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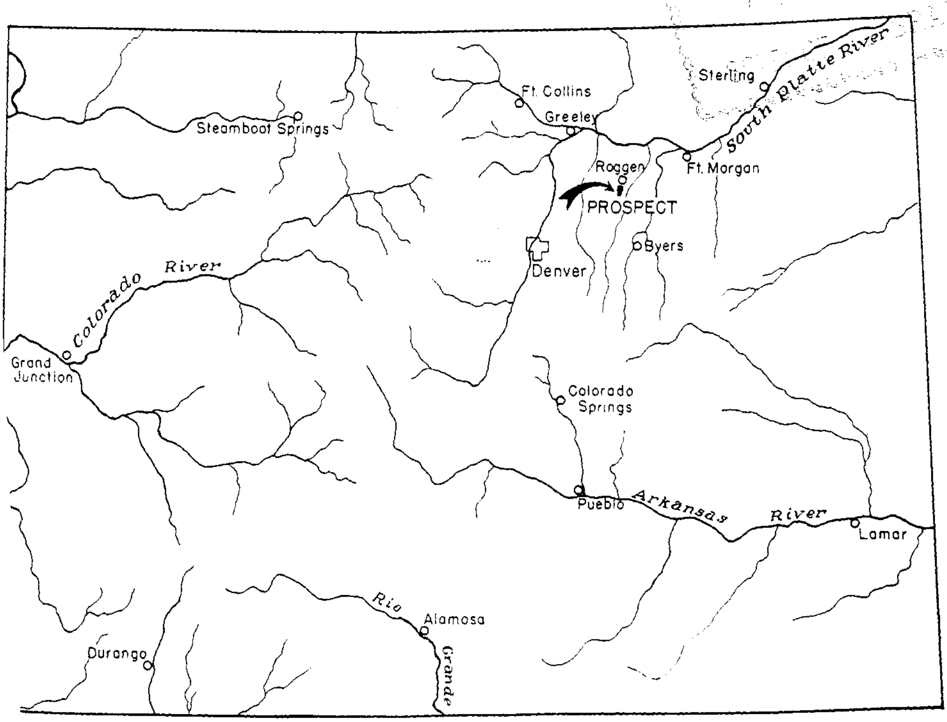
Ground Water Supply of Prospect Valley, Colorado

W. E. CODE



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Ground Water Supply Of Prospect Valley, Colorado[1]

W. E. CODE[2]

Contents

Introduction

THIS REPORT is the result of a study of water-table fluctuations in Prospect Valley. The study was begun in 1933 in connection with a general program of observation of water-table fluctuations in pumping districts of the South Platte Valley. Some of the data on use of ground water were obtained as part of a survey made in 1940 and 1941 of the South Platte Valley (1). During 1942 and 1943, a more detailed study was made in which the quantity of water pumped was determined, many more observation wells established, checks on surface supplies made, and the elevation of measuring points on observation wells determined by spirit leveling. Observations were continued into 1944 incidental to other work.

The work was planned to involve only a procedure which could be carried out with a minimum of expense. Therefore, observation wells were limited to those existing and available and, as might be expected, some parts of the area were not adequately covered. The topography as shown on the map (figure 6) was obtained in conjunction with levels run to observation wells and therefore is only approximate. Advantage was taken of a topographic map accompanying a report on ground-water availability in 1933 prepared by the engineering firm of Douglas and Thwaits (2) which covered part of the area on a different datum. Samples of gravels from the water zone were obtained from wells being currently drilled with drop-tool rigs. Data on surface water supplies were obtained from the Henrylyn Irrigation Dis-

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[1]The work on which this report is based was done in cooperation with the Division of Irrigation, Soil Conservation Service, U. S. Department of Agriculture.

[2]Associate irrigation engineer, Colorado Agricultural Experiment Station.

trict, and comparative checks were made by current meter measurements on three different occasions in 1942 and 1943.

Immediately upon the inception of pumping in Prospect Valley in 1932, the water table started to decline, and from 1933 to the spring of 1942 a maximum fall of 21 feet had occurred. Because the water-bearing gravels exist in a relatively thin formation above the shale, this lowering was assuming serious proportions which, had it continued, would certainly have led to economic exhaustion in a relatively short period. It was because of this situation and the offered cooperation of the affected residents that a closer study of the conditions was proposed by the Experiment Station.

The residents of the Valley were unusually cooperative in supplying necessary data, an essential factor in work of this character, and the author here wishes to express to them his sincere appreciation. Henrylyn Irrigation District officials, R. P. Culverwell, secretary, and Earl Hubbart and Floyd Parker, ditch riders, provided all required information asked for in a most helpful manner. Thanks are here expressed to them and to their Board of Directors. Logs of wells were freely furnished by well drillers who had operated in the area, particularly B. A. Holden who collected the gravel samples. Logs of wells contained in the Douglas and Thwaits report previously referred to were found very valuable in developing valley cross-sections. Historical information was provided by F. F. Claycomb, F. F. Cuykendall, N. A. Pippin, W. O. Timms, C. H. Bell, James Painter, and several other early residents.

HENRYLYN IRRIGATION DISTRICT

The Henrylyn Irrigation District has an irrigated area of 32,870 acres lying roughly east from Hudson and embracing Keenesburg. Prospect Valley is at the east edge of the district, 12 miles east of Hudson and, with the exception of lands along Boxelder Creek, offers the only possibilities for developing ground water for irrigation. The district was organized in 1907, and the first water was delivered to lands in 1912. Originally the proposed area to be irrigated was considerably larger than at present, being reduced very early as the water supply was found to have been greatly overestimated.

The original area included land above the present canals and the canal serving it extended several miles farther east. Sand Creek Reservoir located in section 36, T. 1 N, R. 63 W. was to be filled from this canal. The earth dam of the reservoir failed on the first filling in the spring of 1915 when a section about 400 feet long washed out. Since the upper ditch was abandoned shortly after its construction, no attempt was ever made to repair the breach. The present area is the result of land withdrawals and adjustments but it is still greater than the water supply warrants over long periods of subnormal stream flow. The difficulty arises from the fact that most of the water rights of the Henrylyn Irrigation District are of late date and are composed largely of those for storage. The supply is therefore determined by the stage of the South Platte River. Opportunities for storage during the irrigation season occur only when all rights to direct flow are satisfied. The situation changes during the fall and winter season when storage is regularly permitted.

Water is diverted from the South Platte River for the district through the Burlington Canal which heads at the north city limit of Denver. About 4 miles below the heading the water is divided and the eastern branch is called the O'Brian Canal. The flow in the O'Brian Canal is divided at Barr Lake, part going into Barr Lake and part going around through the Denver and Hudson Canal, serving lands in the vicinity of Hudson and acting as a feeder for Horse Creek Reservoir. From Horse Creek reservoir, which has a capacity of 21,000 acre-feet, water is drawn through a canal, still bearing the Denver and Hudson name, to serve lands near Keenesburg and through a lateral, the Low Line Canal, lands in the northern part of Prospect Valley. Water in

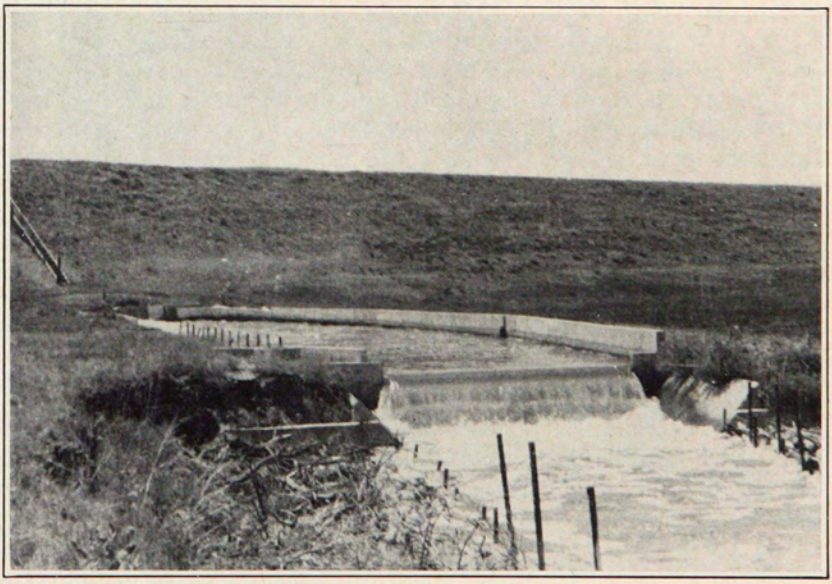

Figure 1.—Eighteen-foot weir at outlet of Prospect Reservoir.

the Denver and Hudson canal then flows on to feed Lord and Prospect Reservoirs.

Lord Reservoir has a capacity of 1,100 acre-feet and is not regularly used. Water from it is discharged into the Low Line Canal. Prospect Reservoir has a capacity of 5,600 acre-feet. Water from Prospect Reservoir is measured over an 18-foot sub-standard rectangular contracted weir and conveyed eastward about 4 miles through Prospect Canal before reaching the southern part of Prospect Valley. There are several diversions from it in this distance. At the west side of the valley, Sub-Lateral Number 2 takes off to serve lands on the west side and can be used to feed Olds Reservoir.

GEOGRAPHY

Topography and Geology

Sand Creek and Lost Creek form approximate east and west boundaries of the southern half of the study area. They have well defined drainageways here, but these disappear toward the north end of the area. Both creeks are normally dry, and flood flows of any consequence are infrequent. Floods in Lost Creek are captured in Lord Reservoir. Flood flows in Sand Creek are absorbed on cultivated land and the larger flows cause considable damage to crops. These conditions may be seen by consulting the map (figure 6). In the years 1942 and 1943, flows during runoff periods amounted to only a few second-feet. On July 4, 1944, a flood reaching a maximum of probably 50 cubic feet per second and lasting about 10 hours occurred in Sand Creek and reached a point about 2 miles north of Prospect. A similar flood occurred in Lost Creek. These streams are short and have narrow drainages. Lost Creek has a length of about 10 miles and Sand Creek about 16 miles.

As may be seen from the map, the smooth land is about 1 mile wide at the upper or south end of the area, becoming wider to the north until the sand-dune area along the north edge is encountered. These dunes, which are quite rough, constitute the southern boundary of a sand dune area which extends about 10 miles to the north.

A geological* examination indicates that the sands and gravels beneath the study area are deposited in an erosion channel in the Laramie formation from which they are largely derived.

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*Statement on geology provided by R. G. Coffin, geologist, Colorado Agricultural and Mechanical College.

The Laramie formation occurs in the late Cretacious or early Tertiary and consists of black shales, coal seams, and some sandstones. The gravel strata are broken up by numerous clay strata up to 50 feet in thickness. The east and west boundaries of the study area approximately delineate the boundaries of the gravels. Outside of these, little or no gravel occurs and the formations yield but scant water supplies for stock or domestic use. The north and south boundaries of the study area are arbitrary, and the water-bearing gravels in which irrigation wells may be obtained extend beyond them. The pumping district is restricted on the south by the lift and on the north by sandy soil or sand dunes. The depth to water at the south end is now about 100 feet and at the north end about 25 feet. The greatest depth of alluvium occurs at the south end where it is about 175 feet deep, while at the north end it is about 100 feet deep. The shape of the erosion channel in the Laramie formation is shown in the cross-section in figure 2.

The erosion channel bears northeasterly in the northern part of the study area toward Roggen, and at some place south of that point it evidently joins another channel as indicated by another branch of Lost Creek to the east, known locally as Long Draw. At Roggen the depth to water is from 5 to 7 feet, varying seasonally, and water flows almost continually on the surface in Long Draw at the railroad. Northward from the railroad for 8 or 9 miles, there is a living stream in a valley varying in width from several miles to less than one-half mile as it winds among the sand dunes. The land north of the study area is

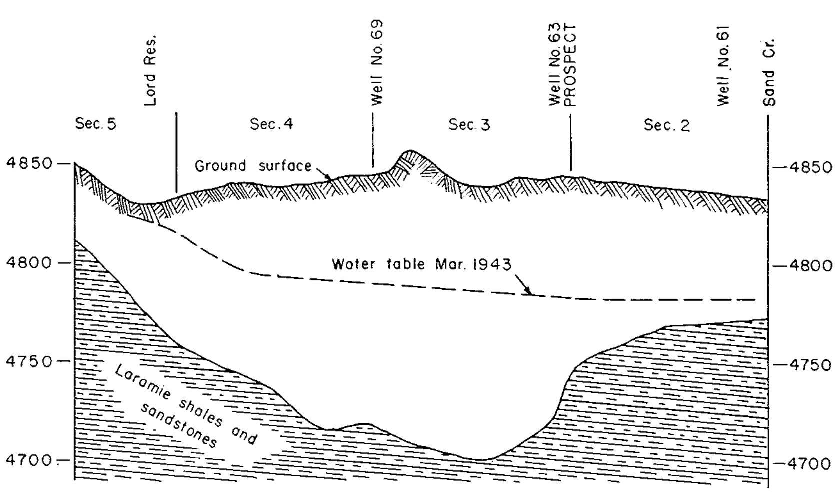

Figure 2.—East and west section through valley at Prospect.

held by cattle raisers, and the shallow water areas support good grasses which are cut for hay.

Crops and Soils

All the land within the study area is not irrigated, part being operated for dry-land cropping and part as pasture (see figure 3). Wheat is the usual dry-land crop, although beans and sorghums are also grown, all under the summer fallow system. Crops on the lands irrigated only from the canal system are generally limited to grains and forage. There is considerable diversification of crops on the lands served by pumps. Of these, alfalfa, sugar beets, and corn are most important. Potatoes, pinto beans, grains, and truck crops also are grown. A branch line of the Chicago, Burlington, and Quincy Railroad serves the area only during the sugar-beet harvest season. Wheat is stored at the nearby towns of Keenesburg and Roggen or is trucked out. Potatoes and onions are sorted and stored in a newly built storage warehouse at Keenesburg. Alfalfa and corn are largely consumed in winter cattle-feeding operations and to a small extent in dairying.

Rago silt loam and Rago clay loam are the predominating soil types* in the Prospect Valley area. They are deep, well drained, and very productive soils.

The surface soil is from 7 to 12 inches thick and is generally quite friable and easily worked when the organic matter supply is maintained. The upper subsoil varies in thickness from 12 to 16 inches and ranges in texture from a clay loam to a silty clay loam. This layer has pronounced structure and when dry is quite hard. A lower subsoil layer of limy silt loam, 8 to 12 inches thick, underlies the upper subsoil and grades into the limy, loess-like parent material at an average depth of about 36 inches.

Over the greater part of the valley the slope is less than 2 percent. An area comprising about 1,000 acres which lies in the southwest part of the valley and a few isolated areas smaller in size have a slope of from 2 to 5 percent. On these more sloping areas the soils are classified as Weld silt loam and Weld clay loam. The Weld soils resemble the Rago soils in arrangement and number of profile layers but are more shallow throughout. The surface soil is less than 6 inches thick and the subsoil ranges in thickness from 8 to 10 inches. Lime occurs at depths ranging

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*Statement on soils furnished by D. S. Romine, associate agronomist, Colorado Agricultural Experiment Station.

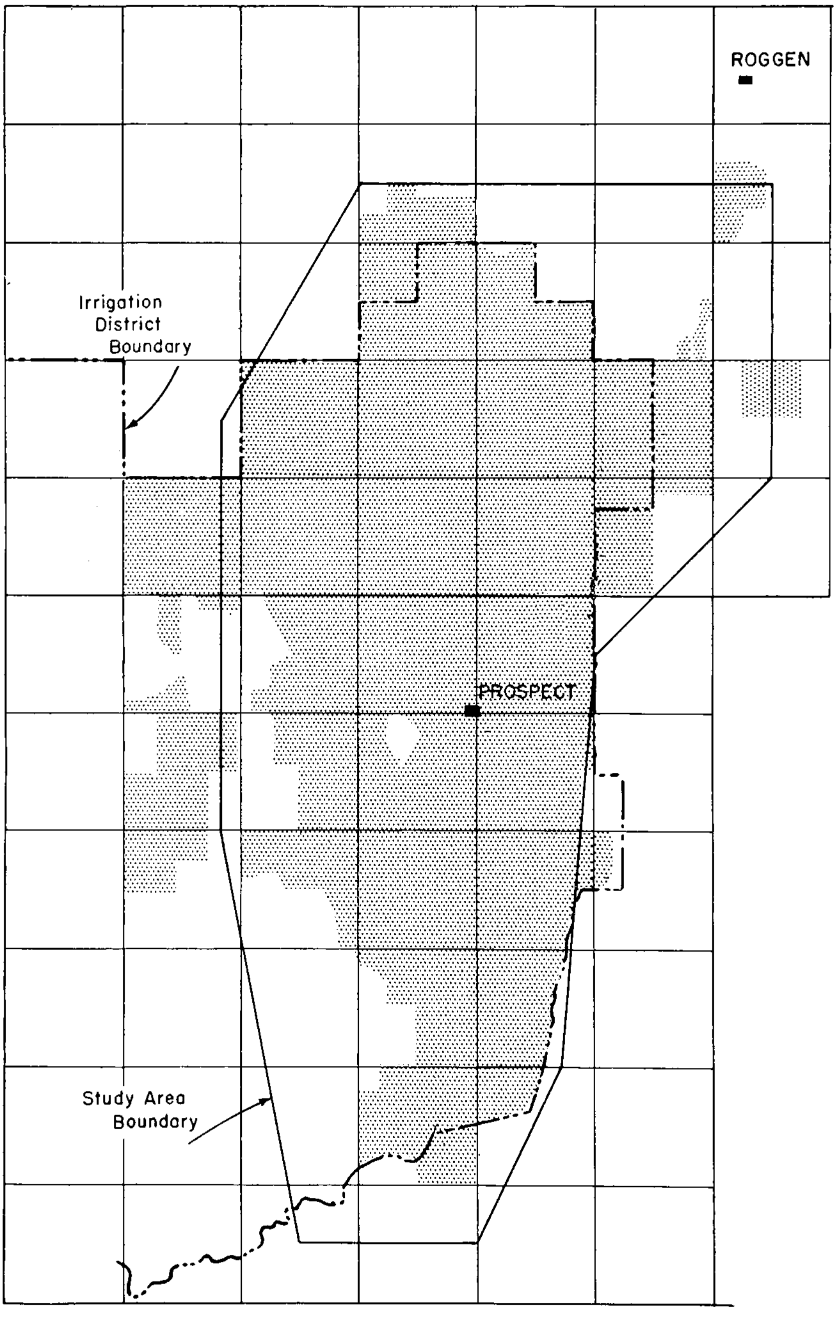


Figure 3.—Map showing the irrigated area in Prospect Valley.

from 14 to 16 inches. The Weld soils are less productive than the Rago series in the area.

A narrow band of nearly level arable, sandy soils, classified as Vona sandy loam, lies across Prospect Valley between the area of Rago soils and the adjacent sand hills on the north.

Water Quality and Temperature

Samples of water for chemical analysis were obtained from three wells late in the 1944 season. They were selected as representing the salt content for the upper, central, and lower parts of the valley. Number 1 of table 1 is from irrigation well Number 92, which is 171 feet deep. Number 2 is from a domestic well at Prospect 80 feet deep. Number 3 is from well Number 11A, which is 84 feet deep. These samples which were analyzed by J. W. Tobiska* indicate an increasing hardness from south to north, showing the influence of seepage water from irrigation.

Five scattered observations of ground-water temperatures were made in September 1944 which ranged from 53.5° to 55.7° Fahrenheit.

WATER SUPPLY AND USE

The water supply for crops in the area is derived from 3 sources—precipitation, canals, and wells.

Precipitation in the spring is depended upon to provide moisture for seed germination and early growth of crops so that irrigation is not required until the early part of May. Later rainfall is of value only in delaying or supplementing irrigation but has a definite effect on total irrigation requirements. Except during intense storms causing run-off in stream channels, it is unlikely that any substantial ground-water replenishment occurs directly from precipitation. In the stream channels, a large part of the water absorbed probably joins the ground water

TABLE 1.—*Chemical composition of well waters in parts per million.*

	Number 1	Number 2	Number 3
Total solids	369	1006	2191
Volatile solids	25	58	366
Silica (SiO_2)	22	19	27
Nitrates (NO_3)	1	16	4
Chlorides (Cl)	20	68	160
Carbonates (CO_2)	53	79	62
Sulfates (SO_3)	88	402	832
Lime (CaO)	88	229	461
Magnesia (MgO)	17	67	100
Soda (Na_2O)	50	44	3
Reaction (pH)	7.7	7.9	7.3

*Chemist, Colorado Agricultural Experiment Station.

and no doubt there were small contributions in the springs of 1942 and 1944 and on July 4, 1944. An unofficial rain gauge station is maintained by the Great Western Sugar Company field agent at Keenesburg and the record for the period 1941 to 1944 is shown in table 2. The maximum intensity during this period did not exceed 1.50 inches in 24 hours. Precipitation for a longer period of time for Fort Lupton, Greeley, Byers, and Fort Morgan is given in table 3.

Surface water supplies come into the area at two points. Prospect Canal serves the upper part of the area and the Low Line Canal the lower part. Olds Reservoir originally built for water storage, can be supplied from Prospect Canal, but water is run into it only when there is a surplus available. About 250 acre-feet is the maximum storage for Olds, and at this stage the loss appears to be about 50 acre-feet per day. At a stage of about 75 acre-feet the loss was measured by survey at about 17 acre-feet per day. It will be seen that this reservoir is useless for water storage but does afford an ideal water-spreading ground. About 1,050 acre-feet of water was run into Olds in the spring of 1939 and the effect on ground-water replenishment was evident in nearby wells. Water was again run into Olds from March 14 to May 13 and June 19 to June 28, 1942 in a total amount of 3,150 acre-feet as measured by the ditch rider, or 3,780 acre-feet when corrected for over-delivery as explained later. The next runs of water were from November 5 to Novem-26 amounting to 1,060 acre-feet (corrected), and from March 22 to March 28 and April 12 to April 20, 1943, amounting to 740 acre-feet (corrected). In 1944 about 550 acre-feet was run into the reservoir between May 8 and 18.

During the 10 years previous to 1942, water was held in Lord Reservoir only in 1939, and no record was preserved as to

TABLE 2.—*Monthly precipitation at Keenesburg, Colo. (inches).*

	1941	1942	1943	1944
January	.84	1.10	.18	.87
February	......	.63	.21	.08
March	.43	.40	.87	2.21
April	3.30	3.92	1.62	3.96
May	1.45	2.05	3.22	1.80
June	1.14	2.52	.48	.39
July	1.57	1.38	.30	.65
August	2.04	......	.26	......
September	1.42	.95	......	......
October	1.10	2.55	......	......
November	.52	.18	......	1.04
December	......	.53	......	.31
Partial totals	13.81	16.21	7.14	11.31

TABLE 3.—*Annual precipitation at four stations near Prospect Valley (inches).*

Year	Fort Lupton	Greeley	Byers	Fort Morgan
1921	14.78	14.48	....	11.61
1922	9.14	8.32	....	11.49*
1923	19.49	18.20	....	14.54
1924	9.57	9.72	....	10.78
1925	11.75	15.89	....	12.18
1926	11.13	11.11	....	11.98
1927	11.75	14.31	....	15.20
1928	14.28	16.31	....	14.12
1929	9.84	12.09	....	15.71
1930	12.26	12.50	....	12.77
1931	9.94	7.94	7.25	10.09
1932	9.49	10.37	10.74	10.96
1933	12.36	9.47	12.29	14.70
1934	7.68	8.69	7.23	6.41
1935	16.23	12.93	15.52	16.46
1936	9.59	10.39	17.58	14.55
1937	8.50	11.32	9.12	9.91
1938	17.95	10.89	22.65	13.20
1939	6.77	5.68	7.44	5.15
1940	13.39	10.60	15.56	11.12
1941	18.10	16.00	20.84	14.29
1942	17.43	16.25	20.64	18.57
1943	10.02	8.90	10.01	10.99
1944	11.39	13.19	14.18	11.80
Means	12.97	2.97	12.65	13.86

*Data for February missing.

the amount. Its capacity is 1,100 acre-feet. In 1942 water was stored from March 8 to September 15; from November 1, 1942, to August 1, 1943; and in 1944 from April 27 to August 7. The seepage rate from the reservoir was not accurately determined for the entire period. By examination of the gage readings during periods of no flow in 1943, the loss appeared to be about 0.05 foot per day. This figure was checked by means of a hook gage in the fall of 1944 when the reservoir was at very low stage.

The records of water delivery furnished by the Henrylyn Irrigation District are for the net amount delivered at the user's headgate. The weirs in use are of the suppressed rectangular type, but the crest is not standard and checks indicate that they deliver about 10 percent in excess of the rating tables used. Table 4 shows the deliveries as provided by the district for the period for which they are available.

The total irrigated area is roughly 12,500 acres. Part of this lies outside the boundaries of the district and, as also will be seen from figure 3, not all the land within the district boundaries is irrigated. In no year, except perhaps 1928 and 1942, was there sufficient irrigation water for general farming on district

TABLE 4.—*Water delivered by canals to users in Prospect Valley, Colo.*

Year	Acre feet	Year	Acre-feet
1928	11,510	1937	940
1929	6,750	1938	6,650
1930	9,230	1939	3,800
1931	8,520	1940	540
1932	200	1941	1,320
1933	3,520	1942	10,540
1934	1,120	1943	4,940
1935	810	1944	6,790
1936	1,850		
		Average	4,650

lands. The deficiency is met by pumping to bring up the total to from 18,000 (1942) to 20,000 acre-feet (1943), or a field duty of 1.6 to 1.8 acre-feet per acre.

There were 68 pumps operated in 1942, producing 6,500 acre-feet of water which was applied to about 8,460 acres. In 1943, there were 76 pumps operated, producing 14,580 acre-feet which was applied to about 9,620 acres. In 1944, 87 pumps produced an estimated 13,100 acre-feet for about 10,150 acres. The amount of water pumped from individual wells is shown in table 5.

THE GROUND-WATER PROBLEM

General Considerations

Under natural conditions a water table will vary from season to season and from year to year according to weather conditions and the nature of discharge. Losses from surface flow usually are the major source of ground water, and frequency or infrequency of stream flow causes the water table to rise or fall. Except in very special cases, ground water moves slowly to points of lower elevation to join other moving bodies of ground water. More often than not the water will move in the general direction of the land slope at velocities less than 200 feet per day. Ground water escapes from an area in several ways. It may continue to flow underground, or it may be forced to the surface by constrictions or other physical conditions to flow as a surface stream or form a lake. In regions of shallow water tables, water may be discharged by transpiration from vegetation such as grasses, shrubs, and trees. Water tables under such conditions have usually reach a equilibrium and do not vary greatly from an average condition.

When land is irrigated, losses occur in the ditches and from irrigated fields. This water rapidly percolates downward and joins the free ground water, causing it to rise. This is the his-

TABLE 5.—*Essential data on all wells used in study area.*

Well Number	Well depth	Year com- pleted	Pump dis- charge	Date of measure- ment	Kind of power in 1944	Motor size	Depth to water March 31, 1943	Water pumped 1942	Water pumped 1943	Water pumped 1944
	Ft.		G. p. m			Hp.	Ft.	Ac.-ft.	Ac.-ft.	Ac.-ft.
1	60	....	....	....	Dom.	....	6	......	......	......
2	10	....	....	....	A	....	7	......	......	......
3	125	1932	....	....	Dom.	....	23	......	......	......
4	78	1935	725	[illegible]	Elec.	15	23	184	227e	200e
5	101	1943	950	10-6-43	Elec.	10	25	......	35e	37
6	93	1940	795	8-4-43	Elec.	15	19	171	274	275e
6A	79	1944	530	8-7-44	Elec.	15	....	......	......	98
7	15	....	....	....	Dom.	....	13	......	......	......
8	......	....	....	....	A	....	18	......	......	......
9	87	1936	340	8-7-44	Elec.	25	32	0	201	223
9A	96	1944	....	....	Elec.	40	....	......	......	45e
10	100	1933	1025	7-9-43	Elec.	25	35	263	412	286
11	96	1936	887	9-2-43	Elec.	30	27	350	521	182
11A	84	1944	1110	9-28-44	Elec.	25	....	......	......	148
12	......	1943	942	7-8-43	Elec.	25	27	285	344	270
13	119	1940	955	7-9-43	Elec.	25	34	0	371	286
14	87	1943	1168	7-9-43	Elec.	30	34	36	103	127
15	51	1929	... .	....	A	....	34	......	......	......
16	86	1937	776	9-2-43	Elec.	25	....	108	160	160e
17	58	1933	303	7-9-43	Elec.	....	....	3	18	14e
18	80	1937	....	....	Elec.	....	44	5e	0	0
19	55	....	....	....	A	....	38	......	......	......
20	54	1936	....	....	A	....	40	......	......	......
21	......	1942 }	470	8-7-44	Elec.	20	....	......	54e	75e
22	60	1937 }			Elec.	10	39	22	19e	57e
23	69	1940	774	8-5-43	Elec.	25	....	125	164	170e
24	72	1940 }	578	7-9-43	Elec.	5	....	118	195	159
25	74	1937 }			Elec.	15	48	......	......	......
26	70	1940	225e	1943	Elec.	7½	....	45e	71e	60e

TABLE 5.—*Essential data on all wells used in study area.*—Continued.

Well Number	Well depth	Year com-pleted	Pump dis-charge	Date of measure-ment	Kind of power in 1944	Motor size	Depth to water March 31, 1943	Water pumped 1942	Water pumped 1943	Water pumped 1944
	Ft.		G. p. m			Hp.	Ft.	Ac.-ft.	Ac.-ft.	Ac.-ft.
27	70	1937	763	8-5-43	Elec.	25	48	57	187	170
28	95	1940	880	8-4-43	Elec.	30	....	110	250	256
29	92	1933	787	7-6-43	Elec.	30	....	114	255	287
30	128	1933	250	9-2-43	S D E	....	....	39	52	0
31	122	1941	855	9-8-43	Elec.	20	46	113	269	237
32	101	1935	891	7-9-43	Elec.	30	48	188	349	289
33	102	1934	835	8-11-42	Elec.	20	40	225	325	347
33A	......	1944	....	....	....	....	....	......	......	12e
34	112	1935	945	6-7-43	Elec.	30	48	30	190	170
34A	121	1944	....	....	Elec.	25	....	......	......	40
35	79	1932	1028	8-12-42	Elec.	25	....	88	216	194
36	87	1938	898	7-6-43	G E	....	35	50e	247	200e
37	97	1936	1500	8-7-44	Elec.	40	39	211	360	331
38	80	1933	580	7-7-43	Elec.	25	44	115	233	167
39	55	1940	300e	....	G E	....	....	2e	37e	11e
40	......	1938	300e	....	G E	....	28	0	38e	1e
41	41	1934	....	....	A	....	34	......	......	......
42	72	1937	....	....	A	....	42	......	......	......
43	74	1937	510	7-7-43	Elec.	15	....	26	140	79
44	82	1935	562	7-8-43	Elec.	15	53	65	155	72
45	81	1940	764	7-6-43	Elec.	25	50	84	176	239
45A	......	1944	570	9-28-44	Elec.	25	....	......	......	102
46	90	1935	497	7-6-43	Elec.	25	....	18	104	109
47	105	1937	791	7-6-43	Elec.	30	56	53	177	126
48	91	1939	790	7-8-43	G E	....	43	21e	75e	70e
M	80	1933	....	....	A	....	....	......	......	......
49	125	1936	975	7-7-43	Elec.	30	....	122	324	298
50	......	1933	448	8-4-43	G E	....	54	0	28	0

TABLE 5.—*Essential data on all wells used in study area.*—Continued.

Well Number	Well depth	Year com-pleted	Pump dis-charge	Date of measure-ment	Kind of power in 1944	Motor size	Depth to water March 31, 1943	Water pumped 1942	Water pumped 1943	Water pumped 1944
	Ft.		G. p. m			Hp.	Ft.	Ac.-ft.	Ac.-ft.	Ac.-ft.
51	115	1933	866	7-6-43	Elec.	30	....	217	238	180e
52	115	1934	975	7-6-43	Elec.	40	60	208	334	270
53	114	1932	285	8-4-42	Elec.	10	....	66	77	86
54	91	1934	500e	7-6-43	Elec.	25	51	151	188	208
55	102	1939	850	7-6-43	D E	....	58	60	161	157
56	95	1937	528	7-8-43	D E	....	53	95	89	180
57	80	1938	332	7-6-43	Elec.	25	....	78	92	127
58	71	1933	412	7-9-43	Elec.	10	....	32	112	58
59	......	1941	538	7-9-43	Elec.	15	....	42	218	138
60	76	1936	354	7-9-43		20	51	52	98	76
61	53	....	....	....	Dom	....	49	......	......	......
62	86	1933	395	6-1-43	Elec.	15	....	0	56	0
63	123	1935	....	....	Elec.	10	59	0	0	80e
63A	96	1934	....	....	A	....	....	......	......	......
64	95	1933	481	7-9-43	Elec.	20	....	0	155	72
65	100	1932	696	7-5-43	Elec.	30	....	55	204	138
66	......	1941	820	7-7-43	Elec.	30	....	74e	299	282
67	130	1937	1068	9-4-43	Elec.	30	....	79	189	145
67A	129	1944	....	....	Elec.	30	....	......	......	65e
68	128	1936	940	7-6-43	D E	....	60	0	187e	150e
69	122	1942	954	7-5-43	Elec.	25	52	47	164	110
70	127	1938	1560	8-4-43	Elec.	50	....	126	431	392
70A	......	1944	....	....	Elec.	30	....	......	......	60e
71	106	1941	823	8-7-42	Elec.	20	....	32	88	73
72	110	....	766	9-24-44	Elec.	25	57	......	......	89
73	128	1937	1130	8-8-42	DE	....	55	105	151	80
74	120	1939	1130	8-8-42	D E	....	54	107	90	124
74A	126	1944	1415	9-29-44	Elec.	40	....	......	......	127

TABLE 5.—*Essential data on all wells used in study area.*—Continued.

Well Number	Well depth	Year com-pleted	Pump dis-charge	Date of measure-ment	Kind of power in 1944	Motor size	Depth to water March 31, 1943	Water pumped 1942	Water pumped 1943	Water pumped 1944
	Ft.		G. p. m			Hp.	Ft.	Ac.-ft.	Ac.-ft.	Ac.-ft.
75	120	1935	870	7-5-43	D E	....	56	18	215	148
76	130	1940	922	8-3-43	Elec.	30	61	128	235	215
77	120	1938	1183	7-5-43	D E	....	....	51	260	231
78	139	1933	990	8-3-43	D E	....	....	34	162	100e
79	110	1933	932	8-3-43	D E	....	....	40	145	150
80	......	....	....	....	A	....	40	......	......	......
81	......	....	....	....	D	....	59	......	......	......
82	......	1933	635	9-3-43	Elec.	30	84	122	140	196
83	157	1941	770	7-6-43	Elec.	30	....	85	223	171
84	149	1937	858	9-1-43	D E	....	68	69	153	120
85	147	1933	970	7-5-43	Elec.	40	....	115	372	216
85A	......	1944	785	8-16-44	Elec.	40	....	......	......	55
86	140	1940	925	7-5-43	Elec.	30	72	114	303	211
87	108	1933	527	8-3-43	Elec.	25	....	27	88	46
88	98	1934	538	7-5-43	Elec.	20	....	8	109	110e
89	60	....	....	....	S	....	32	......	......	......
90	......	1940	928	8-3-43	Elec.	50	83	142	284	256
90A	141	1944	776	8-8-44	Elec.	50	....	......	......	114e
90B	143	1944	1130	8-8-44	Elec.	40	....	......	......	131
91	176	1937	996	7-5-43	Elec.	50	87	204	370	232
92	171	1933	986	8-16-44	Elec.	60	....	99	189e	175
93	173	1936	1080	8-16-44	Elec.	75	98	159	258e	82
94	159	1933	710	8-3-43	D E	....	....	14	99	0
95	......	....	....	....	A	....	84	......	......	......
Totals								6501	14,582	13,114

Symbols used: e, estimated; Dom., domestic well; A, abandoned well; S, stock; Elec., electric motor; D E, diesel engine; S D E, semi-diesel engine; GE, gasoline engine.

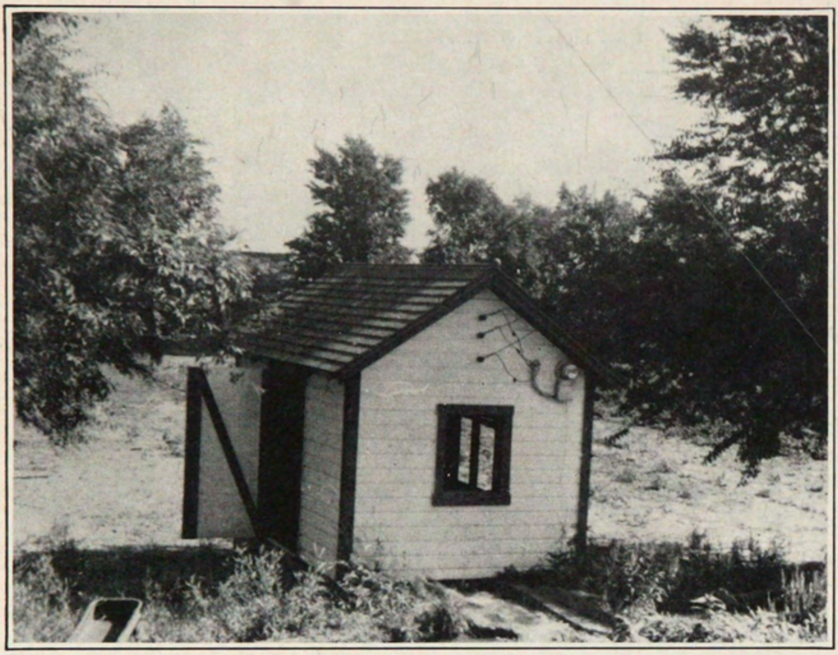


Figure 4.—Pumping plant at Well Number 13.

tory of all irrigated areas. When the under-drainage is not adequate, the water table rises to the surface causing great damage when adequate artificial drainage is not possible. Thus man can upset a condition of equilibrium in one direction. Although this already has been demonstrated in Colorado, the history of pumping in Arizona and California has been of greater significance. Certain pumping areas in California have suffered a ground-water lowering of more than 200 feet. Here operators were able to deepen their wells and thus keep up with the receding water table. In Colorado no such relief is possible because the alluvium is of relatively shallow depth and nearly all irrigation wells are drilled through it originally. By excessive artificial withdrawals, ground water can be exhausted to a point where it becomes of no economic importance for irrigation.

Moderate pumping primarily may cause establishment of a new point of equilibrium at a lower level when attended by increased flow from the sides induced by steeper water-table slopes, decreased discharge following the drying up of stream flows and lakes, and shrinking shallow-water areas that dissipate water by useless vegetation. A new state of equilibrium may also be effected by recharging the ground water by spreading flood waters in receptive places. California leads the way with many such successful projects.

Prospect Valley Conditions

As previously mentioned, the pumping area is limited to the gravel-filled old erosion channel. The east and west boundaries are rather well defined, and the boundaries of the study area indicated in figure 6 were selected in conformance with them. The north and south boundaries are arbitrarily set to include all the irrigation wells.

It is probable that the gravels extend a considerable distance to the south and have an intake area in some unknown drainage channel. Tests made in 1941 at a location 2 miles south of the area revealed sands and gravels to a depth of 180 feet and the water table at 125 feet. Northward all the evidence indicates that the sands and gravels are continuous to the South Platte River 12 miles distant. A thick clay stratum covers most of the gravel from Roggen north, evidently restricting the escape channel and causing it to flow under pressure. Water flows on the surface from the railroad for a distance of about 7 miles north. In this distance there are several springs and one flowing irrigation well. The proximity of ground water affords moisture to

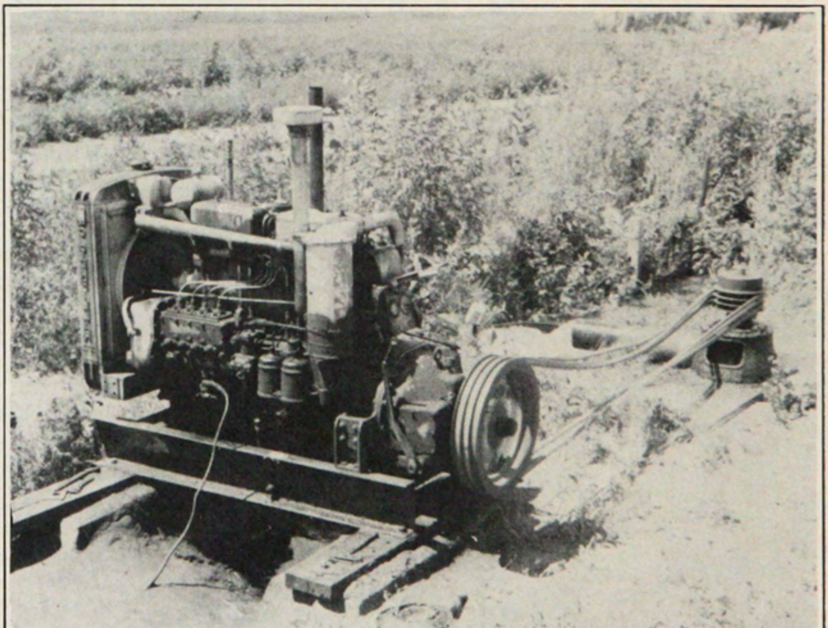
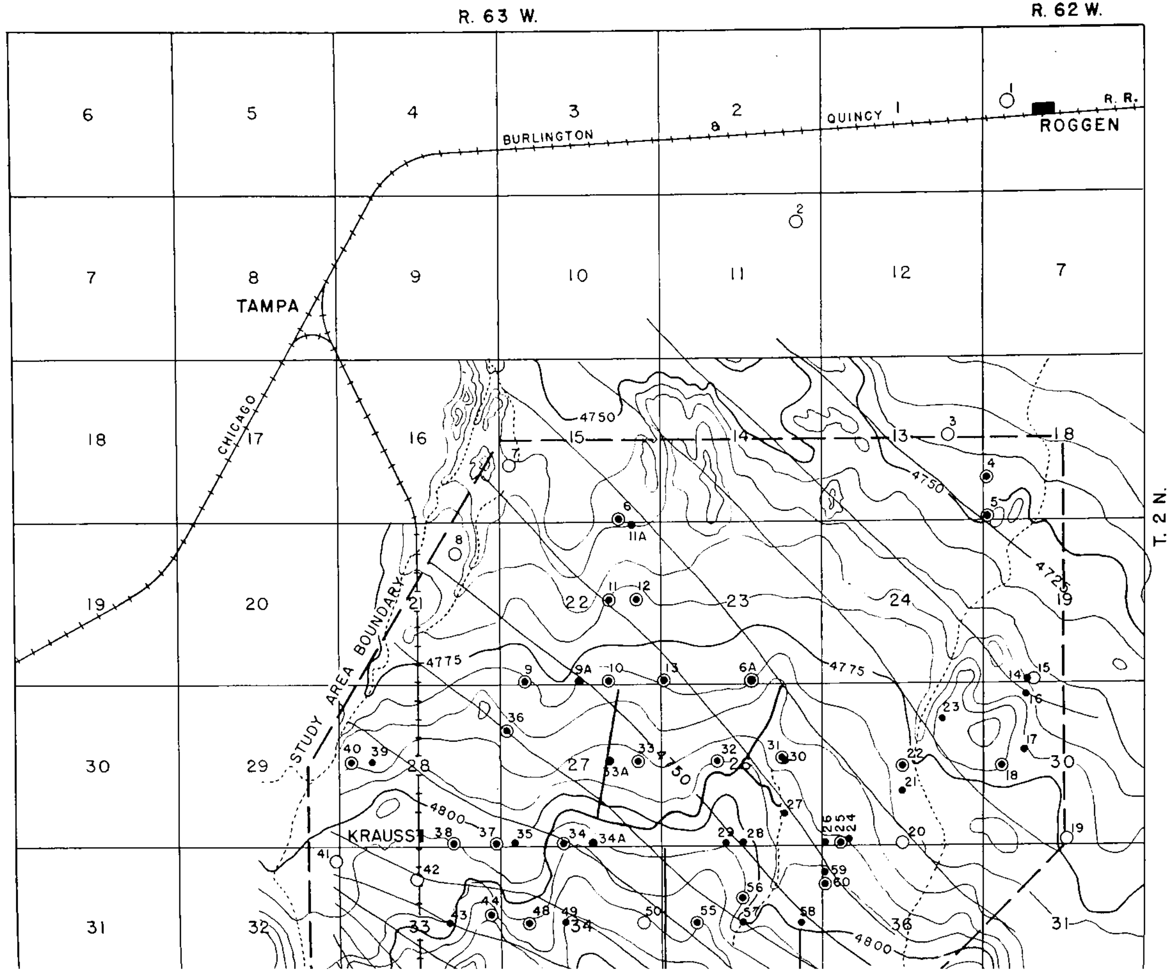


Figure 5.—Diesel engine equipment at Well Number 93.


R. 63 W.
R. 62 W.
T. 2 N.
ROGGEN
R. R.
QUINCY
BURLINGTON
CHICAGO
TAMPA
KRAUSS
STUDY AREA BOUNDARY
4725
4750
4775
4800

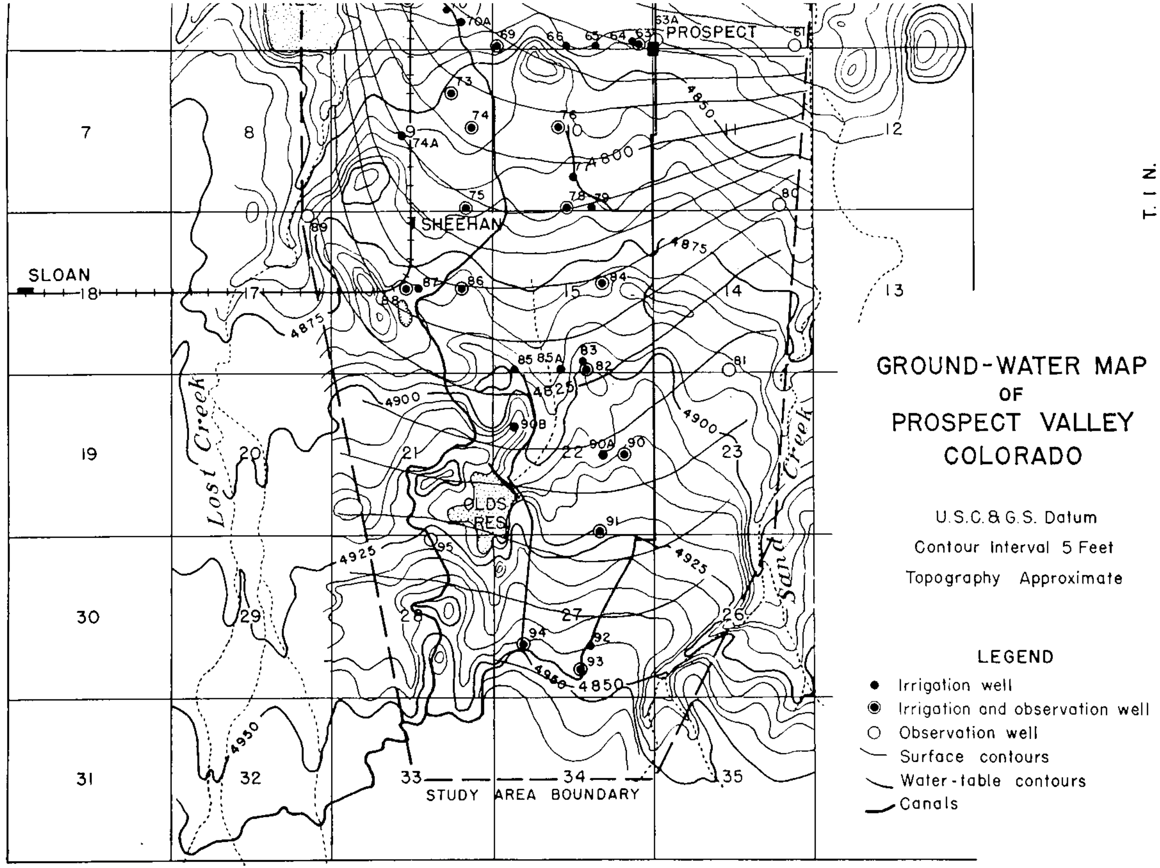


Figure 6.—Map of Prospect Valley showing topography (approximate) and ground-water contours of March 31, 1943. Depth to water may be determined at any point where the blue lines cross the black lines by computing the difference in elevation. Interpolation will be required at points where the lines do not cross.

pasture grasses which are cut for hay. In some years as much as 3,000 tons of hay is cut. Transpiration from grasses and evaporation as well as underground flow account for the water escaping naturally from the pumping area.

From the recollections of a number of early settlers, it is quite evident that following the inception of the irrigation project in 1912, the water table began to rise. In 1892 a domestic well was dug very close to well Number 3 at the north end of the area, and at that time the water table stood at about 24 feet. It remained at that stage until irrigation started, when it began to rise, reaching 16 feet in 1927. It now stands at about 21 feet. Between 1907 and 1930 the water table rose 25 feet in section 22 near well Number 10, and low land in the northwest quarter of that section became seeped. At Prospect the water table stood at about 80 feet in 1906. By 1928 it had risen to 45 feet. At a point 3 miles south of Prospect indications are that the water table rose 15 feet between 1915 and 1932. It is probable that the ground water reached its highest stage in 1931, the last good water year before pumping started.

The first irrigation well in the district was Number 15. This well was put down in 1929 but was used very little until 1940 and then was abandoned in 1941. Well Number 35 was put down early enough in 1932 for use that year. The following winter many test holes were drilled by an exploration company which determined quite closely the location of the old erosion channel and the areal extent of water-bearing gravels. As a result of these findings about 19 wells were drilled in 1933 and many more in 1934. By 1944, 87 wells were in operation.

In the beginning of well construction, several were started by first digging a pit by hand to the water surface, then completed by sinking 16- or 18-inch casing with a well-drilling machine. Until about 1937 all the wells were drilled with drop tools, but now the reversed rotary method is used almost exclusively. In this, a 42- to 50-inch hole is drilled, and, after setting an 18- or 20-inch casing, the space remaining is filled with screened gravel. Some casings 48 inches in diameter were sunk with orange-peel buckets. The few horizontal centrifugal pumps tried at first soon gave way to the turbine type now used exclusively. This area was in a way a proving ground for the high-speed Diesel engine. Many of them were used but as they wore out they were replaced by electric motors. Electricity became available for use the first time in 1940.

Observation of changes in the water table were begun in 1933 on four wells, this number being increased to eight in 1934.

For the purpose of this study the number of observation wells was increased to 63. The results of these measurements are plotted in figures 8, 9, and 10. They show a consistent and considerable decline from 1933 through 1941, a decline that would justify serious concern over the future water supply for the area. This study was made to establish a basis for estimating the length of time before economic exhaustion of the ground water would occur should the trend of the past persist and determining what conditions would be required to stabilize the water table at a new position. Fortunately water supply conditions were very favorable in 1942 and a substantial rise in the water table occurred, quite upsetting the previous trend. The problem was somewhat complicated by this change, but results from an analysis of the data were good. The situation has been greatly relieved, but it cannot be assumed that the threat of exhaustion has been removed.

Figure 7.—Pumping plant at Well Number 83.

Effect of Pumping and Replenishment on Water Table

To determine the shape of the water table and the reaction to influencing factors, every well in the area was investigated for its possible use in observing fluctuations. A total of 68 such wells were found, but the maximum number observed at any one time was several less because of losses from construction changes at the well openings, preventing their use. Gains in number resulted from the discovery of new wells. It would have been highly desirable to have had more wells at the borders of the area at the upper end. Measurements were made monthly, except during the winters, in 1942 and 1943. The old observation wells with records dating back to 1933 were included among them. Only two series of measurements were made in 1944. Since the elevation of all measuring points had been determined, it was possible to plot ground-water contours which show the shape of the water surface and the direction of flow. These contours are shown in blue on the map (figure 6). They show that for March 1943 a distinct trough exists at the upper end, the slopes are quite steep east of Lord Reservoir, and the ground-water movement is northward to a point near Prospect where it changes to a northeasterly direction in a broad flat stream.

The graphs of the water-table fluctuations reveal a summer decline followed by a winter rise of less magnitude except for the years 1939 and 1943 which followed periods of good surface water supplies. This cycle does not occur in those wells near the borders as shown in Numbers 4, 15 and 41 (figure 8). The first two are below the effect of immediate application of canal water and show the general effect of lessened outflow from the district. Number 41 shows the draining-out process as water from the sides flows toward the central depression caused by the pumping. On August 2, 1943 an automatic recorder was placed on well Number 63. This remained in operation until April 3, 1944 when it had to be removed. On April 27 the recorder was reinstalled in a well about 400 feet east (Number 63A), the existence of which had not been previously known. The first location was 230 feet from an operating well (Number 64), and its influence can be plainly seen (see figure 11). On the removal of the recorder from Number 63, a small irrigation pump was installed and although the record at Number 63A shows the influence from the two wells, the amplitude of the fluctuations is much less. The graph reproduced in figure 12 reveals the rather rapid recovery during the fall months followed by a gradual rise at nearly a constant rate. Well No. 95 near the upper end of Olds Reservoir, being unaffected directly by pumping, shows the effect of losses from that reservoir. Annual fluctuations in the pumping area south from Prospect are of greater amplitude than to the north. This might be expected since the eroded valley is much narrower to the south, making the reservoir capacity less and the side gradients steeper.

ANALYSIS OF DATA

Specific Yield

Specific yield by definition (3), is the ratio of the amount of water that a saturated sand will yield when drained, to the original gross volume of the sand. It is dependent on the fineness of the material, the assortment of sizes, and the elapsed time during which drainage takes place. Clays and silts yield very little water and they drain out at an extremely slow rate, while sands yield water freely and at a much faster rate. Specific yield has no relation to porosity. Sands may be of lower porosity than clays, but natural sands may have a specific yield of 32 percent, whereas that of clays may be as low as 1 percent.

Porosity may be very useful in the determination of specific

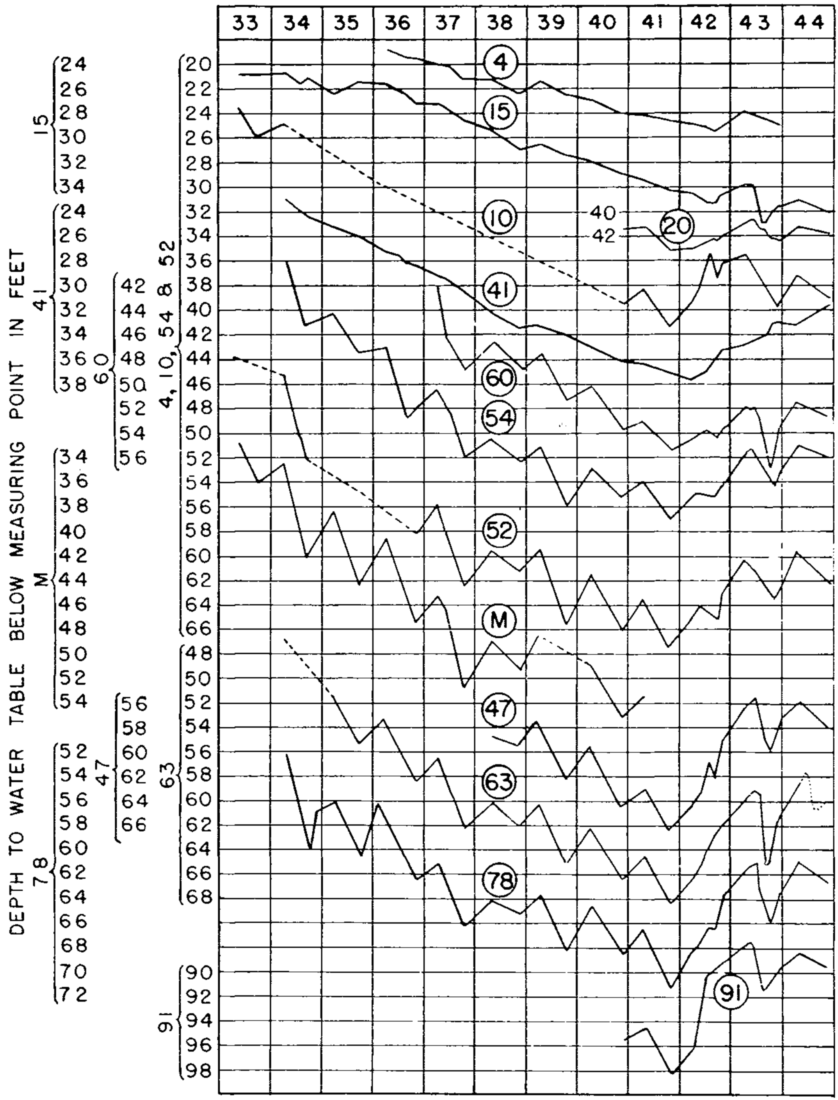


Figure 8.—Fluctuations in observation wells where 4 or more years of record are available.

yield in that when specific retention (the relative amount of water that a sample will retain against gravity drainage) can be determined, specific yield is calculated by subtracting specific retention from porosity. Specific retention can be computed by determining the moisture content of a thoroughly drained sample or by subjecting a small sample to a centrifuging process which

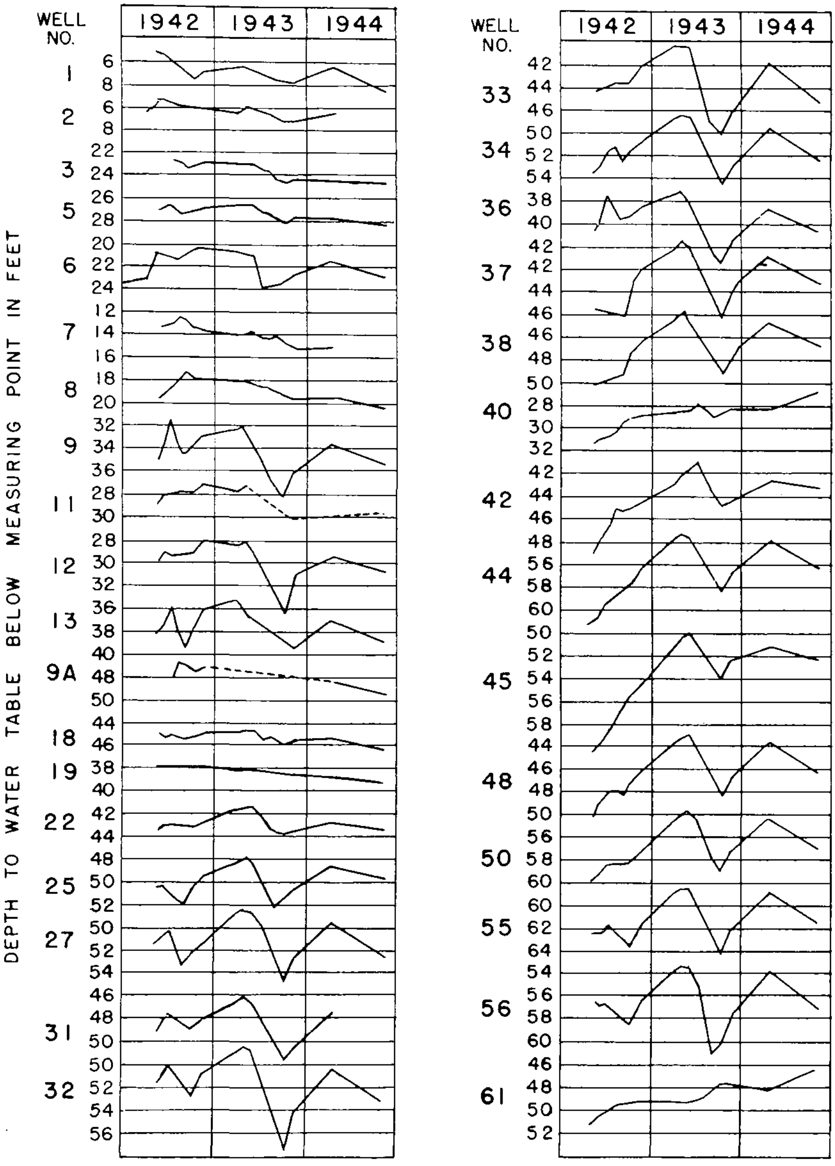


Figure 9.—Fluctuations in observation wells during period of study.

removes water under a driving force of 1000 times gravity. The difficulty with the latter method is that large particles usually occurring in gravel formations cannot be incorporated in a small sample. To make it at all useful the data previously obtained on work with soils have been extended and modified by A. M.

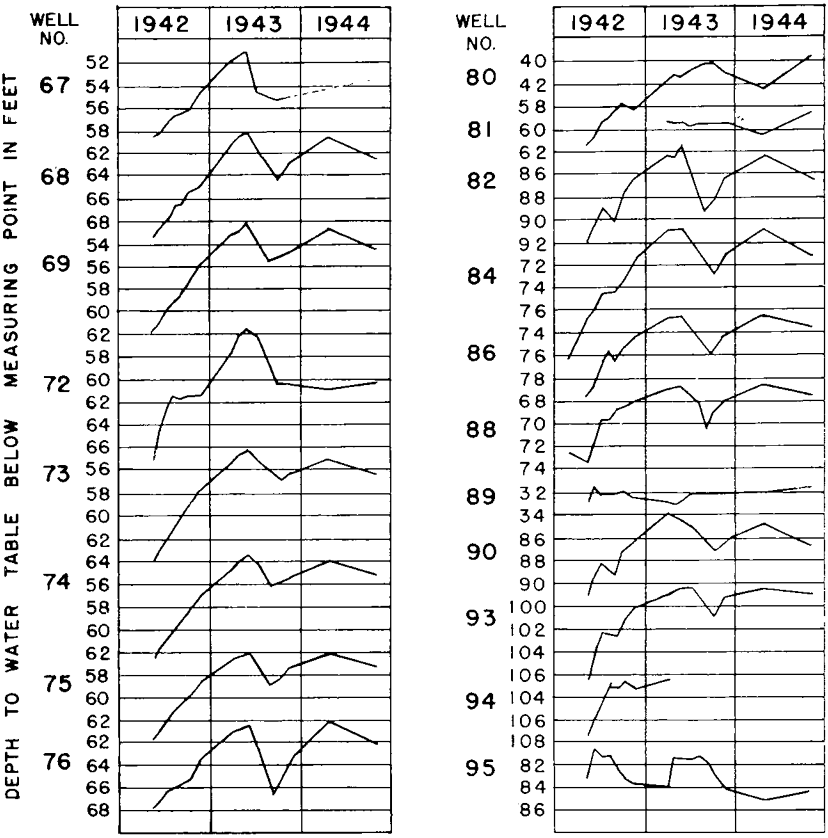


Figure 10.—Fluctuations in observation wells during period of study.

Piper (4) to apply to coarser materials. Cylinders may be driven into the natural formations and an undisturbed sample removed for laboratory experimentation. The gross volume of sample occupied by measured quantities of water added or withdrawn is noted in this case (5, 6, 7).

The simplest method is that of using well drillers' samples and repacking them in long cylinders so arranged that flooding or draining is possible. This later method was employed in the laboratory on samples from the Prospect area. Another method, an indirect one, has been suggested by Eckis and Gross (6) in which porosity and specific retention are computed from the character or mechanical composition of the sample. All the methods which have been used are subject to errors because of the complexity of the factors affecting the results. It is not possible to know if representative samples are being examined,

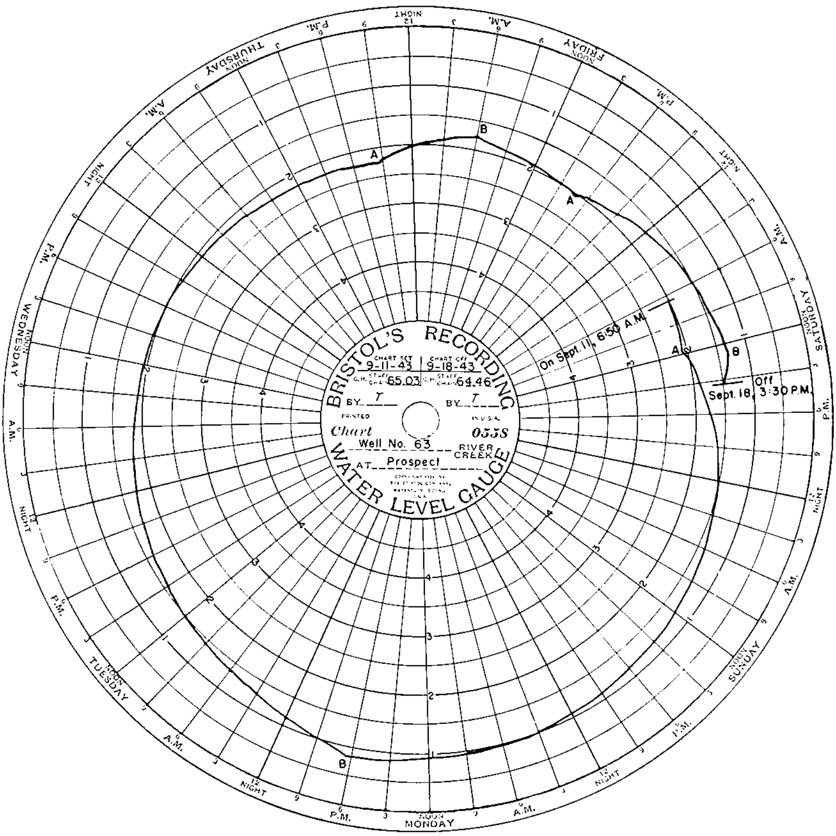


Figure 11.—Copy of original chart taken from recording instrument at Well Number 63. Points marked A indicate the stopping of Well Number 64, 230 feet distant. Points B indicate starting of pump.

and in testing by the draining method entrapped air which cannot be entirely eliminated accentuates the effect of temperature changes.

Since time is an important factor, great precaution is required to eliminate effects from evaporation. Repacked samples cannot have the identical characteristics of the material in place. Sands and gravels are likely to be deposited in thin strata, each stratum being composed of similar size particles. Such sorting would normally result in greater porosity and water yield than when all the strata are mixed together as in a driller's sample.

Specific yield in the field may be determined by observation of the volumetric change which would occur over a large

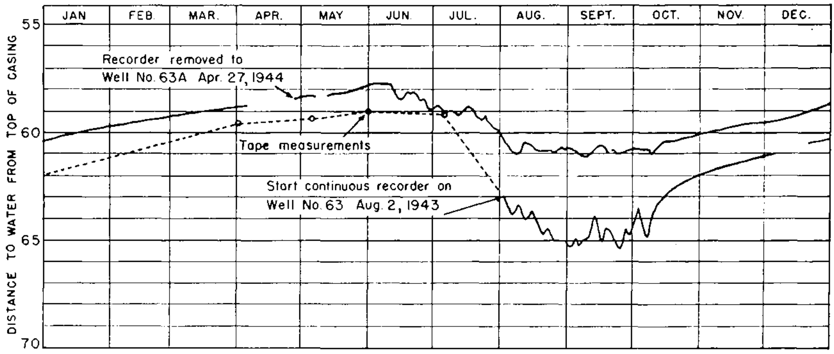


Figure 12.—Graphs of record obtained from continuous recording instrument at Wells Number 63 and 63A. The two records are joined on the same datum by subtracting an observed difference of 2.6 feet from readings at Well 63A.

area upon removal of a measured quantity of water. This method was employed by G.E.P. Smith (8) in a study of the Eloy ground-water district of Arizona. The volume of water can be computed in such a case by noting the discharge from pumps in the area. Specific yield also may be determined by detailed observation of conditions adjacent to a pumped well as reported by L. K. Wenzel (9) in a Nebraska study.

In the Prospect area specific yield was calculated both from field observation and in the laboratory from repacked well samples. To obtain the volume of unwatered sediments, contours of equal fall or rise which occurred within periods of irrigation activity and periods of rest were drawn on maps of the area. By planimeter the area under each contour was determined which permitted volume to be calculated. This method of computing gains and losses accounts for all inflow and outflow from the area. Calculations were made for the five use seasons from 1940 through 1944 and for four periods of non-use. Only for the years 1942 and 1943 were observations made in detail; the data for the other years cannot be considered of equal accuracy but are included because they offer valuable checks.

The amount of water pumped was determined in nearly all cases by measuring the discharge and applying the time of operation. The length of time electrically driven pumps were operated was calculated by dividing the total kilowatt consumption for the season by the observed power demand. This required the reading of meters at about monthly intervals. A very small percentage of record was lost by reason of change or damage to meters. In the case of engine-operated plants of which

TABLE 6.—*Data on*

Period		Water pumped	Water supplied through canals[A]	Water lost from canals, 1/3 of 4	Water lost from reservoirs	Water lost from laterals and fields, 15% of 3 and 4
Dates	Days					
1	2	3	4	5	6	7
		Ac.-ft.	Ac.-ft.	Ac.-ft.	Ac.-ft.	Ac.-ft.
Apr. 25, '40 to Nov. 30, '40	219	12,700	590	200		1,990
Nov. 30, '40 to May 5, '41	156					
May 5, '41 to Nov. 4, '41	183	12,000[B]	1,460	500		2,020
Nov. 4, '41 to Apr. 15, '42	162				1,530	
Apr. 15, '42 to Nov. 17, '42	216	6,500	11,600	4,000	3,660	2,720
Nov. 17, '42 to May 4, '43	168				2,900	
May 4, '43 to Nov. 17, '43	197	14,580	5,430	1,800	570	3,000
Nov. 17, '43 to Apr. 26, '44	161	25				
Apr. 26, '44 to Nov. 9, '44	197	13,100	7,470	2,500	1,330	3,100

A. Adjusted by adding 10 percent to reported figures.
B. A rate of 110 acre-feet per day has been assumed.

there were 24 in 1942 and 25 in 1943, only on 6 was it necessary to make quantity estimates, the remainder being covered by hour counters, daily records, or fuel consumption. The amount of water pumped in 1940 is based on a partial record, that of 1941 is entirely estimated, while calculation of the 1944 amount was based on electric power consumption or records on all but 22 plants, on which controlled estimates had to be made.

Table 6 summarizes the data relating to pumping, and in addition, the surface water supply, losses of surface water which replenish the ground waters, and the gross volumetric changes occurring, either gains or losses. In column 4 the figures on water delivered through the canal system have been increased 10 percent because the measuring weirs, by their construction, *Specific Yield Computations*

Total recharge	Gross volumetric changes indicated by water-table changes			Winter rate of recharge applied to summer drawdown[D] Gross volume	Volume of sediments that would be flooded by recharge 8[C]	Gross volume change caused by pumping, 11+12+13 or 12+13—9	Specific yield 3 ÷ 14
	Gain		Loss				
	Total	Daily rate	Total				
8	9	10	11	12	13	14	15
Ac.-ft.	Ac.-ft.	Ac.-ft.	Ac.-ft.	Ac.-ft.	Ac.-ft.	Ac.-ft.	Percent
2,190			39,100	24,100	12,900	76,100	16.7
	14,610	94					
2,520			38,100	20,100	14,800	73,000	16.4
1,530	20,410	126[E]					
10,380	46,900			23,800	61,100	38,000	17.1
2,900	26,630	158[E]					
5,370			30,300	21,700	31,600	83,600	17.4
	17,650	110					
6,930			11,500	21,700	40,800	74,000	17.8

C. Computed by using a specific yield of 17 percent.
D. Estimated.
E. Affected by losses from reservoirs.

will over-deliver about that much. The fraction of one-third applied to delivery figures in column 5 to determine the seepage losses from the canals was arrived at by three current meter measurements on various dates in 1942 and 1943 compared with reported deliveries from the Prospect canal only. It was assumed that the Low Line canal supplied similar losses. The seepage losses from both reservoirs are shown in column 6. All water diverted to Olds was considered lost while that from Lords was based on a uniform loss of 0.05 foot in depth per day while water was in storage. Columns 9, 10 and 11 give the gross volumetric gains or losses and the daily rate of winter gains.

The rate of gain for the winter of 1943-44 is considered best since that of the first year is based on inadequate data and during the following two winters, losses from reservoirs added to the rate of gain. For the purposes of this report the rate used in column 12 of 110 acre-feet per day is based on the 1943-1944 winter season. This would be water flowing into the area from the sides and south end, plus whatever water was in transit that had been added from deep percolation the previous season and was moving slowly downward through the soil column, minus the water flowing out of the area to the north. It was assumed that this rate could be applied to the summer pumping period and that all water lost during the pumping season reached the water table within the period. This may not be quite true but it is thought to have little effect on the problem.

The specific yield used in column 13, of 17 percent, was anticipated by trial and error methods. The specific yield in the final column is computed by dividing the amount of pumped water by the sum of columns 11, 12, and 13; or by the result of subtracting column 9 from 12 and 13 when there is an increase in ground-water storage. This use of an anticipated specific yield in column 13 may be criticized. This criticism would be valid were in not for the wide range of conditions to which it was applied. It was not possible here to set up equilibrium equations for solution without having one more unknown than the number of equations. There is every likelihood that specific yield would remain approximately constant since the water table moved back and forth through approximately the same soil material.

As a check on the field results, the specific yield of samples of gravel obtained with a sand bucket from newly drilled wells was determined in the laboratory. These samples were loaded into a 4-inch cylindrical can that would hold a sample 34 inches in length and were consolidated by tapping on the sides. Weight and volume were then determined and from them the apparent specific gravity was calculated. Apparent specific gravity divided by the specific gravity of the material equals percentage of voids and this subtracted from 100 equals porosity percentage. The sample was then flooded until a water table was established at from 12 to 16 inches below the surface. From 3 to 7 days was required before equilibrium was obtained and then a measured amount of water was slowly drained out. After this a period of from 5 to 28 days was allowed to elapse before the final reading was made.

Temperature of the sample was obtained from a thermometer attached to the side of the cylinder and the initial and final readings were take at the same temperature. The location of the cylinder was such that a variation in temperature of 5 to 6 degrees occurred regularly. The water table fluctuated considerably with the temperature, but by plotting scale readings against temperature, a straight-line variation was found and thus a scale reading for any included temperature was possible. Evaporation from the surface of three of the samples was prevented by a paraffin seal. Some samples appeared to be unaffected by evaporation, while others, in spite of a protective layer of dry sand, showed some evidence of water loss through evaporation.

A summary of results on the specific yield of eight samples is given in table 7. Samples 85A and 90A were too small to test separately, so they were loaded into the can one above the other and a foreign gravel of similar nature was added to provide space for a capillary fringe to form. Since entrapped air is always present and cannot be removed by ordinary means, an experiment designed to dissolve it was tried by passing water continuously for 28 days through the sample from well No. 56 (depth 55 feet). Following this procedure, water was withdrawn. The specific yield was found to have increased to 18.8 percent from a previous value of 15.9 percent, showing that some air had been removed. Water subsequently added indicated a return to the original air conditions.

The laboratory work done in this connection lacked the refinements employed by other investigators in this field but the results and their application are probably commensurate. A high degree of accuracy, although desirable, would have required more elaborate apparatus and closer temperature control. However, it is well known that tests of this character yield values of specific yield which are only approximate as compared with yields from the material in its natural state. Water was both withdrawn and added to each sample, and it was found that the results seldom checked, the difference being as much as 3 percent with no consistency appearing to indicate which method produced the higher values. The lowest value observed was 10.9 percent, the highest 18.8 percent, and the average 14.5 percent. These values are comparable in magnitude with the field value, but agreement was not expected.

There is no way of being assured that these eight samples represent the average water-bearing gravels and as mentioned previously, repacked samples should give lower values. The field value of 17 percent specific yield is not that of sand and gravels only, but includes clays. Logs of about 100 wells sufficiently distributed over the area indicate that the material in the region of water table movement is about 30 percent clay, for which specific yield is negligible. Thus it would appear that the sands and gravels alone might have a specific yield of about 24 percent.

TABLE 7.—*Specific yield of eight samples of gravel from Prospect wells.*

Well Number	Depth at which sample was taken	Column length	Porosity	Effective size of sand	Depth to water table	Column length: Flooded	Column length: Unwatered	Specific yield or absorption	Elapsed time
	Feet	Feet	Percent	Mm	Feet	Feet	Feet	Percent	Hours
9A	80	2.590	30.2	0.30	2.26		.924	11.9	175
					1.45	.798		12.9	207
11A	70	2.779	20.2	0.24	2.48		.495	15.4	457
					1.32	1.430		12.3	308
32(near)	60	2.413	32.3	0.32	1.58		.320	18.1	23
					1.90		.319	18.0	26
					0.96	.849		18.8	162
34A	115	2.237	29.7	0.22	1.78		.618	12.6	48
					1.40	.581		13.0	534
56(near)	55	2.810		0.39	2.30		.883	13.1	147
					1.55	.752		15.9	336
					1.93		.855	18.8	168*
					1.10	.831		15.8	264
56(near)	80	2.277	31.7	0.37	1.89		.840	16.1	23
					1.14	.749		15.6	26
85A	95	1.106			1.84		.591	13.3	116†
90A	140	0.860			2.30		.468	18.1	147†
85A and 90A combined		2.730			1.40	.901		17.6	216

*Preceded by passing water through sample continuously for 28 days.
†These two samples were loaded in cylinder one above the other.

For comparison, the values of specific yield as found elsewhere by investigators in this field may be interesting. Smith (8) computed values from 8.9 and 13.4 percent for the Eloy district in Arizona. Eckis and Gross (6), in their report on the South Coastal Basin, evaluated areas of equal specific yield by weighing well log descriptions and arrived at these values: San Fernando Valley 3 to 16 percent; San Gabriel Valley, 4 to 20 percent; Upper Santa Ana Valley, 4 to 18 percent; and the Coastal Plain 6 to 22 percent. They based their data on laboratory tests of all grades of gravel, sand, and sandy clay. A specific yield of about 14 percent was found for coarse gravel, 32 percent for coarse sand, and 10 percent for sandy clay. From a pumping experiment near Grand Island, Nebraska, in 1931 Wenzel (9) computed the specific yield of 22 percent for gravels within the cone of influence. An intensive study of the Mokelumne area in California reported by Piper et al (7) shows laboratory values of specific yields of about 35 percent for gravel and coarse sand, 24 percent for medium and fine sand, and 4 percent for very fine sand, silt, and clay. In an earlier report on this area a field value of 10 percent was used.

Conditions for Equilibrium

Ground water has been drawn from storage in the Prospect pumping area each year beginning with 1933 except for 1938, 1942, and 1944. This is evident from an examination of the water-table fluctuations as shown in the graphs (figures 8, 9, and 10). An approximate balance occurred in 1938 between use and replenishment. It was previously estimated (1) that about 9,000 acre-feet was pumped from the ground water supply and about 7,300 acre-feet delivered to it through canals. Unknown quantities were diverted to Olds and Lord reservoirs in that year. On a proportionate basis, about 55 percent of the water was pumped. In 1940 about 96 percent was pumped with an average lowering of the water table of about 1.9 feet within the study area boundary of 19,000 acres. In 1941, the estimated figures show that 89 percent was pumped and the lowering was only 0.9 foot. This decrease in lowering was attributed to winter flows into reservoirs. In 1942, 36 percent of the total water used was pumped, and an average rise of 3.9 feet occurred. In 1943, 73 percent was pumped, and the average lowering was about 0.2 foot. In 1944, 64 percent was pumped, and an average rise of 0.3 foot occurred. Losses from reservoirs influenced conditions in all of the last 3 years.

If D is taken as the total annual water demand, m the proportion of that total that is pumped, and 17 percent the specific yield, an equilibrium equation for periods when there is no net gain or loss in ground-water storage may be written as follows:

$$Dm = \frac{D\ (1-m)}{3} + .15\,D + (110 \times 365)\ 0.17 \qquad (1)$$

The quantity on the left side of the equation is the amount of water pumped. The quantities on the right side of the equation add up to the necessary replenishment to balance it. The first quantity on the right side is the loss from canals, the second is the loss from field irrigation, and the last is the net rate of inflow, or column 10 in table 6.

The equation reduces to:

$$1.333\ Dm - 0.483D - 6830 = 0 \qquad (2)$$

from which

$$m = 0.362 + \frac{5120}{D} \qquad (3)$$

When D is chosen as 20,000 acre-feet, m is 62 percent; when D is 18,000 acre-feet m is 65 percent; and when D is 16,000 acre-feet m is 68 percent. Should water be stored in Olds or Lord Reservoir, the value of m will increase because whatever is added to the ground water by leakage from the reservoirs will be available for pumping. Thus an addition of 2,000 acre-feet to the ground-water supply from these sources will increase the value of m to 69, 73, and 78 percent, respectively.

The foregoing computations are based on the conditions as they now exist. It is not reasonable to expect frequent occurrences of good water years such as 1942, but it should be permissible to anticipate a surface water-supply equal to an average of all the years of record, which is 4,650 acre-feet as shown in table 4. Using 5,000 acre-feet as an adjusted figure, because of over-delivery, 500 acre-feet as the contribution from reservoirs, and 18,000 acre-feet as the irrigation demand, the calculated value of m in the equilibrium equation (2) becomes 67 percent. A further consideration which appears evident and must be taken into account is that, as the water table lowers, the depth of inflow from the sides of the area will decrease, hence those contributions will decrease. That quantity, which is approximately expressed in column 10, table 6, and considered as 6,620 acre-feet of water annually under present conditions could no doubt decline 20 percent in a few years of adverse conditions. This is somewhat indicated by the quantity computed for the winter

TABLE 8.—*Apportionment in acre-feet of the total water requirement as computed from equations (4) and (5) to provide equilibrium.*

Total water requirement	No water stored in reservoirs		500 acre-feet lost from reservoirs	
	From pumps	From canals	From pumps	From canals
20,000	11,300	8,700	11,700	8,300
18,000	10,600	7,400	11,000	7,000
16,000	9,900	6,100	10,200	5,800
14,000	9,200	4,800	9,600	4,400
12,000	8,400	3,600	8,800	3,200

of 1940-1941. Should these conditions occur, then equation (2) becomes

$$1.333\,Dm - 0.483D - (88 \times 365 \times .17) = 0 \qquad (4)$$

and

$$m = 0.362 + \frac{4100}{D} \qquad (5)$$

The quantities in table 8 are computed for these conditions.

If the previously mentioned average figure of 5,000 acre-feet annually is taken as the surface supply and 500 acre-feet as a contribution possible from reservoir losses, it will be seen under the last column of table 8 that 5,000 falls between 4,400 and 5,800. By interpolating between these numbers, a value is found indicating **that the total annual water requirement should be planned not to exceed 14,900 acre-feet and that part of this amount of water which is to be pumped should not exceed 9,860 acre feet.** It goes without saying that the present demand for water exceeds 14,900 acre-feet and that quantities removed by pumping have exceeded the proportions expressed as safe in the preceding discussion. The potentialities are present for continued withdrawal from storage and a corresponding continued lowering of the water table.

There is in actual storage beneath these lands 170,000 acre-feet of free water, as computed by using a specific yield of 17 percent. Of this about 100,000 acre-feet may be considered as dead storage in that it would not be economical to operate the pumps when so low a stage is reached. The removal of 70,000 acre-feet from storage would involve a general lowering of about 30 feet from the present stage. At this time the output of the best situated wells would be reduced in the neighborhood of 35 percent and many others as much as 75 percent. The efficiency of the present pumps would be severely reduced, since the power requirements will remain approximately constant but the water output will be much less.

The time required to lower the water table 30 feet of course is not predictable with accuracy, since the surface supply is not predictable. Should conditions prevail that would require an annual withdrawal from storage of 4,000 acre-feet, the water table would be lowered 30 feet in 18 years. If 5,000 acre-feet were removed this would be accomplished in 14 years. More than 5,000 acre-feet has been withdrawn a number of times in the past.

A study of the graphs of water-table fluctuations in 11 wells where observations were made over a period of 8 or 9 years shows that the average annual decline previous to 1942 was 1.9 feet. The net average would be less than 1.9 feet because perimeter wells are lacking. It is safe to assume that during this period more than 5,000 acre-feet were drawn from storage in each year except 1938. A decline of 1.9 feet annually would bring about a 30-foot lowering in 16 years.

Remedial Measures

The only solution of the problem of maintaining a stable water table, should the present demand continue, is the importation of more water. There seems no opportunity to effect this except through the contemplated Blue River trans-mountain diversion plan. This project would not only provide an ample supply for the Henrylyn Irrigation District but for much new land as well. Because of its great cost and complicated economic aspects, its building may occur only in the distant future.

Besides the use of Olds Reservoir for water spreading, some similar use might be made of Sand Creek Reservoir as a means of increasing the ground-water supply. Materials at hand for repairing the breach in the dam are rather sandy but still might be satisfactory if flat slopes were employed. The repaired portion need not be built as high as the remaining portions of the dam for the reservoir to function for the temporary detention of surface flows. A spillway would be required and probably would have to be built into the dam. An outlet continuously open to pass only such flows as would be absorbed in the first mile below the reservoir would increase the spreading area and reduce the depth of impounded water. All water lost from this source would become available as ground water for the pumping area. The dam would also prevent the flood damage to roads and farm lands that now occurs. There are years when such a reservoir would receive no water, but at times several hundred acre-feet could be captured. Because of this uncertainty no large sum of money should be spent for such works.

Probably the choice of really effective measures is between voluntary curtailment of pumping and continuing pumping on the present scale until a time is reached when part of the plants will cease to operate, thus automatically creating a balance in water supplies that will establish a water-table equilibrium at a lower level. Even if plants are not abandoned it is conceivable that their rate of output could be so low as to make it impossible to cover the present area even with continuous pumping. The alternative choice, the voluntary curtailment of pumping, would not be easy to put into effect. The finding of an acceptable curtailment formula would be a rather difficult task. It could well be based on a percentage of lands now being served with pumps but other influencing factors enter also. Not all the lands receive water from the canal system nor do all lands receiving canal water receive like proportions. Another consideration is that of seniority of use, a fundamental upon which all irrigation in Colorado is predicted.

One needs to be realistic in putting forth a plan of voluntary cooperation in limiting the pumping in any such area as this. There is nothing to keep all users strictly in line and anyone may abrogate an agreement when he chooses. The only effective plan would be to form a legally constituted district which would vote itself police powers to enforce conformity to a plan which would be of its own making. A legislative enabling act would be required to form such a district.

SUMMARY AND CONCLUSIONS

Prospect Valley, comprising about 12,500 irrigated acres, is a part of the Henrylyn Irrigation District which diverts water from the South Platte River at the north edge of Denver. The Valley is underlaid by good water-bearing gravels deposited in an old erosion channel which offers excellent opportunities for obtaining irrigation wells. The water table now stands at from 25 to 100 feet below the ground surface.

Extreme water shortage in 1932 forced the residents of the Valley to search for a supplemental ground-water supply. In this they were successful and a well-drilling program started which has continued to the present time. From the beginning the effect of pumping on the water table was noticeable. Measurements in a few wells at the start with more added later indicated a drop of nearly 2.5 feet annually in the central part of the pumping area. A more intensive study of the situation begun in 1942 was continued into 1944. During this period, the number of operated wells increased from 68 to 87.

During the period 1942 to 1944 the surface water supply was considerably above the average, and in 1942 the water table rose. However, in 1943 and 1944 it declined. Methods of conducting the field work involved the establishment of an arbitrary study area and permitted computation of the specific yield of the materials in the zone of water-table fluctuation. This specific yield figure is necessary for the determination of the quantity of water in storage and appeared to be about 17 percent. Laboratory tests on 8 samples of gravels obtained from wells being drilled indicated a specific yield of about 15 percent. Water-table fluctuations revealed the effect of pumping, the losses from reservoirs and irrigation, and the replenishment from other sources. Analysis of the data indicated that with the average surface water supply of 5,500 acre-feet, the safe yield of water from underground sources was about 9,860 acre-feet. With the indicated field duty of 1.8 acre-feet per acre, the irrigated area would thus be limited to about 8,300 acres. This would necessitate a reduction of about 4,000 acres from the present irrigated area. Should water conditions prevail as in average years and the present area be maintained, indications are that economic exhaustion would occur in from 14 to 18 years. Before that time exhaustion symptoms would be severely felt in some portions of the Valley.

It appears certain that the surface water supply must be increased if the present irrigated area of 12,500 acres is maintained. Since an increased water supply does not appear likely in the near future, the alternative of a reduction of the area or any program that will reduce the draft on the ground water seems necessary for a stabilized water table.

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