SHORT PAPERS ON WATER RESOURCES IN NEW MEXICO, 1937-57

By C. V. Theis and Others

U.S. GEOLOGICAL SURVEY

Open File Report 91-81

Prepared in cooperation with:
State Engineer of New Mexico
U.S. Corps of Engineers
U.S. Army
Defense Plant Corporation
U.S. Atomic Energy Commission

Reston, Virginia
1991

U.S. DEPARTMENT OF THE INTERIOR
MANUEL LUJAN JR., *Secretary*

U.S. GEOLOGICAL SURVEY
Dallas L. Peck, *Director*

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FOREWORD

During his long and productive life, C.V. Theis, regarded by his scientific peers as the father of quantitative ground-water hydrology, authored about 150 reports. About one-third of these reports were prepared for various U.S. Federal and military agencies before, during, and following World War II and never released to the public. These agencies (or their present day equivalents) have agreed that it is desirable to make these reports available for study by historians, scholars, and others interested in the development of the science of ground-water hydrology.

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TENTATIVE COMPUTATION OF RECHARGE OF PECOS VALLEY SHALLOW WATER BASIN AND OF EFFECT OF PUMPING BY PRESENT HOLDERS OF WATER RIGHTS

By Charles V. Theis

July 23, 1937

The problem of the expected effect of pumping resolves itself into the following factors: (1) the amount of recharge to the valley fill, (2) how much of this recharge may be abstracted from the fill by the present and already permitted pumps without loss to the valley other than in the flow to the river, (3) how much excess water must be taken from storage over and above that taken from recharge, (4) how this abstraction from storage will take place, and (5) the combined effect of the diversion of the underground flow and the pumping from storage upon water levels in the future. To elucidate these points requires an accurate knowledge of the pickup of the river and tributaries from the alluvium, of the shape and average slope of the water table, of the shape and attitude of the floor of the valley fill, of the local and average values of transmissibility and specific yield of the fill, of the amount of water probably to be pumped in each locality, and finally a clarification of the theoretical principles of hydraulic flow in an aquifer. All these points cannot be satisfactorily determined at the present time. Yet it appears that approximations to the proper values can be made at present with sufficient accuracy to at least indicate the proper course of development of the shallow water.

The Slope of the Water Table

The slope of the water table is at this season distorted by pumping. As a consequence of this and some other causes, the slopes of the water table so far determined are erratic in amount and direction. On the whole it appears at present that the general slope of the water table is about southeast at a rate of about 10 feet per mile. The pressure head controlling the flow of the water is therefore applied from the northeast to the southeast. The actual flow of the water is probably diverted somewhat from this direction by different transmissibilities in different directions in the alluvium.

Character of Floor of Valley Fill

Mr. Morgan has plotted the floor of the valley fill as represented in artesian well logs and, to a lesser extent, shallow well logs. These logs leave much to be desired for this purpose and considerable interpretation is necessary. However, it seems rather evident that the lowest points on the floor of the aquifer, and consequently the greatest depths of the aquifer, are found along an axis a few miles west of the present river. As a consequence, there is greater transmissibility and greater ease of movement in the southerly direction than in the easterly, at least in the lower part of the aquifer.

Character and Thickness of the Aquifer

Cross sections of the aquifer made from logs of shallow wells by Mr. Morgan appear to indicate that in general the upper part of the valley fill to a depth of 60 or 80 feet is clayey and that in most places the remainder of the fill is coarser and more permeable. It also appears that there is an east-west pattern of this fill in that the fill in the areas near the transverse streams appears to be coarser than in the interstream areas. Average thickness of fill and average depths to the water table in different localities are as follows on page 3.

The data on thickness of saturated valley fill and depth to water level in Eddy County are not complete enough for the compilation of tables such as those above. The thickness of the valley fill underlying the area of shallow-water development in Eddy County averages approximately 200 feet. The zones of equal depth to water have a north-south trend except in the northern part of the country where they swing westward along Cottonwood Creek to connect with the corresponding zones on the north side of Cottonwood valley. The 80-foot to water zone lies approximately 2 miles west of Artesia and a north-south line through that zone will, in a general way, form the western limit of the shallow water development so far as irrigation is concerned. The depth to water decreases to the east and in the area east of the A.T. & S. F. Railway the depth to water varies from 40 to 10 feet.

Movement of Water in the Valley Fill

From the foregoing it appears that the pressure gradient is to the southeast, that the trough in the floor of the valley fill is somewhat west of the river and that, therefore, at least the lower part of the water moves into the river with difficulty across the ridge separating the trough from the river and that in the fill itself there may be an east-west pattern which, contrary to the effects of the trough, tends to make movement to the east somewhat easier than to the south. Just what the combined effects of these two contrary tendencies affecting the movement of the water are cannot be foretold at present. It may be that the lower water moves generally south-southeast--deflected to the south from the water-table gradient--while that in the upper part moves east-southeast--deflected to the east from the gradient by the pattern of the valley fill. It would appear that on the whole these two opposing tendencies neutralize each other so that the general direction of movement of the whole mass of the water is down the gradient of the water table or to the southeast.

Character and Amount of Recharge to the Valley Fill

Recharge to the valley fill must come, in proportions as yet undetermined, from: (1) rainfall penetration, (2) absorption of water from ephemeral streams crossing the outcrop, (3) return from irrigation, (4) natural leakage from the artesian reservoir through permeable places or fractures in the confining bed, and (5) leakage from artesian wells. Mr. Morgan's observations of puddles and ponds after the late period of heavy rain make it appear that rainfall penetration cannot be very important, excepting perhaps in a few gravelly areas in the western portion of the alluvial basin. It would appear also from the few times a year the tributaries flow across the westward part of the alluvial basin that the recharge from stream absorption cannot be large. Return from irrigation must be of considerable amount in most of the basin,

AVERAGE THICKNESS OF SATURATED VALLEY FILL, IN FEET, ROSWELL BASIN, CHAVES COUNTY

	R. 23 E. 6th mi	R. 24 E. 1st mi	R. 24 E. 2nd mi	R. 24 E. 3rd mi	R. 24 E. 4th mi	R. 24 E. 5th mi	R. 24 E. 6th mi	R. 25 E. 1st mi	R. 25 E. 2nd mi	R. 25 E. 3rd mi	R. 25 E. 4th mi	R. 25 E. 5th mi	R. 25 E. 6th mi
T. 10 S. 1st mi	20	30	60	100	110	110	120	140	120	100	90		
T. 10 S. 2nd mi	50	80	100	130	140	150	150	130	111	100	90		
T. 10 S. 3rd mi	60	90	110	130	110	90	150	140	120	100	--		
T. 10 S. 4th mi	30	80	90	140	170	170	160	160	130	100			
T. 10 S. 5th mi	30	50	90	180	190	190	170	190	170	140	100		
T. 10 S. 6th mi	40	140	140	170	190	190	190	180	140	110	90		
T. 11 S. 1st mi	70	100	110	140	190	190	190	160	140	90	--		
T. 11 S. 2nd mi	50	90	110	160	190	190	190	140	100	90	--		
T. 11 S. 3rd mi	30	90	100	120	170	190	190	190	190	140	90		
T. 11 S. 4th mi	10	20	30	130	120	110	150	140	150	130	120	90	--
T. 11 S. 5th mi	--	--	20	70	170	189	190	190	130	130	100	90	--
T. 11 S. 6th mi	--	20	30	90	100	160	150	170	120	100	--	--	--

AVERAGE THICKNESS OF SATURATED VALLEY FILL, IN FEET, ROSWELL BASIN, CHAVES COUNTY (continued)

	R. 24 E. 6th mi	R. 25 E. 1st mi	R. 25 E. 2nd mi	R. 25 E. 3rd mi	R. 25 E. 4th mi	R. 25 E. 5th mi	R. 25 E. 6th mi	R. 26 E. 1st mi	R. 26 E. 2nd mi	R. 26 E. 3rd mi	R. 26 E. 4th mi	R. 26 E. 5th mi	R. 26 E. 6th mi
T. 12 S. 1st mi	20	40	40	50	70	100	150	80	80	--			
T. 12 S. 2nd mi	10	20	60	110	140	190	120	80	--	--			
T. 12 S. 3rd mi	--	20	100	130	170	170	140	120	90	--			
T. 12 S. 4th mi		10	80	150	170	140	130	100	80	--			
T. 12 S. 5th mi		--	20	70	160	150	140	100	90	--			
T. 12 S. 6th mi			--	30	110	150	140	120	80	--			
T. 13 S. 1st mi			--	20	105	180	170	120	80	70	--		
T. 13 S. 2nd mi			--	20	70	150	150	100	150	110	60	--	
T. 13 S. 3rd mi			--	70	110	140	160	160	170	100	70	--	

AVERAGE THICKNESS OF SATURATED VALLEY FILL, IN FEET, ROSWELL BASIN CHAVES COUNTY (continued)

	R. 24 E. 6th mi	R. 25 E. 1st mi	R. 25 E. 2nd mi	R. 25 E. 3rd mi	R. 25 E. 4th mi	R. 25 E. 5th mi	R. 25 E. 6th mi	R. 26 E. 1st mi	R. 26 E. 2nd mi	R. 26 E. 3rd mi	R. 26 E. 4th mi	R. 26 E. 5th mi	R. 26 E. 6th mi
T. 13 S. 4th mi			--	50	80	130	150	180	160	120	110	90	--
T. 13 S. 5th mi			--	70	140	150	160	170	170	120	100	80	--
T. 13 S. 6th mi			--	40	70	80	130	160	170	140	120	80	--
T. 14 S. 1st mi			--	40	80	130	150	180	190	155	110	90	--
T. 14 S. 2nd mi		--	10	70	140	150	170	190	190	150	160	100	80
T. 14 S. 3rd mi		--	10	60	100	130	160	160	180	190	155	100	70
T. 14 S. 4th mi			--	10	50	110	160	140	140	180	130	80	70
T. 14 S. 5th mi				--	430	60	70	80	130	170	110	90	60
T. 14 S. 6th mi					--	20	50	60	120	180	110	100	80

AVERAGE DEPTHS TO WATER TABLE, IN FEET, ROSWELL BASIN, CHAVES COUNTY

	R. 23 E. 1st mi	R. 24 E. 2nd mi	R. 24 E. 3rd mi	R. 24 E. 4th mi	R. 24 E. 5th mi	R. 24 E. 6th mi	R. 25 E. 1st mi	R. 25 E. 2nd mi	R. 25 E. 3rd mi	R. 25 E. 4th mi	R. 25 E. 5th mi	R. 23 E. 6th mi
T. 10 S. 1st mi	60	50	40	30	20	10	10-	10-	10-	--		
T. 10 S. 2nd mi	60	50	40	30	20	20	10	10	10-	--		
T. 10 S. 3rd mi	50	40	30	20	20	10	10	10-	10-	--		
T. 10 S. 4th mi	50	40	30	20	20	10	10-	10	10-	--		
T. 10 S. 5th mi	50	40	30	20	20	10	20	10	--			
T. 10 S. 6th mi	30	20	10	10	10	20	10	10	--			
T. 11 S. 1st mi	50	40	25	20	15	15	10-	10-	--			
T. 11 S. 2nd mi	60	50	40	40	30	20	10	10-	--			
T. 11 S. 3rd mi	70	65	60	50	40	30	10	10-	10-	10-	--	
T. 11 S. 4th mi	--	80	70	55	40	30	10	10-	10-	10-	10-	--
T. 11 S. 5th mi	--	--	80	60	50	35	15	10	10-	10-	10-	--
T. 11 S. 6th mi	--	--	80	70	55	40	20	20-	20-	20-	10	--

AVERAGE DEPTHS TO WATER TABLE, IN FEET, ROSWELL BASIN, CHAVES COUNTY (continued)

	R. 24 E. 1st mi	R. 24 E. 2nd mi	R. 24 E. 3rd mi	R. 24 E. 4th mi	R. 24 E. 5th mi	R. 24 E. 6th mi	R. 25 E. 1st mi	R. 25 E. 2nd mi	R. 25 E. 3rd mi	R. 25 E. 4th mi	R. 25 E. 5th mi	R. 25 E. 6th mi
T. 15 S. 1st mi									60	55	50	40
T. 15 S. 2nd mi									60	50	45	40
T. 15 S. 3rd mi										60	50	40
T. 15 S. 4th mi									50	45	45	40
T. 15 S. 5th mi			60	50	50	50	50	45	40	40	35	30
T. 15 S. 6th mi		40	30	30	30	35	30	25	25	25	25	20

AVERAGE DEPTHS TO WATER TABLE, IN FEET, ROSWELL BASIN CHAVES COUNTY (continued)

	R. 26 E. 1st mi	R. 26 E. 2nd mi	R. 26 E. 3rd mi	R. 26 E. 4th mi	R. 26 E. 5th mi	R. 26 E. 6th mi
T. 15 S. 1st mi	30	25	20	15	10	10-
T. 15 S. 2nd mi	30	25	20	15	10	10-
T. 15 S. 3rd mi	30	25	20	10	10-	10-
T. 15 S. 4th mi	30	25	20	10	10-	--
T. 15 S. 5th mi	25	20	10	--		
T. 15 S. 6th mi	15	10	--			

and this water will become tributary to properly spaced pumps. The present drainage system should become largely inoperative in localities of considerable pumping. Thus part of the water discharged from wells will be balanced by loss of water in the Hagerman Canal and in the Pecos River. It would appear that the preponderant part of the recharge to the valley fill may come from this source. The Cottonwood hydrographic survey indicated that the cottonwood developed about 100,000 acre-feet--about 1 second-foot per mile--of water in a distance of 16 miles primarily from return flow from irrigation. The leakage from artesian wells must also have furnished a significant quantity of water to the alluvium. It is estimated that west of the river a loss of from 15,000 to 20,000 or more acre-feet of water per year has now been stopped by plugging artesian wells. Natural leakage from the artesian beds is an unknown quantity, but it is evident that in the northern part of the area where the artesian aquifers are shallow, and where springs formerly flowed large quantities of water at the surface, there must still be considerable discharge into the alluvium. The Elder survey of 1925 reported a flow of the Hondo River of 78 second-feet from springs and seeps, which made up about half of the total pickup of the Pecos from Acme to Dayton. It is probably significant that the larger part of the pickup of the Pecos occurs in the part of the area where the cover of the artesian beds is thin.

The best evidence as to the total recharge of the valley fill is probably furnished by the increase in flow of the Pecos River in its course through the Roswell Basin. From October 26-28, 1925, C.C. Elder, in the course of investigations by the Bureau of Reclamation on the Pecos River, made a seepage run from Acme to Dayton. Results of this run were as follows:

Station	River distance (miles)	North-South distance (miles)	Discharge (c.f.s).	Gain in section (c.f.s.)	Gain per mile in north-south direction (c.f.s.)
Acme (above Salt Cr.)	0	--	61	--	--
Acme Gage	1	0	64	3	--
Roswell Br. (above Hondo)	17	14	87	23	1.64
Roswell Br. (below Hondo)	17	14	165	78	--
Felix River	--	--	17		
Hagerman Br.	42	32	204	39	2.16 (including Felix)
Drain channels		--	9		
Artesia Br.	72	50	233	29	1.61
Dayton Gage	81	--	224	-9	--
Total				163	

All flow of the Pecos and tributaries resulted from seeps and springs. The mean flow of the Pecos at Dayton in October 1925 was 277 second-feet. The average flow in October from 1903 to 1925 was 310 second-feet, but the average was large because of heavy floods in 2 or 3 years. The median value for October was 214 second-feet. It would thus appear that the river during the month in which this run was made was somewhat higher than usual, and that the pickup might have been somewhat larger than normal.

A gage was maintained at Acme from midyear in 1921 to midyear 1923. Records for this time can be compared with those at Dayton to show pickup. Considerable pumping from the river for irrigation is done in the Roswell Basin, and consequently, pickup records during the irrigation season are not indicative of the actual pickup of the river. During November and December 1921, January, November and December 1922, and January 1923, there was probably little pumping; there were no floods and it seems probable that the increased flow of artesian springs and seeps probably compensated for decreased drain flows at this time. The records, in acre-feet, are as follows:

	Acme	Dayton	Increase
November 1921	2,570	9,490	6,920
December	4,170	12,030	7,860
January 1922	5,990	14,470	8,460
November	3,510	8,590	5,080
December	3,170	10,050	6,880
January 1923	3,880	11,600	7,720
Average			7,150

At the average rate this would represent an annual increase of about 86,000 acre-feet, or a continuous flow of about 125 second-feet. The river during each of these months was lower than normal. It therefore appears that the increase in flow was probably somewhat less than normal. Considering all the evidence, it would appear that the average annual increase in flow in the Pecos from Acme to Dayton amounted to about 100,000 acre-feet, most of which occurs above the mouth of the Hondo--on the basis of Elder's seepage run, about 0.6 of it. On this basis about 40,000 acre-feet of recharge occurs from the mouth of the Hondo to Dayton. In this area, probably about 10,000 or 15,000 acre-feet of recharge from leaky artesian wells has now been stopped. The recharge in the future will therefore probably be of the order of 25,000 or 30,000 acre-feet, or about 550 to 675 acre-feet per mile per year. This is about the same rate of flow as the Cottonwood develops from irrigation drainage. Presumably a large part of the recharge along the river is also gained from irrigation return and is therefore picked up near the river or, in other words, there is probably a cumulative ground-water flow from northwest to southeast.

Average Transmissibility of Valley Fill

If there is an average accretion to the river of about 1 second-foot per mile (measured along a north-south line) and the slope of the water table is about 10 feet to the mile southeast, the average coefficient of transmissibility is:

$$1 \text{ times } \frac{646{,}317}{1} \text{ gal/day times } 1.414 \text{ times } \frac{1}{10} \text{ equals } 91{,}500.$$

This coefficient of transmissibility is considerably greater than that indicated for the Mimbres Valley, larger than that determined for the Rio Grande in the vicinity of Albuquerque (50,000), and probably larger than that of the Portales Valley. Considering the nature of the sediments and the thickness of the aquifer this value seems reasonable. Inasmuch as the average flow may be somewhat smaller and that there is probably a pickup of recharge toward the river, so that the entire flow assumed does not pass the western part of the irrigated belt, the coefficient of transmissibility is probably somewhat less than that computed. In the following computations a coefficient of 80,000 will be assumed.

Probable Effects of Pumping on the Water Levels in the Valley

The Roswell shallow-water basin may be divided into several sections from the standpoint of ground-water development.

1. The area from the Hondo River north. The shallow water in this area is at present only lightly developed. According to Elder's seepage run, there appears to be more shallow water recharge here than elsewhere in the valley. It appears also that the alluvial fill is thick over a large part of the area. The danger in this area is that by reducing the head in the shallow water, more opportunity will be given for discharge of artesian water through breaks in the capping beds.

2. From the Hondo to Orchard Park. This shallow water in this area is comparatively lightly developed.

3. From Orchard Park about 16 miles south almost to Lake Arthur. This is the most highly developed part of the basin and the shallow ground-water problem is therefore most critical here.

4. From 2 miles north of Lake Arthur to Dayton, a distance of about 20 miles. Development of shallow water is more scattered and less intense than that to the north.

5. From Dayton to Seven Rivers, a distance of 10 miles. Development is scattered and there is no immediate problem of depletion of ground water.

The conditions in the area between Orchard Park and Lake Arthur will first be considered. In this area the pumps are rather solidly massed for a distance of 6 or 7 miles back from the river. In this area permits have been granted for 149 wells, of which 106 are known to have been drilled. Wells having water rights to about 11,500 acres have already been drilled and permits have been granted for about 7,000 acres more. Wells having supplemental rights to about 2,950 acres have been drilled and permits for about 400 additional acres have been granted. Assuming a use of 3 feet of water on non-supplemental land, a half a foot on land with supplemental rights, a use of water of about 58,000 acre-feet a year is indicated. This is an average of about 3,600 acre-feet a year for each east-west row of sections, or about 3,000 acre-feet a year more than would be supplied by the recharge, leaving a total for the 16-mile strip of about 47,000 acre-feet a year that must be supplied from storage. If it is assumed that the use of the water supplied by recharge will cause no lowering of the water table, that the remainder must be supplied from storage in a six-mile strip north and south, and that the specific yield of the sediments is 20 percent, the average lowering per year would be:

$$\frac{3{,}000}{0.2 \text{ times } 640 \text{ times } 6} \quad \text{equals 3.9 feet.}$$

The lowering in 10 years would be 39 feet.

Another computation can be made on the basis of formulae based on pumping from storage in a trench. If water is pumped from a trench, the lowering of the water table at any point will be given by the formula:

$$v \text{ equals } \frac{720\,F\,x}{T}\, f(u)$$

$$\text{where } u \text{ equals } 1.367\, x \sqrt{\frac{s}{Tt}}$$

in which F is flow in gal./min. per foot of trench
x equals distance to point of observation in feet
T equals coefficient of transmissibility
s equals specific yield
t equals time in days

Assume as before that the use of the water derived from recharge will cause no lowering of the water table. Assume that the water taken from storage is taken in equal amounts from five north-south trenches one mile apart. The pumping rate for each trench will then be

$$F \text{ equals } \frac{600}{5{,}280} \text{ times } \frac{1}{724} \text{ times 449 equals 0.0705 gallon per minute}$$

foot of trench.

Assume:

T equals 80,000
s equals 0.2

Let:

x equal 1,000 feet, 5,280 feet, 2 miles, 3 miles, 4 miles, and 5 miles
t equal 1, 5, 10, 15, and 20 years

$$\text{Then } u \text{ equals } 1.367\, x \sqrt{\frac{0.2}{80{,}000\, t}} \text{ equals } 1.367\, x \sqrt{\frac{0.0000025}{t}} \text{ equals } 0.00216\, \frac{x}{\sqrt{t}}$$

Values of u

		1 yr. (365 da.)	5 yrs. (1,715 da.)	10 yrs. (3,650 da.)	15 yrs. (5,365 da.)	20 yrs. (7,300 da.)
x equals	1,000 feet	.113	.0521	.0362	.029	.025
	5,280	.596	.275	.191	.154	.133
	10.560	1.192	.55	.382	.308	.266
	15,840	1.790	.932	.574	.462	.399
	21,120	2.38	1.10	.765	.616	.532
	26,400	2.92	1.375	.955	.770	.665

Values of $f(u)$[1]

		1 yr.	5 yrs.	10 yrs.	15 yrs.	20 yrs.
x equals	1,000 feet	4.05	9.9	14.2	18.0	23.0
	5,280	.265	1.20	2.0	2.69	3.30
	10,560	.04	.32	.69	1.00	1.27
	15,840	--	.07	.29	.47	.63
	21,120	--	.04	.13	.24	.35
	26,400	--	.02	.06	.13	.20

[1] The values of $f(u)$ are the values of a peculiar function of u, taken from tables prepared by me. The nature of this function was determined by C.I. Lubin at my request. Its value is given by the equation

$$f(u) = \frac{e^{-u^2}}{\sqrt{\pi}\, u} - \frac{2}{\sqrt{\pi}} \int_u^\infty e^{-u^2}\, du$$

The lowering, in feet, will be

$$V \text{ equals } \frac{720\,F\,x}{T}\,f(u)$$

$$\text{equals } \frac{720 \text{ times } 0.0705\ x\ f(u)}{80,000} \text{ equals } .000635\ x\ f(u)$$

for 1,000 feet	V equals	.635 $f(u)$
5,280		3.35 $f(u)$
10,560		6.70 $f(u)$
15,480		10.05 $f(u)$
21,120		13.40 $f(u)$
26,400		16.75 $f(u)$

Lowering, in feet, due to pumping trench

		1 yr.	5. yrs.	10 yrs.	15 yrs.	20 yrs.
x equals	1,000 feet	2.57	6.28	9.00	11.40	14.60
	1 mile	.89	4.02	6.70	9.00	11.10
	2 miles	.27	2.14	4.62	6.70	8.50
	3 miles	.00	.70	2.92	4.71	6.32
	4 miles	.00	.54	1.74	3.22	4.70

Lowering at each of the trenches, in feet

Drawdown	1 yr.	5. yrs.	10 yrs.	15 yrs.	20 yrs.
1st trench	3.73	13.68	24.98	35.03	45.22
2nd trench	4.62	17.16	29.94	40.81	51.62
3rd trench	4.89	18.60	31.64	42.80	53.80
4th trench	4.62	17.16	29.94	40.81	51.62
5th trench	3.73	13.68	24.98	35.03	45.22

The last group of figures is merely the addition of the effects of the five trenches at the trench in question. Thus the third or middle trench should show the effects due to its own pumping, assumed to be that produced at a distance of 1,000 feet by pumping at an equivalent rate uniformly throughout the year, plus the effects of two trenches 1 mile distant and 2 trenches 2 miles distant. At the first and fifth trenches, the effects will be those of pumping at a distance of 1,000 feet, 1 mile, 2 , 3, and 4 miles.

GROUND-WATER CONDITIONS NEAR DEMING, NEW MEXICO

By Charles V. Theis
1942

General Statement

A large supply of ground water of excellent quality is available in the vicinity of Deming. This water has been used for irrigation for several decades. It occurs in a deposit of silt, sand, and gravel of irregular thickness but probably averaging around 1,000 feet. These bolson deposits form a very large reservoir into which there is a comparatively small-flow--about 10,000 acre-feet annually--and out of which there is unavoidable leakage of about the same amount. The water that is pumped is therefore at least largely taken from storage in the reservoir and water levels must on the whole decline as long as there is pumping; but the reservoir is so large that there is no prospect of exhaustion in the predictable future. The area is under the New Mexico law for the conservation of ground water, and permits from the State Engineer are required for the drilling of irrigation wells. Any projected development of ground water in the Deming area should be discussed with T.M. McClure, State Engineer, Santa Fe. It is the policy of Mr. McClure's office to interfere in no way with defense needs.

Quality of Water

The following analyses, in parts per million, represent the range in quality of water that might be obtained on the proposed site. The analyses are by the Geological Survey.

Water source	1	2	3	4
Silica (SiO_2)	46	33	44	33
Iron (Fe)	.08	.03	.04	.13
Calcium (Ca)	44	30	57	29
Magnesium (Mg)	11	5.9	13	7.0
Sodium (Na)	30	35	42	35
Potassium (K)	2.8	3.8	3.8	3.3
Carbonate (CO_3)	2.4	3.9	3.9	0
Bicarbonate (HCO_3)	202	183	205	177
Sulphate (SO_4)	22	18	49	18
Chloride (Cl)	7.6	7.0	49	9.8
Nitrate (NO_3)	4.5	1.7	8.3	1.1
Total dissolved solids	269	225	367	220
Total hardness as $CaCO_3$	155	99	196	102

1. Well 60 feet deep, 1 mile east of Deming, SW 1/4, Sec. 25, T. 23 S., R. 9 E.
2. Well 146 feet deep, 4 miles south of Deming, SW 1/4, SE 1/4, Sec. 15, T. 24 S., R. 9 W.
3. Well 80 feet deep, 2-1/2 miles southeast of Deming, NE 1/4, NW 1/4, Sec. 12, T. 24 S., R. 9 W.
4. Test well 1,000 feet deep, 3-1/2 miles southwest of Deming, SW 1/4, SE 1/4, Sec. 6, T. 24 S., R. 9 E. Water from 300-442 feet.

Depth and Capacity of Wells

A test well 1,000 feet deep in Sec. 6, T. 24 S., R. 9 W., drilled under the supervision of the State Engineer and the U.S. Geological Survey, indicates that water-bearing beds are present in the fill to a depth of about 450 feet. Analysis No. 4 gives the quality of the water between 300 and 442 feet in this well, which is below the depth reached by other wells in this vicinity. The lower water is of better quality than the average water struck at more shallow depths. By drilling the wells to a depth of from 450 to 500 feet, a somewhat better water will probably be obtained and the interference effects of each well upon the others will be decreased. The casing should, however, be perforated opposite all water-bearing beds, unless perhaps unexpected occurrences of unusually highly mineralized waters should be found. Wells of this depth are expected to produce about 500 gallons a minute each without exorbitant drawdowns.

Spacing of Wells

In an area roughly comprising sections 1 and 12, T. 24 S., R. 10 W., and sections 6 and 7, T. 24 S., R. 9 W., the water levels fell a little over 10 feet in the decade from 1930 to 1940. This decline was largely caused by the pumping in this area, which probably averaged about 1,500 acre-feet annually in these four sections, and an additional 2,000 acre-feet in a neighboring area of about 14 square miles. The extraction of about 3,500 acre-feet annually, or roughly 3,500,000 gallons a day, for military purposes in an area west of Deming, will probably cause a proportionate lowering of water level in that area. That is, the water level may be expected to fall at the rate of 2 or 3 feet a year.

The specific capacities of wells in the Deming area range from about 15 to 30 gallons per minute per foot of drawdown. If wells are drilled to a depth of about 450 feet, their specific capacities will probably be close to or greater than the larger figure. Pumps of about 500 gallons per minute capacity, and not affected by pumping of nearby wells, may be expected to pump from a depth of about 100 feet.

The gravels from which the wells in the Deming area derive water are lenticular. Certain of the irrigation wells affect some of the neighboring wells but do not significantly affect others at no greater distances. It is therefore impossible to predict what the interference effects of the prospective wells upon each other will be. As an average for the area, and for purposes of preliminary design, the following values of interference by one 500-gallon well upon other wells at the given distances may be used.

Lowering of water level, in feet, is to be expected in a well in the Deming area because of continuous pumping of another well at the rate of 500 gallons a minute at the given distance and after the given time.

Distance	After 1 year	After 5 years	After 10 years
0.124 mile	5.5	7.2	8.2
0.25 mile	4.0	5.3	6.6
0.5 mile	2.4	4.2	5.0
1.0 mile	1.1	2.7	3.4

Because of the interference effects to be expected, it is recommended that the wells be spaced as widely as feasible and in no case at closer intervals than 1,500 feet.

OUTLINE OF GROUND-WATER CONDITIONS AT ALBUQUERQUE

Talk Given to Chamber of Commerce

By Charles V. Theis
January 1953

Introduction

The Geological Survey active in New Mexico for 25 years. All work not for other Federal Agencies done in cooperation with the State Engineer and other State and county organizations. Have been more than busy keeping up with problems that have been brought to its attention by interested local people. Up to end of my tenure, Albuquerque had never expressed any interest in the status of its ground-water supply and had never asked a question about it. This invitation is an encouraging sign.

Many questions to be touched on here cannot be answered specifically because basic information is not available. The 1952 report on the Municipal Water System by the Southwest Engineers & Burns & McDonnell calls attention to the dearth of data on the performance of the wells. Apparently no one knows how much any one well pumps, or how much the water level is drawn down, or any changes in quality that may occur. Albuquerque has drawn upon its water in the bank for years and never tried to strike a balance. Two or three years ago some wells quit pumping water. Responsible officials of the city said that the water table dropped 35 feet overnight and no one could have foreseen it! What happened was that the city got a notice from its bank that its account was overdrawn and when it complained that no one could have foreseen this, only said in effect that it had no bookkeeping system.

The Aquifer at Albuquerque

Rio Grande trough--extending from Sandia's to Puerco River--several thousand feet deep in places. Filled with Santa Fe formation and perhaps other Tertiary formations, and Quaternary deposits--unconsolidated sand, gravel, and silt. Perhaps 10 percent porous. Filled with water to river level at center, slightly higher near mountains. Same aquifer in the valley and under the mesas. Wells about as successful one place as another. Movement of water in this aquifer before wells. Water table slopes from near mountains to river, proving that water is added near mountains. Arroyo runs and probably some rainfall infiltration. It moves to river and most there discharge.

Actual movement very slow--a foot per day perhaps. Total quantity moving as shown by Rio Grande Joint Investigation--1 perhaps 2 acre-feet/day/mile of river.

Superimposed on this movement near river is the irrigation water put on the flood plain of the river, the excess of which is drained off back to the river. Perhaps the first point that should be made is that the source of the ground-water is in the immediate vicinity. No drop of water, taken from the sand other than the return irrigation water, has gone underground more than 10 or 15 miles distant. The statement that has appeared in the newspapers that the ground water originates in the Jemez Mountains or any other distant point is just a common old wives' tale.

General Conditions of Discharge by Wells

Every aquifer under a condition of nature is in a state of quasi-equilibrium, water from rainfall and snowfall called the recharge is added on its higher parts; that water moves slowly underground, and finally after a lapse of years or decades or centuries discharges at a lower elevation. All water that enters the aquifer is eventually discharged naturally through springs and seeps. No water in any significant quantity is added or subtracted underground. A well is a new discharge superimposed on this previously stable system. As a consequence, all the water pumped by the well is balanced by (1) an increase of recharge, (2) a decrease in natural discharge, or (3) a reduction of storage in the aquifer--or by some combination of these. In the Albuquerque area we cannot increase the recharge without some artificial construction. <u>Hence all the water pumped by Albuquerque has been represented and all the water pumped will be represented either by less storage, meaning a fall in water level, or less water draining to the river.</u>

Let's try to be a little more definite about how much has or will come from storage and how much is or will be represented by less flow in the Rio Grande. To do so we should look a little more closely at what we call the cone of depression around a well. When a well is pumped, water levels in its vicinity fall. This produces a slope of the water table in all directions toward the well and provides the force driving the water to the well. As the water table falls, the water that was in storage is discharged from the well. This cone continually grows and expands. Given the characteristics of the aquifer the rate of growth of this cone can be computed. In computing this rate of growth for the Albuquerque wells we are at a disadvantage because no one knows just how any one of the Albuquerque wells acts, but certain data gathered in the Rio Grande Joint Investigation enable us to arrive at an approximate solution. The city wells of Albuquerque range in distance from about 1,000 to 15,000 feet from the river. This table gives the percentage of the total pumpage represented by a loss in flow to the Rio Grande.

	Distance from River				
Years of pumping	1,000 feet	3,000 feet	5,000 feet	10,000 feet	15,000 feet
1	85%	68	47	17	3
5	95%	80	75	52	35
10	98%	85	80	66	50
20	--100	95	85	73	62
50	--100	--100	90	85	75

Quality of Water and Changes in It

There are three kinds of water that are tributary to the Albuquerque pumps. First of all there is the water that moves down from the mesas. This has the quality of the University or Sandia wells and approximately that of the deep wells of the city.

This has a hardness of about 115 ppm and a total solids content of about 300 ppm. Second, there is the shallow water on the flood plain of the Rio Grande typified by the shallow at wells of the city plant. One of these 56-foot--deep wells had a hardness of 229 ppm and a total solids content of 419. The extreme character of this water is shown by the water in the Interior drains of the GRSCD. In 1936, the water in the interior drains in the vicinity of Albuquerque had an average hardness of about 385 ppm and a total solids content of 725 ppm. Finally there is the water in the river. The average character of the water at Otowi in the water year 1949-50 had a total solids content of 231 ppm and a hardness of 137 ppm and in 1950-51 had 242 and 146 ppm, respectively. The river at Albuquerque probably has an average hardness somewhat greater, say 160 ppm.

A deep well in its first stages of pumping will pump the first class of water. This water will come out of storage and depending on the distance of the well from the river and irrigated areas, it can intercept a quantity of water moving from the mesa to the river. However, all the water used by Albuquerque even now cannot permanently come from this source. The city in 1951 used an average of 16 m.g.d., and this flow, according to the figures quoted, amounts only to 1/3 x 1/2 m.g.d. per mile. Hence the wells would have to intercept the flow over a distance of 35 to 50 miles along the river to satisfy the demands. If the usage increases four-fold in the next 20 years to give this quality of water, the wells would have to be spaced over 125 to 200 miles--if there were that much Middle Rio Grande Valley.

The other two kinds of water will make up a mounting percentage of Albuquerque water. The proportion of each of the two kinds will depend on the location of the wells. Those located at the inner edge of the flood plain will draw most of their water from irrigation return--water roughly three times as hard as the present deep well supply--for as the cones of depression deepen about the wells, the return irrigation water will flow toward the wells instead of going to the interior drains. The wells close to the river will draw in river water--water that is about as good as the deep well supply. Wells on the mesa will also give good water which will be drawn from storage for many decades.

Conclusions

1. Nearly all water drawn from Albuquerque wells represents an equal loss of water from the Rio Grande.

2. This loss is almost immediate for wells close to the river, but will be in large part delayed for 1 to several decades for wells at a distance from the river.

3. This loss is to some extent made up by storm and sanitary sewer return.

4. It is also to some extent balanced by the spread of the city over formerly irrigated lands and by the wiping out of bosque and vega which would be using water if the city were not here.

5. Wells can be obtained on the mesa as well as on the flood plain of the river.

6. Water from wells on the inner side of the flood plain can be expected to increase in hardness.

7. Water from wells near the river may increase in hardness temporarily, but over a long period should maintain about its present quality.

8. The closer wells are to the river in general the less the drawdown will be.

9. Properly located wells can continue to satisfy Albuquerque's needs for the foreseeable future, but it must not be overlooked that they are still a diversion of water from the Rio Grande.

10. As pointed out in the Burns-McDonnell-Southwest Engineers 1952 report on the municipal water system, practically nothing is known about the characteristics of the Albuquerque water supply, pumpage of individual wells, lowering of water level, changes in quality--effect of industrial wells on municipal pumping. That reports states "a ground-water survey should be started immediately." Albuquerque is drawing on a community account and no one knows what the bank balance is. It is in the embarrassing position of an ostrich in its traditional pose.

GROUND-WATER CONDITIONS NEAR THE WINGATE ORDNANCE DEPOT

By C. V. Theis

In cooperation with the U.S. Corps of Engineers

July 1941

Stratigraphy

The strata of interest in drilling a test well at the Wingate Ordnance Depot are of Permian, Triassic and Jurassic ages. The prominent lower cliff north of the depot is the Wingate sandstone, a red sandstone, assigned doubtfully to the Jurassic system. The limestone now being quarried for road material at the depot, forming a prominent bench north of the road, has been taken as the base of this formation. (Darton, N.H., "Red Beds" and associated formations in New Mexico, Geol. Survey Bull, 794, p. 144, 1928)

About 130 feet of the Wingate sandstone, including the basal lime, is present in the Indian Service well north of the Santa Fe Railroad, now furnishing water to the depot. Over the depot itself the Wingate has been removed by erosion.

Underlying the Wingate formation is about 900 feet of variegated shale, in most part red, with a few sandstone members which has been assigned to the Chinle formation of Triassic age. Only one sandstone member has been noted in this region. This member occurs about 200 feet above the base of the Chinle and forms a prominent south-facing escarpment from east of Wingate Station west through the depot area. Near the western edge of the area this escarpment swings around to the south and faces east. The sandstone forms a cuesta; the topographic slope north and west of the escarpment is almost exactly the surface of the sandstone. This sandstone was present in the Fire House well at the depot from 270 to 300 feet depth. It is also present in the Indian Service well (16B-40) now being used by the depot at a depth of about 840 feet. Apparently this bed splits to the east and north, for in both the Indian Service well and in the Santa Fe well at Wingate Station a thinner upper sandstone is present about 100 feet above the main mass of sandstone and the upper sandstone can be traced from a point a few thousand feet south of Wingate Station into the prominent bluffs of the depot grounds. This sandstone produced water at the rate of two bailers an hour in the Indian Service well.

Lying below the Chinle formation is a fine, white to buff, saccaroidal sandstone, locally conglomeratic, from 30 to 50 feet thick. It is torrentially crossbedded. According to the usage of the Geological Survey, this is regarded as the Shinarump conglomerate. It is so designated in this report. The Shinarump forms a second cuesta and prominent escarpment about 1 mile south and east of that formed by the sandstone in the Chinle. The Shinarump is recognizable in the logs of the Indian Service well north of the depot, in the Wingate Station well, and in another Indian Service well about 2 miles east of Wingate Station. In these logs its location is represented by 50 to 100 feet of limestone and sandstone. The Shinarump yielded 8 gallons a minute of water in the Indian Service well north of the depot and a small amount in the Indian Service well about 2 miles east of Wingate Station.

Below the Shinarump conglomerate lie about 500 feet of shaly beds. These beds were considered correlative with the Moenkopi formation by Darton (op.cit., p.143) but later work has assigned them to the Chupadera formation of Permian age (Baker, A.A., and Reeside, J.B., Correlation of the Permian and southern Utah, northern Arizona, northwestern New Mexico, and Southwestern Colorado, Bull Am. Assoc. Petroleum Geologists, Vol. 13, no. 11, p. 1433, 1929). These beds are referred to as the "upper Chupadera" beds in this report. In the escarpments on the depot grounds, the upper 60 feet lying just below the Shinarump is composed of dark- purple shale. Below this is about 20 feet of whitish shale and white conglomerate overlying about 50 feet of brick-red shale. A greenish white sandstone, weathering maroon, forms a less distinct cuesta about 3/4 mile south and east of the Shinarump cuesta. It was apparently not present in the deep wells of the area. It is underlain by red shale.

All these well logs report a limestone or "limestone and iron" about 350 feet below the base of the Shinarump. At about this horizon on the Sheep Laboratory road about 1/2 mile north of the Sheep Laboratory, a black, fine-grained, iron- bearing rock was noted. This rock contains a few small quartz pebbles and gives a distinct red streak when scratched. It has some of the characteristics of a flint fire clay. This probably represents a widespread ferruginous and calcareous deposit which probably will furnish a key bed in drilling. About 100 to 200 feet of red and purplish shale apparently lie between this deposit and the base of the Moenkopi in this region. The total thickness of the Moenkopi seems to be about 500 feet.

The lower part of the Chupadera formation underlies these "Upper Chupadera" beds. It is exposed near the Sheep Laboratory spring (also called the Milk Ranch spring) where it consists of about 40 feet of apparently inberbedded fossiliferous limestone and calcareous sandstone underlain by about 60 feet of calcareous fine-grained sandstone to the base of the exposure seen. In other exposures farther east the lower Chupadera consists of about 400 feet of limestone and sandstone near Grants and about 300 feet near Sawyer (Darton, N.H., op. at. p. 141 Idem. p. 142) The Santa Fe well at Wingate Station apparently penetrated these beds to a depth of nearly 300 feet, finding them to be almost entirely sandstone.

The lower Chupadera formation is the main water-bearing formation of the vicinity. At the Sheep Laboratory it is the source of a spring flowing about 60 gallons a minute and many small springs occur in it in the canyons in the vicinity. It is the source of water in the Indian Service well furnishing the depot, which is reported to have had an initial flow of 300 gallons a minute. It is also the source in the Santa Fe well at Wingate Station which is reported to have flowed 45 gallons a minute at 30 pounds pressure and in the Indian Service well east of Wingate Station, where a flow of only 8 gallons a minute was obtained.

The deeper wells in the vicinity of Wingate are locally said to derive their water from the Shinarump conglomerate. This view is apparently based on the opinions of some geologist working in the neighborhood that the beds once called "Moenkopi" and now called Chupadera by the Geological Survey (the "upper Chupadera" of this report) are in reality part of the Chinle, that the Shinarump sandstone of the Geological Survey is also a member of the Chinle, and that the true Shinarump is represented by a sandstone lying upon the Chupadera limestone. The correlation of the Triassic and Permian beds of the general area is very difficult and much geological work needs to be done in northwestern New Mexico. However, no publications supporting this view have appeared in the literature and until they do the loose usage of these terms in a sense at variance with the published literature only confuses the subject further. From the immediate practical and local viewpoint of drilling a well at the ordnance depot, this geological dispute has no significance. The artesian aquifer furnishing the wells in the vicinity is at least approximately at the horizon of the Chupadera limestones and limy sandstones as shown on the geologic profile. This also is the horizon of nearly all the springs on the flanks of the Zuni Mountains.

The Abo sandstone also of Permian age, lies beneath the Chupadera. It is composed of about 600 feet (Idem. p. 140) of redish sandstone with a thin limestone near the base. The Abo probably carries some water as it is extensively exposed in the Zuni Mountains and some beds probably have sufficient porosity, but how much is not known. The Abo is underlain in this vicinity by pre-Cambrian granite and schist which would in all probability be barren of water.

The logs of the deeper wells in the vicinity are shown in Figure 1 [not found in archives], with correlations as to formation by the writer.

Geological Structure

The Ordnance Depot is located near the axis of the Zuni Mountain uplift. In the higher parts of the Zuni Mountains pre-Cambrian granite is exposed. On the flanks of this core of granite the sedimentary rocks dip to the northeast and southwest. Paralleling this uplift on the southwest and west sides, the hogbacks so prominent just east of Gallup occur. West of these hogbacks the surface rocks are those that would be some thousand feet above the surface of the Ordnance Depot and conversely the aquifer of the deeper wells near Ft. Wingate would be several thousand feet below the surface in the Gallup Area.

The Ordnance Depot lies near the northern end of the axis of this structure. East of range line 2W the dips in the depot grounds are quite uniformly 2 or 3 degrees about N. 10° W. West of range line 2W the dips are influenced by the proximity to the hogbacks and are about the same amount but swing around to west in the southern part of the area.

Because of these dips the harder strata form cuestas with a sharp south- or east-facing scarp and gentle dip slopes to the north or west. These topographic slopes represent almost exactly the dip of the rocks.

Figure 2 [not found in archives] is a geologic profile along the line AB on the accompanying map. The line runs from the Indian Service well south easterly to coordinate 23.88 2.7 E and thence to the Sheep Laboratory. It follows the line of dip rather closely. There is an unusually good correlation between the beds found in the Indian Service well and those seen at the surface along this line. It will be seen that lines drawn parallel to the dip slopes of the cuestas in the depot area intersect corresponding sandstones in the well and that even the basal aquifer in the well corresponds with the outcrop of the limestone and limy sandstones near the spring at the Sheep Laboratory. The lines bounding the recognizable members are drawn straight and parallel to bring out the remarkably good correlation but it must be remembered that practically all geological formations thicken and thin and that it is to be expected that those members also thicken and thin and vary in interval from one to another. If enough data were available the lines would probably be much more broken and irregular than they appear. As a consequence in predicting depths to any certain bed at a given place the lines should be considered as giving the approximate depth only.

Previous Drilling on Ordnance Depot Area

Three wells have been drilled within the Depot area during the past year. The position of well No. 1, or the Fire House well, is shown on the profile, figure 2. The log of this well reports only red clay down to its depth of 558 feet except for surficial material from the surface to 80 feet and sandstone from 270 to 300 feet. The sandstone is the same as that forming the cuesta south of the well site and is the one about 225 feet above the base of the Chinle. This well apparently should have reached the upper part of the Shinarump conglomerate but no sand is mentioned. It is probable that the Shinarump here lies somewhat lower than its average position.

Well No. 2 was a shallow well apparently only 65 feet deep and of no significance as a test.

Well No. 3, located at coordinates 21 S., 8 W., is reported to have been drilled 360 feet and to have been dry. It started at about the top of the Shinarump conglomerate. The main aquifer of the area is at a depth of about 600 feet at this location.

Ground-Water Conditions

The higher sandstones in the area, the Shinarump and that about 225 feet higher, seem to outcrop only on high mesas in the vicinity and have apparently little area in which water can enter them. It is to be expected that they will be in general either dry or will yield little water, as the existing wells indicate.

The Chupadera formation has a large area of outcrop on the flanks of the Zuni Mountains and the fact that it receives water in relative abundance is proved by the many springs from it throughout its extent. There is probably no outlet for this water within the State to the north, south, or west. The motion of water thru it must be very slow.

Prospective Conditions at a Well Site Near the Fire House

As shown in Figure 2, a well drilled near the Fire House would be expected to penetrate the following materials. The depths given must be considered only approximate.

Surficial alluvium and red shale	0 - 270 feet
Sandstone essentially dry	270 - 300
Red clay	300 - 560
Sandstone, essentially dry	560 - 600
Dark purple shale	930 - 935
White shale	930 - 935
Perhaps conglomerate	930 - 935
Red shale	930 - 935
Greenish sandstone	930 - 935
Red shale	930 - 935
Lime or iron-stone	930 - 935
Red shale	935 - 1,100
Limestone and sandstone with artesian water	1,100 - 1,450
Red sandstone, probably water bearing	1,450 - 2,050
Granite	2,050 - ?

It is probable that the water in the Chupadera formation circulates largely in solution channels and joints in the limestone and calcareous sandstone, judging from the wide divergence in quantity of flow from the various wells tapping the formation and their various depths into the lower Chupadera. Hence, drilling should be continued well into the formation, as was done at the Wingate Station well, unless an adequate supply is struck at higher levels.

MEMORANDUM ON WATER SUPPLY FOR THE PROPOSED AIR BASE NEAR HOBBS, NEW MEXICO

By Charles V. Theis
In cooperation with the U.S. Corps of Engineers
February 1942

General Geological and Hydrological Conditions

Hobbs lies near the south edge of the Staked Plain of New Mexico and Texas. The Staked Plain is a plateau sloping gently to the east-southeast about 10 feet to the mile, and extending southward from the Canadian River. Geologically it consists of a deposit of permeable alluvial and wind-blown materials, of Tertiary and later age, from 0 to a few hundred feet thick resting upon a similarly sloping surface of largely impermeable shaly beds of Triassic and Cretaceous age. In the vicinity of Hobbs these underlying impermeable beds are red shales of Triassic age. Water occurs in abundance in the sandy and gravelly beds of the Tertiary deposits, but is scarce and generally of bad quality in the underlying Triassic beds. In the neighborhood of Hobbs, the water-bearing deposits are about 200 feet thick.

The underlying largely impermeable bed rocks also form a buried plateau whose surface rises above the Pecos drainage on the west and the Canadian drainage on the north. Inasmuch as this surface slopes to the east-southeast, the entire recharge to the water body in the Tertiary of the Staked Plains must therefore be from rainfall penetration and seepage from the ephemeral lakes on its surface. Late work in Texas and New Mexico indicates that the recharge probably averages about 0.1 or 0.05 inch of water annually. The recharge area of the Hobbs district is bounded on the west by the escarpment of the Staked Plain, which lies about on the western boundary of Lea County, about 40 miles west of Hobbs, and on the north by a buried ridge of Cretaceous rocks at about the latitude of Tatum about 35 miles north of Hobbs.

Despite the low rate of recharge to this ground-water body, the amount in storage is very great and there is no question of significant weakening of the ground-water supply for the Air Base near Hobbs within the predictable future. There is probably about 10 million acre-feet of water stored in the recharge area north and west of Hobbs outlined above.

The ground water in the Tertiary deposits is moving slowly to the east-southeast. Some of it discharges along the southern edge of the Staked Plain running about 6 miles south of Hobbs, either as weak springs or seeps or into sand-filled buried channels in the Triassic bed rock in the southern part of Lea County. Most of the ground water, however, continues its slow percolation southeastward into Texas.

Existing Wells

There are five irrigation wells close to the projected Air Base.

Location	Owner	Depth of well (feet)	Depth to water (feet)	Estimated pumping rate (g.p.m.)
T. 17 S., R. 37 E.				
SW1/4 SW1/4 Sec. 26	D.B. Wilhoit	117	27	420
SE1/4 SE1/4 Sec. 34	J.D. Murrell	117	27	600
SE1/4 NW1/4 Sec. 36	M.J. Waltman	120	26	600-800
T. 17 S. R. 38 E.				
NW1/4 SW1/4 Sec. 30	G.S. Pruett	56	29	700?
NW1/4 NW1/4 Sec. 30	Jesse Pruett	45	25	?

Apparently none of these wells have gone through the water-bearing formation. The log of the Wilhoit well is reported as follows:

Black loam	0 to 3 feet
Caliche	3 to 5
Boulders	5 to 10
Sand and boulders	10 to 28?
Sand, water	28 to 117

The only well in the neighborhood known to have penetrated the entire thickness of the water-bearing material belongs to the Hobbs Water Company.

During a pumping test made on the Wilhoit well in 1930, the well produced 420 gallons a minute and after pumping 51 hours, the drawdown was 18.08 feet. The specific capacity was therefore about 23 gallons per minute per foot of drawdown.

Log of well of Hobbs Water Company
Sec. 34., T.18 S., R. 38 E.

Material	Thickness (feet)	Depth (feet)
Subsoil	3	3
Caliche and broken lime shells	27	30
Lime shell	5	35
Soft red sand; a little water	15	50
Soft quicksand	13	63
Hard white sand	11	74
Lime shell	2	76
Gravel and coarse sand; water	24	100
Gray sand	5	105
Soft porous sandstone	15	120
Hard sand	5	125
Quicksand	5	130
Hard sand	5	135
Red sand	10	145
White sand	10	155
Sandy clay	3	158
"Indian Flint" (chert)	2	160
Sandy clay	3	163
Caliche	2	165
White sand	2	167
"Indian Flint" (chert)	3	170
Water sand	3	173
Red bed	1	174
Red sand	16	190
Sandy clay	2	192
White sand	3	195
Coarse water sand	5	200
Sandy water gravel, to top of red beds (Triassic)	6	206

Quality of Water

The following analysis of the water from the Wilhoit well is typical of the water from the Staked Plain in Lea County. The sample was collected in 1929 and analyzed by the Geological Survey:

Analysis of water from Wilhoit well
Sec. 26, T. 17 S., R. 37 E.

Calcium (Ca)	95 p.p.m.
Sodium and potassium (Na + K)	125
Bicarbonate (HCO_3)	363
Sulphate (SO_4)	124
Chloride (Cl)	65
Nitrate (NO_3)	12
Hardness as $CaCO_3$	256
Total dissolved solids	597

Conclusions and Recommendations

1. There will be no difficulty in obtaining 1,000,000 gallons of water a day at the site of the proposed Hobbs Air Base.

2. The quantity could be obtained from one well. It is possible, however, that some difficulty with sand flowing into the well may occur and it will probably be advisable to drill a second well as a standby.

3. The wells should be drilled about 200 feet deep or to the base of the water-bearing formation at about that depth. Below the water-bearing formation red clay will be found and drilling should be stopped when this clay is definitely entered.

4. Static water level will be at a depth of about 30 feet.

5. The drawdown during pumping may be estimated as about 1 foot for each 25 gallons a minute pumped or about 30 feet for a pumping rate of 750 gallons a minute. If the well is carried to the base of the water-bearing deposits, the drawdown should be somewhat less.

6. The water will be somewhat hard but of good quality.

GROUND-WATER SUPPLIES IN THE VICINITY OF CLOVIS, NEW MEXICO

By Charles V. Theis

In cooperation with the U.S. Corps of Engineers

February 1942

General Nature of Ground-Water Occurrence in Area

Ground water in the vicinity of Clovis and Portair occurs in unconsolidated deposits of silt, sand, and gravel, about 375 feet thick near Clovis, belonging to the Ogallala formation of Pliocene age. These deposits are underlain by shaly and generally impermeable redbeds of Triassic age.

The ground water is recharged by rainfall on the surface of the Staked Plain, which extends some 35 miles north and west of Clovis, and discharges in larger part by slow movement eastward to the eastern escarpment of the Staked Plain over 100 miles east in Texas. The amount of recharge is small, being equivalent on the average to only a small fraction of an inch a year, but the amount in storage is great enough to have furnished large irrigation developments for many years without a great lowering of the water table.

Present Development

The city of Clovis and the Atchison, Topeka, and Santa Fe Railway are the only large users of water in the vicinity of Clovis. According to the log of Atchison, Topeka, and Santa Fe well No. 1 at Clovis, the first water was struck at 262 feet and the well passed out of the water-bearing formation at 372 feet, giving about 100 feet of water-bearing material of which nearly all was reported as gravel and sand. The log of well No. 4 of the municipal supply, in Lot 14, Block 1 of the Liebelt Addition, is almost the same. This latter well is reported to have pumped 1,335 gallons a minute for 36 hours and to have had a drawdown of 24 feet, thus indicating a specific capacity of 55 gallons per minute per foot of drawdown. The other city wells are reported to have high specific capacities also. The railroad wells have pumped at the rate of about 2/3 million gallons a day for many years, and the pumpage of the city wells has been increased from about 1/4 million gallons a day in 1930 to about 1 million gallons at present. Apparently there has been some lowering of water level in the wells for the municipal supply--reported as about 12 feet in 10 years--but the amount is no larger than is to be expected after continuous pumping for many years. The lift at the city wells is about 285 feet.

The logs of wells No. 1 and No. 2 of the Santa Fe Railway at Portair are nearly identical. That of well No. 1 is as follows. The log was furnished by courtesy of the railway.

Material	Thickness (feet)	Depth to bottom of bed (feet)
Red, sandy clay	50	50
Dry red sand	160	210
Hard red clay	49	259
Light gray sand	56	315
(Struck water at 306 feet; water rose to 174 feet)		
Coarse sand	25	340
Light gravel	8	348
Red clay	14	362

The lower red clay in this log probably represents the upper beds of the Triassic and its top probably marks the base of the water-bearing beds. There are no tests of the productivity of those wells or other wells near Portair. The water-bearing beds appear to be thinner in this area than at Clovis and wells at Portair are likely to produce less than those at Clovis.

Quality of Water

No analyses of water in the close vicinity of Clovis and Portair are immediately available to this office. However, the water throughout the Staked Plain is rather uniform in composition and the following analysis of water from a well about 10 miles northwest of Portair, made by the Geological Survey, is probably typical.

Analysis of water, in parts per million, from a well 372 feet deep in Sec. 1, T. 3 N., R. 34 E.

Silica (SiO_2)	33
Iron (Fe)	1.5
Calcium (Ca)	30
Magnesium (Mg)	23
Sodium (Na)	29
Potassium (K)	6.4
Carbonate (CO_3)	0
Bicarbonate (BCO_3)	226
Sulphate (SO_4)	23
Chloride (Cl)	10
Nitrate (NO_3)	8.7
Total dissolved solids	261
Total hardness as $CaCO_3$ (calculated)	169

Conclusions

1. There is no doubt that 1,000,000 gallons of water a day can be obtained in the vicinity of Clovis and Portair.

2. The quality of the water available is good. It is essentially calcium bicarbonate water and has a hardness of from 150 to 200 parts per million and a total solids content of about 300 parts per million.

3. The wells should be drilled through the sands and gravels of the Ogallala formation to the redbeds of the Triassic and should be approximately 350 or 375 feet deep.

4. The static water level in the area is at a depth of from 260 to 275 feet and the pumping lift approximates 300 feet for wells of moderate capacity.

5. It is possible that one well may be able to furnish a supply of 1,000,000 gallons a day, but it is more probable that two wells will be required.

6. Inasmuch as coarser deposits in the area are most probably aligned in an east-west direction, it would be preferable to locate the wells on a north-south line. It is recommended that they be spaced at least 500 feet apart.

THE AVAILABILITY OF IRRIGATION WATER AT THE ALAMOGORDO AIR BASE

By Charles V. Theis
In cooperation with the U.S. Corps of Engineers
and the State Engineer of New Mexico
February 27, 1942

Introduction

The United States Army desires to obtain water for the irrigation of grass on runways and building sites at the Alamogordo Air Base in order to decrease dust hazards. It is believed that 180,000 gallons of water a day would be sufficient. The water is chiefly needed in the NW1/2 Sec. 13, and NW1/2 Sec. 2, and N1/2 Sec. 15, T. 17 S., R. 8 E. The domestic supply for the camp is obtained from the Alamogordo public supply, derived from springs in Alamo Canyon, but sufficient water is not available for irrigation. The following information is taken almost entirely from U.S. Geological Survey Water-Supply Paper 343 by O.E. Meinzer and R.F. Hare.

Hydrological Data

The base is located on the lower slope of the alluvial apron from the Sacramento Mountains in the Tularosa Basin. The underlying sediments were deposited partly by streams from the mountains at the lower end of their alluvial fans, and partly by deposition from an evaporating lake. The materials are largely fine grained and contain gypsum and other soluble salts deposited from the ancient lake. Because of the fineness of the sediments, it is probable that wells will not produce very large quantities of water, although it appears that the requisite quantity of water will be obtained without much difficulty. Because of the gypsum and other soluble salts included in the sediments, all of the available water is highly mineralized. The depth to water at the air base varies between about 25 and 50 feet.

According to available information there are no wells in the township in which the base lies. A small spring, Salt Spring, located in the northeast corner of Sec. 6, rises from the alluvial material, and another small spring, located in the southwest corner of Sec. 28 near a small outcrop of limestone, probably derives its water from this limestone bedrock. Both springs are highly mineralized. The following table taken from Water Supply Paper 343 summarizes the data available on these springs and the nearest wells. All wells produce only small quantities of water and are used for watering stock, except as otherwise noted.

Analyses and other data concerning springs and wells near the Alamogordo Air Base

(Townships are south of the New Mexico Base Line and range east of the New Mexico Principal Meridian. Depths are given in feet. "White alkali" includes the sulphates and chlorides of magnesium and sodium.)

Location	S 23 T 17 R 7	S W1/4 S 1 T 17 R 9	SE1/4 S 1 T 17 R9	SW1/4 S 2T 17 R 9	NW1/4 S 3 a/ T 17 R 9
Depth of well	10	50+	104	80	65
Depth to water	5	50	98	?	24
Analyses in parts per million					
Total solids	4,196	5,660	2,516	3,288	2,533
White alkali	1,937	3,890	1,324	2,024	1,401
Ca	558	426	262	316	252
Mg	214	307	137	149	80
Na + K	322	802	233	470	329
CO_3	47	179	104	134	104
SO_4	2,329	2,680	1,194	1,472	1,111
Cl	336	878	221	465	288

a/ Used for irrigation.

Location	NE1/4 S 5 T 17 R 9	SE1/4 S 8 T 17 R 9	NE1/4 S 15 b/ T 17 R 9	NE1/4 S 6 T 17 R 8	SW1/4 Sec. 28 T 17 R 8
Depth of well	60	100	62	(Salt)	(Black)
Depth to water	32	24	31	(Spring)	(Spring)
			Analyses in parts per million		
Total solids	7,280	4,740	11,640	7,504	8,970
White alkali	4,974	2,194	7,286	5,304	6,386
Ca	470	521	755	585	623
Mg	371	165	750	144	187
Na + K	1,211	517	1,482	1,734	2,060
CO3	37	53	149	72	85
SO4	2,580	2,057	3,786	2,570	2,971
Cl	1,897	620	2,841	2,143	2,526

b/ Used for irrigation. Reported to have pumped 125 gallons per minute.

Conclusions

1. The necessary quantity of water can almost certainly be obtained from alluvial and lake deposits underlying the base.
2. The water level will be between 25 and 50 feet below land surface.
3. The water available contains between 4,000 and 10,000 parts per million total solids.
4. If vegetation can be grown, it will necessarily be of an alkali-resistant type. The advice of the Grazing Service and the Soil Conservation Service should be of value in selecting appropriate vegetation.

5. Because no data are available in the immediate locality, drilling should be of a semi-experimental nature. One well, at least, should be carried to a depth of 200 or 250 feet and samples of water taken at several depths and analyzed to determine if better water is available at some particular depth.

6. The sediments are quite fine. It will probably be necessary to construct the producing wells either with well screens especially designed for the type of sediment encountered and of material resistant to corrosion or by the gravel pack method.

GROUND-WATER SUPPLIES NEAR CERRILLOS, NEW MEXICO

By A.M. Morgan and C.V. Theis
In cooperation with the U.S. Corps of Engineers
February 17, 1942

The formations underlying the valley of Galisteo Creek in the vicinity of Cerrillos consist of Cretaceous and early Tertiary sandstone and shale and Quaternary deposits made up of silt, clay, sand, and gravel. The Cretaceous and early Tertiary rocks in this area are essentially barren of water and they present little possibility of developing ground water in any quantity. The Quaternary deposits consist of terrace deposits that mantle the upland bench south of Galisteo Creek and valley fill that underlies the floor of the valley. The upland terrace deposits are thin and they lie high above the water table and are consequently dry. The valley fill along Galisteo Creek extends below the water table and at least locally is a source of ground water.

The valley floor along Galisteo Creek is formed by a low terrace into which the channel of the stream is incised about 14 feet. It ranges in width from one-eighth to about 0.3 of a mile. Near Cerrillos, bedrock, consisting of steeply dipping Cretaceous sandstone and shale, is exposed in the channel of the stream and in the banks beneath the low terrace. One of the outcrops extends unbroken across the channel about 0.5 mile above Cerrillos. The distribution of the outcrop of bedrock in the floor of the valley at this locality indicates that if any buried channel exists, it is extremely narrow and is probably not deep.

About 2-1/2 miles upstream from Cerrillos in Section 21, T. 14 N., R. 8 E., a shallow well belonging to Mr. Miller Frock is used for irrigation. The well is located on the floodplain of Galisteo Creek near the south margin of the valley floor. It is 18 feet square and about 12 feet deep. The water level in the well on February 15, 1941, was 3 feet below the curb, which is about 2 feet above the level of the adjoining floodplain. The well is reported to yield about 800 gallons per minute. It has been in operation since some time previous to 1934 and furnished water for irrigating about 15 acres of land. Field tests made on the standing water in the pit on February 15, 1942, indicated a hardness of about 290 parts per million and a chloride content of about 16 parts per million. The water is drunk by the operators during the pumping season without ill effects.

Another irrigation pumping plant owned by Mr. Clarence Sweet is located 0.8 mile upstream from the Miller Frock well. It pumps water from a 4-foot sump in an abandoned meander of Galisteo Creek. A nearby pit penetrated 14 feet of alluvium and did not encounter bedrock. Bedrock is exposed in the south wall of the channel of the stream about 500 feet south of the sump. The abandoned meander in which the sump is located is cut off from Galisteo Creek by a dam at the upper end and a 3-foot sandbar at the lower end. The lower half of the meander floor is occupied by a small pond that is fed by the underflow of the creek.

Mr. Sweet reported that an old test well located near the railroad bridge north of Galisteo Creek opposite the Miller Frock well penetrated 90 feet of valley fill, of which 85 feet was saturated with water. The test well as located near the north side of the valley floor approximately 1,600 feet north of the Miller Frock well and 900 feet north of the present channel of the creek. If true stream deposits were encountered in this well to a depth of 90 feet it indicated a buried channel of at least that depth. However, in the vicinity of Cerrillos, only 2.3 miles downstream there appears to be little possibility of a buried channel of any depth, and the report of deep river fill at the Sweet place must be received with some reservation.

Due to the pinching out of the valley fill in the vicinity of Cerrillos most of the underflow along Galisteo Creek would be forced to the surface above the town. On February 15, 1941, the flow of the stream at Cerrillos was roughly estimated to be about 5 second-feet, and opposite the Sweet pumping plant it was very little less. The small increase in flow between the Sweet pumping plant and Cerrillos suggests that the underflow which should be forced to the surface above Cerrillos is small, probably less than 1 second-foot.

Pumping from the valley fill 2 miles or more above Cerrillos at a rate of 3,500,000 gallons per day would pick up much of the underflow and in addition would draw water from the stream and from storage in the alluvium in the vicinity of the well. In the summer, during intervals between floods, the stream is often dry, at which time withdrawals from storage would constitute the principal supply. If a buried channel, as indicated by the report of Mr. Sweet that the alluvium is 90 feet deep near the railroad bridge, actually exists, it could not be more than 300 feet wide and still pass the outcrops in the channel at Cerrillos. The remainder of the valley floor is underlain by a relatively thin deposit of alluvium which, for the width of the valley floor (1,600 feet), probably averages less than 20 feet in thickness below the water table.

Assuming that the fill of silt, sand, and apparently subordinant gravel has a specific yield of about 10 percent, the storage would amount to about 40,000,000 gallons of water for each 1,000 linear feet of valley if the deep channel exists and to about half of this figure if the channel does not exist. It would be difficult to entirely drain these sediments and obtain the entire amount of stored water.

At times of flood in Galisteo Creek, the stored water would be at least largely replenished. No stream-flow records are available on the Galisteo. However, in the summer, extended periods of drought are likely to occur, and at such times water shortages would be likely to be acute.

The entire area irrigated by the Frock and Sweet pumps amounts to about 30 acres. Apparently not more than 90 acre-feet of water a year is pumped. Although the Frock well is reported to have water throughout the year, it is reported that its yield is diminished in late summer, and Mr. Sweet reports that the sump in the abandoned meander from which he draws water is so depleted in late summer that he can pump only about 1 hour a day. The two pumps, therefore, appear to have difficulty in pumping as small a total as 90 acre-feet or about 30 million gallons, distributed throughout the growing season, from the alluvium.

Conclusions

1. There appears to be no water supply in the vicinity of Cerrillos that can be depended upon to yield 3,500,000 gallons of water a day.

2. It is possible, although in our opinion not probable, that an expensive system of wells or collecting galleries beneath the alluvium might develop such a supply. In case it becomes imperative to attempt to develop such a supply, an intensive exploration should be first carried out to determine the thickness and extent of the alluvium by well drilling and to determine the productivity of the alluvium by pumping.

GROUND-WATER CONDITIONS NEAR SEPAR, NEW MEXICO

By Charles V. Theis
In cooperation with the U.S. Corps of Engineers
July 11, 1942

Statement of Problem

A military establishment using about 770,000 gallons of water a day has been proposed near Separ, New Mexico. As this demand is to be satisfied in 16 hours, wells producing about 800 gallons a minute would be required. Separ lies just west of the continental divide and about 20 miles southeast of Lordsburg, New Mexico.

General Hydrologic Conditions

The vicinity of Separ is underlain by at least 600 feet of bolson deposits consisting of silt, sand, and gravel. In common with much of the bolson filling near Deming and Lordsburg, the lower part of the bolson fill seems to be considerably less permeable to water than the upper 300 feet.

At Separ the depth to water is about 300 feet. Both north and south the depth decreases but to the north the water found at shallow depths near the Burro Mountains probably represents only a small ground-water flow over a shelf of impervious granitic rock extending out from the mountains. Several miles to the southwest, south and southeast of Separ, the depth to water is from 150 to 250 feet, the alluvium is probably thicker than it is to the north, and the prospects of obtaining a considerable supply of water are much better than at Separ or north of Separ.

Existing Wells

The log of the Southern Pacific well at Separ is as follows (Schwennesen, A.T., Ground water in the Animas, Playas, Hachita and San Luis Basins, U.S. Geological Survey, Water-Supply Paper 422, Pl. V, 1918).

Material	Thickness (feet)	Depth (feet)
Soil	3	3
"Cement" (Caliche?)	7	10
Clay	40	50
Sand and gravel	10	60
"Cement" and gravel	5	65
Clay	5	70
"Cement" and gravel	20	90
Running sand	10	100
Clay	3	103
"Cement" and gravel	114	217
Running gravel	5	222
Clay	10	232
Cemented gravel	14	246
Running gravel	10	256
Cemented gravel	20	276
Clay (water level at 300 feet)	24	300
Gravel, water bearing	10	310
Clay	30	340
Gravel, water bearing	10	350
Clay	14	364
Gravel, water bearing	4	368
Clay	34	402
Gravel	4	406
Clay	56	462
Gravel, water bearing	2	464
Clay	60	524
No record	86	610

This and another well 25 feet distant are reported to furnish 4,000 gallons of water an hour to the railroad when pumped from 8 to 14 hours a day. No data on drawdown are available and hence the ultimate production cannot be estimated.

The depth to water decreases southward from the railroad in this vicinity, being about 160 feet in a stock well in Sec. 23, T. 25 S., R. 16 W., 198 feet in Sec. 15, T. 25 S., R. 15 W., 202 feet in Sec. 18, T. 25 S., R. 14 W., and 120 feet in Sec. 15, T. 25 S., R. 14 W.

Quality

The water in the vicinity of Separ is generally a sodium sulphate or sodium bicarbonate water. The following analyses are available.
(Schwennesen, A.T., op. cit., pp. 129, 142.)

Location	Sec. 21 T.25 S., R. 16 W.	Sec. 26 T. 24 S., R. 17 W.	Sec. 8 T. 24 S., R. 17 W.
Distance & direction from Separ	8 miles SW.	8 miles W.	8 miles W.
Constituents		Parts per Million	
Calcium, Ca	31	104	17
Magnesium, Mg	22	28	12
Sodium + potassium			
Na + K (calc)	280	136	127
Bicarbonate, HCO_3	398	281	209
Sulphate, SO_4	365	253	138
Chloride, Cl	50	126	36
Hardness as $CaCO_3$	168	375	92
Total dissolved solids	1,023	861	466

Conclusions

1. In the close vicinity of Separ, the depth to water is about 300 feet and the water-bearing part of the bolson fill appears to be of comparatively low permeability. The pumping lift is high and the prospects of obtaining around 800 gallons of water a minute are not good.

2. In an east-west strip about 6 miles south of Separ, the ground-water is much shallower and the water table rises into the generally more permeable upper part of the bolson fill. It seems probable that 800 gallons of water a minute could be obtained from two or three wells in this vicinity with pumping lifts of 200 to 250 feet depending on the exact location.

GROUND-WATER CONDITIONS NEAR WILNA, NEW MEXICO

By C. Richard Murray and C.V. Theis
In cooperation with the U.S. Corps of Engineers
and State Engineer of New Mexico

September 23, 1942

A report on ground-water conditions in the vicinity of the continental divide along the Southern Pacific Railroad in Grant County, New Mexico, was requested by the U.S. Corps of Engineers. A water supply of 700,000 gallons a day obtained during a 16-hour pumping period is desired in this area. The basic data used in preparing this report were largely obtained during an investigation of the general area by the writer in October 1939, but the area was also visited on September 13, 1942.

Geology and Topography

The continental divide near the southern Pacific Railroad in Grant County is a smooth bolson plain above which isolated mountain masses project. Drainage west of the divide flows toward the Animas drainage basin and that east of the divide toward the Mimbres Valley. The bolson is underlain by clay, sand, and gravel of Tertiary and Quaternary age.

The principal mountain mass in the area is the Burro Mountains, which attain an altitude of over 8,000 feet about 30 miles northwest of Wilna. They are composed largely of pre-Cambrian igneous and metamorphic rocks. The Grandmother Mountains, about 10 miles northeast of Wilna, are composed of felsitic rhyolite of Tertiary age and attain an altitude of about 5,400 feet. The Victorio Mountains, about 7 miles east of Wilna, reach an altitude of about 5,000 feet. The southern part of the Victorio Mountains is formed of Paleozoic sediments and the northern part, of Tertiary igneous rocks. The Klondike Hills and Cedar Mountains lie south-southeast of Wilna, the Little Hatchet Mountains southwest, and the Pryamid Mountains about 25 miles west.

Hydrology

Wells in the vicinity of Wilna penetrate alluvium which is largely clay, and considerable trouble has been experienced in obtaining sufficient water from the wells to supply stock and domestic needs. The depth to water at Wilna is about 200 feet and increases toward the north. As the Burro Mountains are approached, however, water is found at shallower depths and two wells about 8-1/2 miles northwest of Wilna obtain water at a depth of about 20 feet in scattered patches of alluvium in a box canyon underlain by granite. The area between Wilna and this shallow water zone is practically devoid of wells, and it is believed that only a small amount of water is obtainable in the locality of the shallow wells because of the limited extent of the alluvium. North-northeast of Wilna the depth to water progressively increases until at a distance of 10 miles, the water table is 475 feet below the land surface. East and south of Wilna the depth to water decreases; however, few wells have been drilled in these areas, and some wells south of Wilna are reported to have failed to obtain water.

Southwest of Wilna along the road to Hachita, which meets the Deming-Lordsburg highway about 4-1/2 miles west of Wilna, there are a number of stock wells. Wells are also fairly numerous in the area east of the Hachita road for a distance of about 3 miles to the continental divide. The depth to water is about 200 feet in the wells near the road but decreases toward the continental divide to about 120 feet. This shows that the westerly slope of the water table is steeper than the westerly slope of the land surface.

West of Wilna toward Separ, the depth to water increases, being about 300 feet at Separ. Clay is the most abundant material below the water table, and wells with only small yields are obtained. The combined yield of the two railroad wells at Separ is reported to be 4,000 gallons of water an hour.

Summary and Conclusions

Attempts to develop water in the area along the Southern Pacific Railroad on the continental divide in Grant County have been only partly successful. Numerous wells have been drilled and abandoned as dry holes. Other wells that have been equipped with windmills only partially meet the needs of the ranchers. A few of the wells supply sufficient water for both stock and domestic use.

In the area about 6 miles south-southwest of Wilna along the continental divide, where the water table is at a shallower depth, conditions are favorable for obtaining better than average wells. The upper part of the bolson deposits appears to be more permeable than the lower part in the Deming-Lordgsburg region, and where the water table is high enough so that the more porous materials are saturated, better wells are obtainable. It appears unlikely, however, that the required amount of water can be obtained from a few wells within a feasible distance of the proposed sites, lying on the north and south sides of the railroad west of Wilna.

GROUND-WATER CONDITIONS NEAR CAMBRAY, LUNA COUNTY, NEW MEXICO

By C. Richard Murray and Chas. V. Theis
In cooperation with the U.S. Corps of Engineers
and the State Engineer of New Mexico

September 23, 1942

At the request of the U.S. Corps of Engineers, a brief field investigation was made of ground-water conditions in the vicinity of Cambray, New Mexico. It is estimated that a supply of 700,000 gallons of water a day obtainable during a 16-hour pumping period will be required in this area.

Geology and Topography

Cambray is on the Southern Pacific Railroad about 25 miles east of Deming, New Mexico. The land surface is a bolson plain having a gentle southwesterly slope and is underlain largely by sand and clay of Tertiary and Quaternary age. Goodsight Mountain and the Sierra de Las Uvas are north of Cambray, the West Potrillo Mountains southeast, and the Little Florida and Florida Mountains west and southwest. Goodsight Mountain and the Sierra de Las Uvas consist of Tertiary igneous rocks overlain by Quaternary basalt. The basalt in Goodsight Mountain dips easterly and that in the Sierra de Las Uvas westerly, giving rise to a synclinal structure. At two places near Cambray, one 5 miles east and the other 5 miles southeast, igneous rocks project up above the bolson plain, the former being a basalt flow of Quaternary age and the latter a butte of Tertiary igneous rock.

Farther south, in the West Potrillo Mountains, Tertiary igneous rock is again overlain by Quaternary basalt, suggesting a southerly extension of the Goodsight Mountain-Sierra de Las Uvas rocks and structure. A number of wells in the Cambray area encounter bedrock within a few feet of the surface. It is probable that the Tertiary rhyolitic flows, tuffs, and agglomerates, which outcrop both north and south of Cambray and in the isolated butte southeast of Cambray, form the surface on which the bolson materials at Cambray were deposited. This bedrock surface is only a few feet below the surface at Cambray and apparently slopes toward the west, the depth to bedrock increasing and the bolson deposits becoming thicker west of Cambray as the Mimbres Valley irrigated area is approached.

Hydrology

A number of wells have been drilled at Cambray, and most of these enter bed rock at shallow depth. Water is obtained when a crevice is encountered in the rock below the water table, which is about 150 feet below the surface. Two hundred feet is about the average depth for these wells. Yields of as much as 25 gallons a minute have been reported from such wells, and the Southern Pacific Railroad is said to have obtained 50 gallons a minute by driving tunnels out from a shaft 258 feet deep. South and southeast of Cambray ground-water conditions are similar to those at Cambray; however, as Aden is approached, water is more difficult to obtain, and the water is said to contain alkali and to be of poor quality. A well is reported to have been drilled to a depth of about 1,500 feet by the railroad at Aden and to have been abandoned as a dry hole. East and northeast of Cambray a number of stock wells have been drilled, several of which failed to obtain sufficient water to supply windmills. These unsuccessful wells are said to be largely in sticky, rubbery clay, which is said to resemble fuller's earth and may be largely altered volcanic ash.

In the vicinity of Akela, near the center of the south line of Sec. 6, T. 24 S., R. 5 W., a number of wells have been drilled. Two of these belong to the Southern Pacific Railroad. The railroad wells are 200 feet deep, are cased with 16-inch double stove pipe casing, and are equipped with turbine pumps driven by a gasoline engine. The water level is about 85 feet below the land surface. These wells encountered clay, caliche, sand, and gravel before encountering bedrock at 200 feet. The sand is a quicksand containing water, which is cased out of the wells. The gravel is struck at about 185 feet and is approximately 15 feet thick. The pumps on each of the two railroad wells are reported to yield 225 gallons a minute; usually, however, only one of the wells is pumped for about 10 hours daily as the railroad requires approximately 120,000 gallons of water a day. The water is said to be of excellent quality. Two domestic wells in Akela belonging to C. R. Dickinson and Mrs. W. S. Mullins encountered practically the same conditions as the railroad wells. Similar conditions appear to extend to the southwest as the L. N. Brandburg well in the SE1/4 Sec. 13, T. 24 S., R 6 W., encountered water in gravel at about 230 feet. West of Akela in the vicinity of Myndus, wells are reported to obtain large yields of water in gravel.

MEMORANDUM NO. 3 OF THE PUMPING TEST OF THE ARMY TEST WELL ON MRACEK LAND NEAR SILVER CITY, NEW MEXICO

By Charles V. Theis
In cooperation with the U.S. Corps of Engineers
and the State Engineer of New Mexico
February 3, 1943

Introduction

This memorandum supplements two previous memorandums submitted to the Corps of Engineers in August 1942, concerning the possibility of obtaining a ground-water supply of about 2 million gallons a day near Ft. Bayard, New Mexico.

In order to more thoroughly test the ground-water supply suggested by the reports on the Mracek domestic well just east of the Ft. Bayard reservation, a new well was drilled by Wininger Bros. for the Army, 307 feet east of the Mracek domestic well and 541 feet northwest of the Three Brothers mine shaft. The well started in the upper part of the Syrena formation of the Magdelena group and carried to a depth of 288 feet. The driller's log reports only limestone in this interval, but it is probable that some sills of igneous rock were passed through. Water was encountered in the lower part of the hole. The normal water level is at a depth of 220 feet below the surface or an altitude of 6,089 feet above sea level.

The well was tested by pumping during the period January 8 to January 12 under the direction of James A. Conklin of the Corps of Engineers. The well was pumped for 10 hours on January 8, for 10 hours during the night of January 9 and 10, and for 24 hours beginning at 5:30 a.m. January 11. The well produced 570 gallons per minute and the drawdown at the end of the 24-hour test was 28 feet. All water level measurements in the pumped well were made by air line and those in the Mracek domestic well, from which the sucker rods were pulled, were made by a sounding apparatus accurate only to 1/2 foot.

The data on the pumping tests are not as complete as would be wished. Measurements of recovery of the water level after the 24-hour pumping test were discontinued after 6 hours when the water level was still 4 feet below its original position. It is, therefore, unknown whether there was a permanent lowering of water level. The reported rate of lowering of water level in both wells and of rise after pumping stopped is somewhat irregular and suggests instrumental errors in measurement. The water level in the pumped well is reported to have returned to its original static level within 20 minutes after stopping the pump after the first 10-hour pumping period but to have recovered slowly after the second 10-hour pumping period and after the 24-hour pumping period. Such an action is not easy to explain, and it appears most probable that the determination of rapid recovery after the first pumping period was in error.

Near the bottom of the page 2 of Mr. Conklin's report he computes a ground-water flow of 80 to 90 feet per hour based upon the apparent lag of about 4 hours in the drawdown of the Mracek domestic well and its distance of 307 feet. The lowering of water level in a nearby well is to no extent a function of the velocity of the water in the aquifer and, therefore, the estimate made has no validity.

Significance of Test

It is of some importance to determine if the test well found water in the same beds which furnish water to the Mracek domestic well. Mr. Mracek reports that samples were collected during the drilling and are now in the possession of the Bureau of Mines at Silver City, where a log of the well will be prepared from an inspection of the cuttings. The log, when available, will indicate more definitely than does the driller's log the correlation of the beds in the test well with those in the Mracek domestic well and the geologic horizon from which the water was obtained.

Determination of the hydraulic characteristics of the aquifer have been made from the data on the pumping test according to the methods described in Water Supply Paper 887, "Methods of determining permeability of water-bearing materials," by L.K. Wensel. The methods that were necessarily used presuppose a uniform aquifer of considerable areal extent. The nature of the aquifer at the Mracek locality is known only from the incomplete reports on the two wells, and it is quite doubtful if the assumption of uniformity of the aquifer is justified. The figures given below are, therefore, to be considered only tentative and to give the order of magnitude of the quantity of water moving through the aquifer and of the ease with which it moves.

When the water levels during the recovery period after the 24-hour pumping test are plotted against the log of the ratio between the time pumping started and the time pumping stopped, the resulting plot appears to indicate that the water level would eventually return to its original position although the plot indicates a discrepancy of about 2 feet between the first three and the last three readings of water level, which is probably to be ascribed to inaccuracy in the gage used to measure water level. The coefficient of transmissibility indicate by the rate of recovery is about 24,000; that is, it is indicated that about 24,000 gallons of water a day would move through each vertical strip of the aquifer 1 foot wide under a unit hydraulic gradient.

The rate of drawdown and recovery in the Mracek domestic well appeared to indicate a coefficient of transmissibility of from 25,000 to 32,000 and a coefficient of storage of about 10 percent. The coefficient of storage is the amount of water in cubic feet that is taken from each vertical column of the aquifer 1 foot square when the water level falls 1 foot. The relatively high coefficient of storage is characteristic of water-table conditions and it appears probable that the water in the Mracek locality is under water-table conditions in the immediate vicinity, perhaps through fractures associated with the faulting a few hundred feet southeast of the well or perhaps in an area about 1/2 mile north where the beds penetrated by the well rise to the surface of the ground.

Mr. Conklin reports that the static water level in the Mracek domestic well is about 1 foot higher than that in the test well, indicating a slope of water level at the rate of about 15 feet in a mile between the two wells. This figure indicates the minimum value of the hydraulic gradient in the locality. An hydraulic gradient of 15 feet to the mile and a coefficient of transmissibility of 25,000 would represent a flow of ground water of about 430,000 gallons a day through each mile of the aquifer perpendicular to the hydraulic gradient.

Conclusions

1. A quantitative interpretation of the pumping test data is made difficult because the data were not taken with the proper accuracy and because of the inherent difficulties of making such interpretations in limestone aquifers.

2. However, the amount of water produced by the well is greater than would have been expected in formations of this nature. Although the figure must be considered only tentative, the coefficient of transmissibility seems to be of the order of 25,000, indicative of an aquifer of moderate productivity.

3. The coefficient of storage appears to be high and indicates that much of the water pumped was taken from local storage. The gradual and continuous lowering of water level in both wells during the pumping corroborate this conclusion. An equilibrium drawdown was not obtained and it is probable that the ultimate drawdown at the same rate of pumping would be considerably greater than observed.

4. A production of 2 million gallons of water a day from the limestone in the vicinity of Ft. Bayard seems to be just within the bounds of probability. Considering the element of doubt in the determination of the hydraulic constants of the aquifer, it is possible that a few wells in one locality might furnish the requisite water. It is more probable, however, that it would be necessary to develop the water from several localities in the limestone area.

5. If it is still deemed desirable to construct military facilities demanding 2 million gallons of water a day at Ft. Bayard, the following recommendations are made.

   a. Another pumping test of 48 hours should be made on the present test well. The pump on the Mracek well should be removed again to open the well for measurement. Water levels should be measured accurately by steel tape if possible, or by electric sounder, and measurements of recovery should be continued until the water level returns to within a foot of its original level or until it is seen to approach a new, lower, static water level.

   b. A member of the Geological Survey, familiar with the procedures involved in well testing, should be present.

   c. Further test drilling in the limestone area north of the Mracek locality should be done to test the occurrence of water in the Magdelena limestones in other localities. Practical considerations suggested that such testing be done in the east part of the Ft. Bayard reservation, somewhere in the northeastern triangular half of Sec. 25 T. 17 S., R. 13 W. A geologist should approve the site before construction is started. Such drilling may show whether or not the limestone of the area are generally porous or whether, on the other hand, the porosity and permeability is confined to faulted areas such as the Mracek locality. Obviously, the probabilities of continuously obtaining large quantities of ground water increase with the size of the area in which considerable quantities can be developed.

GROUND-WATER CONDITIONS NEAR BELEN, NEW MEXICO

By C.V. Theis and A. M. Morgan
In cooperation with the U.S. Corps of Engineers
(1952)

Materials in Which Water Circulates

The Rio Grande Valley in the vicinity of Belen is underlain to a depth of at least several hundred feet by deposits of clay, sand, and gravel. These deposits belong to at least two formations. The bulk is made up of the Sante Fe formation, of Tertiary age, which is exposed west of the Manzano Mountains throughout the area, except in the inner, irrigated valley of the river. Later alluvium, of Quaternary age, fills the inner valley to a depth of perhaps 100 feet and lies upon a much greater thickness of the Santa Fe formation.

There are two sources of water in the valley fill. Floods in the mountain arroyos to the east percolate into the Santa Fe formation near the mountain front. The ground water thus recharged moves slowly to the river to discharge there. This water is comparatively soft. Within the inner valley, irrigation water applied to the land and the normal underflow of the river maintain a water body in which water is hard and rather alkaline. The water from the Santa Fe, recharged near the mountain front, discharges into and merges with this second water body. It has been computed by observations on the rate of lowering of water levels in the irrigated area and the rate of discharge through drains during the nonirrigating season that the average flow of water into the river valley from the Santa Fe formation is about 1 second-foot per mile of valley.

The Belen city well is representative of wells in the valley that have penetrated both the Quaternary alluvium that fills the inner valley and the underlying Santa Fe deposits. The upper water in this well is cased off and the well draws water from water-bearing beds encountered between 240 and 339 feet--beds that probably belong to the Santa Fe formation. The following table shows the log of this well.

Belen city well

(Located west of the Santa Fe Railway two blocks south of the depot. Owned by the Power Company in Belen; used as the municipal supply of that city.)

Sandy clay	0 to 4 feet
Sand	20
Gravel	23
Clay	24
Quick sand	37
Sand and gravel	40
Clay	40.5
Water and gravel	65
Gravel	69
Sand	71
Red clay	83.5
Fine sand	95
Sand and gravel	100
Coarse sand and gravel	101.5
Cemented gravel and clay balls	104
Fine sand and gravel	109
Coarse sand and gravel	114
Quick sand	122
Yellow sandy clay	131
Fine sand	136.5
Reddish brown sandy clay	139.5
Soft limestone (?), some clay	150
Red clay	153
Fine red sand, some gravel	158
Quick sand	160
Red clay, streaks of sand, yellow clay, and gravel	200
Red sandy clay	223

Gypsum (?), some gravel	226
Pink clay (SET 10-inch SHOE: TOP OF PERFORATED PIPE)	240
Red sand and gravel (water stands at 32 feet)	247
Red clay	251
Tight formation, sand and small gravel (water stands at 25.5 feet)	262
Red clay	267
Cemented sand, some water	299
Red clay	300
Cemented sand (tight)	304
Yellow clay	304
Gravel and sand (water stands at 12 feet 7 inches)	334
Yellow clay	339

Present Development in Neighborhood of Area

The wells nearest to the prospective well site that produce water in quantity are located in Belen. The data regarding these wells is given below. The Belen City Well and the two wells of the Atcheson, Topeka, and Santa Fe Railway draw water only from the deeper aquifers (probably belonging to the Santa Fe Formation) and the two wells at the Ice Plant draw water from the upper aquifers which are probably Quaternary in age.

Belen city well
Depth: 339 feet, 7-5/8-inch casing perforated between 240 and 339 feet
Yield: with old pump, 290 gallons per minute with 15-foot drawdown
with new pump, 450 gallons per minute (drawdown unknown)
Specific capacity: 19 g.p.m. per foot of drawdown

A. T. and S. F. Ry. (Well No. 2 at roundhouse in Belen, 100 yards south of Belen city well)
Depth: 260 feet, Casing perforated between 160 and 243 feet
Yield: 330 gallons per minute with 43-foot drawdown
Specific capacity: 7.6 g.p.m. per foot of drawdown

A.T. and S.F. R. (Well No. 4 in Belen)
Depth: 236 feet
Yield: 275 gallons per minute with 32-foot drawdown.
Specific capacity: 8.6 g.p.m. per foot of drawdown

Ice plant in Belen (Well No. 1, located east of the railroad 3/4 mile south of the Belen city well)
Depth: 140 feet
Yield: 388 gallons per minute with less than 23-foot drawdown
Specific capacity: 17 + g.p.m. per foot of drawdown

Ice plant in Belen (Well No. 2)
Depth: 82 feet
Yield: 151 gallons per minute with 2.5 (?) feet of drawdown
Specific capacity: 60 g.p.m. of drawdown (?)

--The Ice Plant wells are used only for cooling purposes. Drinking water is piped into the plant from the Santa Fe water supply.

The well site under consideration is located about 3.25 miles south of Belen and about 3/4 mile east of the Rio Grande. The site is on the mesa east of the river at an elevation about 120 feet above the level of the river. The material underlying the site consists of sand, clay, and gravel belonging to the Santa Fe formation. The thickness of the Santa Fe formation at that locality is unknown but is probably in excess of 1,000 feet. The water level in a well near an abandoned section house on the railroad 3/8 mile west and 1/4 mile north of the site was 62.6 feet below the top of the concrete base at the well which is about 1 foot above ground level. This well is located about midway on the slope from the mesa to the valley floor and the elevation at the well is about 60 feet below the site under consideration. Taking into consideration the difference in surface elevation and the regional slope of the water table, it appears that the depth to water at the well site will be between 110 and 120 feet.

Quality of Water

It is probable that the water encountered in the Santa Fe formation at the site in question will be comparable in quality to that pumped from the Belen city well, an analysis of which is given below. The highly mineralized water that was cased off in the city well appears to be confined to the valley floor and will probably not be encountered in wells drilled on the mesa.

Analysis of water from the Belen city well in parts per million.
well 339 feet deep; water is derived from the Santa Fe Formation.

Calcium (Ca)	20
Magnesium (Mg)	7
Sodium (NA)	138
Potassium (K)	--
Bicarbonate (HCO_3)	165
Sulphate (SO_4)	207
Chloride (Cl)	18
Fluoride (F)	0.6

Conclusions

It is probable that a water supply of 1,000,000 gallons per day can be developed at this site, but it may be necessary to drill two or three wells to obtain that amount of water.

A 300-foot well or wells will probably encounter a sufficient thickness of sand and gravel below the water table to produce 350,000 gallons per day or more but it is possible that it may be necessary to drill deeper.

The specific capacity of wells on the mesa will probably be in the same order of magnitude in the deeper wells in Belen--between 8 and 20 gallons per minute per foot of drawdown. The water level at the site will probably be about 110 feet so the lift for a 350,000 gallons per day well will be around 125 to 150 feet.

If it is necessary to drill more than one well to develop the required amount of water, the wells should be spaced not less than 1,000 feet apart.

GROUND-WATER CONDITIONS IN THE VICINITY OF OROGRANDE, NEW MEXICO

By Charles V. Theis
In cooperation with the U.S. Army
July 1942

Nature of Problem

The Army proposes to establish an anti-aircraft firing range in the vicinity of Ft. Bliss. One of the prime requirements of such a range appears to be a large area of open and practically uninhabited country to minimize the danger from falling shrapnel and improperly set or defective shells. Such a requirement has a direct bearing on the water-supply problem inasmuch as few or no large uninhabited areas can be found in a ranching country if the water supplies in the area are adequate. Proximity to highway and railroad make an area west of Orogrande, New Mexico, the most feasible location for such a range in the vicinity of Ft. Bliss.

The camp will simulate field conditions and the water requirement has been set at 15 gallons per day per capita for 1,500 men. A total supply of about 15 gallons per minute will therefore meet the entire requirement. The authorities are further prepared to haul drinking water for the men if the water obtainable at the site is not of proper quality, the locally available water being then used for shower baths and sanitary facilities. The writer spent a part of June 2 in conference with, and most of June 21, 1942, in a field examination of the prospective site with Colonel McCatty, Captain Hammon, and Mr. Redcliffe, to whom he wishes to express his appreciation for the facilities made available to him for rapid reconnaissance of the area.

General Hydrologic Features

The proposed site for the camp is near the southwest end of the Jarilla Mountains, a few miles west and somewhat north of Orogrande, New Mexico. The Jarilla Mountains are a group of low mountains, covering in all 35 or 40 square miles and rising about 600 feet above the plain of the Tularosa Basin. There are no large individual drainage basins in the mountains and they are too low to receive more than the normal desert precipitation of about 10 inches per year. The mountains are formed by a mass of granitic igneous rock, near monsonite in composition, intruded into limestone and shale of the Chupadera group. The igneous rock forms the western part of the mountains and underlies the small water sheds in the vicinity of the proposed camp site.

The quality of the water in the vicinity of the Jarilla Mountains is so poor and the quantity so small, that the mines, railroad, and town of Orogrande have been compelled to use water from the Sacramento Mountains, bringing it in by a 6-inch pipeline about 20 miles long. The water is of excellent quality but the quantity available is at present inadequate for the town and expanded needs of the railroad. The possibility of using any of this water for the camp, except perhaps for drinking and cooking purposes, has been given up by the authorities.

All the drilling in the vicinity of Orogrande has been disappointing. A well was drilled at the Orogrande railway station in 1902 to a depth of 960 feet.[1] It passed

[1]Meinzer, O.E., and Hare, R. F., Geology and Water Resources of Tularosa Basin, U.S. Geological Survey Water-Supply Paper 343, p. 168, 1915.

through "granite," probably the rock making up most of the Jarilla Mountains, between about 80 and 580 feet, and through limestone from 580 feet to the bottom of the hole. An unknown amount of water was struck at several horizons below 480 feet but the water was impotable, being very high in magnesium and sodium sulphate and chloride.

Analysis of water from the Orogrande railroad well[2]

	Parts per million
Calcium	167
Magnesium	128
Sodium and potassium	1,358
Carbonate	294
Sulphate	1,420
Chloride	1,333
Total Solids	4,776

Water was also struck near the bottom of a shaft in the Lucky Flat mine in the Jarilla Mountains in Sec. 3, T. 22 S., R. 8 E. about 4 miles northwest of Orogrande. The water was comparatively good in quality and it is reported that while the mine was being worked, about 175,000 gallons of water was pumped from the shaft.[3] It is now reported that the water level has subsided permanently since the unwatering operations were carried on. The water carried 2,015 parts per million total solids, 1,177 parts calcium sulphate, 377 parts magnesium sulphate, and 536 parts sodium sulphate (incomplete analysis).

Water was also struck in a dug well at the R. L. Raley ranch in about Sec. 14, T. 22 S., R. 7 E., about 3 miles west and 1 mile south of the proposed site. This well was reported shortly after its construction to be 250 feet deep and the water level was reported at 245 feet.[4] Mrs. Raley, who helped during the digging of the well, reports that a "trickle" of water was found at 82 feet, above 4 feet of clay, that "good" water making about 6 barrels a day was found at 200 feet, and that "a river" of salty water with epsom salts ($MgSO_4$), was found at 362 feet in beds containing clam shells. Perhaps the earlier recorded data are correct, although Mrs. Raley gave considerable evidence of having an accurate memory. No analysis of this water is available, but Mrs. Raley states that it was used for stock but not for domestic purposes. On the authority of Mrs. Raley also, a well was drilled near the tank (at present supplied by the water from the Sacramento River) about 4 miles southwest of Orogrande. The well was 300 feet deep and was of sufficiently good quality to be hauled for drinking water at the Raley ranch.

Conclusions

It is apparent from the resume of the hydrological conditions in the vicinity that the probability of finding potable water at the prospective site is small. Ordinarily the site would be condemned on the basis of the lack of a probable water supply. However, the fact that no alternate sites with comparable firing range and accessibility to railways and highways seem to be available justifies the attempt to find water.

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[2]Idem. p. 298, 299. Analysis furnished by the El Paso and Southwestern Railroad Co.

[3]Idem., p. 169

[4]Idem., p. 298

The only possibility of obtaining potable water in the vicinity of the site appears to be to locate underflow in probable buried channels in the igneous rock west of the range. Showers in the vicinity are frequently torrential, the rock slopes are steep, and a considerable part of the runoff doubtless escapes evaporation and seeps underground. The igneous rock is rather fresh and unweathered and the water that seeps underground near the mountain front is probably concentrated in rock valleys eroded in past geologic time before the Tularosa Basin was filled to its present level. It is improbable that much water will be found under such conditions, but there is a possibility that at least enough for drinking water for the camp--2 or 3 gallons a minute--can be found.

In the absence of good geological data it is impossible to estimate the depth at which bed rock may be struck near the mountain front. There may be a rock shelf--a "pediment"--extending under the prospective site at shallow depth. On the other hand, there may be a buried fault scarp between the site and the mountain so that the valley fill may extend at the site to depths below the normal water table in the valley. Hence the drilling will be of an exploratory nature and should be carefully watched.

In case water is not found in the vicinity of the camp site, water of poor quality, almost certainly unsuitable for drinking or cooking but usable for bathing and sanitation, can be found in the valley fill west of the prospective site at depths of 250 feet (if the published data are correct) or 350 feet (if Mrs. Raley's present information is correct.

Recommendations

1. Test drilling should be done at the site chosen with and marked by Colonel McCatty at approximately grid 1019500 north and 882500 east, Orogrande quadrangle. The site appears to be better than the originally selected camp site at Elephant Mountain as a large drainage area in the mountains seems to be tributary to it.

2. The drilling should be carried to bedrock or to water. If bedrock is found at depths of less than 300 feet, without water, the drill should be moved north or south about 1,000 feet in an attempt to find a depression in the bedrock floor representing a valley which might concentrate the small underflow.

3. If after drilling several holes no water is found in this area, the attempt to find potable water should be abandoned and a well should be drilled west of the site to a depth of about 450 feet. The distance from the site to the well location will depend to some extent on the logs of the holes drilled at the site but will probably be about 1-1/2 miles.

4. Inasmuch as the drilling may reveal geologic conditions not foreseeable from the surface evidence and which might affect the plan for drilling, it is requested that this office be informed daily of the progress of the drilling and the log of the hole being drilled.

MEMORANDUM NO. 2 ON GROUND-WATER SUPPLIES IN THE VICINITY OF FT. BAYARD, NEW MEXICO

By Charles V. Theis
In cooperation with the U.S. Army
September 1942

Introduction

This memorandum supplements a previous memorandum on the same subject, submitted to the District Engineer, Albuquerque District, U.S. Corps of Engineers, under date of August 3, 1942. The writer spent the period August 16 to 20 in and near Silver City making some field examinations and contacting various geologists and engineers of the vicinity. The writer is greatly indebted to Messrs. Gerald Ballmer, geologist of the Nevada Consolidated Copper Co. of Santa Rita; A.P. Mracek, Secretary of the New Mexico Miners and Prospectors Association; and Ira Wright and Carl Flayer, consulting mining engineers at Silver City, for information and opinion cordially furnished.

The general geologic conditions in the area were discussed in the previous memorandum. That memorandum recommended: (1) that the Mracek well, near the east line of the Ft. Bayard reservation, be tested by pumping, (2) that a study be made of the area north of Lone Mountain centering about 5 miles southwest of the buildings at Ft. Bayard, and (3) that further information be obtained concerning an area of Quaternary gravels about 12 miles south of the fort.

Attempt to Test the Mracek Well

It was hoped that some preliminary information as to the capacity of the Mracek well could be obtained with its present equipment. Accordingly, a hole was bored in the cap of the well and measurements were attempted with a steel tape. However, material from the well wall had evidently lodged around the couplings of the pump pipe and it was impossible to get a tape lower than 238 feet below the surface, at which point the well was dry. Previous information had indicated that the water level was within 120 feet of the surface. In a mine shaft about 750 feet distant, the water level stands about 245 feet vertically below ground level at the well, and this figure almost certainly represents the approximate depth to water in the well. It was, of course, impossible to measure the drawdown in the well while it was pumping.

No information was developed to change the recommendation made previously that the Mracek well be pumped to determine its capacity as a first step in an exploration for water supplies.

Santa Rita Water Supply

In the previous memorandum it was pointed out that the mines in general develop little water. The camp and mines at Santa Rita use an average of about 300 gallons of water a minute. Great difficulty was encountered in developing this water supply. Several wells contribute to the supply but most of the water is obtained from two wells, one of which is about 1,000 feet deep and the other 2,100 feet deep. The latter well enters the pre-Cambrian rocks and passes through practically all the rocks that might carry water. In the deeper well the water level stands below 800 feet while in the shallower of the two, only about 450 feet distant, the water level is

400 feet higher. The development of this supply had the advantage of considerable geologic investigation. It illustrates the difficulty of obtaining water in the older bedded rocks of the region.

Area North of Lone Mountain on Cameron and Whiskey Creeks

The second possibility suggested in the previous memoradum was that water might be developed in an area north of Lone Mountain. Cameron and Whiskey Creeks rise in the Pinos Altos Mountains and cross an area underlain by gravels of Quaternary and Tertiary age extending about 2 miles north of Lone Mountain. Cameron Creek is perennial in this section, but Whiskey Creek is intermittent. At the points where these streams and their tributaries intersect the bedded rocks of Lone Mountain, their water is forced to the surface. A small area is subirrigated so that cottonwoods and crops, such as corn, can grow. No wells have been drilled to test the thickness of the gravel deposits. They are principally recharged by the two streams and Cameron Creek, the larger of the two, had an average measured flow at Ft. Bayard of only 0.72 cubic foot per second in the period 1907-1910. The total area of water-loving vegetation is probably less than 100 acres, and if the vegetation uses about 3 acre-feet of water per acre annually, the usual irrigation use in New Mexico, the total use by vegetation would be some 300 acre-feet of water annually, corresponding to a continuous flow of about 200 gallons a minute. Some water arises as springs at the north end of the rocks of Lone Mountain, perhaps in all another 200 gallons a minute. It appears, therefore, that the total perennial underflow would not be sufficient to satisfy the needs of the prospective camp. There is undoubtedly some water stored in the gravels that might be withdrawn from wells, but although the thickness of these gravels is not known definitely, they are probably rather thin. Tight and indurated Tertiary gravel appears in the creek bottoms at places.

Many years ago the Chino Copper Company developed water on Whiskey and Cameron Creeks to the total extent of about 400 gallons a minute from shallow wells drilled where the water rises at the north edge of Lone Mountain. The water was used in the plant at Hurley. Large reciprocating pumps were installed and a power-line was run from Hurley. The amount of water obtained was too small for their needs and the cost excessive. The whole project was abandoned. The abandonment of the project, although the pumping plants were at the same altitude as Hurley, in favor of a supply from Apache Tejo, at an equal distance from Hurley and some 400 feet lower in altitude, confirms the other evidence that no large quantities of water will be found in the vicinity of Lone Mountain.

It appears, therefore, that the required supply of water probably cannot be found at this locality and that its only possible value to the present needs might be as a supplement to a supply possibly obtained nearer the fort.

Wells in the Bolson Plains South of Lone Mountain

No wells have adequately tested the gravels in this area. Stock wells obtain water at depths of 100 to 150 feet below San Vicente Arroyo. The total lift from these localities to Ft. Bayard would be in excess of 1,000 feet. The plant at Hurley obtains about 2,500 gallons of water a minute from several wells near Apache Tejo, about 5 miles south of Hurley. These wells are located at the site of a warm spring rising from the bolson gravels, but they are drilled into the bed rock and obtain most of their water from a cavity in the underlying limestone. They are, therefore, not typical of wells in the bolson gravels. It is altogether probable, however, that the requisite supply could be obtained from wells in these gravels as pointed out in the previous memorandum.

Conclusions

1. There is no assured water supply of approximately 1,500,000 gallons of water a day closer to Ft. Bayard than that in the bolson gravels about 12 miles distant and 1,000 feet lower in elevation.

2. It is probable that an intensive program of exploration, entailing considerable time and expense, would result in developing the requisite water in the area of limestone east of Ft. Bayard at altitudes about equal to those at the Fort. Considering the comparatively small amounts of water developed by the mines, it is to be expected that some wells would be failures and that several wells would be needed to develop the requisite supply. As there are approximately 1,000 feet of limestone underlying the area, exploratory wells should go to this depth unless, by chance, adequate supplies were found at higher levels. Any exploratory drilling should be under geologic supervision.

   As a preliminary procedure, the Mracek well should be tested. The easiest procedure would probably be by airlift. The sucker rods in the present well should be pulled and a portable air compressor obtained, probably by loan from one of the mining companies. If the well is not too much obstructed, measurements of water level could be made outside the present 3-inch pump pipe. Otherwise, an airline to measure the pressures at the bottom of the well would have to be installed in addition to the pumping airline. If the test were encouraging, a deeper and larger hole should be drilled nearby and tested.

3. If it should appear that a good part but not all of the needed water could be obtained from wells near the fort, the possibility of developing around 400 gallons of water north of Lone Mountain should be entertained. The towers for the transmission line to the old pumping plants are still in place.

4. If drilling near Ft. Bayard is not encouraging, the water supply could, with little doubt, be obtained in the bolson gravels southwest of Hurley.

PRELIMINARY REPORT ON GROUND-WATER CONDITIONS SOUTHWEST OF PORTALES

By Charles V. Theis

In cooperation with the U.S. Army and the State Engineer of New Mexico

November 16, 1942

Introduction

The U.S. Army has tentatively selected a site for a military establishment in sections 16, 17, 20 and 21, T. 2 S., R. 34 E. The water requirement of the establishment will be approximately 600,000 gallons a day to be delivered in 16 hours.

General Geological and Hydrological Conditions

The proposed site lies on the southwest slope of Portales Valley, a depression in the surface of the high plans about 15 miles wide and extending southeast throughout Roosevelt County, New Mexico, and contiguous areas. The valley is not now occupied by any stream. A veneer of sand, gravel, and silt of Pleistocene and Pliocene ages, hereafter referred to as the valley fill, about 100 feet thick underlies the valley and lies upon nearly impermeable Triassic shales. On the southwest slope of the valley this veneer thins to an inconsiderable thickness in the vicinity of Elida.

Practically all the ground water used in Portales Valley is found in the valley fill. Wells in the underlying Triassic rocks are weak and the water from them isgenerally of poorer quality than that in the valley fill. The water in the valley fill is fed by rainfall penetration over an area approximately corresponding to the topographic drainage basin. It moves southeastward from an area of sand hills north of the valley and northeastward from the vicinity of Elida toward the axis of the valley.

The water in the valley fill is, in general, of good quality. The following analysis, given in parts per million, of one of the wells furnishing the public supply of Portales is typical.

Silica (SiO_2)	42
Iron (Fe)	.01
Calcium (Ca)	86
Magnesium (Mg)	20
Sodium (Na)	45
Potassium (K)	3.7
Carbonate (CO_3)	0
Bicarbonate (HCO_3)	224
Sulphate (SO_4)	125
Chloride (Cl)	53
Nitrate (NO_3)	6.2
Total hardness as $CaCO_3$ (calculated)	297
Date of collection, Nov. 26, 1931	

However, in many places near the axis of the valley, the water is "gyppy" and rather highly mineralized. The occurrence of water of poor quality in the lower part of the valley apparently arises from the fact that normally much of the ground water is evaporated or transpired in small lakes and salt grass meadows along the axis of the valley, and therefore the dissolved salts are concentrated in these localities. At times of high rainfall, however, surface water runs into the lakes and sometimes floods the meadows, reversing the normal circulation and driving the saline water back into the aquifer. This concentration occurs at the surface of the ground and, as a consequence, the deeper water tends to be, but is not in all localities, of better quality than that near the surface.

Existing Wells

Several windmill wells are located on the proposed site reported to Mr. Winsor of the Corps of Engineers to be 60 to 80 feet deep. Records in the Geological Survey include the well of Claude Martin in section 17 of unknown depth and with water level at a depth of 50 feet. The well of Mr. Tinsley in section 19, about a mile west of the southwest corner of the site, is reported to have found several feet of gravel and sand above red Triassic clay at a depth of 100 feet. The water level in this well is about 60 feet below the ground surface. Several irrigation wells have been drilled to the east and northeast of the area in the adjoining sections 10 and 15, and many more have been drilled farther north and east. The water in the wells on the site was reported to Mr. Winsor to be of a "gyppy" character. There are no analyses of water from these wells available at present. It is probable that by drilling to the base of the valley fill at about 100 feet and drawing water only from the lower part of the fill, the quality of the water from wells in this locality could be improved.

Conclusions

1. The site selected lies just beyond the southern edge of the area in Portales Valley and proved to contain large quantities of available water.

2. It is probable that 600,000 gallons of water a day can be obtained from the site, from not more than two wells.

3. The wells should be approximately 100 feet deep. Drilling into the Triassic red clay -- called "birdseye clay" by local drillers -- below this approximate depth would almost certainly be valueless. Water levels in wells at the site would lie between about 40 feet at the northeast corner of the site to about 60 feet at the southwest corner.

4. The probabilities of obtaining large quantities of water are greater toward the northeast corner of the proposed site and the probabilities of obtaining water of the best quality are greater toward the southwest corner.

5. In the event sufficient water of good quality could not be developed at the site, an adequate and satisfactory supply could certainly be obtained at a distance of 1 or 2 miles to the north and east.

Memorandum on Ground-Water Supplies near Valmont, New Mexico

By Charles V. Theis

In cooperation with the U.S. Army and the State Engineer of New Mexico

1942

The possible water supply for a camp at Valmont can be derived from two types of sources: from springs in the limestones in Dog Canyon in the Sacramento Mountains a few miles east of Valmont and from wells in the alluvial fans near the mouths of this and other nearby canyons.

Information on existing sources is fragmentary and in part conflicting. The Dog Canyon Springs are reported by one apparently competent authority to have a minimum flow of 150 gallons a minute and the reports of the Park Service apparently indicate a flow of only 27 gallons a minute. It is altogether possible that the first report concerns the flow of the stream and the latter concerns only certain springs near the mouth of the canyon.

The water from springs in the mountains is hard but otherwise excellent in quality. Alamogordo and other nearby towns derive their water supplies from similar springs. Pipelines to carry this water should be made larger than theoretically necessary because the calcium carbonate precipitates rapidly from the water and encrusts the pipes. Alamogordo has had considerable trouble because of the reduction in area of flow due to the formation of this crust in the pipe line. A system of aeration of the water at the source would probably minimize this difficulty.

In case the spring flow occurring naturally at present is insufficient to supply the demand for water, it is probable that shallow wells in the vicinity of the spring site will increase the production materially by lowering the water table in the vicinity.

A supplementary supply of water very probably can be obtained from the alluvial fans at the mouths of the canyons. Care should be taken in locating wells in this section. Water of good quality is without doubt added to the alluvial deposits near the mountains, but in its progress toward the center of the Tularosa Basin, it rapidly deteriorates in quality, and a short distance from the mountain front, the water becomes unfit for drinking purposes. Wells, therefore, should be located primarily for the purpose of obtaining water of good quality and at the sacrifice, if necessary, of convenience of site and economy of pumping.

There appears to be little doubt that the necessary quantity of 150 gallons of water a minute can be obtained in the neighborhood of Dog Canyon. However, as there has been little development of water in this locality, as the data are necessarily fragmentary, and as little ground-water study has previously been made in this immediate locality, a rather complete exploration of the vicinity should be made in advance of the actual development of water supplies.

Memorandum on the Water Supply of Alamogordo, New Mexico

By Charles V. Theis
U.S. Department of the Interior, Geological Survey
In cooperation with the U.S. Army and the State Engineer of New Mexico
May 19, 1945

The Problem

At the request of Mayor L.A. Hendrix of Alamogordo, the writer spent parts of May 14 and 15 at Alamogordo to consult with city officials regarding the drilling of test wells at Alamogordo. The writer wishes to acknowledge the courtesy of city officials, particularly that of Mayor Hendrix, and of Mr. Hagaman of the office of the Post Engineer of the Army Air Field.

Alamogordo furnishes water to the airfield, and the combined needs of the town and airfield are expected to reach 1,800,000 gallons a day during the summer. The local water supply is obtained from springs in Alamo Canyon. From 1937 to 1940, these springs produced slightly under 1,000,000 gallons a day, but after the extraordinarily heavy rains of 1941, the flow of the springs increased to about 2,000,000 gallons a day and this rate was maintained until about the beginning of 1944. Since that time, the flow has decreased rather steadily to about 1,500,000 at the beginning of 1945 and to less at present. Apparently the flow is approaching that previous to 1941 or about 1,000,000 gallons a day. It has already been necessary to curtail the use of water both at the base and in the town.

The other sources of water available to the town are (1) irrigation water from La Luz canyon at present brought into town for irrigation, which would require the construction of a treatment plant and some litigation; (2) springs in Dog Canyon, the use of which would require several miles of pipeline; (3) springs on the east side of the Sacramento Mountains, the use of which would involve several miles of pipeline, lifting the water over the crest of the mountain, and purchase of water rights; and (4) wells. If wells producing adequate quantities of good water could be obtained, they would furnish the best solution to the water-supply problem.

Ground-Water Conditions

The general ground-water conditions in the vicinity of Alamogordo are described in U.S. Geological Survey Water-Supply Paper 343, "Geology and ground-water resources of Tularosa Basin" by O.E. Meinzer and R.F. Hare. Water from the west slope of the Sacramento Mountains feeds the ground-water body in the valley fill of Tularosa Basin. The ground water in the northern part of the basin percolates to the west and southwest to the vicinity of Lake Lucero, there to be transpired. As the water percolates westward, its quality rapidly deteriorates so that a few miles west of the mountain front, it contains from 3,000 to 10,000 parts per million total solids. However, near the mountain front south of Alamogordo, several wells yield water containing less than 1,000 parts per million, and one, the Bowles well in sec. 18, T. 17 S., R. 10 E., yields water of 580 parts per million total solids, which is approximately the mineral content of the present city supply.

Wells in the vicinity of Alamogordo tested by Meinzer in his studies in 1911 yielded from 1 or 2 to about 7 gallons a minute per foot of drawdown. The Bowles well was pumped for the present writer, and yielded 85 gallons a minute with a drawdown of about 50 feet, or approximately 1-1/2 gallons per foot of drawdown. The depth and condition of casing in this well were unknown, and it seems probable that a properly constructed well in this locality would have a greater specific capacity. However, the sediments found in most of the wells are fine, and specific capacities of a few gallons a minute are probably as high as can be expected.

The factors affecting the location and use of wells for the city supply are therefore as follows:

1. They should be located as near the mountain front as possible, and in no case farther west than the west line of R. 10 E., in order to avoid the water of poor quality lying farther west.

2. They should be as close to the present city reservoir in the north center of sec. 33, T. 16 S., R. 10 E., as possible in order to minimize the length of pipe line necessary.

3. If successful wells are obtained, they should be used no more than necessary in order to minimize the danger of encroachment of the poor water of the valley. Samples of water should be taken periodically from these wells and nearby wells for chemical analysis, so that encroachment of the poorer water will be noted in time to reduce the draft on the wells if necessary.

Recommendations as to Test Drilling

At the time of the writer's visit, a test hole had been drilled with rotary tools to a depth of 501 feet in the NE1/4 sec. 5, T. 17 S., R. 10 E., about a mile south of the reservoir. The site is near the mouth of Alamo Canyon and very close to the mountain front. According to the driller, the entire depth was drilled in bouldery material in which there was no loss of the drilling mud. No water was struck. Barometric levels indicated that the site was at an altitude of about 4,610 feet, some 40 feet above the town reservoir. The water level in the Bowles well about 2-3/4 miles southwest was indicated to be about 4,070 feet or 540 feet lower than the site. The barometric levels, although observed during the afternoon of May 14 and again during the morning of May 15, cannot be relied on implicitly because of atmospheric disturbances, and the water level at the drilling site would be expected to be between 50 and 100 feet higher than at the Bowles well; but it is indicated that the well had just about reached water level when drilling was suspended at the 500-foot depth. It appears probable that the material penetrated by the drill was largely talus and possibly landslide material, as the site is quite close to the mountain front, and the material appears to be bouldery and unsorted, and therefore not good water-yielding material. However, as the hole at 500 feet apparently had not penetrated far below the water table, if at all, it is recommended that drilling in this hole be continued to a total depth of 600 feet.

If water is not found in this hole at 600 feet, and probably in any case for use as a supplementary source, a hole should be drilled at a location more or less down the trend of the arroyo from the canyon, to the west and southwest of the present site. The new location should be about a half mile from the present site and about 150 feet lower in elevation.

Care should be taken in exploration with the rotary rig that no aquifers are mudded off and overlooked.

In order for one to know at what level water is to be expected, the elevation of the sites drilled and of nearby existing wells in which the depth to water is known should be determined by spirit leveling.

GROUND-WATER SUPPLIES NEAR CARLSBAD, NEW MEXICO

By C.V. Theis and W.E. Hale
In cooperation with the Defense Plant Corporation
1940

In the vicinity of Carlsbad, there are three sources of ground water, namely the Carlsbad limestone, the Rustler formation, and the valley fill.

The water supply of the city of Carlsbad is drawn from the Carlsbad limestone by wells near the west side of the town from 150 to 257 feet deep. The water is hard but potable. The type of water in those wells is given by the following analyses, the first two of which are for water from two of the city wells in Sec. 1, T. 22 S., R. 26 E., and the other from an irrigation well of the Happy Valley Farms in Sec. 3, T. 22 S., R. 26 E.

Owner	City	City	Happy Valley Farms
Depth	150 feet	250 feet	345 feet
Chemical content, parts per million			
Calcium	125	133	214
Magnesium	55	64	63
Bicarbonate	214	162	198
Sulphate	331	398	709
Chloride	144	170	264
Hardness, calculated	538	595	793

An average of 4 second-feet is pumped from wells in the Carlsbad limestone in the close vicinity of Carlsbad by the city and by irrigators. It appears that an additional 12 second-feet coming from the limestone discharges in the Carlsbad Spring area along the Pecos River just north of Carlsbad. The wells produce large quantities of water per foot of drawdown and the aquifer has a high transmissibility.

Water from the Carlsbad limestone is only known to be available in quantity in a few square miles in the immediate vicinity of Carlsbad. Few wells have been drilled in the outcrops of the limestone in the foothills of the Guadalupe Mountains southwest of Carlsbad. Some springs are present along Black River, the largest being Blue Spring in Sec. 28, T. 24 S., R. 26 E., which maintains a flow of between 10 and 15 second-feet. The perennial water in Black River is all used for irrigation.

Water somewhat better than that obtained from the Carlsbad limestone is obtained from the Rustler limestone and from the valley fill in several wells between Dark Canyon Arroyo, which follows the foothills of the Guadalupe Mountains, and the Southern Canal, bounding the Carlsbad irrigation project on the west. Both the Rustler limestone and the valley fill in this area are recharged by seepage from flood flows in Dark Canyon Arroyo and probably also by seepage from the Carlsbad limestone to the west. The water in the fill becomes much more highly mineralized as the Southern canal is neared and passed, where it is contaminated by drainage from the irrigated lands. The following analyses show the character of the water west of the canal.

Owner	Airport	Snyder & Cass	Lovejoy	Nymeyer	Forehand
Location	Sec. 35 T. 22 S, R. 26 E	Sec. 3 T.. 26(??)S, R. 26 E	Sec. 15 T.23S, R. 26 E	Sec. 23 T. 23 S, R. 26 E	Sec. 20 T. 23 S, R. 27 E
Depth (feet)	154	290	315	176	136
Aquifer	Rustler	Rustler	Rustler	Fill	Fill
Chemical content, p.p.m.					
Calcium		60	109	82	78
Magnesium		37	42	35	44
Bicarbonate		243	228	288	284
Sulphate	35	117	249	115	130
Chloride	14	28	14	10	22
Hardness	327	302	445	548	375

There are no accurate data on the amount of this water that might be obtained. The airport well is reported to pump an average of about 50 gallons a minute and to have been pumped for a short time at the rate of 600 gallons a minute. A well close to the Nymeyer well and of the same depth is pumped for short periods at a rate of about 200 gallons a minute, but only a small total quantity is used. The others are windmill wells. It is improbable that any quantities much in excess of those needed for domestic use could be produced from these wells.

In the areas east of and immediately west of the canal, some few wells produce enough water for irrigation purposes, but the water has the same chemical character as the river water and is in most of the area still more highly mineralized.

In the areas near the potash mines and apparently the most feasible sources of magnesium, water is found chiefly in the Rustler limestone which underlies the entire area at depths of a few hundred feet. Some wells have failed to find water in the Rustler limestone but nearly all of these have been on Quahada ridge, which bounds on the west the broad Nash draw, along which the mines are situated. The comparatively minor needs for water at the mines of the U.S. Potash Company in sec. 12, T. 21 S., R. 29 E., are satisfied from drainage from the Rustler limestone encountered in the main shaft. Water for the refinery is surface water diverted from the Pecos River. The water needs of both the refinery and mines of the Potash Company of America in Sec. 4, T. 20 S., R. 30 E., are satisfied from water in this limestone pumped from the shafts of the mine. The Union Potash Company, in Sec. 12, T. 22 S., R. 29 E., has several wells into this limestone, which are reported to have a combined pumping rate of about 1,700 gallons a minute and which are pumped at an average rate of 1,200 gallons a minute.

The following analyses show the general character of the Rustler water in this vicinity.

	U.S. Potash Co.	Union Potash Co. Well 1	Union Potash Co. Well 2	Surprise Spring
	Sec. 12 T. 21 S, R. 29 E	Sec. 12 T. 22 S, R. 29 E.		Sec. 4 T.23 S, R. 29 E.
Chemical content parts per million				
Calcium	656	744	736	778
Magnesium	161	249	199	310
Sulphate	1,977	3,136	2,078	2,580
Chloride	814	1,416	1,328	2,840

The water supply situation as affecting the establishment of a plant for magnesium recovery in the vicinity of Carlsbad may be summed up as follows. About 12 second-feet of water similar to that furnishing the city supply is available at Carlsbad. Any large wells in the vicinity should be located under geological advice inasmuch as more highly mineralized water leaking from Lake Avalon is also present in the same general locality. The use of ground water at Carlsbad would probably diminish the flow of the stream by the amount used and might cause protest by Texas irrigation interests. A somewhat less mineralized water is available in smaller quantity south of Carlsbad. A highly mineralized water is available in quantities of probably a few second-feet in the neighborhood of the potash mines and apparently the most feasible sources of magnesium.

All data available on the water supplies in a particular locality will be gathered immediately if the locality is specified.

Memorandum No. 2 Concerning Magnesium Brine Wells of the Emro Corporation Near Carlsbad, New Mexico

By C. V. Theis and W. E. Hale

In cooperation with the Defense Plant Corporation
March 15, 1942

As it now appears that the U.S. Geological Survey will be only casually connected with any further exploration of the magnesium brines in Red Bluff Draw, south of Carlsbad, New Mexico, it seems proper to record certain tentative hypotheses and tentative estimates of the reserve available arrived at as the result of the work already done. The hypotheses are based upon insufficient data and can only be said to be reasonable geologically and to fit the available data better than any others that have occurred to the writer. If the question of further exploration arises they may furnish a means of estimating the chances of success in finding a usable reserve of brine, and if further work is done they will furnish a rational background to guide the exploration.

Nature of the Aquifer

The materials penetrated by the drill in this area consist primarily of massive, selenitic, alabastine, and saccaroidal gypsum, with which is admixed some minor amount of clay and siltstone and some dolomite. Below the horizon of the brine some anhydrite is encountered. The brine has been encountered at depths between 100 and 200 feet and is always under pressure, sufficient to result in flowing wells at the lower elevations. No definite confining bed is present and there is no abrupt and definite change in material at any horizon. Gypsiferous water is found at shallow depths, between 14 and 52 feet in most of the holes and at a depth of 80 feet in Etz No. 1, also in gypsum apparently indistinguishable from the remainder of the gypsum. The material appears, therefore, to be heterogeneous in detail but rather uniform en masse and yet possesses sufficient bedding to give rise to porous zones and impervious confining beds over sufficient area to yield considerable pressure on the brine.

Two hypotheses have been proposed to explain the nature of the material in which the brine occurs. The first considers the gypsum a fill in an older valley excavated to a considerable depth below the present surface. The second, apparently originally proposed by Lang, considers the gypsum a weathering product of the anhydrite originally making up the Castile formation. The difficulties facing the acceptance of the fill hypothesis seem insurmountable. The valley must be filled with a gypsum debris to the almost entire exclusion of other material more resistant to abrasion and solution. The debris must be arranged in beds or perhaps shoe-string lenses that have continuous permeability over considerable distances and must be overlain by material, indistinguishable in drill cuttings from the porous material, that is impermeable over an area sufficient to give rise to considerable head in the underlying brine. These porous beds must be at various elevations but must also be to some degree interconnected. On the other hand, weathering commonly works down some beds at a faster rate than in adjacent more resistant beds. Given the thorough weathering of a thick mass of bedded anhydrite to gypsum it would be expected that certain beds would be opened up in a porous manner whereas others would be left impervious either because of less weathering or because of more weathering reducing the original beds to a mass of gypsum blocks embedded in a clayey residuum. Further the fact that the brine occurrences can be interpreted as being in one or two beds, as will be shown later, is contributory evidence that we are dealing here with a weathered residuum.

The origin of the brine appears obscure. The process which gave rise to it must be one capable of giving a saturated solution of magnesium, sodium, and sulphate with a high boron content, with the almost complete exclusion of calcium, although it occurs in high-calcium rocks, and of chloride, the radical commonly accompanying sodium and magnesium in the Permian basin. The origin forms a very interesting problem for a physical chemist. The brine is apparently not connate because in the first place it seems difficult to produce a mother liquor of its composition by the processes of evaporation, although considering the complex chemistry of saline deposits it might not be impossible. Probably more conclusive evidence is found in the apparent fact that the brine occurs in weathered zones. The brine itself, being saturated, must insulate the rocks that it covers from weathering, and apparently the only way the rocks could be weathered would be by first diluting the brine. Lang has proposed that the constituents have been concentrated from minute quantities of the elements brought in from long distances and that the solutions because of their density have settled in the traps. This hypothesis may hold the nucleus of the truth but needs some amplification. The ground-water circulation must have been quite abnormal and the solutions must have been concentrated before they arrived at the traps. This would point to an extremely slow ground-water circulation.

The simplest hypothesis from the geological standpoint would be to consider the brines as a product of the weathering that converted the anhydrite to gypsum. The problem lies in the realm of physical chemistry. There are sources of magnesium present in the deposits themselves in the form of thin dolomite beds. Sources of sodium and boron are problematical but it would seem possible that they might be present in traces. Zeoloitic minerals in the clay may possibly be a source of the sodium. It would seem probable that as weathering proceeded in these beds, concentrated solutions would be formed of the most soluble materials available because there would be a tendency for any increment of fresh water to be bound as water of crystallization as the anhydrite was changed to gypsum. There would be a multiple phase system of anhydrite, gypsum, and a concentrated solution of highly soluble salts. If such an hypothesis is acceptable to the physical chemist, it would probably to most acceptable to the geologist.

It may be noted that this hypothesis implies that the accumulations of brine are geologically temporary and that its quantity is limited. As the brine becomes saturated, weathering of the bed enclosing it is arrested. Fresher water added at the surface by rainfall infiltration weathers down the more resistant beds between the brine traps. As these are lowered the brine overflows its dams and joins the ground-water circulation.

Perhaps the simplest explanation of the brine from a geological standpoint would be to assume that there is or has been ground-water circulation along the strike of the beds. If the beds are assumed to have in themselves small amounts of sodium, magnesium, and boron, water seeping into the beds at a higher elevation and discharging at a lower would in one continuous process probably prepare the solution cavities and fill them with the concentrate. In the initial stages of solution the water would move from the higher level to the lower converting the anhydrite to gypsum and opening solution passages probably by a combination of physical disruption of the bed in the process of hydration and solution of gypsum. This process would begin at the surface and gradually work down the dip of the bed. Near the base of the weathered zone at any time the solutions would probably always be more concentrated because they would travel more slowly thru the incipient openings they were in process of enlarging and perhaps also because some of the water would be bound in the gypsum molecule. In the initial stages this more highly mineralized water would be swept onward with the general circulation. As the action progressed, however, down the dip, the flow lines become more and more circuitous and longer giving additional opportunity for solution and concentration. A point would be reached where the density of the brine and the height it must be lifted from the base of the weathered zone to the outlet would be sufficient to balance the longer column of fresh water behind it. The heavier solution would remain in the aquifer and fresher water moving near the surface would override it. As the heavy brine accumulated it would fill part of the openings, thus restricting and slowing the flow of the fresher water and giving it more opportunity to pick up soluble salts. The brine trapped in the bed would probably approach or attain saturation. Eventually an equilibrium would be attained in which the top level of the brine extended nearly horizontally from the point of outflow.

Fortunately, all the questions about the origin of the brine do not have to be resolved before reaching some conclusions as to the probable amount of brine in the vicinity, although because the nature and occurrence are so intangible any evidence that makes more definite our concepts related to it helps also to make our estimates more valid.

Probable Structure of the Rocks in Which the Brine Occurs

The accompanying table gives the elevations of the piezometric surface at each of the wells and the elevations at which the brine was encountered. Wells Nos. 1 and 2 were pumped and the water levels in Nos. 5 and 7 were lowered, the latter conclusively as a result of pumping No. 2 and the former almost certainly so. It will be observed that the static water levels in Nos. 2 and 7 had almost exactly the same elevation before pumping, the small differences being probably the result of slightly different densities of the brine operative over columns about 100 feet long. The level of No. 5 could not be measured before pumping began but it is probable that its static level was also at about the same elevation within the differences resulting from different densities.

If we assume that these three occurrences of the brine known to be connected lie in the same bed and at the same horizon, the dip as shown in figure 1 (not found in archives) is about 90 feet to the mile north 30^{0} east. This is about the same dip as noted by Lang in the beds of the reef in the Barrera del Guadalupe. Although the three wells lie too nearly on a straight line to sharply define the structure yet the brine occurrences at Nos. 3 and 6 lie also within a few feet of the plane containing the occurrences at Nos. 2, 5, and 7. Neither well 3 nor well 6 was affected by the pumping; the peizometric surface of No. 3 was a little higher than that of the three wells known to be connected, and that of No. 6 was about 10 feet higher. Hence there is definite evidence that Nos. 3 and 6 are not connected with Nos. 2, 5, and 7, at least in a direct manner. However, if the brines do occur in solution passages in a weathered bed it would seem altogether possible that there might be fairly independent systems of passages in beds at or near the same geologic horizon. It would seem therefore that the location of these brine occurrences apparently in or near the same plane that contains the others supports the conception that we are dealing with one bed or a thin series of beds, notwithstanding the fact that the occurrences have no direct connection.

A lower horizon of brine, 48 feet below the upper, was struck in well No. 5. The brine occurs in wells 4 and 1 at elevations respectively 60 and 35 feet below the supposed plane of the brine in the other wells. There is a suggestion that these also may be related to one bed but if so an explanation must be found for the fact that the static level of No. 1 is over 100 feet below that of No. 4.

Significance of Pumping Tests

The pumping test on well No. 1 did not yield data that are of particular significance in determining the nature of the aquifer. By its low yield and high drawdown it indicated that the aquifer near it is of comparatively low transmissibility. Its very low piezometric surface and the fact that no other wells reacted to its pumping indicates that the body of brine that furnishes it is probably of quite local extent.

The data on well 2 are more complete. It was pumped at practically a constant rate and an automatic record is available for the fluctuations of water level in well 7 during the time that well 2 was pumping. The rate of fall in well 7 indicates a transmissibility of around 15,000 and a coefficient of storage of the order of 0.0001. The zone in which the brine is found is thought to average about 3 feet thick, which thickness would make the coefficient of permeability about 5,000. The coefficient of storage represents the amount of water in cubic feet withdrawn from each column of the aquifer with base 1 foot square when the head is reduced 1 foot. This low coefficient of storage indicates that the aquifer is under artesian conditions and that there is for instance no significant seepage of liquid through the confining bed.

It was found that the drawdown curve of well 7 could be made to fit the type curves for withdrawal either from a point source, as for instance a well, or from a line, as for instance a trench. There was no difference in the order of the coefficients determined by the two methods. So far as this curve indicates the wells might be drawing from an areally extensive aquifer or from a trench-like aquifer. During the first 24 hours of recovery the rate of recovery in well 2 followed the rule for recovery of a well drawing from an aquifer extensive in all directions and for the next 10 days it appeared to follow that for recovery from a trench-like aquifer. This phenomenon could be explained as the effects produced in a linear aquifer bounded by more or less parallel impermeable walls. Under such an interpretation the early part of the recovery would cover the period before the readjustment of water pressure had reached the boundaries of the aquifer and the remainder of the recovery would represent the extension of the readjustment linearly along the aquifer.

Addendum

Note on Use of Producing Well as a Monitoring Well, with Special Reference to a Proposed Well at Sandia Corporation, Albuquerque, New Mexico

By C. V. Theis
In cooperation with the U.S. Atomic Energy Commission
October 1957

It is assumed that the reactor to be built by the Sandia Corporation will incorporate all safety provisions to guard against loss of radioactive liquid to the underlying ground water in case of any foreseeable accident. However, in order to (a) guard against the remote possibility of an unforeseen hazard, (b) give more assurance of safety to all those responsible for the construction and operation of the reactor, and (c) allay any apprehension, justified or unjustified, on the part of the public, it is desirable to monitor the ground water passing the reactor to the greatest degree possible. The need for a well for water supply at the reactor makes such monitoring possible without additional expense.

An unpumped well will not effectively monitor ground-water flow. At best such a well intercepts only a cross section of water of a depth equal to that of the well and of a width twice the diameter of the well, and so, even in an ideal aquifer, it monitors only a very small volume of water. Unknown, and to a great degree unknowable, irregularities in the sediments through which the ground water flows make it improbable that any one unpumped well could be located to intercept contamination originating in one spot, even if the exact spot were known.

On the other hand, a pumped well intercepts a cross section of water somewhat thicker than the depth of the well below the water table and of plan view as indicated in the accompanying report (not jound in archives). Hence, such a well located as shown on the illustration in the accompanying report will almost certainly intercept any contamination from the reactor area that reaches the water table. If radioactive liquids are contained according to design, the water from the well is uncontaminated; if they are not, the owners of the reactor are the first to know about it.

In order to serve most effectively as a monitor, the specifications for the water-supply well should be modified somewhat. If any contamination results from the operation of the reactor and reaches the ground-water body, it will be present near the water table. As a consequence, the water entering the well should be drawn from as near the water table as possible, which implies that the water-supply well should penetrate only sufficiently far below the water table to yield the requisite quantity of water. In ordinary water-supply practice it is customary to deepen the well considerably below the water table in order to improve its efficiency, but this results in a deeper and narrower cross section of water entering the well, which is contrary to the desirable characteristics of a monitor for contamination originating near the land surface.

Further, there is a possibility that contaminated water from the reactor would be "perched" above a relatively impermeable bed above the water table. A gravel pack around the well extended to the land surface would give an opportunity for any such perched water to travel down through the gravel to the water table and into the well.