AQUIFER TESTS IN THE GALLUP SANDSTONE NEAR YAH-TA-HEY, NEW MEXICO

BY JOHN S. McLEAN

U. S. GEOLOGICAL SURVEY
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Aquifer tests of the Gallup Sandstone and associated units in the Yah-ta-hey well field have yielded values of transmissivity ranging from 250 to 400 feet squared per day and values of storage coefficient ranging from 5×10^{-5} to 10^{-4}. A 2 1/2-month aquifer test was conducted in the spring of 1976 to provide data to better refine these values. The results of the long-term aquifer test were simulated in a digital model. A transmissivity of 300 feet squared per day, storage coefficient of 10^{-4}, and vertical hydraulic conductivity of the overlying Crevasse Canyon Formation of less than 10^{-4} feet per day gave the best fit of simulated to observed drawdown in the pumped well and the two observation wells.

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INCH-POUND UNIT TO METRIC UNIT CONVERSION FACTORS

In this report figures for measurements, except water temperature, are given in inch-pound units only. The following table contains factors for converting to metric units:

Multiply inch-pound units	By	To obtain metric units
in (inch)	2.54	cm (centimeter)
ft (foot)	0.3048	m (meter)
ft^2/d (foot squared per day)	0.0929	m^2/d (meter squared per day)
ft^3/s (cubic foot per second)	0.02832	m^3/s (cubic meter per second)
mi (mile)	1.609	km (kilometer)
gal (gallon)	3.785	L (liter)
gal/min (gallon per minute)	0.06309	L/s (liter per second)
(gal/min)/ft (gallon per minute per foot)	0.207	(L/s)/m (liter per second per meter)
lb (pound)	0.4536	kg (kilogram)

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AQUIFER TESTS IN THE GALLUP SANDSTONE

NEAR YAH-TA-HEY, NEW MEXICO

By J. S. McLean

ABSTRACT

Aquifer tests of the Gallup Sandstone and associated units in the Yah-ta-hey well field have yielded values of transmissivity ranging from 250 to 400 feet squared per day and values of storage coefficient ranging from 5×10^{-5} to 10^{-4}. A 2½-month aquifer test was conducted in the spring of 1976 to provide data to better refine these values. The results of the long-term aquifer test were simulated in a digital model. A transmissivity of 300 feet squared per day, storage coefficient of 10^{-4}, and vertical hydraulic conductivity of the overlying Crevasse Canyon Formation of less than 10^{-4} feet per day gave the best fit of simulated to observed drawdown in the pumped well and the two observation wells.

INTRODUCTION

The Gallup Sandstone aquifer in western McKinley County, New Mexico, is an important source of potable water for individuals and communities in the area. Communities in western McKinley County, including the city of Gallup, are experiencing rapid population growth and consequent increase in water consumption from the Gallup Sandstone aquifer. In order to estimate the useful life of this aquifer, improved values for the transmissivity and storage coefficient of the aquifer and hydraulic conductivity of the confining beds are required. An area in which several observation wells are available and well construction details are well known is the city of Gallup's well field near Yah-ta-hey, about 7 miles north of Gallup (fig. 1). A long-term aquifer test was conducted in this well field in the spring of 1976 to provide additional data for this analysis.

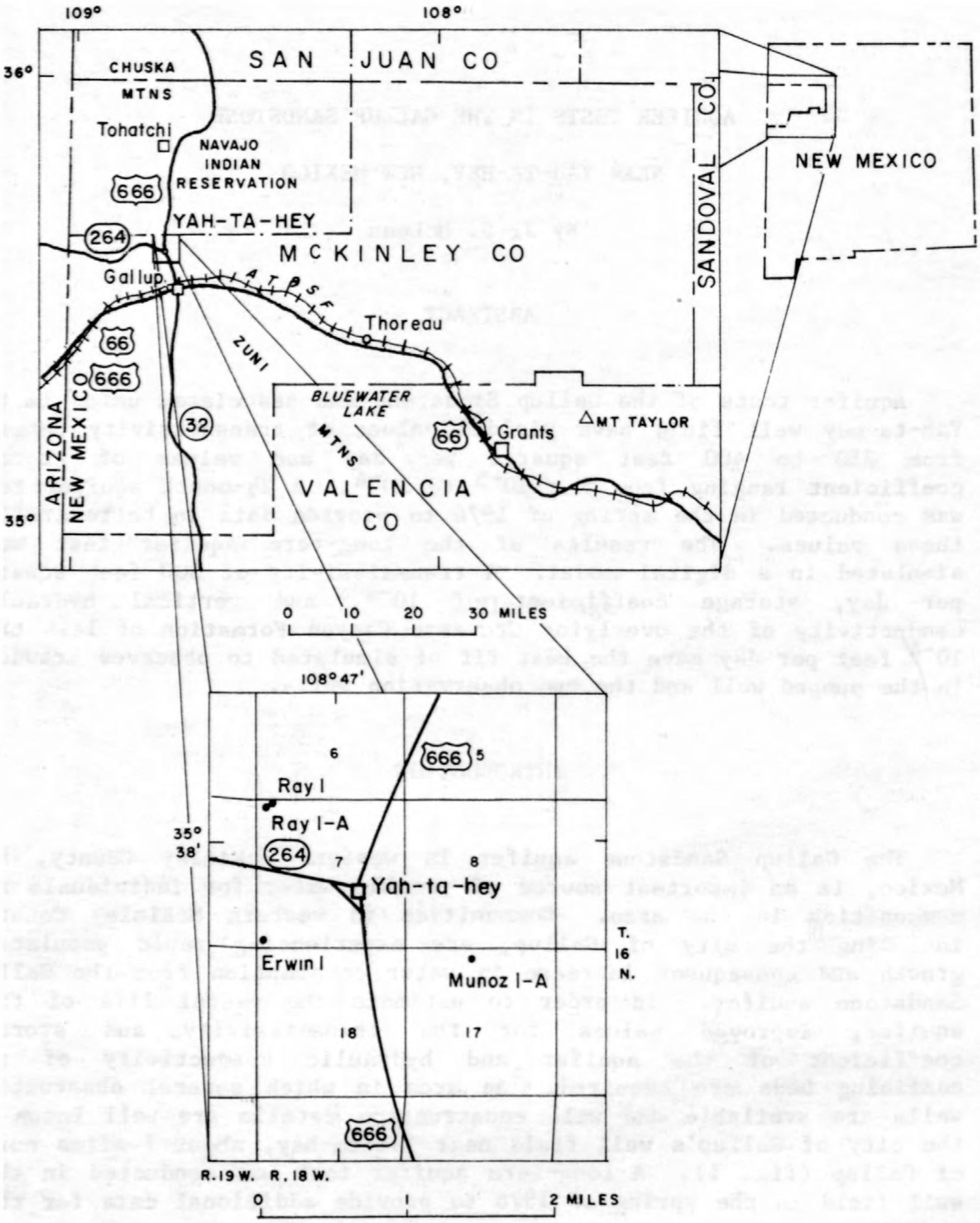

Figure 1.--Index maps showing location of the Yah-ta-hey well field.

The purpose of this report is to:

(1) report the results of a long-term aquifer test in the Yah-ta-hey well field;

(2) reevaluate and summarize previous aquifer tests in the well field;

(3) simulate the results of the long-term aquifer test with a digital model to obtain reasonable ranges of transmissivity and storage coefficient for the Gallup Sandstone aquifer, and vertical hydraulic conductivity for the overlying Crevasse Canyon Formation.

The Yah-ta-hey well field consisted of three wells at the time of the long-term test in 1976: the Munoz 1-A, Erwin 1, and Ray 1-A wells (fig. 1). These wells together provided about one third the water used by the city of Gallup during 1975, the remainder being supplied by an older well field in Gallup.

Previous investigations

Investigations by the Geological Survey of the availability of ground water in the Gallup area began with reports by S. W. West in 1957 and 1961. The geology and hydrology of the area between Gallup and Tohatchi were studied by Mercer and Cooper (1970). They also described the drilling and testing of the Munoz 1-A well, the first well in the Yah-ta-hey well field. The Geological Survey, in cooperation with the New Mexico State Engineer and the city of Gallup, reported the results of drilling and testing the Erwin 1 well (Mercer and Lappala, 1972). Completion and log data of the Ray 1 well were reported by Hiss and Marshall (1975).

Acknowledgments

This study was conducted as part of a cooperative program with the New Mexico State Engineer Office to study water supplies for selected urban areas in the State.

Without the cooperation of the city of Gallup this test would not have been possible. Mr. G. William Petranovitch, Gallup City Engineer, supplied well pumpage data and scheduled the pumping periods. John Komadina and Henry Tillien of the city water department measured water levels, changed recorder charts, and measured and adjusted discharge from the pumping well. Mr. Richard A. Allgood, of Allgood, Sterling and Mataya Engineers, designed and supervised the drilling of the Ray 1 and Ray 1-A wells, and provided data on well construction and performance.

Water-bearing units

The Munoz 1-A well was drilled to a depth of 3,200 feet and obtained water from the Dalton Sandstone Member and sandstone stringers in the Dilco Coal Member of the Crevasse Canyon Formation of Cretaceous age, from the Gallup Sandstone of Cretaceous age, and from the Westwater Canyon Sandstone Member of the Morrison Formation of Jurassic age. The Munoz 1-A well was later plugged back to eliminate poorer quality water from the Morrison Formation. The Erwin 1 well was perforated adjacent to sandstones in the Bartlett Barren Member, the Dalton Sandstone Member, and the Dilco Coal Member of the Crevasse Canyon Formation, and the Gallup Sandstone. The Erwin 1 well bottomed in the Mancos Shale at a depth of 2,100 feet. The Ray 1-A well was completed to a depth of 2,148 feet and draws water from the same units as the Erwin 1 well. Based on electric logs and sample descriptions these units include about 240, 370, and 330 feet of productive sandstone in the Munoz, Erwin, and Ray wells, respectively. The Gallup Sandstone is coarser grained and better sorted than the other sands penetrated, and therefore probably supplies most of the water pumped from these wells. The Gallup Sandstone and overlying sandstones are hydraulically separated to varying degrees by shale units in the Crevasse Canyon and Menefee Formations. In the Yah-ta-hey well field the Gallup Sandstone is an artesian aquifer with about 1,500 feet of static head.

RAY 1-A PRODUCTION WELL

The Ray 1-A well was drilled 37 feet southwest of the Ray 1 well after a casing string collapsed in the Ray 1 well. The casing in the Ray 1 well was perforated at about 850 feet and water levels (fig. 2) were measured in the well during and after the testing of the Ray 1-A well. The Ray 1-A well was drilled to a depth of 2,148 feet, cased with blank 16-inch casing to a depth of 1,238 feet and slotted 8-5/8-inch casing to 2,108 feet. Construction details are shown in figure 3.

The Ray 1-A well was developed by pumping and surging beginning June 24, 1975 (fig. 2). The well was shut down at 7:30 p.m. on June 25th and allowed to recover until June 26th at 7:30 a.m. At this time a 4-day step test, with pumping rates of 599, 708, 805, and 876 gal/min, was begun. The specific capacity of the well 12 hours after the start of each step is shown in figure 4. The specific capacities ranged from 1.76 to 1.55 (gal/min)/ft of drawdown. The Erwin 1 well was pumping during the test.

Because the pumping rate fluctuated during the early part of the test, the data for the Ray 1-A well were plotted as drawdown divided by discharge versus the log of time since the start of the first step (fig. 5). A transmissivity of 330 ft^2/d was determined from this plot. Recovery data were obtained for 2 days following the step test (fig. 6). These data were analyzed using the method outlined by Harrill (1971), in which the value of time plotted on the semilog axis is adjusted by the ratio of the change in discharge for each step (Q_1, Q_2, etc.) to the final discharge (Q_n). A transmissivity of 360 ft^2/d was determined by Harrill's method.

The discharge of the Erwin 1 well, 4,990 feet south of the Ray 1-A well, was held constant prior to and during the pumping and recovery of the Ray 1-A well. At the end of the first pumping step, the water level in the Erwin 1 well was 7.5 feet lower than the projected prepumping trend. This drawdown was used to roughly estimate a storage coefficient of 10^{-4}.

The water level in the Ray 1 well was recovering from the effects of development during the test of the Ray 1-A well. The water level recovered steadily and showed no response to pumping during the test, indicating that the units overlying the Gallup sandstone and associated aquifers at the Ray 1-A well have a relatively low vertical hydraulic conductivity.

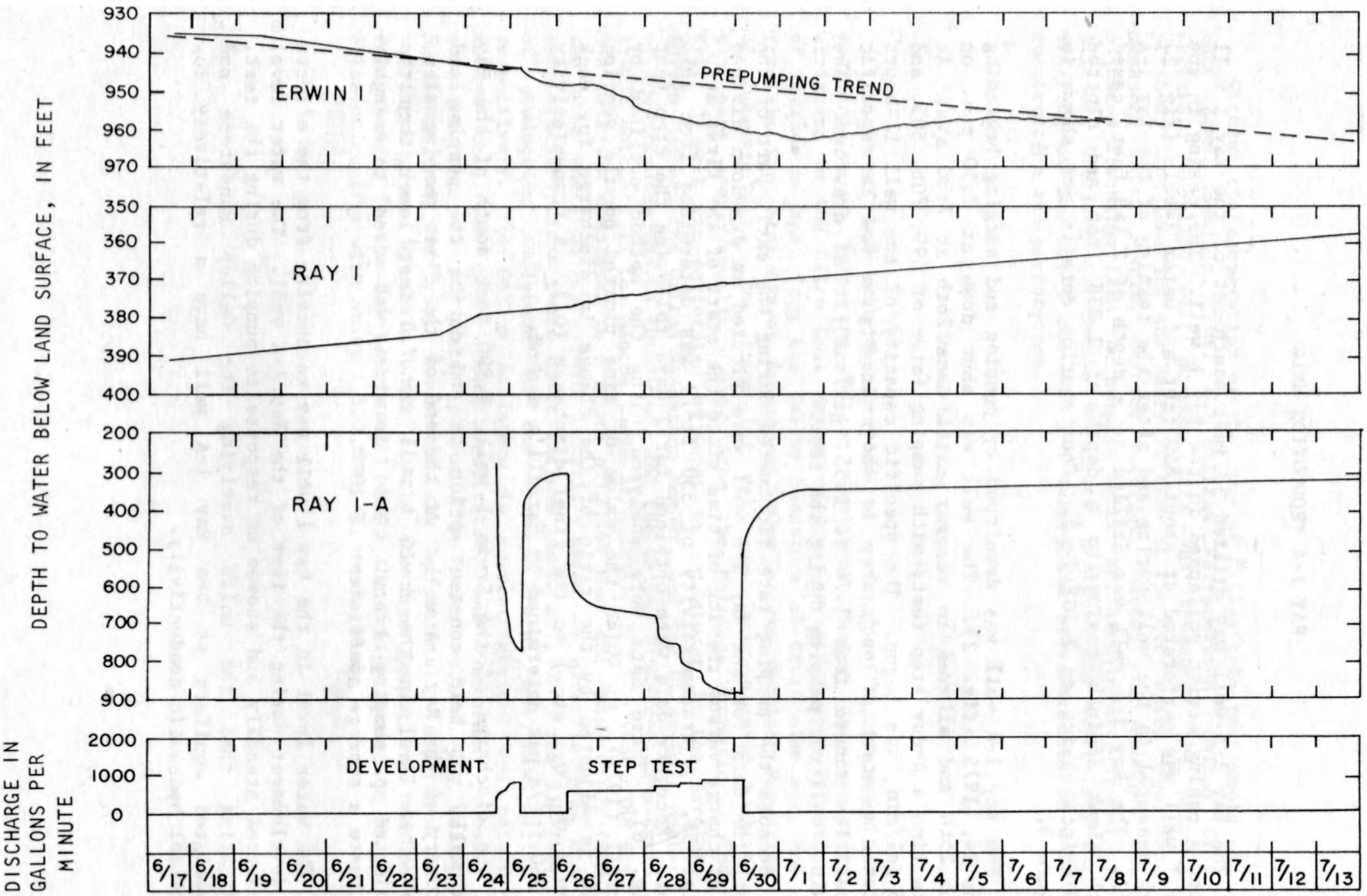

Figure 2.--Water levels and discharge during the Ray 1-A pump test, June 24-30, 1975.

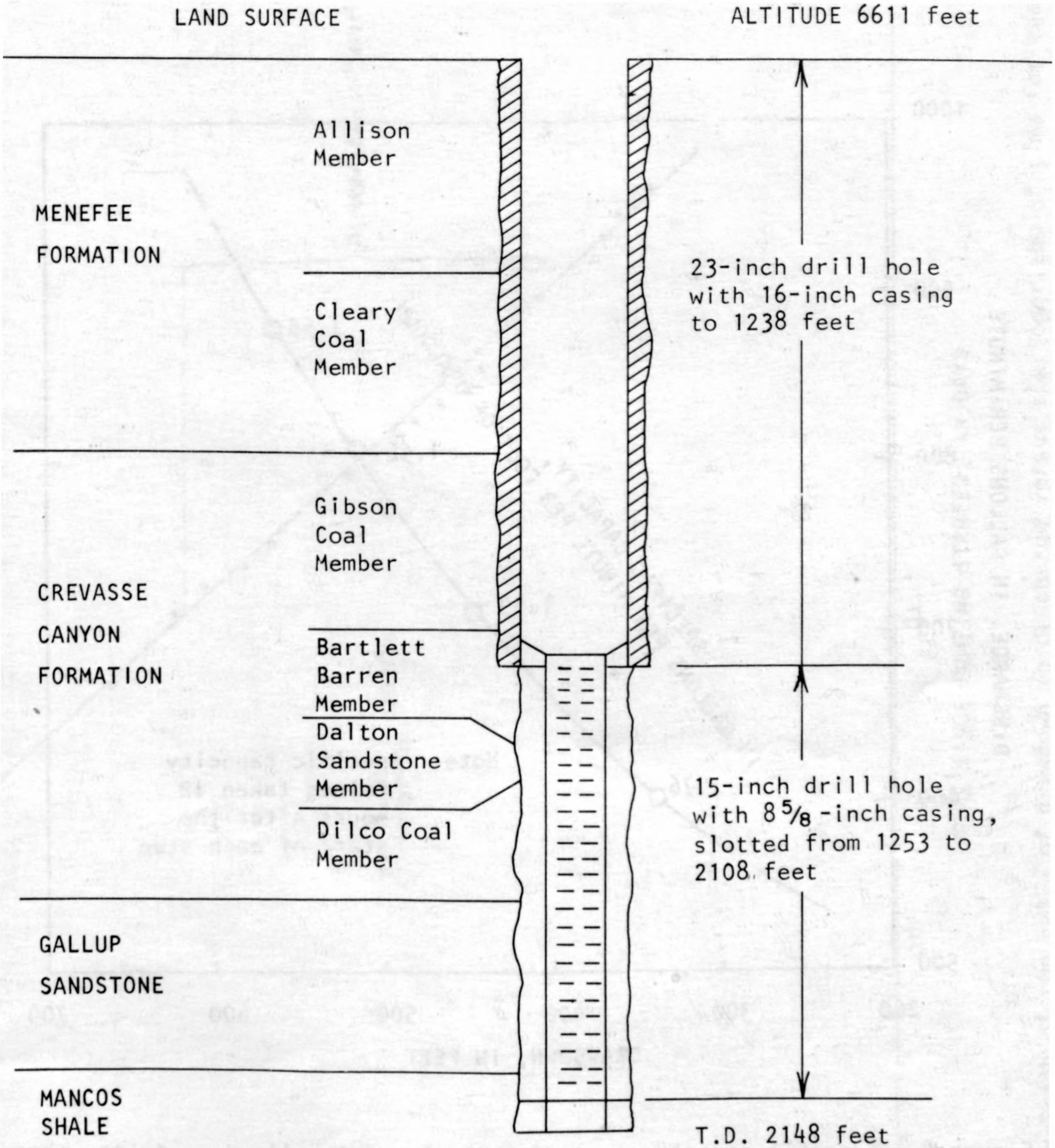

Figure 3.--Construction details and geologic units penetrated by the Ray 1-A well.

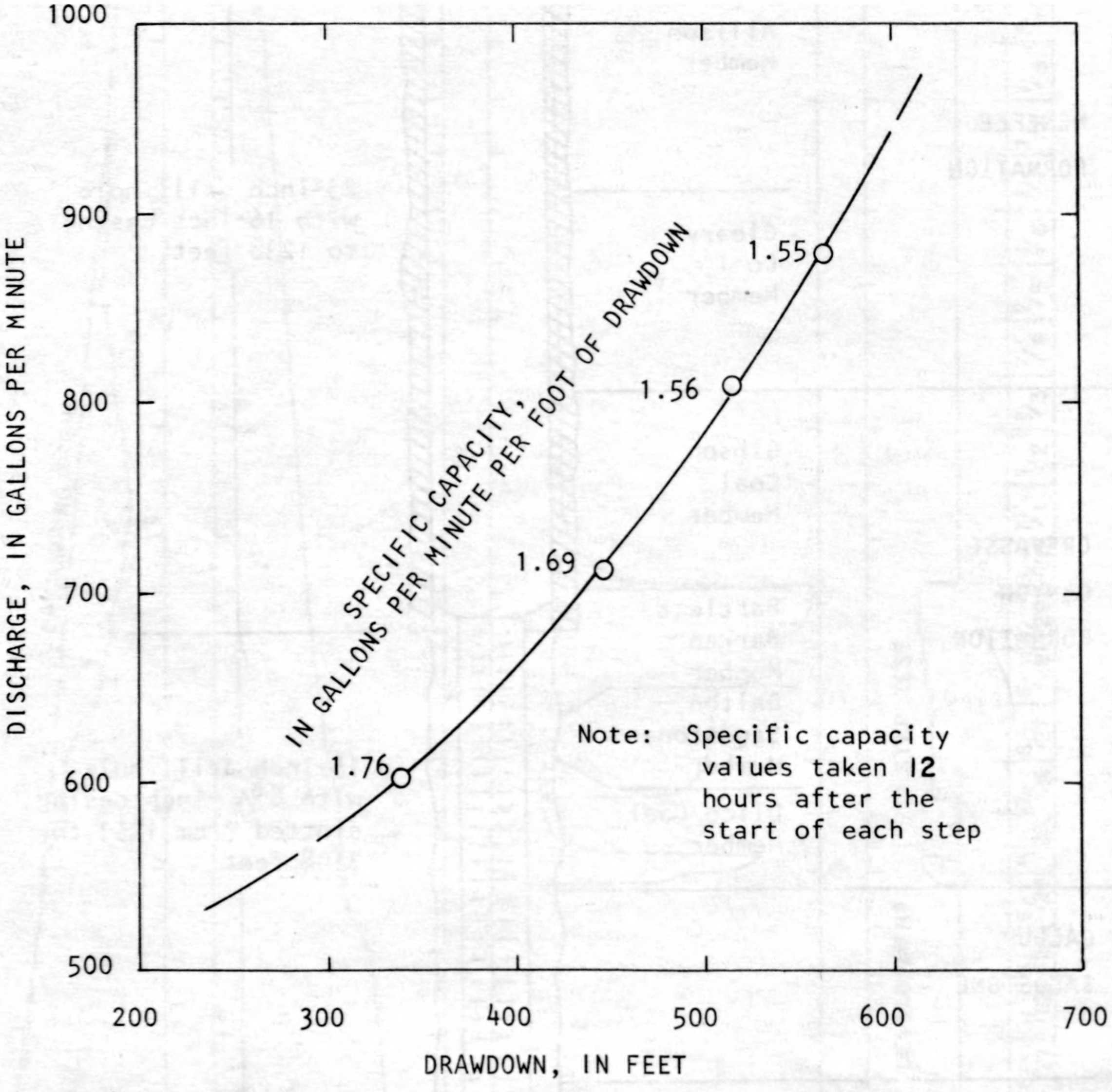

Figure 4.--Specific capacity curve for the Ray 1-A well, June 24-30, 1975.

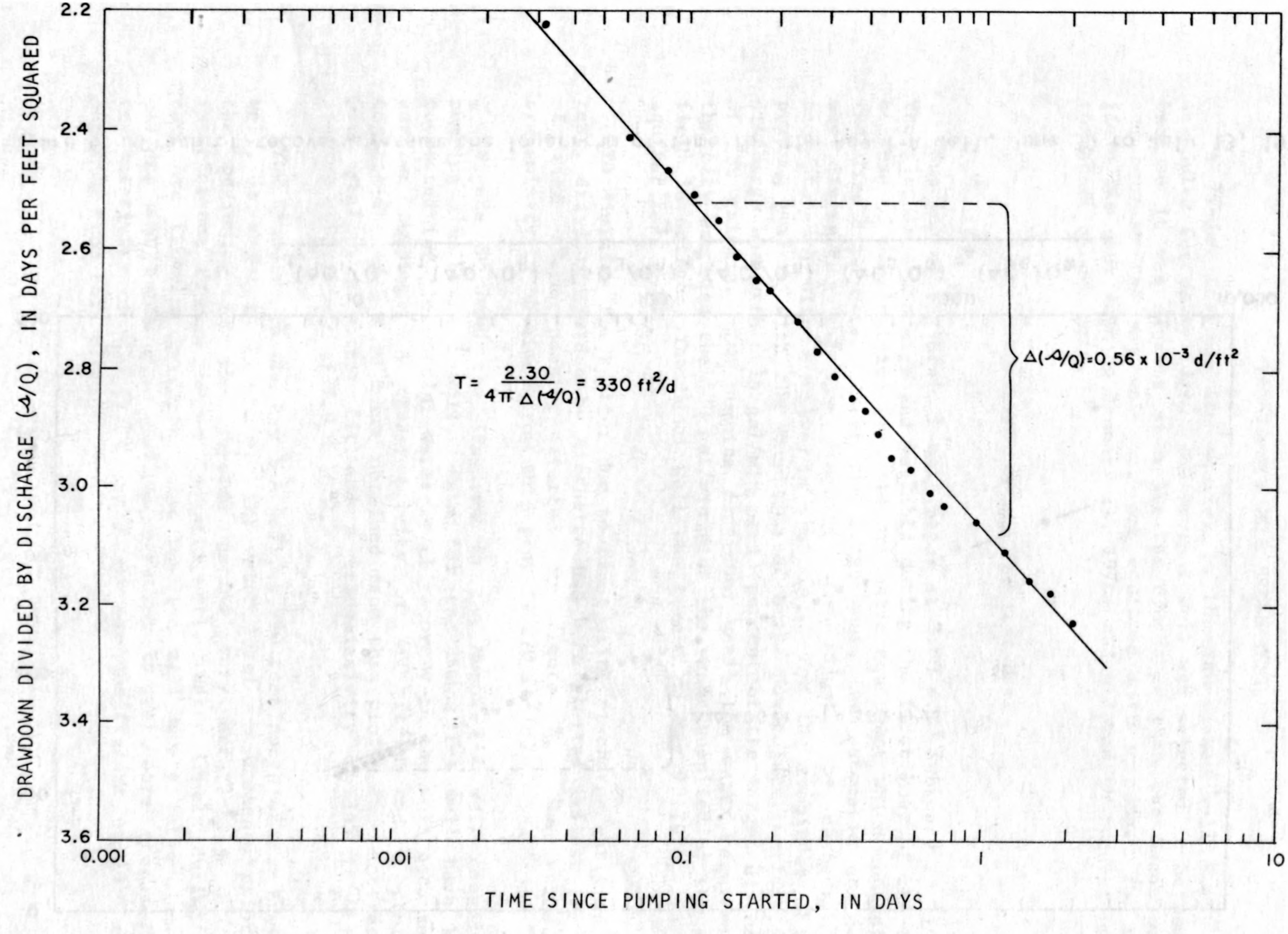

Figure 5.--Graph of the ratio of drawdown to discharge versus the logarithm of time for the Ray 1-A well, June 26-28, 1975.

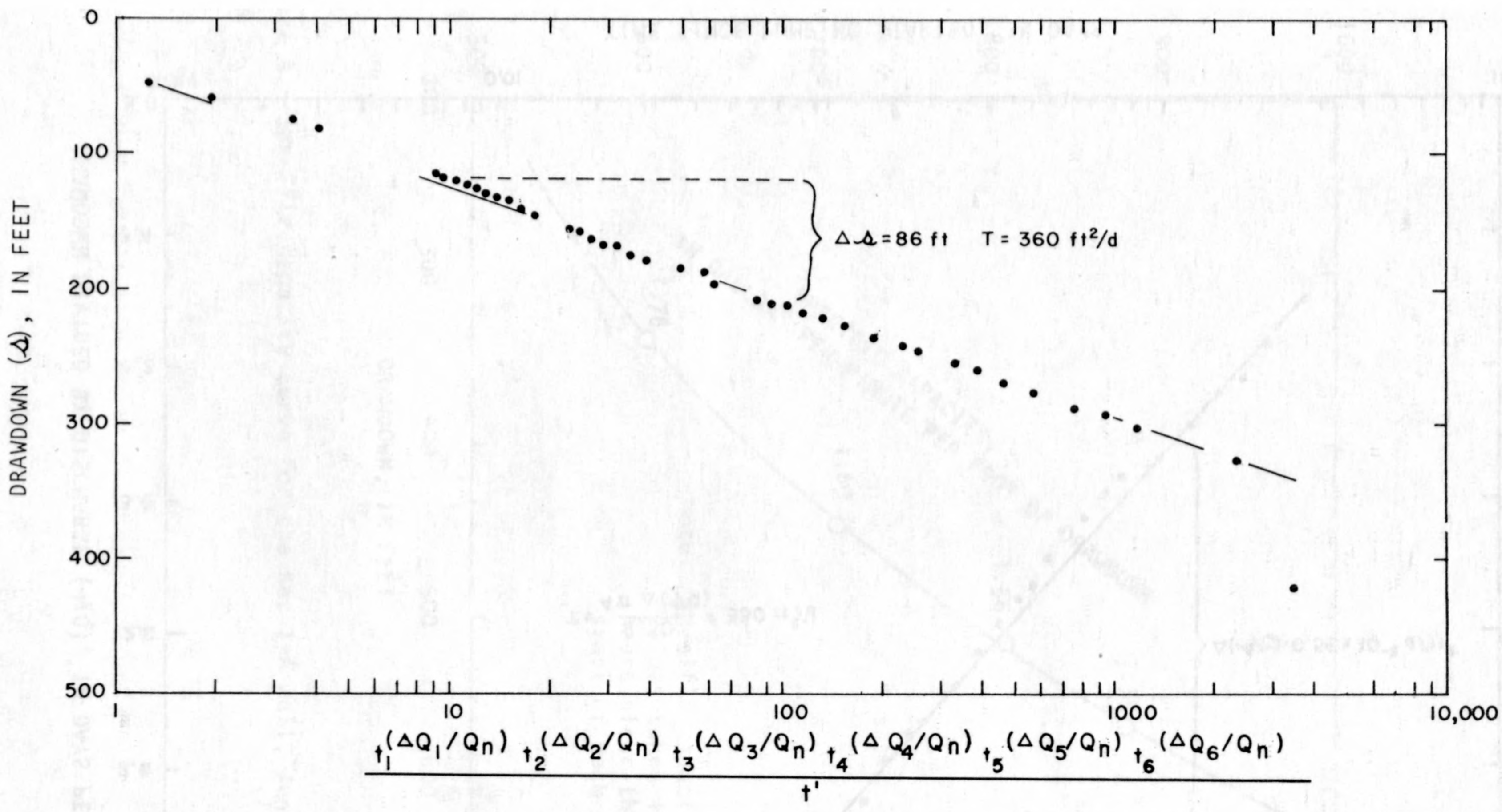

Figure 6.--Graph of recovery versus the logarithm of time for the Ray 1-A well, June 30 to July 13, 1975.

YAH-TA-HEY WELL FIELD TEST

A 75-day test of the aquifer in the Yah-ta-hey well field was scheduled for early 1976. The Erwin 1 well was selected to be pumped because it was capable of a greater discharge than the Munoz well, and because the Ray well was not equipped with a pump. The well field was shut down on January 11, 1976, and allowed to recover until the start of the test.

Analysis of aquifer test data

Pumping of the Erwin 1 well began at 3:00 p.m. February 23, 1976. The discharge was high and variable during the first hour of the test because of difficulties with the automatic equipment which controlled the discharge rate. After the first hour, the automatic equipment was disengaged and the discharge was adjusted by changing the back-pressure with a valve in the line. For the remainder of the pumping period, with the exception of brief power interruptions, the discharge was within 15 gal/min or ±3 percent of the target discharge of 580 gal/min. The pumping continued until the water required by the city exceeded the 580 gal/min plus the water supplied by the well field in Gallup. The Munoz well was turned on May 9, 1976, and the aquifer test ended.

To minimize the scatter due to fluctuating discharge early in the test, drawdown divided by discharge has been plotted against the log of time since pumping started in figure 7. The value of transmissivity obtained from this plot is 270 ft^2/d.

Figure 8 shows the drawdown in the Munoz 1-A well caused by pumping the Erwin 1 well. Data for the Munoz 1-A well have been corrected for the partial water-level recovery in the well because of earlier pumping. A transmissivity of 400 ft^2/d and a storage coefficient of 8×10^{-5} are obtained from this plot. The uncorrected plot yielded a poorer fit and a transmissivity of 365 ft^2/d and storage coefficient of 7.9×10^{-5}.

The drawdown in the Ray 1-A well, 4,990 feet north of the Erwin 1 well, is shown in figure 9. The water level measurements prior to the beginning of the pumping period vary erratically due to interference from a nearby domestic well. Water levels during the test are likewise variable. The Ray 1-A well has a large-diameter casing, and early data may be affected by well-bore storage. A transmissivity of 400 ft^2/d and a storage coefficient of 10^{-4} were obtained from this plot.

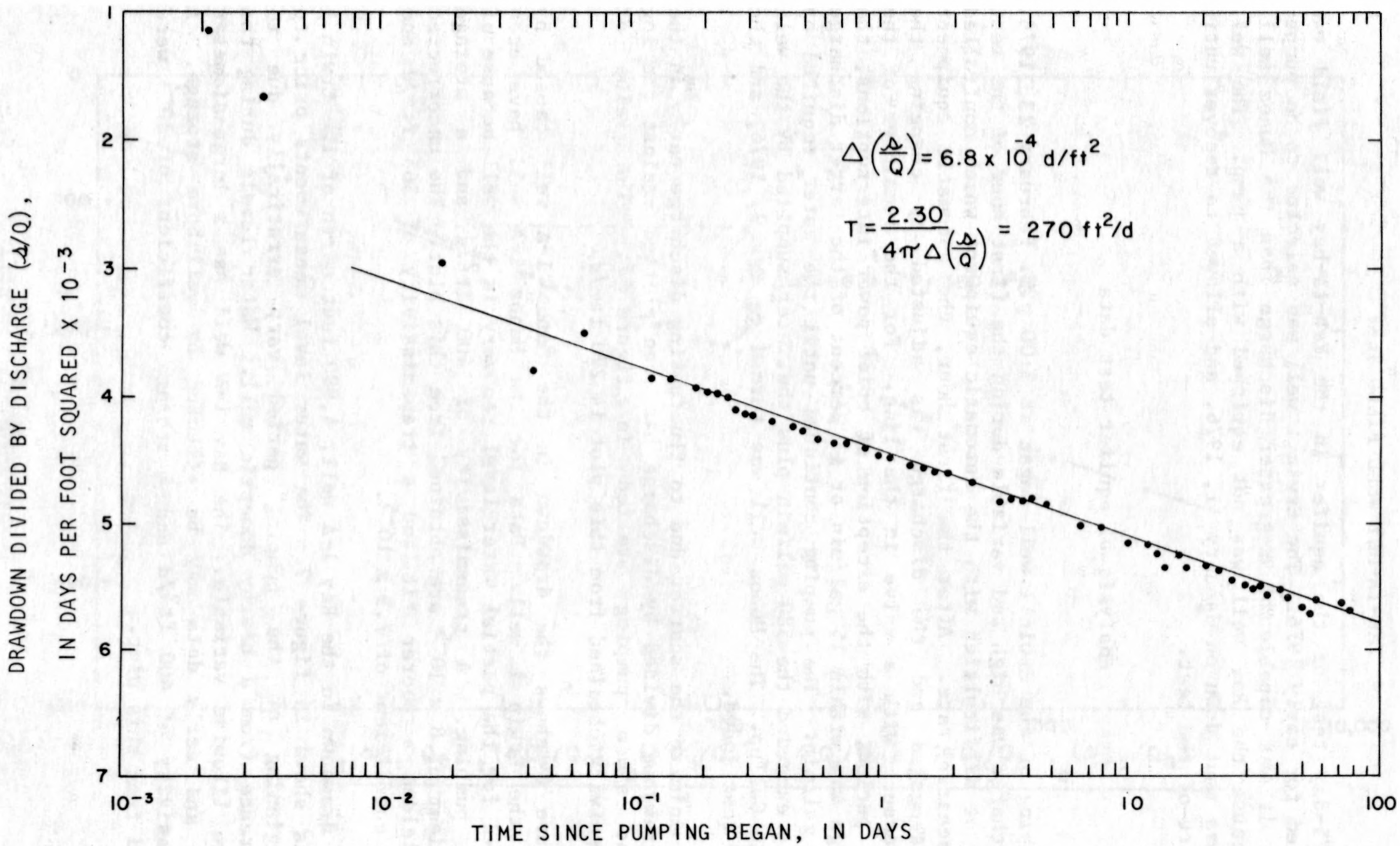

Figure 7.--Graph of the ratio of drawdown to discharge versus the logarithm of time for the Erwin 1 well, February 23 to May 9, 1976.

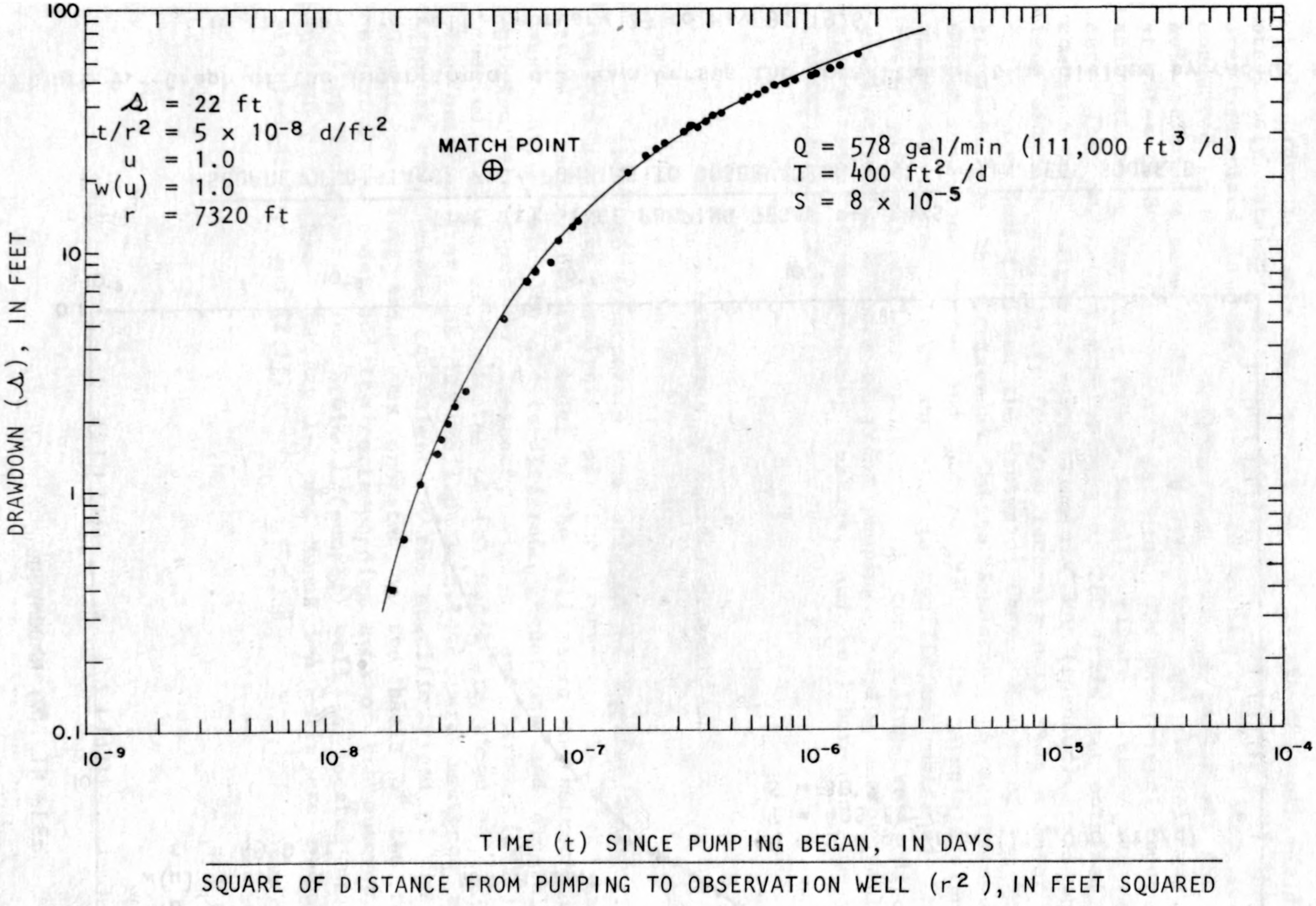

Figure 8.--Graph of the logarithm of drawdown versus the logarithm of time divided by radius squared in the Munoz 1-A well, February 23 to May 9, 1976.

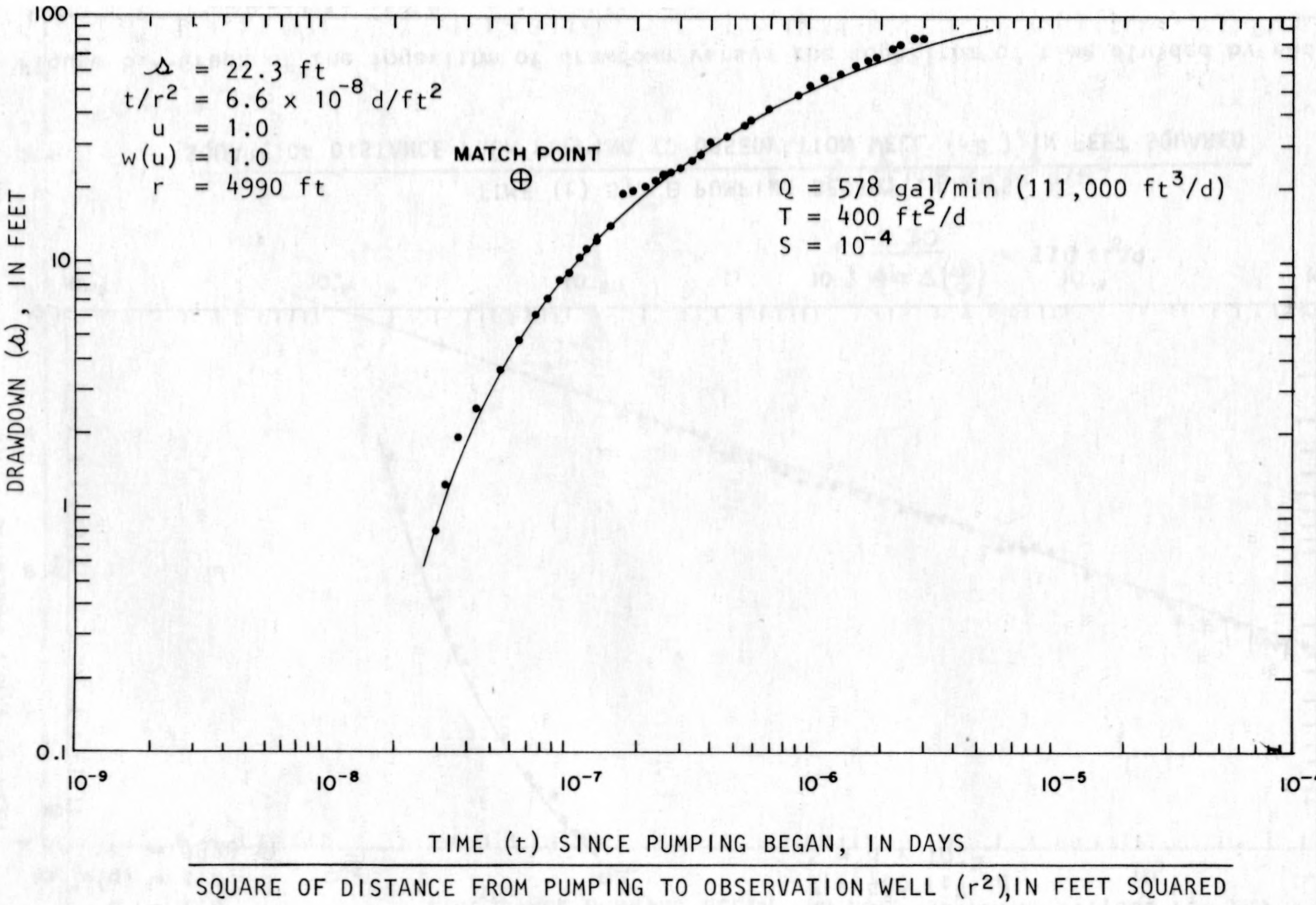

Figure 9.--Graph of the logarithm of drawdown versus the logarithm of time divided by radius squared in the Ray 1-A well, February 23 to May 9, 1976.

Previous aquifer tests

In order to check the results of the Yah-ta-hey well field test, previously obtained data were reexamined. The results of the tests are summarized in table 1. During January 1969 a step test was conducted in the Munoz 1-A production well. A packer was set in the hole below the base of the Gallup Sandstone, and the well was pumped at rates of 805, 708, and 575 gal/min. The water-level recovery was analyzed using Harrill's (1971) method. Figure 10 shows the recovery curve from which a transmissivity of 260 ft^2/d was obtained. This compares with values of approximately 300 (rounded) ft^2/d obtained from drawdown and 250 ft^2/d from recovery data from a later 10-day test, which had included the Westwater Canyon Member of the Morrison Formation and the Cretaceous Dakota Sandstone in addition to the Gallup Sandstone (Mercer and Cooper, 1970). The large differences in values of transmissivity and storage coefficient obtained from the tests probably reflect problems in controlling well discharge, eliminating the effects of prior pumping, pumping nearby wells, and the effects of boundaries, leakage, and well-bore storage on the aquifer test data.

Estimates of aquifer properties

In order to incorporate the effects of aquifer boundaries and leakage in the analysis of the long-term aquifer test, a two-dimensional digital model of the well field and surrounding area was constructed. The finite-difference equations and digital model program are given by Trescott, Pinder, and Larson (1976). The modeled area and grid spacing of the model are shown on figure 11. The outcrop areas of the Gallup Sandstone were assigned a large storage coefficient, equivalent to the specific yield of the Gallup Sandstone. This value was prorated on the basis of the relative areas of the nodes and the corresponding area of the outcrop of the Gallup Sandstone. The Erwin 1 (pumped) well is located at row 12 column 8 (12,8). The Ray 1-A and Munoz 1-A wells are respectively located at 10,8 and 12,11.

Table 1.--Aquifer tests in the Yah-ta-hey well field

Pumped well	Observation well	Date	Method of analysis	Period of pumping	Transmissivity (ft^2/day)	Storage coefficient	Reference
Muñoz 1-A	Muñoz 1-A	January, 1969	Semilog drawdown[1/]	10 days	300*	-	Mercer and Cooper, 1970
Do.	do.	do.	Semilog recovery[2/]	do.	250	-	Do.
Do.	do.	do.	Harrill's method[3/]	24 hours	260**	-	Do.
Do.	J.B. Tanner well	do.	Theis curve	10 days	30***	3×10^{-4}	Mercer and Cooper, 1970
Erwin 1	Erwin 1	July, 1970	Semilog drawdown	30 hours[4/]	350	-	Mercer and Leppala, 1972
Do.	do.	do.	Semilog recovery	111 hours	240†	-	Do.
Do.	Muñoz 1-A	do.	Theis curve	81 hours[5/]	145	3×10^{-5}	Do.
Do.	do.	do.	do.	111 hours	300††	5×10^{-5}	-
Do.	Erwin 1	January, 1976	Semilog drawdown	75 days	270	-	-
Do.	Ray 1-A	do.	Theis curve	do.	400†††	10^{-4}	-
Do.	Muñoz 1-A	do.	do.	do.	365§	9×10^{-5}	-
Do.	do.	do.	do.	do.	400§§	8×10^{-5}	-
Ray 1-A	Ray 1-A	June, 1975	Semilog drawdown	2 days	330	-	-
Do.	Erwin 1	do.	Theis curve	do.	-	10^{-4}	-
Do.	Ray 1-A	do.	Harrill's method	4 days	360	-	-

Table 1.--Aquifer tests in the Yah-ta-hey well field - Concluded

1/ Cooper and Jacob's modification of the Theis equation, described in Lohman (1972) p. 19.

2/ Theis recovery method, described in Ferris and others (1962) p. 100.

3/ Modified recovery method described by Harrill (1971).

4/ First step of a 111 hour step-test.

5/ Drawdown was corrected by projecting the drawdown curve for step 1 and plotting the difference in drawdown against the time since the start of step 2.

* Rounded.

** Rounded value, see figure 10. A packer was placed at 2,100 feet, isolating the Gallup Sandstone and higher units from the Dakota Sandstone and lower units.

*** Recomputed from data in Mercer and Cooper (1970). The observation well was pumped prior to and during the early part of the test. The value of transmissivity is erroneous, but the coefficient of storage may be approximately correct.

† Recovery, using a time-weighted discharge value of 725 gal/min. This test was recomputed using Harrill's method, also giving a transmissivity of 240 ft^2/day.

†† These values were computed by using Mercer and Lappala's 1972 data and fitting a Theis curve to the drawdowns for step 3. A value of 10^{-4} is more reasonable for storage.

††† Some interference from nearby domestic well.

§ Unadjusted data.

§§ Data corrected for the effects of earlier pumping.

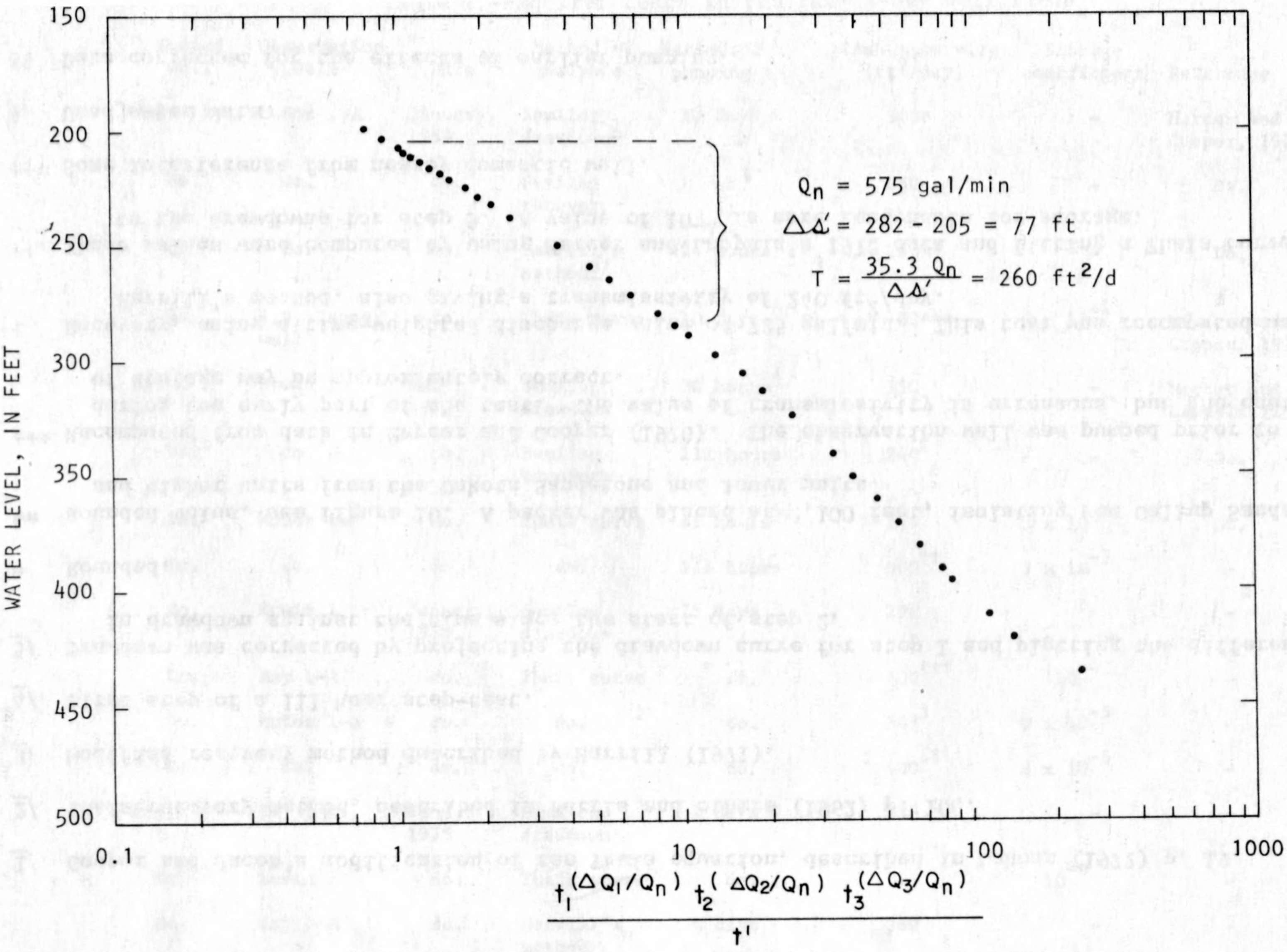

Figure 10.--Graph of recovery versus the logarithm of time in the Munoz 1-A production well, January 1969.

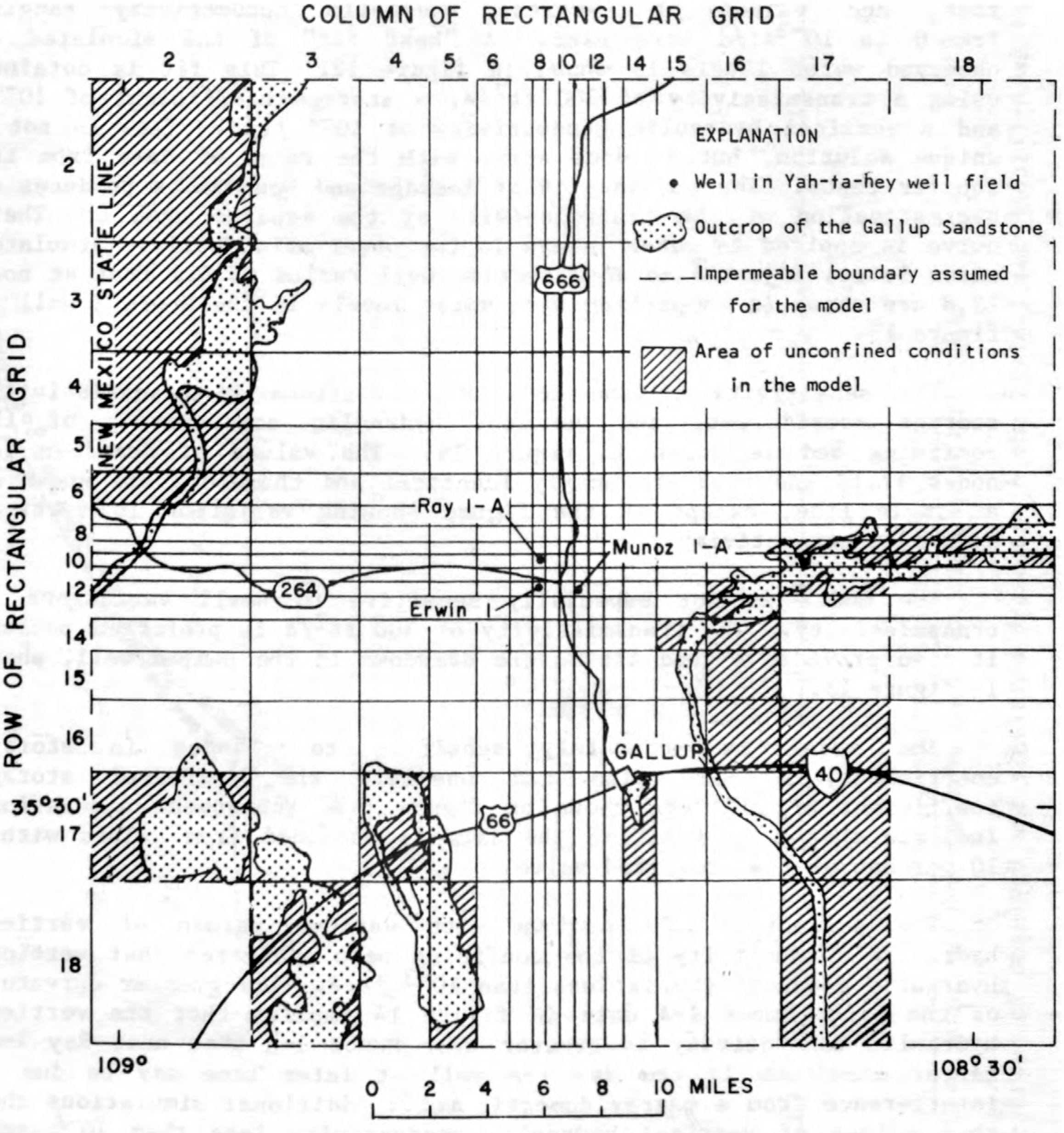

Figure 11.--Finite-difference grid and boundaries of the area modeled.

The ranges of values of transmissivity and storage coefficient obtained from the aquifer tests were used in a series of simulations. The specific storage of the confining beds was assumed to be 10^{-6} per foot, and values of vertical hydraulic conductivity ranging from 0 to 10^{-3}ft/d were used. A "best fit" of the simulated to observed water levels is shown in figure 12. This fit is obtained using a transmissivity of 300 ft^2/d, a storage coefficient of 10^{-4}, and a vertical hydraulic conductivity of 10^{-4} ft/d. This is not a unique solution, but it does agree with the range of data from the aquifer tests. The combination of leakage and boundaries produces an overestimation of the transmissivity of the aquifer when the Theis curve is applied to water levels in the observation wells. Simulated water levels adjusted to an effective well radius of 0.7 foot at node 12,8 are shown in comparison with water levels in the Erwin 1 well in figure 13.

The sensitivity of the model to variations in transmissivity, storage coefficient, and vertical hydraulic conductivity of the confining bed is shown in figure 14. The values of drawdown for nodes 12,11 and 10,8 are nearly identical and therefore are shown as a single line, except in the figure showing variation in vertical hydraulic conductivity.

The model is not especially sensitive to small variations in transmissivity. The transmissivity of 300 ft^2/d is preferred because it also provides a good fit to the drawdown in the pumped well, shown in figure 13.

The model is moderately sensitive to changes in storage coefficient. Values twice and one-half the preferred storage coefficient of 10^{-4} are shown on figure 14. Subsequent simulations indicate that a good fit to the data is obtained from values within 10 percent of the preferred value.

The comparison of drawdown with various values of vertical hydraulic conductivity of the confining beds indicates that vertical hydraulic conductivity is less than 10^{-3} ft/d. The greater curvature of the later Munoz 1-A data in figure 14 implies that the vertical hydraulic conductivity is greater near Munoz 1-A than near Ray 1-A. Larger drawdowns in the Ray 1-A well at later time may be due to interference from a nearby domestic well. Additional simulations show that values of vertical hydraulic conductivity less than 10^{-4} ft/d are not significantly different from a vertical hydraulic conductivity of zero. Therefore, vertical hydraulic conductivity in the confining beds is certainly less than 10^{-3} ft/d, and is probably less than 10^{-4} ft/d. These values probably represent the minimum vertical hydraulic conductivity of any continuous layer within the Crevasse Canyon Formation, rather than an average value for the entire unit.

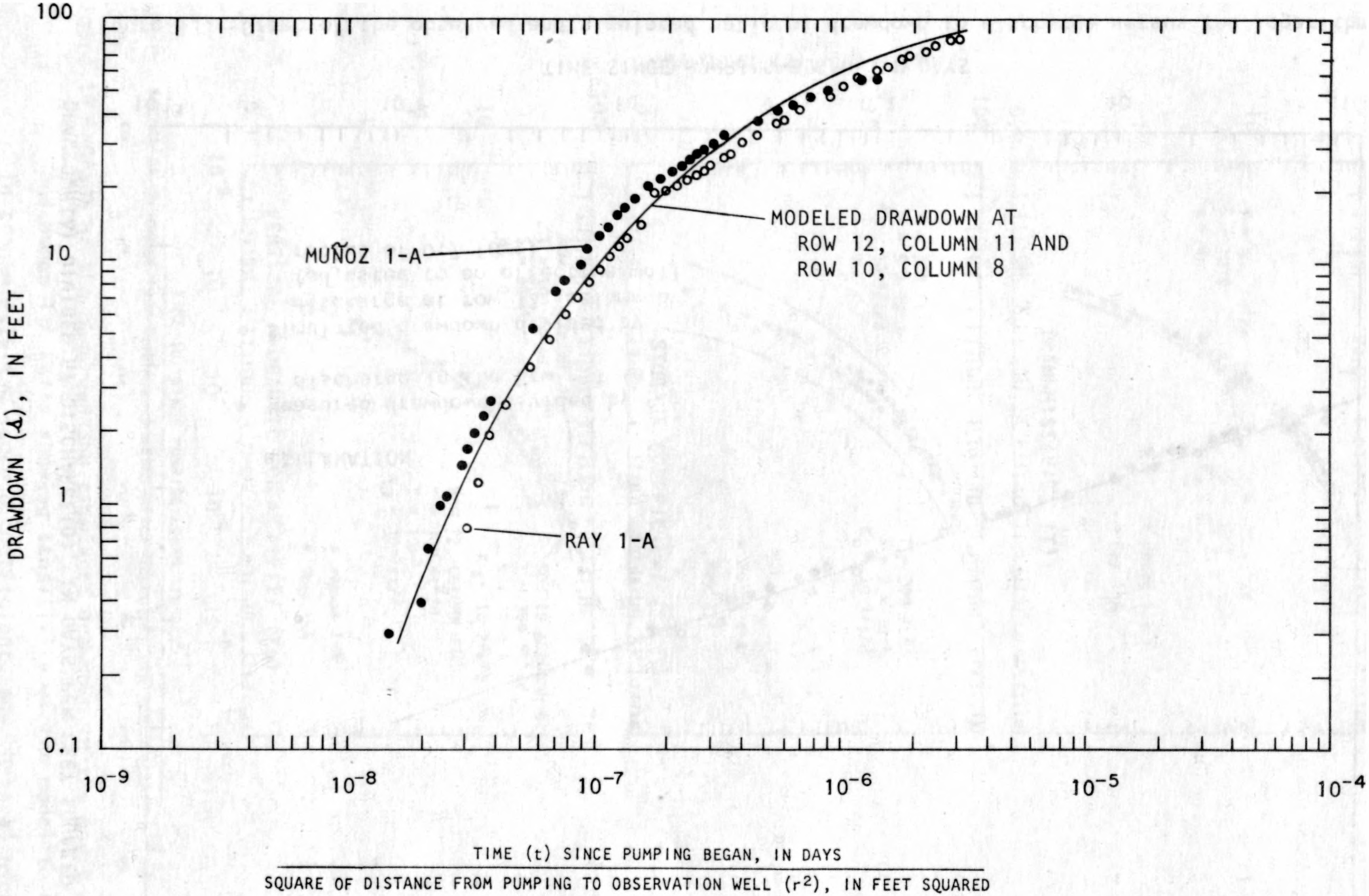

Figure 12.--Graph of observed and simulated drawdown in the Erwin 1 and Munoz 1-A wells, February 23 to May 9, 1976.

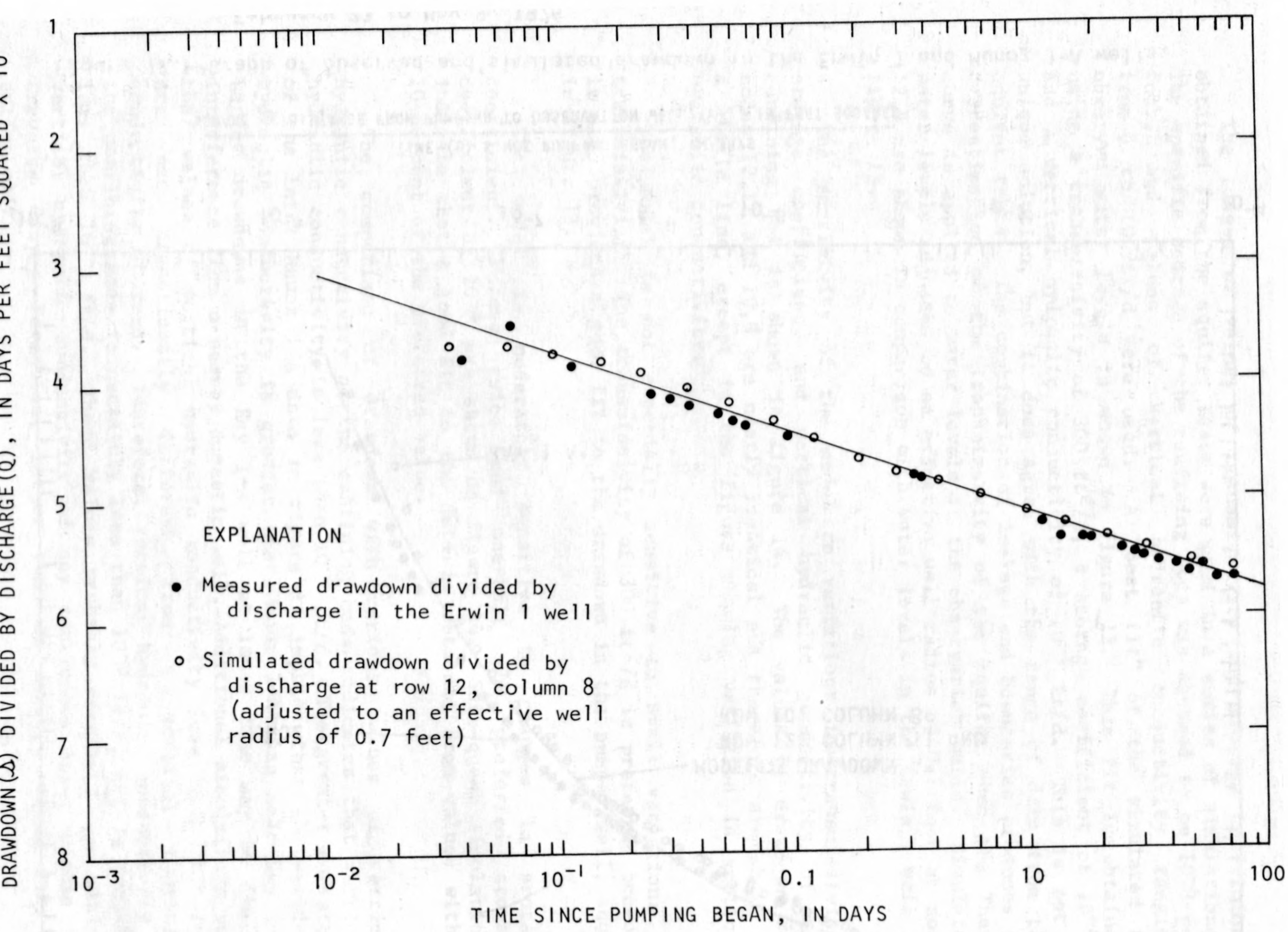

Figure 13.--Graph of the observed and simulated ratio of drawdown to discharge versus the logarithm of time for the Erwin 1 well, February 23 to May 9, 1976.

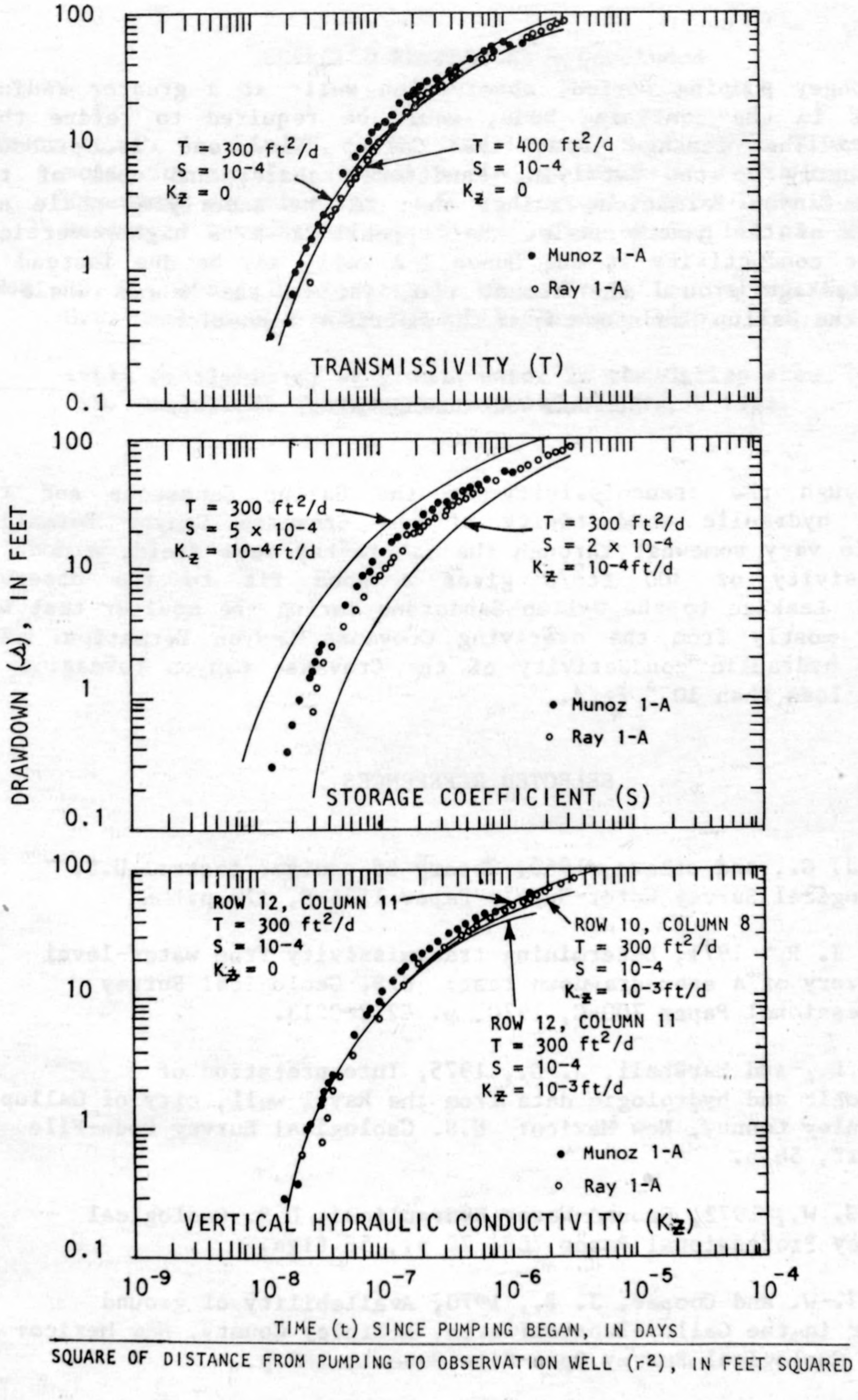

Figure 14.--Graph of the observed and simulated drawdown in the Ray 1-A and Munoz 1-A wells showing sensitivity of the model to changes in transmissivity, storage coefficient, and vertical hydraulic conductivity.

A longer pumping period, observation wells at a greater radius, or wells in the confining beds, would be required to refine this estimate. The leakage from the Gallup Sandstone is probably predominantly to the overlying sandstone, shale, and coal of the Crevasse Canyon Formation, rather than to the underlying shale and siltstone of the Mancos Shale. What appears to be a higher vertical hydraulic conductivity at the Munoz 1-A well, may be due instead to slight leakage around the cement plug set in the Mancos Shale to isolate the Gallup Sandstone from the Morrison Formation.

SUMMARY AND CONCLUSIONS

Although the transmissivity of the Gallup Sandstone and the vertical hydraulic conductivity of the Crevasse Canyon Formation appear to vary somewhat through the Yah-ta-hey well field, a modeled transmissivity of 300 ft^2/d gives a good fit to the observed drawdown. Leakage to the Gallup Sandstone during the aquifer test was probably mostly from the overlying Crevasse Canyon Formation. The vertical hydraulic conductivity of the Crevasse Canyon Formation is probably less than 10^{-4} ft/d.

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