RESULTS OF ARTIFICIAL RECHARGE OF THE GROUND-WATER RESERVOIR AT EL PASO, TEXAS

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Prepared cooperatively by the Geological Survey,
United States Department of the Interior

July 1952

Reprinted March 1957

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INTRODUCTION

In 1947 the city of El Paso requested the United States Geological Survey to make an investigation to determine the feasibility of storing treated surface water from the Rio Grande in the ground-water reservoir of the Hueco bolson, which is the principal source of municipal and industrial water supply at El Paso. At that time the following pertinent facts were known: (1) Pumping from the ground-water reservoir was exceeding the natural recharge or replenishment to the city's well field by an average of about 5,000,000 gallons a day, or 25 percent of the total pumpage; (2) chloride content of the ground water in parts of the heavily pumped area was increasing steadily, in some places at an alarming rate; (3) records of stream flow showed that excess surface water from the Rio Grande was usually available during the winter when the demands for irrigation were at a minimum; (4) the demands for water to supply the city of El Paso were at a minimum during the winter; (5) the surface-water and ground-water supply facilities of the city of El Paso were adequate during the winter and pumping could be controlled in a manner that would facilitate any pumping and recharge tests that might be made; and (6) existing distribution facilities were such that, during the winter, the city could pump treated surface water from the Rio Grande into the wells in the Hueco bolson at the Montana well field at a moderate cost to the city.

With the above facts in mind, it was decided that experimental tests in artificial recharge could be conducted only during the winter and that the study, if favorable results were obtained from the initial test, should be continued over a period of several winters. The initial experiments, made during the winter of 1947-48, indicated that the injection of treated surface water into existing supply wells in the Montana well field was practicable. Further studies and test have been made during each of the four following winters with the exception of 1949-50, when the surface-water treatment plant was shut down for expansion.

The investigation has been made on a cooperative basis between the U. S. Geological Survey, the City of El Paso, and the Texas Board of Water Engineers. The field work and study have been done by the senior author, who has been associated with the entire investigation; D. E. Outlaw of the Geological Survey, who worked on the project in 1948; R. A. Scalapino of the Texas Board of Water Engineers, who worked on the project in 1949 and 1950; and J. W. Wood of the Geological Survey, who worked on the project in 1951 and 1952. Able assistance has been given also by E. J. Umbenhauer, superintendent of the El Paso Water Department, and C. R. Jensen, assistant engineer of the department.

OBJECTIVES OF THE INVESTIGATION

In determining the practicability of injecting treated surface water into the ground-water reservoir, the following objectives of the investigation were apparent: (1) The ability of the ground-water reservoir to transmit and store water must be determined so that the effect of the artificial recharge on the artesian pressure in the reservoir could be computed; (2) the accuracy of the computed effect of recharge on the artesian pressure should be checked by actual recharge tests; (3) the amount of injected water that could be recaptured by pumping should be determined; (4) the results of injecting water at a rate of 4,000 gallons a minute into a line of four wells in the Montana well field for a period of 90 days each winter should be determined; (5) the effect of artificial recharge on the ingress of salt water should be studied; (6) the harmful effect, if any, of the injection of treated surface water through the existing water-supply wells should be investigated; and (7) the possibility of injecting treated surface water into the ground-water reservoir in the Mesa well field should be studied.

SUMMARY OF CONCLUSIONS

The investigation described in this report resulted in the following principal conclusions:

1. In the Montana well field, treated surface water could be injected into four wells spaced 1,500 feet apart at a total rate of about 6 million gallons a day for an indefinite period.

2. In the Mesa well field, where the water occurs under water-table conditions and the loss in storage due to pumping is estimated at 29 billion gallons of water since 1946, treated surface water could be injected at many times the rate possible in the Montana well field.

3. Experimental artificial recharge in the Montana well field since 1949 resulted in a reduction in the chloride content of the ground water in the vicinity of the well (city well 4) used for the experiments. Continued large-scale recharge over a long period would be required to determine the effect on the encroachment of salty water into the ground-water reservoir as a whole, but it is reasonable to assume that the present encroachment would be retarded and, in some places at least, halted altogether.

ABILITY OF THE GROUND-WATER RESERVOIR TO TRANSMIT AND STORE WATER

The ability of the ground-water reservoir to transmit and store water at and in the vicinity of the Montana well field was studied by means of pumping and recharge tests. From the data obtained from these tests, the coefficients of transmissibility and storage have been computed by the Theis nonequilibrium method. This method of analysis is discussed by L. K. Wenzel in U. S. Geological Survey Water-Supply Paper 887, describing methods for determining permeability of water-bearing materials. Extensive discussions of the method are found also in many other publications of the Geological Survey and other agencies. It is not the purpose of this report to outline the method in detail but only to discuss its application to the recharge problems at El Paso. For more detail on the Theis nonequilibrium method, the reader is referred to the published reports on the subject.

The coefficient of transmissibility may be defined as the number of gallons of water, at the prevailing temperature, that will move in 1 day through a vertical strip of the aquifer 1 foot wide and having the height of the aquifer when the hydraulic gradient is unity (1 foot per foot). For field use it may be conveniently expressed as the number of gallons per day across a section of the aquifer 1 mile wide for each foot per mile of hydraulic gradient. The coefficient of storage may be defined as the relative volume of water that would be released from storage in each vertical prism of the aquifer, having a base 1 foot square and a height equal to the thickness of the aquifer, as the piezometric head undergoes a unit decline.

In the Montana well field coefficients of transmissibility and storage were computed from the recharge test made in February 1948 and from the pumping tests made in March 1948. In February 1948, recharge water was injected into city well 4 or (U. S. G. S no. 49) for a period of 15 days at a rate of 1,060 gallons a minute, and the effect of the recharge on the artesian pressure was observed in city well 3 (U. S. G. S. no. 52), 3,450 feet from the recharge well. In March 1948, city well 4 was pumped at a rate of 1,360 gallons a minute for a period of 48 hours and the effect of pumping on the artesian pressure was observed in city well 1 (U. S. G. S. no. 50), 1,000 feet from the pumped well; in the Loretto College well (U. S. G. S. no. 53), 3,200 feet from the pumped well; in city well 3, 3,450 feet from the pumped well; and in city well 18 (U. S. G. S. no. 48a), 4,000 feet from the pumped well. The data obtained from these tests were analyzed by means of the Theis nonequilibrium formula and the coefficients of transmissibility and storage were computed. Figures 1, 2, 3, and 4 show the alinement of the data obtained from the tests with the type curve of the Theis nonequilibrium formula and the computations of the coefficients of transmissibility and storage. The coefficients of transmissibility and storage are given in the following table.

Table 1.- Coefficients of transmissibility and storage obtained from recharge and pumping tests of city well 4, February and March 1948

Well	Coefficient of transmissibility (gpd/ft)	Coefficient of storage
City well 1	124,000	0.00271
City well 3	82,000	.00063
City well 18	129,000	.00138
Loretto College well	140,000	.00117

The above coefficients of transmissibility and storage were used in computing by means of the Theis formula the theoretical effect on the artesian pressure in the groundwater reservoir that should take place during periods of artificial recharge. The computed effect of recharge is discussed in a later section of this report.

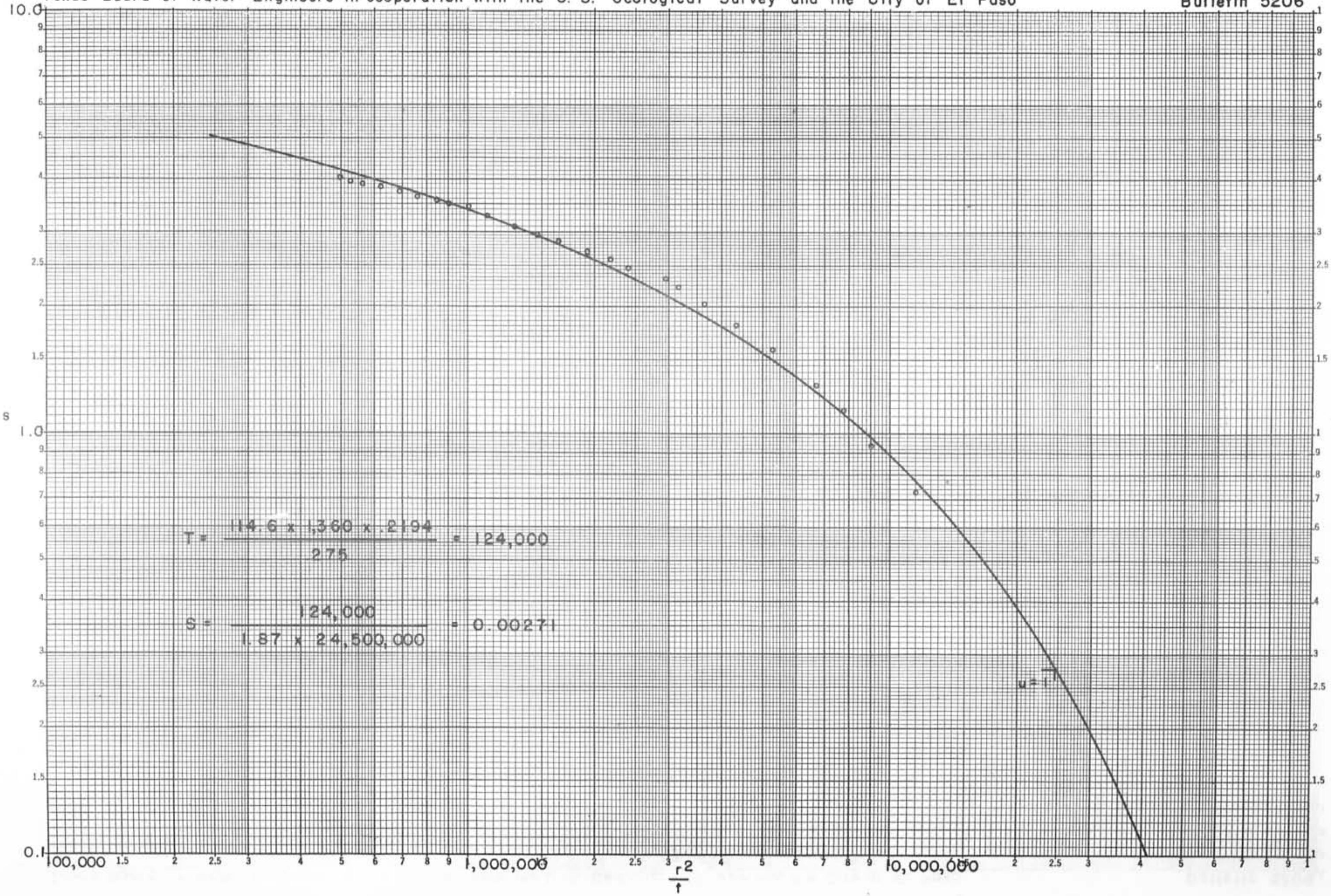


FIGURE 1.-Pumping test of El Paso well 1, March 22-24, 1948.

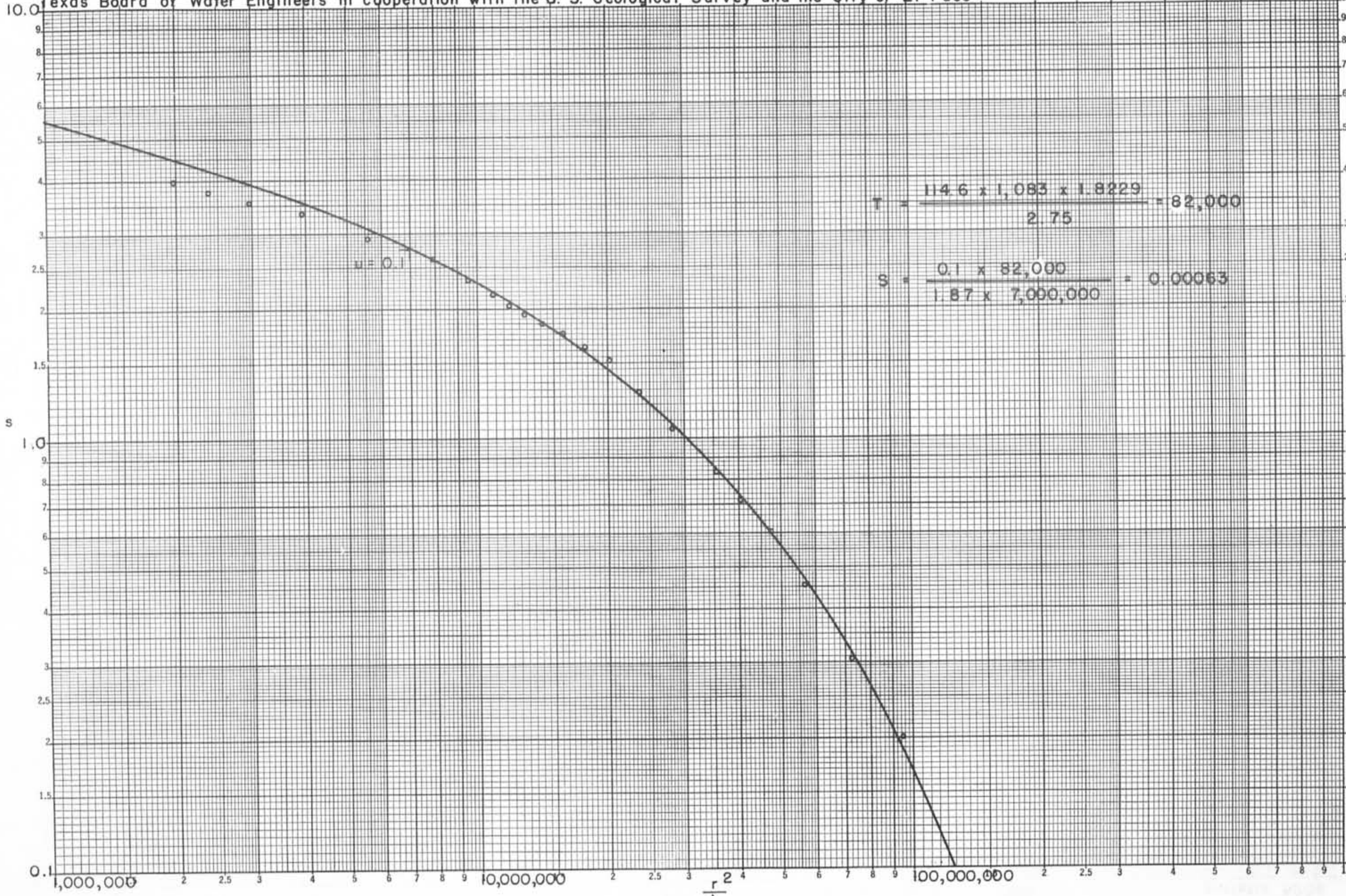


FIGURE 2.- Recharge test of El Paso well 3, February 1948.

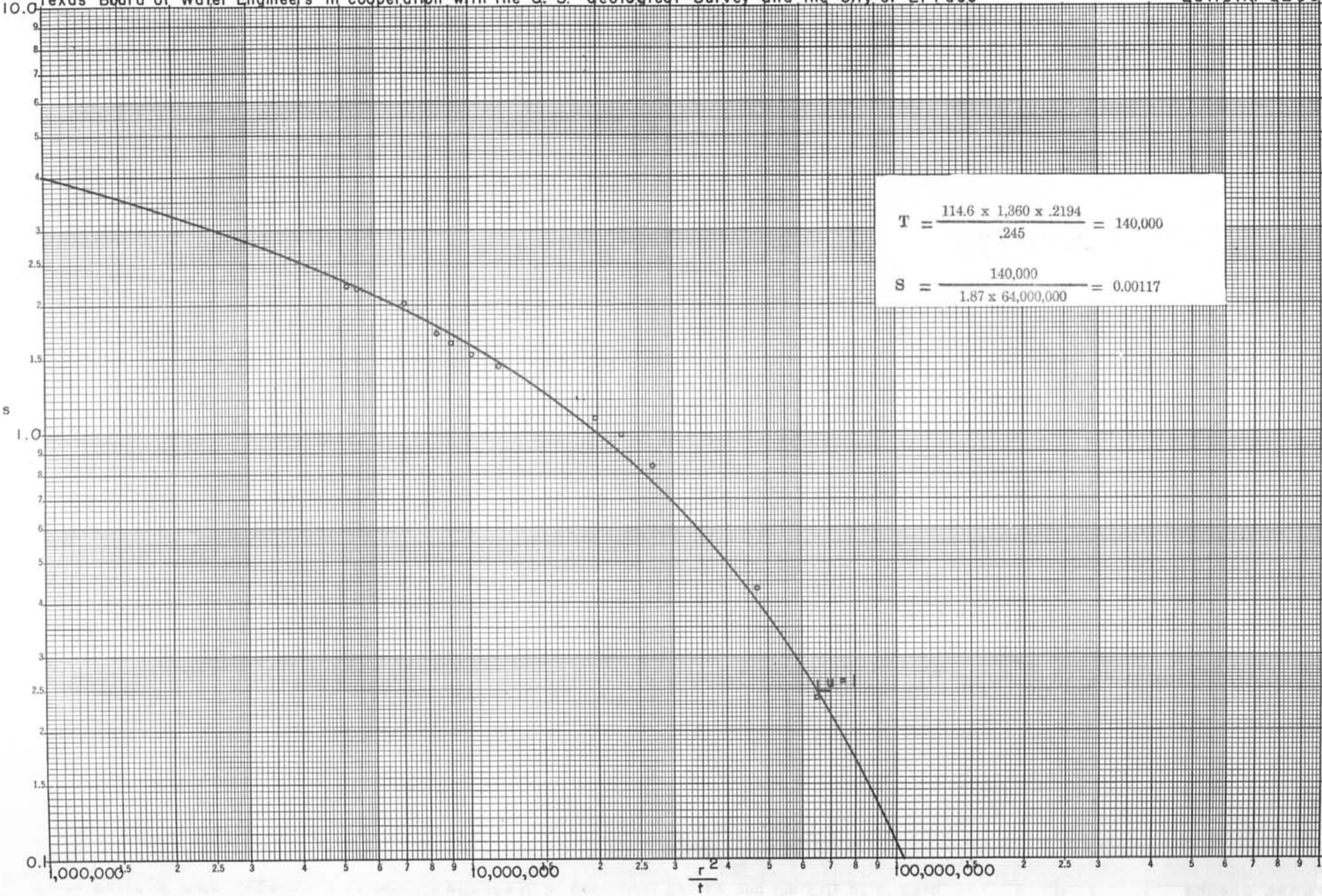
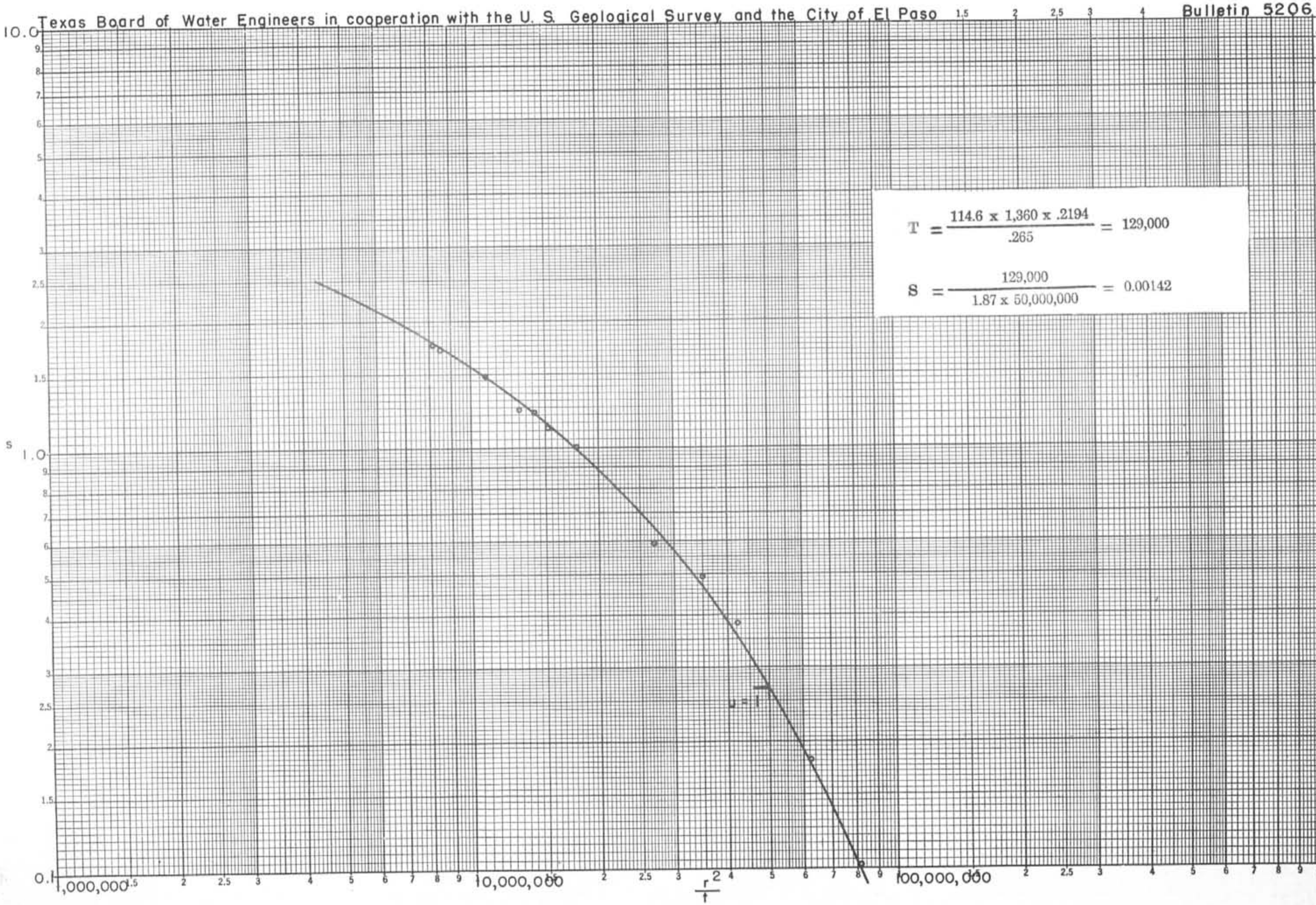


FIGURE 3. - Pumping test of El Paso well 18, March 22-24, 1948.



$$T = \frac{114.6 \times 1{,}360 \times .2194}{.265} = 129{,}000$$

$$S = \frac{129{,}000}{1.87 \times 50{,}000{,}000} = 0.00142$$

FIGURE 4.- Pumping test of Loretto College well, March 22-24, 1948.

TEST TO DETERMINE ACCURACY OF THE COMPUTED EFFECT OF ARTIFICIAL RECHARGE

During a 12-day period February 23 to March 7, 1949, treated surface water was injected into city well 4 in the Montana well field at a rate of 500 gallons a minute for 3 days and at a rate of 700 gallons a minute for 9 days. The water levels were measured in city wells 1, 3, 18, and the Loretto College well for a period of several days before recharge began and at frequent intervals during the period of recharge.

By using the coefficients of transmissibility and storage obtained from the tests made in February and March 1948 shown in table 1, computations were made of the theoretical rise in water level in city wells 1, 3, and 18 and the Loretto College well that should have occurred from the effect of artificial recharge during the 12-day period. The theoretical or computed rise in water level in the wells was then compared with the actual measurements. A comparison of the actual and computed effects in each of the four wells is shown in figure 5. The computed effect of artificial recharge was found to agree very closely with the observed effect.

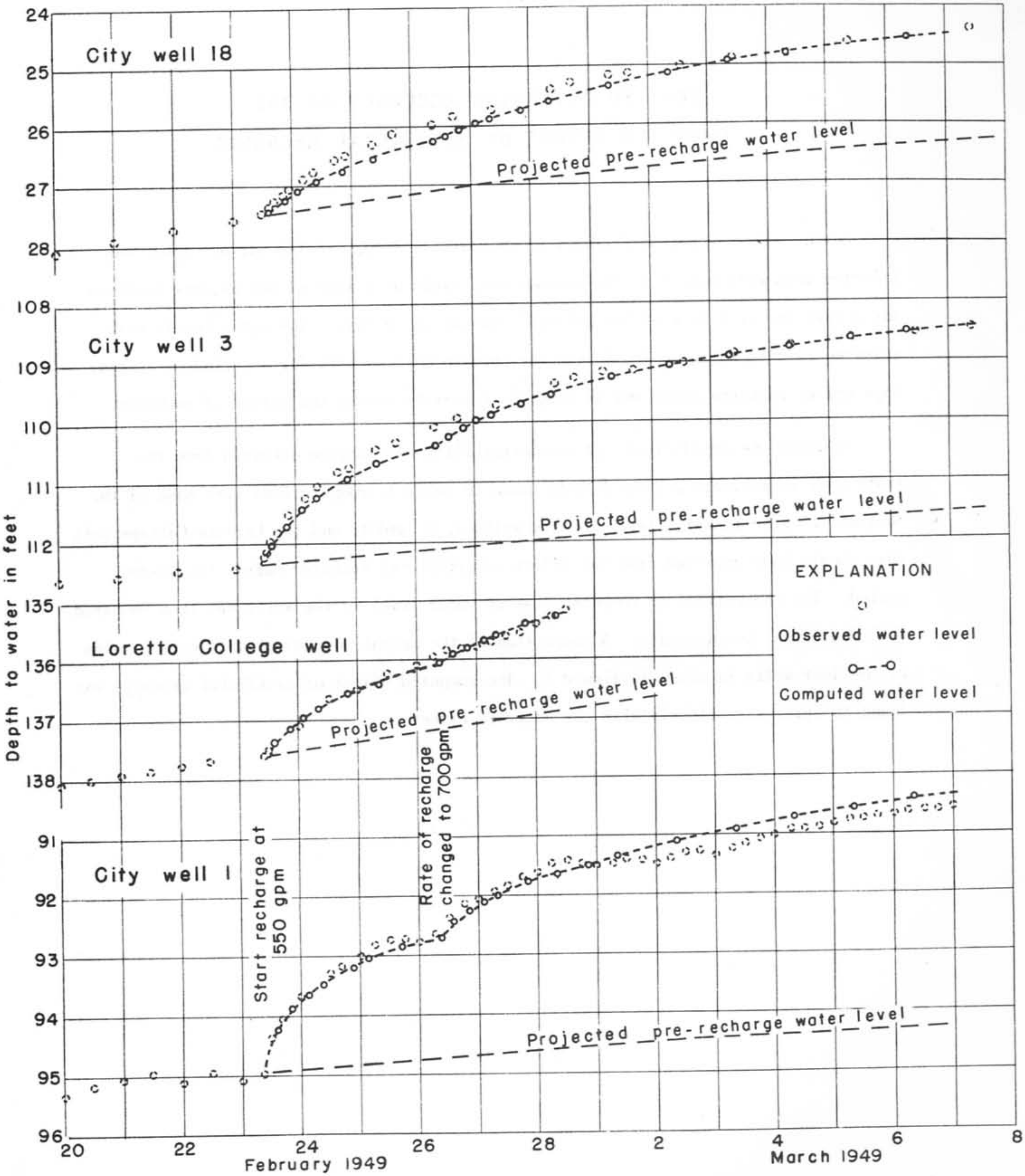
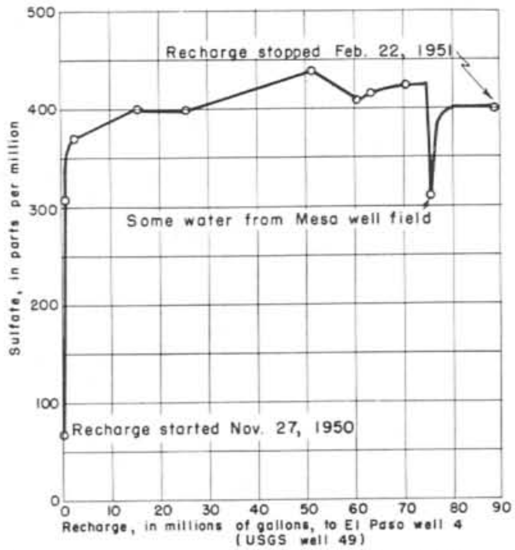


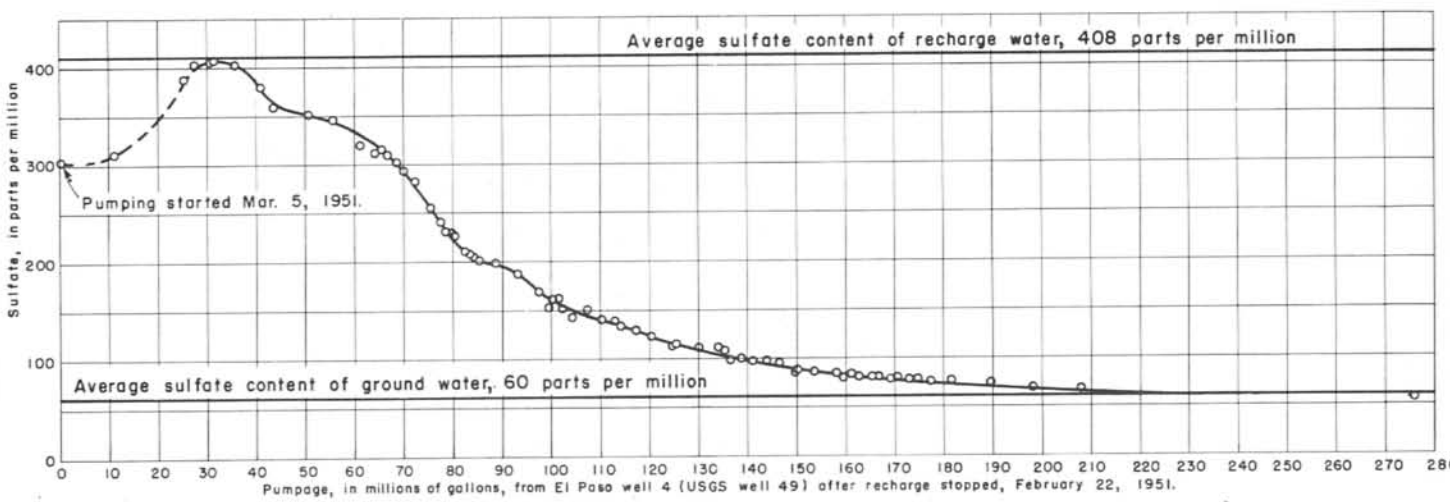
FIGURE 5.- Rise in water levels in observation wells due to recharge of city well 4, and theoretical rise as computed by means of the Theis nonequilibrium formula.

RECOVERY OF INJECTED RECHARGE WATER

During the period November 27, 1950, to February 22, 1951 recharge and pumping tests were made to determine the amount of recharge water that could be recaptured by pumping from the ground-water reservoir after recharge stopped. The results of these tests are based on the chemical quality of the water injected by artificial recharge, the chemical quality of the native water in the ground-water reservoir, and the chemical quality of the water pumped from the ground-water reservoir after recharge stopped. The treated surface water injected into city well 4 from November 27, 1950, through February 22, 1951, had a sulfate content averaging 408 parts per million. The range in sulfate content of the injected water is shown in the top graph of figure 6. An analysis of the ground water before recharge began showed that the ground water contained about 60 parts per million of sulfate. A total of 88,413,000 gallons of recharge water was injected into the ground-water reservoir. After recharge was stopped, pumping was started on March 5, 1951, and water samples were collected at frequent intervals during the pumping period for chemical analysis of the sulfate content of the water. The results of the analyses of the pumped water are shown in the center graph of figure 6. The amount of recaptured recharge water and the amount of native ground water pumped were computed on the basis of the relation of the sulfate concentration of pumped water to the sulfate concentration of the recharge and the original ground water. Table 2 gives the computed amounts of recharge water and ground water contained in each 10 million gallons pumped from the time pumping started to the time that 230,000,000 gallons was pumped. The computations indicate that, by the time 220,000,000 gallons was pumped, all the water pumped was native ground water. The computed percentage of recharge water in each 10,000,000 gallons of water pumped is shown in the lower graph of figure 6.



Graph showing sulfate content of water injected into El Paso well 4 (USGS well 49), November 27, 1950 to February 22, 1952.



Graph showing sulfate content of water pumped from El Paso well 4 (USGS well 49), March 5 to September 18, 1951.

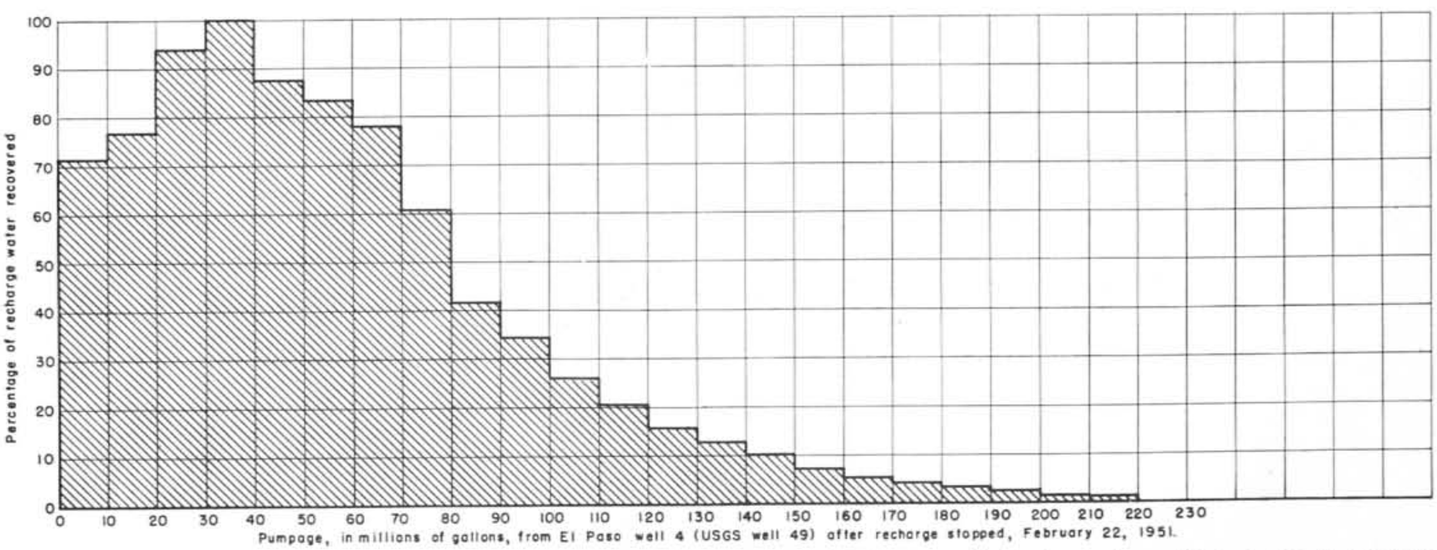


FIGURE 6.- Percentage of recharge water recovered from El Paso well 4, based on difference in sulfate content of recharge water and ground water during pumping period beginning March 5, 1951.

Table 2.- Computed amounts of recharge water and ground water pumped after artificial recharge, November 27, 1950 to February 22, 1951

Amount pumped (million gallons)	Recharge water (gallons)	Ground water (gallons)
10	7,110,000	2,890,000
20	7,660,000	2,340,000
30	9,400,000	600,000
40	10,000,000	0
50	8,750,000	1,250,000
60	8,320,000	1,680,000
70	7,800,000	2,200,000
80	6,070,000	3,930,000
90	4,190,000	5,810,000
100	3,470,000	6,530,000
110	2,600,000	7,400,000
120	2,080,000	7,920,000
130	1,590,000	8,410,000
140	1,300,000	8,700,000
150	1,010,000	8,990,000
160	720,000	9,280,000
170	580,000	9,420,000
180	430,000	9,570,000
190	350,000	9,650,000
200	290,000	9,710,000
210	170,000	9,830,000
220	120,000	9,880,000
230	0	10,000,000
TOTALS	84,010,000	145,990,000

Total amount of water injected as recharge		88,413,000 gallons
Recharge water recovered		84,010,000 gallons
	Difference	4,403,000 gallons

Table 2 indicates a difference of 4,403,000 gallons between the total amount of water injected as recharge and the amount of recharge water recovered, or about 5 percent of the total amount of recharge. However, the difference may be somewhat less than that indicated. Only two analyses were made during the pumping of the first 20,000,000 gallons. It is reasonable to believe that if more analyses had been made, the average sulfate content of the water during the pumping of the first 20,000,000 gallons might have been higher than indicated by the results of only two samples, one of which was taken at the very beginning of the test and the other at a time when recoveries of recharge water from the Mesa well field, relatively low in sulfate, could have influenced the analysis (see fig. 6). Thus, most of the water pumped during the initial period might have been derived from recharge, and the actual average sulfate concentration might have been considerably higher than shown by the two analyses.

EFFECT OF INCREASING ARTIFICIAL RECHARGE IN THE MONTANA WELL FIELD

The results of the pumping and recharge tests clearly indicated that, if properly spaced injection wells were used, water might be injected into the ground-water reservoir at a rate of several thousand gallons a minute for periods of several months. In discussing this possibility with officials of the city of El Paso, consideration was given to the facilities available and the alterations necessary in the distribution system to deliver recharge water from the surface-water treatment plant and the need for providing recharge wells to inject the water. It was concluded by the City Water Department that facilities could be made available for supplying recharge water to the Montana well field area for a period of 90 days, or longer, during the winter and that three or four injection wells might be drilled. On this basis, the effect of artificial recharge through four injection wells spaced 1,500 feet apart was computed for a rate of injection of 1,000 gallons a minute at each well for a period of 90 days. Figure 7 shows the theoretical rise in artesian pressure, in feet, after recharge of the Montana well field for a period of 90 days at a rate of 4,000 gallons a minute or 5.76 million gallons a day. Because the ground-water reservoir is under water-table conditions north and northeast of the Montana well field, no attempt was made to show the effect of recharge in that part of the reservoir. The exact boundary between the portions of the reservoir having artesian and water-table conditions has not been established definitely. Where there is some doubt, the contours showing the theoretical effect of recharge have been shown by means of dashed lines.

The results of this study indicate that water could be injected into the Montana well field at a rate of about 6 million gallons a day indefinitely. The increased pumping by the city and industries during the spring, summer, and fall would counteract the effect of recharge during those seasons. However, during the winter, it appears that it would not be practicable to recharge the Montana well field at a rate greater than 6 million gallons a day, because injection of water into the field at a much greater rate would cause some of the downtown wells to flow.

EFFECT OF ARTIFICIAL RECHARGE ON THE INGRESS OF SALT WATER

Since 1935 the mineral content of the water from some of the wells in the El Paso area has increased steadily, although the total increase has not caused the content to rise much above acceptable standards for public supply in any of the City wells. The increase has been largely in quantities of sodium and chloride but the sulfate content has not risen above 139 parts per million in any of the wells. The records of analyses show that the chloride content of the water from city well 3 in the Montana well field increased from 152 parts per million in 1936 to 298 parts per million in 1951. The chloride content in city well 4 in the Montana well field rose from 256 parts per million in 1935 to 350 parts per million in 1945. The analyses of six samples of water collected since recharge began between August 1949 and September 1951 show ranges in the chloride content of the water in city well 4 from 240 to 278 parts per million. It appears probable that the decrease in the chloride content of the water was caused by the injection of recharge water into the well. The chloride content of the water in city well 3 in the Montana well field was 282 parts per million in March 1946. In June 1948 the chloride content of the water was 228 parts per million, a decrease of 54 parts per million in the 2-year period. However, the results of five analyses made since June 1948 show that the chloride content of the water steadily increased, to 298 parts per million in September 1951. At the Texas and New Orleans Railroad yard, about a mile north of the Montana well field, the chloride content of the water from the railroad's well 8 increased from 38 parts per million in 1921 to 1,130 parts per million in 1951, and in well 5 from 402 parts per million in 1941 to 1,260 parts per million in 1951. However, in well 5 there was a drop in the chloride content from 958 to 920 parts per million between June 1948 and April 1949. Except for this drop, the chemical analyses of the water from the railroad wells do not indicate any beneficial effect of the short periods of recharge to city well 4.

Further study during and after prolonged periods of artificial recharge will be necessary to ascertain whether the recharge will be beneficial to the whole area in which the chloride content of the water is rising. The data at hand show conclusively that the chloride content of the water has been lowered appreciably only in the vicinity of city well 4, the point at which the recharge water was injected. However, it seems reasonable to expect that, if large quantities of water are injected into the Montana well field for a considerable period, the rate of encroachment of salt water will be retarded in many parts of the area and in some places the encroachment may be halted.

Texas Board of Water Engineers in cooperation with the U. S. Geological Survey and the City of El Paso — Bulletin 5206

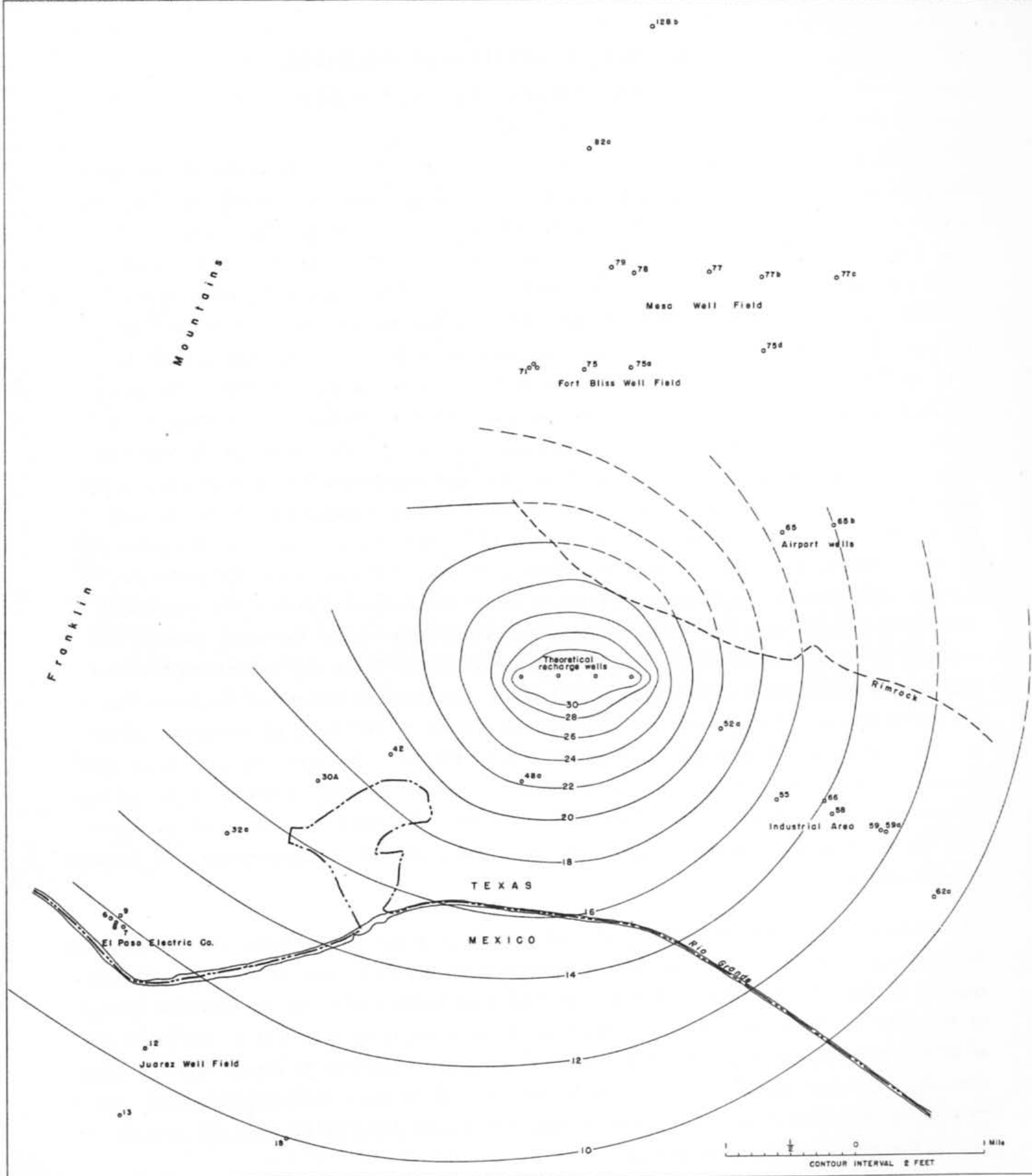


FIGURE 7.- Map of the El Paso area showing the theoretical rise of artesian pressure, in feet, after recharging the Montana well field for 90 days at a rate of 5.76 million gallons a day.

In certain areas on the Mesa to the north of the Montana well field, the water from wells has actually decreased in chloride content as more and more water has been removed from the wells. For example, in city well 15 (U. S. G. S. no. 77b) the chloride content steadily decreased from 171 parts per million in 1938 to 86 parts per million in 1951; in city well 19 (U. S. G. S. no. 75d) the chloride content decreased from 94 parts per million in 1942 to 80 parts per million in 1951; and in the El Paso Natural Gas Company well (U. S. G. S. no. 128) the chloride content decreased from 208 parts per million in 1935 to 134 parts per million in 1950. The decline in the chloride content is attributed to the removal of many millions of gallons of water from the wells and its replacement by water from other areas that contained less chloride. The same type of movement may be taking place in those areas where the chloride content is increasing, except that the water moving into the pumped area is of poorer quality than the original water in the ground-water reservoir.

EFFECT OF ARTIFICIAL RECHARGE ON THE YIELD OF CITY WELL 4

City well 4 was drilled in 1924 to a total depth of 882 feet. It is cased with 24-inch pipe from the surface to 200 feet; with 13-inch blank pipe from 186 to 403 feet, and with 13-inch slotted pipe from 403 to 820 feet. In 1928 the well yielded 1,360 gallons a minute with a drawdown of 75 feet, showing a yield (specific capacity) of about 18.1 gallons for each foot of drawdown.

During the four recharge tests made since 1947, a total of 177,470,000 gallons of treated surface water was injected through city well 4. During the recharge test begun on November 27, 1950, a total of 88,400,000 gallons of water was injected at an average rate of 706 gallons a minute. On November 26, 1950, before recharge started, the water level in city well 4 was 71.5 feet below the top of the well casing. On February 22, 1951, just before recharging stopped, the water level in the well was 22 feet below the top of the casing. Thus the well took water at the average rate of 14.3 gallons per foot of rise over a period of 87 days. During the recharge test from January 14, 1952, to March 8, 1952, a total of 55,070,000 gallons of water was injected into city well 4 at a rate that averaged 702.5 gallons a minute from January 14 to February 11 and 772.7 gallons a minute from February 11 to the time of shut-down on March 8. On January 11, before recharge began, the static water level was 72.83 feet below the top of the casing. On March 4, near the end of the recharge period, the water level was 29.30 feet below the top of the casing. On the basis of the rate of recharge during the latter part of the test, the well took water at the average rate of 17.8 gallons a minute for each foot of rise. This latter figure indicates that the specific capacity of the well was about the same in 1952 as in 1928.

POSSIBILITY OF INJECTING TREATED SURFACE WATER IN THE MESA WELL FIELD

Although no experimental study has been made in the Mesa well field similar to that in the Montana well field, the results of the study in the Montana well field indicate that it probably would be practicable to store large quantities of treated surface water in the Mesa well field. The principal differences between the two well fields are: (1) The ground water occurs under water-table conditions in the Mesa well field and under artesian conditions in the Montana well field; (2) the Mesa well field is about 100 feet higher than the Montana well field; (3) the Mesa well field is 3 to 5 miles farther from the surface-water treating plant; (4) so far there is no evidence of salt-water encroachment in the Mesa well field; and (5) the removal of ground water from storage beneath the Mesa well field has created a depression in the water table that would provide excellent storage capacity for many billions of gallons of recharge water. It is estimated that the loss in storage in the Mesa well field has been about 29 billion gallons since 1946.

Existence of a ground-water reservoir beneath the Mesa well field under water-table conditions and pumpage there from in excess of the replenishment to the extent of about 29 billion gallons since 1946 have combined to create storage capacity that would hold many billions of gallons of recharge water without any appreciable loss from the reservoir. The amount of water that could be stored in the Mesa area is many times the amount of water that could be injected into the Montana well field. The principal objection to artificial recharge in the Mesa well field is the increased cost of lifting the water an additional 100 feet and the increased cost of pipeline facilities to get the water to the Mesa well field from the surface-water treatment plant.

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