BAD WATER LINE TRANSECT PUMPING TEST AT SAN ANTONIO CITY WATER BOARD'S ARTESIA STATION, MARCH 25, 1987

Prepared for

City Water Board of San Antonio
and
Edwards Underground Water District
San Antonio, Texas

By

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Gentlemen:

Transmitted herewith is our report on the pumping test that was made at the City Water Board's Artesia Station on March 25, 1987.

The results from the test show an apparent transmissivity for the Edwards aquifer that is large and in the range from about 6,000,000 to 8,000,000 gallons per day per foot. Because of the way in which hydraulic boundaries affect the results from pumping-test analysis, the actual transmissivity of the Edwards between boundaries is believed to be considerably larger than this.

Drawdowns of water level occurred in both the fresh and saline zones of the aquifer as a result of pumping at a rate of 36 million gallons per day for 12 hours, and ranged from less than 2-1/2 feet at the nonpumped wells at and near Artesia Station to about 1.4 feet at Well J-17 located about 3-1/4 miles north of the station.

Chemical analyses show there was no significant change in the quality of the water produced by the pumped wells during the 12-hour pumping period.

We will be glad to answer any questions you might have about the pumping test.

With best regards,

Sincerely yours,

WILLIAM F. GUYTON ASSOCIATES, INC.

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INTRODUCTION

This report discusses the pumping test that was made of wells located at the City Water Board's Artesia Station to stress the Edwards aquifer. Artesia Station is located at the north end of a line of monitor wells that comprise the Edwards Aquifer Bad Water Line Transect in San Antonio.

The pumping test was planned jointly by the City Water Board, U. S. Geological Survey, and William F. Guyton Associates, Inc. It consisted of a 12-hour nonpumping period during which water levels at the various wells were measured to identify water-level trends, a 12-hour period of continuous pumping at a constant rate from three of the production wells at Artesia Station, and a 6-hour nonpumping period during which water-level recovery measurements were made at the nonpumping wells. In addition, two sets of water samples were collected from each of the pumped wells during the test for chemical analysis by the U. S. Geological Survey. Data from the test were analyzed to determine hydraulic conditions in the aquifer in the vicinity of the Bad Water Line Transect and the impact of this large-scale nearby pumping.

The City Water Board made its Artesia Station facilities available for the pumping test, and its operating personnel assisted in conducting the test. It also conducted tests of its pumping and measuring equipment prior to the pumping test to assure trouble-free operation during the test and to develop current pump-performance data required for evaluating the distribution of pumping. Personnel of the U. S. Geological Survey installed and operated water-level measuring equipment at all the wells, assisted the City Water Board in making preliminary checks of its production wells and measuring equipment, and provided around-the-clock collection of data during the test. William F. Guyton Associates, Inc. assisted in the conduct of the test and analyzed the data that were obtained. The assistance provided by Mr. Donald Pollard of the City Water Board and Messrs. Paul Rettman and Ted Small of the U. S. Geological Survey in arranging for the pumping test and making measurements during the test are especially appreciated.

LOCATIONS OF WELLS

The locations of wells utilized for the pumping test are shown on Figure 1. As noted on Figure 1, Well J-17 (AY-68-37-203), commonly known as the San Antonio index well and used as one of the observation wells during the test, is located about 3-1/4 miles north of Artesia Station.

City Water Board wells located at Artesia Station are constructed to draw water from the full thickness of the Edwards aquifer. Well J-17 is open to the full thickness of the Edwards above the regional dense bed and a part of the Edwards below the dense bed. The dense bed hydraulically separates the Edwards into an upper and lower section. Monitor Wells A-1, C-2, and D-1 are constructed to draw water from parts of the Edwards aquifer below the regional dense bed, and Monitor Wells A-2, A-3, C-1, and D-2 are constructed to draw water from above the regional dense bed.

The A, C, and D monitor wells comprise the Artesia Station Bad Water Line Transect that was constructed in 1985 and 1986 as part of the Edwards Aquifer Bad Water Line Experiment. That project was cooperatively sponsored by the City Water Board of San Antonio, Edwards Underground Water District, Texas Water Development Board, and U. S. Geological Survey.

PUMPING-TEST MEASUREMENTS

Measurements made during the pumping test include the combined pumping rate for the three production wells, water levels at production wells, monitor wells, and Well J-17, and discharge pressures at the production wells while pumping. Arithmetic plots of the water-level measurements and of the combined pumping rate for the three production wells during the pumping test are presented on the graphs that are included in the pocket at the end of this report. In addition to the above measurements, a record of the barometric pressure during the test period was obtained for use in analyzing the test data.

Pumping Rate

Wells 3, 4, and 5 at Artesia Station were pumped concurrently for pumping-test purposes. The three wells were started and stopped within a period of a few seconds so that pumping the three wells together was essentially the same as pumping one large production well for pumping-test purposes. Well 1, the fourth well at Artesia Station equipped with a pump, was not operated during the pumping test because the distribution system served by Artesia Station was not able to accept the extra water due to limited local water demand at that time. In fact, the system was not able to accept all the water the three wells pumped during the pumping test. As a result part of the water produced during the test had to be discharged to waste.

Wells 3, 4, and 5 are not equipped with individual flowmeters. Therefore, the pumping rates of the individual wells were determined by using the head-capacity curves that had been developed for the pumps prior to the pumping test and the proportional relationship of these rates to the combined pumping rate for the three wells. The combined pumping rate for the three wells during the test was measured at an in-line orifice installed in the common pipeline through which the water was discharged to the ground storage tank. This orifice was equipped with a manometer which measured the differential head across the orifice. It also was connected to a recording flowmeter which registered the flow in million gallons per day (mgd) on a chart located in the pump station. The orifice had been checked and calibrated prior to the pumping test to be sure it was providing reliable measurements. The flow measurements made during the pumping test are plotted on one of the graphs that are included in the pocket at the end of this report.

For purposes of pumping-test analysis, an average total pumping rate of 36 mgd was used. This is equivalent to a continuous pumping rate of about 25,000 gallons per minute (gpm). This average flow rate is somewhat greater than that indicated by the chart in the pump station and slightly less than that determined from readings of the manometer at the orifice. The pumping rates of the production wells during the test were computed to average 13.1 mgd (9,100 gpm) at Well 3, 10.3 mgd (7,160 gpm) at Well 4, and 12.6 mgd (8,760 gpm) at Well 5. These individual pumping rates and the relative locations of the wells were used to determine the approximate center of pumping for pumping-test purposes. The location of the approximate center of pumping is shown on Figure 1.

Water Levels

Water levels at all wells, with the exception of Well J-17, were above ground level throughout the pumping test. Graphs of the water-level measurements expressed in feet above mean sea level are presented in the pocket at the end of this report. The depth of the producing interval for each well in which water levels were measured is noted on the graphs.

Pressure gauges were used to measure water levels at the pumped wells. A water manometer was used to measure the water level at Well 5 during part of the pumping period when water levels had declined to near land surface. The measurements made with the manometer were analyzed with other water-level data to determine aquifer transmissivity. Water levels at the other Artesia Station wells and the monitor wells that comprise the Bad Water Line Transect were measured with transducers tied to data recorders which recorded the measurements and stored them for later retrieval. The measuring equipment at Well J-17 also was tied to a data recorder. A graphical pressure recorder was installed at Well C-1 during the latter part of the pumping test when the transducer failed to register acceptable measurements.

Measurements for identifying water-level trends for the nonpumped wells began at about 6:00 p.m. on March 24 and continued until pumping began at 6:00 a.m. on March 25. Extrapolation of the trends provided the base line from which water-level drawdowns were determined during the pumping period, which extended from 6:00 a.m. to 6:00 p.m. on March 25. At 6:00 p.m. pumping stopped, and measurements of the recovering water levels continued until midnight when the test was concluded.

Measurements of water levels in the pumped wells include trend measurements from midnight on March 24 until pumping began at 6:00 a.m. on March 25, pumping-level measurements from 6:00 a.m. to 6:00 p.m. that evening when pumping stopped, and then a few recovery measurements after pumping stopped. The primary purpose for making measurements of water levels at the pumped wells was to provide information for determining the field discharge head against which the pumps operated, so that pumping rates could be adjusted if necessary to maintain a constant pumping rate and so that the pumping rates of the individual wells could be estimated. The measurements also were used to arrive at conservative values of specific capacity for each of the three pumped wells.

The measuring equipment installed at the wells was checked periodically during the test to find out if it was operating satisfactorily. Problems with the transducers installed at Wells A-1 and C-1 were discovered when they failed to produce good measurements. Replacement transducers were not available to replace those that failed. As noted earlier, the one pressure recorder that was available was installed at Well C-1 when the transducer failed to provide acceptable water-level measurements. Some of the early recovery data for Well A-1 were salvaged for analysis by drawing an approximate trend line and recovery curve through the data. Analysis of the data for Well 1 at Artesia Station indicates there may have been a problem with some of the drawdown measurements at this well, but both drawdown and recovery data were analyzed.

Pumping at an unknown location outside the general area of Artesia Station affected the water levels that were measured during the pumping test. This is reflected by the cyclic water-level drawdown and recovery pattern that is superimposed on the general water-level trends during the various phases of the test. The pumping that caused these small cyclic fluctuations in water levels appears to have been quite regular in terms of amount, frequency, and duration. Therefore, they were compensated for by drawing a smooth curve through the plotted points that appeared to be unaffected by the cyclic fluctuations and using this curve to determine the amount of water-level drawdown and recovery that resulted from pumping at Artesia Station. These amounts of drawdown and recovery were used in analyzing the pumping-test data.

Drawdowns of water levels at the various observation wells after 12 hours of pumping 36 mgd (about 25,000 gpm) from Wells 3, 4, and 5 at Artesia Station were as follows:

Well	Drawdown (feet)	Well	Drawdown (feet)
A-2	1.00	D-2	2.36
A-3	1.37	Art. 1	2.40
C-2	0.88	Art. 6	2.13
D-1	1.80	J-17	1.39

These drawdowns have been corrected for trend, and show that the effect that pumping has on water levels is relatively small but widespread. Drawdown occurred in the saline-water zone of the Edwards aquifer as well as in the fresh-water zone.

Drawdowns of water levels in the pumped wells after 12 hours of continuous pumping were about 21 feet at Well 3, 30 feet at Well 4, and 17 feet at Well 5. Using the estimated pumping rates for individual wells given above, conservative specific-capacity values at those pumping rates of about 435 gallons per minute per foot (gpm/ft) for Well 3, 240 gpm/ft for Well 4, and 515 gpm/ft for Well 5 are calculated. These are truly conservative values because the drawdowns in the pumped wells include the interference effects from pumping the other wells.

Barometric Pressure

Changes in barometric pressure that occur during a pumping test can cause significant changes in water levels that need to be considered in analyzing the pumping-test data. Therefore, records of barometric pressure during the pumping-test period were obtained to determine whether corrections needed to be applied to the water levels that were measured at the wells. The following measurements reflect barometric pressure during the pumping-test period.

Date	Time	Barometric Pressure (inches of mercury)
3-24-87	9 p.m.	29.82
	12 midnight	29.83
3-25-87	3 a.m.	29.87
	6 a.m.	29.89
	9 a.m.	29.98
	12 noon	29.97
	3 p.m.	29.90
	6 p.m.	29.90

As can be seen from an examination of the above measurements, the maximum change in barometric pressure during the pumping-test period was 0.16 inches of mercury between 9 p.m. on March 24 and 9 a.m. on March 25. If the response of water levels in the wells to changes in barometric pressure was at 100 percent efficiency, an efficiency seldom if ever achieved, the maximum change in water levels during the 12-hour period would be less than 0.2 feet. This maximum change in water levels due to changes in barometric pressure is relatively insignificant when the total changes in water levels caused by pumping and the fluctuations in water levels due to other factors are taken into consideration. Therefore, no attempt was made to correct the measured water levels for changes in barometric pressure.

Water Quality

The lowermost part of the Edwards aquifer at Monitor Well D-1 contains highly mineralized water. Therefore, water samples were collected from each of the pumped wells during the pumping test to determine whether the quality of the water produced from these wells increased in mineralization as a result of stressing the aquifer so near the bad water line. One set of water samples was collected immediately following the start of pumping, and a second set was collected just prior to the time that pumping stopped. The water samples were sent to the U. S. Geological Survey laboratory for chemical analysis.

Water samples were not collected from the monitor wells during the pumping test because of concern that producing water from the wells during the pumping-test period might affect water levels in the wells and jeopardize the data for analysis. The monitor wells are allowed to flow naturally for a few hours to flush the system and to be sure that the water sample is representative of water in the section of the Edwards aquifer that supplies water to the well before water samples are collected for chemical analysis.

AQUIFER COEFFICIENTS

The Jacob, Theis, and Thiem methods for pumping-test analysis are commonly used to arrive at aquifer coefficients. The Jacob method is an adaptation of the Theis equation. All three methods of analysis apply to aquifers that are homogeneous, isotropic, and of infinite areal extent. None of these conditions apply to the Edwards aquifer in the Artesia Station area on a local basis. Therefore, the coefficients of transmissivity (T) obtained by using all three methods actually are apparent values in that they indicate how the Edwards aquifer in this locality with its hydraulic boundaries compares to an areally extensive aquifer meeting all the assumptions that are inherent in the equations. Coefficients of storage (S) were obtained by using the Theis method of analysis, but they are meaningless because of how the results of analysis are affected by hydraulic boundaries in the Edwards.

A total well field pumping rate of 25,000 gpm (about 36 mgd) was used for calculating aquifer properties in all cases. This approach was taken because there is no way to measure the percentage of the water being pumped that moves through each segment of the aquifer. It also is possible that the storage-to-transmissivity ratio for the aquifer probably is nearly the same for each aquifer segment, in which case this approach would be acceptable with the results of analysis reflecting values for the full aquifer thickness. Data obtained during construction of the Bad Water Line Transect show a common static water level (pressure head) for all water-bearing intervals at each well site, and the water level was drawn down to a common level at the center of pumping.

Jacob Method

An adaptation of the Theis equation, referred to herein as the Jacob equation, was used as one method for analyzing the pumping-test data. Semi-logarithmic plots of water levels used with the Jacob equation for determining transmissivity values for the aquifer are shown on Figures 2 and 3. Drawdown data are shown on Figure 2 and recovery data are shown on Figure 3. The Jacob equation for computing transmissivity (T) is given on each graph and the drawdown or recovery value(s) per log cycle utilized in the equation with the pumping rate (Q) is identified for each straight-line portion of the plotted data. These portions are referred to as an early time (early) portion and a late time (late) portion because of a change in the slope of the plotted data that is shown for most wells. Computed values of transmissivity are given in Table 1.

It will be noted that the water-level drawdown measurements determined for Artesia Well 1 do not approximate a straight line for any part of the test. Therefore, no transmissivity value was calculated for these data by using the Jacob equation. Lack of acceptable water-level trends and/or poor definition of water-level changes precluded analysis of measurements made at Wells A-2, A-3, C-2, and J-17 during the water-level recovery period.

Theis Method

Log-log plots of water-level drawdown or recovery data are required for analysis of pumping-test data using the Theis method. Plots of water-level data for all the wells having what appear to be acceptable measurements are shown on Figure 4, together with the Theis equation for transmissivity and storage coefficient. None of the recovery measurements were analyzed using the Theis method.

Water-level drawdown(s) and time since pumping started (t) values from the pumping test are plotted on the log-log graphs. The curved line drawn through the plotted points is the type curve for which the W(u) and u values required for solving the Theis equation are obtained. W(u) and u values that apply to the type curve at a "match point" for each portion of the plotted data are shown on the graph, and the corresponding respective drawdown(s) and time since pumping started (t) values can be read from the coordinates of the "match point" on the graph. As was the case for the Jacob method, the type curve has been fitted to data points representing early and late times for most wells. The results of calculations using the Theis method of analysis are given in Table 1, together with the distance each observed well is from the approximate pumping center. This distance (r) is required for determining a value for the storage coefficient.

The coefficient of storage values that were obtained from analysis of the data are inordinately large and not reasonable for this type of aquifer. They undoubtedly reflect the effects of boundaries within the aquifer, and while meaningless, are presented to show the results of calculations using the Theis equation.

Thiem Method

The Thiem method of analysis involves plotting the amount of water-level drawdown that occurs in a series of wells after steady-state conditions have been reached against the distance the wells are located from the pumped well. For purposes of analysis, steady-state conditions occur when water levels in the observed wells are all declining at the same rate. Drawdowns after 300 minutes of pumping are plotted against distance from the pumped well on semi-logarithmic paper on Figure 5. The Thiem equation and the related value used for calculating transmissivity are shown on the graph.

Plots of the drawdown values for progressive times during the pumping test show that steady-state conditions probably are established fairly early during the pumping test. The arithmetic plots of water levels presented on the graphs in the pocket at the end of the report also illustrate this in that the downward slope of the plotted points for most of the wells is essentially the same after a few hours of pumping. A time of 300 minutes was selected for analysis because it appears that water-level changes later in the test were somewhat less stable.

It can be seen that at least three separate straight lines might be drawn through the plotted points on Figure 5 rather than just the one that is shown. There is no way of knowing for sure which line of many might be the correct one, but the line that is shown falls between the bounding lines that might reasonably be drawn to reflect minimum and maximum slopes. By using the drawdown per log cycle value for the line shown on the graph, an apparent transmissivity value of 9,000,000 gpd/ft is calculated. This value is somewhat greater than the averages for the individual Jacob and Theis values given in Table 1, which are 7,980,000 gpd/ft for early data and 6,210,000 gpd/ft for late data. It also is greater than the averages by sections of the aquifer presented in Table 2, which are 7,410,000 gpd/ft based on early data and 5,900,000 gpd/ft based on late data.

WATER QUALITY

The results of chemical analyses for the two sets of water samples collected from each of the three wells pumped during the pumping test (Artesia Wells 3, 4, and 5) are presented in Table 3. Analyses of water samples collected from the basal part of the test hole drilled at the site of Well D-1 which show highly mineralized water in the basal part of the Edwards also are given in Table 3. While water samples were not collected from Wells D-1 and D-2 during the test, chemical analyses of water samples collected during the monthly sampling program a few days prior to the test and about one month later are included in Table 3.

Chemical analyses made of the two sets of water samples collected from each of the wells that were pumped during the pumping test show there was no significant change in the quality of the water that was produced during the test. The quality of the water was essentially the same as that produced from Monitor Well D-2 (upper Edwards) a few days before the pumping test. If a significant amount of highly mineralized water, such as that encountered by the test hole in the lowermost part of the Edwards aquifer, had been drawn into the pumped wells, its effect on the quality of the produced water should have been detected during the test. It should also have been noted during long-term production of water over the years the wells have operated. Thus, it appears that very little of the water produced from the production wells comes from the lowermost part of the Edwards.

Comparison of chemical analyses of water samples collected from Wells D-1 and D-2 as part of the regular monthly sampling program a few days before the pumping test with analyses of water samples collected from the wells about one month later indicates that the water from both wells may have increased in mineralization between March and April 1987. Numerically, the change at Well D-1 is most evident, but percentagewise the changes in quality for both wells are approximately the same. The increases in values probably are due to natural variations in water quality rather than changes resulting directly from pumping water at Artesia Station. Analyses of water samples collected at both wells at earlier and later times show that the apparent changes in quality are within the range through which the values have fluctuated historically.

SUMMARY OF PUMPING-TEST RESULTS

The results from the pumping test show that the hydraulics of the Edwards aquifer in the vicinity of the Artesia Bad Water Line Transect are very complex. This probably results from extensive faulting that is present in the area, especially at and near Artesia Station, and the development of solution openings within the Edwards. Thus, the aquifer is not homogeneous, isotropic, and of infinite areal extent as is required for proper application of Jacob, Theis, and Thiem formulas to determine aquifer coefficients.

Transmissivity values obtained by applying the Jacob, Theis, and Thiem formulas for determining aquifer properties, while being highly variable, show that the Edwards has a very high transmissivity in the Artesia Station area. It probably is considerably greater than the average apparent values obtained from analysis of the data which are in the range from about 6,000,000 to 8,000,000 gpd/ft. Values for coefficients of storage determined from applying the formulas to the water-level data are meaningless because of the way aquifer boundaries affect the results of pumping-test analysis.

The results from the pumping test show that the amounts of water-level drawdown in the Edwards aquifer due to pumping are small but widespread within both the fresh-water and saline-water zones. This is illustrated by the fact that the largest drawdown in the pumped wells during the pumping test, including the effect of pumping from two nearby wells, was about 30 feet after 12 hours of continuous pumping about 25,000 gpm from all three wells. At the same time, the drawdown at Artesia Well 1, about 1,500 feet away from the center of pumping, was about 2.4 feet, and at Well J-17, about 3-1/4 miles to the north, it was about 1.4 feet.

Chemical-analysis data show that even though poor quality water is present in the basal part of the Edwards aquifer a short distance from the wells that were pumped heavily during the pumping test, there was no detectable change in the quality of the water produced from the wells. In addition, the monthly chemical-analysis data for Monitor Wells D-1 and D-2 prior to and following the pumping test do not show a change in water quality that would reflect a permanent shift in the position of the bad water line as a result of pumping for the pumping test and to supply system demands.

TABLE 1. ANALYSIS OF PUMPING TEST WATER-LEVEL CHANGES
(Pumping rate used for analysis is 25,000 gallons per minute)

Well Number	Distance from Center of Pumping (feet)	Type of Analysis[1/]	Analysis of Early-Time Data: Transmissivity (T), gpd/ft, From Plot	Analysis of Early-Time Data: Transmissivity (T), gpd/ft, Average	Analysis of Early-Time Data: Storage Coefficient (S)	Analysis of Late-Time Data: Transmissivity (T), gpd/ft, From Plot	Analysis of Late-Time Data: Transmissivity (T), gpd/ft, Average	Analysis of Late-Time Data: Storage Coefficient (S)
Artesia Well 5	-	Jacob (Dd)	-	-	-	5.40×10^6	5.40×10^6	-
Artesia Well 6	530	Jacob (Dd) Theis Jacob (Rec)	9.04×10^6 8.43×10^6 6.73×10^6	8.07×10^6	0.00209	4.71×10^6 5.12×10^6 6.73×10^6	5.52×10^6	0.0120
Artesia Well 1	1,530	Theis Jacob (Rec)	3.02×10^6 7.59×10^6	5.30×10^6	0.0137	3.02×10^6 7.59×10^6	5.30×10^6	0.0137
D-1	1,125	Jacob (Dd) Theis Jacob (Rec)	13.20×10^6 12.73×10^6 9.43×10^6	11.78×10^6	0.00204	7.33×10^6 8.95×10^6 5.50×10^6	7.26×10^6	0.00456
D-2	1,100	Jacob (Dd) Theis Jacob (Rec)	11.78×10^6 12.19×10^6 8.57×10^6	10.85×10^6	0.00129	4.61×10^6 5.62×10^6 8.57×10^6	6.27×10^6	0.00660
C-1	2,220	Jacob (Rec)	4.00×10^6	4.00×10^6	-	2.56×10^6	2.56×10^6	-
C-2	2,150	Jacob (Dd) Theis	9.85×10^6 6.82×10^6	8.34×10^6	0.0288	6.73×10^6 6.82×10^6	6.77×10^6	0.0288
A-1	6,300	Jacob (Rec)	4.05×10^6	4.05×10^6	-	4.05×10^6	4.05×10^6	-
A-2	6,200	Jacob (Dd) Theis	5.24×10^6 2.86×10^6	4.05×10^6	0.00307	11.79×10^6 11.46×10^6	11.62×10^6	0.00085
A-3	6,250	Jacob (Dd) Theis	4.62×10^6 3.58×10^6	4.10×10^6	0.00274	4.62×10^6 3.58×10^6	4.10×10^6	0.00274
J-17	17,000	Jacob (Dd) Theis	13.20×10^6 10.60×10^6	11.90×10^6	0.000144	5.79×10^6 6.10×10^6	5.94×10^6	0.000160
AVERAGE			7.98×10^6	7.24×10^6	0.00673	6.21×10^6	5.89×10^6	0.00868

FOOTNOTE:

1/ (Dd) indicates analysis is based on water-level drawdown plots on Figure 2, and (Rec) indicates analysis is based on water-level recovery plots on Figure 3. Theis analysis is based on water-level drawdown plots on Figure 4.

TABLE 2. PUMPING-TEST RESULTS BY SECTIONS OF AQUIFER
(Pumping rate used for analysis is 25,000 gallons per minute)

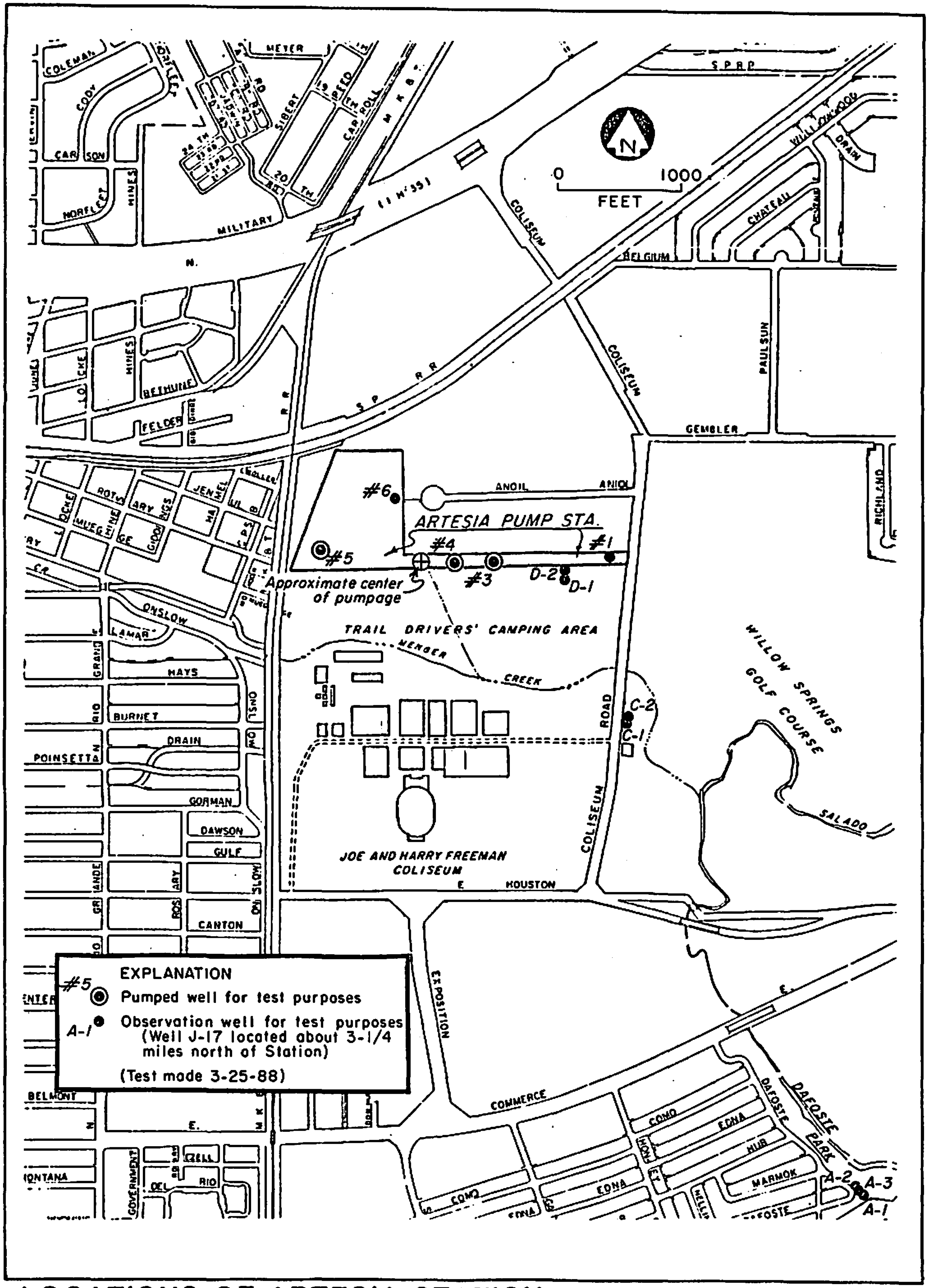
	Averages from Table 1			
	Early Data		Late Data	
Well Number	Transmissivity (gpd/ft)	Storage Coefficient	Transmissivity (gpd/ft)	Storage Coefficient
Full Section of Edwards				
Artesia 5	-	-	5.40×10^6	-
Artesia 1	5.30×10^6	0.0137	5.30×10^6	0.0137
Artesia 6	8.07×10^6	0.00209	5.52×10^6	0.0120
J-17	11.90×10^6	0.000144	5.94×10^6	0.000163
Average	8.42×10^6	0.00531	5.54×10^6	0.00862
Section Above Dense Bed				
D-2	10.85×10^6	0.00129	6.27×10^6	0.00660
C-1	4.00×10^6	-	2.56×10^6	-
A-2	4.05×10^6	0.00307	11.62×10^6	0.000851
A-3	4.10×10^6	0.00274	4.10×10^6	0.00274
Average	5.75×10^6	0.00237	6.14×10^6	0.00340
Section Below Dense Bed				
D-1	11.78×10^6	0.00204	7.26×10^6	0.00456
C-2	8.34×10^6	0.0288	6.77×10^6	0.0288
A-1	4.05×10^6	-	4.05×10^6	-
Average	8.06×10^6	0.0154	6.03×10^6	0.0167
Average for above	7.41×10^6	0.00769	5.90×10^6	0.00957

TABLE 3. CHEMICAL ANALYSES OF WATER FROM EDWARDS AQUIFER
(Analyses by U. S. Geological Survey and expressed in milligrams per liter except pH and specific conductance)

Well Sampled	Producing Interval (feet) 1/ From	To	Date Sampled	Water Temperature (°C)	Specific Conductance (micromhos/cm)	pH	Alkalinity ($CaCO_3$)	Total Hardness ($CaCO_3$)	Noncarbonate Hardness ($CaCO_3$)	Calcium (Ca)	Magnesium (Mg)	Chloride (Cl)	Sulfate (SO_4)
Packer Tests in Test Hole at	1,158	1,384	3-25-86	26.5	1,862	6.90	204	-	-	170	69	220	470
Monitor Well D-1	1,225	1,384	3-26-86	-	6,380	-	-	-	-	630	280	1,100	2,000
Monitor Well D-1	1,150	1,223	3-18-87	26.5	1,110	7.10	202	430	230	110	38	110	220
			4-17-87	26.0	1,180	7.10	197	460	270	120	40	120	230
Monitor Well D-2	874	926	3-18-87	26.0	472	6.90	199	220	23	61	17	18	22
			4-17-87	26.5	472	6.80	193	230	42	66	17	19	24
Artesia Well 3	862	1,108			Field/Lab								
6:45 a.m. sample	862	1,108	3-25-87	25.5	408/473	7.30	200	220	25	62	17	19	22
5:20 p.m. sample	862	1,108	3-25-87	25.5	473/475	7.00	196	220	26	61	17	19	22
Artesia Well 4	982	1,308											
6:30 a.m. sample	982	1,308	3-25-87	25.0	421/473	7.30	198	220	24	61	17	18	22
5:55 p.m. sample	982	1,308	3-25-87	25.0	459/476	7.00	195	220	30	62	17	19	22
Artesia Well 5	968	1,412											
6:15 a.m. sample	968	1,412	3-25-87	26.0	411/473	7.30	200	220	25	62	17	18	21
5:35 p.m. sample	968	1,412	3-25-87	26.0	465/471	7.00	197	220	28	62	17	18	21

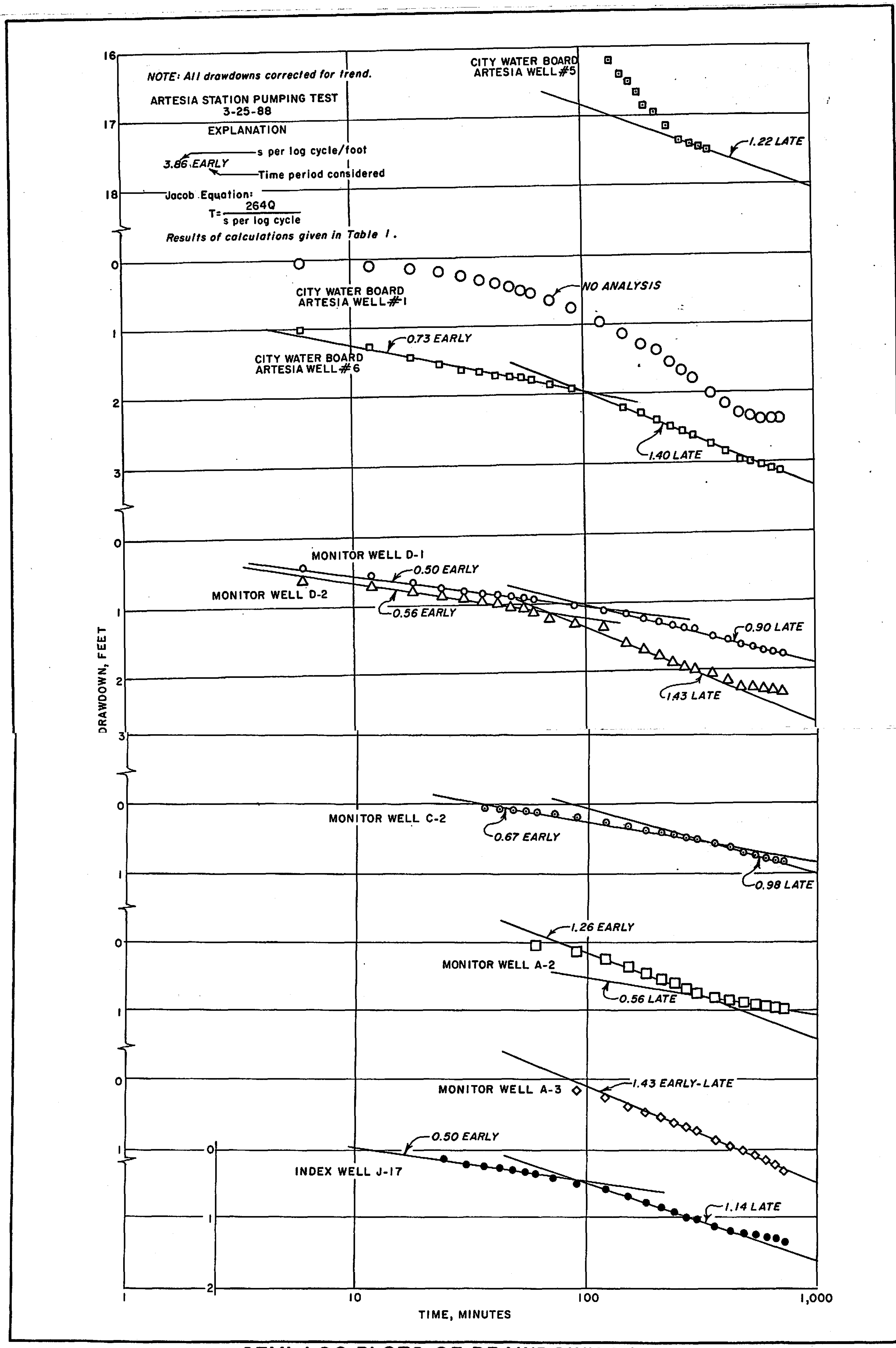
FOOTNOTE:

1/ Producing interval is in feet below land surface.



LOCATIONS OF ARTESIA STATION PUMPING TEST WELLS

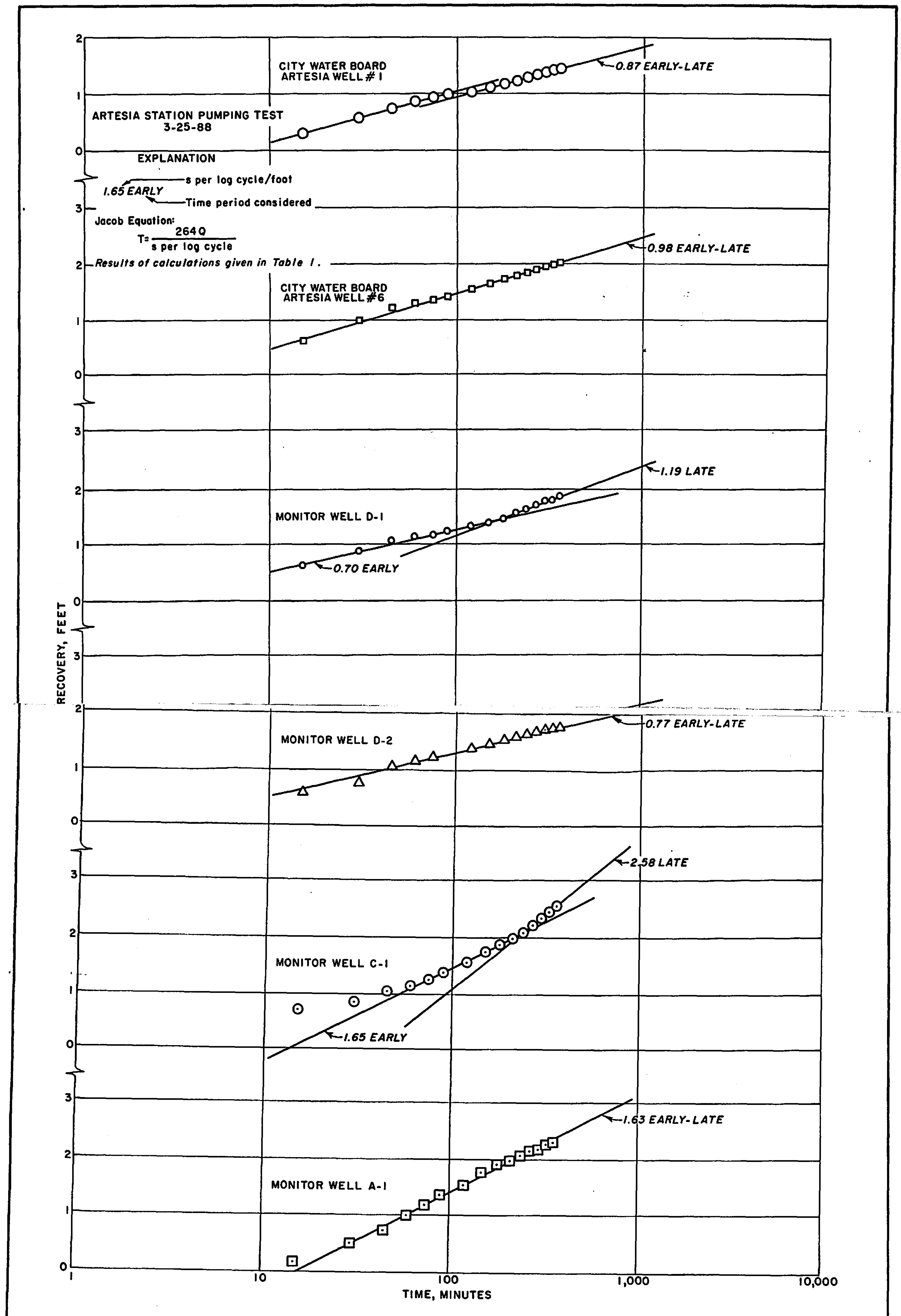
Figure 1



SEMI-LOG PLOTS OF DRAWDOWN DATA

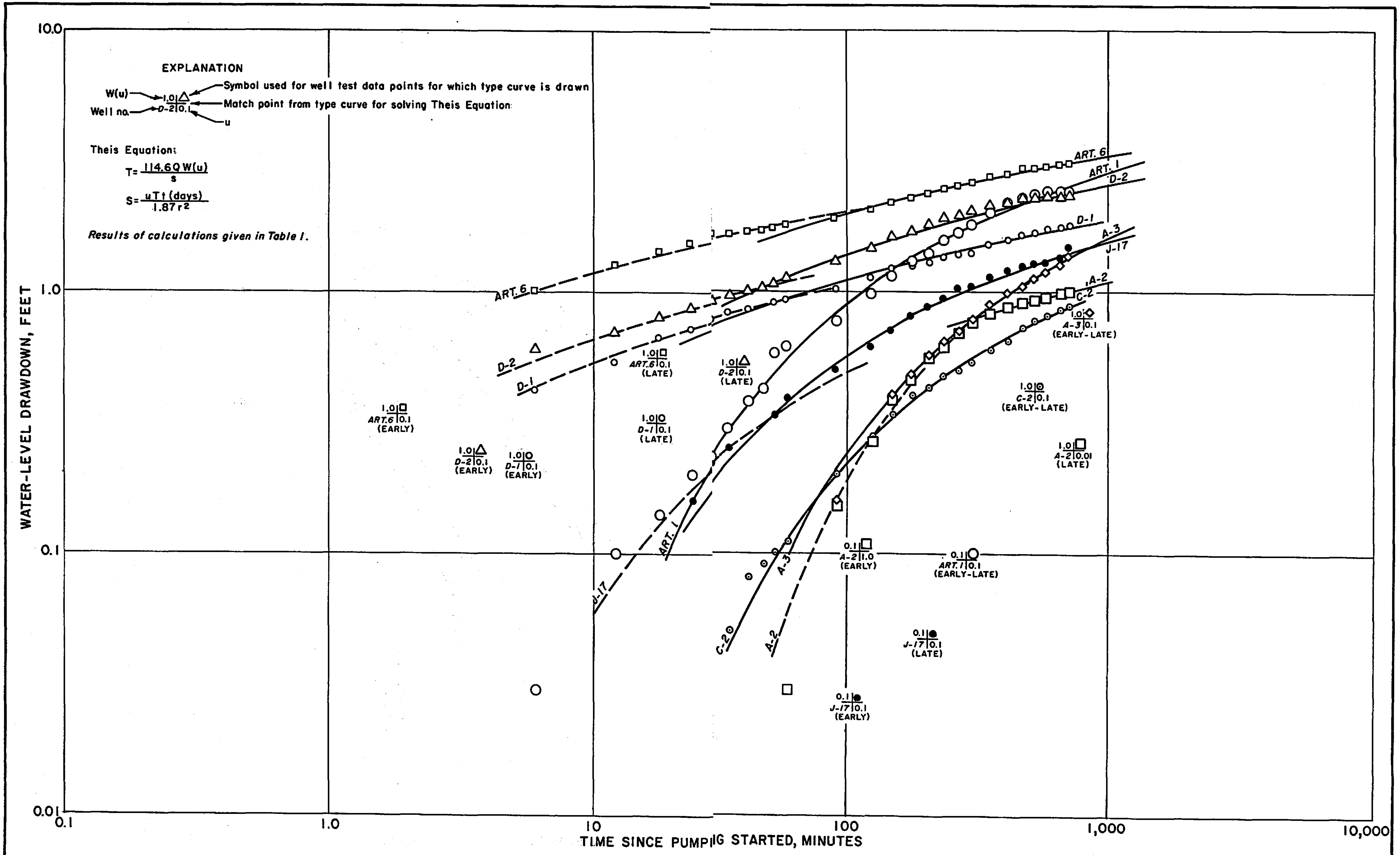
Figure 2

Figure 2



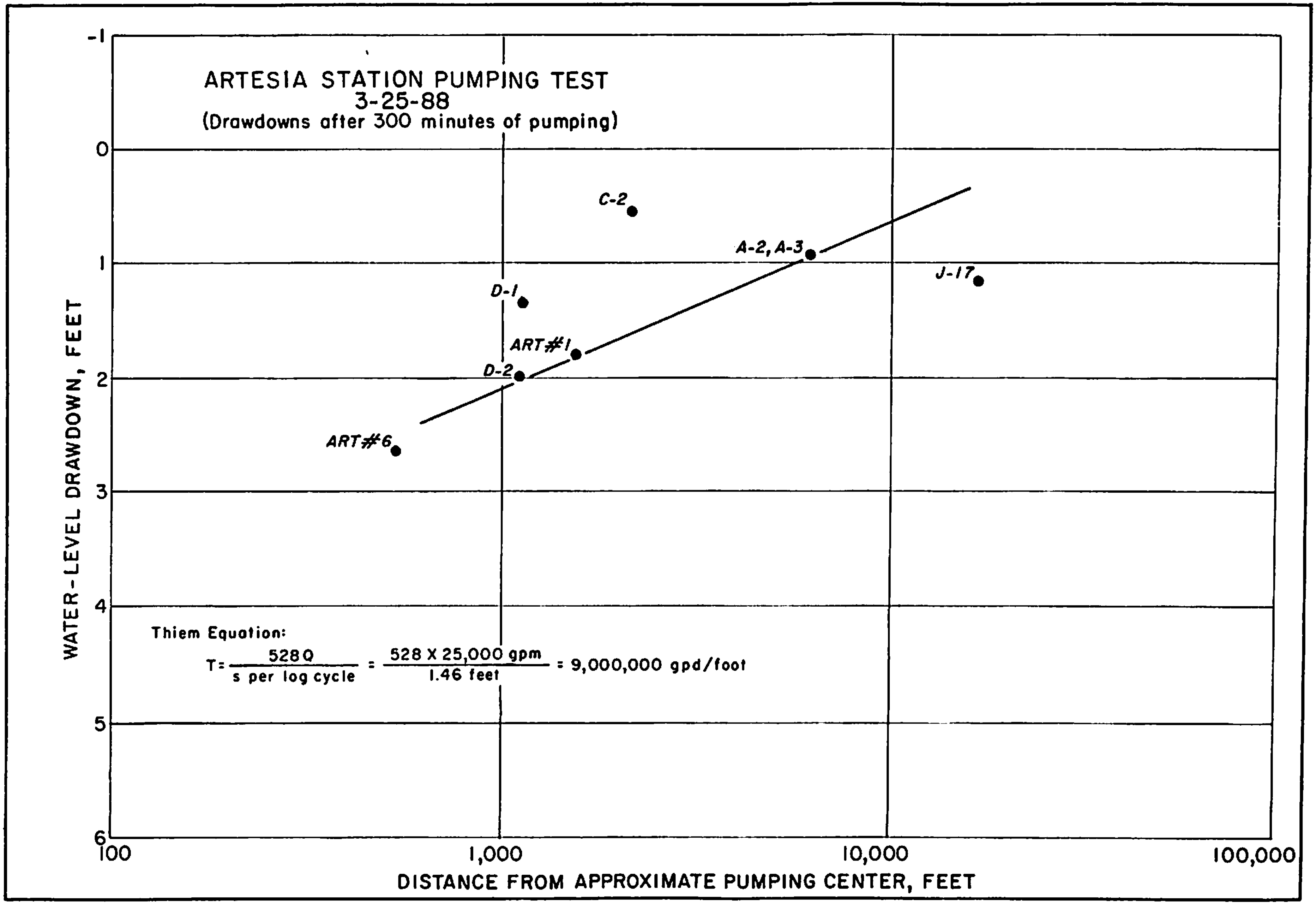
SEMI-LOG PLOTS OF RECOVERY DATA

Figure 3



LOG-LOG PLOTS OF DRAWDOWN DATA

Figure 4



DISTANCE-DRAWDOWN DATA PLOT

Figure 5

Figure 5