UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
Albuquerque, New Mexico

Estimated ground-water flow, volume of water in storage, and potential yield of wells in the Pojoaque River drainage basin, Santa Fe County, New Mexico

By

F. C. Koopman

Open-file report

Prepared by the U.S. Geological Survey in cooperation with the Bureau of Indian Affairs

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Abstract

The hydrology of a major part of the Pojoaque River drainage basin, a tributary of the Rio Grande in north-central New Mexico, was studied by the U.S. Geological Survey at the request of the Bureau of Indian Affairs. The flow of ground water in the alluvium and Tesuque Formation was estimated after constructing a resistance model, drilling exploratory holes, and conducting tests, to be about 2.7 cubic feet per second toward the Rio Grande for each section 1 mile wide. The volume of ground water in storage, estimated from geologic information and assumed values of porosity, is about 5.5×10^7 acre-feet for the Tesuque Formation, and about 1.33×10^4 acre-feet for the alluvium. Shallow wells constructed in the alluvium yield 10 gallons per minute per foot of drawdown. Wells in the alluvium have a specific capacity about 200 times that of wells in the Tesuque Formation. Wells penetrating 1,000 feet of aquifer of the Tesuque Formation may yield several hundred gallons per minute with long-term depletion effects on both the overlying alluvium and surface-water sources.

Introduction

In September 1969 the U.S. Bureau of Indian Affairs requested the U.S. Geological Survey to investigate the hydrology of a major part of the Pojoaque River drainage basin. This report fulfills this request and includes a discussion of the estimated ground-water flow, volume of ground water in storage, potential yield of wells in the basin, and an attempt to define the relation between the ground water in the Pojoaque River drainage basin and the ground water in the main valley of the Rio Grande. This report supplements a reconnaissance report (Trauger, 1967) that was prepared to provide a general description of the geology and hydrology of the Pojoaque River system.

Data in the report are needed by the Bureau of Indian Affairs in connection with litigation--State of New Mexico, ex rel. S. E. Reynolds, State Engineer, Civil No. 6639, U.S.D.C., N.M.,--

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United States of America, et al., v. R. Lee Aamodt, et al.,

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involving the use of water in the Pojoaque River drainage basin, Santa Fe County, New Mexico.

The study area includes the Indian Pueblos of San Ildefonso, Pojoaque, Nambe, and Tesuque and covers about 122 square miles along the westward slope of the Sangre de Cristo Mountains (fig. 1).

Geology

Alluvium of Holocene age and the Tesuque Formation of middle(?) Miocene to early Pliocene age are the principal aquifers in the area; the underlying older rocks play a lesser role in the movement of ground water. The crystalline rocks in the eastern part of the area are considered impermeable. The rocks within the study area are described by Trauger (1967, p. 8-11).

The saturated thickness of the alluvium was determined from water-level measurements in wells and test holes and by examining cuttings from drill holes that were drilled by a contractor for the Bureau of Indian Affairs in January 1970. A seismic survey was conducted in several parts of the area prior to test drilling in an attempt to determine the thickness of the alluvium. Data from the seismic survey were inconclusive, as it was difficult to interpret the small differences between the alluvial material and the material composing the Tesuque Formation. The saturated thickness of the alluvium ranged from about 20 feet at the Pojoaque River near San Ildefonso Pueblo (fig. 2) to more than 80 feet at the Tesuque River near Tesuque Pueblo (fig. 3).

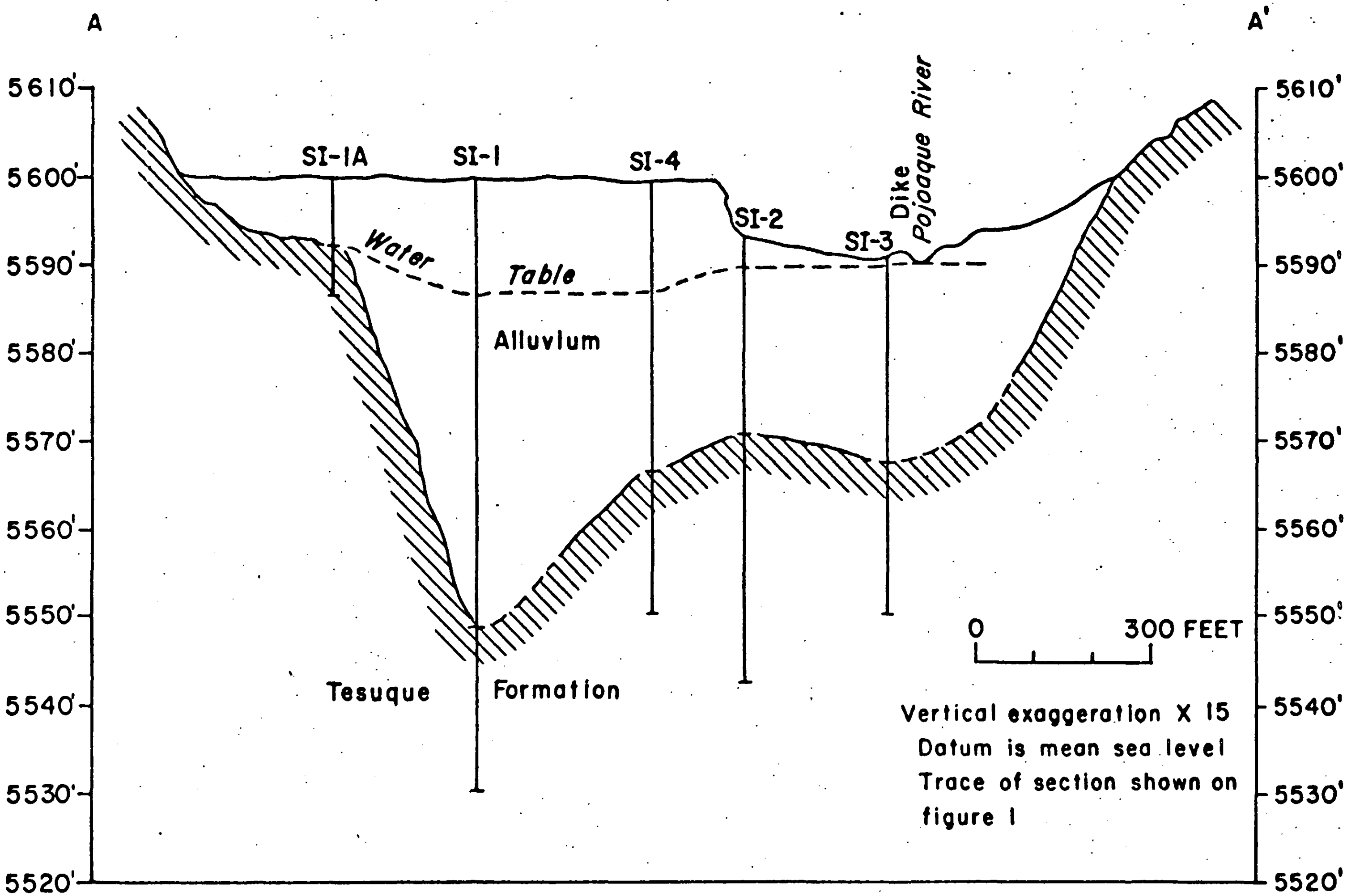


Figure 2.--Geologic section across the Pojoaque River, San Ildefonso Pueblo.

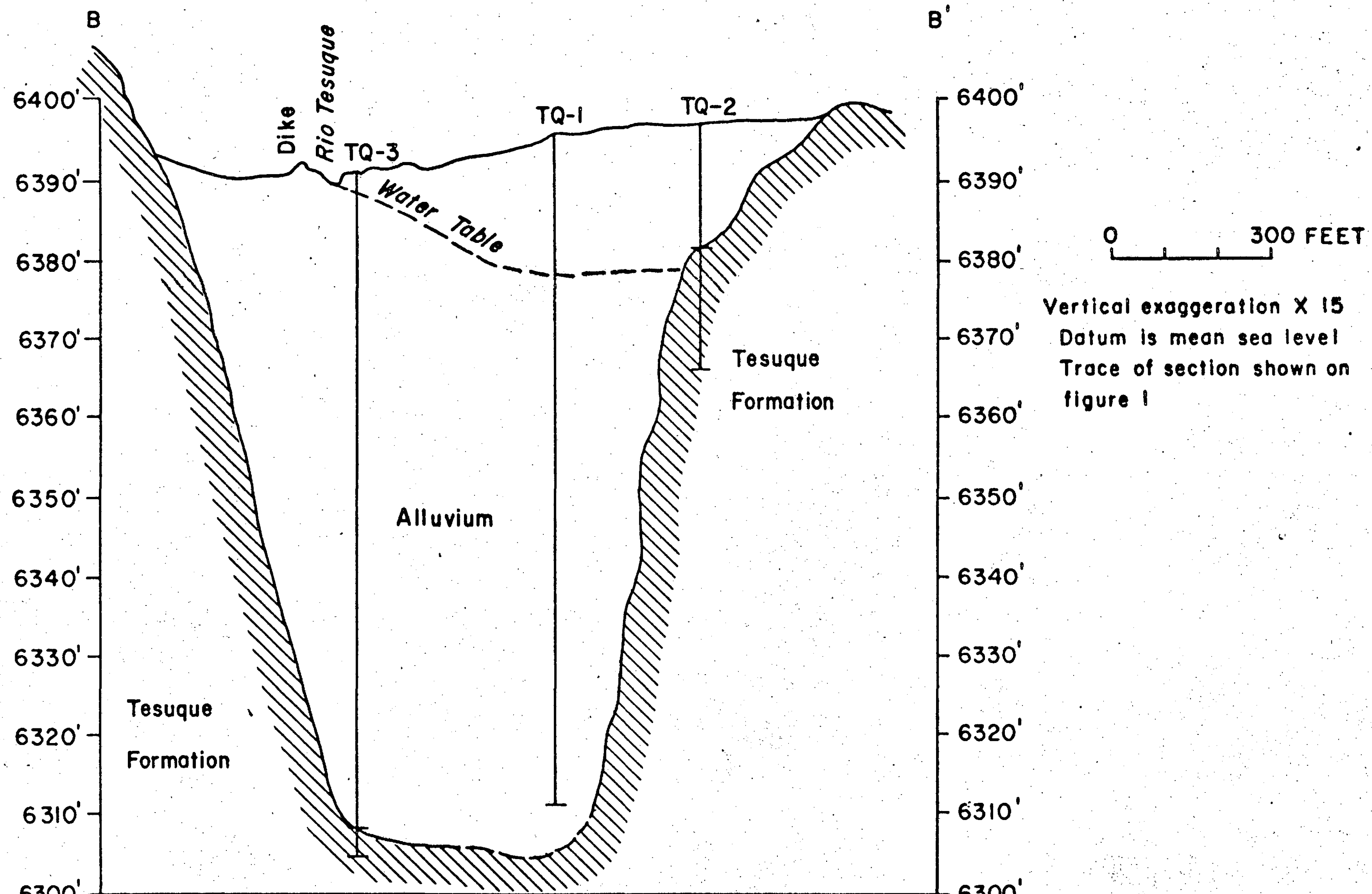


Figure 3.--Geologic section across the Rio Tesuque, Tesuque Pueblo.

The thickness of the Tesuque Formation cannot be calculated by projecting the dip of the formation because of strike faults in the area. The dip was determined by Spiegel and Baldwin (1963, p. 76-77) to be 10 degrees west. Preliminary gravity work by Lindreth Cordell, U.S. Geological Survey, Washington, D.C. (written commun., December 1969) suggests a formation thickness of more than 10,000 feet. This entire thickness is assumed to be all Tesuque Formation. The Paleozoic, Mesozoic, and lower Tertiary rocks are considered hydrologically insignificant in this study and are assumed to be thin or nonexistent. A thickness of 10,500 feet was used in this report for the Tesuque Formation aquifer at the Rio Grande, and a thickness of 3,500 feet was used for this aquifer at the intersection of section used to calculate ground-water flow and section C-C'.

Ground-water flow

The amount of ground-water flow that passes under Indian lands in the Pojoaque River drainage basin was calculated along a section across the drainage basin. This 12.5-mile section was selected by the Bureau of Indian Affairs and is shown on figure 1; the distance is between the southwestern corner of Tesuque Pueblo and the northeastern corner of Nambe Pueblo.

Information on flow was obtained by constructing a gradient-flow profile, simulated by an electrical-resistance analog model (Muskat, 1937, p. 321). This ground-water analog model simulated the ground-water flow that moves from the recharge area, near the outcrop of crystalline rocks on the east side of the study area, toward the Rio Grande and passes through the section. Line C-C' on figure 1 shows the line of profile. Figure 4 is a diagram of a scaled vertical model showing flow and pressure-gradient lines along the profile.

The occurrence of clay beds in the Tesuque Formation causes an anisotropic effect that results in the horizontal permeability being considerably greater than the vertical permeability. It is estimated that the horizontal permeability is 25 times greater than the average vertical permeability.

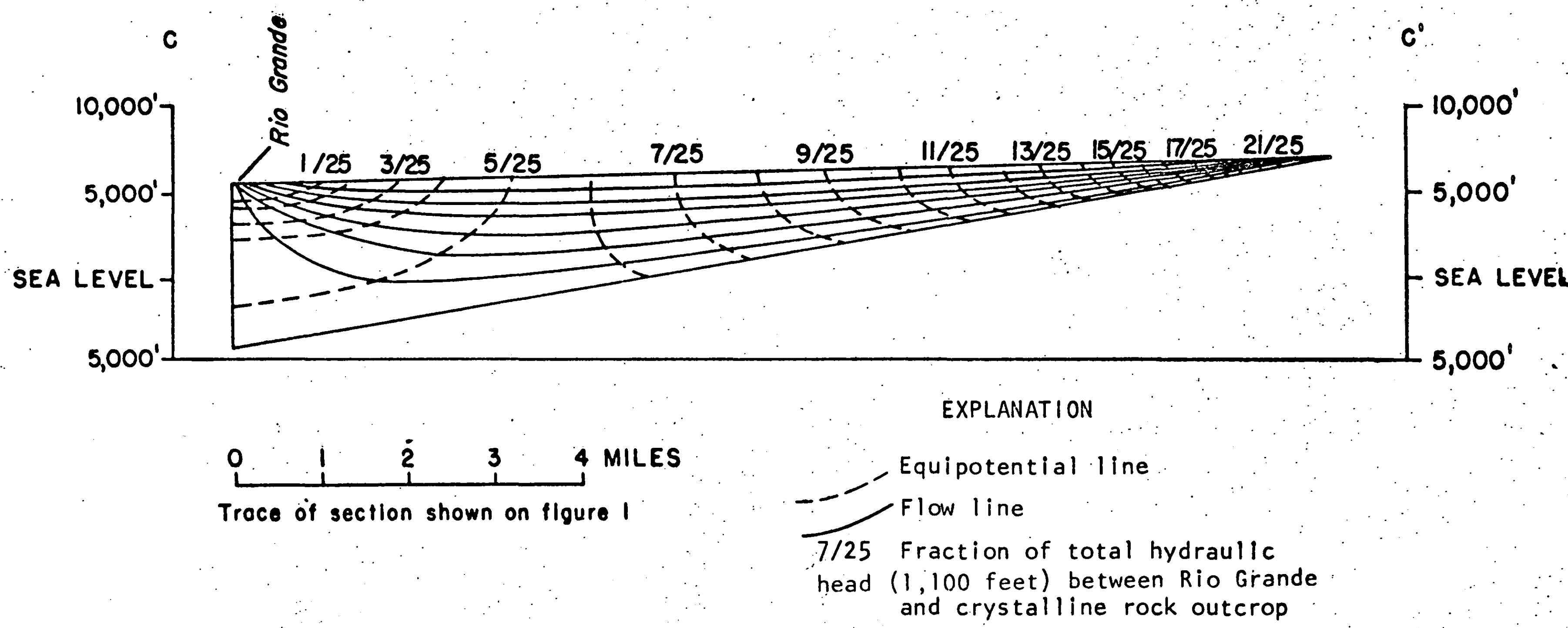


Figure 4.--A scaled vertical model showing flow and pressure-gradient lines under anisotropic conditions, simulated by electrical resistance in a section roughly parallel to the lower reach of Pojoaque River drainage basin.

Conductance paper was used to construct an electrical-resistance analog model of an idealized ground-water system under isotropic conditions. The vertical distance (thickness of aquifer) was constructed five times greater than it should be if the model were to represent the actual aquifer thickness. (Five is the square root of 25, which is the factor indicating the difference in directional permeability.) The discharge per-unit section was assumed to be the same throughout the entire profile of the model. Equipotential and flow lines were located and drawn on the idealized resistance model. Another resistance model, with the vertical scale representing actual aquifer thickness, was then constructed. The potential and flow lines of the first model were mechanically projected to the scaled-down model. These lines become somewhat distorted in the resultant model, which is believed to represent anisotropic conditions and therefore a more realistic picture of actual conditions (fig. 4).

The model indicates that a potential for recharge to the ground-water system exists in the area along the eastern two-thirds of the line of profile. The western third of the line of profile, nearest the Rio Grande, is an area of potential loss of ground water to the surface-water system. The model also indicates that artesian pressures occur in the Tesuque Formation near the Rio Grande. Artesian pressures were encountered during the drilling of shallow test holes near San Ildefonso Pueblo in January 1970.

With reference to the artesian pressure, the ground-water level at point C' in figure 4 is about 1,100 feet above the discharge point at the Rio Grande. This hydraulic head change (1,100 feet) along the profile has been fractioned to 25 parts, i.e., 1,100 + 25 = 44 feet. Note that if a well 1,000 feet deep were drilled at the point on the profile where the 1/25 hydraulic-head contour is at the water table--and if this well were constructed to accept water only from the bottom--the water would rise about [(2-1)/25x1,100] feet or 44 feet above the level of the water table. If at the same site the well were drilled to a depth of about 7,500 feet to intercept the 5/25 contour and was open only to that depth, the water would rise [(5-1)/25x1,100] feet, or 176 feet above the level of the water table, provided there is 7,500 feet of saturated material of about the same hydrologic characteristics as there is in the interval from land surface to the 1,000-foot depth.

The sediments underlying the Tesuque were not considered in the model and some downward distortion or warping of the flow lines would occur if the model were constructed to include underlying and older sediments of questionable hydrologic significance.

Tesuque Formation

An apparent T (transmissivity[1/]) of 160 ft^2/day for 100 feet of aquifer was determined for the Tesuque Formation from an aquifer test (fig. 5) on a well located in SE¼NE¼SW¼ sec. 8, T. 19 N., R. 8 E., about 1,000 feet southeast of San Ildefonso Pueblo. This well penetrated only 60 feet of the formation; however, as much as 100 feet of the saturated part of the aquifer might be considered as contributing to the well. A transmissivity of 670 ft^2/day was estimated from data accumulated from wells generally more than 1,000 feet deep drilled a short distance from the area on the west side of the Rio Grande.

The transmissivity of the Tesuque Formation at the point where the section used to calculate ground-water flow intersects section C-C' is approximated at 2,350 ft^2/day by using a transmissivity value of 670 ft^2/day for 1,000 feet of the aquifer and adjusting it for the thickness (3,500 feet) of the formation.

The flow Q, in ft^3/day through a 1-mile segment of section used to calculate ground-water flow (fig. 1) can be calculated by:

$$Q = TIL$$

$$= (2,350)\left(\frac{100}{5,280}\right)(1.0)(5,280)$$

$$= 2.35 \times 10^5\ ft^3/day,\ 2.72\ ft^3/sec,\ \text{or } 1,970 \text{ acre-feet per year}$$

Where T = transmissivity adjusted to about 2,350 ft^2/day for a 3,500 foot thickness of aquifer; I = the apparent head gradient of 100 feet per mile (Trauger, 1967, fig. 1); and L = the length, in feet.

1/ transmissivity is in units ft^3/day/ft-which reduces to ft^2/day

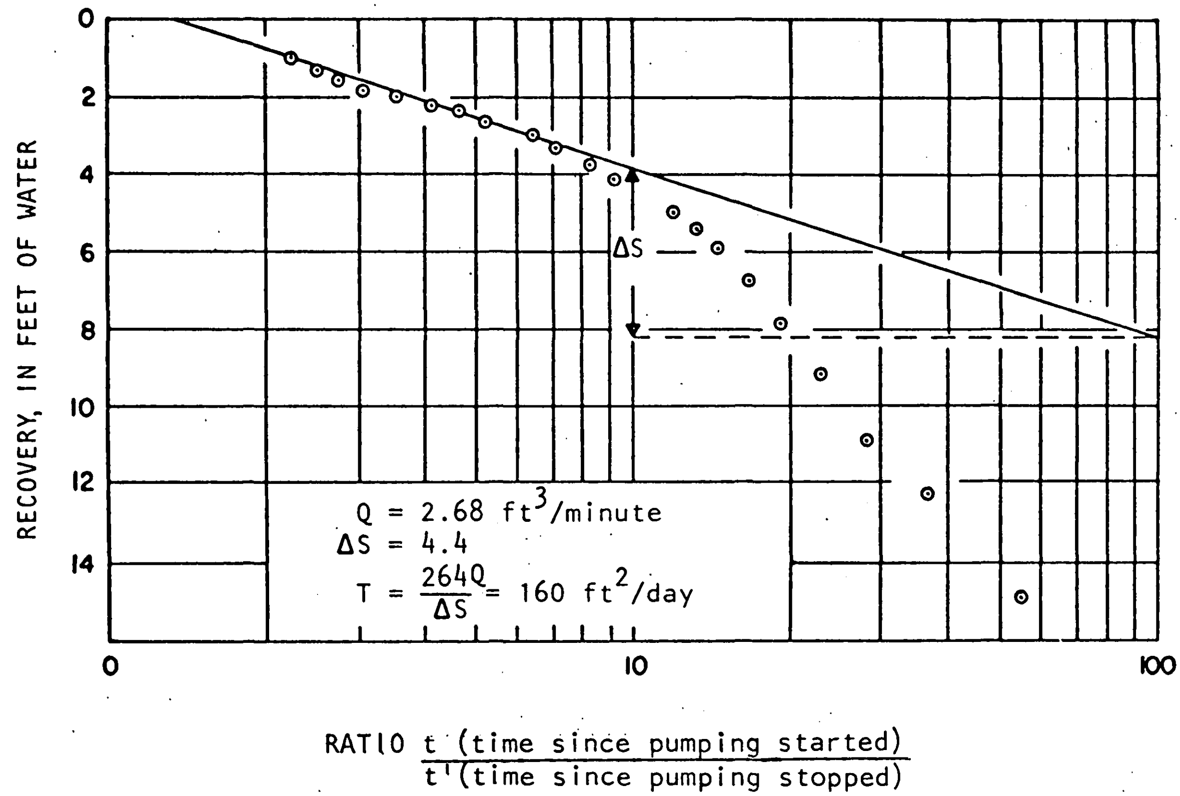


Figure 5.--Aquifer-response test of a well (SE¼NE¼SW¼ sec. 8, T. 19 N., R. 8 E.) that taps the Tesuque Formation near San Ildefonso Pueblo, January 1970.

The ground-water flow through the Tesuque Formation for the entire width of section used to calculate ground-water flow would be 12.5 times 1,970 or about 24,600 acre-feet per year with the assumption that the thickness of the Tesuque Formation is uniform in the section.

The flow of 24,600 acre-feet per year through the section is for ideal conditions and may be in excess of the actual flow because of anisotrophic conditions. C. V. Theis, U.S. Geological Survey, was consulted on this problem of anisotropic flow. His calculations of impediment to flow, using tensor analysis, show that the flow to the Rio Grande can be restricted to about 0.6 of the idealized calculated flow because of influence of a 10 degree dip of the strata and anisotropic conditions within the Tesuque. This would reduce the 24,600 acre-feet per year to about 14,700 acre-feet per year.

A figure of 20,000 acre-feet per year would be about midway between that computed assuming isotropic conditions and that computed assuming anistropic conditions. This figure for flow through the Tesuque at the section used to calculate ground-water flow is considered reasonable after considering all the factors influencing ground-water flow.

Alluvium

The total ground-water flow in the alluvium in the Pojoaque River was calculated at a point about 0.7 mile east of San Ildefonso Pueblo (section A-A' on figs. 1 and 2). Using a transmissivity value of 1,200 ft^2/day obtained from an aquifer test on a well that taps alluvium near San Ildefonso Pueblo (fig. 6) and a gradient of 70 feet per mile, it was calculated that the flow through section A-A' is about 1.9×10^4 ft^3/day, or 160 acre-feet per year.

An apparent transmissivity value of 2,080 ft^2/day was determined from an aquifer test of a well that taps the alluvium near Tesuque Pueblo (fig. 7). The alluvium in section B-B' (fig. 1) near Tesuque Pueblo apparently is thicker and coarser grained than the alluvium near San Ildefonso Pueblo (section A-A'). The estimated flow through the alluvium in section B-B' is 290 acre-feet per year, which is 130 acre-feet per year greater than that flow through section A-A'.

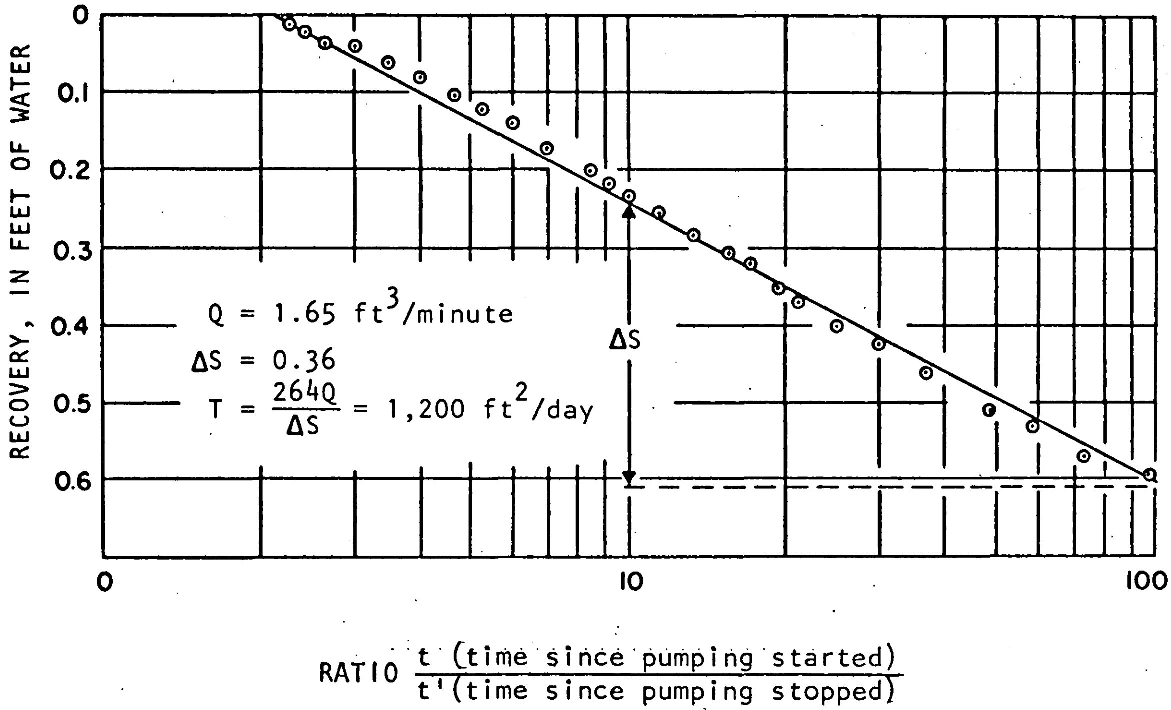


Figure 6.--Aquifer-response test of a well (NE¼NE¼NW¼ sec. 8., T. 19 N., R. 8 E.) that taps alluvium near San Ildefonso Pueblo, January 1970.

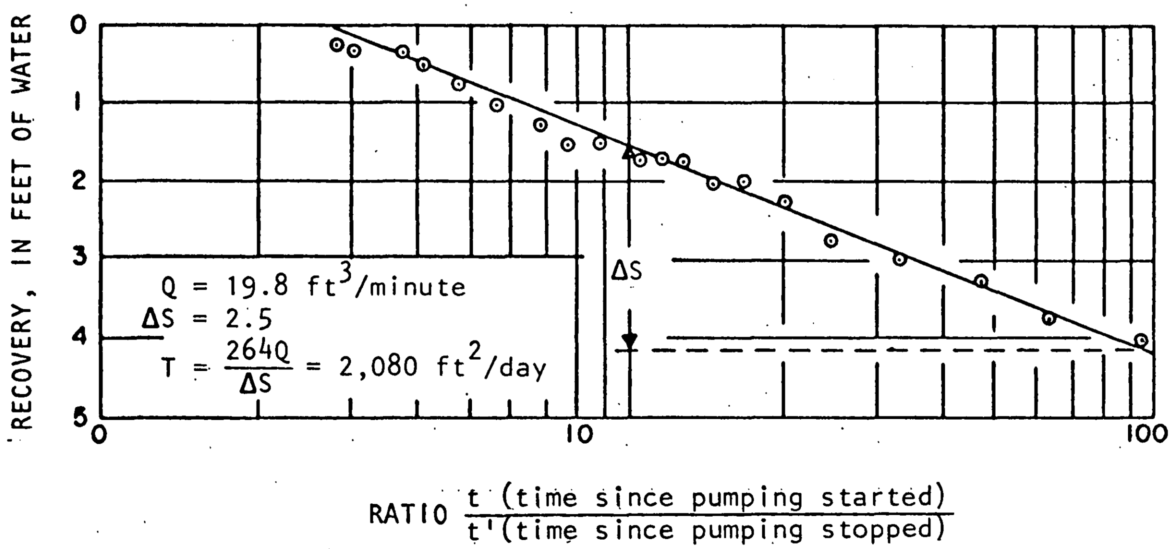


Figure 7.--Aquifer-response test of a well (NE¼NE¼NE¼ sec. 23, T. 18 N., R. 9 N.) that taps alluvium near Tesuque Pueblo, January 1970.

The composite flow through alluvial material would include the flow in the alluvium near Tesuque Pueblo at section B-B' and flow in the alluvium of Pojoaque Creek about 1 1/2 miles east of Nambe Pueblo. The alluvium is visibly coarser in Pojoaque Creek than near Tesuque Pueblo, permitting higher velocity of underground flow, but the channel appears to be restricted more than in the Tesuque Pueblo area, and this would indicate a lesser volume of underflow at Pojoaque Creek.

The flow in the alluvium where Pojoaque Creek crosses the section used to calculate ground-water flow is estimated to be about the same as that at section B-B' (about 290 acre-feet per year). The composite ground-water flow of the Pojoaque Creek and Tesuque Creek areas would be about 580 acre-feet per year, assuming the saturated alluvium in the smaller tributaries is not contributing significantly.

The discharge of ground water to the Rio Grande was estimated by Griggs (1964, p. 95) to be 500 to 600 gpm (gallons per minute) per mile through a reach of the river including all of the reach for a river-mile distance of 21 miles south of the Otowi gaging station (fig. 1). This discharge measured as gains in the river totals about 1.06×10^5 ft^3/yr or 900 acre-feet per year average flow per unit mile of both sides of the river to the Rio Grande. The gains in the river calculated by Griggs includes discharge from both the alluvium and the Tesuque Formation. Actual outflow of ground water into the Rio Grande trough would be somewhat higher were it not for the evapotranspiration losses before the water enters the river channel.

The discharge of ground water to the Rio Grande probably varies along the river, and it seems plausible that those reaches containing the confluence of large side drainage such as the Pojoaque River would contribute more than those reaches without major side drainages.

Potential yield of wells

Deep wells tapping the Tesuque Formation have a specific capacity of about 2.5 gpm per foot of drawdown per 1,000 feet of penetration of the saturated part of the formation. A well penetrating 1,000 feet of saturated formation will yield 500 gpm with 200 feet of drawdown, and a well penetrating 2,000 feet will yield more than 750 gpm with the same drawdown. These yields (table 1) are based on data from aquifer tests on wells that tap the Tesuque Formation about 5 miles west of the study area (fig. 1). The data from these wells are thought to be the most reliable for use in predicting individual well performance within the project area.

Hydrologists have used a "factor" of 2,000 times the specific capacity to obtain an estimate for transmissivity in gallons per day per foot. The 2.5 gpm per foot of drawdown times the factor results in a transmissivity of 5,000 gallons per day per foot or 670 ft^2/day. There is some justification for using a value higher than this because of the Tesuque aquifer test resulting in a transmissivity of about 1,600 ft^2/day for a thickness of 1,000 feet. However, the well upon which the test was conducted may have been constructed in a more permeable nonrepresentative part of the aquifer, and the thickness tested for transmission rate represents only a small part of the total aquifer thickness.

The lower transmissivity of 670 ft^2/day was used to calculate theoretical drawdowns at selected distances from a pumped well 1,000 feet deep (table 2) by using an assumed storage coefficient of 0.2 and the Theis (1935) nonequilibrium formula.

Table 1.--Yields of wells that tap the Tesuque Formation 1/

Well number 2/	Local well number	Location T. 19 N., R. 7 E.	Completed depth (feet)	Saturated section penetrated (feet)	Specific capacity (gpm/ft of drawdown)	Yield (gpm/100 feet of saturated sediments)
1	G3	NW¼SW¼NW¼ sec. 4	1,792	1,512	6	0.39
2	L3	NW¼NE¼NE¼ sec. 4	870	870	1.4	.16
3	G2	NW¼NW¼SE¼ sec. 4	1,990	1,731	7	.40
4	G1	SE¼SE¼SE¼ sec. 4	2,000	1,808	4.8	.26
5	G5	NE¼NW¼NW¼ sec. 5	1,850	1,439	5.4	.37
6	G4	NW¼SW¼NE¼ sec. 5	1,940	1,593	4	.25
7	L6	NE¼NW¼SE¼ sec. 14	1,790	1,790	6.9	.38
8	L5	SE¼SW¼SE¼ sec. 15	1,750	1,697	3.2	.18
9	L4	NE¼SW¼NW¼ sec. 22	1,965	1,776	6.3	.35
						.30 Average 3/

1/ Data from Griggs (1964, p. 70-71)
2/ As noted on figure 1.
3/ Average for 1,000 feet of sediments would be 3.0 gpm per foot of drawdown.
(2.5 used in calculations in this report.)

Table 2.--Theoretical drawdowns in feet at selected times and distances from pumped wells constructed in the Tesuque Formation

Time in days	Distance, in feet, from well pumping 500 gpm			
	1	10	100	1,000
1	102	50	4	-
10	129	76	24	-
100	155	102	50	4
1,000	181	129	76	24
	Distance, in feet, from well pumping 750 gpm			
1	153	74	6	-
10	193	114	36	-
100	233	153	74	6
1,000	273	193	114	36

Wells constructed in and withdrawing water directly from the Tesuque Formation would affect the surface-water supplies only indirectly through some leakage from the alluvium and surface-water sources. Effects of withdrawal from the Tesuque Formation would have only subtle effects on water levels in shallow wells in the alluvium and on surface-water sources during each year. However, greater long-term effects will occur. The seasonal withdrawals from the Tesuque Formation, as for irrigation, will permit recharge during the non-pumping periods to replenish a large part of the withdrawn water. It is presumed that pumping from the Tesuque Formation would more fully utilize the underground water reserves.

The alluvium aquifer is in hydraulic connection with the surface waters in the study area and will yield several hundred gallons per minute of water to shallow wells. The total volume of water in the alluvium is much smaller than the volume of water stored in the underlying Tesuque Formation; however, the permeability of the alluvium is greater, and will transmit about 40 times more water per unit thickness than the Tesuque under natural gradients.

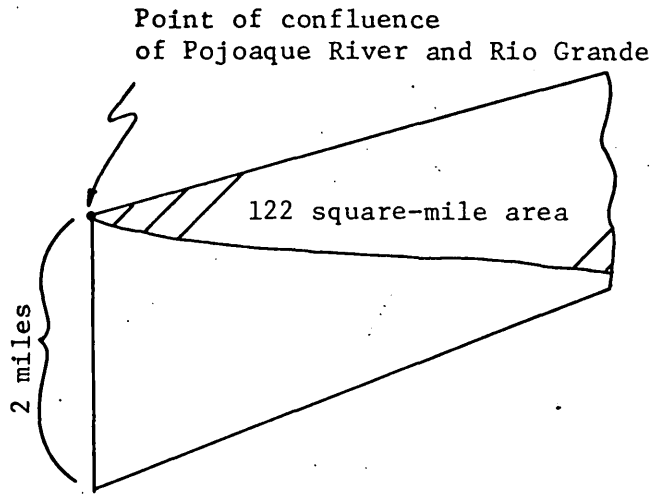
Wells constructed in the alluvium have a yield of more than 10 gpm per foot of drawdown from about 20 feet of saturated alluvium. If the capacity of a well is rated for 100 feet of saturated thickness, as was done for wells that tap the Tesuque Formation, the specific capacity would be more than 50 gpm per 100 feet of thickness. This is 200 times the specific capacity of the Tesuque Formation.

Volume of ground water

The volume of saturated sediments under consideration for computing the volume of water underlying the pertinent part of the Pojoaque drainage boundary has the following physical boundaries:

The thickness of the sediments, which includes the Tesuque Formation (about 3,500 feet thick) and other continental sediments, is about 10,500 feet at a point near the confluence of Pojoaque River and Rio Grande. It grades into a feather edge along the outcrop of crystalline rocks which extend a north-south distance of 14 miles along the eastern margin; the east-west distance across these sediments is about 14 miles.

The area is a triangular-shaped surface (base) of about 122 square miles with an apex 2 miles (height) below the river confluence, resulting in a figure like this:



The total volume is calculated as:

$$Vs = 1/3\ Ah$$

$$Vs = \frac{122 \times 640 \times 10{,}500}{3}$$

$$Vs = 2.76 \times 10^{8} \text{ acre-feet}$$

Where Vs = the volume of sediments,

A = area of the base in acres (122 miles^2 x 640 acre/mile^2), and

h = height in feet (10,500 feet).

The volume of water in these sediments with an estimated porosity of 0.2 is equal to 5.5×10^{7} acre-feet. It is feasible to recover only a small percentage of this water.

The amount of water in the alluvium was estimated by assuming a distance of 20 miles of alluvial-fill channel comprising an average cross-sectional area of about 56,000 square feet of saturated alluvium in the area. Information from topographic maps and data from figures 2 and 3 were used as the basis for these assumptions. If the average porosity of this saturated alluvium is assumed to be 0.1, the calculated volume of water in the alluvium would be 5.83×10^8 ft^3 or 1.33×10^4 acre-feet. The alluvium is "reworked" Tesuque Formation, which in general has lost some of the silts and clay particles. A porosity of 0.2 for the Tesuque Formation was used in this report, but the removal of silts and clays would decrease the porosity because silts and clays may have porosity greater than 40 percent.

Summary

The hydrology of a major part of the Pojoaque River drainage basin, a tributary of the Rio Grande in north-central New Mexico, was studied by the U.S. Geological Survey at the request of the Bureau of Indian Affairs. The important aquifers in the area are the alluvium and the Tesuque Formation, although some water may also be present in the deeper sediments. The alluvium yields several hundred gallons per minute to shallow wells and is considered to be about 40 times more transmissive per unit of thickness than the Tesuque Formation.

A simplified electrical-analog model was constructed to simulate equipotential and flow lines; it indicates that recharge to the ground-water system takes place in the eastern two-thirds of the area and that a potential loss of ground water to the surface-water system exists in the western part of the area.

Ground-water flow in the Tesuque Formation and alluvium was determined for a section which extends roughly north-south through the northern boundary of the Nambe Grant to the southwestern corner of the Tesuque Grant (fig. 1). At this 12.5 mile-long section, the westward ground-water underflow of the Tesuque is about 20,000 acre-feet per year, and the flow through the alluvium is estimated to be 450 acre-feet per year; the total is about 20,450 acre-feet per year or about 30 cubic feet per second. Only a small amount of this total ground-water flow is recoverable through wells. A flow of about 2.7 cubic feet per second per unit mile flows into the Rio Grande, and it appears that a large part of the total underflow is lost by evapotranspiration before it enters the Rio Grande channel.

An average surface-water runoff of about 11,000 acre-feet per year across the section used to calculate ground-water flow has been computed by using data from nearby gaging stations. A large part of this runoff is lost by evaporation downstream and by infiltration to the subsurface for a distance of about 5 miles. Some of these subsurface losses reappear as ground-water inflow downstream beyond the distance of 5 miles from the section used to calculate ground-water flow.

The total volume of water in storage in the Tesuque Formation under the area was estimated at 5.5×10^7 acre-feet. The amount in the alluvium was estimated at 1.33×10^4 acre-feet. The amount of water in the alluvium is significant but represents only a small fraction of the total amount. Only a small part of the total water in storage, however, would be available through wells.

Wells constructed in 20 feet of alluvium yield 10 gallons of water per minute per foot of drawdown, which is about 200 times the specific capacity of wells tapping the Tesuque Formation. However, discharge from wells constructed in the alluvium would affect surface-water supplies more directly than wells constructed in the Tesuque. Wells in the Tesuque with 1,000 feet of saturated material may yield several hundred gallons per minute with long-term depletion effects on the alluvium aquifer and consequently on the source of water for the gaining streams as well.

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Estimated ground-water flow, volume of water in storage, and potential yield of wells in the Pojoaque River drainage basin, Santa Fe County, New Mexico

Figure 1.--Map showing the Pojoaque River drainage basin, Santa Fe County, New Mexico