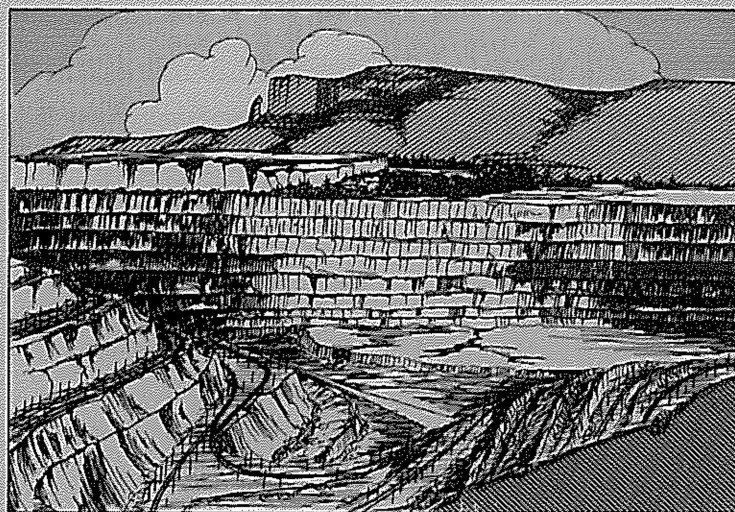
TECHNICAL REPORT 36

New Mexico State Engineer
Santa Fe, New Mexico



Water Resources Appraisal of the Silver City Area New Mexico

by

F. C. Koopman, F. D. Trauger,
& J. A. Basler

TOWN OF SILVER CITY
INCORPORATED
1878
GRANT COUNTY NEW MEXICO

Prepared in cooperation with
the United States Geological Survey

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1969

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WATER-RESOURCES APPRAISAL OF THE SILVER CITY AREA, GRANT COUNTY, NEW MEXICO

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F. C. Koopman, F. D. Trauger, and J. A. Basler

ABSTRACT

The towns of Bayard, Central, and Silver City in central Grant County obtain ground water from alluvium of Quaternary age or from the Gila Conglomerate of Quaternary and Tertiary age. Presently developed supplies of water (1968) are now inadequate to meet demands in Bayard; they will become inadequate within 10 years in Central and within 20 years in Silver City.

The populations of Bayard, Central, and Silver City were about 3,000, 2,200, and 10,400, respectively, in mid-1967, and per capita use of water was about 70, 33, and 95 gallons, respectively, per day. The populations are expected to increase to 7,000, 5,000, and 40,000, respectively, by the year 2000 and per capita use of water is expected to increase to about 150, 100, and 200 gallons, respectively, per day.

Silver City by the year 2000 will need about 8,900 acre-feet of water annually, as compared with the 1967 use of 1,125 acre-feet. Bayard used 236 acre-feet in 1965 and will need 1,180 acre-feet by the year 2000. Central used 70 acre-feet in 1965 and will need 185 acre-feet by the year 2000.

The yield from present wells in the Bayard well field cannot be increased appreciably, and the prospects are poor for developing additional wells in the area. The yield from present wells in the Central well field can be increased enough to meet demands of the next 10 years, but not thereafter. Additional wells could be developed in the area to meet demands for another 5 years. The Silver City well fields can meet demands for the next 10 years with existing wells, and additional wells could be drilled that would meet demands for the next 20 years. Thereafter, the well fields would fail rapidly.

Large supplies of water of quality suitable for most uses are available for development in the Gila Conglomerate and the bolson fill in parts of the drainage basin of San Vicente Arroyo. Wells tapping the Gila Conglomerate in parts of this area should yield as much as 500 gallons per minute, and wells tapping the bolson fill may yield as much as 1,000 gallons per minute.

INTRODUCTION

The municipal governments of Bayard, Central, and Silver City in southwestern New Mexico (fig. 1) have been concerned in recent years that their present water supplies might not be adequate to meet increased demands. Silver City, county seat of Grant County, requested that the U.S. Geological Survey investigate the town water supply in order to make a quantitative appraisal of its adequacy for present and future needs, and to make a qualitative evaluation of potential areas for future development of additional supplies of ground water for Silver City and for nearby communities. The results of the investigation provide a basis for long-range plans to develop and utilize ground-water resources in the Silver City area.

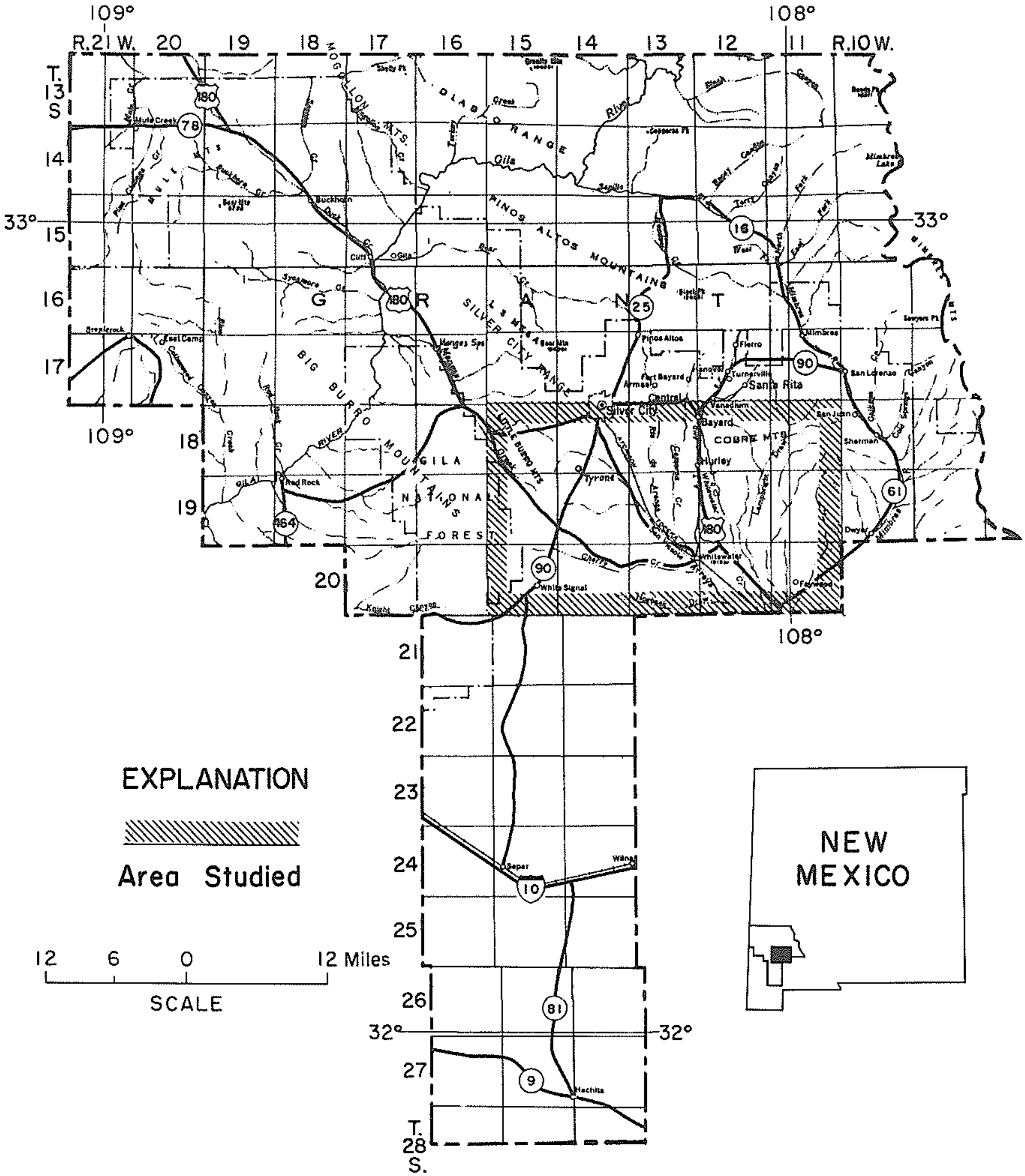
The efficiency of the wells in the present Silver City well fields was determined by pumping tests and by an evaluation of long-term water-level declines and pumpage records. Other well fields were evaluated by comparing well performances, by analysis of water-level fluctuations, and by relating well-field performance to geologic conditions.

The investigation of the potential for future development was limited to the vicinity of the present well fields and to the drainage basin of San Vicente Arroyo, because of legal, economic, and engineering reasons.

Well-Numbering System

The system of numbering wells and springs in this report is based on the Federal system of subdividing land into townships, ranges, and sections. The well number, which consists of four parts separated by periods, also indicates the location to the nearest 10-acre tract in the section. The first three parts represent, in reading order, the township south, the range west, and the section (fig. 2).

The fourth part of the number usually consists of three digits which indicate the 10-acre tract in which the well is located. The section is divided into quarters, quarter-quarters, etc., and numbered 1, 2, 3, 4, as indicated in figure 2. The first digit of the fourth part of the well number gives the quarter section; the second digit gives the quarter-quarter, and the third digit designates the 10-acre tract. Thus well 19.14.8.342 is in the NE$\frac{1}{4}$SE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 8, T. 19 S., R. 14 W. Letters a, b, c, etc., are added to the last part of the well number to designate the second, third, fourth, and succeeding wells listed in the same 10-acre tract.



Base from U.S. Geological Survey State Base Map, 1955

FIGURE 1. -- Map of Grant County, N. Mex., and location of the area studied.

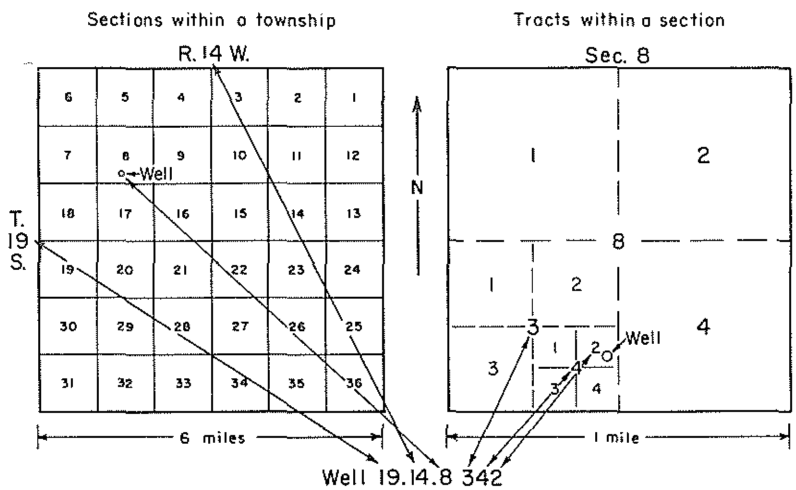


FIGURE 2. -- System of numbering wells in New Mexico

The well numbers in table 1 are not given in full for each well. The wells are grouped by townships and ranges for easier reading, and the full well number is used only for the first well in each township and range. The last two parts of the well number, showing the section and location in the section, are given for other wells in that township and range.

HISTORY OF PRESENT WATER SUPPLIES

Development

All incorporated communities in central Grant County utilize ground water exclusively for public supplies. Bayard, Central, and Silver City have developed well fields. Central has, in addition, an infiltration gallery that can supply some water. Hurley has a public distribution system, but is supplied with water by Kennecott Copper Corp. Kennecott supplies water also to the unincorporated community of North Hurley, and furnished water to the town of Santa Rita prior to razing of most of the community in the period 1964-67 to facilitate mining the ore-body that extends under the townsite.

Silver City, after experiencing many years of uncertain water supply, in 1945 developed and put into production a well field on the Franks ranch in the Gila River drainage basin, some 5 miles west of town. Pumping water across the continental divide, the city, for almost the first time in its history, was assured a continuous, though later inadequate, supply of water.

Bayard, after incorporation, developed and first operated its public distribution system with water obtained from privately owned wells at the Foy ranch, on Cameron Creek, west of town. The supply later proved inadequate and the city developed its own well field southwest of town, on the flood plain of Cameron Creek.

Prior to 1952, Central obtained a small supply of water from an infiltration gallery northwest of town on Twin Sisters Creek which flows into Cameron Creek immediately above the Bayard well field.

The drought of the late 1940's and early 1950's placed a severe strain on the water supplies for the communities of central Grant County. Increasing population and per capita use of water, and decreased precipitation and runoff resulted in water rationing in Silver City and Bayard. The public supply system in Central failed completely when the infiltration gallery went dry. Only Hurley and other communities supplied by Kennecott Copper Corp. had an adequate supply of water.

About 1953 Central drilled two deep wells, adjacent to its infiltration gallery, but failed to find an adequate supply of water. Bayard drilled more wells in its field on Cameron Creek and increased its water supply slightly.

In 1954 F. D. Trauger was assigned by the Geological Survey to study the ground-water resources of Grant County in cooperation with the Grant County Commission and the New Mexico State Engineer. An early result of that study was the completion in 1955 of a new well field and water supply for Central, and the location and start of development of a well field for Silver City on the Woodward ranch some 5 miles southwest of town, and on the east side of the continental divide. Information collected for the Grant County study also has provided the basic data from which the conclusions presented in this report have been drawn and much of the basic data for the Grant County section of State Engineer Technical Report 29D, Municipal Water Supplies and Uses, Southwestern New Mexico.

The interruption of the drought in the mid-1950's by normal, or near-normal, precipitation and increased runoff in Cameron Creek resulted in recharge to the aquifer of the Bayard well field and a temporary respite from the extreme shortage of water.

Present Use of Water

Water pumpage for nearly all communities in central Grant County has increased steadily over the years. The increased pumpage is due mostly to increases in population. However, an appreciable increase in per capita use of water in the past 10 years is responsible for much of the increased pumpage for Silver City. The principal factor controlling the per capita increase in the various communities is believed to be the availability of water. Per capita use in Silver City increased from 84 gpd (gallons per day) to 100 gpd in the period 1956-65, while in Bayard it decreased from 74 gpd to 70 gpd (table 2). Silver City could furnish, as a result of its newly developed Woodward field, all the water the

TABLE 1

RECORDS OF MUNICIPAL WELLS AND OTHER WELLS MENTIONED IN TEXT AND TABLES, OR SHOWN ON ILLUSTRATIONS,* IN CENTRAL GRANT COUNTY, N. MEX.

EXPLANATION:

Location number: See page 2 of text for explanation, locations are south of New Mexico Base Line and west of New Mexico Principal Meridian.

Depth: Depth of well and water-level measurements followed by letter "R" were reported--all other measured.

Altitude: Most altitudes interpolated from U.S. Geological Survey topographic maps altitudes of Woodward and Franks field wells obtained by spirit level.

Stratigraphic unit: The principal water-bearing formation; TpЄr, rocks of Precambrian to Tertiary age, undifferentiated; QTg, Gila Conglomerate of Quaternary and Tertiary age; Qal, alluvium and bolson deposits of Quaternary age.

Method of lift and power source: N, none; P, plunger or cylinder; T, turbine pump; Ts, submersible type turbine pump; e, electric; w, wind.

Use of water: Irr, irrigation; PS, public supply; S, stock; parentheses indicate purpose for which hole was drilled if well is not presently in use.

Remarks: All wells are drilled with rotary or cable-tool equipment; dd, drawdown; gpm, gallons per minute; Rept., reported, reportedly; T, temperature; °F, degree Fahrenheit.

Location number	Owner or tenant	Year completed	Depth of well (feet)	Diameter of well (inches)	Altitude above mean sea level (feet)	Water level: Depth below land surface (feet)	Water level: Date	Stratigraphic unit	Method of lift and power source	Use of water	Remarks
17.13.35.331	Town of Central	1953(?)	-	-	5,952	-	-	TpЄr	P,e	PS	East well of two 20 ft apart; reptd. yield 20 gpm.
35.331a	do.	-	-	-	5,950	-	-	Qal	T	PS	Collection gallery. Water supply for Town of Central. Collection gallery consists of a 6-foot diameter perforated 16-gauge galvanized-iron culvert, 200 feet long, buried crosswise 2 feet below the surface in the channel of Twin Sisters Creek. Two 75-gpm turbine pumps deliver water from a 15-foot sump below the culvert. Chemical analysis available.
18.13.12.113	Thomas Foy	1944	129	6	5,855	Dry	-	Qal	N	(PS)	Formerly Bayard well No. 1; drilled 500 ft, rept. penetrated fault and water drained away; plugged back to 125 ft; north well of four.
12.113a	do.	1944	345R	6	5,855	69.0 87.6	3-21-49 3-23-54	Qal	P,w	S	Formerly Bayard well No. 3; yield rept. 40 gpm but would pump out if No. 5 well pumping; dd 88 ft at yield of 25 gpm in 1954 when used by Town of Central.
12.113b	do.	1944	224R	8	5,855	69.2 88.0	3-21-49 3-23-54	Qal	T,e	Irr	Formerly Bayard well No. 5; yield 40 gpm; now used for small orchard.
12.113c	do.	1944	343R	8	5,855	69.5 88.1 57.9	3-21-49 3-23-54 1- 3-67	Qal	N	(PS)	Formerly Bayard well No. 2; used by Town of Central in 1954; west well of four.
14.221	Village of Bayard	1950	[illegible]50R	8	5,830	61.3	3-23-54	Qal	T,e	PS	Formerly Bayard well No. 10, now called No. 6.
14.221a	do.	1950	-	8	5,830	49.8	1- 4-51	Qal	T,e	PS	Formerly Bayard well No. 9, now called No. 5.
14.221b	do.	1965	350R	12	5,830	-	-	Qal	Ts,e	PS	Formerly Bayard well No. 12, now called No. 7; yield rept. 75 gpm.
14.222	do.	1948	101R	12	5,830	65.2	3-23-54	Qal	T,e	PS	Formerly Bayard well No. 6, now called No. 1.
14.222a	do.	1948	120R	12	5,830	64.8	3-23-54	Qal	T,e	PS	Formerly Bayard well No. 7, now called No. 2; yield rept. 75 gpm.
14.222b	do.	1950	-	8	5,830	51.2	1- 4-51	Qal	T,e	PS	Formerly well No. 8.
14.222c	do.	1956	250R	12	5,830	65 R	1956	Qal	T,e	PS	Formerly Bayard well No. 11, now called No. 3; yield rept. 100 gpm on test.
14.244	Kennecott Copper Corp.	1953	274	10	5,818	46.4 55.6	2-13-54 1- 3-67	Qal	N	(Irr)	Rept. drilled to 310 ft, cased to 263 ft, dd 8 ft at 145 gpm.
15.433	Town of Central	1961	555R	10	5,830	75.7	4-11-62	Qal	T,e	PS	Central No. 3, rept. cased 401.5 ft, yield 375 gpm.
15.434	do.	1954	472	12	5,920	167.6 174.4	10-13-54 1- 3-67	Qal	T,e	PS	Central No. 1; dd 46 ft at 108 gpm; T 70°F, bottom 50 ft of hole drilled in granitic rock; 1st well drilled in Lone Mountain well field.
15.444	do.	1954	387	18-10-6	5,815	144.8	10-22-54	Qal	P,e	PS	Central No. 2; yield 24 gpm; T 68°F; 2nd well drilled in Lone Mountain well field.

TABLE 1 (concluded)

RECORDS OF MUNICIPAL WELLS AND OTHER WELLS MENTIONED IN TEXT AND TABLES, OR SHOWN ON ILLUSTRATIONS,* IN CENTRAL GRANT COUNTY, N. MEX. - CONCLUDED

Location number	Owner or tenant	Year completed	Depth of well (feet)	Diameter of well (inches)	Altitude above mean sea level (feet)	Water level: Depth below land surface (feet)	Water level: Date	Stratigraphic unit	Method of lift and power source	Use of water	Remarks
18.14.27.434	Elmo McMillen	1944	1,395R	10	5,636	102.0 108.6	12-30-49 3- 9-54	QTg	N	(PS)	Test hole for Silver City; yield rept. about 45 gpm with no increase in water below depth of 400 ft; hole open to 700 ft in 1954.
30.312	Town of Silver City	1954	769	14-12	5,907	315.7 356.8	7-13-54 1-22-67	QTg	T,e	PS	Woodward field No. 2, cased 769 ft, dd 55 ft at 285 gpm; water semi-confined; T 70°F.
30.324	do.	1954	895	14-12	5,892	300.3 344.0	4-21-54 1-22-67	QTg	T,e	PS	Woodward field No. 1, cased 600 ft, dd 110 ft after 14 days continuous pumping at rate of 400 gpm; water semi-confined; T 70°F.
30.343	do.	1957	835	16	5,908	318.4 350.5	8-16-57 1-22-67	QTg	T,e	PS	Woodward field No. 3; water semi-confined, T 71°F.
30.432	do.	1966	954	15	5,853	273.7 289.0	5-23-66 10- 5-67	QTg	Ts,e	PS	Woodward field No. 4; water semi-confined.
34.214	Elmo McMillen	1944	620R	16-10-6	5,610	106.7	3- 9-54	QTg	N	(PS)	Test hole for Silver City; yield rept. about 8 gpm.
18.15.10.441	Town of Silver City	1954	659R	14-8	5,762	192.0 201.9 205.0	10-11-54 3-24-57 10- 3-67	QTg	T,e	PS	Franks field No. 5; cased 659 ft, dd 192 ft after pumping 410 gpm for 4 hrs., T 68°F.
11.313	Randolf Franks	1930	275R	6	5,797	200R 248R	1930 12-23-49	QTg	N	(S)	Rept. cased 250 ft, not in use; rept. dry in 1967.
11.313a	Town of Silver City	1945	597R	12	5,799	207R 242.8 243.1	3-30-45 3-24-57 10- 2-67	QTg	T,e	PS	Franks field No. 1; cased 417 ft, yield about 350 gpm when drilled; T 68°F.
11.323	do.	1945	580R	12	5,829	237R 264.8 266.9	6- 6-45 3-24-57 1- 2-67	QTg	N	(PS)	Franks field No. 3; used as an observation well and equipped in 1958 with an automatic water-level recorder.
11.331	do.	1945	547R	12	5,815	220R 252.2 253.0	8- 2-45 3-24-57 10- 3-67	QTg	T,e	PS	Franks field No. 4; yield 350 gpm on test when drilled; dd 62 ft at 137 gpm.
11.341	do.	1945	558R	12	5,830	240R 264.3 269.0	4-19-45 3-24-57 10- 3-67	QTg	T,e	PS	Franks field No. 2; yield rept. about 150 gpm when drilled and still 150 gpm in 1967
25.442	Marvel Woodward	1924	449	10	5,935	333.8 355.9	3- 5-54 1- 9-67	QTg	P,w	S	Woodward ranch lower house well; cased 20 ft; first 20 to 30 ft below water table yielded 1 to 2 gpm but yield increased markedly with increase in depth.
32.234	Mangas Cattle Co.	1954	400R	14	5,345	59.0	8-31-54	QTg	N	(Irr)	Drilled by Lee Childress; cased 217 ft; test pumping at well depth of 210 ft produced 236 gpm with dd of 141 ft from 22 ft of water-bearing strata; an additional 29 ft of water-bearing strata were rept. by driller between the depths of 210 to 400 ft but the well was not tested at the completed depth; alluvial fill to 70 ft, upper Gila Conglomerate from 70 to 400 ft.
36.422	Pacific Western Land Co.	1947	480	8	5,989	399.4 400.1 420.4	3- 5-54 8-21-56 1- 9-67	QTg	P,w	S	School section well, rept. drilled 500 ft, water level rose 12 ft; static level rept. remained constant within one foot from time of drilling to time of visit in 1954.
19.12. 8.242	Kennecott Copper Corp.	1927	1,542R	17-13	5,500	69	1927	TpGr	N	(Ind)	Bottom No. 1; cased to 470 ft; yield dropped from 1,150 gpm to 230 gpm when hole caved back to 491 ft; at 900 ft depth the water level raised 400 ft in 4 hours; not used since 1952.
19.12.19.132a	do.	1920	2,445R	20-16	5,375	153	1924	TpGr	N	(Ind)	Apache No. 5; cased 827 ft; deepened to Precambrian granite in 1924; this well and Nos. 4 and 6 together yielded 1,400 gpm when first drilled.
19.134	do.	1951	370R	18	5,360	201.2	6- 8-54	TpGr	T,e	Ind	Apache No. 11; cased 296 ft; water found at 300 ft; dd rept. 26 inches at 500 gpm in 1951.
19.14. 1.143	Elmar Salars	1944	390R	10	5,520	138R	9- 1-44	QTg	N	(PS)	Test hole for Silver City; dd 190 ft at 7 gpm.
1.143a	do.	1944	1,003R	16	5,520	133.7	4-20-54	QTg	N	(PS)	Test hole for Silver City; 20 ft south of well 1.143; reptd. could be bailed dry.
14.443	do.	1937	540R	8	5,510	363.4	3-12-54	QTg	P,w	S	Rept. water rose in casing when found; pumped 40 gpm for 8 hours.
19.15.10.221	Pacific Western Land Co.	1944	1,180R	14-12	5,633	145.4	4-20-54	QTg	N	(PS)	Test hole for Silver City; rept. yield 40 gpm.
20.11.31.113	John Stark	1951	1,607	-	4,924	-	-	-	N	-	Oil test hole; rept. bottomed in bolson fill.
20.12.36.111	do.	-	140+	8	4,937	123.5	2- 3-55	Qal	P,w	S	Drawdown 0.44 ft at 6.5 gpm; T 63°F.

* Plate 1 has been adapted from Trauger (in preparation)--not all wells and test holes shown on the figure are included in Table 1.

people wanted; Bayard, with its water supply limited, could not. In fact, Bayard, with its population increased sharply by the influx from Santa Rita in the period 1964-67, is again faced with an acute water shortage, this time because of increased demands and not as a result of drought. Another drought in the near future could prove a near-disaster to Bayard with respect to its water supply.

Most of the water supplied to towns in central Grant County is for home use, and for small businesses such as laundries and service stations. No industries using large quantities of water are supplied by any of the city distribution systems. Water utilized for irrigating yards is included in home-domestic use. Such use is not extensive at present because most communities in the county never have had enough water available to permit landscaping around homes and businesses. As more water becomes available to the communities, more will be used for such purpose unless the water is priced to curtail such use.

The quality of water presently available to the towns from the various well fields is good -- suitable for domestic and most industrial uses. Ground water obtained from the Gila Conglomerate and from both the alluvium and bolson fill generally is hard to moderately hard and contains from about 200 to 400 ppm (parts per million) dissolved solids. The principal constituent is bicarbonate. Chloride and sulfate content generally is less than 25 ppm. The pH averages about 7.8, hence the water is slightly alkaline. Fluoride is present generally in amounts less than 1 ppm.

Chemical analyses show little difference in waters from the Gila Conglomerate and from the bolson fill. Wells tapping these aquifers anywhere in the area can be expected to yield water comparable in quality to that presently being used. Water in the limestone of Paleozoic age generally is of good quality -- satisfactory for most uses, but commonly somewhat harder than water from other aquifers.

Adequacy of Present Supplies

Formulation of reliable conclusions concerning the adequacy of the presently developed water supplies of the various communities to meet future needs require accurate forecasts of population trends and climatic variations--factors which strongly influence annual and seasonal water demands. Population trends can be estimated within reasonable limits but climatic variations cannot, at least not with any assurance, and the safest procedure is to assume that conditions of severe drought always are imminent. However, other more stable data are available upon which some firm conclusions can be made concerning the present and future adequacy of the community supplies.

Hurley and North Hurley are assured their present supply of water even if Kennecott Copper Corp. must curtail its own use in order to supply the communities it serves. However, the commitment of Kennecott does not require expansion of its service unless the company wishes to

TABLE 2

URBAN USE OF WATER IN CENTRAL GRANT COUNTY, N. MEX.*

Community	Year	Ground water pumped (gallons)	Acre-feet	Population	Daily per capita use (gallons)
Bayard	1956	60,500,000	185	2,250	74
	1965	76,900,000(a)	236	3,000	70
Central	1956	13,800,000	42	1,300	29
	1965	22,900,000	70	2,000	33
Hurley and	1956	-	-	2,000	-
North Hurley	1965	66,100,000	203	2,200	83
Santa Rita(b)	1956	17,300,000	53	1,900	25
	1965	16,000,000	49	1,000	44
Silver City	1956	216,000,000	673	7,000	84
	1965	312,900,000	960	8,500	100
	1967	362,100,000	1,125	10,400(c)	95

* Population figures furnished by the towns, or estimated from 1950 and 1960 census; pumpage records furnished by the towns.

(a) Master meter broken from April 1964 to May 1965; pumpage for period January-May estimated--based on pumpage during the same period for previous and succeeding years, and the precipitation records.

(b) Razing of town will be completed by 1970; population and water use partly estimated. The usage will decline to zero but will be compensated by equivalent increases in nearby communities.

(c) Population increased rapidly in 1967; at the end of 1967 it was estimated to be 11,000 but the estimate for July has been used for computing the average daily per capita use for the year.

do so. Thus the rate of growth of the communities could be restrained through lack of water to supply a large population.

Bayard operates one well field of six or seven wells but does not have an assured adequate supply of water. The water supply is sufficient to meet present minimum needs during periods of normal or near-normal annual precipitation. The town probably would have difficulty in meeting minimum demands for water in the event of the recurrence of 2 to 3 years or more of drought, such as occurred in the late 1940's and early 1950's.

Central operates a well field of three wells and an infiltration gallery, and probably can meet minimum to average water needs, based on present usage, for the next 10 to 20 years. The supply is reliable but not adequate to meet the needs of a much greater population or to permit a large increase in daily per capita use. In the event of severe drought, the supply might be insufficient to meet present minimum needs.

Silver City with its two well fields, one on the east side of the continental divide, the other on the west, can meet present needs and long-term modest increased demands for water resulting from increased population and per capita use. Any shortages of water in the immediate and near future are apt to result more from the inadequacy of the distribution system than from failure of the available supply of water. However, the city is pumping water from storage, water levels are declining in the well fields, and eventually the supplies will be depleted to the extent that yields will be appreciably smaller and the unit cost of producing the water will be greater.

The supplies of water available from the present well fields eventually could become inadequate to meet more than minimal demands. How long before this eventuality becomes reality is dependent entirely on the rate of pumping from the present well fields, which in turn is dependent upon the demand for water. The city government to a large extent can control that demand by its policies concerning extension of service and the charges it makes for water.

FUTURE NEEDS FOR WATER

The future need for water in central Grant County will depend mostly on population growth, and to a lesser extent on increased per capita use and industrial growth. Hurley, Central, and Bayard can expect steady increases in population based on past growth rates of about 3 percent annually and the expansion of the larger mining companies such as Kennecott. The population has increased sharply in Central and Bayard the past few years (1964-67) because most people who moved from Santa Rita relocated in these communities. Only a few people still remain in Santa Rita and the effect of further population shift should be slight. The population of Silver City probably will increase more rapidly than that of other communities because: Silver City is closer to the new mining development at Tyrone; New Mexico Western College at Silver City probably will expand; the general tendency is for the largest city in an urbanized region to increase in size at a rate greater than nearby smaller communities up to a point. When the increased size becomes an inconvenience to many people movement to suburban areas begins. While Silver City probably will increase appreciably in population, it is doubtful that it will reach a size that will cause people to move out.

The population estimates in table 3 are derived from projections of the 1960 census. They are modified to reflect recent and anticipated economic changes in the area and resulting population trends as indicated by the mid-1967 population estimates made by the communities.

TABLE 3

POPULATION CHANGES AND PREDICTED CHANGES IN COMMUNITIES IN CENTRAL GRANT COUNTY, N. MEX., 1940-2000*

Community	1940	1950	1960	1967	1970	1980	1990	2000
Bayard	764	2,119	2,327	3,000	3,400	4,500	5,900	7,000
Central	-	1,511	1,075	2,200	2,400	3,200	4,000	5,000
Hurley and North Hurley	-	-	1,851	1,900	2,000	2,400	2,600	2,800
Santa Rita	-	2,135	1,772	200	-	-	-	-
Silver City	5,044	7,022	6,972	11,000	15,800	23,000	31,000	40,000
Tyrone(a)	-	-	-	300	500	850	1,000	1,100

* Figures for 1940-1960 from 1960 U.S. census report, 1967 estimates furnished by civic governments; 1970-2000 projections based on populations as of 1967, available data concerning factors that may inhibit or promote growth, and a normal 3 percent annual increase as determined by the Bureau of the Census.

(a) Estimates are for the new townsite started in 1967.

Predictions of the 1970 populations are likely to be reasonably accurate, but predictions for the next few decades are less reliable. The estimates in table 3 for years beyond 1970 appear to be high, but a sharp drop below the normal national growth rate of about 3 percent annually, as determined by the U.S. Bureau of the Census, would be required to materially decrease the population predictions for the year 2000. No valid reason is apparent at this time to justify an assumption that such a drop in growth rate will occur. Therefore, the seemingly high estimates of populations are used to predict the total water needs (table 4) of the communities by the year 2000.

The estimates of increase in daily per capita use (table 4) are based on several imponderable factors such as price of water (how might rates be changed?), increased numbers of water-using appliances, construction of new homes, beautification of yards and parks, availability of water, and any combination of these and other factors. Obviously, if water supplies are severely limited, per capita use will not rise, and may even decrease if costs are raised to hold down usage. The immediate result of an abundance of water and low rates generally is a sharp increase in daily per capita use.

TABLE 4

ESTIMATES OF PER CAPITA USE AND TOTAL WATER NEEDS FOR URBAN COMMUNITIES IN CENTRAL GRANT COUNTY, N. MEX., BY THE YEAR 2000

Community	Daily per capita use, in gallons, in 1965	Daily per capita use, in gallons, by the year 2000*	Population by the year 2000 (estimated)	Water needed, in millions of gallons per year, by the year 2000	Acre-feet per year	Gallons per minute continuous pumping
Bayard	70	150	7,000	385	1,180	715
Central	33	100	5,000	185	570	350
Hurley and North Hurley	83	150	2,800	160	490	305
Silver City	100	200	40,000	2,900	8,900	5,500
Tyrone	-	200	1,100	80	250	150
AVERAGE or TOTAL	75	160	55,900	3,710	11,390	7,020

* Based on the assumption that water will be available in the quantities wanted, and at a price that does not greatly restrict usage.

Most of the new homes now being built have more water-using appliances than do the older homes. Communities that have much new-home construction can expect sharp increases in per capita use of water. However, the factor that tends most to increase per capita use of water is land beautification. Communities that have many parks and a high percentage of homes with landscaping that requires regular watering have, by far, the highest per capita use rates. A successful campaign to encourage landscaping in a community could drastically increase the per capita use of water.

It is obvious, therefore, that accurate and current records on the daily per capita use of water and realistic estimates of population increases are essential for making reasonably accurate predictions of future water needs.

HYDROLOGY

Geologic Control of Ground Water

The type, distribution, thickness, and structure of rocks present in an area largely control the occurrence of ground water. These factors must be known before an appraisal of water resources can be made. Earlier water-resources investigations in Grant County have resulted in the accumulation of many data concerning the geology and occurrences of water in the area, and these data are the basis for the following discussion.

Rock Units and Their Water-Bearing Characteristics

For the purpose of this report the rocks of the region are divided into three principal categories: 1) the sedimentary rocks of Holocene age that include the alluvium in the stream valleys and the upper part of the bolson fill; 2) the sedimentary rocks that comprise the Gila Conglomerate of Quaternary and Tertiary age; and 3) the bedrock, which is considered to be crystalline rocks of Precambrian to Holocene age and those sedimentary rocks older than the Gila Conglomerate. The areal distribution of the three rock units is shown in plate 1.

The bedrock has almost no effect on the problems involved and has little potential as a source of water for the various communities. It is either densely crystalline intrusive or volcanic rock, or it is limestone, shale, and tuffaceous sandstone that yield little water or water at depths too great for economical development. Only in the vicinity of Apache Tejo are large yields of water obtained from the bedrock. The alluvium, bolson fill, and Gila Conglomerate are the principal aquifers in Grant County and they are the only rock units this report will consider in detail.

Gila Conglomerate

The Gila Conglomerate of Pliocene and Pleistocene age consists of poorly sorted unconsolidated to strongly consolidated nonbedded to well-bedded sediments and locally monolithic rocks. Two major divisions of the Gila, an upper and a lower, can be recognized in the area.

The upper and lower parts of the Gila Conglomerate are difficult to differentiate in detail because their lithology is similar. Contacts are concealed by a mantle of weathered rocks, and the weathered products of similar conglomerates and related deposits are not easily distinguished. The principal differences are those of degree of consolidation and, locally, the lithologic character of included constituent rocks.

The lower part of the Gila generally is strongly indurated, and locally is deformed and intruded by igneous rocks. The materials making up the beds consist mostly of fragments of light-colored volcanic rocks derived by weathering from deposits of early Tertiary to middle Tertiary age; the fragments are largely from the Datil Formation. The conglomerates are coarse; the larger rock fragments are characteristically subrounded to angular, and the matrix binding them contains a high percentage of fine sand, silt, and tuffaceous material. Good exposures of the lower part of the Gila can be seen in a creek bank in the NW$\frac{1}{4}$ sec. 16, T. 18 S., R. 14 W. and in Pipe Line Draw in the SW$\frac{1}{4}$ sec. 29, T. 18 S., R. 14 W.

The upper part of the Gila Conglomerate generally is only slightly consolidated. It may be somewhat deformed locally but much of the apparent dip results from deposition on slopes that fanned out from the base of the uplands from which the deposits came. The mode of origin of most of the Gila Conglomerate, both the lower and upper parts, is analogous to the present formation of overlapping alluvial fans. The upper part of the Gila can be observed in road cuts west of Pipe Line Draw on New Mexico Highway 90 between Silver City and Lordsburg.

The composition of the upper part of the Gila varies more from place to place than does the lower part, even though the two parts were formed in the same manner. The variation resulted from the exposure of a greater variety of rocks when the upper part of the Gila was deposited. The lower part was derived mainly from the volcanic rocks of the Datil Formation which covered nearly all the older rocks. The upper part of the Gila was deposited after an interval of time in which all rocks of the region, including the lower part of the Gila, were faulted and deformed. The deformation and faulting brought some of the older nonvolcanic rocks to the surface and made them also subject to erosion. All of the older rocks thus have contributed material to the upper part of the Gila; therefore, its component sediments have a variety not found in the lower part.

Because erosion of the lower part of the Gila also contributed sediment to the deposits forming the upper part, it is difficult to distinguish between the two parts on the basis of rock types alone. They are best distinguished at the surface on the basis of percentage of volcanic rocks, degree of consolidation, attitude, and topographic position. Generally the "hardness," or degree of consolidation, can be used to differentiate the two parts in drill holes. Locally, the percentage of volcanic rocks is significant--the lower part commonly is composed mostly of light-colored volcanic rocks and rarely contains material of granitic origin such as that found in the upper part.

It is important from the standpoint of finding ground water to be able to distinguish between the upper and lower parts of the Gila at the surface and in drill holes. The lower part of the Gila furnishes very little water to wells; the upper part can furnish moderate to large amounts.

Silver City's Woodward field well 1 (18.14.30.324) penetrated about 890 feet of unconsolidated to poorly consolidated deposits considered to be the upper part of the Gila. The rocks consisted largely of feldspar and quartz fragments derived from the granitic rocks exposed to the west in the Big Burro Mountains. From 890 to 895 feet the drill penetrated very hard conglomerate, composed mostly of volcanic rock, which was considered to be the lower part of the Gila. The well had a drawdown of about 110 feet after pumping 400 gpm (gallons per minute) continuously for 2 weeks. All water yielded came from the upper part of the Gila.

A test well, 19.14.1.143a (table 1), was drilled in 1945, about 5 miles east-southeast of the Woodward field, to a depth of 1,000 feet, all in the well-cemented lower part of the Gila. The well reportedly would yield no more than 40 gpm when it was tested.

The yields of these two wells show the characteristic effect that the upper and lower parts of the Gila have on the hydrology of the area and why it is important to be able to recognize the two parts in drill holes.

Alluvium and Bolson Deposits

The sands and gravels in the channels and under the flood plains of the creeks and washes are unconsolidated continental deposits of Holocene age; so also is the material immediately underlying the surface of the bolsons in the vicinity of Whitewater and Faywood. The composition of these deposits is varied because the streams that deposit them flow across rocks of many types and pick up material of all kinds. The texture ranges from fine to coarse -- from clay and silt to beds of boulders.

The deposits generally are thin in the stream valleys but attain great thickness in the bolson areas. The alluvium in the channel of San Vicente Arroyo and its major tributaries generally is not more than 10 to 20 feet thick although locally it may be more. The alluvium locally may contain appreciable amounts of water at shallow depth, as in Cameron Creek, near Bayard. However, the alluvial aquifers generally will not sustain large yields for prolonged periods because the fill is thin and the valleys narrow. Wells tapping the alluvium may sustain large yields of water seasonally but not annually. Water may accumulate in the alluvium during the wet season but drain away during the drier periods. The alluvial aquifers may fail if they do not receive an appreciable amount of recharge annually.

Bolson deposits are those continental sediments which fill the broad inter-mountain basins of the southwest. The deposits underlying the plains in the Faywood Springs-Whitewater area are examples. The bolson deposits are composed of a heterogeneous mixture of all the kinds of rock found in the surrounding uplands. They are mostly unconsolidated but some beds locally may be strongly cemented with carbonate, iron, or silica to varying degrees. Most of these cemented beds, regardless of the depth at which they are found, became cemented at a time when they were within a few feet of the land surface, and when that surface remained stable for an appreciable time. These hardpan layers, as they commonly are called, may be a few inches or many feet thick. They should not be mistaken for "bedrock."

The bolson deposits generally are not well sorted and individual beds are not sharply defined or widespread. Wells within short distances of one another commonly will have no beds that can be correlated from well to well. Rarely are beds of clean sand or gravel found in bolson deposits -- more commonly they are a mixture of clay, silt, sand, and gravel, in varying proportions.

The bolson deposits range in thickness from a few feet where they lap onto the bedrock along the foothills to several thousand feet in the central parts of the larger basins. Oil test well 20.11.31.113, $2\frac{1}{2}$ miles southwest of Faywood Springs, bottomed in bolson fill at a depth of 1,807 feet. Another test well, in Luna County about 9 miles southeast of Faywood, was drilled in bolson fill to a depth of 6,171 feet. These and other tests in southwestern New Mexico show that the bolson deposits are of great thickness in most of the large valleys; the full thickness is not known. These deposits constitute a ground-water reservoir of great capacity.

The specific capacities of wells -- the yield in gallons per minute per foot of drawdown of the water level under pumping conditions -- tapping the bolson fill commonly are low, from 1 to 10, but may be as high as 44 (Conover and Akin, 1942, p. 259). Large volumes of water can be pumped from the deposits, in spite of their low specific capacities, because of their great thickness. Irrigation and industrial wells tapping bolson deposits near Whitewater and Faywood have yields ranging from 100 to 1,500 gpm and average about 600 gpm. Some of the wells were drilled to depths of 1,500 to 2,000 feet but most of them are between 300 and 500 feet deep.

Structure

The regional and local structure of rocks in central Grant County has a pronounced effect on the occurrence of ground water. The lowland occupied by Mangas Creek and San Vicente Arroyo is a major complex fault zone. A structural block including the Mogollon, Diablo, Pinos Altos, Silver City, Cobre, and other ranges (fig. 1) along the east side of the Mangas-San Vicente lowland was elevated relative to the area immediately west of the lowland. The faulting occurred subsequent to the deposition of the lower part of the Gila Conglomerate, which was elevated along with all older rocks. The wedge-shaped trough which resulted from the faulting was then filled with alluvial debris that now constitutes the upper part of the Gila and which, west of San Vicente Arroyo and Pipe Line Draw, is known to be at least 900 feet thick. The upper part of the Gila is, in general, missing, or is thin, east of the arroyo and the draw.

All large-capacity wells within the study area that obtain water from the Gila Conglomerate do so from the upper part; thus, the faults that separate the lower Gila from the upper Gila also delineate areas where large supplies of ground water may be found. Silver City's two well fields tap water in the upper part of the Gila in the part of the wedge-shaped structural trough that lies between the Little Burro Mountains and the Silver City Range.

Analysis of Aquifer and Well-Field Performance

Withdrawal of water from an aquifer causes the potentiometric surface (the water surface in an unconfined or semiconfined aquifer) to decline in the vicinity of the withdrawal. The decline in the vicinity of a pumped well or well field is proportional to the amount of water removed and inversely proportional to the storage capacity (storage coefficient times aquifer volume) of the aquifer. The distance away from the well that these withdrawal effects extend is a function of time and the ability of the aquifer to transmit water (expressed as transmissivity).

The storage coefficient, commonly indicated by the letter "S," is dimensionless and is the volume of water released, or taken into storage, in an aquifer per square foot of surface area per foot of vertical change in head (lowering or raising of the water level). The transmissivity, indicated by the letter "T," is the rate of flow of water (at the prevailing temperature) in gallons per day, through a vertical strip of the aquifer, 1 foot wide, extending the full thickness of saturation (saturated thickness) under unit gradient (1 foot per foot of flow distance).

These coefficients are assumed to be constant for purposes of calculating pumping effects, and the assumptions are valid for predicting short-term effects where no appreciable dewatering of the aquifer takes place. Obviously, over a long period of time, extensive dewatering may occur in an aquifer that has little recharge and the saturated thickness of the aquifer will be appreciably decreased. Inasmuch as the value of "T" is dependent upon the saturated thickness, the value of "T" becomes less. This factor must be considered when long-term effects are being calculated for a water-table aquifer. The result of this factor is a lowering of the water table at an increased rate as the saturated thickness of the aquifer is decreased. This problem will be considered further in the discussion of the Silver City well fields.

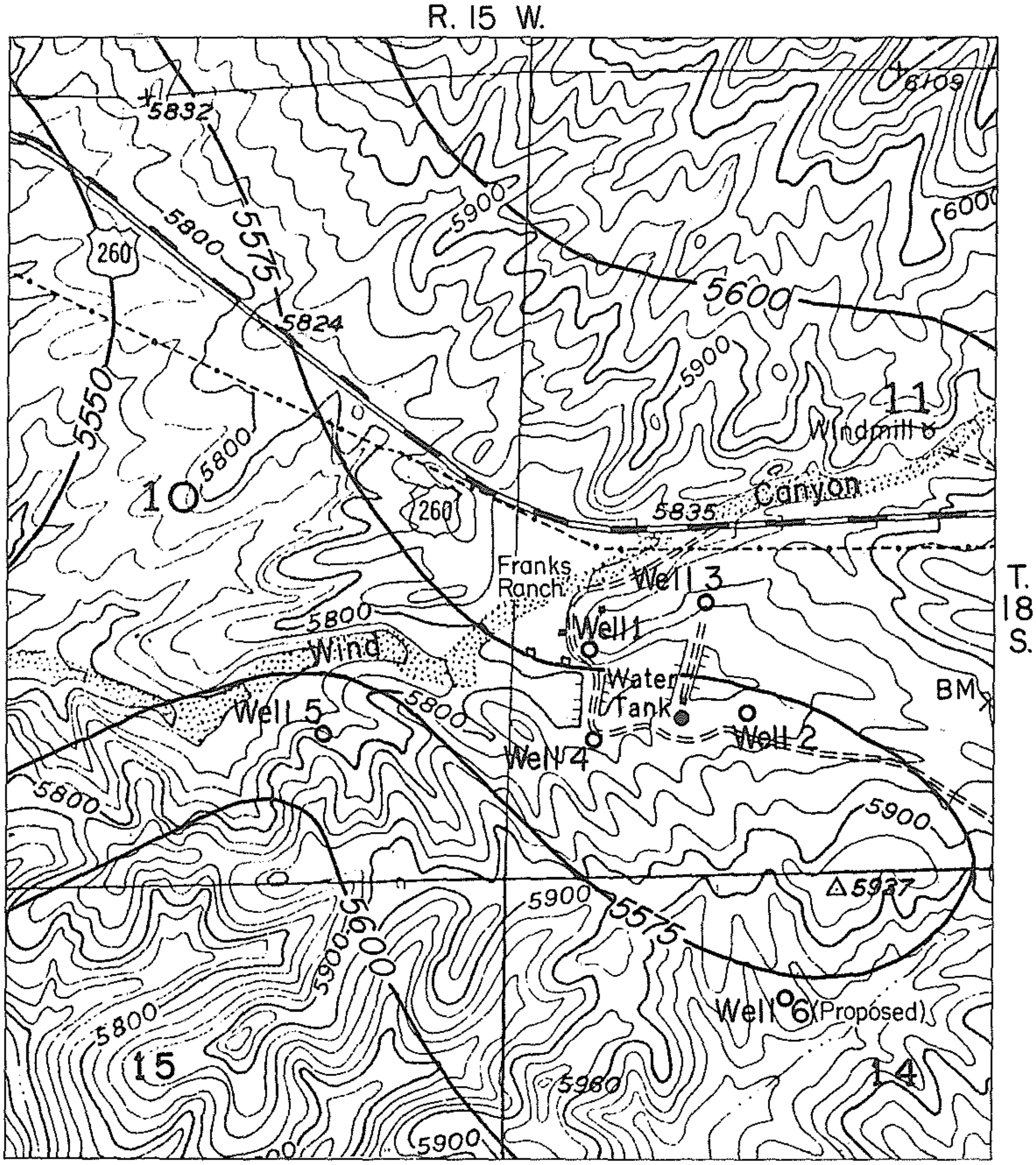
In the analysis of aquifer performance it is assumed not only that the hydrologic coefficients remain constant, but that the aquifer is of uniform thickness, infinite in areal extent, homogeneous, and isotropic. With these assumptions, the hydraulic properties of the aquifer may be expressed by the nonequilibrium formula developed by Theis (1935) and a modification of this formula by Jacob (1946). In practice, however, few aquifers can satisfy the necessary assumptions. The heterogeneity and discontinuous nature of portions of an aquifer cause departures and boundary influences to appear in the analysis of data from pumping tests, and greatly affect the values of hydrologic coefficients as determined by tests on individual wells. Therefore, it is necessary, when evaluating the results of pumping tests, to consider carefully the physical characteristics of the aquifer, and to make adjustments where the need is indicated.

The pumping tests made of the individual wells in the Silver City well fields gave conflicting results because the Gila Conglomerate and the bolson fill are examples of aquifers that are not homogeneous or isotropic, nor are they of uniform thickness or infinite in extent. The character of the beds of clay, sand, and gravel that make up these aquifers varies horizontally and vertically within short distances. The strata in general have greater continuity horizontally than vertically; thus water may be assumed to move more easily parallel to the bedding than across bedding planes.

Silver City Well Fields

Hydrologic and geologic data for the Silver City area were collected by F. D. Trauger of the U.S. Geological Survey during the period 1954-58 in the course of a county-wide investigation in cooperation with the New Mexico State Engineer and the Grant County Commission. As one result of that investigation Silver City drilled its well 5 (18.15.10.441) in the Franks field (fig. 3), and developed the Woodward field (fig. 4). Additional data have been collected periodically since 1956.

Pumping tests were made during the period 1954-58 by Trauger in conjunction with the development and expansion of the Silver City well



Base from U.S. Geological Survey

0 1000 2000 FEET

Topographic contour, interval 20 feet. Datum is mean sea level.

Hydrology by F. D. Trauger

EXPLANATION

5600

Potentiometric contour, interval 25 feet. Datum is mean sea level.

FIGURE 3. -- Location of Silver City wells and proposed wells in the Franks field, and contours on the potentiometric surface, Grant County, N. Mex.

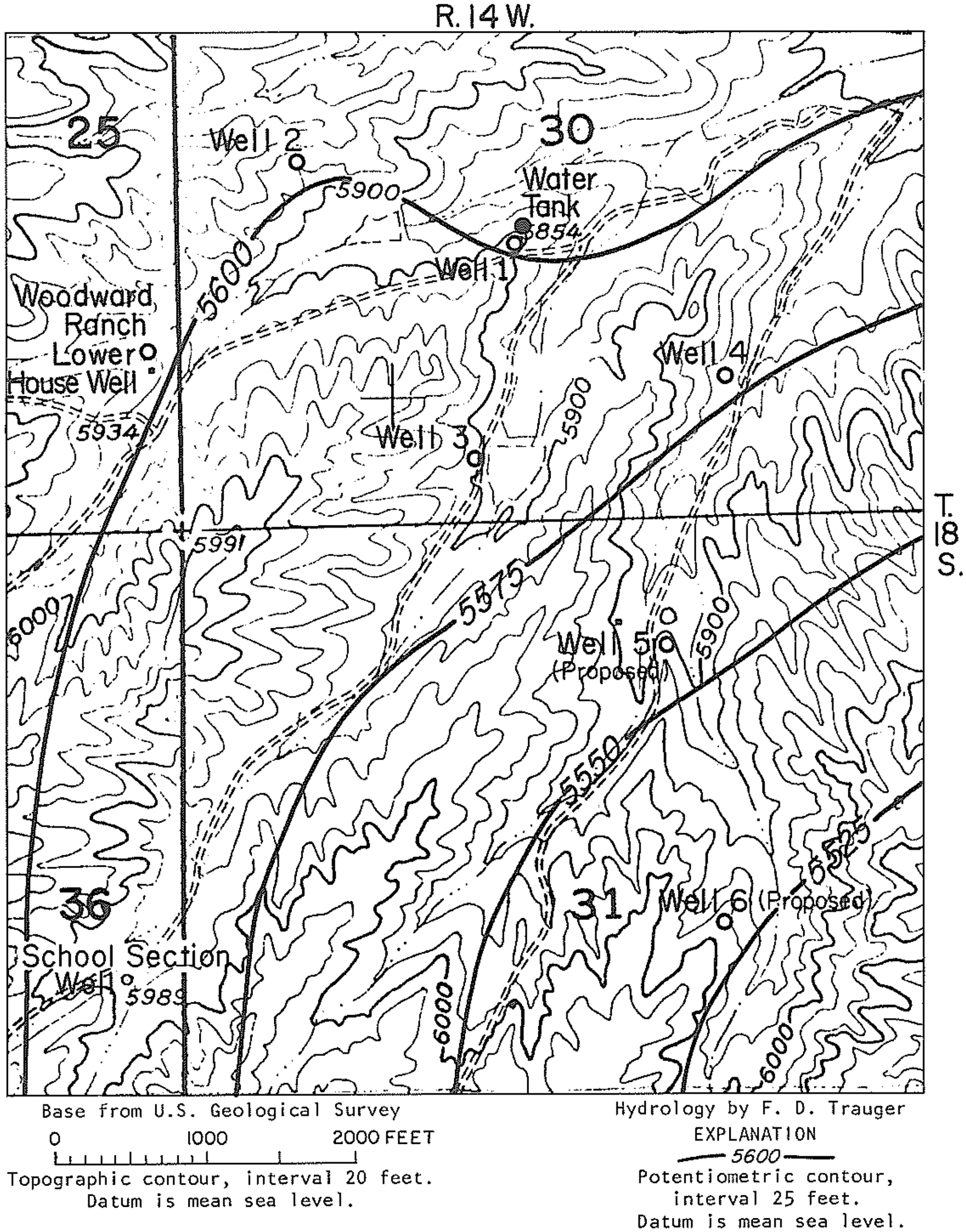


FIGURE 4. -- Location of Silver City wells and proposed wells in the Woodward field, and contours on the potentiometric surface, Grant County, N. Mex.

fields. F. C. Koopman and J. A. Basler made additional tests in November 1967 to determine well and pump efficiencies, to obtain additional data for evaluating the individual wells and the well fields, and to determine the ability of the aquifer to supply the water needs of Silver City.

The supply wells at present are pumped only during the day, and water is put into storage tanks. For ease of computation the daily withdrawal of ground water from each well is averaged over a 24-hour period. For example, a well pumped at the rate of 400 gpm for 12 hours is considered as being pumped at the rate of 200 gpm for 24 hours. Errors introduced by making this assumption would be local in nature and would not affect the results of the overall long-term predictions.

The first step in analyzing the performance and potential of the Franks and Woodward fields requires determination of the average storage coefficient and transmissivity for the aquifer. The coefficients then can be used to calculate the long-term effects of pumping at various rates and to predict the effective life of the well fields and their ability to meet increased future demands for water.

STORAGE COEFFICIENT

The average storage coefficient used for the analysis was selected after determining the coefficient by the following approaches: 1) comparing the long-term water-level decline in well fields with the total volume pumped for the period of decline; 2) observing changes in water levels in individual wells as the result of pumping and changes in water levels in wells caused by pumping a nearby well; and 3) observing changes of water levels resulting from a change in the rate of pumping from the field.

The method utilizing the long-term decline of water levels in the Franks field compared with the total pumpage for the same period gave a storage coefficient of about 0.15. This value is considered to be somewhat unreliable owing to lack of data on declines in water levels adjacent to the well field. Approaches 2 and 3 above involve the use of methods of determining aquifer characteristics developed by the U.S. Geological Survey (Theis, 1935, and Jacob, 1946).

Pumping tests on individual wells generally gave values of about 0.02 for the storage coefficients. The low values indicate possible artesian or semiartesian conditions which probably are due to lack of continuity of beds and widespread presence of clayey material in the aquifer. Trauger collected data in 1954 that show semiartesian conditions are present in the Woodward field, and they are presumed to exist in the Franks field. However, over long periods of time--several months to several years--head differences within the aquifer tend to equalize and the aquifer behaves as it would under strictly water-table conditions. The true value of the storage coefficient would be somewhat higher than the 0.02 value determined by pumping tests of a few hours, days, or weeks when the aquifer was still mostly under semiconfined conditions.

It is an exception rather than the rule to have the results of pumping tests agree perfectly with the equations used in the analysis; therefore, in addition to the theoretical analysis, factors such as judgment, experience, and knowledge of the aquifer must be utilized in the selection of reasonable values of the hydraulic parameters to be used in predicting effects of pumping on water levels. For this reason the value of 0.04 (one of the many computed values) for the storage coefficient was used in the equations for predicting water levels resulting from future pumping. Its application in the formulas gave results that best fitted the observed results of long-term pumping from the aquifer, thus confirming its greater reliability over values obtained by the other methods.

TRANSMISSIVITY

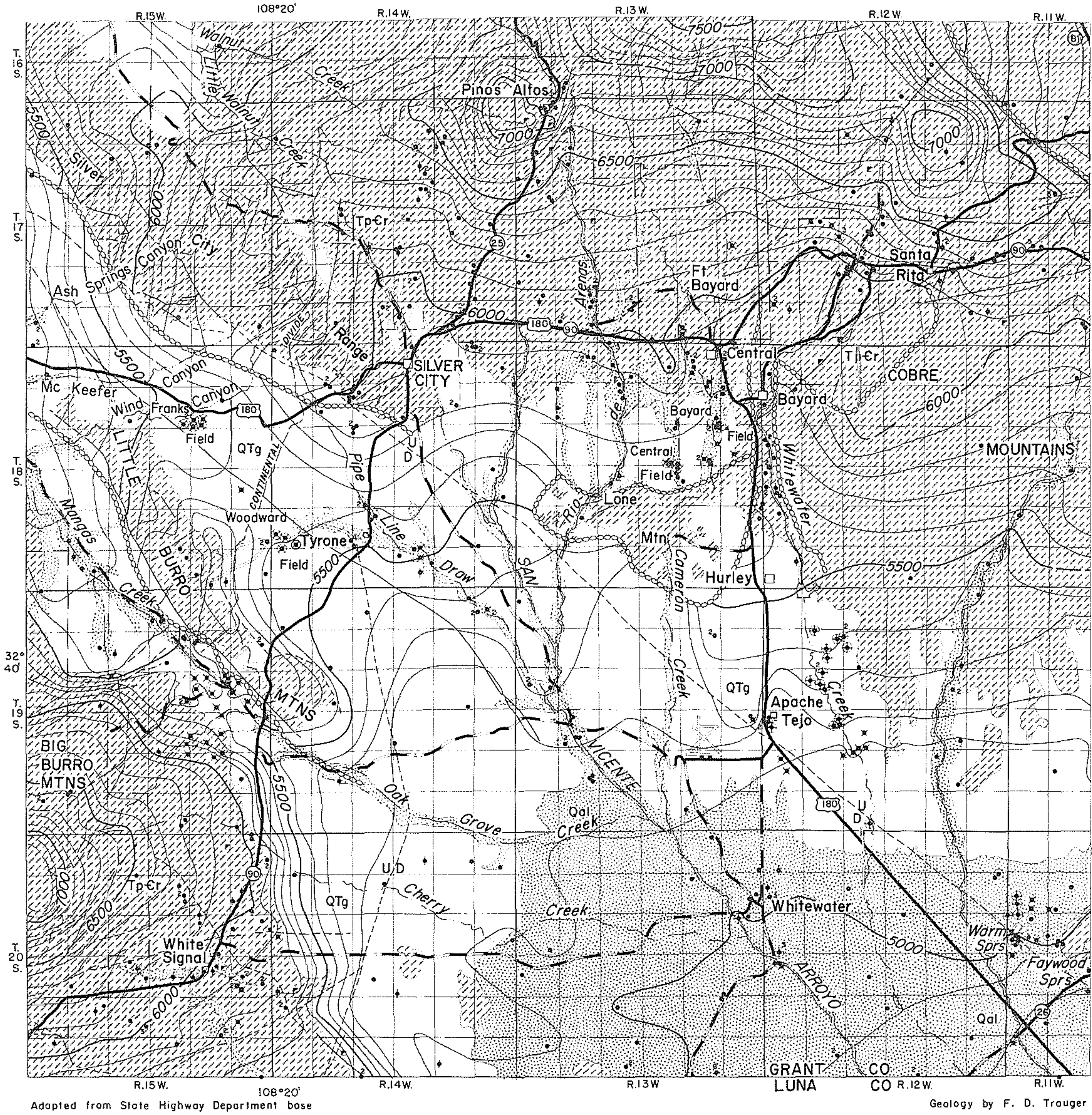
The values for transmissivity were calculated from the same pumping-test data used to determine the storage coefficient. The computed transmissivities ranged from a low of 1,500 gpd/ft (gallons per day per foot) in the Franks field to a high of 18,000 gpd/ft in the Woodward field.

The pump-test data show that no two wells in the well fields perform exactly the same or have the same hydrologic characteristics. Transmissivity values for the Franks field were mostly lower than those for the Woodward field. A transmissivity of 5,000 gpd/ft was selected as representative for use in calculating effects in the Franks field and a transmissivity of 10,000 gpd/ft was selected for Woodward field.

A transmissivity of 40,000 gpd/ft was used for calculating pumping effects in wells tapping the bolson fill in the San Vicente basin. Tests by Conover and Akin (1942, p. 258) show that the transmissivity of the bolson fill near Deming averages about 47,000 gpd/ft. Wells tapping the bolson fill near Whitewater and Faywood have performance characteristics almost as good and may be presumed also to have relatively high transmissivities.

Many of the test problems resulting from lack of observation wells, and from pumping a semiconfined aquifer for a brief time, can be avoided by conducting a test for a time sufficient to allow the pumping level to reach near-equilibrium under water-table, or nearly water-table, conditions. The rate of pumping is then changed and levels again allowed to stabilize. Rarely can such a test be conducted in a well field, but essentially the same data sometimes are available in the operating records of the field. Such was the case with the Franks field. Good pumping records and water-level change records were available, or could be reconstructed, for the entire period of operation of the field from 1947 to the present.

The decrease in pumping rate in mid-1958 (fig. 5) resulted in a rise in water levels in the Franks field. Water levels continued to rise through early 1961, remained more or less steady into 1963, then began a decline at a rate less rapid than that for the period 1947 to 1958. This effect on the well field was used to compute the storage coefficient; the value of 0.04 which was obtained is thought to be more reliable than the storage coefficient of 0.015 determined by pump tests of less than one week duration.



EXPLANATION

Qal

Alluvium and bolson fill of Quaternary age

QTg

Gila Conglomerate of Quaternary and Tertiary ages

TpЄr

Rocks of Precambrian to Tertiary age, undifferentiated

Small capacity well, mostly domestic and/or stock; a number beside the symbol indicates more than one well at the location

Irrigation well

Municipal, school, or public supply well

Industrial well

Test hole, for water, oil, or metal ores

Mine shaft in which water level was measured

Spring

Vertical line through well symbol indicates well is dry, not in use, destroyed, or apparently abandoned

U
D

Fault

Dashed where inferred
U; upthrown side
D; downthrown side

5000

Potentiometric contour

Shows altitude of potentiometric surface, dashed where approximate

Contour interval 100 feet. Datum is mean sea level

Hydrologic discontinuity separating aquifers

1 0 1 2 3 MILES

Plate 1.--Map showing the distribution of the Gila Conglomerate and bolson fill, the potentiometric surface, and the locations of wells in central Grant County, N. Mex.

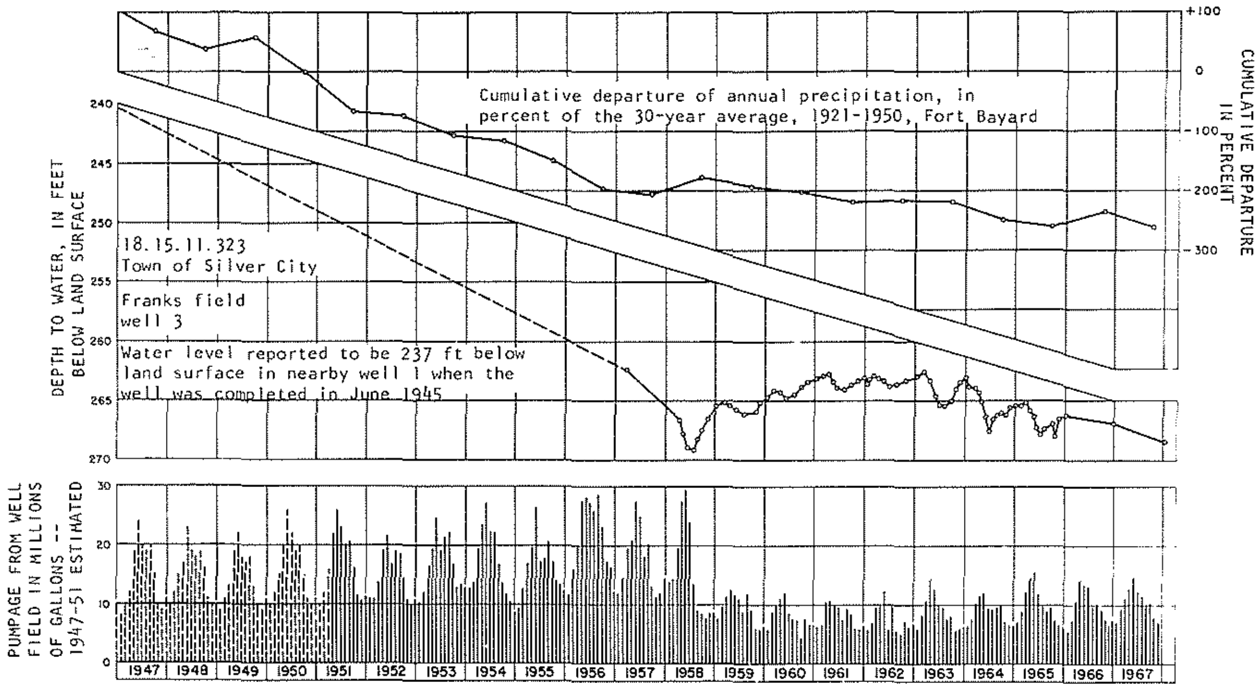


FIGURE 5. -- Graphs of pumpage and water level in Silver City well 3 (18.15.11.323) in the Franks field, and graph of the cumulative departure in percent of the average precipitation at Fort Bayard, Grant County, N. Mex.

CRITICAL PUMPING LEVEL

The best index available for determining the life of a well, or a well field, is considered to be the pumping water level. When pumping levels fall below a certain point, here designated as the critical pumping level (or simply, critical level), the future usefulness for which the well, or well field, was designed will be limited.

The critical level for either an individual well or the average level in a well field is considered to be that point at which, when reached by the declining pumping level, the operator must either appreciably reduce the average pumping rate to preserve the useful life of the well or field, or prepare to abandon it for the purpose for which it was developed. The term "critical pumping level" is a working-tool term for circumstances that involve long-term planning for development and utilization of ground-water resources, where depletion of the aquifer, or aquifers, must be considered.

The term "critical pumping level" is adopted for this study to facilitate discussion of the Silver City well fields on the Franks and Woodward ranches. It should be emphasized that the concept of a critical pumping level as used in this study would not necessarily apply to a well or well field drilled elsewhere for either a similar or different purpose unless depletion is anticipated. The concept of the critical pumping level, as used in this report, is illustrated by the following: A well is developed and pumped initially to yield 500 gpm with the understanding that the pumping level will lower, perhaps rapidly, that the yield will diminish as the pumping level declines, and that eventually the pumping rate will have to be drastically reduced. Presumably there will be a pumping level or point reached, at some time prior to curtailment of pumping, when the operators must begin planning to develop additional supplies of water. That pumping level could properly be designated as the critical level for that particular well and use. Clearly, pumping could continue for some time after the critical level was reached, but at a reduced rate.

If there were no need or possibility of developing additional water, then the critical level could be designated as that pumping level at which, when reached, pumping would be discontinued as uneconomical and the well would be abandoned for the purpose for which it was drilled. The well might then be used for another purpose requiring a smaller yield that the well could easily satisfy, in which case the original "critical level" would become meaningless. A new critical level might or might not be designated, depending on whether the water levels continued to decline at the new pumping rate. If there were no probability of aquifer depletion at the new pumping rate, there would be no point in designating a critical level.

The critical level for a municipal well field should be selected at a high enough level to allow time to develop additional supplies. There should be no serious interruption of service between reduction of pumping from a declining field and development of a new supply. The selection of the critical level is dependent also on geologic as well as economic factors.

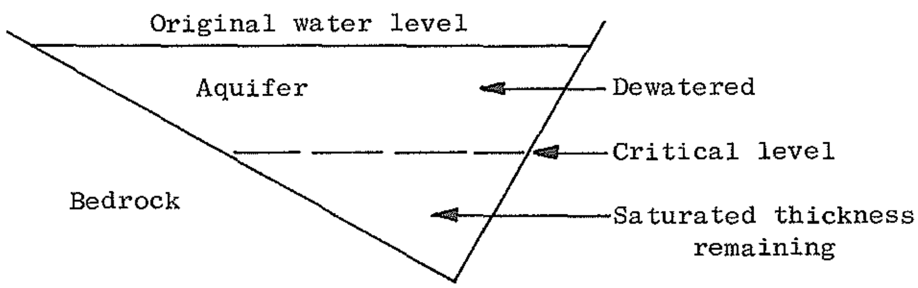
An important consideration in designating a critical pumping level is the aquifer response to pumping. An aquifer having a low transmissivity can be easily overpumped to the extent that steep cones of depression form in the vicinity of the wells, resulting in sharp declines in yield and increased pumping costs. Such overpumping could lead to erroneous conclusions concerning aquifer depletion and to abandonment of a well or well field from which large quantities of water still could be obtained economically. It might be both desirable and economical to pump heavily from an aquifer in its initial development, but a realistically selected critical pumping level would serve as a warning index to reduce pumpage in time to avoid excessive aquifer depletion, and thus assure continued economic productivity for a long period of time.

The critical pumping level arbitrarily selected for this study is the depth at which one-half of the vertical saturated portion of the aquifer remains. For example, if a well is 700 feet deep, and the original static water level was 300 feet below land surface, then the original saturated thickness was 400 feet. The critical level would be 300 feet plus one-half of 400 feet, or 500 feet below the land surface.

After water levels have declined to the critical level, further declines generally are greatly accelerated and the future life of the well is shortened. The accelerated decline results largely from the fact that the value of the transmissivity coefficient, which is dependent on the saturated thickness of the aquifer, decreases as the saturated thickness decreases (Jacob, 1964). The result is a more rapid lowering of the pumping level per unit volume of water removed by pumping. The effect operates throughout the life of the well but becomes of practical importance when the saturated thickness has been approximately halved. Pumping may continue for some time after the saturated thickness has been reduced by half, but the yields will lessen noticeably at the same time the pumping levels begin to decline at a more rapid rate.

A correction for change in transmissivity as a result of decreased saturated thickness of the aquifer cannot be introduced directly into the basic formulae (Theis, 1935, and Jacob, 1946). However, the correction can be made by first calculating the future water-level declines, assuming that the transmissivity remains constant, and then applying a positive correction factor, $s^2/2m$, where "s" is equal to the theoretical change in water level due to pumping and "m" is equal to the remaining saturated thickness of the aquifer.

Another factor that will hasten the decline of pumping levels after the critical level is reached in the Silver City well fields is the shape of the aquifer which is similar at both fields. The declines will be further accelerated because the bedrock boundaries of the aquifer slope toward the well fields from the west and east and the aquifer thus is wedge shaped. The volume of water available to the wells is much less in the lower part of the wedge than in the upper part, as the diagrammatic sketch below illustrates.



The Woodward field taps a more extensive aquifer than does the Franks field and therefore will have a longer effective life.

If withdrawal rates remain constant, the rate of decline must accelerate because there is less water in a unit thickness of the lower part of the aquifer than in the upper part of the aquifer. However, the effect on the life of a well field of reducing the pumping rate by half is illustrated by the following: If a given pumping rate would lower the water level to the critical level in 10 years, then pumping at half this rate would permit 40-60 years of pumping before the critical level is reached. This is illustrated by the change in rate of water-level decline in well 3 (18.15.11.323) in the Franks field (fig. 5), as the result of decreasing the yield from the field in 1958.

TABLE 5

POPULATION AND WATER-USE DATA FOR THE PERIOD 1950-67, AND ESTIMATES OF SILVER CITY POPULATION AND WATER NEEDS TO THE YEAR 2000.*

Year	Population served by city water system	Daily per capita use in gallons	Annual average pumping rate in gpm from both fields	Franks field: Pumping rate required to supply 2/5 of total demand (gpm)	Woodward field: Pumping rate required to supply 3/5 of total demand (gpm)	Woodward field: Pumping rate required if rate from Franks field is maintained at 235 gpm
1950	7,022	75	365	365(b)	-	-
1960	6,972	100	515	175(b)	340(b)	-
1965	8,500	100(a)	595	220(b)	375(b)	-
1967	10,400	95(a)	690	235(b)	455(b)	-
1970	15,800	115	1,250	500(c)	750	1,015
1975	19,400	135	1,800	725(c)	1,075	1,565
1980	23,000	150	2,400	960(c)	1,440	2,165(d)
1985	27,000	160	3,000	1,200(c)	1,800	2,765(d)
1990	31,000	170	3,650	1,460(c)	2,190	3,415(d)
1995	35,000	185	4,550	1,820(c)	2,730	4,315(d)
2000	40,000	200	5,500	2,200(c)	3,300	5,265(d)

* Based on figures used in tables 2, 3, and 4.

(a) In the period 1965-67, service was extended to areas outside the city and to large numbers of trailer-house units, where daily per capita use of water normally is appreciably less than within the city area, thus reducing the overall average per capita use. Per capita use is expected to increase sharply when occupants of the newly serviced units become adjusted to availability of adequate water.

(b) Actual average pumping rate for the year to the closest 5 gpm.

(c) Inasmuch as a pumping rate in excess of about 420 gpm would deplete the Franks field by about 1970, the larger sustained yields are not attainable.

(d) A pumping rate in excess of 2000 gpm would largely deplete the field in the period 1985-95.

In the analyses of the well fields that follow, the estimates of future demands for water are based on estimated increases in population and per capita use as shown in table 5. The demand is expressed both as an average pumping rate in gallons per minute from the well fields and as yield from the individual wells (tables 6-12) to facilitate computations and to indicate which wells will be economically productive for the longest time.

FRANKS FIELD

The Franks field (fig. 3) in the Gila drainage, on the west side of the continental divide, was put into production in 1945. Withdrawals increased annually until mid-1958 when the Woodward field began production. Pumpage from the Franks field was then decreased by almost half. It is obvious from the hydrograph (fig. 5) that the effective life of the field will be greatly extended by the reduction of pumping. However, if increasing demands for water result in increased pumpage by the amounts shown in table 5, then water levels will begin an accelerated decline.

Table 6 shows the effects on water levels in the Franks field that would result at the withdrawal rates as indicated in table 5 for selected periods to the year 1990. These data are based on a storage coefficient of 0.04 and a transmissivity of 5,000 gpd/ft. The pumping levels were computed for each well by assuming that production from the well field will be increased to meet the future demand and that each well will be required to supply a part of the increase. Thus, a well that has delivered 20 percent of the daily well-field requirements will continue to supply 20 percent of the future well-field requirements even though the total well-field pumpage may double.

From table 6 it may be noted that at increased pumping rates water levels in all of the wells in the Franks field will reach the critical level on or before 1970. An additional well with production characteristics similiar to well 5 (18.15.10.441) would extend the life of the field by no more than 2 or 3 years (table 7, last column) if pumping rates are increased to provide up to two-fifths of the total demand of the city. It is therefore obvious that the required pumping rates indicated in table 5 for the Franks field are hypothetical beyond about 1975. The field simply cannot maintain a yield of even 500 gpm beyond that time.

The effective life of the Franks field can be extended appreciably, as is indicated in table 8, stabilizing production at the present rate of about 235 gpm. By introducing an additional well (well 6, fig. 3) having production characteristics similar to well 5, the life of each well is extended further although, again, not appreciably (table 9).

Reducing the average pumping rate to 235 gpm, and thereby appreciably extending the life of the Franks well field, will result in a much greater recovery of water over the years. For example, the well field would be virtually depleted within 5 years (by 1973) at an average pumping rate of about 400 gpm, and the pumpage over that period would total about 3,000

TABLE 6

WELL DATA FOR FRANKS FIELD BASED ON INCREASED PRODUCTION TO MEET A PROPORTIONATE SHARE OF FUTURE DEMANDS

Well number	Depth of well, in feet	Water level in 1965, in feet below land surface		Calculated pumping water level, in feet below land surface(a)	Well efficiency, in percent(b)	Average daily pumping rate in gpm for the period 1965 to the year indicated / Calculated pumping water level, in feet below land surface for year indicated				Pumping water level (corrected to include the effect of well efficiency and decrease in saturated thickness of the aquifer) in feet below land surface for years indicated				Critical pumping level in feet below land surface	Year in which the pumping level exceeds the critical level
		Non-pumping	Pumping			1970	1980	1990	2000	1970	1980	1990	2000		
1	597	240	326	272	37	80 / 304	117 / 351	160 / 400	212 / 461	420	565	737(c)		418	about 1970
2	558	265	355	291	29	68 / 319	100 / 360	137 / 405	182 / 460	457	616(c)			411	before 1970
4	547	249	463	285	17	91 / 317	134 / 365	182 / 416	243 / 480	659(c)				398	before 1970
5	659	201	399	291	44	181 / 293	268 / 352	365 / 417	485 / 497	422	582	788(c)		430	about 1970

(a) Calculated (Theis, 1935) by using formation hydrologic characteristics of of storage = 0.04 and transmissivity = 5,000 gpd/ft.

(b) Calculated drawdown divided by the 1965 actual drawdown times 100.

(c) Pumping water level would exceed depth of well.

acre-feet of water. However, with one or two additional wells and proper management the field can continue to pump at an average rate of 235 gpm for the next 35 years or more. The total pumpage at that rate for that length of time would be about 13,000 acre-feet.

Another obvious benefit accrues from the continuing use of the expensive pumping plant and distribution system, an investment that would be mostly lost if the field were pumped to depletion within the next 5 years.

WOODWARD FIELD

The first exploratory hole drilled for Silver City on the Woodward ranch, east of the continental divide, was completed as well 1 (18.14.30.324) in April 1954 (fig. 4); well 2 (18.14.30.312) was completed the following July. Well 3 (18.14.30.343) was drilled in August 1957; well 4 (18.14.30.432) was drilled in 1966. Although the first two wells were

TABLE 7

WELL DATA FOR FRANKS FIELD BASED ON INCREASED PRODUCTION TO MEET A PROPORTIONATE SHARE OF FUTURE DEMANDS AND THE CONSTRUCTION OF AN ADDITIONAL WELL (FIG. 3)

Well number	Depth of well, in feet	Water level in 1965, in feet below land surface		Calculated pumping water level, in feet below land surface (a)	Well efficiency, in percent (b)	Average daily pumping rate in gpm for the period 1965 to the year indicated / Calculated pumping water level, in feet below land surface for year indicated				Pumping water level (corrected to include the effect of well efficiency and decrease in saturated thickness of the aquifer) in feet below land surface for years indicated				Critical pumping level in feet below land surface	Year in which the pumping level exceeds the critical level
		Non-pumping	Pumping			1970	1980	1990	2000	1970	1980	1990	2000		
1	597	240	326	272	37	55 / 291	82 / 332	111 / 375	147 / 426	396	504	646(c)		418	about 1972
2	558	265	355	291	29	47 / 311	70 / 348	96 / 389	127 / 438	427	567(c)			411	before 1970
4	547	249	463	285	17	63 / 305	94 / 347	127 / 391	170 / 462	584(c)				398	before 1970
5	659	201	399	291	44	127 / 270	187 / 318	255 / 370	339 / 468	364	487	634	995(c)	430	about 1976
6	est. 700	est. 300			est 45	127 / 369	187 / 418	255 / 470	339 / 568	est. 460	est. 587	est. 741(c)		est. 500	about 1973

(a) Calculated (Theis, 1935) by using formation hydrologic characteristics of storage = 0.04 and transmissivity = 5,000 gpd/ft.

(b) Calculated drawdown divided by the 1965 actual drawdown times 100.

(c) Pumping water level would exceed depth of well.

completed and tested in 1954, a lack of funds prevented the completion of the transmission system until 1958.

Water-level measurements have been made by the U.S. Geological Survey periodically in all the wells since they were drilled, and the city has kept records of all water withdrawn. The hydrographs (fig. 6) for wells 1 and 2 in the well field show both the natural trends of water levels (not influenced by any nearby heavily pumped wells) during the period 1954-58 and the declines that began in 1958 when the field went into production.

It was demonstrated in the discussion of the Franks field that the wells there cannot yield a proportional part of the increased future demand, and cannot long support even a modest increase in production without drastically decreasing the life of the well field. Therefore, only the yield from the Woodward field should be increased to meet the increased needs. The following discussion shows that the Woodward field

TABLE 8

WELL DATA FOR FRANKS FIELD BASED ON CONTINUED PUMPING OF 4 WELLS
AT PRESENT RATE OF ABOUT 235 GPM

Well number	Depth of well, in feet	Water level in 1965, in feet below land surface: Non-pumping	Water level in 1965, in feet below land surface: Pumping	Calculated pumping water level, in feet below land surface (a)	Well efficiency, in percent (b)	Average daily pumping rate, in gpm for the period 1965 to the year indicated: 1970	Calculated pumping water level, in feet below land surface for year indicated: 1970	Average daily pumping rate: 1980	Calculated pumping water level: 1980	Average daily pumping rate: 1990	Calculated pumping water level: 1990	Average daily pumping rate: 2000	Calculated pumping water level: 2000	Pumping water level (corrected to include the effect of well efficiency and decrease in saturated thickness of the aquifer) in feet below land surface for years indicated: 1970	1980	1990	2000	Critical pumping level in feet below land surface.	Year in which the pumping level exceeds the critical level.
1	597	240	326	272	37	45	276	45	282	45	284	45	286	339	356	362	367	418	after 2000
2	558	265	355	291	29	38	295	38	301	38	304	38	306	370	392	402	409	411	about 2000
4	547	249	463	285	17	51	287	51	293	51	296	51	298	476	511	529	542	398	before 1970
5	659	201	399	291	45	102	253	102	259	102	261	102	263	322	337	342	347	430	after 2000

(a) Calculated (Theis, 1935) by using formation hydrologic characteristics of storage = 0.04 and transmissivity = 5,000 gpd/ft.

(b) Calculated drawdown divided by the 1965 actual drawdown times 100.

could for a time--possibly 10 to 15 years-- supply all the increased needs even though the yield of the Franks field is stabilized at the rate of 235 gpm.

The effect on pumping water levels of increasing the yield from the present four wells in the Woodward field to meet the increase in demand is shown in table 10. Such an increase in well yield decreases the life expectancy of the individual wells by 8 to 11 years under that which would be expected if the Franks field could bear a proportionate part of the increase. This can be in part overcome by adding additional wells in the Woodward field. The effects of adding a fifth and sixth well in the Woodward field while maintaining the yield from the Franks field at the rate of 235 gpm are shown in tables 11 and 12.

The effects of increased demands, under various sets of conditions, on the pumping water levels in the Woodward field, assuming that the production of the Franks field is maintained at the present average daily rate of about 235 gpm, are summarized in figure 7.

TABLE 9

WELL DATA FOR FRANKS FIELD BASED ON CONTINUED PUMPING AT PRESENT RATE OF ABOUT 235 GPM AND CONSTRUCTION OF AN ADDITIONAL WELL (FIG. 3)

Well number	Depth of well, in feet	Water level in 1965, in feet below land surface: Non-pumping	Water level in 1965, in feet below land surface: Pumping	Calculated pumping water level, in feet below land surface (a)	Well efficiency, in percent (b)	Calculated pumping water level, in feet below land surface for year indicated: 1970	1980	1990	2000	Average daily pumping rate, in gpm for the period 1965 to the year indicated: 1970	1980	1990	2000	Pumping water level (corrected to include the effect of well efficiency and decrease in saturated thickness of the aquifer) in feet below land surface for years indicated: 1970	1980	1990	2000	Critical pumping level in feet below land surface.	Year in which the pumping level exceeds the critical level.
1	597	240	326	272	37	269	275	277	280	31	31	31	31	319	337	342	351	418	after 2000
2	558	265	355	291	29	292	297	299	301	27	27	27	27	359	377	384	392	411	after 2000
4	547	249	463	285	17	280	286	289	291	36	36	36	36	433	470	489	499	398	before 1970
5	659	201	399	291	45	238	246	248	250	71	71	71	71	287	305	311	315	430	after 2000
6	est. 700	est. 300			est. 45	339	345	347	349	71	71	71	71	est. 389	est. 403	est. 407	est. 412	est. 500	after 2000

(a) Calculated (Theis, 1935) by using formation hydrologic characteristics of storage = 0.04 and transmissivity = 5,000 gpd/ft.

(b) Calculated drawdown divided by the 1965 actual drawdown times 100.

It becomes apparent that while the Woodward field can meet all increased demands for water for the next 20 years, to require it to do so would be to seriously jeopardize the municipal water supply after that time. The field could, with proper management, continue to supply as much as 1,000 gpm of water for 60 to 70 years after 1990, thus protecting the large financial investment the city has in the present system.

ADDITIONAL WELL FIELDS

An additional 60 to 70 years of life for the Woodward field can be assured, provided new well fields are developed that will permit a reduction in the pumping rate from the Woodward field after about 1980. Assume that a new well field with a starting yield of about 1,165 gpm and a potential yield of up to 2,500 gpm is placed in operation by the year

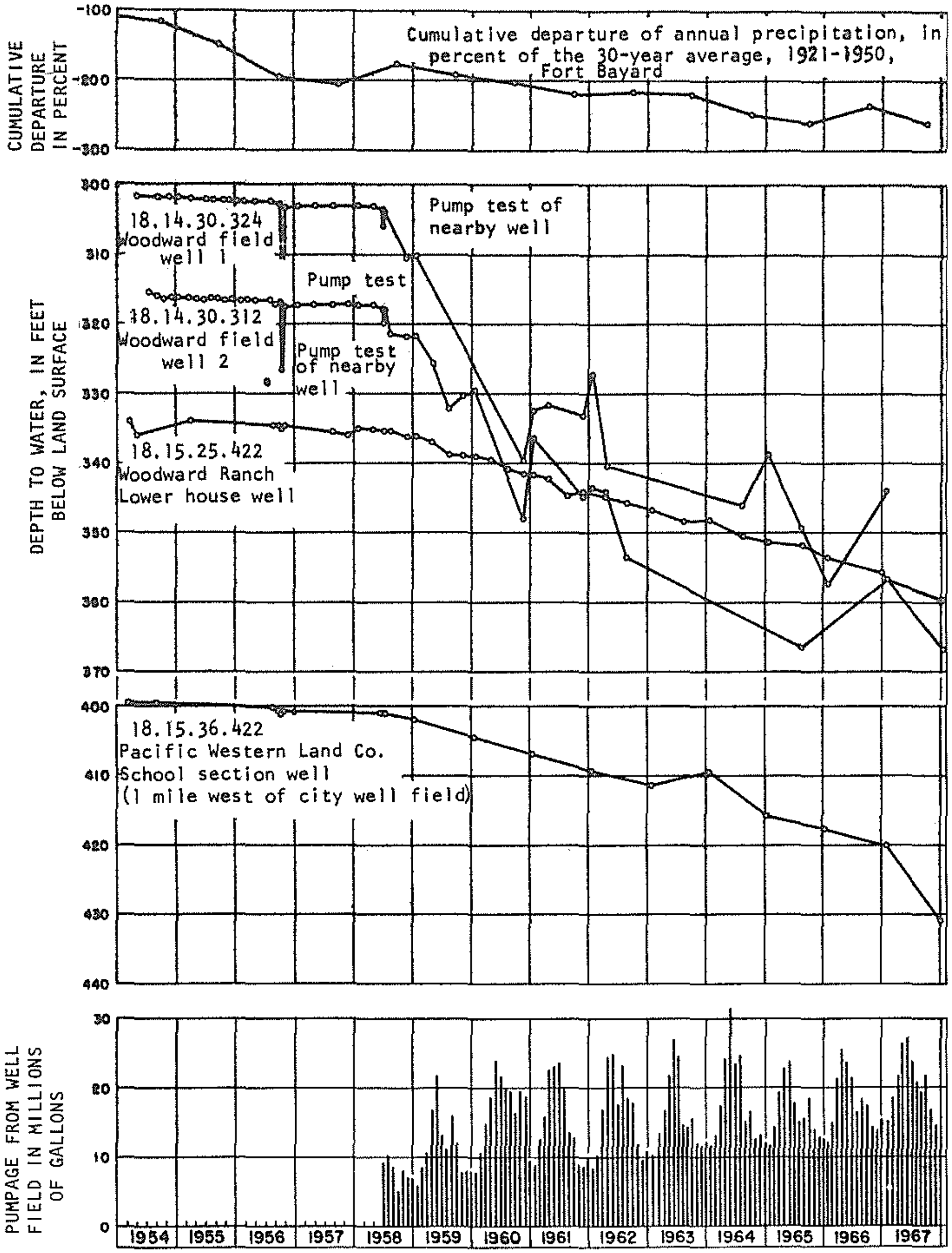


FIGURE 6. -- Graphs of pumpage and water levels of four wells in the Woodward field and vicinity near Silver City, and graph of the cumulative departure in percent of the average precipitation at Fort Bayard, Grant County, N. Mex.

TABLE 10

WELL DATA AND WATER LEVELS IN THE WOODWARD FIELD BASED ON INCREASED PRODUCTION TO MEET DEMANDS AND ASSUMING FRANKS FIELD PRODUCTION IS MAINTAINED AT PRESENT RATE OF ABOUT 235 GPM

Well number	Depth of well, in feet	Water level in 1965, in feet below land surface		Calculated pumping water level, in feet below land surface(a)	Well efficiency, in percent(b)	Average daily pumping rate, in gpm for the period 1965 to the year indicated. / Calculated pumping water level, in feet below land surface for year indicated								Pumping water level (corrected to include the effect of well efficiency and decrease in saturated thickness of the aquifer) in feet below land surface for years indicated.				Critical pumping level in feet below land surface.	Year in which the pumping level exceeds the critical level.
		Non-pumping	Pumping			1970		1980		1990		2000		1970	1980	1990	2000		
						Rate	Level	Rate	Level	Rate	Level	Rate	Level						
1	895	340	431	390	55	179	408	289	466	412	531	565	613	469	587	737	968(c)	618	about 1982
2	769	356	455	401	45	179	420	289	475	412	537	565	615	504	645	829(c)		562	about 1974
3	835	348	401	394	87	174	413	281	469	401	532	551	611	428	507	616	804	592	about 1988
4	954	284	394	357	66	282	366	455	432	648	507	890	601	414	529	678	907	619	about 1986

(a) Calculated (Theis, 1935) by using formation hydrologic characteristics of storage = 0.04 and transmissivity = 10,000 gpd/ft.

(b) Calculated drawdown divided by the 1965 actual drawdown times 100.

(c) Pumping level would exceed depth of well.

1980. The yield of the Woodward field could then be cut back and maintained at the projected 1970 rate of about 1,000 gpm (table 5). The effect would be comparable to that achieved when withdrawal from the Franks field was reduced in 1958. The remaining life of the Woodward field would be approximately tripled by such a reduction.

The new field could supply water to meet increased demands for another 20 years, or to about 2000, but by that time it too would be overtaxed and its effective remaining life probably would be short. This assumption is made on the basis that the aquifer supplying the new field would have hydrologic characteristics similar to those in the Woodward field.

Development of a single new field with a potential yield of up to 2,500 gpm might not be possible within a distance of 3 to 4 miles of the present Woodward field. However, a new field would not necessarily need to have a yield of 2,500 gpm to be useful. It would need only to yield

TABLE 11

WELL DATA AND WATER LEVELS FOR WOODWARD FIELD BASED ON INCREASED PRODUCTION TO MEET DEMANDS AND THE CONSTRUCTION OF ONE ADDITIONAL WELL (FIG. 4), AND ASSUMING FRANKS FIELD PRODUCTION IS MAINTAINED AT PRESENT RATE OF ABOUT 235 GPM

Well number	Depth of well, in feet	Water level in 1965, in feet below land surface: Non-pumping	Water level in 1965, in feet below land surface: Pumping	Calculated pumping water level, in feet below land surface (a)	Well efficiency, in percent (b)	Average daily pumping rate, in gpm for the period 1965 to the year indicated: 1970	Calculated pumping water level, in feet below land surface for year indicated: 1970	Average daily pumping rate: 1980	Calculated pumping water level: 1980	Average daily pumping rate: 1990	Calculated pumping water level: 1990	Average daily pumping rate: 2000	Calculated pumping water level: 2000	Pumping water level (corrected to include the effect of well efficiency and decrease in saturated thickness of the aquifer) in feet below land surface for years indicated: 1970	1980	1990	2000	Critical pumping level in feet below land surface.	Year in which the pumping level exceeds the critical level.
1	895	340	431	390	55	133	397	214	448	305	506	419	578	447	549	677	861	618	about 1986
2	769	356	455	401	45	133	408	214	457	305	510	419	619	475	596	744	(c) 1,082	562	about 1978
3	835	348	401	394	87	130	405	210	456	300	513	412	585	416	486	580	732	592	about 1991
4	954	284	394	357	66	209	353	338	412	482	478	661	561	392	493	618	802	619	about 1991
5	est. 900	est. 320			est. 75	209	386	338	443	482	506	661	586	est. 412	est. 501	est. 612	est. 788	est. 610	about 1990

(a) Calculated (Theis, 1935) by using formation hydrologic characteristics of storage = 0.04 and transmissivity = 10,000 gpd/ft.

(b) Calculated drawdown divided by the 1965 actual drawdown times 100.

(c) Pumping level exceeds depth of well.

the difference between the demand in 1980 and the combined output from the Franks and Woodward fields (about 1,250 gpm with the Woodward field cut back to approximately the 1970 pumping rate).

The total demand of the city by 1980 will be about 2,400 gpm (table 5); thus, the new field would need to have a yield of about 1,200 gpm, or only 200 gpm more than the stabilized pumping rate from the Woodward field. The new field could then supply water needs for another 10 years, or to about 1990. This would require greater-than-optimum pumping rates from the new field for the period 1985-90 but the same pattern of use could be followed as in the case of the Franks and Woodward fields. A fourth field of equal capacity could be developed by 1990 and the yield from the third could be cut back to the initial 1980 rate of about 1,200 gpm, thus assuring it an effective life as long as that of the Woodward field.

Whether one or two new fields are developed to meet needs to the

TABLE 12

WELL DATA AND WATER LEVELS IN THE WOODWARD FIELD BASED ON INCREASED PRODUCTION TO MEET DEMANDS AND THE CONSTRUCTION OF TWO ADDITIONAL WELLS (FIG. 4), AND ASSUMING FRANKS FIELD PRODUCTION IS MAINTAINED AT PRESENT RATE OF ABOUT 235 GPM

Well number	Depth of well, in feet	Water level in 1965, in feet below land surface		Calculated pumping water level, in feet below land surface(a)	Well efficiency, in percent(b)	Average daily pumping rate, in gpm for the period 1965 to the year indicated. / Calculated pumping water level, in feet below land surface for year indicated.				Pumping water level (corrected to include the effect of well efficiency and decrease in saturated thickness of the aquifer) in feet below land surface for years indicated.				Critical pumping level in feet below land surface.	Year in which the pumping level exceeds the critical level.
		Non-pumping	Pumping			1970	1980	1990	2000	1970	1980	1990	2000		
1	895	340	431	390	55	106 / 389	171 / 435	244 / 487	334 / 551	431	523	633	789	618	about 1988
2	769	356	455	401	45	106 / 410	171 / 444	244 / 492	334 / 553	458	563	691	884(c)	562	about 1980
3	835	348	401	394	87	104 / 398	168 / 445	240 / 497	329 / 562	408	472	552	678	592	about 1993
4	954	284	394	357	66	166 / 343	268 / 396	382 / 455	524 / 529	376	465	572	726	619	about 1993
5	est. 900	est. 320			est. 75	166 / 379	268 / 432	382 / 491	524 / 565	est. 402	est. 482	est. 579	est. 737	est. 610	about 1992
6	est. 850	est. 460			est. 75	166 / 514	268 / 563	382 / 617	524 / 686	est. 536	est. 615	est. 723	est 918(c)	est. 655	about 1984

(a) Calculated (Theis, 1935) by using formation hydrologic characteristics of storage = 0.04 and transmissivity = 10,000 gpd/ft.

(b) Calculated drawdown divided by the 1965 actual drawdown times 100

(c) Pumping level would exceed depth of well.

year 2000, it seems certain that still another field of even larger capacity will be needed after that time. It may be noted (table 5) that the demand increases by almost 2,000 gpm in the period 1990-2000, and the demand almost surely will continue to increase thereafter. It is doubtful if three, or possibly four, fields developed within a distance of 8 miles of the Woodward field could continue indefinitely to meet such large demands; thus, ultimately, another field will become a necessity. The availability of water for the development of new well fields is discussed in a following section on new areas for development.

SIGNIFICANCE OF PUMP EFFICIENCY

As a matter of interest and of importance in the economics of operating the well fields, the efficiencies of the pumps in the Silver City well fields were computed from data obtained while conducting the pumping tests in 1967 (table 13).

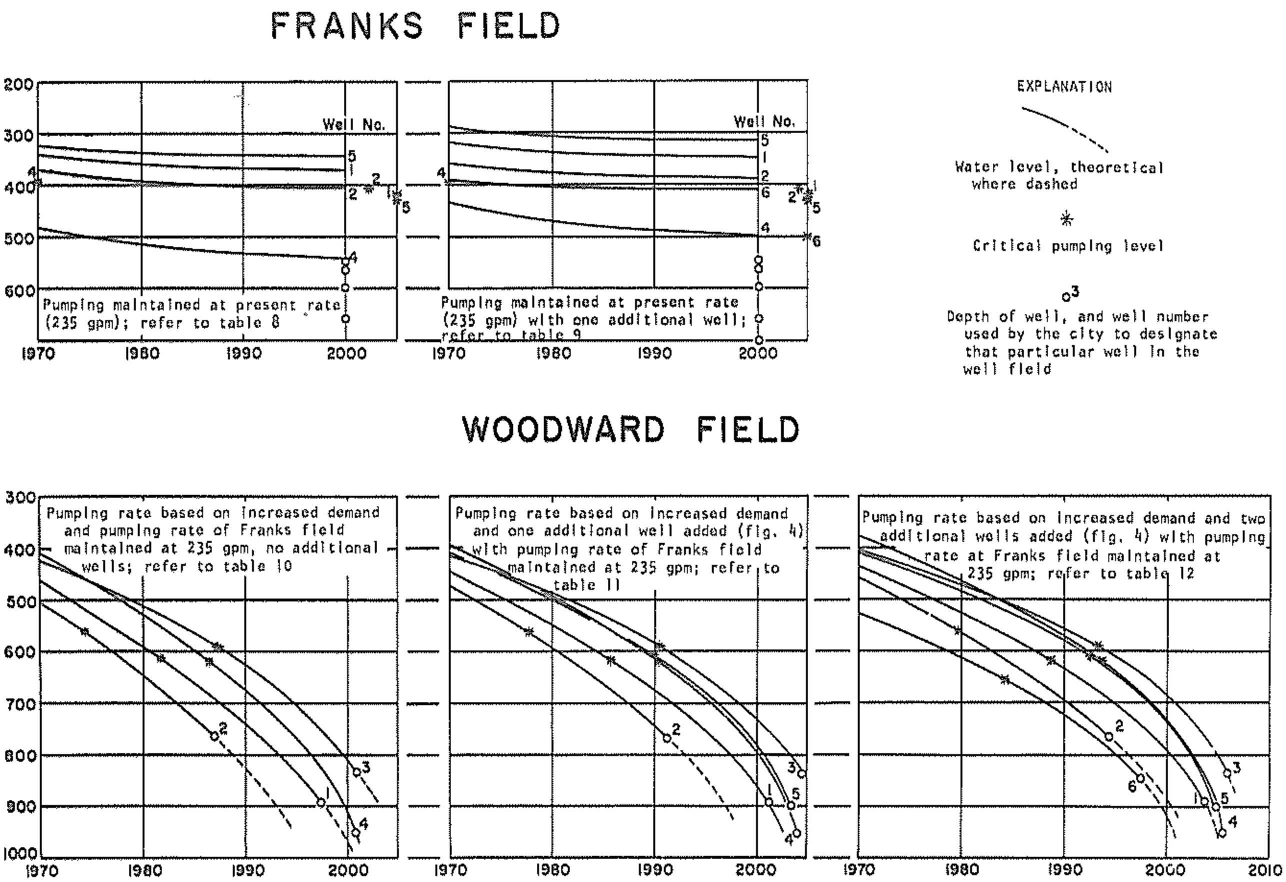


FIGURE 7. -- Graphic plot of predicted water-level changes in Silver City Franks and Woodward well fields from 1970 to 2000 under various sets of conditions.

The pump efficiency (not well efficiency) is found by comparing the electro-mechanical energy required by the pump in removing a given volume of water from the well to the actual energy needed.

The pumping rate, amount of lift (distance from pumping water level to land surface), friction losses in the pipe and fittings, and well-head pressure are all used to compute the energy needed. The energy actually used by the pump is calculated from the type of electrical system used (440 volt, 3 phase) and the measured current consumed during operation of the pump.

The pump efficiency is expressed as a percent and is determined by dividing the energy needed (in horsepower) by the energy used, and multiplying by 100. The efficiency of a pump has no bearing on the effective life of a well, but it does have a direct bearing on the cost of producing water through power consumption. An inefficient pump, compared with an efficient one, requires more power per unit volume of water produced, thus increasing the cost of water.

TABLE 13

EFFICIENCY OF PUMPS ON SILVER CITY WELLS IN THE FRANKS AND WOODWARD FIELDS, NOVEMBER 1967, GRANT COUNTY, N. MEX.

Franks field			Woodward field		
Well number*	Pump efficiency (percent)	Approx. yield, gpm (reported)	Well number	Pump efficiency (percent)	Approx. yield, gpm (reported)
1 (18.15.11.313a)	40	175	1 (18.14.30.324)	43	450
2 (18.15.11.341)	28	150	2 (18.14.30.312)	51	450
4 (18.15.11.331)	28	200	3 (18.14.30.343)	47	435
5 (18.15.10.441)	53	400	4 (18.14.30.432)	92	710

* Franks field well No. 3 (18.14.11.323) is used only as an observation well.

The economic importance of considering pump efficiency is best illustrated by example: Assuming that electrical energy to operate the pumps in the Franks field costs 1 cent per kilowatt hour and that well 2, operating at an efficiency of 28 percent, is lifting water from a pumping level of 360 feet, then the cost per thousand gallons of water pumped is 4.4 cents. A pump having an efficiency of about 90 percent would produce a thousand gallons of water at a cost of 1.4 cents, or 3 cents less per thousand. The savings on each million gallons of water pumped would be $30.00.

The Franks field in 1967 produced about 122 million gallons of water of which an estimated one-half came from well 5. If the other three producing wells pumped the other half in amounts proportionate to their potential yields (table 13), then well 2 pumped about 17 million gallons at a cost for electrical energy of about $748.00. The same amount of water could have been pumped for $238.00 with a pump having 90 percent efficiency.

The pump efficiencies for the wells in the Franks field range from 28 to 53 percent and in the Woodward field from 43 to 92 percent. The wells are all equipped with turbine pumps with the exception of well 4 in the Woodward field, which is equipped with a submersible pump. The average peak pump efficiency for turbine pumps generally is about 80 percent.

The lowest yields in the Franks field are from those wells having the least efficient pumps, but this does not mean that new large-capacity pumps should be installed or the old pumps repaired to yield more water. This could be done, but to do so would shorten the life expectancy of the wells. It has been shown that the yield from the field should be decreased if the life of the field is to be prolonged. Although it is possible to produce the same amount of water with fewer pumps at less cost if the pumps are working at full efficiency, this also would not be advisable. Three, possibly only two, large pumps operating at maximum efficiency could produce the same amount of water now produced by four pumps but the life of each well, and again the effective life of the field, would be greatly shortened.

The question of pump size as well as efficiency and yield should be considered in the case of both the Franks and Woodward fields to help achieve maximum life for both. The lives of the wells and the well fields would be extended and operating costs reduced by utilizing smaller pumps producing the same volume of water from four or five wells distributed over a broader area.

Other Communities

CENTRAL

Central obtains water from three wells in the Lone Mountain well field; the wells tap the upper part of the Gila Conglomerate. Well 1 (18.13.15.434) and well 2 (18.13.15.444) were drilled in the summer and fall of 1954. Well 3 (18.13.15.433) was drilled in 1961. Well 2 had an initial yield, on test, of about 30 gpm. It is not in regular use and will not be considered further.

As in the Silver City well fields, the water pumped from the Central wells is coming mostly from storage, the annual recharge is negligible compared to withdrawals, and the water levels are declining.

The average rate of decline in well 1 has been about 0.6 foot per year since 1955 (fig. 8). Although this decline is relatively minor the aquifer supplying the wells is not extensive and the boundaries of the basin are relatively close to the well field. Therefore, the rate of decline of water level probably will accelerate sharply if the average rate of withdrawal is increased appreciably.

Pumpage from the Lone Mountain well field will need to be increased to meet the increased demand for water that has resulted from recent population increases, and thus it may be presumed that the water-level declines will be further accelerated and will follow a pattern similar to those of Silver City.

Well 1 (18.13.15.434) in the Lone Mountain field is 472 feet deep and the static water level in October 1954 was about 168 feet below land surface. However, as the bottom 50 feet was drilled in biotite-quartz latite,

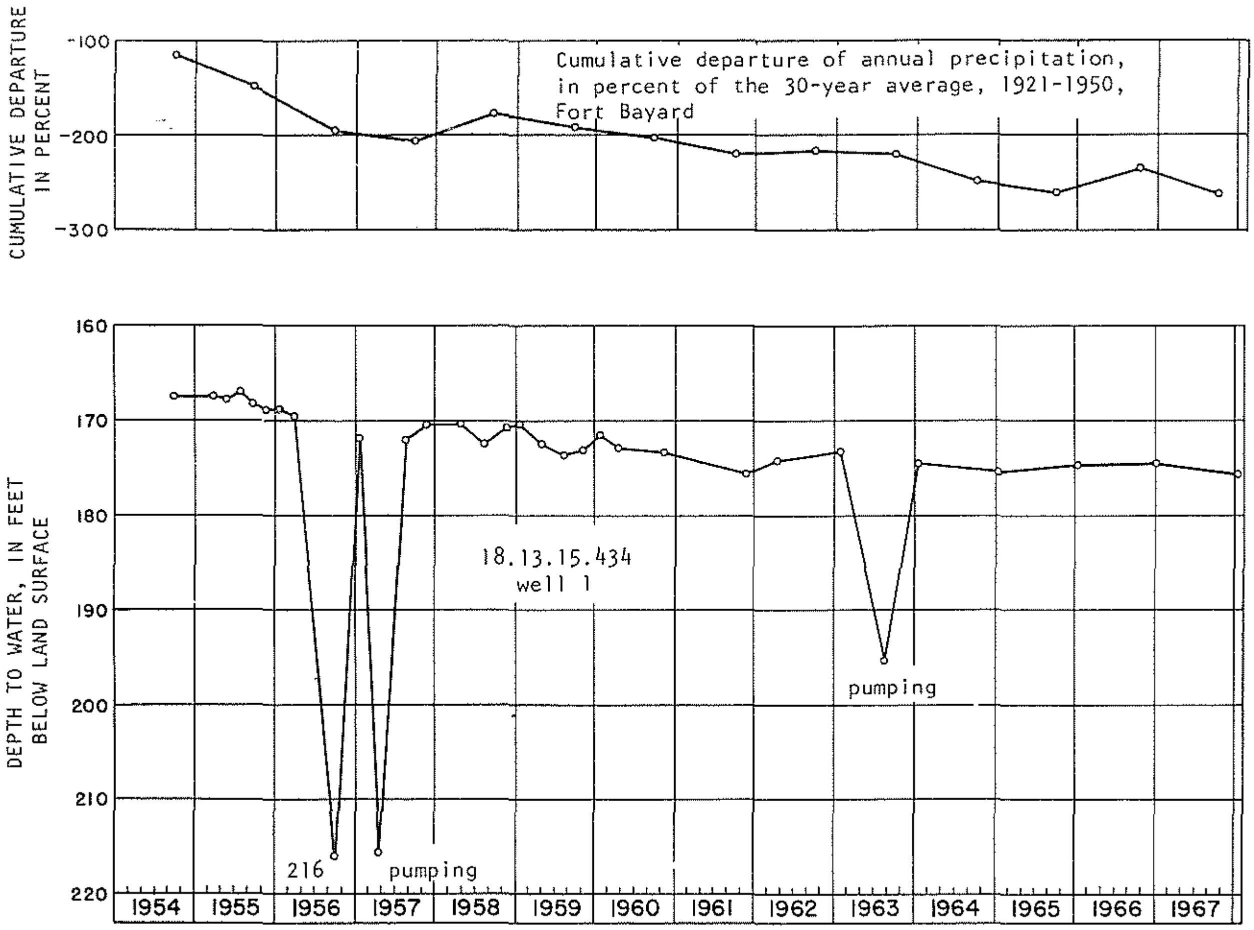


FIGURE 8. -- Graph of water level in village of Central well 1 (18.13.15.434) in the Lone Mountain field, and graph of the cumulative departure in percent of the average precipitation at Fort Bayard, Grant County, N. Mex.

a granite-like rock, the effective depth of the hole is only 422 feet. The saturated thickness thus was about 254 feet, and the critical pumping level would be at about 295 feet below land surface. The pumping level in 1956-57 was about 216 feet (fig. 8) at a reported pumping rate of about 100 gpm, when the pump was relatively new. The specific capacity (yield per foot of drawdown) is thus about 2, or half the average of that for the Silver City wells. By 1963 the yield from well 1 reportedly had dropped to about 50 to 60 gpm but the pumping level had risen to about 195 feet below land surface (fig. 8). These data strongly suggest that the efficiency of the pump had decreased appreciably by 1963 and that the drop in yield was not due to aquifer depletion. On the contrary, the hydrograph shows that the decline in the nonpumping level stopped about the end of 1961 when well 3 went into production, recovered slightly for about 2 years, and has held relatively steady to the present.

The yield from well 1 averaged about 30 gpm (24 hours per day) during the period October 1954 to December 1961 and the decline in the static (nonpumping) water level averaged 1.2 feet per year. These data indicate that the well could continue to produce at that rate for about 60 years before water levels decline to the critical pumping level.

Data on yield and water-level declines are not available for well 3 (18.13.15.433), which is about 700 feet west of well 1, but apparently pumping in this well since 1961 has not had an appreciable adverse effect on levels in well 1 (18.13.15.434). If interference was appreciable, the levels in well 1 would have continued to decline. The inference may be made that the yield from well 1 could be increased to fully utilize the potential of the aquifer.

As in the Silver City wells, the critical level will be reached sooner if withdrawals from the well are increased. As noted above, the specific capacity of well 1 is considerably less than that of the Silver City wells and the hydraulic coefficients may be presumed to be correspondingly smaller. Pump-test data are not available for the Central wells; thus, for purposes of predicting drawdowns, it is necessary to assume values for the storage coefficient and transmissivity. On the basis of a comparison of the performance of the Silver City wells and the Central wells, the storage coefficient for the aquifer supplying Central well 1 is assumed to be about 0.02, and the transmissivity is assumed to be about 2,500 gpd/ft.

Calculations using these coefficients and an assumed steady pumping rate of 75 gpm indicate that the critical level in well 1 will be reached in a little more than 20 years, or by 1990. A steady rate of 75 gpm is equal to about 120 acre-feet per year, or a third of the anticipated needs of the town by the year 1990, based on an estimated population of 4,000, a per capita use of 80 gpm, and an annual need for 360 acre-feet of water. Presumably well 3 can produce about the same amount of water as well 1. Thus, the two wells can produce about 240 acre-feet of water annually, or all of the anticipated needs to about the year 1975. Thereafter, an additional source of 120 acre-feet of water per year must be developed or the yield of the wells must again be increased; the latter course of action would result in the critical level being reached by about 1980.

BAYARD

Bayard is unique in the area in that its well field draws water primarily from an alluvial aquifer that is recharged annually during periods of normal or near-normal precipitation, but receives relatively little recharge when precipitation is subnormal. Bayard faces recurring problems of water supply because the alluvial aquifer is shallow and of limited extent, and because it is dependent upon annual runoff in Cameron Creek for recharge. The slight downward trend in the water levels in recent years can be attributed mostly to the effects of deficient precipitation and not to heavy pumping. Pumping effects on water levels in the Bayard well field are minor (fig. 9), compared with the natural changes in levels that result from fluctuations in annual precipitation.

In past years of normal precipitation the Bayard well field has been

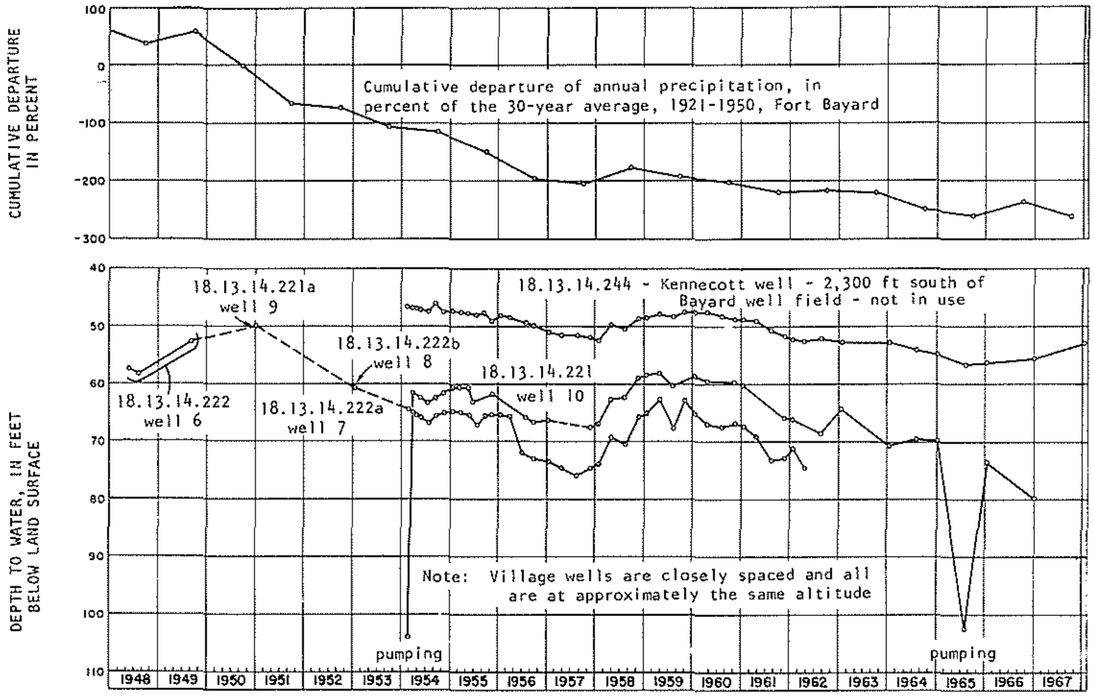


FIGURE 9. -- Graphs of water levels in and near the village of Bayard well field on Cameron Creek, and graph of the cumulative departure in percent of the average precipitation at Fort Bayard, Grant County, N. Mex.

capable of supplying normal demands for water, as is indicated by the higher daily per capita use compared with that of Central.

The recent increase in population (about 40 percent since 1960) has taxed the capability of the well field to provide adequate water during periods of peak demand, even during years of normal precipitation. The well field almost certainly could not meet minimum demands should there occur another succession of very dry years such as those from 1945 to 1952.

Because the aquifer supplying the Bayard wells is thin and of limited extent, any analysis of long-term pumping effects would be meaningless. The long-term life of the field is dependent on annual precipitation and not on factors such as transmissivity, storage coefficient, the extent and thickness of the aquifer, and the amount of water in storage. An analysis based on available data, and considering the factors mentioned, would show the aquifer depleted within about 2 years or less, whereas, in fact, normal annual precipitation will provide sufficient recharge each year to support the present rate of pumping from the well field.

HURLEY AND NORTH HURLEY

Well fields operated by Kennecott Copper Corp. at Apache Tejo and in the Whitewater-Warm Springs-Faywood area furnish the water supply for milling and smelting of ores from the Santa Rita mine and for domestic uses in Hurley, and most of the community of North Hurley. Water from all Kennecott well fields feeds to a central distribution system and no distinction can be made there as to which field supplies the water for domestic use.

Data available are not adequate to permit detailed evaluation of the various well fields operated by Kennecott Copper Corp., but some conclusions can be drawn. Wells in the Apache Tejo field are deep and some of them originally developed water at depths of over 2,000 feet in the limestone bedrock underlying the Gila Conglomerate. Most of the present wells, drilled between 1920 and 1951, are less than 1,000 feet deep but still obtain water from the bedrock. This well field has been pumped almost continuously since the first three wells were drilled about 1913 to recover water lost when the Apache Tejo Spring was dynamited in an attempt to increase the natural flow.

Water-table contours indicate possible lowering of the potentiometric surface in the vicinity of the Apache Tejo field but, as original water-level records are not available, the lowering is not certain; the spring was a natural discharge point for ground water before the wells were drilled and the present shape of the contours, indicating a drain, may have been about the same in 1913. In either case, the present water levels are relatively high and indicate that some 50 years of heavy pumping have had little effect on the ability of the field to produce large quantities of water from the bedrock aquifer.

The Whitewater-Stark ranch and Warm Springs-Faywood Springs well fields tap mostly alluvium and bolson fill; some of the wells in the vicinity of Faywood may obtain part of their yield from volcanic rocks underlying the bolson deposits. The wells are all capable of yields exceeding 200 gpm and all fields (but not all wells) are in continuous operation.

Potentiometric surface contours near Whitewater and Faywood, as at Apache Tejo, show possible deflections as a result of heavy pumping during the past 15 to 20 years, and water levels in observation wells show some declines. However, none of the declines are sharp and there is no evidence to indicate that the fields cannot continue to yield at approximately their present rate for many years to come.

Potential for Development of Additional Supplies of Water

Surface Water

Surface water for use by the communities of central Grant County is available from the Gila and Mimbres Rivers and some of their tributaries, but obtaining it would require acquisition of water rights and construction of extensive and expensive delivery systems.

Silver City for many years used water from Allen Springs (16.15.26.412), located in rugged country on the west side of the continental divide, north of town. The system was expensive to operate and difficult to maintain. The supply of water was unreliable because the discharge fluctuated with climatic conditions--was least when needed the most during drought--and the delivery pipeline from the springs to town frequently was washed out by heavy rains. Use of the water from Allen Springs was discontinued when the Franks ranch well field was placed in operation in 1945.

Phelps-Dodge Corp. has acquired water rights in the Gila River to provide for its mining operation 8 or 9 miles south-southwest of Silver City. It is possible that if water is brought to the area of the mine some could be made available to the nearby urban centers. A detailed cost analysis and feasibility study should be made to determine if these supplies could be economically developed.

Ground Water

EXPANSION OF PRESENT WELL FIELDS

The quickest and most economical way for Bayard, Central, and Silver City to obtain more water for the immediate future would seem to be to expand their present well fields. This is feasible and practical for both Silver City and Central but not for Bayard.

Any additional shallow wells developed in or near the present Bayard well field would interfere with those already in use and the net result would be little or no additional water. One possibility for expanding the present Bayard well field would be to test for water at greater depth in the Gila Conglomerate and bedrock underlying the alluvium from which, at present, all the water pumped is derived.

The town of Central probably could develop additional water from one or two wells drilled at distances of a quarter of a mile and a third to half a mile west of the present producing wells. New wells in these areas would be expected to yield about the same quantity of water as the present wells and, at the distances of 1,300 to 2,600 feet from the present wells, interference between new wells and old would be minimal. Some interference would occur but most of the water pumped by the new wells would come from storage not available to the present well field.

The present well fields of Silver City could be expanded by addition of 1 or 2 wells to increase the effective area of the well fields, thereby reducing drawdown in the individual wells and increasing by a few years the effective life of the fields. The new wells could be spaced to minimize mutual interference with existing wells and to pump water from storage that would mostly not be available to the present wells.

Expansion of the Franks field by addition of one well southeast of the present wells (fig.3) would appear to be justified on the basis of the wider spacing of the potentiometric contours which indicate greater transmissivity toward the southeast, as compared with that toward the northwest. It is possible that wells with capacities of 100 to 200 gpm also could be developed toward the northwest along the course of McKeefer Canyon.

The depth to bedrock might be appreciably less toward the northwest than in the present wells because of structural blocks of bedrock that are believed to extend northward from the north end of the Little Burro Mountains. The saturated thickness of the aquifer would be less than in the present wells if the bedrock is nearer the surface, and wells developed in the area could be expected to have smaller yields and shorter life expectancies. A series of test holes or a seismic-refraction profile along the course of McKeefer Canyon could locate approximately the position of the bedrock and greatly help in determining the feasibility of trying to develop wells in that direction.

The most promising sites toward the northwest would be in the reach from about the center of sec. 10 to the SW corner of sec. 4, T. 18 S., R. 15 W. Wells along this line should be considered as an extension of the Franks field, but the effects on water levels in the present wells resulting from pumping new wells at distances of 3/4 to $1\frac{1}{2}$ miles from the present wells would be so slight as to be negligible, and would not materially shorten the life of the Franks field. Pumping wells located closer than three quarters of a mile probably would have an appreciable effect on the present wells.

The land surface slopes more steeply westward from the Franks field than does the potentiometric surface; thus, the depth to water decreases toward the west. The water table in the SW$\frac{1}{4}$ of sec. 4, T. 18 S., R. 15 W., should be about 100 feet below land surface. The land surface there is at an altitude of about 5,500 feet which means that the potentiometric surface is at about 5,400 feet and, assuming a drawdown of 100 feet, the pumping level would be at about 5,300 feet. The storage tanks at the Franks field are at an altitude of about 5,850 feet.

The proposal to develop new wells in the Woodward field south to southeast of the present wells (fig. 4) is based on inferences drawn from the shape and spacing of the potentiometric contours, and on geologic data that indicate the bedrock may lie at greater depth in that direction. The wider spacing of the contours is interpreted to mean greater transmissivity, and a deeper lying bedrock should mean a greater saturated thickness of the aquifer. If these two inferences are true, then wells drilled south and east of the present field should have yields as good as or better than the present wells.

NEW AREAS FOR DEVELOPMENT

Even if Silver City, Central, and Bayard could expand their well fields to meet present and near-future demands for more water, it would be both desirable and prudent to consider developing new fields, either separately or cooperatively, such as by formation of a metropolitan water district to supply all urban areas. The desirability of a cooperative effort should be immediately apparent in the form of reduced cost of operating one system rather than two or three, the further economic advantage of increasing the number of service outlets with an area-wide distribution system, and the guarantee of uninterrupted water supply through interconnected well fields. Water is available in the area to meet all needs, present and foreseeable, of the towns and industries. The primary problem is locating new areas for development close enough to make development economically feasible. For the present, areas where fields of 2 to 3 wells of moderate yield--100 to 500 gpm--might be developed can be considered, but eventually fields should be found where wells with large yields--over 500 gpm--can be developed.

Available data indicate that the alluvium and underlying Gila Conglomerate in the Arenas Valley in the south part of sec. 16 and north of sec. 21, T. 18 S., R. 13 W., would supply one or two wells having capacities of 50 to 150 gpm. The NE$\frac{1}{4}$ of sec. 8, the NW$\frac{1}{4}$ of sec. 9, and the SE$\frac{1}{4}$ of sec. 10, T. 18 S., R. 13 W., also offer possibilities for developing a well of 50 to 100 gpm capacity by fully penetrating the aquifer.

The alluvium and underlying Gila Conglomerate in Mangas Valley in the Gila River drainage is a potential source of ground water for Silver City and for any community that might become established in the valley subsequent to the development of open-pit mining operations at Tyrone. The ground-water potential in the Mangas Valley has not been adequately tested. Available data are somewhat conflicting but indicate that wells having yields of 200 to 500 gpm might be developed in the upper valley. Well 19.15.10.221, situated in a reentrant on the east side of the valley, was drilled to a depth of about 1,180 feet and reportedly would yield no more than 40 gpm. This well is close to the trace of the fault that delineates the west front of the Little Burro Mountains and may have been drilled in the brecciated zone. Much clay and fractured rock was reportedly found during drilling. Well 18.15.32.234, drilled on the axis of the valley, reportedly yielded 235 gpm when tested at a depth of 215 feet. The static water level at time of drilling was 59 feet and the drawdown was 140 feet. The well was then deepened to 400 feet but reportedly was not tested because it was thought that no additional water was found. Irrigation wells in the vicinity of Mangas Springs (fig. 1) in lower Mangas Valley yield up to 1,400 gpm and are no more than 175 feet deep.

The spacing of the potentiometric contours in the reach of Mangas Valley between the NW$\frac{1}{4}$ sec. 13, T. 18 S., R. 16 W., and the SW$\frac{1}{4}$ sec. 22, T. 17 S., R. 16 W. (fig. 1), indicate that the alluvium and underlying Gila Conglomerate may have high transmissivity. Wells in this area, fully penetrating the aquifers, probably would produce between 500 and 1,000 gpm, thus a well field could be developed in this area.

Silver City could develop one or more new well fields in the upper part of the Gila Conglomerate west of Pipe Line Draw and south from the Woodward field to the junction of Pipe Line Draw with San Vicente Arroyo. The potentiometric surface (pl. 1) flattens markedly in the SW$\frac{1}{4}$ of T. 19 S., R. 14 W. One interpretation of this flattening is that the transmissivity of the deposits is greater, which in turn suggests that wells of large capacity might be developed in that area.

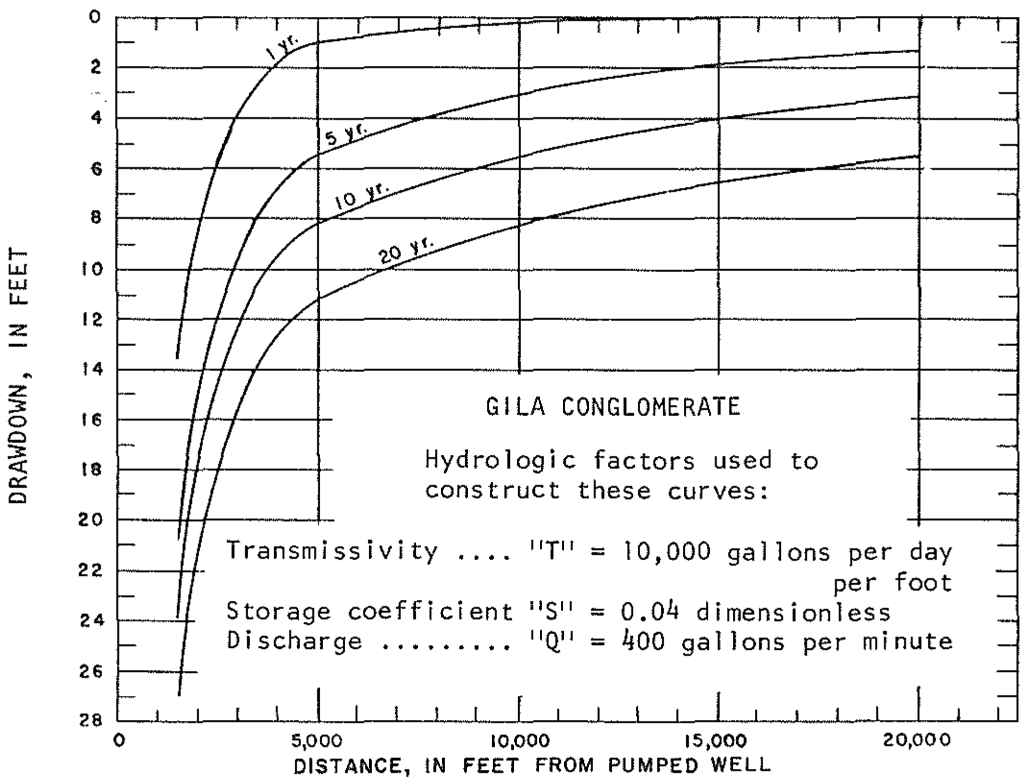


FIGURE 10. -- Graph of effect on water levels of a well pumping continuously from the upper part of the Gila Conglomerate at a rate of 400 gallons per minute.

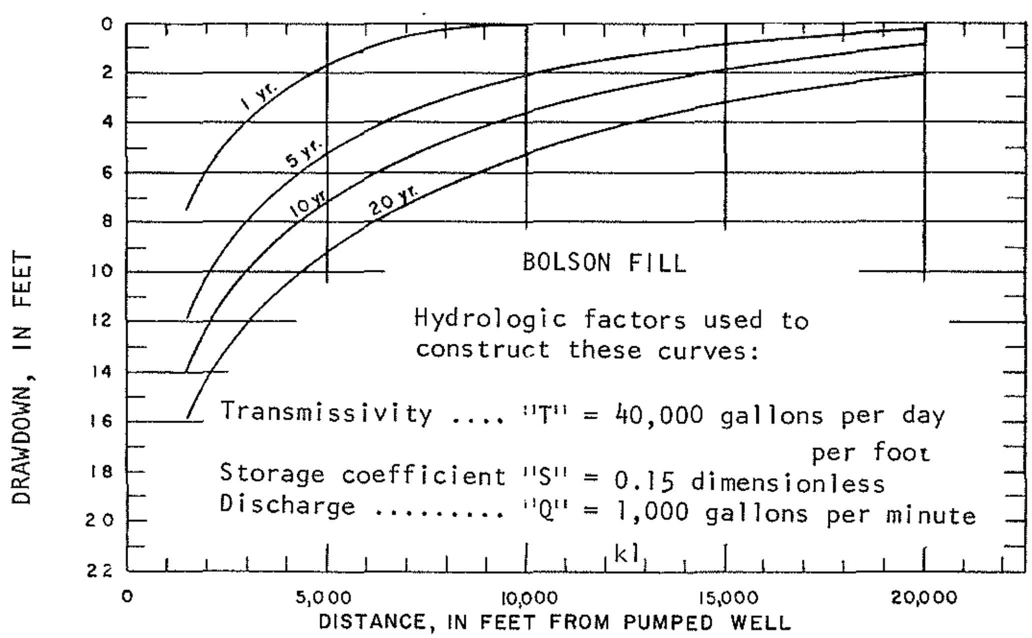


FIGURE 11. -- Graph of effect on water levels of a well pumping continuously from the bolson fill at a rate of 1,000 gallons per minute.

SUMMARY

Sharp population increases of most of the towns in central Grant County within the past 5 years have resulted in greatly increased demands for water. Projections of population increases and per capita use of water show that all the communities will increase water use at rates that will tax the ability of their water-supply systems to meet future demands in the relatively near future.

The principal aquifers furnishing ground water to the communities are the alluvium and bolson fill of Quaternary age, and the upper part of the Gila Conglomerate of Quaternary and Tertiary age.

The Bayard well field taps a thin alluvial aquifer of small extent. Annual withdrawals from the aquifer are relatively heavy but annual recharge during years of normal to near-normal precipitation is sufficient to sustain the present yield. If demands are increased appreciably, or if a 2- to 3-year period of drought should ensue, the well field probably could not satisfy minimum demands and water rationing would be necessary.

Central's Lone Mountain well field taps the Gila Conglomerate; its infiltration gallery taps the alluvium of a tributary to Cameron Creek and cannot be relied upon to furnish any water during a drought. The yield from the well field could be increased to meet increased demands of the next decade but thereafter would begin to decline rapidly. The field cannot be relied upon to meet demands much beyond 1980.

Silver City's two well fields also obtain water from the Gila Conglomerate. The aquifer is extensive in the vicinity of the fields but yields eventually will decline. The aquifer is thinner and less extensive in the vicinity of the Franks field than in the vicinity of the Woodward field. The Franks field also has been pumped longer; therefore, it does not have the capacity to yield as much water as the Woodward field, nor a life expectancy as long.

The time within which pumping levels in the various wells in the two fields will reach the critical level differs appreciably; some will reach the critical level within the next 2 to 4 years at present pumping rates.

The life expectancy of the individual wells and the fields can be extended by the addition of one or more wells in each field, but the benefits to be achieved by drilling more wells are limited.

Increased pumpage, modest or great, from either or both well fields probably can provide the quantities of water that will be needed to meet foreseeable increased demands of the next 10 to 15 years. However, in 30 years (possibly sooner) the water demands will be almost 4 times the present usage.

The present well fields, with the addition of one to two wells, possibly can be made to meet the projected demands for water to about the year 1990, but to do so would greatly shorten their life expectancy and they could not continue to meet demands after that time.

Well 19.14.14.443 reportedly was test pumped at a rate of 40 gpm for 8 hours. This presumably was the capacity of the pump, and not the capacity of the well to yield water. The drawdown apparently was not measured, thus the specific capacity could not be determined. However, the well, which had about 177 feet of water when visited, is believed not to have fully penetrated the aquifer.

A well fully penetrating the aquifer in this area, or a well at least 700 to 900 feet deep, might produce as much as 500 gpm. The aquifer is the upper part of the Gila Conglomerate and it should be as thick as at the Woodward ranch. The spacing of the potentiometric contours indicates that the permeability of the aquifer should be at least equal to that at the Woodward field, and perhaps even greater.

Another area where wells might be developed having a potential to yield up to 500 gpm is the northeast part of T. 20 S., R. 14 W. The bolson deposits in T. 20 S., R. 12 to 13 W., have a good potential for yielding as much as 1,000 gpm. Wells near Whitewater that are no more than 400 feet deep yield as much as 600 gpm and a recovery test made on well 20.12.36.111 indicated a specific capacity of about 15 gpm/ft of drawdown; the aquifer is believed not to have been fully penetrated as the well is only 140 feet deep. Presumably greater penetration would result in larger yields per foot of drawdown.

Some of the areas described above are not suited to irrigation, hence there would be no competition for water from agricultural interests. Only small amounts of water are needed in these areas for domestic and stock use and these needs easily could be supplied despite heavy pumping for urban or industrial use. Most of the areas are located at distances of 4 to 7 miles from presently heavily pumped areas, and, if developed, the withdrawal of large quantities of water would have little adverse effect on present development in the foreseeable future.

The long-term effect on water levels in nearby wells of a well field producing continuously at 400 gpm from the upper part of the Gila is demonstrated in figure 10. It may be seen that the lowering of the water level in a well about 4 miles away from the well field would be a little less than 6 feet after 20 years. The effects of a well pumping 1,000 gpm from the bolson fill would be even less; the lowering at a distance of 4 miles would be about 2 feet after 20 years of pumping (fig. 11).

The east half of T. 19 S., R. 13 W., is also an area where large quantities of water--500 to 1,000 gpm--might be obtained by deep drilling. The surface is underlain by the unproductive lower part of the Gila Conglomerate but limestone rocks of Paleozoic age underlie the Gila and they yield large quantities of water to wells 19.12.19.132, 132a, and 132b at Apache Tejo and to other wells in the vicinity.

Well 19.12.8.242, northeast of Apache Tejo, originally produced 1,150 gpm from the bolson fill and underlying limestone of Paleozoic age. The well was 1,542 feet deep, but subsequently caved and the yield then dropped to about 230 gpm. Apparently most of the water was coming from the limestone in the lower part of the well.

The useful life of both the Franks and Woodward fields could be extended 60 to 70 years by developing new well fields to supply increased demands starting about 1980. A third field could be developed to supply increased demands to about 1990, or a little beyond, and a fourth field could be developed to meet demands after that time.

Water of quality suitable for most uses is available in the area to meet all needs of the cities and industries, present and future. New well fields can be developed to tap the Gila Conglomerate west of Pipe Line Draw and San Vicente Arroyo southeast from the Woodward field for a distance of 10 miles, and in the valley of Mangas Creek. Wells in this area should yield up to 500 gpm. Wells tapping the bolson fill in the vicinity of Whitewater may yield as much as 1,000 gpm, possibly more.

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