relatively thin terrace deposits, the rocks immediately underlying the plains of the Pojoaque drainage basin belong to the Tesuque Formation (of middle(?) Miocene to early Pliocene age) as described by Baldwin (in: Spiegel and Baldwin, 1963, p. 39-45).

The Tesuque Formation, according to Baldwin, "consists of several thousand feet of pinkish-tan soft arkosic, silty sandstone and minor conglomerate and siltstone." The character of the formation is best observed in the exposures in the Los Barrancos in sec. 1, T. 19 N., R. 8 E. Good exposures can be seen in the bluffs along Tesuque Creek between Pojoaque and the community of Tesuque, also in the bluffs along Pojoaque Creek and the Rio Nambe between Pojoaque and Nambe Falls.

The Tesuque Formation is typified by the heterogeneity of its component beds. Strata of sandstone, siltstone, mudstone, and conglomerate, in various stages of cementation from hard to relatively soft, alternate and grade one into the other. Strata of clay are not common although one distinctive bed of dense, almost pure white halloysite (identification by Richard Wilson, oral communication), 2 to 6 feet thick, was observed in the bluffs along the south bank of the Rio Tesuque about a mile below Tesuque Pueblo.

The component sediments making up the Tesuque Formation seem for the most part to be arkosic and to be derived from the crystalline rocks of the Sangre de Cristo Mountains. The description of the formation given by Baldwin (in: Spiegel and Baldwin, 1963, p. 40-42) applies also to the formation in the Pojoaque drainage basin.

Rocks of the Bishops Lodge Member (middle(?) Miocene) of the Tesuque Formation and the olivine basalt flows described by Baldwin were not recognized in the lower reaches of the Pojoaque drainage basin and are present in the upper reaches mostly in the vicinity of Bishops Lodge.

An undifferentiated sequence of continental sedimentary rocks and interbedded volcanic rocks underlies the Tesuque Formation. Nowhere are these rocks exposed, and details of their character can be only guessed at. It is reasonable to assume that, in general, the sediments at depth do not differ greatly from the Tesuque as it is seen in outcrops in this area.

The question of the thickness of the sedimentary deposits under the plains is of considerable importance to the hydrologic problems of the area because the deposits constitute a natural reservoir for water. Baldwin said the Tesuque Formation was "several thousand" feet thick, but the sedimentary rocks of continental origin, particularly the Galisteo Formation (of Eocene and Oligocene (?) age) that lie below the Tesuque may be even thicker.

Winkler (in: Spiegel and Baldwin, 1963, p. 214) states that gravity tests indicate that a sedimentary section in the vicinity of Santa Fe "may be as much as 2 miles thick, though is probably less." An oil test well west of Belen, about 100 miles to the south in Valencia County, reportedly was drilled to a depth of 12,691 feet, nearly 10,000 feet of which was sedimentary fill of Quaternary and Tertiary age (Beaumont, 1961, p. 175).

These thick sedimentary deposits have accumulated in a structural trench known as the Rio Grande trough. The Rio Grande trough extends from southern Colorado through New Mexico to the Texas line and is bounded on both sides by a complex system of discontinuous faults.

The east side of the Rio Grande trough in this region is defined by the up-faulted Sangre de Cristo Mountains. The west side is less distinctly marked by faulting because the Jemez Mountains, a volcanic pile west of the report area, straddle what presumably is a master fault zone marking the west side of the trench. The Jemez volcanic pile is, perhaps, the next best evidence that a major fault zone does exist along the west side of the trough in this area.

Because the Rio Grande trough is a structural trench filled with sedimentary debris, it constitutes a reasonable well-defined "hydrologic basin" and a reservoir for large quantities of water.

Hydrology

All continental water, both surface water and ground water, can be traced back to atmospheric precipitation. Moisture in the form of rain or snow falls on the land surface--one step in what is commonly called "the hydrologic cycle" (fig. 2). At that time some of the water may enter a hydrologic system as surface runoff, to become streamflow, and some soaks into the ground and may, in part, become ground water.

A hydrologic system is considered to be any relatively large area in which the hydrologic characteristics are closely related and which can be isolated, or nearly so, from other areas for consideration of causes and effects pertaining to water. What occurs within one large hydrologic system may have little or no effect on the hydrology of adjacent systems.

Within a hydrologic system such as the Rio Grande there are subdivisions that are, in general, distinct hydrologic units or subsystems. These units generally constitute tributary drainage basins such as the Pojoaque River, or ground-water units in which ground water behaves more or less uniformly and independently of that in adjacent units. Ground-water and surface-water units in a hydrologic system are closely related but the boundaries of these units do not necessarily coincide.

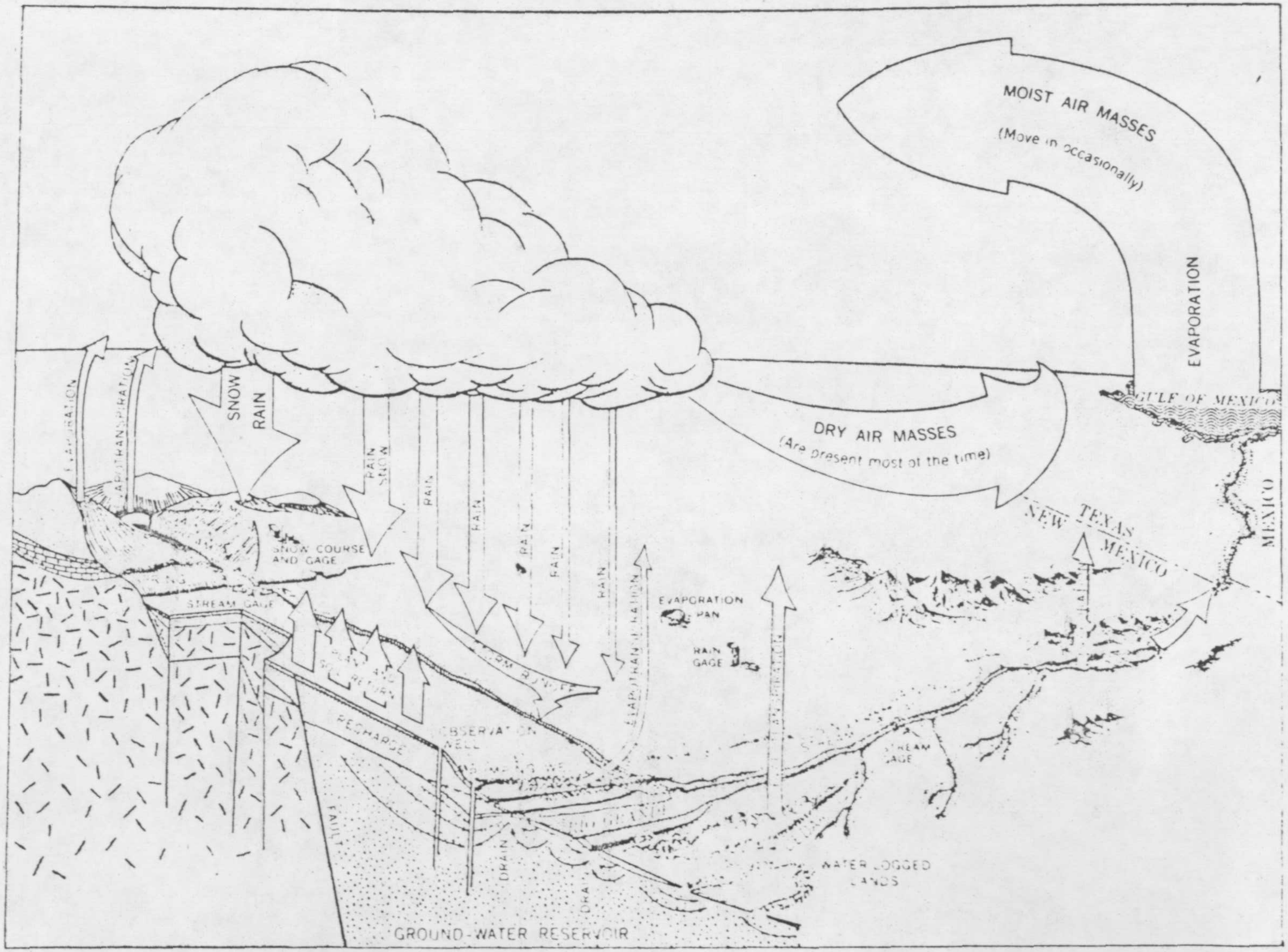

FIGURE 2. --Hydrologic cycle in the upper Rio Grande drainage basin, New Mexico. (Courtesy of New Mexico State Engineer Office.)

Hydrologic units, like systems, can be isolated arbitrarily from other units for reasons such as management and development. However, what occurs in one hydrologic unit of a system may affect other units of the system, and consequently the system as a whole. The hydrologic characteristics of a single hydrologic unit may be simple or complex. An investigation in a unit area may deal with a single element or with all elements of the hydrology and may require only a few days or several years of study.

Water in a hydrologic system or unit occurs mainly as surface water in streams or as ground water beneath the water table. Water occurs also in systems as soil moisture, and in various less obvious ways none of which are of much significance in the problems this report is intended to treat.

This report is concerned primarily with the occurrence of ground and surface water in the Pojoaque River hydrologic unit of the Rio Grande hydrologic system.

The Pojoaque River drainage basin

The principal components of the Pojoaque River drainage basin are: the Pojoaque River; Pojoaque Creek and its tributaries; the Rio Tesuque and its tributaries; the Rio Nambe, and the Rio En Medio which join to form Pojoaque Creek. Pojoaque Creek is indicated on maps as being that section of the Pojoaque River that lies between the mouth of the Rio Tesuque and the confluence of the Rio Nambe and the Rio En Medio.

The Pojoaque River and its tributaries drain about 194 square miles. The Rio Tesuque drainage system embraces about 78 square miles, the Rio Nambe, above the confluence with the Rio En Medio, about 39 square miles. The Rio En Medio and the Rio Chupadero (tributary to Pojoaque Creek) drain about 25 square miles. The remainder of the area of the basin, some 52 square miles, includes Pojoaque Creek and Pojoaque River and their tributaries below the Rio Tesuque--these tributaries are all relatively short arroyos, cut in the piedmont plain, and without extensive headwaters at high altitudes where both precipitation and runoff is relatively great.

The flow pattern of the Pojoaque River and all its tributaries reflect the seasonal character of the climate. The runoff from the upper reaches of the Rio Nambe and Rio Tesuque begins to increase in March and is greatest during May as a result of the melting of the snowpack in the Sangre de Cristo Mountains (table 1). Runoff declines after May but the decline is tempered by the advent of the "summer" rainy season, beginning usually in May and climaxing in August (see Appendix A, Precipitation totals).

Table 1.--Streamflow in the Rio Nambe and the Rio Tesuque

Long Term Average Monthly Stream Discharge in Acre-feet

	Rio Nambe 1/	Rio Nambe at Nambe Falls	Rio Nambe 2/	Tesuque Creek above diversions 3/
	1933-51, 1964-66	1964-66	1937-51	1937-51
Jan.	* 233	260	* 234	60
Feb.	* 196	213	* 197	58
Mar.	* 314	321	* 327	129
Apr.	* 888	738	*1,000	374
May	1,970	1,530	2,240	666
June	1,540	1,320	1,610	415
July	718	725	761	151
Aug.	626	800	563	106
Sept.	* 534	550	* 478	88
Oct.	466	421	457	117
Nov.	* 342	399	* 330	84
Dec.	* 259	309	* 246	63

1/ Composite of Rio Nambe (Station 1 on fig. 1) near Nambe plus Nambe Canal (Station 2 on fig. 1) 1933-51 and Rio Nambe at Nambe Falls (Station 3 on fig. 1) 1964-66.

2/ Composite of Rio Nambe near Nambe, plus Nambe Canal.

3/ Station 4 on fig. 1.

* Nambe Canal record partly estimated.

Runoff in the Pojoaque River, and in the lower reaches of Pojoaque Creek and the Rio Tesuque commonly is greater during July and August than in May. There are years when these lower reaches experience little or no flow during the spring because all, or nearly all, of the spring runoff is diverted for irrigation before it gets to the lower parts of the drainage basin. However, intense thunderstorms occur over the lower reaches during the summer months of almost every year and heavy runoff commonly results. The local floods of August 9 to 11, 1967, were the result of such summer runoff which, in that instance, was compounded by the simultaneous occurrence of heavy rains in the headwater areas as well as in the lower reaches during a period of 2 to 3 days.

The Pojoaque River in its natural state, undisturbed by the influence of man, probably was a perennial stream through all of its course. However, it now is perennial only in certain reaches and in those reaches the flow commonly fluctuates from a few gallons a minute to several hundred gallons per minute.

The flow of the Pojoaque River no doubt always has been characterized by seasonal extremes but the present-day intermittent nature of the stream is due to the total diversion of water for irrigation at various points along the course. The change in regimen of the flow as a result of diversions has made possible observations on gains and losses to the stream that otherwise might not have been detectable without careful measurements of flow. For example, on May 17, 1967, nearly all of the flow of the Rio Nambe, approximately 9 cfs (cubic feet per second), or about 4,000 gpm (gallons per minute) was being diverted through ditch headings above the approximate center of Sec. 14, T. 19 N., R. 9 E. The river channel immediately below the diversion had a flow of no more than 10 gpm. Below that point the channel was observed to gain water until, at point about eight-tenths of a mile downstream, near Nambe Pueblo, the flow had increased to about 4 cfs (1,800 gpm).

Part of the increase undoubtedly was due to seepage and return flow of irrigation water from irrigated areas north of the stream. However, seepage from the south bank of the stream, south of which there is no irrigation, was observed at several places and water was rising in the channel. This pattern of diversion, gaining flow, and again, diversion, was observed to be repeated from Nambe Pueblo to San Ildefonso Pueblo. The channel at intervals would be completely dry below a diversion, yet commonly a few hundred feet downstream a trickle of water would appear, increase, and become sufficient to permit another diversion.

The reach from Nambe Falls to San Ildefonso Pueblo was examined again on July 25, 1967. The pattern of flow was changed slightly due to recent rains, flood runoff, and different diversions. The flow above Nambe Pueblo was distinctly cloudy due to suspended sediments carried into the stream by surface runoff. At about Nambe Pueblo all the flow had been diverted to irrigation. At a point about one-half mile below Nambe Pueblo the creek again was flowing, at an estimated 1,000 gpm (2 cfs), and the water was clear. All of the increment must be presumed to be from ground water as there was no surface inflow in the reach.

Similar observations were made on the Rio Tesuque from its junction with the Pojoaque River to the point upstream in Sec. 5, T. 17 N., R. 10 E., where the Tesuque emerges from the mountains. All the flow, an estimated 600 gpm, was found on May 19 and July 31 to be diverted to an irrigation ditch at that point. No flow was observed in the channel for a distance of 2.1 miles between the diversion and a point about 500 feet upstream from the highway bridge just south of Tesuque. There, water was rising in the channel and the flow increased until at the bridge, it was estimated to be about 250 gpm on both May 19 and July 31.

As on the Nambe-Pojoaque Creek reach, the flow in the Tesuque was diverted at intervals, leaving the channel dry, and water would appear in the channel below the diversion, increase, and again be diverted.

Two reaches were found on the Rio Tesuque where appreciable flow appeared within short distances. The uppermost reach is at a point three-quarters of a mile downstream from Tesuque Pueblo. There, as a result of the narrowing of the valley and the dense character of the bordering rock walls, flow begins to appear and to increase rapidly to an estimated 400 gpm at a point three-quarters of a mile downstream, just west of Camel Rock. Approximately 200 gpm were being diverted between the point of beginning flow and a point about one-quarter of a mile downstream, making a total increase in flow of about 600 gpm in this reach. The diverted flow originated not in the channel but in a boggy spring area on the east side of the channel and about 5 feet above the level of the channel floor. The channel is dry again about seven-tenths of a mile northwest of Camel Rock. The lower reach where appreciable flow appears in the channel is in the southwest corner of Sec. 20, T. 19 N., R. 9 E., about 2½ miles downstream (northwest) from Camel Rock, and about half a mile south of Cuyamungue. There a flow of about 600 gpm develops from a boggy area on the west side of the river.

There can be no doubt that the Rio Nambe, Rio Tesuque, and Pojoaque Creek-Pojoaque River elements of the Pojoaque River drainage system gain water from ground-water discharge. Some of that water is return seepage from irrigation diversions, but much, and perhaps most of it, is from ground water being discharged from the Tesuque Formation.

Ground water

Ground water in a hydrologic system or unit may be closely related at all times to the surface water of the system, as noted in the foregoing discussion, or it may be almost completely dissociated most of the time. A drop of water that infiltrates the land surface and moves down to the water table may not return to the surface for hundreds, or even millions of years. Its movement may be direct or complex and its course straight or circuitious; it may lie in storage at some point for eons, but more likely, it will not know a moments rest and will be in slow, essentially continuous motion. Most ground water is in motion from the time it enters the ground as "recharge" to the time when it returns to the surface as "discharge" to become again surface or atmospheric water. The cycle of recharge, movement, and discharge of ground water concerns man and whenever man develops a supply of ground water or disturbs the natural flow of streams, he affects one or more of the elements of recharge, movement, or discharge of ground water.

Ground water found within the Pojoaque drainage basin enters the hydrologic system (1) by infiltration of precipitation on the surface, (2) by infiltration of streamflow into the bed, and (3) by movement through rock formations from areas outside the drainage basin.

Infiltration of precipitation into the beds of streams and arroyos generally is considered to be the principal place of ground-water recharge in arid and semi-arid regions. Precipitation on inter-stream surfaces contributes to recharge by downward percolation only where that surface is underlain by highly porous material, where vegetation is scant, and where the rainfall is intense. Movement of ground water into the Pojoaque drainage basin area from points outside the basin occurs, but probably in insignificant amounts, from the crystalline bedrock and in small amounts from rocks of the basin fill.

Most of the water in Tesuque Formation occurs under water-table conditions but some may be artesian, particularly that which occurs in the lower part of the Tesuque at appreciable depths.

The source, or point of origin, of unconfined ground water and its direction of movement can be approximated by determining the shape of the potentiometric surface which, in the case of unconfined water, commonly is called the water table. The water table is, in effect, the upper surface of the zone of saturation. The shape of that surface commonly is shown on maps by means of water-table contours (fig. 1). The altitudes used to draw the contours are obtained by measuring the depth to water in wells and subtracting that depth from the altitude of the land surface at the well; they are obtained also by utilizing observations on reaches of streams where flow is gaining due to discharge of ground water.

Ground-water flow lines showing the direction of movement point also to the points of recharge and discharge. Flow lines may be obtained by drawing lines perpendicular to the water-table contours (fig. 1). The direction of movement is down the hydraulic gradient, from higher to lower altitudes (fig. 3).

It is not just the water at or immediately below the water table that moves; all the water moves, from the water table down to the base of the sedimentary fill. The water moves at different rates due to differences in the permeability of the fill; the rate in confined beds may be appreciably different than that in the unconfined deposits. The water also may move in a somewhat different direction at depth, due to changes in the character of the fill. Water may turn aside to move past a mass of impermeable clay or cemented sandstone, but the movement is always down the hydraulic gradient, and water deflected has a tendency to return to the previous line of flow once past the deflecting mass.

The flow lines and water-table contours (fig. 1) show only the direction of movement and gradient of the unconfined water in the upper part of the Tesuque Formation. Some confined water may occur in the Tesuque Formation, and Spiegel (in: Spiegel and Baldwin, 1963, p. 126) suggests that artesian water may occur in the Galisteo Formation, beneath the Tesuque. The source of water in the artesian wells in Sec. 36, T. 19 N., R. 7 E., at the lower end of Canada Ancha, is not known but it probably is a confined bed in the Tesuque Formation.

The recharge area for water confined in the Tesuque and underlying formations is in general the same as for unconfined water, and the direction of movement may be assumed to be essentially the same also -- there is just no other way for it to go. The ultimate destination, or point of discharge for both remains the Rio Grande. The confined water may not be discharged to the river in the same locality as the shallow water but, instead, may move down the valley through the deeper deposits for some distance before discharging to the river.

A projection of flow lines on the water-table contours of the Pojoaque drainage area shows that ground water in the uppermost part of the fill moves in a relatively direct route from its point of recharge toward the Rio Grande. Whether or not the ground-water discharges to the river, or turns and moves downvalley through the sediments at some depth below the riverbed depends on its position relative to the water table as it approaches the river. If it is near, or at the water table, it probably will discharge to the river.

The flow lines and water-table contours show that the direction of movement of ground water is toward the Rio Grande, not only under the Pojoaque River drainage basin but also under the Santa Fe River and Santa Cruz River drainage basins to the south and north, and that no distinct ground-water divides are present, as are distinct divides between the surface drainage basins (fig. 1). To a large degree, the movement of ground water in Pojoaque River drainage basin is independent of the flow of the surface drainage.

A particle of water infiltrating to the water table somewhere within the area of the Pojoaque River drainage basin may, or may not, remain within the basin area in its course down the hydraulic gradient. It is more likely, as shown on fig. 1, that the particle will move outside the basin at least part of the time rather than stay within it all of the time.

A ground-water divide separates the headwater areas of the streams on the west slope of the Sangre de Cristo Mountains from the Pecos River drainage to the east but that divide is of no practical concern to the purpose of this report. It lies within the crystalline bedrock and no reasonable activity of man could affect the position of the divide, or the movement of ground water in the immediate vicinity of the divide, in a manner to affect appreciably the movement of ground water underlying the piedmont alluvial plain.

The development of ground water supplies within that part of the Pojoaque River drainage basin that is underlain by sedimentary fill could appreciably affect the hydrology of the drainage basin and, to some degree, that of the adjoining drainage basins. Ground water is being used in the basin, and locally the effect is noticeable although it may not have been realized. Two infiltration galleries under the bed of the Rio Tesuque collect ground water for diversion to irrigation. Diversion by these galleries directly affects the flow of water in the streams below the galleries. At times the channels below are dry whereas they would not be dry if ground water were not being removed from sands and gravels under the river bed.

This example serves to illustrate what also happens when ground water is pumped. Water is removed through the well and the consequences are the diversion of either ground waters or surface waters, or both, from their normal course and toward the well. This diversion results because pumping water lowers the water table and creates a depression in the water table in the vicinity of the well. This changes the water table gradient near the well and reshapes the water table so that flow lines are bent toward the well. Water moves to smooth out the depression created by the withdrawal and the result is a lowering of the water table. As a consequence of the lowered water table, the hydraulic gradient between the pumped well and the normal point of discharge is flattened and the rate of flow eventually is decreased. The gradient above the well--between the well and the recharge area--is steepened and the rate of flow is increased.

Only if a supply of water is available adequate to keep the intake area fully charged will the water table remain more-or-less stable under long term pumping conditions. Such conditions are rarely attained in New Mexico.

If a shallow well pumps water from permeable alluvial fill alongside a flowing stream, ground water will move from under the streambed toward the well, and also from the formation on the opposite side or away from the stream. The most water will come from the beds that are most permeable, generally those under the stream. Water that comes from the streambed gravels usually is replaced with the first flow to occur in the channel, and by that amount, the flow downstream will be diminished. Thus it may be concluded that the effects of pumping from the alluvium will decrease the flow of the river before the effects will be noticed, if ever, at any appreciable distance to either side of the river.

A pumping well located at an appreciable distance from a stream, and tapping the deposits of the Tesuque Formation will remove water from storage and that water is not soon replaced. The water table will lower and the hydraulic gradient will flatten downgradient. The ultimate effect will be a decrease in the flow of the Rio Grande. That decrease may not be noticeable or determinable, and it may not occur for many years. Further, the pumping may have little effect upon flow in the streams in the Pojoaque River drainage basin. If a particular reach of a stream has no perennial flow, then the water table lies below the streambed and while pumping eventually may lower it further, the lowering generally will not affect any flow that might occur at that point as a result of flood runoff.

A well located within the Pojoaque River drainage basin, but near the margin of that basin, may cause shifts in the flow lines that will result in ground water being diverted to the Pojoaque River drainage basin from an adjacent basin. Conversely, a well located outside the Pojoaque River basin could divert water from the basin.

The effects of pumping on ground water storage and movement are multiplied with increased development; where the effect of one or two wells might go unnoticed, the effect of pumping hundreds of wells may soon become apparent.

The rate at which pumping effects move outward from a pumping well depend upon several factors, most critical of which are the permeability of the water-bearing beds, the volume of the water pumped, and the duration of the pumping. Another important factor is the availability of water for recharge. Water for recharge may be available if a stream is nearby, but in New Mexico this generally is not the case. Recharge generally is sporadic and occurs only in small increments so that, in effect, almost all ground water is pumped from storage and the effects are noticeable as declines in the water levels.

The amount of decline of the water level at a given point in any area is determined mathematically by using the average storage coefficient, transmissibility coefficient, volume of pumping (average rate), and the duration of pumping.

These coefficients for the Tesuque Formation were determined by Spiegel (in: Spiegel and Baldwin, 1963, p. 180-185) for the Santa Fe area. The storage coefficient was found to be about 0.018 gpd per ft (gallons per day per foot) and the transmissibility coefficient about 38,000 to 700 gpd per ft. Spiegel indicated that the transmissibility data were conflicting as values of 38,000, 20,000, and 3,200 gpd per ft were obtained for the same well. It is probable that the average transmissibility coefficient for the Tesuque Formation in this area is nearer to the lowest figure.

Yields from the Santa Fe city Alto Street well tapping the Tesuque Formation ranged from 375 gpm to 600 gpm (Spiegel, 1963, p. 183-184).

For the purpose of illustrating the effects of pumping from the Tesuque Formation, let us postulate a set of conditions: assume that no water is immediately available for recharge (that pumping is from storage), that the well is pumped continuously at a rate of 500 gpm, that the transmissibility coefficient is about 15,000 gpd per ft and that the storage coefficient of the Tesuque Formation is about 0.02 gpd per ft. These figures are based on the data for the Santa Fe area where the geologic and hydrologic conditions are about the same as in the Pojoaque area.

Thus, with these data as a guide, and using methods outlined by Wenzel (1942), it can be shown that the water table at a distance of 1 mile would be lowered about 2 feet at the end of 1 year. The decline would be less than a half a foot at the distance of 2 miles; and less than one one-hundredth of a foot at the distance of 5 miles.

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APPENDIX

U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU

In Cooperation with the UNM Bureau of Business Research

LATITUDE: 35° 40' N
LONGITUDE: 105° 55' W
ELEV. (GROUND) 7,200 Ft

CLIMATOLOGICAL SUMMARY

STATION: SANTA FE
NEW MEXICO

MEANS AND EXTREMES FOR PERIOD OF RECORD 1931 - 1960

	Temperature (°F)							**	Precipitation Totals (Inches)								Mean number of days					
	Means			Extremes								Snow, Sleet						Temperatures				
																		Max		Min		
Month	Daily maximum	Daily minimum	Monthly	Record highest	Year	Record lowest	Year	Mean degree days	Mean	Greatest daily	Year	Mean	Maximum monthly	Year	Greatest daily	Year	Precip. .10 inch or more	90° and above	32° and below	32° and below	0° and below	Month
(a)	30	30	30	30	-	30	-	30	30	30		30	30		30		30	30	30	30	30	(a)
Jan.	41.0	19.3	29.9	60	1950	-11	1949	1090	0.68	1.02	1939	7.4	18.1	1940	5.0	1930	2	0	4	31	1	Jan
Feb.	44.9	22.5	33.7	65	1934+	-15	1951	880	0.69	0.70	1948	6.6	17.1	1940	9.6	1948	2	0	3	26	*	Feb
Mar	51.6	26.8	39.2	74	1946	-2	1948+	800	0.78	1.21	1940	5.0	18.2	1946	12.5	1940	2	0	1	21	*	Mar.
Apr	61.7	34.5	48.0	85	1943	3	1945	510	0.83	0.83	1942	2.4	10.9	1943	6.3	1933	2	0	0	12	0	Apr
May	70.7	42.9	56.6	89	1951+	26	1953	270	1.38	2.47	1948	0.5	4.9	1935	4.0	1936	3	0	0	2	0	May
June	81.4	52.1	66.4	98	1954	33	1947+	50	1.17	1.37	1933	T	0	-	0		3	2	0	0	0	June
July	84.3	56.7	70.4	98	1947	42	1950	0	2.14	2.82	1953	0	0	-	0		6	4	0	0	0	July
Aug.	82.2	55.0	68.6	95	1954	41	1944	20	2.23	1.67	1932	0	0	--	0		6	1	0	0	0	Aug
Sept	76.5	49.1	62.9	93	1948	28	1936	90	1.41	1.57	1940	0.2	4.0	1936	4.0	1936	4	*	0	*	0	Sept
Oct.	65.2	38.7	52.0	84	1950	19	1949+	400	1.09	1.44	1938	0.2	3.0	1936+	3.0	1946+	3	0	0	6	0	Oct
Nov.	51.5	26.5	39.0	70	1934	-1	1952	780	0.60	1.17	1935	3.1	11.5	1938	11.0	1938	2	0	1	23	*	Nov.
Dec	43.3	21.2	32.0	64	1946	-6	1945	1020	0.70	0.95	1960	6.3	14.0	1947	8.2	1945	2	0	1	29	*	Dec
Year	62.9	37.1	50.0	98	June 1954+	-15	Feb 1951	5910	13.70	2.82	July 1953	31.7	18.2	Mar 1946	12.5	Mar. 1940	37	7	13	152	1	Year

* Less than one half.
** Base 65° F (estimated).
(a) Average length of record, years.

T Trace, an amount too small to measure.
+ Also on earlier dates, months, or years.
ϕ Partial year's record considered.

CLIMATE OF SANTA FE, NEW MEXICO

Santa Fe, the State Capital of New Mexico and county seat of Santa Fe County, is located in the Rio Grande valley in the north-central section of the State. The city is situated on the rolling foothills of the Sangre de Cristo mountains, which rise to the east to peaks well above 10,000 feet. Westward the rolling terrain slopes downward to the Rio Grande some 20 miles away. The high mountain range to the east protects the city from much of the cold arctic air that moves down over the eastern plains in winter. The rolling foothills, covered with juniper and pinon, provide sites of distinction for many of the fine homes of the city. In addition to varied activities connected with the state and county governments, Santa Fe is also noted as an art and cultural center. Its fine climate attracts many retired people, its rich historical background and points of interest attract many tourists.

Santa Fe has one of the longest weather records in the State. Rainfall records were begun in 1850, and detailed weather data made by Weather Bureau personnel cover a half century. Only the most recent 30 years of records are used in this summary with additional comments based on the more detailed weather records.

The city has a semiarid continental climate. At this elevation summers are cool and pleasant. In midsummer the high temperature is normally in the low 80s, with an average of only seven days a year when the maximum temperature reaches 90°. Not once in 87 years of temperature record has the mercury officially reached the 100° mark. Summer nights are cool, with the temperature usually falling to the mid-50s before morning. Summer is the rainy season. 70 per cent of the annual precipitation falls during the May-October period, practically all of it brought by brief afternoon and evening thundershowers (this area has one of the highest incidence of thunderstorms in the country). During July and August, the rainiest months, about five days a month can be expected to have rainfall exceeding one-tenth inch in 24 hours. Prolonged rainy or cloudy weather is practically unknown.

Winters are crisp, clear, and sunny. Because of the predominantly clear winter weather there is considerable daytime warming, with shade temperatures normally reaching the low 40s at midday. An average winter includes no more than 13 days when the temperature fails to get above freezing. Winter nights are usually cold, for the temperature falls below the freezing mark most nights from early November to mid-April, and a below-zero reading can be expected about every other year. Cold weather is usually brief in extent and accompanied by brilliant sunshine and low humidities. Each month gets about two thirds of an inch of moisture, with most of this precipitation falling as snow. However, an average of only two days a month gets as much as an inch of snow, only rarely does snowfall exceed six inches. This snow usually disappears in a few days, although nearby mountains remain snow covered throughout the winter and provide excellent winter sports facilities.

The sun shines in Santa Fe 75 per cent of the possible hours, with this percentage fairly constant throughout the year. February and July, with 69 per cent of possible sunshine, show the least sunny weather. June and October, with 80 per cent of possible sunshine, are the sunniest months. Because of the cooler temperatures the relative humidity is somewhat higher than at lower elevations in the State, averaging about 50 per cent for the year. The yearly averages range from near 60 per cent in the early morning to around 40 per cent during the heat of the day. December is the most humid month. Humidities at that time range from 50 per cent to 70 per cent. In June, the driest month, the range is from 27 per cent to 47 per cent. Hot, humid weather is unknown. Wind velocities are light, averaging only seven miles per hour for the year. Spring months are somewhat windier, having an hourly average of around eight miles per hour. On approximately 60 days a year velocities exceed 25 miles an hour for a short time. The growing season is relatively short, averaging 164 days: beginning with May 4, the average date of the last freezing temperature in spring, and ending with October 15, the average date of the first fall freeze.

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State Climatologist
Weather Bureau Airport Station
Albuquerque, New Mexico

Average Temperature (°F)

Year	Jan.	Feb.	Mar	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann'l
1931	29.3	35.6	36.2	47.8	55.0	67.4	70.2	67.0	63.4	52.9	37.1	27.7	49.2
1932	22.9	37.7	36.7	48.1	55.6	63.4	69.6	68.2	60.7	47.4	40.0	25.2	48.0
1933	27.2	27.2	41.8	42.8	53.5	66.1	70.6	67.8	65.5	53.7	41.7	37.4	49.6
1934	32.6	35.6	44.4	51.1	61.1	66.8	72.0	70.2	60.4	54.3	39.8	32.5	52.0
1935	34.7	34.5	40.8	46.8	50.9	66.2	70.6	67.6	61.4	51.5	38.7	31.2	49.6
1936	28.2	33.4	41.2	49.2	59.0	63.6	70.2	69.8	59.6	50.0	39.6	32.5	50.1
1937	23.7	42.6	37.7	47.9	58.8	65.1	69.8	71.2	63.9	52.6	42.2	34.1	49.9
1938	31.7	35.6	40.8	48.4	55.6	66.4	68.9	70.2	61.7	53.2	34.2	34.4	50.1
1939	28.8	27.6	40.8	49.2	58.1	67.5	69.4	67.8	63.5	50.2	40.6	36.8	49.7
1940	29.7	32.2	42.2	47.8	58.6	65.7	70.6	67.2	62.5	53.6	37.8	35.2	50.2
1941	31.4	38.2	39.0	43.8	57.[illegible]	60.1	67.0	66.2	62.2	50.4	40.6	33.2	49.[illegible]
1942	32.1	31.2	36.0	48.0	54.0	64.1	69.2	67.8	60.0	50.0	44.6	37.0	49.5
1943	34.0	37.6	40.8	54.0	57.8	64.9	71.3	71.0	62.2	50.6	39.8	24.1	50.7
1944	22.5	33.3	37.4	45.0	55.0	65.2	68.7	68.6	61.2	52.3	37.5	31.0	48.1
1945	29.8	36.4	37.8	43.7	57.4	63.1	69.4	69.9	62.2	51.3	39.8	27.2	49.0
1946	29.0	34.0	41.1	54.8	55.8	70.0	71.2	68.0	64.0	49.6	36.0	35.3	50.7
1947	26.7	36.0	38.9	46.0	58.4	63.6	72.4	69.6	65.2	54.7	34.0	29.8	49.5
1948	28.[illegible]	42.4	34.5	51.2	58.0	64.7	71.0	68.4	64.1	50.1	34.5	33.0	49.2
1949	25.2	30.4	40.4	43.4	57.8	64.8	69.6	68.2	64.2	49.1	43.4	29.0	49.1
1950	3[illegible].7	35.3	39.9	50.0	55.3	70.9	67.5	66.7	59.1	58.5	42.8	37.0	51.1
1951	[illegible]	34.5	39.2	47.3	58.9	65.3	74.8	68.3	64.2	52.1	36.3	29.3	50.2
1952	33.6	31.7	34.3	47.3	56.4	69.6	69.8	70.5	63.8	54.9	34.5	23.3	49.6
1953	45.3	36.9	42.1	47.2	52.6	68.4	71.7	68.9	65.1	52.1	41.1	27.4	50.2
1954	33.[illegible]	40.0	37.3	53.9	59.4	68.3	73.1	69.2	66.3	55.5	44.5	34.5	52.3
1955	28.5	30.2	41.0	47.7	55.5	62.5	69.3	67.5	64.1	53.5	39.2	33.5	49.5
1956	34.8	28.4	41.4	46.0	60.5	70.8	69.9	66.7	66.4	54.2	36.0	31.1	50.5
1957	33.2	40.4	38.7	45.1	52.0	65.3	71.4	66.8	61.7	50.0	34.1	34.5	49.4
1958	29.6	37.2	34.9	45.4	60.0	69.5	71.6	69.9	62.4	51.0	40.6	37.7	50.8
1959	31.5	33.4	37.7	48.1	56.6	68.0	70.6	68.2	62.6	50.4	38.1	34.3	49.9
1960	26.1	27.2	41.3	49.3	55.4	67.4	69.4	69.2	63.7	49.4	40.8	28.3	49.0

Total Precipitation (Inches)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann'l
1931	.25	.73	1.18	1.98	.46	.85	1.90	2.10	4.55	1.10	1.16	.50	15.90
1932	.93	.74	.41	1.28	1.27	1.82	2.17	3.36	1.97	.96	T	.55	15.36
1933	.73	.21	.29	.80	.59	2.32	2.00	1.90	1.24	1.15	1.62	.47	13.11
1934	.63	.79	T	.46	2.67	.54	1.48	2.35	1.14	.23	1.47	.80	13.26
1935	1.11	.56	.06	1.02	2.72	.07	1.89	2.63	.99	.58	1.57	.36	12.89
1936	.99	.98	.63	.20	1.75	.42	3.29	1.36	3.33	.93	T	.64	14.42
1937	.53	.84	.69	.49	3.97	3.51	.71	1.11	2.71	.65	.12	.31	15.63
1938	.03	1.02	.81	.50	.80	2.70	1.29	1.41	1.48	1.60	1.09	.45	15.58
1939	1.93	1.08	.54	1.19	.51	.01	2.19	.94	2.53	1.2[illegible]	.74	.57	13.45
1940	.77	1.97	1.52	.42	1.54	1.17	.72	1.66	2.55	.50	.45	2.67	16.4[illegible]
1941	1.23	.84	1.72	1.52	2.2[illegible]	1.76	1.42	1.16	2.88	2.75	.53	.29	17.3[illegible]
1942	.02	.14	.39	4.29	.18	.42	.61	2.23	1.67	1.30	[illegible]	1.29	12.54
1943	.66	.38	.82	.20	1.53	.55	.65	2.18	.61	.27	.46	[illegible]	[illegible]
1944	.16	.23	.18	.81	.51	1.78	3.52	2.35	1.25	2.33	1.14	.66	15.22
1945	.34	.52	1.10	1.18	.15	.49	2.43	2.76	.96	.45		.81	[illegible]
1946	.44	.63	1.71	.28	.32	.06	3.48	3.72	.64	.52	[illegible]	[illegible]	[illegible]
1947	.39	.34	.44	.10	2.47	.38	.53	3.03	.42	.70	.76	1.4[illegible]	[illegible]
1948	.09	1.86	.87	.50	3.48	2.40	.45	1.70	1.12	2.3[illegible]	[illegible]	.27	[illegible]
1949	1.71	.32	.45	.81	1.37	4.33	5.21	1.79	1.21	.34	T	[illegible]	[illegible]
1950	1.04	.32	.05	.29	.63	.92	4.22	1.47	1.22	[illegible]	T	T	[illegible]
1951	.23	[illegible]	.31	.43	1.59	.30	[illegible]	3.94	.05	.37	[illegible]	.54	[illegible]
1952	.55	.49	.92	1.07	1.12	.35	2.57	2.26	.79	.07	.30	.51	[illegible]
1953	.32	.44	.80	.94	.84	.39	3.12	.94	1.08	.51	1.34	.74	[illegible]
1954	.35	.18	1.43	T	1.33	1.14	3.38	3.42	1.09	.68	.3[illegible]	[illegible]	[illegible]
1955	.81	.27	.25	.89	1.29	.23	1.87	2.57	1.35	.24	[illegible]	[illegible]	[illegible]
1956	.83	.26	T	[illegible]	1.22	.53	.77	1.39	T	.24	.02	.29	[illegible]
1957	1.00	.92	1.61	1.22	1.59	.30	2.34	3.61	.20	1.2[illegible]	1.33	.26	17.5[illegible]
1958	.73	1.02	1.74	1.43	.18	.67	.57	3.71	2.38	1.26	.60	.12	14.67
1959	.32	.32	.91	1.00	1.46	1.20	1.03	2.79	.08	2.27	.18	1.42	12.92
1960	1.30	1.39	1.28	.22	.13	2.52	3.45	1.36	.66	2.99	.38	1.34	17.62

STATION HISTORY

Precipitation records from 1850 to 1871 were made by medical officers of the Army, probably at a nearby fort. From 1871 to 1891 records were maintained by the Army Signal Corps at various sites in the city. A first-order Weather Bureau station was established in 1891 and continued in operation until May 1941 with a variety of roof and ground exposures. A cooperative climatological station continued temperature and precipitation records at various sites in the city.

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

OFFICIAL BUSINESS

POSTAGE AND FEES PAID
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