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GROUND WATER IN THE ESCALANTE VALLEY, BEAVER, IRON, AND WASHINGTON COUNTIES, UTAH

(A progress report)

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ABSTRACT

Escalante Valley in southwestern Utah is one of the largest and most important ground-water areas of the State, with 1,300 square miles of arid land and an additional 1,500 square miles in its tributary drainage basin. Ground water is obtained from gravel and sand beds in the unconsolidated valley fill. In 1950 more irrigation wells were pumped than in any other basin of Utah, and their total pumpage exceeded 80,000 acre-feet. Farming is done chiefly in the Beryl-Enterprise district at the south (upper) end of the valley, where it depends almost entirely upon ground water, and in the Milford and Minersville districts in the northeast-central part of the valley. This progress report concerns chiefly the Beryl-Enterprise and Milford districts.

The Beryl-Enterprise district has about 190 irrigation wells, which have yields ranging from 400 to 2,500 gallons per minute, and the total pumpage was more than 50,000 acre-feet in 1950. This pumpage is probably several times as great as the annual recharge to the ground-water reservoir. Natural discharge, believed to be less than 10,000 acre-feet per year, can be eliminated economically only by extensive mining of ground water in the higher areas now under cultivation, because the low medial part of the district is unsuitable for farming as the result of excessive alkali in its soil. The valley fill of this district probably contains several million acre-feet of ground water that could be extracted over a period of several decades to support present or greater development.

Pumpage in the Milford district in 1950 was about 32,000 acre-feet, from about 125 irrigation wells, which had a large

range in yield. The chief problem of this district is the close relation between surface water and ground water resulting from the fact that ground-water recharge for more than three decades has been materially affected by diversion of the Beaver River from its natural channel over its alluvial fan. Proposed changes in the pattern of diversion might have serious effects upon the ground-water recharge.

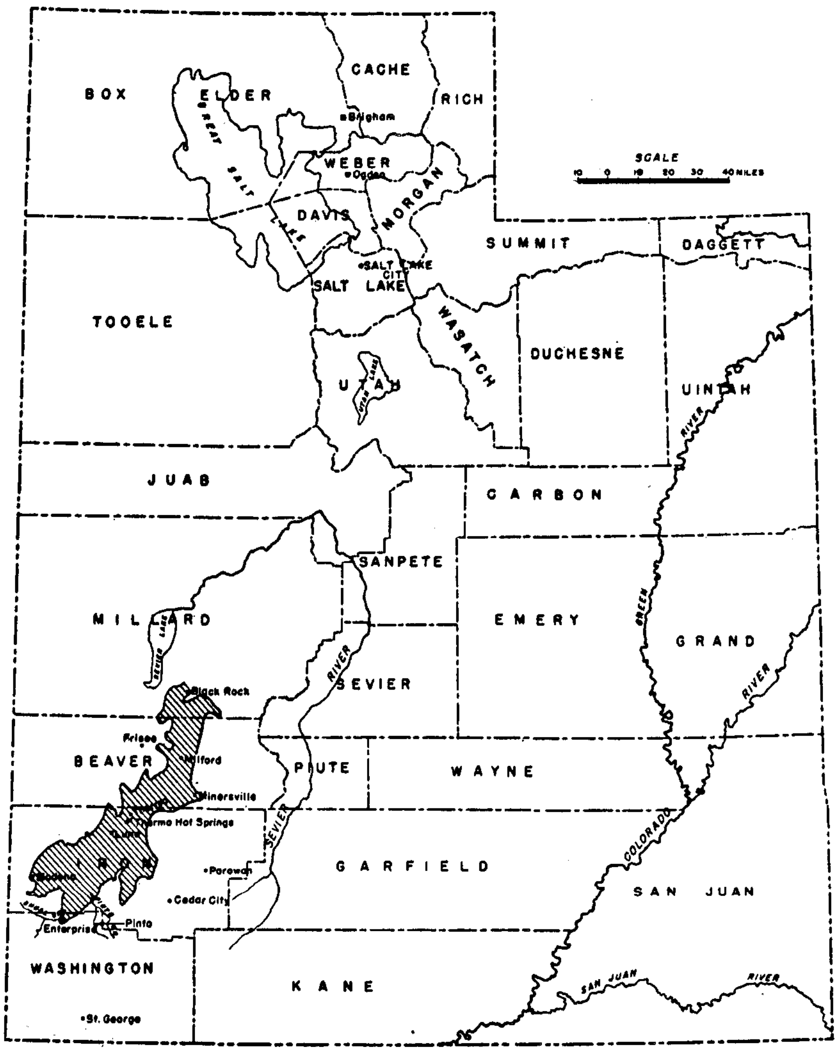


Fig. 1. Index map of Utah showing location of Escalante Valley.

I. INTRODUCTION

Escalante Valley[1] in southwestern Utah (fig. 1) is one of the largest and most important ground-water areas in the State. The valley has an area of about 1,300 square miles, and the drainage basin tributary to it is about 1,500 square miles additional.[2] The valley is traversed by the Los Angeles-Salt Lake line of the Union Pacific Railroad from Black Rock to the Nevada State line, a distance of about 100 miles.

The inhabitants of the valley in 1940 numbered fewer than 4,000; most of them lived in Milford (1,390), Enterprise (620), and Minersville (570). Since 1944 the population has increased, chiefly in rural areas, and the 1950 census may list as many as 5,000 persons in the valley. This marked change from the declining trend of the preceding decade reflects the transition from desert wasteland or long-abandoned dry-farm land to fields of irrigated crops. (pl. I)

In 1950 more irrigation wells were pumped in Escalante Valley than in any other area of ground-water development in Utah. A typical large irrigation well is shown in plate II. The quantity of water discharged from these wells—about 80,000 acre-feet—was undoubtedly greater than the use from any other of the State's ground-water reservoirs. Since 1940 the number of irrigation wells has trebled, and the pumpage from them has more than quadrupled.

It is because of this ground-water development that the

1—Not to be confused with the town of Escalante, Utah, nor the Escalante River, which are more than 60 miles to the east, in the Colorado River basin.

2—This does not include the drainage basins of Beaver Valley (550 square miles) and Cedar City and Parowan Valleys (1,100 square miles), which are east of Escalante Valley proper. Outflow from Beaver Valley reaches Escalante Valley via the Beaver River at Minersville, but there is no outflow from the other two valleys under present climatic conditions.

Plate I-A—The Beryl-Enterprise district of Escalante Valley at Table Buttes.

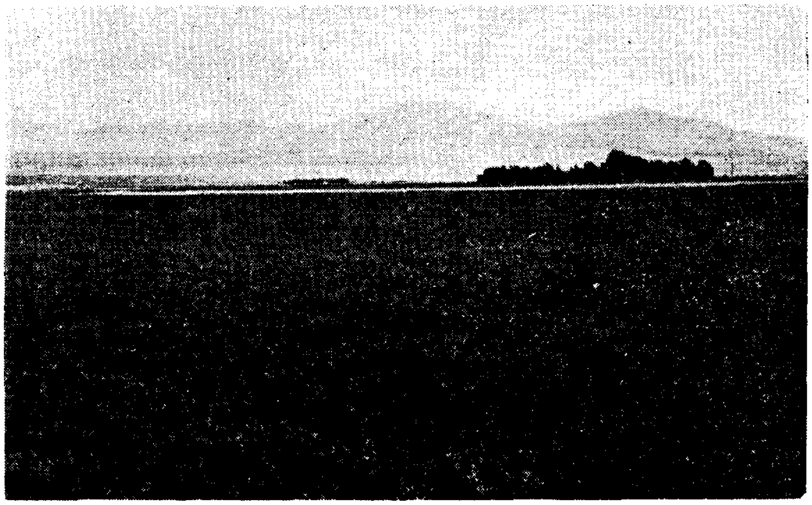


Plate I-B—Irrigated alfalfa in the Milford district, Escalante Valley.

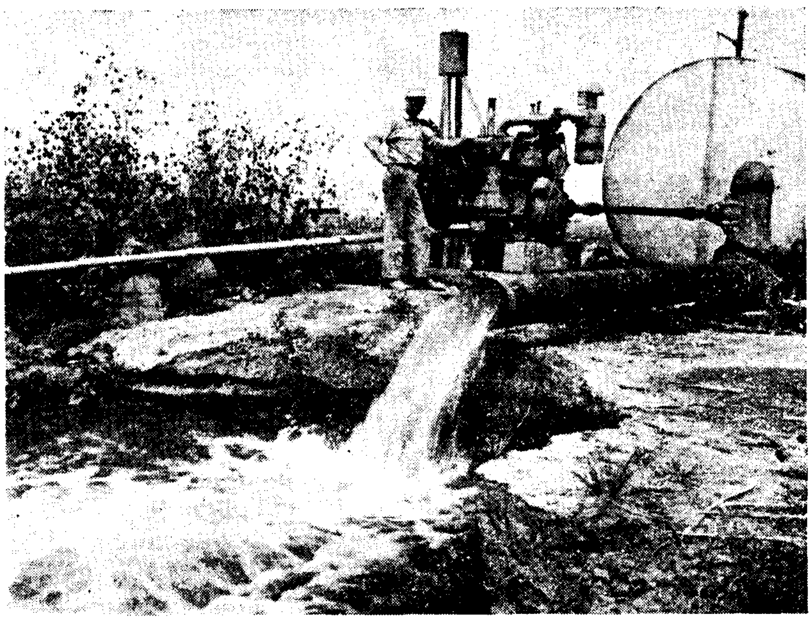


Plate II—The Russell Mayer well, (C-29-10)18add-1, near Milford discharges about 5 second-feet.

Plate III-A—Irrigated potatoes near Milford.

Plate III-B—Harvesting potatoes on the M. F. Persons farm near Milford.

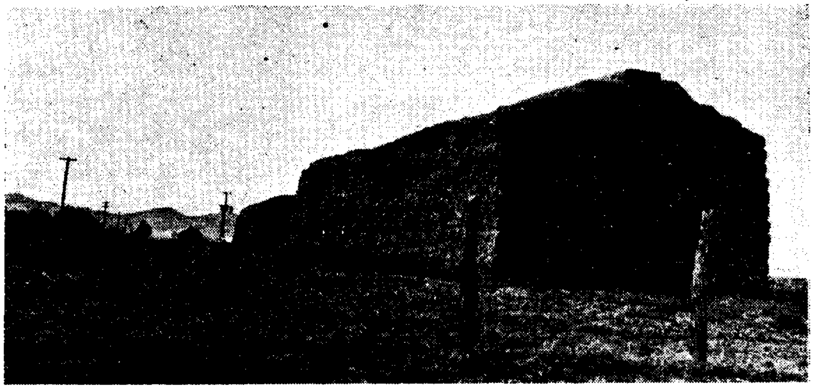


Plate IV-A—Alfalfa hay on the Weyl-Zuckerman farm near Enterprise.

Plate IV-B—Second crop of alfalfa on the Wilson Scott farm near Enterprise, 1950.

productivity and wealth, as well as the population, of the valley have increased so greatly in the past decade. Good land with a reliable water right is at a premium in the valley. An acre of typical land that was sold in 1945 as rough sagebrush land for $8.00 raised an irrigated crop of 400 bushels of potatoes in 1950 and was valued at more than $200.00. The largest irrigated farm in Utah, having more than 3,500 acres under cultivation, is a short distance northeast of Enterprise. Potatoes (pl. III), hay (pl. IV), and grain are at

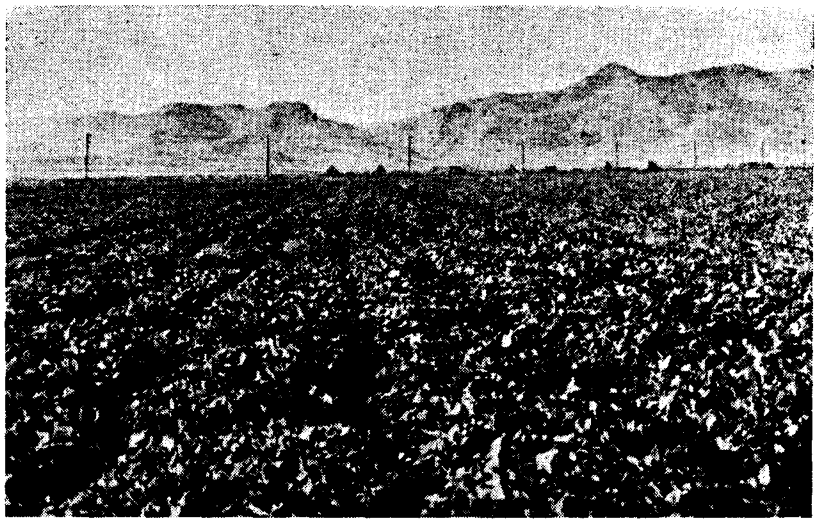


Plate V-A—Turnips on the Pancho Jimenez farm near Newcastle.

Plate V-B—Carrots on the Bruno Biasi farm near Beryl.

present the most important crops in Escalante Valley. Production of livestock, sugar beets, carrots, and other vegetables is increasing rapidly (pl. V).

COOPERATIVE INVESTIGATIONS OF WATER RESOURCES

The State of Utah, like other States in the arid West, has long realized the critical importance of water to its entire economy. For nearly half a century, investigations of the resources of surface water and ground water have been made in various parts of the State, by cooperative agreement between the Utah State Engineer and the United States Geological Survey.

Long before there was any significant use of water from wells in Escalante Valley, these cooperative investigations led to reconnaissance reports on the availability of ground water in an extensive area which included that valley.[3] Similarly by cooperative agreement, the flow of the Beaver River near Minersville has been measured since 1914.

The Utah Legislature in 1935 enacted legislation which declared all waters of the State to be the property of the public, and required the State Engineer to administer ground water in substantially the same manner as surface water, according to the doctrine of prior appropriation for beneficial use. The State Engineer was authorized to cooperate with the Geological Survey for the purpose of making a survey of the ground-water supply of the State, and arrangements for a cooperative investigation were made accordingly. These studies have continued to the present time.

In the early years of this State-wide program the principal effort in Escalante Valley was directed toward collection of records of water-level fluctuations in selected wells in both developed and undeveloped ground-water reservoirs. Many of these records now span a period of 12 years or more, including some years of deficient precipitation and runoff as well as some years when water supplies have been relatively abundant. These records have been invaluable in analyzing the effects of wells drilled in recent years, for in many places they show the conditions in years prior to that development.

In the biennium ended June 30, 1950, most of the work

3—Lee, W. T., Water resources of Beaver Valley, Utah: U. S. Geol. Survey Water-Supply Paper 217, 54 pp., 1908.
Meinzer, O. E., Ground water in Juab, Millard, and Iron Counties, Utah. U. S. Geol. Survey Water-Supply Paper 277, 158 pp., 1911.

under the cooperative ground-water program was devoted to an intensive investigation of the two areas of heavy pumping in Escalante Valley: the Beryl-Enterprise district and the Milford district. The purpose of these studies has been to gain more knowledge concerning the ground-water reservoir and the quantity of water stored in it; the replenishment to the ground-water reservoir, and where and when it occurs; the quantity and quality of water that is discharged from the reservoir by all methods; and the effect upon the reservoir of pumping from wells and other types of water development. Much more investigation remains to be done, both in the developed districts where additional development may occur in the future, and in the parts of the valley that lie beyond these areas of development. The present report is a progress report on these studies.

The State Engineer has provided information concerning the locations of wells, elevations of bench marks established at each well constructed prior to 1940, many of the photographs used in this report, and available drillers' logs of wells. (For wells constructed since 1935 drillers have been required by law to furnish copies of logs to the State Engineer). In addition, the State Engineer has prepared topographic maps of the Beryl and Milford pumping districts, based on information collected during his well surveys. Records in his office contain information as to the depth and diameter, date of completion, use, and yield of existing wells, and similar facts for proposed wells covered by applications. Since 1941 the administration of the State ground-water law has been under the immediate direction of J. A. Ward, Senior Ground-Water Engineer of the State Engineer's office.

The investigation during the biennium was directed by the senior author, who is Acting District Geologist, under the general supervision of A. N. Sayre, Chief of the Ground Water Branch, U. S. Geological Survey. Messrs. Nelson and Lofgren respectively were responsible for the work in the Milford and Beryl-Enterprise districts. Arthur Barlocker, Gael Elmer, and Howard Gospill have operated the recording gages and made other measurements of water levels in the observation wells for a number of years. The chemical analyses by the Geological Survey in 1949-50 were made under the direction of C. S. Howard, Regional Chemist of the Quality of Water Branch, U. S. Geological Survey, who also aided in preparation of the material on quality of water

in the report. H. E. Thomas, of the Ground-Water Branch of the Geological Survey, intensively reviewed, and extensively revised, the report.

ACKNOWLEDGMENTS

This investigation has been facilitated by many persons and agencies to whom the authors wish to acknowledge their gratitude. The Union Pacific Railroad Co., the Telluride Power Co., the Southern Utah Power Co., and the Rural Electrification Administration furnished much helpful information. The United States Department of Agriculture and the Utah Agricultural Experiment Station furnished unpublished soil-survey maps and notes that were used freely. Grant Clove, George C. Goodwin, Frank Hard, Albert Holt, T. W. Jones, Kay Knell, John C. McGarry, Austin Moyle, Don Olmstead, and McCoy Williams permitted installation of recording gages on their wells that provided essential data as to ground-water conditions. Well drillers and residents of the area likewise furnished helpful information or contributed to the investigation in other ways.

II. GENERAL FEATURES IN RELATION TO WATER RESOURCES

Essentially all water used throughout the Nation for municipal, industrial, irrigation, domestic, and other purposes comes ultimately from precipitation upon the continent, and is known as meteoric water. Geologists know of other but negligibly minor sources: water from volcanic (magmatic) sources deep in the earth that may be coming to the surface for the first time, and that contributes to the flow of some thermal springs; water that has been trapped for geologic ages in sedimentary rocks but that originally was meteoric; and water yielded as a product of decomposition or chemical changes in minerals. These sources, however, are of slight importance to man because of the small amount and the generally high mineral content of the water.

Nearly all the water in the Escalante Valley area is of meteoric origin, although one or more of the minor sources may be represented in the waters of the hot springs and mines of the area. To the extent that the supply of meteoric water is renewable, it is dependent upon a natural circulation of water that is known as the *hydrologic cycle*. By this circulation, water that falls as rain or snow may move as a liquid over the surface or underground, always under the influence of gravity, but it eventually reaches places – lakes, marshes, river banks, or the sea—where it is returned to the atmosphere by evaporation or transpiration.

The disposal of water moving through the hydrologic cycle follows definite priorities. Some of the water that falls as precipitation is returned to the atmosphere immediately by evaporation from the surfaces of roofs, roads, vegetation, and similar objects, upon or above the land surface. The soil or surficial rock has the next priority, and overland runoff does not occur unless or until the rate of precipitation exceeds the rate at which that surface layer can absorb water. The soil holds water by molecular attraction against the force of gravity until it reaches its water-holding capacity, and not until then does water start to percolate downward.

Ground-water reservoirs receive the water that percolates downward from the soil zone. These reservoirs, or aquifers, are composed of materials sufficiently permeable that water can move through them under the influence of gravity. Ground water accumulates until the reservoir is filled sufficiently to overflow through springs or seeps, or until the water level rises near enough to the surface for water to be discharged by evaporation or by transpiration. Streams generally have the lowest priority on the water that falls as precipitation, for water that has escaped evaporation enters them only if it falls directly in the channel, or if it cannot get into the ground by infiltration, or if it is discharged into them from ground-water reservoirs. After water has reached a stream it may be lost by evaporation from the stream's surface or from its wetted banks, or disappear by seepage into a ground-water reservoir, or reach the terminus of the stream in a playa lake or in the sea, where it is evaporated and begins the cycle once more. Occasionally, when the soil is frozen, streams have a higher priority than normally because water that ordinarily would enter the soil is shed from it.

The contrasts in the ground-water resources as well as surface-water resources of various parts of the Nation are traceable to differences in rates of precipitation and other climatic factors, and to differences in the materials in and below the soil zone, through which the water may pass. In the Escalante Valley, as in other areas, the climatologic setting and the geologic setting are important factors in determining the water supplies available for development.

CLIMATOLOGIC SETTING

The climate of Escalante Valley is less conducive to success in agriculture than that of many of Utah's valleys. Precipitation averages only about 8 to 11 inches per year. Most of the drainage basin tributary to Escalante Valley is nearly as arid, but it includes parts of mountain ranges and plateaus with crest elevations of 10,000 feet or more, where the annual precipitation is commonly several times greater than that upon the Escalante Valley floor. The average length of the growing season, according to U. S. Weather Bureau records, ranges from about 105 days in the vicinity of Black Rock to 138 days in the vicinity of Modena. The relatively high wind velocity is another obstacle to successful farming; official records indicate that the average wind velocity is about 30 percent greater than at Salt Lake City. One must travel through the valley to see the full import of this aerial attack (pl. VI): migrating sand dunes, fences and buildings partly buried, soils removed down to stony or hardpan layers, and dust storms that originate in newly plowed fields. The wind direction is so constantly from the southwest that some of the early wells were equipped with windmills that operated only when the wind was from that quadrant. Few windmills remain in the valley; they wear out too quickly.

The records of precipitation at communities within the valley show that a large proportion of the storms, particularly during the summer, are local rather than valley-wide in distribution. As a result, there is rather marked variation in an-

Plate VI-A—Fence line on north side of cultivated field near the Clark ranch buried by wind-drifted sand and silt.

Plate VI-B—Sand dunes west of Table Butte, typical of several areas in the Beryl-Enterprise district.

nual precipitation from place to place, as shown by the accompanying table. Because of this geographic variability, the existing records are inadequate for quantitative estimates of total rainfall in the valley. The records do indicate that precipitation is least toward the north end of the valley, near Black Rock, and increases slightly toward the southwest along the valley floor. Judging by the record at Minersville, precipitation may also be slightly greater on the sloping flanks of the valley than on the valley floor. The least recorded annual precipitation in the valley was 3.6 inches at Nada in 1934, and the greatest was 23.5 inches at Enterprise in 1911.

Records at Milford and Modena show that, on the average, slightly less than 40 percent of the annual precipitation occurs during May, June, July, August, and September—the months that generally include the entire frost-free growing season. The average precipitation in these five months is less than 4 inches, and rainless periods of 30 days or longer are common. The records thus confirm the experiences of dry-farming attempts: that there is generally insufficient rainfall to provide soil moisture for growing crops. On the other hand, a single cloudburst in this season may produce considerably more than 2 inches of rainfall in a restricted area, resulting in flood flows in washes draining that area.

During the other seven months of the year precipitation is somewhat greater, evaporation from the soil is less because of the lower temperatures, and transpiration by plants is at a minimum. Thus conditions are more favorable for accumulation of water in the soil, and in areas where the geologic conditions are favorable there may be downward percolation to the ground-water reservoir in the valley.

ANNUAL PRECIPITATION, 1900-49, IN INCHES
(Records from U. S. Weather Bureau)

	Communities in Escalante Valley							Communities in tributary drainage basin	
Station:	Black Rock	Milford	Minersville	Nada	Jozella Ranch	Modena	Enterprise	Pinto	Frisco
Altitude (feet above sea level):	4,870	4,960	5,070	5,060	5,200	5,480	5,320	5,910	7,320
Year:									
1900			6.94					9.71	4.73
1901	7.61		9.70			9.24		15.10	10.07
1902	6.38		9.57			5.09		11.30	5.58
1903	13.36					6.93		10.90	10.72
1904	6.39					9.83		14.41	7.58
1905	14.28					12.39		18.95	11.81
1906						19.08	23.12	25.60	
1907			16.55			12.80			
1908		8.74				16.62	16.97	19.85	10.13
1909	8.89	8.14				11.49	16.17	18.59	10.02
1910	6.85	8.35	11.16			9.50	14.12	12.48	8.91
1911	8.34	9.04	10.60			10.46	23.52	14.95	9.47
1912	6.17	9.61				10.07	15.37	14.28	
1913	8.92	6.16	7.95			8.51		11.34	
1914	12.28	8.46	9.28			10.55	13.24	12.73	
1915	8.32	9.27	9.72	14.68		13.00	17.07	14.34	
1916	8.70	12.17	12.72	14.90	13.14	16.67	16.61	20.07	
1917	6.30	9.01	7.01	10.46	8.58	8.41	7.41	11.17	
1918		9.36	11.12	13.44	10.65	10.48	15.88	16.02	
1919		9.60		9.44		10.45	16.61	11.11	

ANNUAL PRECIPITATION, 1900-49, IN INCHES (Continued)
(Records from U. S. Weather Bureau)

	Communities in Escalante Valley							Communities in tributary drainage basin	
Station:	Black Rock	Milford	Minersville	Nada	Jozella Ranch	Modena	Enterprise	Pinto	Frisco
Altitude (feet above sea level):	4,870	4,960	5,070	5,060	5,200	5,480	5,320	5,910	7,320
Year:									
1920	9.12	13.17		14.20		12.25		18.51	
1921	9.95	9.36		10.89	13.43	14.57		19.94	
1922	9.86	10.08		10.74	9.80	11.57	15.87	20.89	
1923	8.75	9.98		8.58		9.96			
1924		10.61		11.41		7.54			
1925		8.42		9.72		16.27			
1926	6.05	5.95		7.18		7.64			
1927		8.20		9.99		13.35			
1928		5.98		6.68		6.95			
1929		8.00		7.24		7.38			
1930		8.46		10.62		11.31			
1931		6.95		6.89		8.66			
1932		10.12		11.42		9.40			
1933		6.75		6.56		8.60			
1934		6.37		3.62		6.80			

ANNUAL PRECIPITATION, 1900-49, IN INCHES (Continued)
(Records from U. S. Weather Bureau)

	Communities in Escalante Valley							Communities in tributary drainage basin	
Station:	Black Rock	Milford	Miners-ville	Nada	Jozella Ranch	Modena	Enter-prise	Pinto	Frisco
Altitude (feet above sea level):	4,870	4,960	5,070	5,060	5,200	5,480	5,320	5,910	7,320
Year:									
1935		9.27		8.16		9.51			
1936		9.52				11.44	Enter-prise Airport altitude 5,200		
1937		8.94				9.97			
1938		8.94				15.20			
1939		5.26				8.83			
1940		5.50				8.63			
1941		13.22				16.28	16.53		
1942		7.21	6.11			8.01	9.43		
1943		8.26				13.18	10.14		
1944		8.06	11.28			8.57	7.32		
1945		9.49	9.05			11.35	11.51		
1946		11.13	14.18			15.32	13.14		
1947		11.98	10.51			8.83	6.99		
1948		6.99	7.54			8.01			
1949		9.42	10.57			15.23			
	42-year average	8.80			49-year average	10.86			

In most of the tributary drainage basin the climate may be quite similar to that in Escalante Valley. Judging by the precipitation record at Frisco and by the types of vegetation and the lack of perennial stream flow, the precipitation on the low ranges bordering the valley to the west and east is little if any greater than that in the valley.

South of Escalante Valley the drainage basin includes mountainous areas where precipitation is appreciably greater than in the valley, as shown by the record at Pinto. The existence of perennial streams indicates that in some places precipitation is more than enough for the evapo-transpiration demand. Most of this surplus results from winter accumulation of snow and most of it is used for irrigation in Escalante Valley.

To the east the potential drainage basin includes parts of the Markagunt and Kolob Plateaus and the Tushar Range, in which some peaks exceed 12,000 feet in altitude. The annual precipitation in these higher areas exceeds 20 inches and gives rise to numerous perennial streams. There, too, the bulk of the surplus accumulates as snow during the winter, and flows down the streams in an annual freshet. These streams drain into Beaver Valley, Parowan Valley, and Cedar City Valley, where there are extensive diversions for irrigation. In historic time there has been no outflow from Parowan or Cedar City Valleys, and thus the only contribution

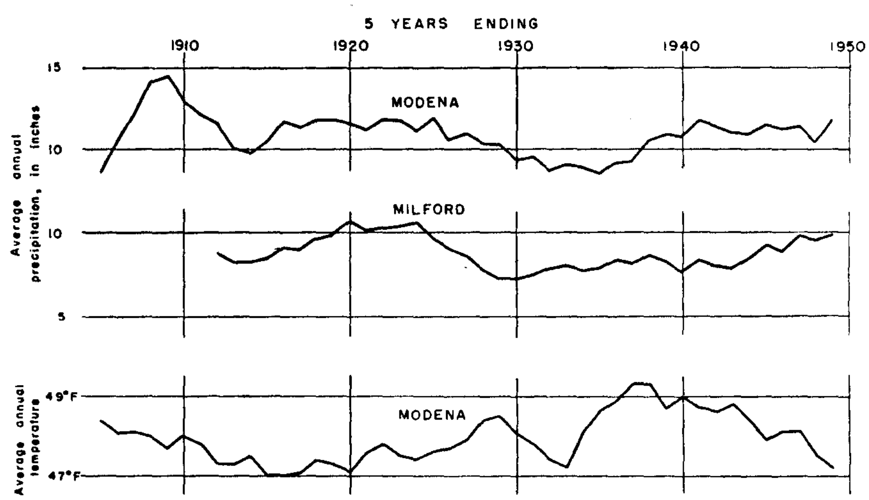


Fig. 2. Progressive 5-year average precipitation and temperature.

of surface water to Escalante Valley from these areas of high precipitation is that of the Beaver River.

Although the records tabulated above show considerable variation in precipitation from place to place each year, and also from year to year at each place, they also show regional patterns in precipitation. As examples, the precipitation was well above average at all reporting stations in 1906, 1916, and 1941, and was far below average in 1900, 1917, and 1934. Furthermore, precipitation has been above average throughout the valley for periods of several years in succession, as in the period 1911-16, and has been below average in series of years such as 1933-35. Long-term trends are indicated by 5-year progressive averages of annual precipitation at Modena and Milford (fig. 2). The successive series of wet and dry years can be expected to cause corresponding fluctuations in the surface-water supplies available for use, and also in the quantity of water stored in the ground-water reservoir.

GEOLOGIC SETTING

The geology of Escalante Valley and its tributary drainage basin has not been studied in the detail that would be necessary for effective development of the mineral resources of the area. Indeed, the geologist does not yet have the tools that are prerequisite to modern geologic-mapping techniques, for very little of the area is covered by standard topographic maps, and extensive areas are not covered by aerial photographs. The only geologic information available for a large part of the Escalante Valley area was collected during reconnaissances prior to 1880, when a growing Nation was making a preliminary assessment of the natural resources of its Western territories.[4] These early reports are admirable in their presentation of the general geologic features, but they did not attempt to describe the geologic setting in detail. They constitute an important source of the information compiled on State geologic maps in subsequent years.[5]

Gilbert[6] in 1875 described the "peculiar characteristics"

4—Dutton, C. E., Geology of the High Plateaus of Utah: U. S. Geog. and Geol. Survey of Rocky Mtn. Region (Powell survey), pp. 1-81, 143-159, 169-210, 251-253, 1880.
Gilbert, G. K., Geology of portions of Nevada, Utah, California, and Arizona: U. S. Geog. and Geol. Survey west of the 100th meridian (Wheeler survey), vol. 3, pp. 21-42, 93, 120, 132, 151, 179, 1875.
Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Mon. 1, 426 pp., 1890.
Howell, E. E., Geology of portions of Utah, Nevada, Arizona, and New Mexico: U. S. Geog. and Geol. Survey west of the 100th meridian (Wheeler survey), vol. 3, pp. 250-257, 1875.

5—Butler, B. S. Loughlin, C. F., and Heikes, V. C., Ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, pl IV, 1920.

6—Gilbert, G. K., op. cit. (Wheeler survey), p. 22.

of the Great Basin in Nevada and western Utah, where "ridges are distributed with tolerable regularity and parallelism throughout an extended area. . . . Between them are valleys floored with detritus from the mountains, which conceals their depths and leaves to the imagination to picture the full proportions of ranges of which the crests alone are visible, while the bases are buried beneath the debris from the summits." Some of these ridges form the borders of Escalante Valley, which lies entirely within the Great Basin. Detailed geologic studies have been made in several small areas in these ranges, notably the silver-mining districts of the San Francisco Mountains,[7] the tungsten-bearing areas of the Mineral Range, Star Range, San Francisco Mountains, and Beaver Lake Mountains,[8] and the iron-mining districts south of the valley.[9] According to these studies, the drainage basin includes sedimentary rocks ranging in geologic age from Cambrian to Tertiary, some igneous rocks, and widespread volcanic flows and associated rocks. In each of the areas of detailed geologic study numerous faults have been traced, and it is likely that in many of the areas not studied the structure may be similarly complex.

There are a few permeable beds or zones in the mountainous areas that give rise to springs, but geologic studies of mining areas in parts of the bordering ranges have shown a number of relatively impermeable rocks.

Escalante Valley long has been the site of deposition of the debris eroded from mountain ranges within the drainage basin. This debris, or valley fill, consists principally of fragmental materials—clay, silt, sand, gravel, and boulders that are loose and unconsolidated,—although there has been cementation in some places. In several places bedrock projects above the present valley floor, notably at Blue Buttes and Table Buttes.

The thickness of the valley fill is known in only a few places, where wells have encountered bedrock near the edge of the valley not far from rock outcrops. The great majority of the wells throughout the valley are drilled entirely in un-

7—Butler, B. S., Geology and ore deposits of the San Francisco and adjacent districts, Utah: U. S. Geol. Survey Prof. Paper 80, 206 pp., 1913.

8—Hobbs, S. W., Tungsten deposits in Beaver County, Utah; U. S. Geol. Survey Bull. 945, pp. 81-111, 1945.

9—Leith, C. K. and Harder, E. C., The iron ores of the Iron Springs district, southern Utah: U. S. Geol. Survey Bull. 338, 96 pp., 1908.
Wells, F. G., Origin of iron deposits in Bull Valley and Iron Springs districts, Utah: Econ. Geology, vol. 33, pp. 477-507, 1938.
Mackin, J. H., Some structural features of the intrusions in the Iron Springs District: Utah Geol. Soc. Guidebook 2, 62 pp., 1947.
Young, W. E., Iron deposits of Iron County, Utah: U. S. Bur. Mines, Rept. Investigations 4076, 102 pp., 1947.

consolidated materials. These records show only that the thickness of valley fill at the well location exceeds the depth of the well. It seems certain that the thickness differs considerably from place to place, as the result of deposition on an uneven bedrock floor that was produced by ancient erosion and by faulting before deposition of the valley fill.

Two oil-test wells recently drilled about 15 miles north of Milford are reported to have penetrated more than 3,000 feet of unconsolidated valley fill without reaching bedrock. On the other hand, the log of the railroad well at Milford, where the valley is only about 8 miles wide, shows that bedrock was encountered at a depth of only 525 feet. Railroad wells at Thermo and Lund penetrated respectively 401 and 746 feet of valley fill without reaching bedrock. Wells south of Beryl have been drilled as deep as 450 feet without reaching bedrock.

The geologic processes of erosion and sedimentation are very active today in Escalante Valley, and in places they have been accelerated by man. The effects of erosion are most marked in the small drainage basins tributary to the valley. When the first settlers arrived in the vicinity of Enterprise in 1862, to quote from the diary of the late Orson W. Huntsman, they found "beautiful green grass on a thousand hills, and in the valleys; in fact, the whole face of the land was covered with green grass. Up and down the creek, and around the springs, the grass was heavy and stood from four to eight feet high. A man riding into it on horseback could hardly be seen in some places. There was nothing to eat this grass except a few jackrabbits, a few deer in the hills and also antelope from the big valley or the desert as it was called (Escalante Valley); not a desert for vegetation but a desert for water, it being entirely dry except in time of snow or rain."

Mr. Huntsman noted a vast change within the next 15 years: "Great floods have come and changed the looks of the country. I will mention that of the Mountain Meadows. There grass or hay was up to a horse's sides, but as cattle and sheep ate up the vegetation there was nothing to hold water back and when a heavy storm came and the water from the many little canyons came together with a great rush, the stream was so large that it took everything before it. Until after the year of '69 there was no stream down the Meadow canyon. The traveler, in order to get a drink, had to go up the canyon a mile or more. About 1870 the meadows began to wash out slowly so that water ran down farther . . . In 1875-76 the meadows practically all washed away and everybody moved from Hamblin. The country was so badly washed away that anyone who had left two or three years before would not have known the place had they gone back; there were washes 50 to 60 feet deep." Today in the vicinity of the old town of Hamblin abandoned fields and irrigation ditches have been left high and dry by the entrenchment of Mountain Meadow Creek (pl. VII). Thick sections of accumulated sand, silt, and peat exposed by the gullies suggest that, for thousands of years prior to the arrival of settlers,

Plate VII—Mountain Meadow Creek intrenched in 50 feet of sand, silt, and peat about 6 miles southeast of Enterprise. Abandoned townsite of Hamblin in left middle ground, and Mountain Meadow in the distance.

marshy vegetation had grown in the valley. The tragedy of erosion at Hamblin, however, appears to have worked to the benefit of Escalante Valley, for Mountain Meadow Creek is now a perennial source of water near Enterprise. Pinto Creek and adjacent areas have experienced similar destruction, and many of the once-fertile bottom lands have been abandoned.

In Escalante Valley proper, running water has effected some changes in the landscape since the first settlers arrived, both by cutting of gullies during flash floods and by deposition of sediment where these flood waters lose their velocity and are ponded. However, the major changes in the valley since settlement have resulted from wind action. Two distinct periods of extensive wind erosion are evident in the valley, the first coincident with the dry-farming attempts early in the century and now partially "healed" by a cover of vegetation, and the second beginning about 1945 with the renewed efforts at cultivation in the valley. This second period of wind erosion has continued to the present, and in some areas dunes that were started in 1946 and 1947 were more than 14 feet high by 1950. Many areas have been denuded of topsoil, and other areas buried beneath a blanket of fine blowsand. Action of wind and water in comparatively recent times has developed many of the features described in a report on soils in Escalante Valley.[10]

These changes in historic time are merely the current phase of geologic processes of upland erosion and valley deposition that have during millions of years been responsible for the great accumulation of debris that is called the "valley fill," and that have been accelerated by man. Long-continued alluvial deposition is indicated by the huge coalescing fans that form the sloping sides of Escalante Valley—small, steep cones at the mouths of small tributary canyons, broader fans at the mouths of larger washes—and by the graded plains that are traversed by larger tributaries such as the Beaver River, Shoal Creek, and Crestline Wash. Beneath the valley floor sediments of alluvial origin can be identified from logs of wells.

Streams and wind have not always been the only agents of deposition in Escalante Valley. Many thousands of years ago, in Pleistocene time when glaciers covered much of the continent, the waters of Lake Bonneville extended into Escalante Valley. The features left by this lake, including the prominent shore lines that are visible in many parts of central and northern Utah, have been described by Gilbert.[11] Escalante Valley was occupied by the lake only during its highest stage, which represented a relatively short interval in the lake's history. In recent years the shore line has been traced southward in the valley as far as Nada, where it is at an altitude of about 5,120 feet above sea level.[12] At that altitude the lake extended southwestward into the Beryl-Enterprise district. The valley fill, as shown by the logs of the deepest wells, comprises a succession of alluvial and lacustrine sediments.

10—Bartholomew, O. F., Foulger, J. C., and Peterson, J. D., Soil survey of Beryl-Enterprise area: U. S. Bur. Plant Industry preliminary report, unpublished 1940.
11—Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Monograph 1, 426 pp., 1890.
12—Dennis, P. E., Shorelines of the Escalante Bay of Lake Bonneville: Utah. Acad. Sci., Arts, and Letters Proc., vols. 19 and 20, pp. 121-124, 1942.

WATER IN THE VALLEY

Irrigation is generally prerequisite to agriculture in Escalante Valley because the valley does not receive enough precipitation to provide the soil moisture needed by crops. There are a few areas, however, where the water table is shallow enough to provide subirrigation. The small supplies of surface water from perennial streams were fully appropriated long ago, and reservoirs have been developed on the principal streams to augment the supplies throughout the irrigation season. These surface-water supplies serve a very small proportion of the area of the valley, chiefly in the vicinities of Enterprise, Newcastle, and Minersville.

Water for irrigation, domestic, and other uses elsewhere in the valley must be obtained from wells. Any increase in agriculture acreage or population in the future, as in recent years, must be dependent upon ground water.

The ground-water reservoir that must support this development is in the valley fill of Escalante Valley. That valley fill is saturated practically to the top in the lower central part of the valley, and to within less than about 200 feet of the land surface in practically all areas where slopes are gentle enough for cultivation. The total volume of saturated materials is unknown, because the thickness of the valley fill is unknown. Even less is known as to the total volume of water contained in the valley fill, because that would depend upon the porosity and texture as well as the total volume of the unconsolidated sediments. Escalante Valley has an area of more than 800,000 acres, and the average thickness of saturated valley fill is at least several hundred feet. Thus the total volume of water in the valley fill must be several million acre-feet.

Not all this water can be extracted by wells, however. Judging by logs of wells which, for the most part, penetrate only the upper 200 feet of valley fill, most of that fill is so fine-textured that it can hold all or most of its water against the force of gravity. Only the permeable beds in the valley fill—the beds of uncemented gravel and coarse sand—yield large quantities of water to wells. These permeable beds are thick enough and numerous enough to store quantities of water that are very large in comparison to those withdrawn each year in the valley.

The natural outlet of Escalante Valley is to the north at Black Rock. As described by Gilbert, this was once the location of a strait connecting Escalante Bay with the rest of Lake Bonneville, and "the strait was occupied by standing water with an approximate depth of 50 feet and a width at the most constricted point of about 2 miles."[13] There is no river channel in this strait, nor indication of large surface outflow from Escalante Valley since the recession of Lake Bonneville from its highest stage. There has been no surface outflow from the valley in historic time, except on rare occasions following cloudbursts in the vicinity of Black Rock.

There is no significant underground flow through the Black Rock strait from Escalante Valley so far as inferred from the available scanty information. The springs at Black Rock discharge about 2 second-feet from basalt, but they are believed to have only a local origin in the basalt. The Union Pacific Railroad, seeking fresh water in the Sevier Lake basin, drilled wells at Goss and Neels, respectively about 15 and 25 miles north of Black Rock. These wells, respectively 1,775 and 1,998 feet deep, passed through all the valley fill and penetrated some bedrock, but they found no fresh water that might have been derived by underflow from Escalante Valley.

It appears, therefore, that most of the water that falls as precipitation upon the Escalante Valley drainage basin is ultimately returned to the atmosphere within that basin. It is properly termed a closed basin because of this lack of significant outflow, and the entire hydrologic cycle is completed within it. Thus any perennial water supplies must be salvaged from the quantity of water that would otherwise be returned to the atmosphere by natural processes of evaporation and transpiration.

Escalante Valley was long ago recognized as typical of numerous closed basins of the West. As stated by White,[14] "In such valleys under natural conditions the average annual ground-water recharge from precipitation on the valley and tributary mountains is about balanced by the average annual discharge by evaporation and transpiration from the areas of shallow ground water, usually located in the lowest parts of the valley, and a measurement of the quantity of ground water withdrawn by these processes may give a close approximation of the quantity of water that annually enters the underground reservoir. The water is largely lost so far

13—Gilbert, G. K., op. cit. (Lake Bonneville), p. 363.
14—White, W. N., A method of estimating ground-water supplies based on discharge by plants and evaporation from soil: U. S. Geol. Survey Water-Supply Paper 659, p. 1, 1932.

as any benefit to man is concerned, but it can be in part reclaimed by means of wells. The amount that can be reclaimed represents the safe yield of the underground reservoir. This can be estimated if the natural discharge is known."

Because little or no water flows out of the Escalante Valley, there can be no substantial outflow of sediment or soluble minerals. Everything that is carried from the tributary drainage areas by the operation of the hydrologic cycle remains in the valley. Most of the water that enters the valley from these drainage areas carries some dissolved mineral matter, picked up from the rock materials through which or over which it flows. This mineral matter must remain behind when the water returns to the atmosphere. It shows up in many places, particularly in the central and lower parts of the valley, where it is commonly known as "alkali." Accumulation of soluble mineral matter is inevitable in all closed basins, and is a factor to be considered in the utilization of the soil and water resources of Escalante Valley. The soluble minerals may be removed from soils in some areas by excess irrigation, but they must remain in the valley, either in soils elsewhere or in the waters of the ground-water reservoir.

There is a wide range in the amount of dissolved mineral matter in ground waters in Escalante Valley, as shown by more than a hundred analyses of water taken from wells and springs. The chemical quality of water from some mountain springs is excellent, and Enterprise and Modena obtain their culinary supplies from such springs. On the other hand, the water from one shallow well contained 5,650 parts per million of dissolved solids. Some ground waters are unsatisfactory for irrigation because of high sodium content, some are unsuitable for use untreated in boilers because of hardness and/or foaming, and some are unsatisfactory for other uses because of other mineral content. Industries with exacting requirements as to water quality might find no suitable water supply anywhere in the valley, for all sampled waters contained more than 200 parts per million of dissolved solids, nearly all had a calculated hardness greater than 150 parts per million, and many would be otherwise unsuitable.

Residents of the valley have long recognized that the shallowest ground water is likely to be inferior to deeper waters in quality. Progressive deterioration in quality of shallow ground water is to be expected in the lower part of the valley, as long as it remains a closed basin. The comparative freshness of the water in the deeper parts of the valley fill is indicative that Escalante Valley has not been a closed basin throughout its geologic history. Rather, some outflow must have occurred in times past, probably northward to the Sevier Desert, to carry soluble minerals from the valley as those deeper beds were accumulating.

It is likely that a small amount of highly mineralized water enters Escalante Valley from the bedrock basement under the valley fill. Volcanic activity was an important part of the geologic history of the valley prior to the advent of Lake Bonneville, and there are indications that magmatic heat still remains under the floor of the valley in a number of places. At the Thermo and Roosevelt Hot Springs, temperatures as high as 185° F. have been recorded. Such high temepratures are considered to be conclusive evidence of magmatic origin. Farther south, at Newcastle, the thermal gradient is exceedingly high, as shown by temperatures in a dug dry hole (p. 159). The waters of the Thermo Hot Springs are sodium sulfate and bicarbonate waters containing about 1,600 parts per million of dissolved solids. Sodium sulfate and chloride predominate in the water of the Roosevelt Hot Springs, 8 miles northeast of Milford, that has a high content of silica also. Geologic studies have not been made of these hot springs areas.

HISTORY OF SETTLEMENT

Escalante Valley for many years has supported a small but stable population. Several of the older communities, including Enterprise, Newcastle, Minersville, and Black Rock, were established where water supplies from perennial streams or springs could be used for irrigation. The Union Pacific Railroad has been the principal reason for existence of several other communities, notably Milford, Lund, and Modena.

Elsewhere in the valley the mood of Nature has been grim enough to discourage many a settler. Several ghost communities and numerous ghost ranches bear witness to former human activity. Some of these enterprises were dependent upon mining in the Frisco district in the mountains west of Milford between about 1875 and 1900. Others were centers of dry-farming activity in the early years of this century. Malone, Yale, and Heist are now only names on maps drawn years ago to represent then-active towns; other communities, such as Nada and Thermo, have decreased considerably in size since their day of greatest activity.

The first permanent residents in the area settled along the perennial streams—Pinto Creek about 1855, the Beaver River at Minersville in 1859, and Shoal Creek in 1862. Several reservoirs have been constructed on these streams to store water for irrigation. Two reservoirs in the Shoal Creek drainage basin have a total capacity of about 10,200 acre-feet and provide irrigation water for about 1,800 acres near Enterprise. Construction of one of these reservoirs was commenced in 1893; the other was built later. The large Grass Valley Reservoir was built about 1910 along Pinto Creek 16 miles south of Newcastle. The reservoir was on highly permeable rocks and failed to hold water. Thus, the construction of canals and ditches and plans for extensive agricultural development near Newcastle were abandoned at that time. The Newcastle area still depends largely upon the natural flow of Pinto Creek, which in most years suffices for irrigation of about 500 acres until June. The Rockyford Reservoir, with a capacity of 23,260 acre-feet, was constructed in 1914 on the Beaver River a few miles above Minersville to provide adequate irrigation water for that area, as well as for lands father downstream toward Milford. These streams, with their reservoirs, for many years have supported a population of somewhat less than 2,000.

The old Utah and Southern Railroad was constructed south from Salt Lake City beginning in 1870, and by 1880 it reached Milford and the mining towns to the west. Subsequently, as the Salt Lake, Los Angeles, and San Pedro Railroad (now a part of the Union Pacific system), it was extended through the valley and to the West Coast by 1905. Springs provided water supplies for the railroad at Black Rock and Modena. The need for water in the long intervening stretch led to a well-drilling program that proved the existence of usable ground-water supplies, and the railroad became the first user of water from wells in the valley. Wells at Milford, Thermo, Nada, Lund, and Beryl still furnish water supplies for the railroad at those points.

During the period from 1909 to 1919, several hundred settlers entered the valley and established homes with the intention of developing dry farms. Hundreds of wells were dug or drilled for domestic water supply. The efforts at dry farming were fruitless, and nearly all homesteads were abandoned within a few years. These attempts showed that: (1) the area did not receive enough precipitation to support dry farming, (2) ground water of good quality could be obtained at shallow depth in many places, and (3) the soil in many parts of the valley, when cleared of native vegetation, is exceedingly susceptible to wind erosion. On many of the now-abandoned ranches where dry farming was attempted, it was literally true that, when the homesteader gave up and left, the topsoil did likewise.

Irrigation from wells began about 1916, and in the next decade about 75 wells were constructed and equipped with pumping plants, of which about three-fourths were in the Milford district. Many of these old wells were abandoned during the depression of the 1930's and some new ones have been constructed, particularly since 1945. Several of the wells, however, have been in operation for more than 20 years. The effect of ground-water development has been to increase materially the productive agricultural area south of Milford and in the Beryl-Enterprise district, and to provide a means of livelihood for many additional people.

The development of ground water for irrigation in the Beryl-Enterprise district, although begun at about the same time as in the Milford district, was slower and less successful for many years. By 1927 there were 17 pumping plants in the district, but practically all were idle that year. By 1937 a total of 80 irrigation wells had been drilled but only 22 were being pumped. Throughout the period prior to World War II, abandonment of developed irrigation wells very nearly kept pace with drilling of new ones, and the total pumpage probably did not exceed 4,000 acre-feet in any year. The population on the "flat" was small and unstable. At one time there were several White Russians and other refugees from World War I. Later the valley had a sizable colony of Japanese-Americans. Most of the wells of that period were in the lower parts of the district where the depth to water was less than 30 feet, and where also the soils are prevailingly of poorer grade and contain more "alkali" than in higher areas. Many of the pumping plants were primitive and likely to break down when the water was needed most. These factors probably loomed large in the decisions of many temporary residents to abandon their enterprises. Other factors may have included the lack of facilities that have become necessities in American community life elsewhere: electricity, improved roads, telephones, and modern schools.

Major changes in the Beryl-Enterprise district began during World War II. Between 1940 and 1950 a total of about 140 new irrigation wells were drilled and equipped with pumping plants. In addition, 12 wells were put into service that had been inactive or intermittently operated prior to 1940. The area irrigated by ground water increased from less than 900 to 16,000 acres in the decade, and the annual pumpage of water increased from about 2,600 to 51,000 acre-feet. The new wells are generally on higher lands than the wells constructed prior to 1940. About half the irrigation wells of 1950 are in areas where the water table is more than 30 feet below the land surface, and where pumping lifts range from 40 to 150 feet.

The ground-water development has resulted in a marked increase of community and service facilities in the Beryl-Enterprise area. Electric lines serve the irrigation pumps and new homes. The district now boasts of oiled roads to Cedar City and to Nevada, and of improved roads throughout the area. Many of the farms are still operated by "suitcase" farmers who remain in the valley only during the summer, but the number of permanent residents and of substantial homes is increasing.

III. GROUND-WATER PROBLEMS

The recent development of the water resources of Escalante Valley is creating some perplexing problems which originate in the hydrologic conditions of the region, but which will require consideration of social and economic factors also if they are to be solved satisfactorily. One of the major problems is "mining" of ground water, and this problem is more urgent in the Beryl-Enterprise district than in any other ground-water area in Utah.

The water stored in the valley fill in the Beryl-Enterprise district alone may total several million acre-feet, which is many times the quantity pumped annually from wells. The extent to which ground water is renewed depends ultimately upon the precipitation in the drainage basin, and upon the proportion of that precipitation that percolates downward through the soil zone. The limit of pumpage on a perennial, sustained basis is thus set, not by the quantity of water stored underground at any given time, but by the average annual recharge. The natural recharge to and discharge from the ground-water reservoir of the district each year is very small. Pumpage in excess of the average annual replenishment will deplete storage in the reservoir, and can continue only so long as there is water left within practicable pumping lift.

If the average annual recharge to the ground-water reservoir in the Beryl-Enterprise district is large enough to provide a perennial supply equivalent to current annual pumpage, then the recent development of ground water is a boon to the valley and to the State. If, however, current annual pumpage exceeds the rate of replenishment—that is, if ground water already is being mined from the reservoir in the valley fill, then it is a question of administrative policy whether: (1) pumpage should now be brought back into balance with replenishment, (2) the rate of pumping should be held at the present level, or (3) the rate of pumping should be increased, with the understanding that the more rapid the rate of depletion, the shorter will be the life of the community dependent upon ground water.

The problem is complicated by several factors. For instance, the natural discharge from the ground-water reservoir by evaporation and transpiration is estimated to be several thousand acre-feet a year. This loss can be eliminated only by a sizable reduction of storage in the reservoir, to place the water table beyond the reach of plant roots. Thus, some withdrawal from storage is required in order to salvage the perennial yield of which the ground-water reservoir is capable. It appears, however, that pumping in the area where natural discharge occurs is not profitable because of poor quality of soil and paucity of productive aquifers.

Another important question is the distribution in geographic space and in time of recharge that constitutes the average annual recharge. Recharge may differ greatly from year to year, and from place to place in any given year.

There is also the question of whether a community relying wholly on the renewable supplies of ground water would be large enough to support the facilities that are generally considered essential to present-day living.

In the Milford district the ground-water reservoir is replenished chiefly by water from the Beaver River, which is by far the largest stream entering Escalante Valley. The annual replenishment to the ground-water reservoir is probably greater than in the Beryl-Enterprise district, whereas the quantity of water currently being pumped annually from wells is far less.

The chief problem of the Milford district results from the close relation between surface water and ground water. For more than four decades most of the flow of the Beaver River has been diverted from its natural channel, and the pattern of recharge to the ground-water reservoir has been changed from that which prevailed previously. Irrigation wells were drilled after these modifications were made, and some of them may depend, not upon natural supplies, but upon replenishment from developed surface-water supplies. The supply of such wells is secure only so long as stream diversions continue to furnish water to the same general areas as in the past.

A major change in the pattern of diversions from the Beaver River is underway, and this change may reduce the quantity of water available to some ground-water users in the Milford district. The effect of such changes upon water rights is a problem whose solution is still largely in the future.

Another problem throughout Escalante Valley is the prevention of deterioration in the quality of water obtained by wells. The soils suitable for farming purposes cover an area far larger than can be irrigated by the available water resources, but there are thousands of acres in the valley where soluble minerals limit the productivity of the land. In many places "alkali" is apparent even to the casual observer, and in others crops have failed because of its presence in less obvious form. These soluble salts can be removed, at least in part, by excess irrigation, but if the water containing them returns to the ground-water reservoir the quality of water pumped from wells eventually may become inferior. Effective utilization of the land and water resources of the valley depends not only upon an adequate knowledge of the hydrologic conditions, but also upon selection of soils that will cause the least deterioration in quality of the water in the ground-water reservoir.

IV. GROUND WATER IN THE BERYL-ENTERPRISE DISTRICT

By Ben E. Lofgren

LOCATION AND GENERAL FEATURES

The Beryl-Enterprise district is defined, for this report, as that upper part of Escalante Valley south and west of Lund. The district includes an area of more than 500 square miles on the floor of Escalante Valley in Iron and Washington Counties (see pl. VIII). The communities of Enterprise, Newcastle, Lund, Beryl, and Modena are all in the district, but near its borders. Utah State Highway 56, extending from Cedar City to the Nevada State line, crosses the district from east to west. Practically all irrigation wells operated prior to 1940 were north of that highway (the "Beryl" part of the district), but numerous wells between the highway and Enterprise have been constructed since World War II.

Reconnaissance maps show the total potential drainage area of the Beryl-Enterprise district is about 1,200 square miles. Three perennial streams enter the district, all draining the mountains along the south border. Ephemeral streams may contribute large quantities of flood water after intense rainstorms, but such storms are infrequent. A large part of the potential drainage area may make no visible contribution to the district for years at a time.

Most of the Beryl-Enterprise district is on the floor of Escalante Valley, with a northeastward gradient of less than 5 feet per mile near Lund, 10 feet per mile near Enterprise, and 25 feet per mile near Modena. The prevailingly smooth valley floor is interrupted in places by shallow channels cut by cloudburst floods, and by sand dunes that may be as much as 25 feet high. Merging into the valley floor and somewhat overlapping it are broad coalescing alluvial fans and piedmont slopes that characteristically border the intermontane desert basins of western Utah.

SURFICIAL GEOLOGY

The rocks that form the mountains and foothills bordering the Beryl-Enterprise district are predominantly extrusive igneous rocks, consisting essentially of rhyolite-latite flows and associated tuffs and breccias. Along the southeast margin of the district a thick section of sedimentary rocks is exposed. These sediments, of Upper Cretaceous and Tertiary age, are the oldest rocks that crop out in the area, and they underlie the volcanic flows unconformably. No important aquifers have been found among these bedrocks, either in geologic studies or in the prospecting or mining of mineral deposits. The geologic map (pl. VIII) shows only a very generalized differentiation of these bedrocks that border the valley. So far as known, all are relatively impermeable.

The rocks bordering the district have been displaced along numerous faults. Some of these faults were mapped during reconnaissance but many others were not traced, and none are shown on the geologic map. Undoubtedly some faulting has occurred since the older valley fill was deposited, but the absence of prominent fault scarps in the valley fill suggests that little displacement has occurred in recent times. The effect of buried faults on the movement of ground water in the valley fill is one of the important geologic problems yet to be solved.

Within the Beryl-Enterprise district the surficial materials are predominantly alluvial. Soil maps show a predominance of loam, sandy loam, and loamy sand, all with a high proportion of silt. Gravel occurs chiefly on the higher parts of the alluvial fans bordering the valley, where in some places it is sufficiently abundant to make cultivation difficult. Clay loam is common in the lower parts of the valley floor. In several areas the surficial materials have been redistributed by wind action; the geologic map shows the principal areas of this redistribution. The prevailing wind has elongated these areas of dunes in a general northeasterly direction. Another important agricultural feature, so far as use of the valley is concerned, is the accumulation of soluble salts in some areas where water is returned to the atmosphere. Areas where such "alkali" is prominent are also indicated on the geologic map.

The valley floor in the Beryl-Enterprise area is the upper surface of a considerable thickness of unconsolidated sediments that have been carried into the basin by streams draining the surrounding mountains. The total thickness of these sediments is not known, for no wells have been drilled deep enough to penetrate the sediments where they are thickest. Although most of the older unconsolidated sediments are now buried in the valley beneath more recent materials, some are still to be found at the surface near the margins of the district. Poorly sorted fanglomerates are present especially along the southern margin of the district between Enterprise and Newcastle and along the northern edge near Lund. Near Enterprise some of the fanglomerate has been eroded in the course of development of the present valley floor, leaving terraces as much as 50 feet high.

Along the northern piedmont slopes of the valley, and to some degree on all marginal slopes of the valley, two types of valley filling are in progress. At the mouths of the larger drainage systems, where torrential streams flush the accumulated debris far out into the valley, the gradient of the stream channels is relatively gentle, and massive low-angle fans merge into the valley floor along the trough line of the valley. The smaller drainage systems, on the other hand, give rise to steep cone-shaped fans. Thus an undulating, rolling alluvial surface is produced around the margins of the valley floor, the lower parts of which represent either the depositional areas of major tributaries or the areas of nondeposition between tributary washes.

DEVELOPED AQUIFERS OF THE VALLEY FILL

Information From Well Logs

The characteristics of the sediments that yield water to wells in the Beryl-Enterprise district are shown chiefly in drillers' logs of wells, of which nearly 200 are recorded in the files of the State Engineer. These logs indicate a wide variation in materials even within short distances, as might be expected in alluvial deposits of desert basins. The logs show that well-defined aquifers are not continuous over any large areas. Thick beds of permeable gravel and sand are reported in many wells, particularly near the margins of the valley, but also in some wells near the center of the district. Most of the wells are less than 200 feet deep, but several have been drilled to depths of 400 feet or more and have penetrated water-bearing materials at those greater depths. However, there generally is a greater proportion of fine-textured materials in the lower parts of these deep wells. In the northeastern part of the district many wells have penetrated thick beds of fine silt and clay. These beds may have been deposited in lakes that once occupied the valley, but available logs are not adequate to confirm such lacustrine deposition.

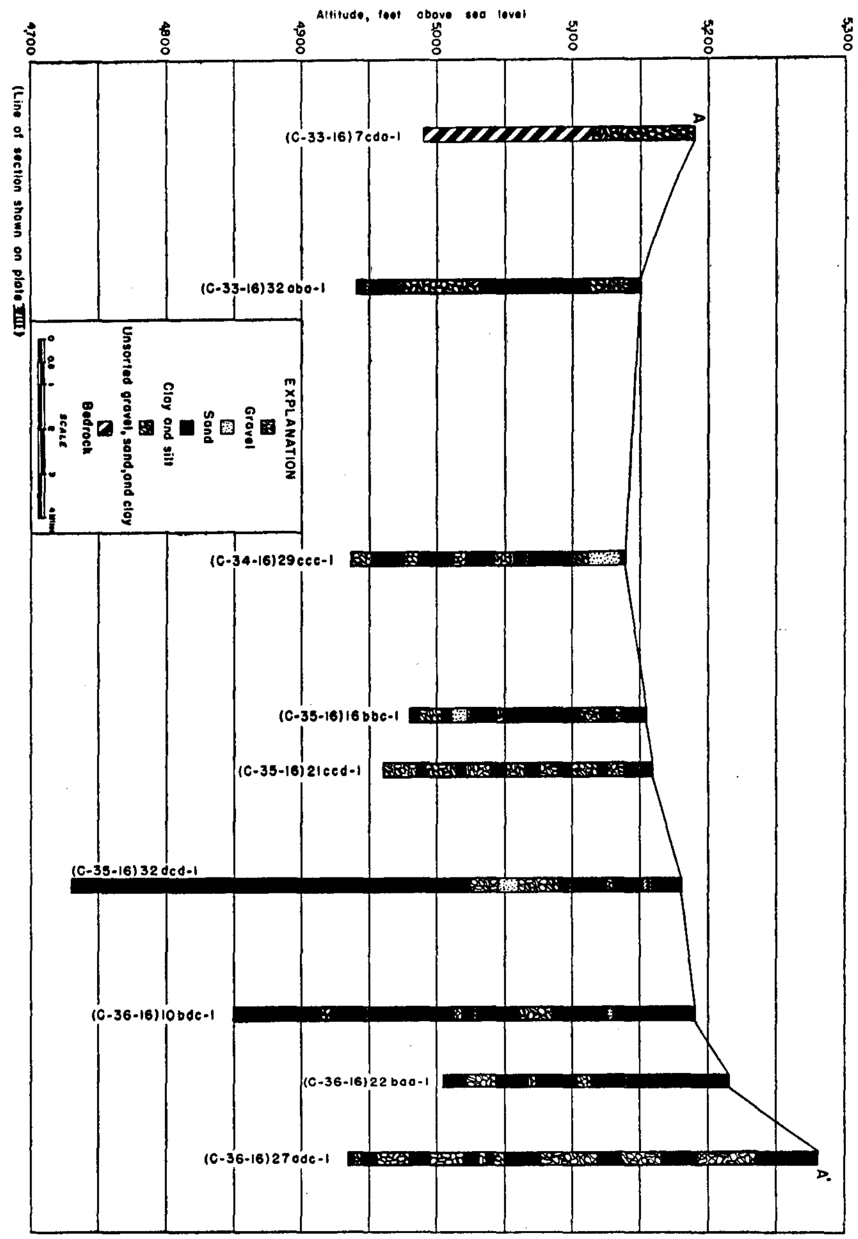


Fig. 3. Logs of nine wells along line north and south through Beryl.

Logs of several wells along a north-south line through Beryl are shown in figure 3. Wells at both ends of this profile penetrated unsorted debris that is probably comparable to the old poorly-sorted fanglomerates exposed along the margins of the valley. The northernmost well is reported to have penetrated 123 feet of water-bearing "broken ledge rock." These logs attest the general nature of the valley fill across the district, and particularly the variability in sediments beneath the land surface.

Artesian Water and Nonartesian Water

Most of Utah's important ground-water reservoirs are in the unconsolidated valley fill of desert basins. Characteristically the valley fill is coarser near the bases of the bordering mountain ranges, and there is an increasing proportion of fine materials toward the central parts of the valleys, although some beds of gravel or sand may extend under the midvalley areas. Water enters the ground-water reservoirs most readily in the coarse, permeable materials, and those in the mouths of tributary canyons are especially suitable for downward percolation of water. In many of these valleys the water in permeable gravel or sand beds may be confined down dip beneath relatively impermeable clay or silt beds. The confined water is under sufficient pressure to rise above the aquifer in which it is tapped by wells, and it may flow at the land surface. Most of the wells in Utah are flowing wells.

The Beryl-Enterprise district is like other areas in Utah in that its large ground-water reservoir is in valley fill, but it is exceptional in that water is under significant artesian pressure in very few wells.

Only one well in the district has an artesian head sufficient to cause the water to flow at the land surface. This is the "Webster" well, (C-34-15)1ada-1,[15] in the low

15—This well number indicates the location of the well by land-office subdivision, according to a system in general use by the State Engineer throughout Utah. The State is divided into four quadrants by the Salt Lake Base and Meridian, and each of these quadrants is designated by a capital letter: A for the northeast quadrant representing all townships north and ranges east, B for the northwest quadrant, C the southwest, and D the southeast. In the well number the designation of the township is enclosed in parentheses and includes in addition to one of these letters, a number indicating the township and a number indicating the range. The number following the parentheses designates the section, and the three lower-case letters after the section number give the location of the well within the section, quarter section, and sixteenth section (the letters a, b, c, and d representing the northeast, northwest, southwest, and southeast quarters of each subdivision). The final number designates the particular well within a 10-acre tract. Thus, well (C-34-151ada-1 represents the first well in the NE¼ SE¼ NE¼ Sec. 1, T. 34 S., R. 15 W.

area west of Table Buttes. It flows about 5 gallons per minute and has a shut-in pressure of about 4 feet above the land surface. The older of the two railroad wells at Lund is reported to have flowed at the surface from several aquifers when drilled, but the artesian pressure has been reduced by pumping, and the nonpumping water level in recent years has been more than 3 feet below surface. According to the driller's report, artesian water was also encountered in several thin gravel strata in well (C-35-15)10ada-1 at the Clark ranch. In the course of drilling, water rose 4 inches above the land surface from an aquifer 292 to 295 feet deep, but after the casing was perforated the water level in the well dropped to about 12 feet below the surface.

Except for these and some other deep wells in the northeast part of the district, drillers report that the water level after completion of drilling and perforating is about the same as that at which the water was first encountered, indicating that artesian pressure is normal in most places.

Within the valley there are clay beds which are certainly impermeable enough to impede the movement of ground water, and which therefore can act as "confining" layers. Water from cloudburst floods forms ponds in the lower parts of the district, and remains on the surface until it evaporates, because of the relative impermeability of the surficial beds of the valley fill. During the current investigation several bore holes were drilled through the surficial clay and hardpan and into underlying beds of sand. Rather commonly the water in the bore hole rose several inches above the horizon in which it was first encountered, indicating a slight artesian pressure beneath the confining beds.

Impermeable beds may prevent downward movement of ground water as well as rain water. As an example, well (C-35-17)21add-1 is ordinarily dry in some parts of each year, but when there is water in it the water level is as much as 25 feet higher than that in a well 400 feet distant that taps the main ground-water reservoir. It is concluded that the water in the shallow well is seasonal underflow from the neighboring foothills, and that it is perched above the main ground-water body on impermeable clay beds.

Data collected at well (C-34-16)17dcc-2 suggest a possible explanation for the low artesian pressure in the Beryl-Enterprise district. This well is finished to a depth of 99 feet with unperforated casing. The water level inside the casing stands about 4 inches higher than the water in the dug pit around the casing. In several years of measurement this differential head has remained practically constant, although the water levels in the pit and in the casing have fluctuated through a range of more than 2 feet. Thus, the ground water is moving upward at the site of the well, or the shallow and deep waters are separated at the well by a confining layer that enables a slight artesian pressure to develop in the deeper water. Either condition could explain the observed fluctuations. The confining bed, if present, must not be very extensive or must be discontinuous.

It is deduced, therefore, that the impermeable clay beds are not continuous over any extensive area, just as well logs have indicated that the water-bearing beds of sand and gravel are discontinuous.

Because of the discontinuity of impermeable beds, the aquifers in most of the Beryl-Enterprise district are hydraulically interconnected, and can all be regarded as parts of a large ground-water reservoir. Wells that pump water from a single water-bearing bed may produce some differential head between that aquifer and others at different depths, owing to the presence of local confining layers. In many parts of the district these differential pressures may be equalized within a few months after pumping ceases. In the northeast part of the district, however, permeable beds are separated by thick sections of clay and silt. There it is possible for water to be drawn from one horizon for long periods without affecting materially the water supply in aquifers at different depths.

DIRECTION OF MOVEMENT OF GROUND WATER

Ground water does not remain stationary beneath the land surface, but moves in the direction of the hydraulic gradient. In a ground-water reservoir where all materials are sufficiently permeable to permit relatively free movement, the water fills all voids within a certain zone called the zone of saturation. The upper surface of this zone of saturation is the water table. The position of the water table of course changes from time to time, as water is added to the ground-water reservoir or discharges from it.

The form of the water table at any time can be depicted on a map, based upon the water levels in wells.

Generally it is necessary to select only those wells which tap unconfined water, because water under artesian pressure may rise considerably above the water table. However, in the Beryl-Enterprise district, except in the northeastern part, artesian pressures are so small that the water levels even in the deeper wells provide a close approximation of the position of the water table.

The form of the water table in the Beryl-Enterprise district in December 1949 is shown on plate IX. The ground-water contours are lines of equal elevation of the water table. The direction of movement of the ground water is down the slope, at right angles to these contours. As indicated by the contours, the general movement is radially inward toward the center of the valley down slopes of 5 to 20 feet per mile, thence northeastward from the district at a gradient of about 3 feet per mile.

RECHARGE TO THE GROUND-WATER RESERVOIR

Water enters the ground-water reservoir of the Beryl-Enterprise district chiefly by (1) underflow from tributary streams which may carry no surface water for long periods; (2) seepage from perennial streams or from canals or irrigated lands that take water from those streams; (3) downward percolation from precipitation within the district; or (4) seepage from ephemeral streams during spring snow-melt runoff and during cloudburst floods. In addition, some of the water pumped from wells returns to the ground-water reservoir by seepage from reservoirs, ditches, or irrigated lands. This returned water is not truly a replenishment, for it is water that has previously been taken from the reservoir. Rather, its quantity should be deducted from the pumpage recorded at each well, in order to obtain the net withdrawal from the ground-water reservoir.

Precipitation in the District

Water-level fluctuations in well (C-34-16)9cbc-1, about 3 miles south of Beryl, provide evidence of recharge, probably localized, to the ground-water reservoir from precipitation on suitable parts of the valley floor. The surficial materials at the well are sandy, and there is an extensive area of dunes immediately to the west. The water table at the well in the past 15 years has ranged from 6 to 9 feet below the land surface.

Recharge to the ground-water reservoir from precipitation is most clearly shown during the autumn of 1946 (fig. 4).

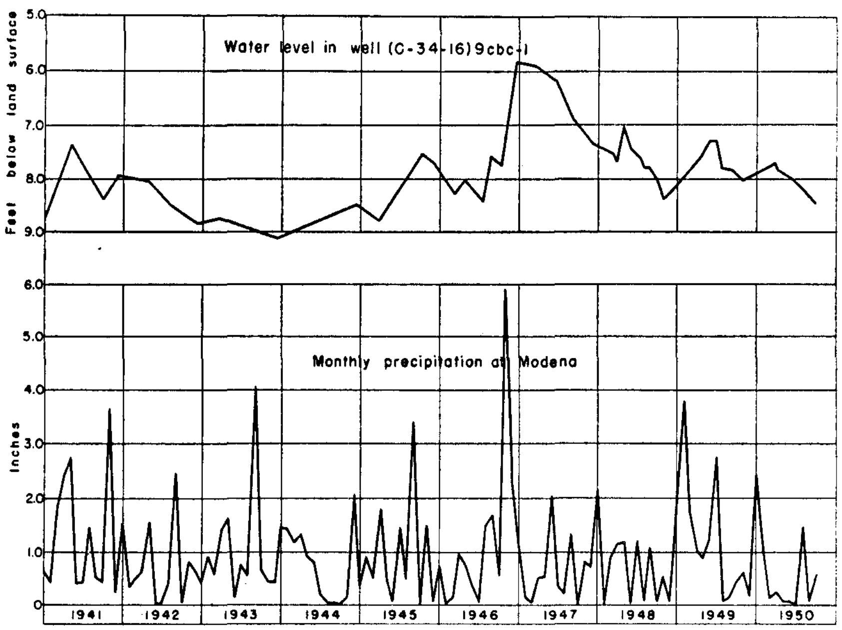


Fig. 4. Correlation of water levels in well (C-34-16)9cbc-1 with precipitation at Modena.

Precipitation at Modena during October and November totaled 8.2 inches, and the water level in the well rose 1.9 feet between October 10 and December 13. The monthly precipitation at Modena exceeded 3 inches in four other months during the decade 1941-1950, and with one exception the water level in the well rose in succeeding months. The exception was in August 1943, when heavy precipitation at Modena resulted from local cloudbursts, and there was only moderate rain at Enterprise and very little at Milford. In general, the major fluctuations of water level in this well appear to be due to recharge from precipitation, followed by recession as the water moves into other parts of the ground-water reservoir.

Recharge from precipitation, especially during the exceptional storms in the fall of 1946, is suggested less clearly in the hydrographs of some other wells near the central part of the district. Thus, in well (C-34-16)21dcc-2 the water level was higher in March 1947 than at any other time since 1940. In most observation wells, however, there has been very little change in water levels after heavy rainstorms in the valley, and it appears that recharge from precipitation has been negligible, or has entered the ground-water reservoir so slowly that there has been no observable effect.

The water-table contours of plate IX indicate that there is appreciable recharge from precipitation in some parts of the district, notably in the extensive sand dunes southwest of Beryl. The 5,128- and 5,132-foot contours are not arcuate in this area but trend southward along straight lines, especially in secs. 19, 20, and 30, T. 34 S., R. 16 W. The form of the water table here suggests that increments of recharge reach the ground-water reservoir by percolation from precipitation within the dune areas.

Water From Perennial Streams

Shoal Creek is the largest stream entering the Beryl-Enterprise district, and records of water levels in wells near that stream show that there is considerable recharge by seepage from water in the channel, as well as by seepage from irrigation canals and irrigated lands that depend upon water from the stream.

Prior to the construction of storage reservoirs in the Shoal Creek drainage basin, much of the winter and spring runoff seeped into the underground reservoir, and the summer flow not used for irrigation did likewise. Residents report that in those days the water table in the town of Enterprise and along the lower channel of Shoal Creek was very near the surface. Since the regulation of Shoal Creek by reservoir storage, however, water levels in the Enterprise area have dropped to as much as 30 feet below the land surface.

The water table along the course of Shoal Creek north of Enterprise rises rapidly in direct response to flow in the stream channel. The water level in well (C-37-17)14acb-1 in Enterprise rose 18.8 feet between November 19, 1936, and May 23, 1937, as a result of large discharge in the Shoal Creek channel, whereas in the preceding year there had been very little change in the water level in the well.

Since 1937 the Shoal Creek channel has carried large quantities of water in only one period. Heavy storms in the fall of 1946 produced nearly 7½ inches of precipitation at Enterprise, raised the water level in the large storage reservoir more than 45 feet, and in addition caused considerable discharge down the Shoal Creek channel. In wells in the town of Enterprise water levels rose more than 12 feet as a result, and irrigation wells farther north along the Shoal Creek channel were similarly affected. As an example, the water level in well (C-37-17)12cbc-1, (fig. 6), in December 1946 was more than 7 feet higher than at any time since 1941.

The reservoirs of the Enterprise Reservoir and Canal Co. have sufficient capacity to provide hold-over storage in years of high runoff for distribution in subsequent years when runoff may be deficient. Since 1935 the quantity of stored surface water distributed for irrigation has ranged from 1,750 acre-feet in 1946 (the heavy precipitation in that year came after the close of the irrigation season) to 6,250 acre-feet in 1937. In 10 of the 15 years the quantity distributed was between 4,500 and 5,700 acre-feet. Since 1944 wells have been used for supplemental supply in dry years, so that the acreage irrigated by the company has a fairly reliable supply year after year. In ordinary years the recharge to the ground-water reservoir from Shoal Creek would be considerably less than the quantities distributed for irrigation, because much of that water is used consumptively by crops.

Pinto Creek also contributes substantially to the ground-water reservoir. During the nonirrigation season (October to March) the runoff of Pinto Creek has ranged from 600 to 3,000 acre-feet, according to records obtained between 1938 and 1942. Part of this so-called "waste water" is eventually lost into the permeable sediments of the district, and thus is a source or recharge to the underground reservoir. Flood water of Pinto Creek seeps readily into a permeable area in the eastern half of T. 35 S., R. 15 W., known locally as the "Pinto Sinks."

Water From Ephemeral Streams

The larger ephemeral streams carry water when snow is melting in the spring, and after intense summer storms. Much of this runoff may collect in ponds on the valley floor, but some evidently seeps into the underground reservoir. Residents report that the water table in shallow wells rises after extraordinary storms. Mr. T. E. Endicott stated that in 1932 the water level in his well, (C-34-16)31bcc-2, rose nearly 2 feet following heavy storms west of Modena, and Mr. Lane Austin has reported that the water level in his shallow well, (C-35-16)7bcc-1, rises noticeably following intense storms that result in flow in Crestline Wash.

Underflow in Tributary Washes

In addition to the larger ephemeral streams in which there is runoff during some period of nearly every year, numerous small washes are tributary to the Beryl-Enterprise district. Some of these smaller tributaries may have no flow for years at a time, for runoff occurs only when there is an intense storm within the drainage area. Ground water recharged during past storms may, however, move into the district by underflow through permeable alluvium beneath the dry channels of these tributaries. Even the smaller washes may make some contribution in this manner, although the largest contributions would be expected from the washes with the largest drainage areas.

Fluctuations of the water level in well (C-36-17)14acc-1 provide evidence of such underflow. This well is about 5 miles north of Enterprise, and was dug 162 feet deep into the alluvium of Park Wash. The water level in this well has fluctuated through a range of as much as 10 feet in a year, and is usually highest in the early spring. The hydrograph of the well suggests that the underflow reaches an annual maximum more or less analogous to the maximum discharge of surface streams in the vicinity but with a lag in time.

The fluctuations of water levels in several wells along the east side of the Beryl-Enterprise district suggest that there is recharge by underflow from the Antelope Range which borders the district. In wells (C-35-15)3dcc-1, (C-35-15)6cdd-1, and (C-35-15)30acc-2, the water levels are generally highest in April or May, and drop to a minimum in the fall of each year. The annual fluctuations are less than a foot in well 30acc-2, but more than 3 feet in well 6cdd-1. Pumping at the Clark ranch was partly responsible for the fluctuations in the water level at well 3dcc-1 prior to 1938 and since 1946. Well 6cdd-1, however, is about 3 miles west of any pumped irrigation well; yet its water-level fluctuations are similar to but of greater magnitude than those in wells on the Clark ranch. Generally in wells in this area water levels reached maximum highs in 1942 and 1947, following years of greater-than-normal precipitation throughout the region.

Around the margin of the district there are a number of small springs, most of which issue from bedrock. These springs discharge only a few gallons per minute and are used chiefly for watering stock. Many of the springs occur where ground water in the mountain masses is forced to the surface by impermeable rocks. Some water from these springs may seep into the ground and eventually reach the valley by underflow, but their contribution to the valley ground-water reservoir is probably negligible.

Return of Water Pumped From Wells

Some of the water pumped from irrigation wells returns to the ground-water reservoir. Such return is evident especially at the overnight-storage reservoirs which have been constructed at many irrigation wells. The well is pumped continuously into the reservoir, from which water is released during the day for irrigation. Some of these reservoirs are lined to reduce seepage, but many have highly permeable bottoms through which water seeps at such a rate that the reservoir level may drop a few inches to several feet in a 24-hour period. The measured loss from an unlined reservoir at well (C-36-16)21cdd-1 amounted to 0.4 acre-foot in 24 hours. Inasmuch as this well pumps about 4½ acre-feet per day when in operation, the loss by seepage from the reservoir represents nearly 10 percent of the total pumpage.

In addition to loss from reservoirs, some of the water used for irrigation returns to the ground-water reservoir from ditches or the irrigated land itself. According to the estimates of pumpage (see table), an average of about 4 acre-feet of water was pumped in 1950 for each acre of irrigated land in the district. For individual wells the pumpage ranged from 2.5 to 7.5 acre-feet per acre. Tests have not been made to determine what proportion of this pumped water is used consumptively by crops, and what proportion is returned to the ground-water reservoir by deep percolation.

Possibility of Water From Other Sources

It is certain that most of the replenishment to the ground-water reservoir of the Beryl-Enterprise district comes from the sources described above: precipitation within the district, seepage from streams and irrigated lands, and underflow in tributary drains. The water-table contours of plate IX are consistent with this premise. They show that ground-water moves into the district from the mouth of Shoal Creek canyon, from smaller canyons and washes draining the bordering mountain ranges, and in places from areas of recharge on the valley floor. The contours indicate no other source from which important quantities of water might be derived. Many have wondered, however, whether water is contributed from any other source, either from deep sources below the valley fill, or from sources entirely beyond the area tributary to Escalante Valley.

Thermal waters have been encountered in several wells near Newcastle in the southeast part of the Beryl-Enterprise district. Volcanic activity is known to have played an important part in the geologic history of the region, and the warm water in these wells may in part be magmatic. However, the thermal water probably is chiefly of meteoric origin (that is, derived from precipitation). Well (C-36-15)-20bac-1 in Newcastle was dug 121 feet deep, and is reported to have yielded water "too hot to touch." When visited on September 12, 1947, the well was dry, but the temperature at the bottom of the hole was 116° F.[16]—about 50° higher than the air temperature at the surface. Thus, the unconsolidated valley fill has an abnormally high thermal gradient at this well, that doubtless is related to volcanic activity in the region. Water moving through that fill from whatever source, will have a higher temperature than the average for the district.

There is less likelihood that appreciable quantities of ground water reach the Beryl-Enterprise district from sources outside the drainage basin. Detailed geologic studies, although covering only a very small portion of southwestern Utah, have been sufficient to show that most of the mountain ranges are formed by a succession of rock strata in which there are very few and thin permeable zones. In the case

16—Temperature measurement by Donald E. White, U. S. Geological Survey.

of the Markagunt and Kolob plateaus, where precipitation is known to be sufficient to produce appreciable runoff each year, detailed hydrologic studies have shown that practically all this water is retained in Parowan Valley or Cedar City Valley until it is returned to the atmosphere.[17] The water that escapes from Cedar City Valley into Escalante Valley has been estimated to be of the order of about 520 acre-feet a year,[18] and this enters the part of the valley northeast of Table Buttes and does not reach the Beryl-Enterprise district.

Summary

Available hydrologic data show that water is contributed to the ground-water reservoir of the Beryl-Enterprise district both by precipitation and irrigation within the district and by surface or subsurface inflow from the tributary drainage basin. The possible sources of ground-water recharge are distributed widely but irregularly around the margins of the valley and over the valley floor. So numerous are these possible sources, and so variable are the effects of climate and permeability upon the amount of recharge, that a quantitative determination of the total recharge in any period would require an immense amount of field study. The funds available for the present investigation were entirely too limited to permit such a quantitative determination.

DISCHARGE FROM THE GROUND-WATER RESERVOIR

Water is discharged naturally from the Beryl-Enterprise district (1) by northeastward movement past Lund beneath the floor of Escalante Valley, and (2) by evaporation and transpiration in areas where the water table is sufficiently close to the land surface. There are no known springs in the valley area of the district, and thus no places where appreciable flows of ground water appear at the surface. In addition to the natural methods of discharge, wells have been taking water from the ground-water reservoir at a rate which has been increasing rapidly in recent years.

17—Thomas, H. E., and Taylor, G. H., Geology and ground-water resources of Cedar City and Parowan Valleys, Utah: U. S. Geol. Survey Water-Supply Paper 993, pp. 10-14, 167-172, 1946.
18—Idem, pp. 102-106.

Underflow Down Escalante Valley

Some movement of ground water northeastward from the Beryl-Enterprise district is suggested by the water-table contours of plate IX that show a gradient of about 3 feet per mile under the central part of the valley. Measurements of depth to water in shallow wells indicate that a comparable low gradient continues at least as far as Lund.

Escalante Valley is more than 15 miles wide at Lund, but throughout much of this width it is likely that ground water is moving toward the center of the valley from the bordering mountain ranges. The central part of the valley, under which ground water moves northeastward, is probably less than 5 miles in width. The thickness of the valley fill through which the water moves is unknown, but the railroad well at Lund shows that it exceeds 746 feet in that area. Most of the material penetrated in that well, however, was clay; the six permeable beds reported in the driller's log total less than 50 feet in thickness. Several other wells have been drilled in that part of the valley, most of which have been unsuccessful because of the lack of aquifers capable of yielding a satisfactory water supply.

Because of the low gradient and the small proportion of permeable sediments in this part of the valley, it is considered that the underflow from the Beryl-Enterprise district is a small quantity, probably of the order of several hundred acre-feet a year, as suggested by White.[19]

Evaporation and Transpiration

Accumulation of soluble salts ("alkali") on the surface of the land is typical of the undrained desert basins of western Utah, and, as shown on the geologic map (pl. VIII), these cover extensive areas in the Beryl-Enterprise district. They are in part transported into the low areas of the valley by flood flows, but they may also be brought to the surface from the ground-water reservoir by capillary action.

In most of the Beryl-Enterprise district the water table is far enough below the land surface that discharge from the ground-water reservoir by direct evaporation does not occur. However, in the northeast part of the district, and near Lund,

19—White, W. N., A method of estimating ground-water supplies based on discharge by plants and evaporation from soil: U. S. Geol. Survey Water-Supply Paper 659, p. 92, 1932.

the water table in some places is within a few feet of the surface. In these areas there may be appreciable losses by direct evaporation, as well as by transpiration.

The discharge of ground water by transpiration in Escalante Valley was the subject of an intensive field study in 1925 to 1927. Concerning the Beryl district, it was concluded that:[20]

"The chief ground-water plants of the area are greasewood, rabbit brush, and shadscale. . . A thin growth of salt grass occurs in places among the shrubs in the lowest parts of the basin, but there are no salt-grass meadows anywhere in the area. In some localities seepweed and pickleweed are present, but the total area where they occur is small. Small, irregular patches of sagebrush are numerous in parts of the area. The greasewood shows a wide range in vigor but averages of fair size and density. Some large rabbit brush is found in places, but for the most part this shrub occurs as a medium to short growth. Large shadscale also occurs in parts of the area, but over the district as a whole the growth is predominantly small.

"It is estimated that small or dwarf shadscale and sagebrush cover practically half of the 60,000 acres within the area of ground-water discharge. Neither of these shrubs is believed to be a ground-water plant. It is further estimated that the discharge of ground-water by greasewood, rabbit brush, and large shadscale on the remaining half of the area amounts to 2 inches per acre per year. On this basis the annual discharge of ground-water from the Beryl district by plants amounts to approximately 5,000 acre-feet."

The Beryl district as mapped by White did not extend as far northeast as the area shown on plate IX. The discharge by transpiration in the vicinity of Lund would serve to increase the total somewhat above White's estimate.

Pumping From Wells

Most of the water that is discharged from the ground-water reservoir in the Beryl-Enterprise district is pumped from wells. The total discharge by natural means probably does not exceed 10,000 acre-feet a year, whereas the pumpage from wells has been greater than that amount in each year since 1945 and is estimated to have exceeded 50,000 acre-

20—White, W. N., op. cit., pp. 91-92.

IRRIGATION WELLS, IRRIGATED ACREAGE, AND ESTIMATED ANNUAL PUMPAGE IN THE BERYL-ENTERPRISE DISTRICT

Coordinate Number	Application or Claim	Owner	Diameter (inches)	Depth (feet)	Acres Irrigated 1950	Estimated annual pumpage acre-feet 1937	1940	1945	1946	1947	1948	1949	1950
(C-33-14)6acb-1	A 14501	J. H. Johnson	12	230	65							*220	*220
(C-33-15)31bcc-1	A 16458	George C. Dodson	12	275	0						*100		
(C-33-16)23aab-1	A 17162	William H. Wood	16	203	160							*400	*400
30aac-1	A 15878	Joseph Del Vecchio	14	154	35							*200	*200
(C-34-16)2bcc-1	A 16236	C. R. Burns	16	240	40							*160	*170
28acc-1	A 16178	Donald Horsley	12	130	*80	70	90	*150	*150	*150	190	290	240
28bcc-2	C 20672	Fred Fisher	12	67	0	20	0	0					
28dcc-2	a 2201	Loren Reber	12	84	160						480	500	550
29ccc-1	A 16524	Monte Miller	14	203	0						310		
30adc-2	C 17699	D. F. Shelley	12	90	0		0				50		
30dcc-1	A 15615	" " "	12	250	40					140	280	560	620
30ddc-2	C 11721	" " "	12	100	10					100	130	120	10
31bcc-3	C 923	S. B. Endicott		22	0	80	30						
31ccc-1	A 15664	Deward Hall	12	160	110				310	610	660	690	850
31dcc-1	A 17011	John Jordan	16	248	0						280		
32cdc-1	a 2393	R. A. Gardner	16	200	200							160	520
32bcc-1	a 2159	" " "	16	199	100								*60
(C-34-17)24acc-2	C 16680	H. L. Austin	12	105	20						120	210	200
24bcc-2	C 16679	" " "	12	120	40							110	310
33dcc-1	A 17269	Roy P. Urie	14	224	0						30		
36acc-1	A 17080	Jack Rall	16	184	0						110	170	
36ddc-1	A 17070	Kay Terrell	14	150	65					80	200	230	220
(C-35-15)3dcc-2	C 3788	E. J. Graff	16	350	80	20			90	*300	*350	*350	340
3ddc-1	C 3789	" " "	16	350	0	220		*200					
7cdd-1		Erwin Schmidt			0							60	
10acc-1	C 3784	E. J. Graff	16	334		460							
10acd-1	C 3785	" " "	16	280									
					240	600		700	*700	*800	*1100	*1100	*300
10adc-1	C 3786	E. J. Graff	16	400		460							330
10add-1	C 3787	" " "	16	350									150
10bdc-1	A 12134	Walter Martin	16	271	160		350	*350	380	490	730	760	890
16ddd-1	A 12838	E. F. Stark	16	300	0							80	
22dcd-1	A 16703	Kumen Gardner	14	257	20								40
28acc-2	A 12095	Robert Reeve	12	163	60				130	130	180	300	340
28adc-1	A 15021	" "	14	200	80				120	150	240	160	280
28bdc-1		Deward Spendlove							240	90	150	130	280
33dcd-1	a 2448	Mike Torres	14	254	40								190
(C-35-16)5add-1	A 12758	Norval Bracken	16	40	60		50				260	200	250
6bbc-2		Woodruff Holt			80							140	470
6ccc-1	C 9748	N. E. Jones	12	80	0	2							
7bbb-1	C 13661	H. L. Austin	16	95	0	70	20						
7bcc-1	C 13660	" " "	12	65	60	60	120			240	210	240	280
7bdb-1	C 14227	Parley Moyle	12	75	45	40	130	*200	250	360	280	190	170
7ccc-1	C 17796	Arnold Barlocker	12	104	50	80	50	*100	140	270	310	240	210
9aad-1	A 15777	H. J. Beechler	16	150	80							*100	*300
9add-1	A 15945	J. M. Monroe	16	150	80					200	160	240	270
9dab-1	a 1915	Clark & Monroe			80								320
10acb-1	C 10338	Edmond Thomas	12	103	60	75	10			190	250	430	490
10bda-1	A 13760	H. B. McReynolds	14	117	80	60	30					*200	*240
14ccc-1	A 16535	Hunter Brothers	14	192	80								120
14cdc-1	A 16534	Manual Duran			0						80		
14dcc-1	A 16223	P. M. Smith	14	167	0					*150		60	
14ddc-1		Jasper White			0						150		
15abc-1		Dewey	12	120	0	180					80		
15bba-1	C 20262	Dee Burgess	12	133	70					240	400	400	340
16add-1	A 17436	" "	14	116	20								40
16bbc-1	A 16835	Earl E. Lewis	14	174	80					130	180	220	110
16bdd-1	A 16834	L. M. Thomas	14	163	60						170	170	100
16cac-1	A 16537	G. F. Wertz	12	122	45					80	80	120	130
16cdd-1	A 14347	Ray Hunt	12	125	85				340	330	310	370	340
16dda-1	a 2390	Calvin Lewis	12	125	80							140	110
16ddc-1	A 15947	Niels Nielson	14	152	25						50	80	190
17acc-2	a 1515	Ray Hunt	20	70	60		40	*200	310	300	300	370	360
17add-2	A 13459	Marion Beckstrom	13	103	60		50		350	200	390	360	490
17bad-1	C 2230	M. Vicerra	12	120	40	130	150	*80	60	120	130	140	130
17cda-2	C 16463	Roy Pectol	12	70	*60	50	100			130	20	220	300
17ddd-1	C 17282	James Dell	12	25	0		30						
18ccb-1	A 15980	J. C. Bosshardt	14	160	75				190		300	360	300
18cdc-1	C 20391	" " "	14	95	75				190	350	410	340	370
20dad-1	a 2012	Mary Wagner	12	200	60								150
21acd-1	A 17208	Milford Barnum	12	105	65					40	210	160	280
21bcc-1	A 15313	A. D. Moyle	14	120	85				290	550	480	390	440
21bdc-1	a 2063	A. D. Moyle	16	178	0						180	400	
21cac-1	a 2122	A. V. Piper	14	155	60						20	160	310
21dcc-1	a 2064	A. D. Moyle	16	204	85								590
22add-1	C 10337	Dewey Goddard	12	147	95	130	130	*200	200	280	340	330	340
22ccd-1	A 16931	Lyman Sevy	14	206	0						280	190	
22dcc-1	A 16930	Lyman Sevy	12	130	0					110	140	90	
23bcd-1	A 15644	O. B. Covington	12	160	100				180	280	250	130	240
28acc-1	A 15771	Bruno Biasi	18	200	105				30	380	470	430	460
28cdc-1	A 16866	C. F. Holland	16	185	120						*250	*300	*350
29acc-1		C. B. Duncan	16	194	85				370	110	570	400	690
29ccd-1	a 2185	E. L. Hunt	16	194	40							230	210
29dcc-1	A 14570	C. A. Thomas	12	140	80				190	130	120	210	230
29ddc-1	A 14569				40								160
31abb-1	A 17125	C. E. Mitchell	14	162	60								160
31abc-1	a 2190		6	70	60					250	280	330	320
31acc-2	a 2137	C. E. Mitchell	14	147	80						230	310	530
31bdc-1	A 16654	E. V. Robinson	12	155	60						140	150	170
31cbb-1	A 16872	Chester Whitelaw	16	195	160					230	170	230	270
31ccc-1	A 15906	Marvis Miller	12	209	65					250	210	340	250
31cdc-1	A 15907	Easton Brown	16		0				130	190	100	140	
31ddd-1	A 15905	L. B. Dalton	14	160	150					180	220	240	360
32acc-1	A 16829	Ivan Alberto	16	167	120					140	320	330	340
32bcb-1	A 16830	Thomas Gibson	16	173	160					180	410	370	510
32ccc-1	A 16623	Willard Randall	14	176	100				270	290	310	490	360
32cdc-1	A 16621		14	176	95								180

IRRIGATION WELLS, IRRIGATED ACREAGE, AND ESTIMATED ANNUAL PUMPAGE IN THE BERYL-ENTERPRISE DISTRICT—Continued

Coordinate Number	Application or Claim	Owner	Diameter (inches)	Depth (feet)	Acres Irrigated 1950	Estimated annual pumpage, acre-feet 1937	1940	1945	1946	1947	1948	1949	1950
(C-35-16)32dcd-1	A 16831	John C. McGarry	16	452	110						170	90	90
33bcc-1	A 16662	Cliff Quinn	12	140	75				*150	*200	*250	*270	390
33ccb-1	A 16662	" "	12	130	75				70	50	140	240	330
(C-35-17) 1acc-2	C 17961	H. L. Bennett	16	265	90							170	190
1bcc-1	A 15654	H. C. Gribble	16	130	0						150		
1cdc-1	a 2090	Demar Bowman	12	114	80						250	170	630
1dcc-1	A 17073	C. M. Gribble	16	260	160						240	230	200
2dcc-1	a 2003	Vern Frailey	16	160	160						*300	*300	260
3ccc-1	A 17133	G. M. Sevy	12	240	0					60			
4acc-1	A 17268	H. E. Christensen	14	176	160					100		130	280
4dcc-1	A 17286	MacFarlane Bros.	14	240	160					80	20	150	320
7daa-1	A 17290	W. W. Adams	12	200	70					20	140	110	170
12acc-1	C 14229	J. B. Moyle	12	90	50				230	230	140	190	210
12bab-1	A 12677	A. L. Daniel	12	86	40		10		180	100	*80	*110	90
12bcc-1	A 14024	F. S. Price	14	161	80								130
12ddc-1	a 2357	Arnold Barlocker	16	200	80							110	320
13acc-1	A 13614	J. E. Moyle	18	101	100		180	*300	270	590	570	640	590
13adc-1	A 13996	" " "	13	182	100			*200	*200	*200	200	290	400
13bcc-1	A 13990	A. D. Moyle	13	183	60			*200	230	110	200	210	250
13bdc-1	C 14228	A. D. Moyle	16	95	0	70	130						
13cbc-1	C 12346	H. G. Moyle	14	150	100	60	160	*200	250	290	220	310	330
13ccc-1	a 2077	" " "	16	200	50							20	220
14ccc-1	a 2017	Eldon Thompson	16	300	80						130	*240	*240
22bcc-2	a 1946	P. L. Morris	16	163	80				*50	*70	*120	*200	*120
22bdc-1	A 16525	Joe Green	12	200	80					20	100		260
23acb-1	A 14749	H. G. Moyle	12	125	50						290	350	310
25dca-2	C 10296	Charles Bosshardt	12	110	95	10	10	*150	290	350	350	330	380
25dcd-1	a 2139	" "			15								*40
36dcc-1	A 16425	M. H. Crosier	16	200	80						150	110	540
(C-36-15) 4cdd-1	a 2057	W. Leo Knell	16	245	0						110	40	
4dcd-1	a 2013	" " "	14	235	190							*600	*670
18bda-1		Floyd Bekins			60				140	190	250	190	270
19ccc-1	a 2101	A. C. Christensen		217	100					100	200	220	310
22cdd-1	A 15590	New Castle Reclamation	12	75	supp					*150	*150	*150	*150
27abb-1	A 16434	" " "	16	66	supp						*150	*150	*150
(C-36-16) 3a-1	A 14709	Mrs. Harry Coon	12	115	10								30
3c-2	A 16860	Floyd Bekins	20	196	240							*200	*300
4a-2	A 16699	Vern Frailey	16	207	80						*200	*240	*240
4b-3	C 1396	Willard Randall	12	144	70		290	160	270	220	350	280	410
4b-4	A 16218	G. S. Holt	16	250	90				20	190	250	210	240
5a-1	C 16592	W. T. Hunt	12	112	100		250			270	300	180	330
5a-8	A 15124	Cleo Crawford	12	180	80			260	300	150	250	210	290
5a-9	A 15774	Leonal Gardner	12	200	90			90	250	260	250	250	320
5a-12	a 1899	Bryant Beacham			70			250	230	110	280	210	290
5b-1	a 1832	Curtis Brinkerhoff	12	150	180				380	190	260	180	340
5b-2	A 15384	Heber Sevy	12	156	100			320	260	10	290	330	390
5b-3	A 16700	" "	16		100			320	290	310	290	300	440
5c-1	a 1833	Gordon Mathis	12	160	60						330	220	250
9acd-1	A 16244	Joseph Judd	14	214	160				150	270	310	280	360
9bcd-1	A 16253	Wilson Scott	14	272	160			40	250	250	300	220	350
10bbd-1	A 16042	N. J. Barlow	14	290	120					50	250	230	240
10bdc-1	A 16043	" " "	14	340	120					20	230	250	290
15cdd-1	a 2158	T. W. Jones	5	200	20					*40	*40	*40	*40
17dbb-1	A 14642	Weyl Zuckerman										320	610
19abb-1	A 15511	T. W. Jones	16	352	100						140	160	260
20abb-1	A 16418	Weyl Zuckerman										410	540
20dbb-1	A 14642	" "										280	530
21abc-1	A 16342	T. W. Jones			220			70	290	280	310	280	520
21cdd-1	A 16317	Arthur Barlocker	14	254	160			50	60	60	250	260	400
24ddc-1		A. C. Christensen			40								160
29bab-1	A 16415	Weyl Zuckerman								190	240	310	690
29daa-1	A 16189	" "	16	380					320	270	290	505	770
30aab-1	A 16414	" "	16	402							310	180	510
30bab-1	A 16413	" "									290	250	460
30cab-1	A 16189	" "	16	380					320	250	370	380	480
30dab-1	A 16189	Weyl Zuckerman	16	393					370	350	370	560	820
30ccc-1	A 15833	Raymond Staheli	14	400	75			100	130	120	200	140	230
31aba-1	A 14642	Weyl Zuckerman	16	349					490	460	480	430	740
31aca-1	A 14786	" "							370	180	140	130	250
31add-1	A 14197	" "	16	381					450	550	430	470	590
31bab-1	A 14197	Weyl Zuckerman	14	419					410	410	540	490	720
31bdd-1	A 14197	" "	12	398					560	370	420	460	680
31cdc-1	A 16416	" "										*390	*300
31ccc-1	A 16153	Leland Huntsman	14	222	80				70	80	220	130	210
32aaa-1	A 14642	Weyl Zuckerman							170	200	550	350	550
32add-1	A 14197	" "								50	140	150	90
(C-36-17) 36add-1	A 16101	Norval Bracken	14	202	120			30	170	190	210	190	220
36ddb-1	a 2241	Albert Holt	14	382	80							50	130
(C-37-16) 6cac-1	a 2202	Edward Hunt	14	304	supp						140	60	520
6ccc-1	A 15509	LeRoy Adams	14	200	240			30	190	70	260	270	380
(C-37-17) 1ccd-1	A 15465	Heber Truman	16	438	supp			100	160	40	90	50	200
1dcd-1	a 2296	Enterprise Reservoir & Canal Co.	14	250	"						50	220	340
1ddc-1	A 16339	Leland Holt	14	205	"			20	200	160	240	170	220
11dac-2	a 1877	A. E. Pickering	16	86	supp				80	70	90	80	90
11ddb-1	C 3139	A. P. Winsor	12	223	45		160	140	230	220	220	200	290
12acc-1	a / 1965	Grant Clove	16	318	supp						180	280	240
12bdc-1	A 14183	Charles Side	14	170	supp				170	180	150	130	180
12cbc-1	A 15585	" "	14	150	"			210	250	110	200	130	210
12cdd-2	A 16183	Arthur Thomas	16	132	supp			10	210	80	180	140	190
14acb-1	C 17896	Enterprise Town	10	185	"			250	280	210	230	210	260
14baa-1	A 16090	Jacob Busher	14	100	"			20	250	180	210	190	220
14dcd-1	A 14213	Roland Bowler	12	152	35			130	220	40	140	90	100
15bab-3		Nelson Thomas	10	125	20				110	60	50	120	90
TOTAL NUMBER OF WELLS PUMPED						22	24	37	74	106	142	157	163
TOTAL NUMBER OF ACRE-FEET PUMPED						2,942	2,570	5,830	16,620	20,900	33,490	38,450	51,320

*Estimated

feet in 1950. The individual irrigation wells of the district yield water at rates ranging from 400 to 2,500 gallons per minute, but the discharge from most wells is in the range from 900 to 1,200 gallons per minute.

No well in the district is equipped with a meter for measuring the quantity of water pumped. Estimates of pumpage are therefore based primarily upon the electric energy used seasonally by each pump. In 1950 about 150 of the irrigation wells in the district were equipped with electrically driven turbine pumps; the total energy consumed at those wells exceeded 6,000,000 kilowatt-hours, at an average cost of somewhat less than 1.7 cents per kilowatt-hour.

Estimates of annual pumpage by irrigation wells are presented in an accompanying table. These estimates are based upon data collected from several representative wells during the irrigation season of 1950. The discharge of the tested wells was measured by means of a Hoff current meter, which was shown by comparison with weir measurements to give best results when the discharge is a smooth, uniform flow through a full horizontal pipe. Pumpage from wells equipped with internal-combustion engines was computed from the measured or estimated discharge of the well, and from the acreage and type of crops irrigated.

The kilowatt-hours required to lift an acre-foot of water 1 foot were computed from the measurements of discharge, pumping lift, and energy input. In twelve wells the energy input ranged from 1.72 to 1.92 kilowatt-hours per acre-foot of lift, with an average of 1.82. Similar tests of eleven wells in the Milford district showed a range of 1.73 to 1.96 kilowatt-hours, with an average of 1.88. Accordingly, for other wells throughout the valley it was assumed that, on the average, 1.85 kilowatt-hours would lift an acre-foot of water 1 foot. Estimates of annual pumpage were computed from total energy consumed and from measurements or estimates of the pumping lift at each well.

For the years 1945 to 1949 the only available data are the kilowatt-hours of energy used at each well. Changes in average pumping lift from year to year were estimated on the basis of recorded changes of water level of observation wells in the vicinity, and the total pumpage was derived by using the factor of 1.85 kilowatt-hours per acre-foot per foot of lift, as for 1950.

Prior to 1945 very few wells were equipped with electric pumps. Most pumps were run by combustion engines, and the pumpage figures are based on estimates of discharge and upon well owners' records of the hours of pump operation, checked by measurements of fuel consumption per hour and seasonal records of fuel purchases. In 1938 Everett Larson measured the discharge and seasonal pumpage from six wells in the Beryl district,[21] and reported that the seasonal pumpage ranged from 80 to 240 acre-feet. The tabulated estimates for those wells in 1937 and 1940 are of the same order of magnitude.

It is recognized that these estimates of pumpage are only rough approximations, particularly for years prior to 1950, but they must necessarily be so because of the lack of basic data. Even the data collected in 1950 are sufficient only for an approximation of the total pumpage, as shown at the end of the table. Accurate computations for future years would require at least one measurement each season of the discharge, lift, and energy input at each well, and periodic measurements at selected representative wells to show the changes in rate of discharge and pumping lift during the season. Such a project would require the time of several men continuously throughout the irrigation season.

As has been pointed out (p. 158) not all the water pumped from wells is withdrawn permanently from the ground-water reservoir. Some is returned by percolation from overnight storage reservoirs, from ditches, or from the irrigated lands. At some wells where the irrigated lands are permeable and the farmer applies water liberally, as much as half the water pumped may return to the ground-water reservoir.

Pumping inevitably causes some lowering of the water level in the well, thus inducing flow of water toward the well from the aquifer. As pumping continues, the cone of depression increases in size so that the well draws water from a progressively larger area. The water level in the well continues to drop, but at a decreasing rate as time goes on, until the cone has expanded far enough to reach either an area of natural recharge or an area of natural discharge of the aquifer. Only when pumping is balanced by increased movement from a recharge area or by decreased natural dis-

21—Larson, Everett, Some irrigation pump efficiencies and pumping costs in southwestern Utah: Univ. Colorado, Dept. Civil Eng., Master's thesis, June, 1943.

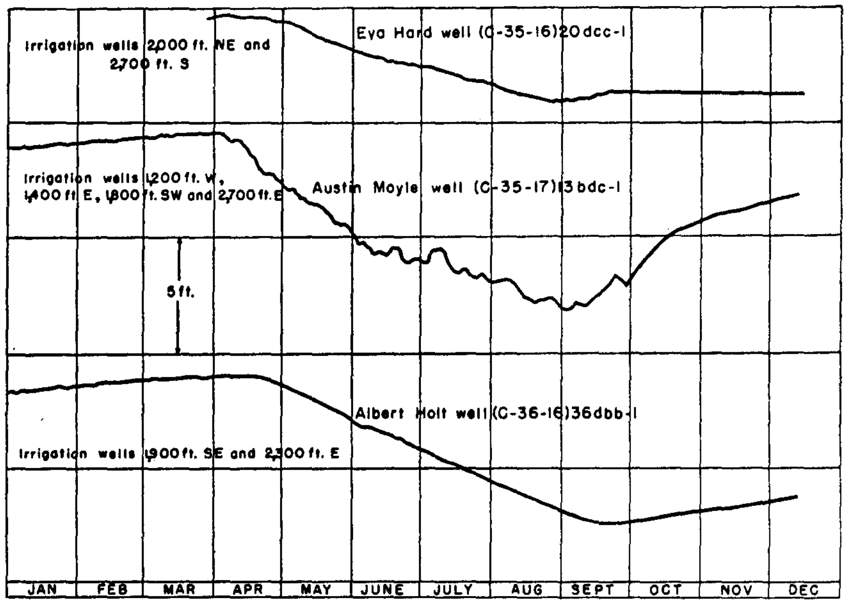


Fig. 5. Fluctuations of water levels in three wells due to pumping from nearby wells.

charge will the progressive decline of water level in the pumped well be arrested.

Pumping in Escalante Valley has produced broad cones of depression at many wells, and has caused appreciable lowering of water levls in unused wells several thousand feet from the pumped wells. Examples of these effects of pumping are shown in figure 5. A seasonal decline of more than 7 feet was recorded at well (C-35-17)13bdc-1, which is within half a mile of four irrigation wells. Well (C-35-16) 20dcc-1 is 2,000 feet from the nearest irrigation well, yet the water level in that well declined about 3½ feet during the irrigation season. In each well there was substantial but not complete recovery within three months of the cessation of pumping in September.

BALANCE BETWEEN RECHARGE AND DISCHARGE

The increments of water added by recharge, and the losses of water due to discharge, change the total quantity stored in the ground-water reservoir. Changes in the position and form of the water table reflect these changes in storage, and wells provide sampling points where the changes in the position of the water table are shown by fluctuations in water level.

The hydrographs of figure 6 show the changes of water level from year to year in observation wells distributed throughout the district. The hydrographs for wells (C-33-15) 31cbb-1, (C-33-16)19ddd-1, (C-33-17)29dcb-1, and (C-34-14)31ccc-1 form nearly horizontal lines, indicating that the position of the water table changed very little during the 15-year period. These wells are remote from the irrigation-pumping district and have not been affected by the pumping. The very slight changes in the position of the water table suggest essential balance between recharge and discharge under natural conditions. These four hydrographs further suggest slight increases in underground storage following years of greater-than-normal precipitation, with resultant increases in runoff and underflow into the basin. Water levels in the wells were generally higher following years such as 1938, 1941, and 1946 (when heavy precipitation occurred as shown by the record) than following years of subnormal precipitation.

The effects of a succession of wet and dry years are shown in most of the hydrographs of the illustration: low levels in 1940, 1943, and 1948 following dry years, and high levels in 1938, 1942, and 1946 following wet years. The high water level in well (C-37-17)12cbc-1 is especially pronounced, and was caused by seepage from high runoff in the channel of Shoal Creek. Climatic variations appear to have been the dominant causes of fluctuations of water level in most wells prior to 1945.

Since 1945, however, the effects of climatic variations have been small in comparison with the effect of pumping upon water levels in wells in the irrigated area. Water levels have dropped several feet in observation wells in T. 36 S., and somewhat less in wells in T. 35 S.

The water level in well (C-35-15)3dcc-1 trended upward between 1940 and 1946. This trend also is an indirect effect of pumping. The well is on the old Clark ranch, where five irrigation wells had been operated since 1928 for irrigation of 320 acres of alfalfa. Pumping ceased in 1939 and the ranch was idle until 1945. The rising water level in the well records the gradual but progressive replenishment of water that had been withdrawn in years prior to 1940.

Pumping has changed the form of the water table considerably in the past decade. On plate IX the 5,136- and 5,140-foot ground-water contours form pronounced embayments around the concentration of irrigation wells in

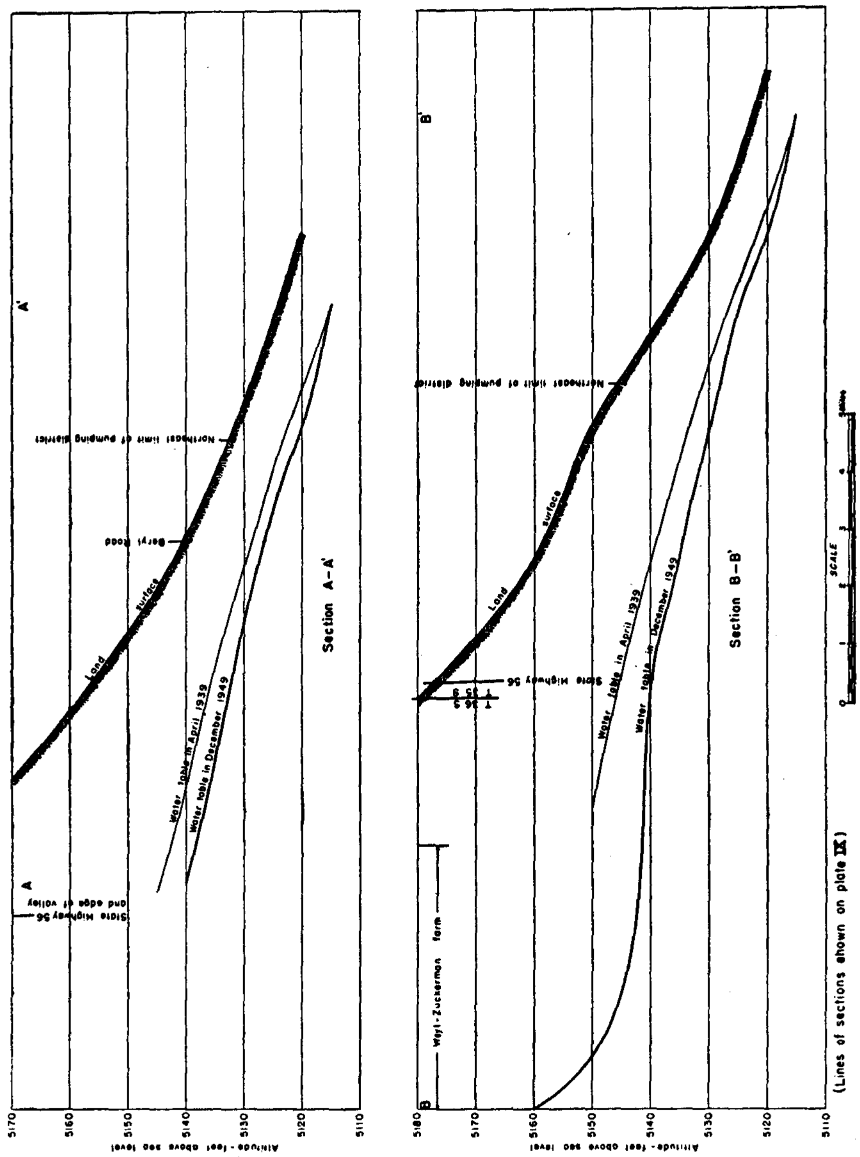


Fig. 7. Profiles of the water table in the Beryl-Enterprise district in 1939 and 1949.

the southwest part of T. 35 S., R. 16 W. These embayments did not exist 10 years earlier, as shown by a map of the water table in May 1939.[22] An embayment of the 5,144-foot contour extending toward Enterprise in 1949 appears also to have been caused by pumping, although there are no data as to the position of the water table in that area before pumping began.

The change in the position of the water table is more clearly demonstrated by the profiles of figure 7. These profiles show that between 1939 and 1949 the water table was lowered more than 2 feet throughout the area where irrigation wells are concentrated, and in some parts of that area the decline of the water table exceeds 8 feet. The effect of pumping appears to have extended as much as 2 miles from the pumping area, but at greater distances the position of the water table changed very little during the decade.

There were very few wells in the area south of State Highway 56 prior to 1945, and therefore there are no comparative data as to the change in position of the water table in that area during the past decade. Water levels were measured in many wells soon after they were drilled, and subsequent measurements have shown the changes in recent years. These measurements, together with data from observation wells throughout the district, are the basis for figure 8, which shows the area where the water table declined between 1945 and 1949. Within an area of more than 30 square miles the water table was lowered more than 5 feet in the 4-year period.

It is noteworthy that the water table is more than 30 feet below the land surface in most of the area where marked declines have occurred in recent years. Referring to figure 7, there has been practically no change in the position of the water table where it is less than 8 feet below the surface, and where it is less than 15 feet below the surface the decline during the decade has been less than 3 feet. This is significant, for it means that pumping to date has affected the position of the water table only slightly in the area of natural discharge by evaporation. That natural discharge presumably is continuing at rates only slightly decreased from those prevailing prior to the beginning of pumping. And if the natural discharge in those days balanced the average recharge, it must be concluded that it is only slightly

22—U. S. Geol. Survey, unpublished data on file in Salt Lake City office.

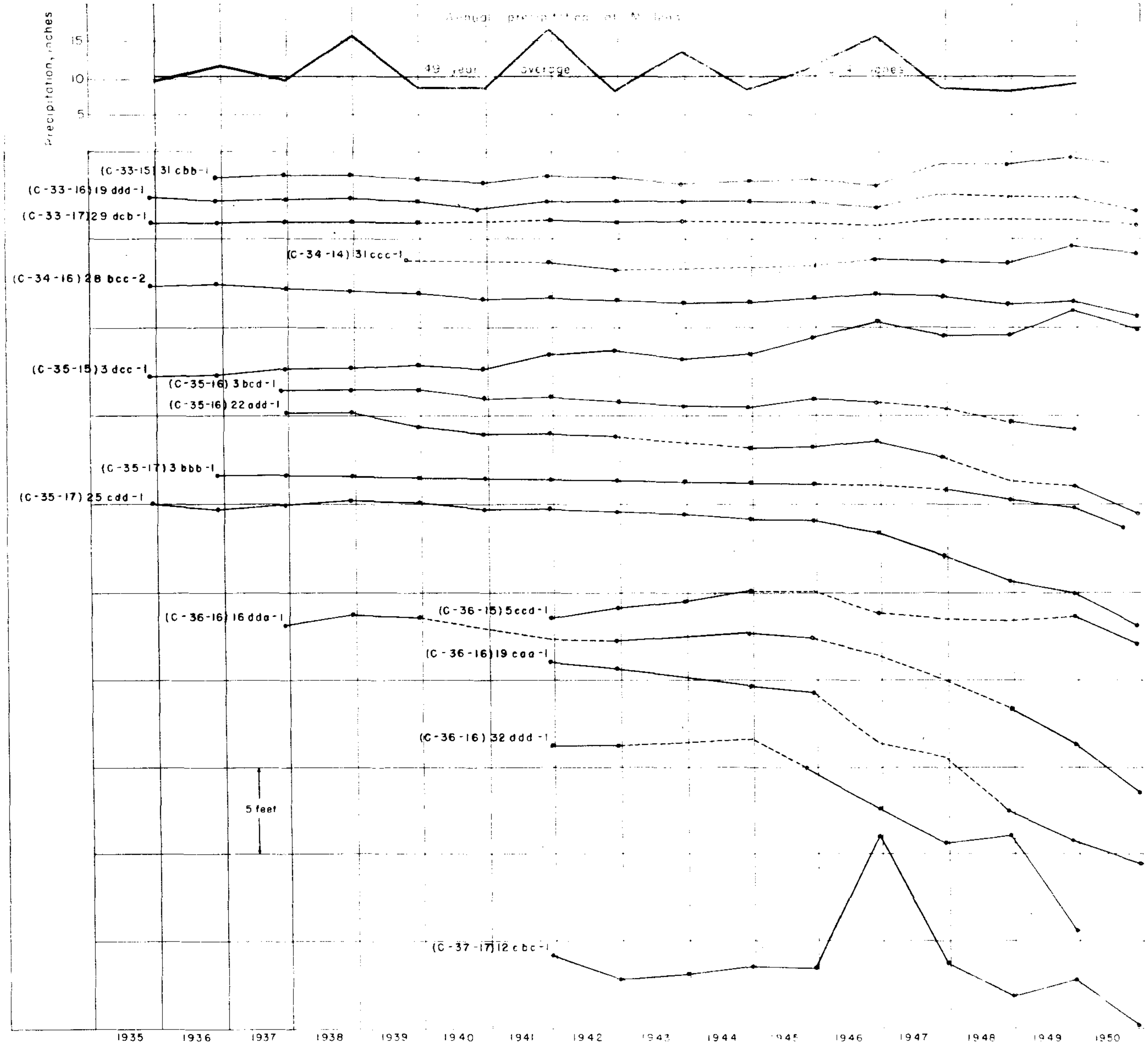


Fig. 6 - Annual changes of water level in 15 wells in the Beryl-Enterprise district, 1935-50.

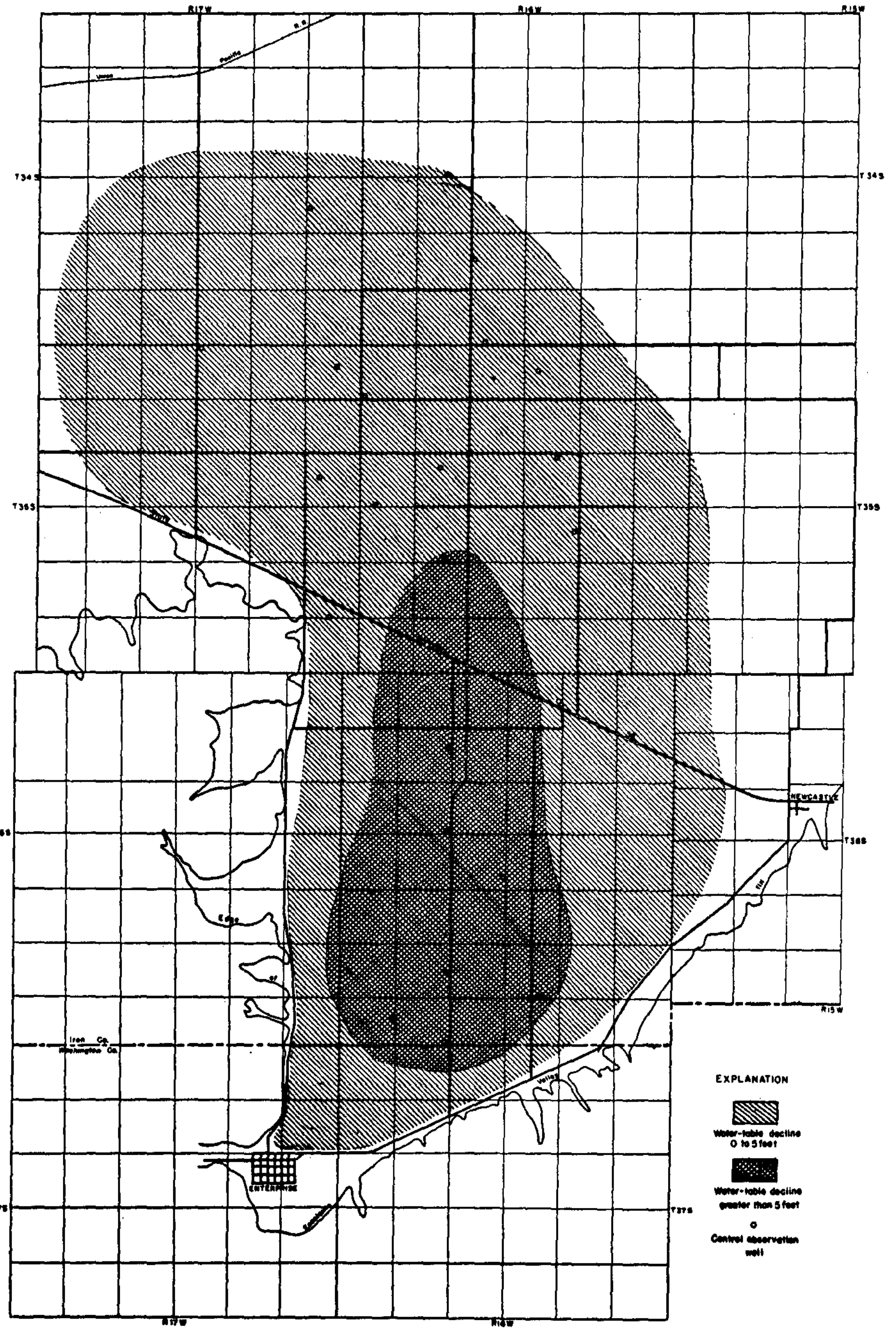


Fig. 8. Area within Beryl-Enterprise district where water table declined between 1945 and 1949.

less today. Therefore, the pumping to date has resulted in salvaging negligible quantities of water from natural discharge.

The net quantity of water withdrawn—that is, the total pumpage less the amount returned by seepage from reservoirs, ditches, and irrigated lands—in the district so far is believed to have been withdrawn essentially from storage. In other words, it has been mined from the ground-water reservoir. The hydrograph for well (C-35-15)3dcc-1 (fig. 6) suggests that even the quantities withdrawn from the reservoir prior to 1945 may have been mined, although the pumpage was so small in comparison with total storage that the effect upon the regional water table was negligible. As the withdrawal continues progressively larger quantities of water will be salvaged from natural discharge and the proportion of water withdrawn from storage will decrease.

QUALITY OF GROUND WATER

Ground water is used in the Beryl-Enterprise district chiefly for irrigation, but it is also important for municipal, domestic, livestock, and railroad use. The usefulness of water for each purpose is determined by its chemical quality.

Irrigation water is disposed of chiefly by the physiologic and transpirational processes of plants, and by evaporation from soil. Mineral matter dissolved in the water, unable to escape by transpiration or evaporation, is left behind to accumulate in the soil unless there is surplus irrigation water to carry it away in ditches or by deep percolation. Such accumulation progressively reduces the productivity and the physical condition of the soil, and may ultimately make the land unfit for agricultural use. If the water has a high content of mineral matter, the deterioration of the soil may be appreciable in just a few years.

The tolerance for dissolved mineral matter of various kinds in irrigation water varies considerably with particular crops, soils, and other factors, but approximate limits for the most important crops have been described by Wilcox.[23] He concludes that the most important factors that must be known in order to evaluate the quality of water for irrigation are (1) the total concentration of dissolved mineral matter, (2) the

23—Wilcox, L. V., The quality of water for irrigation use: U. S. Dept. Agr. Tech. Bull. 962, 40 pp., 1948.

percentage of sodium, and (3) the concentration of boron. Excessive sodium hardens the soil and reduces its permeability to water. Boron in very small amounts is essential for plant growth, but amounts even as large as 1 part per million may be harmful to many plants. Excessive chloride is also undesirable. Certain other dissolved constituents may be harmful to some plants.

Water for human consumption preferably should not contain more than 500 parts per million of dissolved mineral matter, although as much as 1,000 parts per million is permissible. The mineral content, in parts per million, should not exceed 250 parts of chloride, 250 parts of sulfate, 125 parts of magnesium, 1.5 parts of fluoride, or 0.3 part of iron and manganese together. Fluoride in excess of 1.5 parts per million is believed to cause endemic dental fluorosis (mottled tooth enamel) when used by children under about 7 or 8 years of age.[24]. Water having a total hardness greater than 150 parts per million is classed as "hard" water; excessive quantities of soap are required for laundering and washing, unless these waters are treated. Hardness is also a major consideration in industries using water for steam.

Chemical analyses do not indicate the sanitary quality of water, for they do not show the content of bacteria, protozoa, or other organisms. However, nitrate and chloride shown by these analyses are common in organic wastes. Nitrate is generally regarded as indicative of pollution, particularly in shallow wells, although it may also accumulate by natural inorganic processes in desert basins.

The general quality of ground water in the district, as well as the quality in individual wells and springs concerned, is shown by analyses of 100 samples of water from wells and springs presented in an accompanying table. Although these data do not list boron determinations for complete classification of the waters of the district in the manner proposed by Wilcox, the sampled waters would generally be considered "good to permissible" for irrigation insofar as total dissolved mineral matter and percentage of sodium are concerned.[25] Traces of boron were identified in three samples, and 0.3 part per million as reported in well (C-35-15)3ddc-1 in 1927.

24—Drinking water standards, 1946: U. S. Public Health Service, Reprint 2,697, from Public Health Service Reports, vol. 61, no. 11, pp. 371-384, 1946.

25—Wilcox, L. V., op. cit., p. 26.

The waters are also generally suitable for domestic and stock use, except for hardness. Some of the best of the sampled waters are from springs used for culinary supply in Enterprise and Modena. Most of the samples show total dissolved mineral matter, chloride, sulfate, magnesium, and fluoride well within the permissible limits set by the Public Health Service; but exceptions are numerous and some are serious. An excessive fluoride content of 4.7 parts per million was found in well (C-36-15)18acb-1, a deep well about a mile west of Newcastle. Excessive nitrate was found in many samples. All the well waters are hard, and some are very hard.

The water from springs at Modena and from the railroad well at Beryl have been suitable for railroad use without treatment, but the water from the wells at Lund has been softened before use. Conversion to Diesel engines has reduced the railroad's requirement for water at these localities.

The greatest content of mineral matter—5,650 parts per million—was found in water from well (C-35-15)10bac-1, which is 42 feet deep. Except for this well, the total dissolved mineral matter in sampled well waters ranged from 273 to 1,610 parts per million and averaged about 650 parts per million. (For those samples in which the total mineral content has not been determined, the specific conductance provides a rough estimate. On the average the total solids in parts per million is about 0.7 times the specific conductance in micromhos.) The concentration of chloride ranges from 12 to 475 parts per million and of sulfate from 2 to 628 parts per million, again excepting well (C-35-15)10bac-1.

The analyses are listed in order of well number, and are therefore arranged by location in the district approximately from north to south. Scanning of the table indicates that the more highly mineralized waters are in the northern part of the district. Specifically, the waters of best quality are in the areas recharged principally by Shoal Creek and Crestline Wash, and the poorest waters are in the north and east parts of the district. In general, too, the waters of better quality come from wells where the water table is more than 30 feet below the surface. Conversely, the least desirable waters have been obtained from wells where the water table is less than 15 feet below the surface.

There is a good correlation between depth of well and quality of water. Throughout the valley floor the most mineralized waters are obtained from wells less than 100 feet deep, or from deeper wells that have been perforated to admit water from shallow aquifers. Plotting of the specific conductance against depth of well shows the following: in wells less than 100 feet deep the specific conductance ranges from 411 to 2,210 micromhos; in wells 101 to 200 feet deep, the range is 351 to 1,500; in wells 201 to 300 feet deep, 339 to 907; and in wells more than 300 feet deep, 392 to 615.

Because of the inferior quality of shallow water in many areas, wells perforated in both deep and shallow strata yield water more highly mineralized than that of the deeper strata alone. This is illustrated in the analyses of water from well (C-35-15)3dcc-2, located along the western edge of the Clark ranch.

The casing of this well is perforated from 60 to 136 feet, from 260 to 280 feet, and from 285 to 308 feet below the surface. Thus the well can draw from both shallow and deeper ground-water supplies. It is said that water of fairly good quality is obtained when the well is first pumped each season, but that after about 30 or 40 hours of pumping the quality of water deteriorates. Analyses in the table confirm this deterioration. In August 1949 the specific conductance of the water pumped was more than 2,300 micromhos, and it is likely that a large proportion of the water was derived from shallow zones. The water in deeper aquifers is under artesian pressure (see page 151), and that pressure appears to have been sufficient to bring water of better quality into the well during the following winter, for the specific conductance of the water pumped at the beginning of the next irrigation season was less than 1,600 micromhos. By mid-June, however, after 6 weeks of pumping, poorer quality was again manifested by an increase in specific conductance. The water pumped from this well is the poorest of the irrigation waters tested.

In November 1927, soon after well (C-35-15)3dcc-2 was drilled, its water contained only 403 parts per million of dissolved matter. It is likely that the deterioration in quality since that date is due largely to influx of shallow ground water. Furthermore, the mineral content of that shallow water probably has increased over the years because of percolation from the irrigated fields of the Clark ranch. It is noteworthy that the water from well (C-35-15)10add-1 was of good quality in 1950. That well is as deep as well 3dcc-2, and is perforated at depths of 43-65, 200-230, 287-302, and 325-335 feet. However, it is at the high southeast corner of the Clark ranch, where one might expect the least effect of seepage from the irrigated area.

The quality of ground water fluctuates somewhat from season to season, as shown by the specific conductances of samples collected in August 1949 and in the spring of 1950. In shallow well (C-35-15)10bac-1 the specific conductance increased appreciably during the period, indicating an increase in mineralization that was probably caused by deep percolation of irrigation water or precipitation, or both, on the Martin ranch. In four other wells in the vicinity, all more than 100 feet deep, the specific conductance changed only slightly, and in general it decreased during the winter. These changes doubtless depend upon the quality of the water that moves toward the well to replace the water pumped during the irrigation season.

MAXIMUM ECONOMIC UTILIZATION OF GROUND WATER

The current investigation has shown that the storage in the ground-water reservoir is being depleted, and that the rate of depletion is practically equivalent to the pumpage minus return seepage from the irrigation operations. Concurrently there is a considerable loss of ground water by evapotranspiration, and the rate of this natural discharge probably has not been appreciably diminished from the rate that obtained prior to the drilling of wells. Thus, although the current pumpage is far in excess of the natural replenishment to the reservoir, a quantity equivalent to that natural replenishment is lost without serving any beneficial purpose.

In normal years there is no significant surface outflow from the Beryl-Enterprise district, and the ground-water outflow is believed to be small in comparison with the annual pumpage, or even in comparison with the recharge, or with the discharge by evapotranspiration. This fact has an important bearing upon the ultimate development of the land and water resources of the district, for it means that, as in other closed basins, there must be a slow but progressive accumulation of the soluble salts carried into the district from the tributary drainage basin.

These are some of the hydrologic conditions that must be considered in conjunction with social and economic factors if beneficial use of the water resources is to be achieved with maximum benefit to the individual landowners, the community, and the State.

The Salt and Alkali Problem

It is inevitable that the total quantity of soluble materials in the soils and water of the district will increase, because of the lack of facilities for flushing those salts into other areas. But the problem is not only for future generations, for there are already great quantities of soluble salts within the district. White, commenting on the 17 idle pumping plants in the Beryl district in 1927, said:[26] "Not all the reasons for failures are known, but the use of shallow alkali ground water and the poor quality of the land selected for irrigation undoubtedly caused part of the failures."

Studies to date have shown that the valley fill in many parts of the district is permeable enough for percolation of water from the land surface down to the water table. Such percolation does occur from lands that are irrigated, as well as from other areas when they receive heavy precipitation. Chemical analyses show a greater proportion of dissolved materials in water from shallow wells than in water from nearby deep wells, and it is likely that this is due at least in part to the addition of waters that have percolated downward from alkaline or saline soils, or through earth materials that contain soluble matter. Further, the investigation has shown that the aquifers of the valley fill are more or less directly interconnected, so that if water is pumped from deep wells, replacement may occur from shallower zones. Thus eventual deterioration in the quality of the deeper waters due to pumping is a distinct possibility.

Soil surveys and water surveys indicate that the greatest concentration of salt and alkali is in the lower parts of the district, where the water table is at shallow depth. The trend in agricultural development in recent years has been away from these lowlands, and toward the higher slopes where there is a greater proportion of alkali-free land. The success of many of these recent ventures doubtless has been due in part to economic factors, such as crop prices, availability of

26—White, W. N., op. cit., p. 93.

electric power, etc. Comparison with ventures during earlier decades indicates that the best place for ground-water development is not necessarily where the cost of pumping is least.

For maximum beneficial use of the ground-water reservoir over the longest period of time, it is desirable to irrigate soils that contain the least amounts of alkali and salt. Aside from the generally greater productivity of these soils, they will cause least deterioration in the quality of ground water when water returns to the reservoir from irrigated areas.

Rather generally, water of sustained higher quality will be obtained from wells tapping deeper aquifers, provided that well casings are not perforated in the shallowest water-bearing zone. Although the various aquifers are considered to be interconnected, those connections are generally by devious natural routes. Wells perforated opposite several zones at and below the water table, however, provide direct access for the shallow water of inferior quality.

The Problem of Salvaging Natural Losses

The discharge of ground water by evaporation and transpiration in the Beryl district, as outlined by White, has been estimated to be of the order of 5,000 acre-feet a year. Farther northeast, toward Lund, the water table is closer to the surface and the total natural discharge in the area south and west of Lund, including that in his Beryl district, may well be double the amount estimated by White. In areas where the water table is shallow enough, water may rise to the surface by capillary action, where it is evaporated and any dissolved salts are left behind. Most of the natural discharge from the Beryl-Enterprise district, however, occurs by transpiration from phreatophytes, that is, from plants that depend upon ground-water supplies.

Greasewood (*Sarcobatus vermiculatus*) is common in parts of the Escalante Valley where the depth to water ranges from about 3 to 15 feet and other conditions are suitable, and is found in some places where the water table is as much as 40 feet below the surface. Other phreatophytes, such as salt grass (*Distichlis spicata*) and pickleweed (*Allenrolfea occidentalis*), occur where the water table is less than about 8 feet below the surface.[27] In all investigations involving the

27—White, W. N., op. cit., pp. 28-41.

determination of the consumptive use of water by phreatophytes, there has been evidence that the amount of water consumed decreases as the depth to the water table increases.[28] Thus, the natural discharge from the district would be reduced if the water table in the area could be lowered sufficiently.

Pumping from wells is an effective method of lowering the water table. However, there are several objectionable features to any program for pumping from wells located within the area of natural discharge. For one thing, clay and silt are predominant in the valley fill in that part of the district, and productive wells are not easily obtained. Another and major objection is that soluble salts are prevalent both in the soils and in the shallow ground water of the area. Such water used for irrigation probably would not produce a satisfactory crop. There is at present little pumping of groundwater within the area of natural discharge, except from deep wells at Lund for railroad use.

The Problem of Mining Ground Water

The current investigation has proceeded far enough to show that pumpage from the ground-water reservoir is in excess of the natural replenishment. Most of the net withdrawal (the pumpage minus the return seepage from irrigation) is being taken from accumulated storage in the valley. It is certain that pumping cannot be continued at current rates forever, and that the sustained perennial yield must be a much smaller quantity than is being withdrawn annually today.

However, there is no likelihood of early or sudden exhaustion of the ground-water reservoir unless the rate of pumping is increased markedly above that in 1950. The quantity of water in that reservoir is not yet known, but present information shows that there is probably at least several million acre-feet, and each million acre-feet would be enough for about 2 decades of pumping at 1950 rates. Further, the water table in the pumping district is declining at a rate of less than 2 feet a year, so that the energy requirement for lifting the water is increasing only rather slowly. If the reservoir extends to sufficient depth, the economic factor of pumping cost, rather than the hydrologic factor of reservoir ex-

28—Young, A. A., and Blaney, H. F., Use of water by native vegetation: Calif. Div. Water Resources Bull. 50, p. 129, 1942.

haustion, may set the date for reduction or cessation of pumping.

Progressive ground-water depletion in the Beryl-Enterprise district creates a major problem. Ground water in the district is not renewable at the rate of current pumpage. Indeed, it is possible that few of the irrigation wells are in locations where the water pumped out is fully replenished by nature at the current position of the water table. Even the few wells operated prior to 1940 may have been mining ground water locally to some extent, although their pumpage was so small that the effect upon total storage in the reservoir was negligible. On the other hand, there is some replenishment to the ground-water reservoir. The average annual replenishment is considered to be essentially equivalent to the loss by natural discharge, a quantity far less than current pumpage, but nevertheless substantial.

Mining of ground water from areas remote from the areas of natural discharge is one method, and perhaps the most feasible method, of making the maximum beneficial use of the water resources while salvaging as much of the water now lost by natural discharge as may be practicable. It has been stated that pumping to date has probably not made any material reduction in evapo-transpiration because the water table has not been lowered where it is closest to the surface, and has been lowered less than 3 feet where it was once within 12 feet of the surface. But, in comparison with the effects of pumping in many areas in certain other States, the water table has not yet been lowered very much in any part of the district.

The water table throughout the area of greatest concentration of wells (in Tps. 35 and 36 S.) probably would need to be lowered about 60 feet in order to halt the flow of ground-water toward Lund. When it reached that position, the pumping lifts in some of the higher wells might exceed 200 feet. But salty water from the present discharge area might encroach on the wells before this would be accomplished. Complete salvage of the natural discharge is not hydrologically possible, even ignoring economy.

Some techniques of the petroleum industry might be used to improve the extraction of water. In particular, some form of unitization of the ground-water reservoir might be desirable, in order to assure most effective extraction by controlling the spacing, depth, and production of wells. Maintenance of suitable quality of water would require that the alkalinity or salinity of soils be considered in such unitized development. The alternative of haphazard development, with heavy pumping concentrated within small parts of the ground-water reservoir, must inevitably create deep cones of depression in those areas, with consequent high pumping costs to the owners of closely spaced wells.

FUTURE HYDROLOGIC INVESTIGATIONS

Further hydrologic studies in the Beryl-Enterprise district should depend to a great extent upon the State's administrative policy with respect to future ground-water development in the area.

If the annual pumpage should be reduced until net withdrawal from the reservoir does not exceed the average annual replenishment to the reservoir, a continuing basic-data progam could be limited to the data essential to an evaluation of the balance between recharge and discharge throughout the district. For the most part this could be accomplished by periodic measurements in a network of observation wells similar to that which has been maintained in the State-wide cooperative program. Gaging stations should be installed for measurement of the flow of perennial streams into the district, to enable determination of the annual recharge from those sources.

If pumping should continue from existing wells at a rate comparable to that in 1950, the hydrologic program should include studies leading to a determination of the annual changes in form and position of the water table, both in the pumped area and in the area of natural discharge, and a calculation of the volume of sediments unwatered. The proportion of the pumped water that returns to the ground-water reservoir should be determined. Continuing studies of the quality of water should be made, in order to delineate changes resulting from downward percolation to the water table, and from mixing of shallow and deep waters as a result of pumping.

Development for the purpose of obtaining the maximum practicable extraction of ground water for beneficial use would require hydrologic studies in sufficient detail to provide the basic data that would be required for proper selection of the location and depth for each operating well, and the area to be irrigated from it. The hydrologic characteristics of the valley fill must be made known in sufficient detail to permit calculation of the total quantity of water stored in the reservoir, the proportion of that total that is within practicable pumping lift, and the optimum spacing of wells for withdrawing that water from storage. A continuing inventory of the distribution of soluble salts in the area is essential to assure knowledge of the changes in chemical quality of water that might adversely affect irrigated crops.

V. GROUND WATER IN THE MILFORD DISTRICT

By W. B. Nelson

LOCATION AND GENERAL FEATURES

In the north-central part of Escalante Valley the Beaver River has formed a broad alluvial fan whose apex is at the mouth of its canyon, cut in the south flank of the Mineral Range. From Minersville at the apex, this alluvial surface fans out for as much as 12 miles to the west, northwest, and north. The town of Milford and the former settlements of Laho and Thermo are on the Escalante Valley floor near the outer margin of the alluvial fan.

The field work upon which this progress report is based has covered an area of less than 40 square miles, including especially a belt 2 to 5 miles wide, extending south and southwest from Milford for a distance of about 10 miles, in which wells are pumped for irrigation. The area is entirely in Tps. 28 and 29 S., Rs. 10 and 11 W., Salt Lake Base and Meridian. This pumping district occupies part of the northern half of the alluvial fan. The southwest corner of the district is about 25 miles northeast from Lund, which is at the northeast end of the Beryl-Enterprise district.

The channel of the Beaver River is about 5,250 feet above sea level at Minersville, and about 4,950 feet above sea level at Milford. Between the two towns the fan has a northwest gradient averaging about 13 feet per mile, decreasing from 30 feet at Minersville to about 10 feet per mile near Milford. The irrigation well highest on the fan, about

5 miles northwest of Minersville, is about 5,090 feet above sea level.

The Milford district is bordered on the east by the Mineral Range, which includes several peaks more than 11,000 feet above sea level. To the west are the slopes of the broad coalescing alluvial fans that extend eastward from the flanks of the Star Range. North of Milford the channel of the Beaver River continues down the trough of Escalante Valley, bordered on both sides by alluvial plains of varying width and gradient. Southwest of the district there are similar alluvial slopes, but there is no stream channel down the trough of the valley.

The Milford district covers only about one-tenth as much area as the Beryl-Enterprise district. Since 1920 irrigation from wells has been far more successful than in the southern part of Escalante Valley, and in parts of the district alfalfa has thrived by natural subirrigation. The greatest contrast between the districts, however, is the availability of substantial supplies of surface water to the Milford district. The average flow of the Beaver River into the Escalante Valley is several times as great as the combined flows of the streams entering the south end of the valley.

With respect to the hydrology as discussed in this progress report there is another important difference between the two districts. The Beryl-Enterprise district forms a well-defined hydrologic unit, with very little outflow; the inflow to that district is derived in part from a tributary basin where there is very little use of water to compete with the uses within the district. The Milford district, on the other hand, is only a part of a larger ground-water area that receives the bulk of its replenishment from the Beaver River. Detailed hydrologic studies have not yet been extended into this larger area, and some of it has not been probed by wells. Furthermore, a comprehensive analysis of the potential development of ground-water resources must consider also the surface-water development in the area; and the development of the water resources on the alluvial fan of Beaver River is dependent to an important degree upon the extent of development upstream along the Beaver River, in Beaver Valley.

DEVELOPED AQUIFERS OF THE VALLEY FILL

No studies of the areal geology of the Milford district have been undertaken during the current investigation, nor are there any published maps from soil surveys which might show the character of the surficial materials in the area.

So far as ground-water development in the Milford district is concerned, most of the essential geologic data are those of the last, long chapter of the geologic history of the region: the history of the accumulation of the alluvial fan of the Beaver River in Escalante Valley. It might be expected that these stream-borne deposits would include various assortments of gravel, sand, silt, and clay, in lenses, filled channels, tongues, and irregular and discontinuous beds. Details as to the deposition in some parts of the district are obtained from about 100 available drillers' logs of wells. Some conclusions as to the movement of water within the various components of the valley fill are based upon the comparative water levels in wells of different depths, and the changes in those water levels as a result of pumping.

Information From Well Logs

Most of the irrigation wells drilled prior to 1947 are less than 100 feet deep. Commonly they have penetrated several sand and gravel beds, separated by sandy clay. As shown in figure 9, none of these beds appears to be continuous over a wide area. According to the well logs, the surficial materials are prevailingly of sandy or silty texture; they may extend to a depth as little as 5 feet in the southern part of the district, and as much as 40 feet near Milford. These beds are commonly underlain by gravel, coarse and well-rounded in the wells highest on the fan, and smaller in average size toward the north.

Most of the wells drilled since 1947 are more than 150 feet deep. Well (C-28-11)25dcd-1[29] is 431 feet deep and is the deepest irrigation well in the district. Individual gravel beds in the lower part of this well are thicker than those near the surface, but the experience from pumping indicates that they are less permeable. Farther north the deeper aquifers are evidently of finer texture; the railroad wells at Milford penetrated nothing coarser than sand between depths of 90 and 555 feet.

Artesian and Nonartesian Water

Water flows under artesian pressure from wells more than 250 feet deep in the vicinity of Milford. Some of these wells

29—For explanation of well-numbering system, see p. 150.

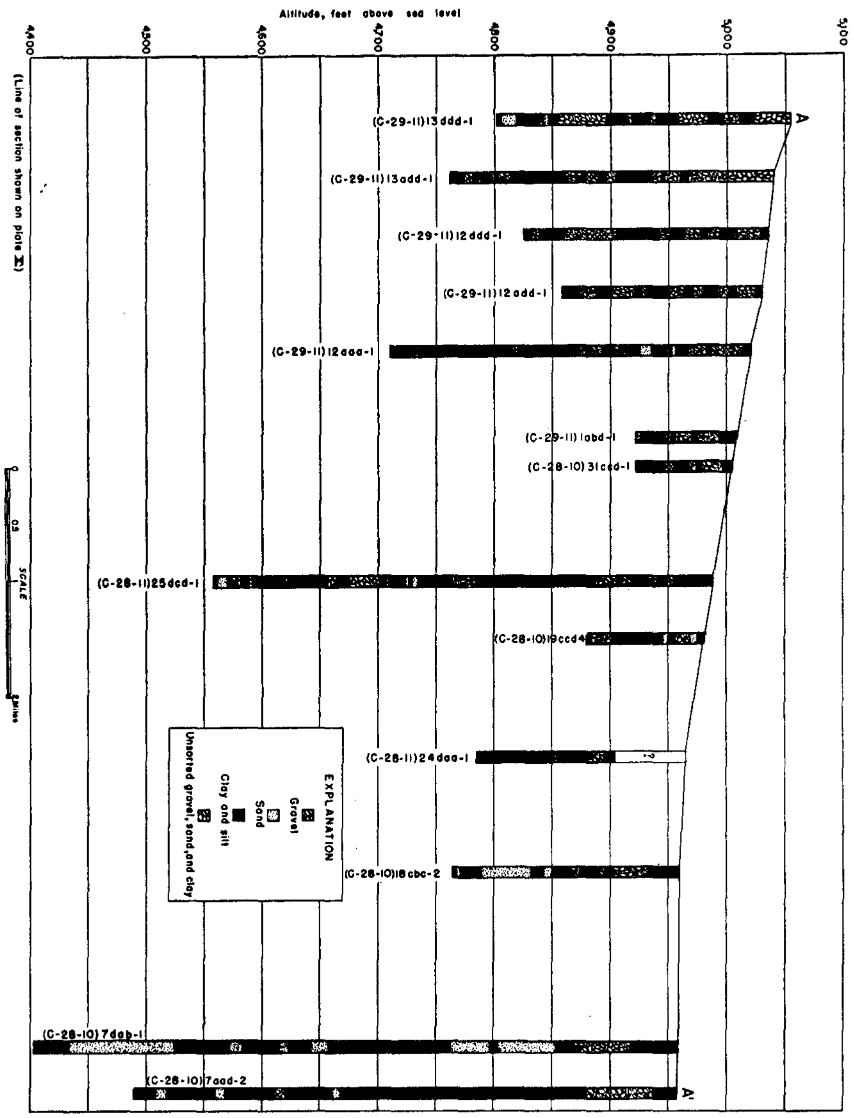


Fig. 9. Logs of 13 wells along line south from Milford.

yield as much as 50 gallons a minute from aquifers of fine to coarse sand. The town of Milford and the railroad obtain their water supply from these artesian aquifers.

North of Milford, for as much as 13 miles, are several small flowing wells, which are either unused or used for stock watering. Prior to the drought of the 1930's several ranches in these "Beaver Bottoms" had artesian wells for domestic supply. These ranches have been abandoned, and most of the wells have been covered over or filled with debris.

The southernmost flowing well in the district is well (C-28-10)19dcc-2, which is reported to be 300 feet deep. Well (C-28-10)19abc-1 is 260 feet deep; in the winter of 1939 it yielded 12 gallons per minute, but the flow is reported to have decreased to 3 or 4 gallons per minute during irrigation seasons. In 1950 the well stopped flowing at the surface early in the irrigation season, and in mid-December the water level was below the surface. Well (C-28-11)13dca-1, at the site of the old Majestic smelter, is 600 feet deep, and has a feeble flow during the winter. All flowing wells in the district are in places where the land surface is less than 4,975 feet above sea level.

In the part of the district where irrigation wells are concentrated, there are few wells in which artesian pressure can be identified. Most well casings are perforated in every sand and gravel bed penetrated. This is particularly true of the wells less than 100 feet deep, for preperforated casing (locally called "Colorado" casing) was used in most of the older wells, and the perforated zone thus extends from the top of the well to the bottom.

DIRECTION OF MOVEMENT OF GROUND WATER

The form and position of the water table in the Milford district are shown on plate X. The ground-water contours of this map are based on measurements of water levels in wells during March 1950, prior to the beginning of pumping for irrigation. The water in the selected wells is essentially unconfined.

The water table has a northwesterly gradient of about 9 feet per mile in the central part of the district, decreasing to about 7½ feet per mile near Milford.

The direction of movement of ground water is at right angles to the contours; thus these contours indicate that ground water in most of the district moves generally northwestward from the apex of the Beaver River alluvial fan. They also show that along the eastern edge of the district the direction of movement is more nearly westward.

RECHARGE TO THE GROUND-WATER RESERVOIR

The ground-water reservoir of the Milford district receives most of its replenishment from the natural channel of the Beaver River and from irrigation canals and irrigated lands supplied from that river. Precipitation within the district is a much less important source of ground water, although the valley fill in many places is sufficiently permeable to permit substantial percolation to the water table from major storms. Underflow westward from the Mineral Range may also contribute ground water to the Milford district. Also, as in the Beryl-Enterprise district, there are indications that a minor quantity of water may be derived from deep sources.

Natural Channel of the Beaver River

Under natural conditions the Beaver River was a perennial stream through the Milford district, and flood flows continued for many miles beyond, until they were dissipated in the Beaver Bottoms.

For the past 25 years, however, the natural channel through the district has carried only the occasional flood flows that could not be stored in the Rockyford Reservoir. (See p. 28) The channel is usually dry through the Milford district, except in the winter when there is generally a flow of less than 5 second-feet in the channel at Milford.

Ground-water recharge from the natural channel is clearly shown in the record of water levels in well (C-29-10) 6ddc-1, 400 feet west of the channel. The water level in the well rose 1.05 feet in response to a large but unmeasured discharge in the channel from September 15 to 19, 1948. Subsequently the water level in the well declined half a foot in 9 days, as water moved outward from the temporary ground-water ridge under the river channel. During the first 3 months of 1948 the water level in the well rose 1.5 feet, likewise because of flow in the natural channel.

River infiltration in May 1937 is shown by the hydrograph for this well for 1937 and 1938 (fig. 10). The discharge of the river at Minersville reached three maxima during that month, and at one time the flow in the channel opposite the well is estimated to have exceeded 600 second-feet. The water level in the well rose in three stages in response to this flow, and the aggregate rise was about 3 feet. This is only a small part of the total rise of water level in the well during the two years. There is no direct correlation between rises of water level in this well and discharge of the river

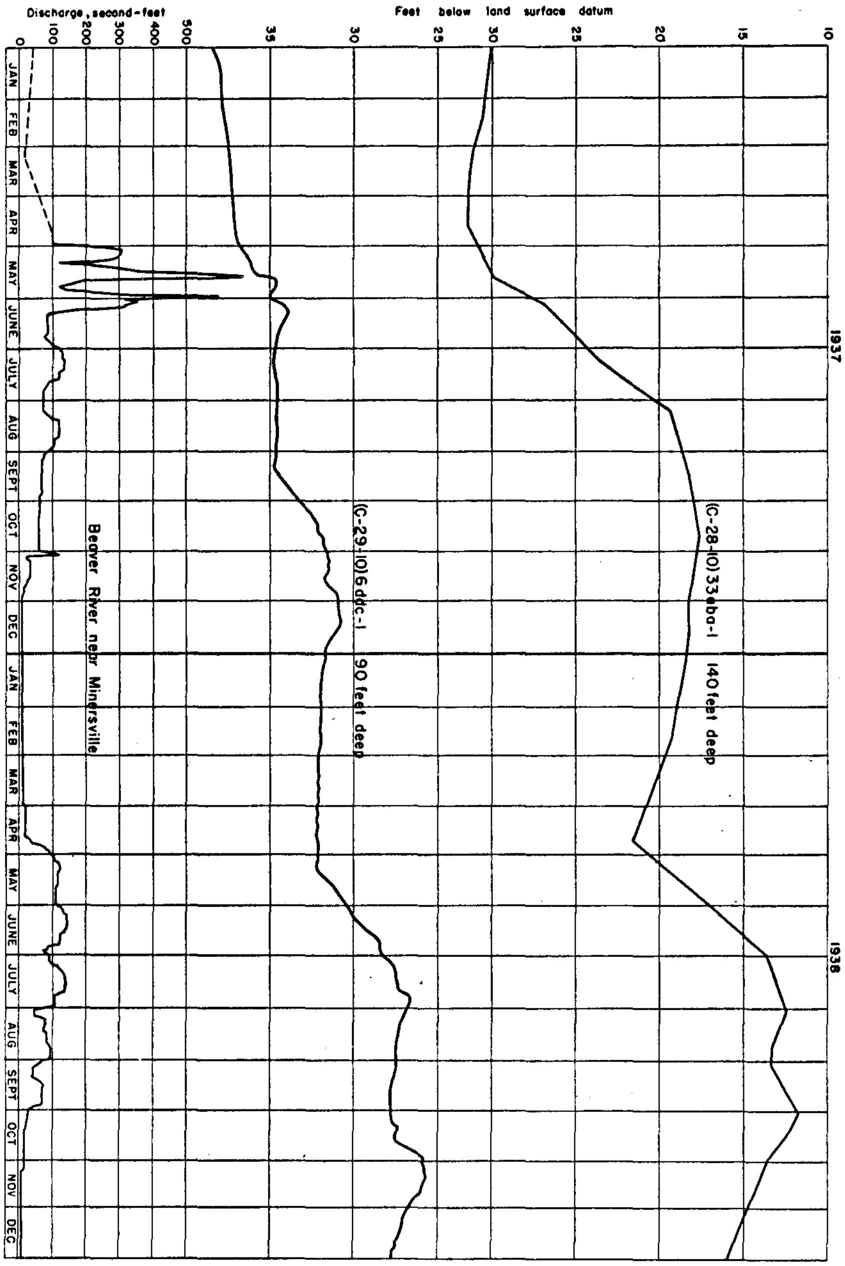


Fig. 10. Effect of flow in Beaver River and in irrigation canals upon water levels in two wells in the Milford district, 1937-38.

at Minersville in other periods in 1937 or 1938; in those periods the flow did not go down the channel but was diverted into canals.

Irrigation Canals and Irrigated Lands

History of diversions from the Beaver River. Water has been diverted from the Beaver River near Minersville for more than 90 years, but until 1914 these diversions were made from the natural flow of the stream. In those early years the remainder of the stream flow continued in the natural channel to Milford and to the Beaver Bottoms farther north, where it is reported to have been used for irrigation of about 2,000 acres of land.

The Rockyford Dam, constructed in 1914, provided a reservoir capacity of 25,270 acre-feet, but the capacity was reduced to 23,260 acre-feet about 1937. The reservoir is necessarily operated in recognition of the prior rights of users near Minersville, and about 10,000 acre-feet is diverted annually to the Minersville area. Originally it had been hoped that the reservoir would permit irrigation of 15,000 acres of land in the Milford district, in addition to supplying water for previously established rights near Minersville and in the Beaver Bottoms. These hopes were not realized. The project land of the Milford district was soon reduced to 7,000 acres. In 1925 the reservoir company purchased the water rights of the Beaver Bottoms; that area soon reverted to desert, and during the drought of the 1930's it was one of Utah's outstanding "dust-bowl" areas. After 1930 the project land irrigated from the reservoir did not exceed 4,500 acres.

The discharge of the Beaver River is measured below Rockford Dam and above diversions in Escalante Valley. The record thus shows practically the entire flow of the stream into the valley. Since 1914 the annual runoff has ranged from 12,700 acre-feet in 1934 to 61,200 acre-feet in 1922, with an average of about 29,500 acre-feet in the 37 years. The graph of annual runoff since 1930, figure 14, shows a range between 12,700 acre-feet in 1934 and an estimated 50,000 acre-feet in 1937.

Except for occasional flood flows, water released from the reservoir is diverted westward into the Minersville canal at Minersville, and northward into the Low Line canal (fig. 12), which serves the Milford district. The water carried by these two main canals is not measured. The estimates of diversions into the Low Line canal, shown in fig. 14, are based on the records of total runoff below the dam, from which have been subtracted the 10,000 acre-feet for Minersville rights and an estimated seepage loss of about 5 percent above the canal headgates. According to this graph, practically no water was available to the Low Line canal in 1934 and 1935, and in seven years since 1930 the water available to that canal has been less than the 10,000 acre-feet in the Minersville canal. Because of the limited capacity of the Low Line canal, it is likely that in years when more than 15,000 acre-feet is available, part of the water goes down the natural channel. The flow down that channel is not recorded.

The wide variations in quantity of water available to the Low Line canal from year to year are reflected in the acreages irrigated from the canal. There was very little irrigation from the canal in 1934 and 1935, and several farms were abandoned in those years. The acreage increased gradually and by 1938 the water from the canal irrigated about 4,200 acres, including several farms that had been irrigated from wells throughout the drought. In 1940, a relatively dry year, the irrigated area was about 1,700 acres. Since World War II parts of the canal system have deteriorated, and the acreage irrigated from the canal has decreased. In 1950 less than 500 acres was irrigated through the full season by water from the canal, although diversions were made to several farms where wells supplemented the supply later in the season. The change in acreage irrigated from the canal since 1936 is shown in figure 11.

Effect of diversions upon water levels in wells. The Low Line canal and the laterals branching from it generally traverse permeable materials where considerable loss by seepage might be expected. The lands irrigated from the canal also have permeable soils for the most part, so that deep percolation from irrigation may occur. Records of water-level fluctuations in wells show that this deep percolation results in substantial recharge to the ground-water reservoir.

The water level in well (C-28-10)33aba-1 rises substantially when the Low Line canal is in use (fig. 10). This is a shallow well about 300 feet west of and down slope from

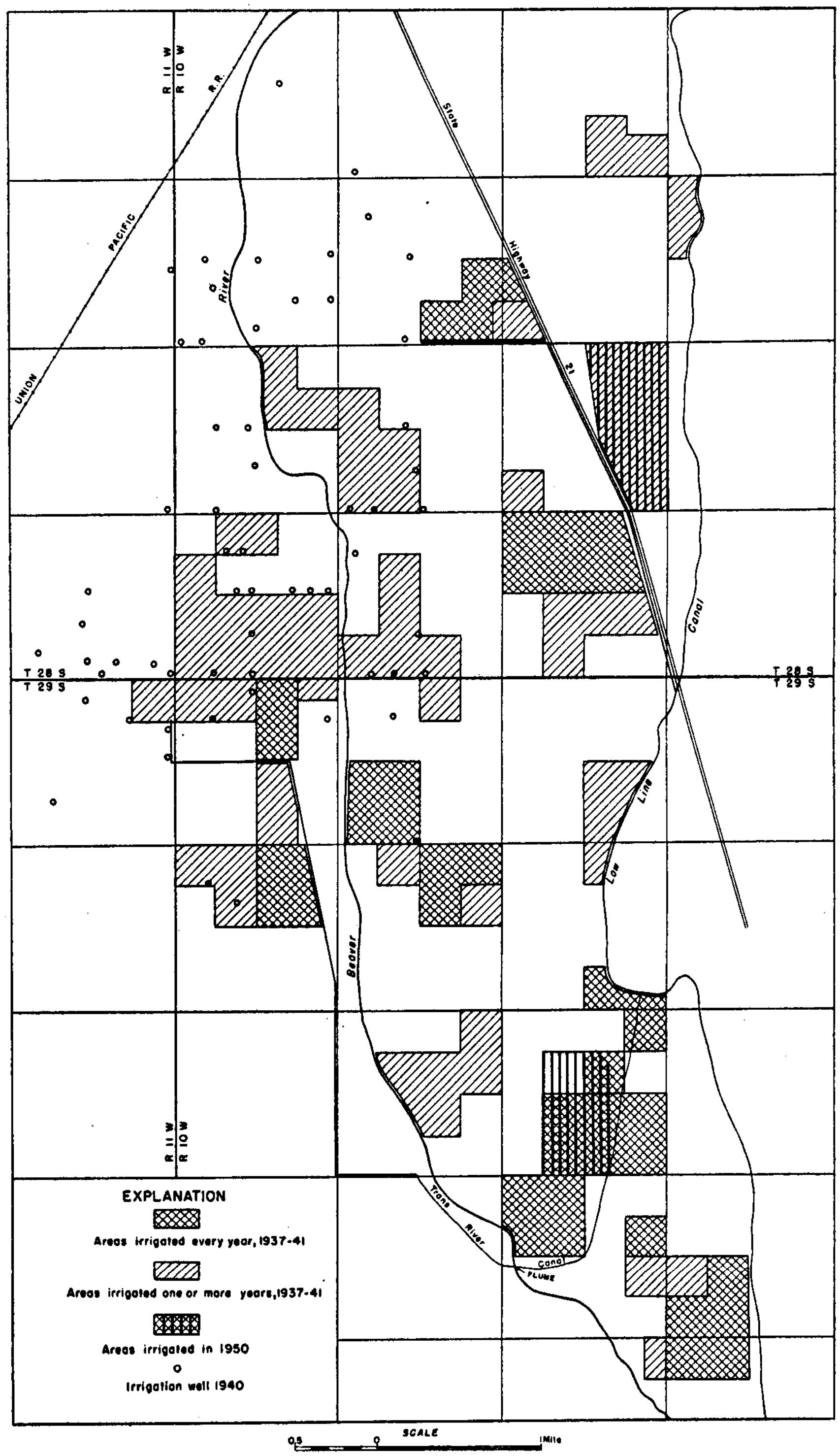


Fig. 11. Areas irrigated by surface water in the Milford district, 1940 and 1950.

the canal. In 1937 the water level started to rise soon after the beginning of the flood discharge in May, and continued to rise until diversons ceased late in October, reaching a level 13.8 feet higher than the minimum level of the preceding March. Thereafter the water level receeded slowly until April 1938. In 1938 the water level rose 9.8 feet during the irrigation season and declined after the season ended. The hydrograph for that year is similar in form to that of well (C-29-10) 6ddc-1, in which the water levels may also be influenced by recharge from stream diversions.

In years when extensive areas have been irrigated from the canal, water levels in observation wells in those areas have risen, partly because of the recharge to the ground-water reservoir by downward percolation, and partly because pumping of some irrigation wells was stopped whenever canal water was available.

Precipitation Within the District

Recharge from precipiation within the district is probably much smaller than the recharge from the Beaver River and from the waters diverted from it. Nevertheless, the surficial materials, particularly in the higher parts of the district, are sufficiently permeable to permit infiltration and percolation; rather generally these surficial materials are underlain by gravel at a depth of less than 15 feet, as shown by well logs. Thus, recharge from precipitation can occur if the storms are of sufficient intensity.

In the lower parts of the district where the water table is shallow, but where the surficial materials are predominantly of medium to fine texture, there is evidence of recharge by water from precipitation. The water level in well (C-28-11)36bba-1 rises after some storms, as shown in the hydrographs of figure 12. This well is 18 feet deep, and the water level commonly ranges from 2 to 6 feet below the land surface. The rise of the water table in March and April 1941 is attributed to percolation from precipitation totaling about 3½ inches. The water table rose more than 3 feet during the first three months of 1944, partly because of the melting of 45 inches of snow.

Underflow From the Mineral Range

Ground water in the eastern part of the Milford district flows more nearly westward than that in the rest of the dis-

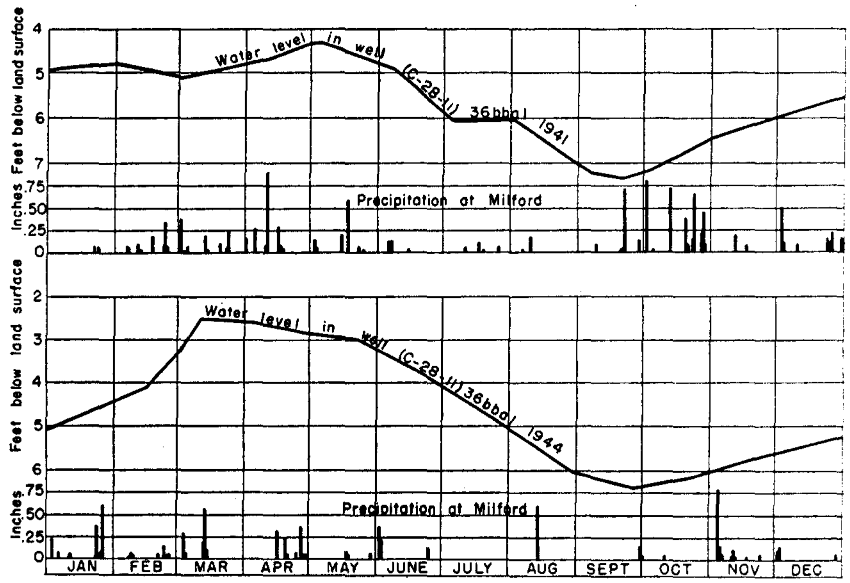


Fig. 12. Effect of precipitation upon water level in well (C-28-11)-36bba-1.

trict, as shown by plate X. The wells upon which the ground-water contours are based are all west of the Low Line canal, from which substantial recharge is known to occur. Some wells have been drilled east of the Low Line Canal, and water has been pumped from them for domestic and stock use. The ranches have long been abandoned, and the wells are covered over or filled with debris. During 1926 and 1927, however, some of these wells were visited by White;[30] according to the measurements obtained by him the water table in the area east of the Low Line Canal had a moderate westward gradient, indicating that there is some ground-water movement from the direction of the Mineral Range. More field work, however, must be done before even a rough estimate can be made of the quantity of ground water that is derived annually by underflow from the Mineral Range. The range is high enough to have considerable precipitation, judging by the moderate forest cover and the substantial snow cover in the winter. On the other hand, no perennial streams issue from the west flank of the mountains.

A reconnaissance of Kays Canyon near the south end of the range showed no springs in the drainage basin, no perennial flow in any part of the channel, and no vegetation

30—White, W. N., op. cit., pl. 1.

indicative of ground water at shallow depth beneath the channel bed. A road follows the dry channel in several places, and there is little indication of large seasonal runoff. Thus this canyon does not appear to be a promising source of ground water. The mouth of Kays Canyon is at the apex of a steep alluvial cone that extends out for 3 miles from the base of the range and appears to be superimposed upon the gently sloping alluvial fan of the Beaver River. State Highway 21 and the Low Line Canal from broad arcs around the base of this alluvial cone in T. 29 S., R. 10 W. Reconnaissances have not been made of the alluvial slopes and mountain canyons farther north to find evidence of underflow toward the Milford district.

Inflow From Upper Escalante Valley

The western part of the Milford district is in the trough of Escalante Valley. If there is ground water moving down that trough, it must enter the western part of the Milford district (not shown in pl. X). The investigation has not yet been extended into the area where such underflow is likely to occur; available data are insufficient to show the direction of movement of ground water, or to justify an estimate of the quantity involved.

The Hay Springs area is likely to be of major importance in evaluating the ground-water contribution to the Milford district from the upper Escalante Valley. At Hay Springs the land surface intersects the water table, and there is some perennial ground-water discharge that reaches its maximum in the winter and spring when the water table is highest. As shown by plate X, ground water moves down the Beaver River alluvial fan to Hay Springs. The contours do not extend far enough west, however, to show whether all the water in Hay Springs is derived from that fan, or whether some water moves toward the spring area from the southwest (that is, down the Escalante Valley floor).

The faults that presumably give rise to the Thermo Hot Springs may have a significant effect upon the movement of ground water down the Escalante Valley. The elongated mounds formed by the hot springs and associated eolian deposits lie athwart the lowest part of the valley and have a combined length of nearly 2 miles. The faults, although they evidently provide access to the surface for water from deep sources, may well act as barriers to down-valley movement of ground water; thus the water discharged from the springs may have both deep and shallow sources.

Water From Deep Sources

One need not travel far from Milford to find thermal waters where the heat is attributed to magmatic sources, and the water also may be in part of magmatic origin. Several thermal springs are alined along the west base of the Mineral Range, probably along a major fault zone. The Roosevelt Hot Spring, about 15 miles northeast of Milford, yields about 1 gallon per minute of "boiling" water (temperature 185°F.) containing hydrogen sulfide. According to Lee, the discharge was about 10 gallons per minute prior to 1908.[31] The spring has formed a mound of siliceous sinter about 300 feet in diameter, adjacent to outcrops of crystalline intrusive rocks. Other warm springs issue about half a mile to the northwest, from the alluvium in Nigger Mag Wash. About 3 miles south of the Roosevelt Hot Springs another mound of sinter gives evidence of a former spring, although there is now no discharge at the surface.

About 4 miles north of Minersville there is a broad mound of siliceous sinter, from which water issues at several places at temperatures not much warmer than those of ordinary springs. And along the bank of the Beaver River about a mile east of Minersville, the Minersville Warm Springs yield about 57 gallons per minute at a temperature of 97° F.[32] Finally, the Thermo Hot Springs rise from the floor of the valley beyond the southwest limit of the district; the waters from those springs have temperatures up to 181°F., and like that of the Roosevelt Hot Springs contain hydrogen sulfide and considerable silica which is deposited as the water cools. These springs are about 5 miles north of the Blue Buttes, which are composed of the basalt flows of the latest stage of volcanic activity in the Escalante Valley region.

There are no thermal springs within the Milford district. However, deep wells in the vicinity of Milford yield waters at temperatures which suggest an abnormally high thermal gradient in the area. Water from several wells more than 250 feet deep is discharged at temperatures of 75° to 80°F., and in most artesian wells the water is likely to be at least 10° warmer than that in nearby shallow wells. It is

31—Lee, W. T., op. cit., p. 20.
32—Lee, W. T., op. cit., p. 45.

likely that magmatic sources may be responsible for this high thermal gradient, as in the vicinity of Newcastle in the Beryl-Enterprise district (p. 140). How much water may be contributed to the Milford district from deep sources is a matter for conjecture. Judging by the chemical analyses of water from numerous wells (see table), the ground water generally does not show the high silica content that is characteristic of most of the thermal waters in the region. However, the railroad well at Thermo (about 3 miles northeast of the hot springs) yields water with a high proportion of silica, which may be coming in part from deep sources.

Summary

The major source of replenishment to the ground-water reservoir of the Beaver River alluvial fan is the Beaver River. Prior to man's occupancy of the area this recharge occurred by seepage from the river channel and from lands overflowed by the river in time of flood. As man has subjected the stream to his regulation and use, substantial ground-water recharge has resulted from diversion of surface water into canals, and from irrigation of land.

The amount of water contributed annually to the ground-water reservoir by the river is not known, but it must be less than the total inflow of the river into Escalante Valley. In 37 years the average annual runoff of the Beaver River near Minersville has been slightly less than 30,000 acre-feet. The average ground-water recharge to the alluvial fan would be only a fraction of this amount, depending upon how much surface water is returned to the atmosphere by consumptive use of irrigated crops and by other evaporation and transpiration.

The Milford district as delimited in this report receives only a part of the ground water that is derived from the Beaver River. Before settlement it must have received a major part, for the channel of the river runs through the district. Since the regulation of river flow by storage in the Rockyford Reservoir, the ground-water contribution to the Milford district has fluctuated from year to year, depending upon how much surface water was diverted into the district for irrigation.

Precipitation within the Milford district is a minor source of ground water, but substantial recharge may occur as a result of exceptional storms. There are several other possible sources of recharge to the ground-water reservoir, but further field work is required before any estimates can be made of the quantity derived from them.

DISCHARGE FROM THE GROUND-WATER RESERVOIR

Ground water is discharged from the Milford district by underground movement down Escalante Valley north of Milford, by springs, by evaporation and transpiration, and by withdrawal from wells.

Outflow to Lower Escalante Valley

Water moves north from Milford down Escalante Valley, both on the surface and underground. The surface water was once sufficient for considerable irrigation in the Beaver Bottoms, but in the past 25 years relatively small quantities have passed Milford. Flood waters are known to have been discharged down the channel from Rockyford Dam during short periods in 1937, 1938, 1941, 1942, and 1948, and in each year some of that water presumably flowed in the channel past Milford. In addition, in nearly every year small quantities of water flow north from Milford throughout the winter. This runoff is derived largely from Hay Springs.

Throughout the Beaver Bottoms ground water is at shallow depth. The water table probably has a gentle northward gradient, comparable to that of the stream channel, which is less than 5 feet per mile. Well logs suggest that the valley fill becomes of generally finer texture toward the north in the Milford district (fig. 9), and presumably the materials in the Beaver Bottoms are still finer and less permeable. It is likely that the underflow through those materials north from Milford is small, probably only a few hundred acre-feet a year.

Springs

The largest spring in the Milford district is Hay Springs, in sec. 15, T. 29 S., R. 11 W., which is an area of seepage that may exceed 300 acres when the water table is highest in the spring. In April 1950 the outflow from the area was estimated to be about 2 or 3 second-feet, and the water flowed northward to enter the Beaver River channel near Milford. The regional water table is commonly lowest in August; the seepage area then amounts to less than 15 acres of pond and tules, and outflow is nil. There are several other small springs in the valley south of Milford that develop small ponds in the winter, but they disappear with the coming of warm weather and the awakening of plant life in the spring of the year. The annual discharge by Hay Springs and these small ephemeral seeps is estimated to be of the order about 300 or 400 acre-feet.

Evaporation and Transpiration

The discharge of ground water by evaporation and transpiration in the Milford district was studied by White in 1926 and 1927. His conclusions as to annual discharge are as folows:[33]

"The meadowlands and adjoining lands in which salt grass is dominant comprise approximately 2,600 acres. Salt grass is by far the largest ground-water user in this area . . . . Some of the grass is cut, but most of it is grazed, a large part of the area being pastured by migrating herds of cattle and horses. The meadows include about 200 acres of grama grass and other unidentified grasses in which the largest daily water-table fluctuations disclosed by the investigation were obtained . . . . indicating that these grasses are large users of ground water. Pickleweed, apparently a fairly large user of ground water, occurs in considerable quantities on the meadows and the adjoining lowlands. Islands of greasewood, shad scale, and rabbit brush occur here and there, and irregular tongues of these plants project into the meadows. The water table beneath the area ranges from 0 to 3 feet in the spring and from 3 to 5 feet in the fall. After consideration of the available data the figure 1 acre-foot per acre is taken as the probable discharge of ground water by transpiration and evaporation from lands of this class. The lands of Class B comprise approximately 7,400 acres, lying for the most part along the trough of the valley southwest of the salt-grass. The chief ground-water plants are greasewood, rabbit brush, and shad scale. A light growth of salt grass occurs among the shrubs on a part of the area, and seepweed and pickleweed are present to some extent. The greasewood and rabbit brush vary considerably in vigor, being moderately large and of a healthy appearance in some localities and rather small and stunted in others. The shad scale generally is moderately large and vigorous. The depth to the water table ranges in different parts of the area from 0 to 5 feet in the spring and from 3 to 8 feet in the fall.

33—White, W. N., op. cit., pp. 86-88.

The soils of the area vary considerably in color and texture, but a reddish-brown to brown clay loam predominates. Most of the lands of the area contain too much alkali to be successfully cultivated.

"On the basis of the computations of ground-water discharge . . . the figure 2½ acre-inches per acre is selected as a reasonable estimate of the depth of water transpired by the ground-water plants of this area. From the results of the soil-tank experiments . . . . it is believed that the discharge of ground water by evaporation in the area may be approximately an equal amount and that the joint discharge by transpiration and evaporation is therefore about 5 acre-inches per acre. On this basis the total annual discharge of ground water from areas of Class B would amount to approximately 3,100 acre-feet.

"Subdivision C takes in the higher uncultivated lands of the area of ground-water discharge and covers altogether about 18,000 acres. The water table beneath these lands is from 8 to 30 feet deep, and probably no ground water is lost by evaporation. The lands practically everywhere support an association of greasewood, rabbit brush and shad scale, the stand of which ranges from light to moderately heavy. The greasewood is noticeably more vigorous than the greasewood found on the lands of Subdivision B where the water table is shallower. The rabbit brush is only of moderate size and vigor. Shad scale is usually of fair to large size where it is associated with order shrubs, but where it occurs by itself it is usually small. The aggregate area of dwarf shade scale is considerable, perhaps several thousand acres. It is believed that 2 acre-inches per acre is a fair figure to assume for the discharge of ground water from these lands. On this basis the aggregate annual discharge of ground water would amount to 3,000 acre-feet.

"Class D [the remainder of the area of ground-water discharge] includes the lands that were under cultivation in 1927 and derived their water supply from ground water. Altogether these lands comprised approximately 3,500 acres, nearly all of which was devoted to the production of alfalfa, seed being the principal crop. About 2,500 acres of the alfalfa was from 2 to 8 years old, and undoubtedly received at least a part of its water supply from the zone of saturation by natural subirrigation; approximately 300 acres of it depended entirely on natural subirrigation. The remaining 1,000 acres consisted of grain and potato land or land newly planted to alfalfa and depending entirely on pumped water. There were 54 pumping plants in the district, of which 6 were operated by gasoline engines and 48 by electric motors; the average capacity for all plants was about 7 horsepower.

"Electric power was delivered at a flat rate, and no record was kept of the amount of power consumed by each plant; if such a record had been available, it might have served as a basis of estimating the total pump discharge. Numerous measurements of pumping-plant discharge were made by the writer. From these measurements and from statements of a considerable number of the plant owners, it is estimated that the average discharge of all pumps in the area was approximately three-quarters of a second-foot, that the average period of pump operation amounted to 65 days of 24 hours, and that the total quantity pumped in the district during the season amounted to about 5,000 acre-feet. If in addition to the pumped water it is assumed that the 2,500 acres of old alfalfa consumed on the average 1 acre-foot an acre by natural subirrigation, the figure 7,500 acre-feet is reached as the estimated total discharge of ground water from the cultivated lands."

The findings by White as to ground-water discharge within the Milford district in 1927 are summarized below:

	Acre-feet
Evaporation and transpiration by non-beneficial vegetation	8,700
Natural subirrigation of alfalfa	2,500
Springs	100
Pumpage from wells for irrigation	5,000

Surveys have not yet been made to determine the changes in vegetative cover in these areas since 1927. Reconnaissances indicate little if any change in the cover of native vegetation, or in the area of subirrigated alfalfa. However, the area irrigated by wells has increased from about 3,200 acres in 1927 to more than 8,000 acres in 1950.

In general the position of the water table in March 1950 was similar to that in the spring of 1927. In some wells the water level was very nearly the same in the two periods. In some parts of the pumping district declines of as much as 4 feet were noted, but in the northeastern part of the district the water table was 2 to 5 feet higher in 1950 than in 1927. From these comparative data it is concluded that the rate of natural discharge by evaporation and transpiration has been nearly as great in recent years as it was during the period of White's studies—of the order of 11,000 acre-feet a year if the consumptive use by subirrigated alfalfa is included.

Discharge From Wells

There are several flowing wells in the vicinity of Milford, but in comparison with the quantity pumped from wells, their annual discharge is so small as to be negligible. There are no records of the quantity discharged by any pumped well in the district. The watermaster for the town of Milford estimates that the quantity pumped from wells for municipal use is about 1,500 acre-feet a year. The pumpage from wells for railroad use in Milford is estimated by Union Pacific officials to have been about 800 acre-feet annually from 1931 to 1941; from 1942 to 1945 the war-emergency use mounted to about 1,100 acre-feet a year, but since then, with conversion from steam to diesel power, pumpage has decreased to less than 300 acre-feet per year.

All these uses of ground water are minor in comparison with the pumpage from wells for irrigation. In 1950 a total of 124 irrigation wells were in operation, and four of the largest wells pumped more water than was needed for all municipal, domestic, stock, railroad, and industrial use in the district.

The tabulated estimates of annual pumpage by irrigation wells are based upon a sampling technique similar to that used for the Beryl-Enterprise district. The computations for 1950 are based upon measurements of pumping lift during July, on the assumption that in the middle of the irrigation season the lift would correspond approximately to the average seasonal lift. The average energy required to lift an acre-foot of water 1 foot, based on tests of 23 wells in Escalante Valley, is taken as 1.85 kilowatt-hours. The annual pumpage is then computed from the average pumping lift at the well, and the record of power consumption. In several wells the lift could not be measured and was estimated from nearby wells. For wells pumped by Diesel or other internal-combustion engines the estimated pumpage is based upon available data as to discharge, length of pumping season, and acreage and types of crops irrigated.

For years prior to 1950 it was assumed that the lift would vary from year to year in about the same degree as the changes of water level in observation wells. In about 19 observation wells the average water level was about the same at the end of 1940, 1947, and 1948 as in December 1949, but it was 1 to 2 feet higher in the other years since 1938. From 1931 to 1937, however, the water levels were generally lower than they have been since 1938, and at the end of 1935 the average water level was more than 5 feet lower than in 1949. The pumping lifts for each year prior to 1950 are calculated from the measured lifts of 1950, with appropriate adjustments for years in which the average water level in observation wells differed by more than a foot from the average for December 1949.

Prior to 1949 the electric energy consumed by irrigation pumps was not metered, and charges were billed on the basis of "horsepower-months" (months of operation times average horsepower used by the pump, based on several ratings each season by the Telluride Power Co.) The horsepower-month is readily converted to kilowatt-hours, but the figure is subject to greater error because of the uncertainty as to period of actual operation of the pump, and the changes in rate of energy consumed throughout the season.

According to the table the annual pumpage between 1931 and 1944 ranged within moderate limits. In 1935, a year when there was practically no water in the Low Line canal, 83 wells were operated and about 15,000 acre-feet was pumped. In 1940 and 1943, two other dry years, the annual pumpage was about 17,000 acre-feet. In 1938, the year of maximum diversions from the Low Line canal, only 42 wells were operated, and the pumpage of 9,500 acre-feet was least for any year since 1930. The pumpage in 1931 was about twice as great as the pumpage in 1927 as estimated by White.

Beginning in 1945 there has been a progressive increase in the number of irrigation wells operated, and in the annual pumpage. In 1950 the annual pumpage was 90 percent greater than in 1944, and the number of pumped wells had increased 80 percent.

As for the Beryl-Enterprise district, the computations of pumpage for years prior to 1950 are rough estimates based largely upon extrapolations of 1950 data, for the only basic data available for those years were the power company's figures on energy consumed, and the positions of water level

CHEMICAL QUALITY OF GROUND WATER IN THE BERYL-ENTERPRISE DISTRICT[1] — Concluded

Well number	Depth of well (feet)	Date of collection	Specific Conductance (Micromhos at 25° C.)	Percent Sodium	Chemical analysis, in parts per million: Total dissolved solids	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)		Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Total hardness as $CaCO_3$
(C-35-17) 12bab-1	86	June 15, 1950	602									149		86			
12bcc-1	161	June 15, 1950	1,010									160		167			
12dcc-1	200	June 15, 1950	715	20	446	66	84	17		31		160	57	110		2.2	280
13acc-1	101	June 15, 1950	1,500									145		332			
13adc-1	182	June 15, 1950	446									159		46			
13bdd-1	75	June 15, 1950	1,770	18	1,060	63	221	41		73		126	110	435	.4	57	720
13ccc-1	200	June 15, 1950	342									165		14			
14ccc-1	300	June 15, 1950	367									164		17			
23acb-1	125	Aug. 22, 1949	581									172	74	51			
25dca-2	110	June 15, 1950	529									180		69			
36dcc-1	200	June 15, 1950	385									169		30			
(C-35-20) 35bab-2		Nov. 2, 1950	609	14	410	68	76	13	19		7	140	67	57	.4	34	243
(C-36-15) 4dcd-1	235	Aug. 22, 1949	867									294	81	72			
do		Apr. 28, 1950	840	38	538	58	81	16		77		310	69	68		16	268
do		June 15, 1950	851									301		72			
9dac-1	170	June 15, 1950	1,320	20	827	39	166	30		62		340	60	144	.1	158	538
18acb-1	400	Aug. 22, 1949			533	62	73	17		66		116	190	63	4.7	.6	252
19ccc-1	217	Aug. 22, 1949	675									216	86	56			
do		Apr. 27, 1950	796									211		84			
(C-36-16) 1ddd-2		June 16, 1950	1,080									148		52			
4b-3	144	June 15, 1950	432	18	276	48	53	11		18		176	15	37		6.9	178

10add-1	350	June 16, 1950	615							210		41			
10bac-1	42	Aug. 22, 1949	8,210		5,650	63	568	317	917	254	1,750	1,900	.2	5.2	252
do		Apr. 25, 1950	8,960							268		2,200			
10bdc-1	271	Apr. 25, 1950	1,780	32	1,150	62	152	62	136	190	344	295	.2	.5	634
23ccc-1	100	Aug. 20, 1949	736							168	99	92			
do		Apr. 25, 1950	658	13	407	48	75	24	20	175	79	73		1.5	286
28acc-2	163	June 16, 1950	828							220		47			
28adc-1	200	June 16, 1950	780							266		70			
28bdc-1		June 16, 1950	849							189		40			
33dcd-1	254	May 22, 1950	907							288		92			
(C-35-16) 7bbb-1	95	June 15, 1950	1,550	13	933	63	212	37	45	220	149	307	.3	11	681
7bdb-1	75	June 15, 1950	1,510							158		332			
7ccc-1	104	Aug. 20, 1949	1,110							156	110	202			
do		June 15, 1950	1,070							160		198			
9add-1	150	June 16, 1950	473							213		32			
10acb-3	103	Aug. 22, 1949	771							190	60	105			
14ccc-1	192	June 16, 1950	644							234		57			
29dcc-1	140	Aug. 22, 1949	537							285	23	30			
29ddd-1	25	Aug. 22, 1949	779		362		83	16	29	200	41	88		6.4	273
31bdc-1	155	June 15, 1950	533							180		63			
31ccc-1	209	June 15, 1950	438							184		40			
31ddd-1	160	June 15, 1950	435							199		30			
32acc-1	167	June 15, 1950	465							214		29			
32cdc-1	176	June 15, 1950	351							183		17			
32dcd-1	452	Aug. 22, 1949	533		273		66	14	15	176	20	66		5.3	222
33ccc-1	80	June 15, 1950	411							170		37			
(C-35-17) 1acc-2	265	June 15, 1950	368							165		22			
1cdc-1	114	June 15, 1950	410							158		35			
1dcc-1	260	June 15, 1950	404							158		32			
2dcc-1	160	June 15, 1950	333							166		13			
7daa-1	200	Aug. 20, 1949	561							184	84	34			
12acc-1	90	June 15, 1950	980							174		164			

CHEMICAL QUALITY OF GROUND WATER IN THE BERYL-ENTERPRISE DISTRICT[1]

Well number	Depth of well (feet)	Date of collection	Specific Conductance (Micromhos at 25° C.)	Percent Sodium	Chemical analysis, in parts per million: Total dissolved solids	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)		Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Total hardness as $CaCO_3$
(C-31-12) 17cad-1	Dug	Mar. 24, 1950	1,460									138		246			530
[2] (C-32-13) 9bdd-1	340	Oct. 13, 1923			668	16	77	41		91		231	254	74			361
[3] (C-32-14) 21bad-1	750	May 7, 1941			408	56	32	25		62			66	66	1.2	Tr	181
[4] 21bcd-1	585	Jan. 1905			517	68	45	16	52			189	2	81			
32add-2	20	Aug. 20, 1949	2,210									134	224	475			
[5] (C-33-14) 15dbd-1	133	1939			411	16	86	42	27			160	107	42			
(C-33-16) 25bab-1	50	June 16, 1950	1,060	77	703	61	38	7.8		190		245	166	117		2.5	127
29bcb-1		June 16, 1950	1,060	17	661	57	132	28		43		205	133	160		6.9	444
[4] 32aba-1	208	Aug. 27, 1905			344	61	44	12	27			150	29	43			159
(C-34-15) 1ada-1	110	Aug. 20, 1949	490									214	58	21			
(C-34-16) 17acd-1	20	June 16, 1950	1,740	75	1,140	81	55	22		318		482	195	219	1.9	9.1	228
17acd-2	65	June 16, 1950	495	34	344	68	42	15		40		166	57	39	1.0	.0	166
28dcc-1		June 16, 1950	1,000	18	591	70	118	23		39		159	66	194		2.6	389
30dcc-1	250	Aug. 22, 1949	466		321	62	54	11		25		166	64	20	.5	2.7	180
[2] 30ddc-2	100	Oct. 13, 1923			1,378	53	262	35		89		196	289	376		Tr	799
31bcc-3	22	Aug. 20, 1949	1,220		687		137	20		77		186	183	172		6.6	424
[2] (C-35-15) 3dcc-2	350	Nov. 29, 1927			403	55	59	21	31		3.8	174	105	35		1.0	234
do		Aug. 22, 1949	2,330		1,610	68	183	92		206		208	628	318	.3	11	835
do		May 3, 1950	1,560									198		200			
do		June 16, 1950	2,610									220		378			
[2] 3ddc-1	350	Nov. 29, 1927			518	72	63	27	45		4.5	156	166	43		.16	268
[illegible]	[illegible]	[illegible]	[illegible]									[illegible]		[illegible]			

5b-2	156	June 15, 1950	472								217		73			
5c-1	160	June 15, 1950	388								188		23			
9bdc-1	272	June 15, 1950	339								176		17			
13ddc-1	207	May 10, 1950	621	15	382	33	72	24		22	222	71	49		1.6	278
15cdd-1	200	Aug. 25, 1949	502								248	20	29			
19abb-1	352	June 14, 1950	392								210		18			
21cdd-1	254	June 15, 1950	401								182		27			
[6] 31aba-1	348	Jan. 28, 1949		19			72	10	23		251	19	35			
[6] 31add-1	380	Jan. 28, 1949			377		81		26		250					
[6] 31bab-1		Jan. 28, 1949		23			65	4	25		214	19	35			
31ccc-1	222	June 13, 1950	488								244		23			
[6] 32aaa-1		Jan. 28, 1949		17			57	5	15		180	10	32			
(C-36-17) 36add-1	202	June 13, 1950	428								210		20			
(C-17-16) 6ccc-1	200	June 13, 1950	573								272		35			
(C-37-17) 1ccc-1	438	June 13, 1950	495	20	316	47	64	12		24	250	16	25		4.6	209
1dcc-1	250	June 15, 1950	550								275		26			
11dbd-1	45	June 13, 1950	537								260		29			
12dbc-1	170	June 13, 1950	613								276		41			
14acb-1	185	June 13, 1950	524								268		21			
Springs																
[5] Modena town supply		Oct. 3, 1939				79	53	5		60		53	60		Tr	133
Sand Spring		Apr. 25, 1950	548	13	282	19	65	13		15	160	20	64		6.9	216
Newcastle town supply		June 15, 1950	828	29	533	45	83	31		61	388	54	65	.2	2.5	334
Enterprise town supply		June 13, 1950	297	25	217	55	33	9.4		18	164	6.6	12	.6	1.2	121

1—Analyses by the U. S. Geological Survey unless otherwise indicated.
2—Analysis published in U. S. Geol. Survey Water-Supply Paper 659, pp. 93-94, 1932.
3—Analysis furnished by the Union Pacific Railroad Company.
4—Analysis published in U. S. Geol. Survey Water-Spply Paper 217, p. 51, 1908.
5—Analysis furnished by the State Chemist of Utah.
6—Analysis by the Nelson Laboratory, Stockton, California; furnished by courtesy of John Zuckerman, Enterprise, Utah.

IRRIGATION WELLS, AND ESTIMATED ANNUAL PUMPAGE IN THE MILFORD DISTRICT—Continued

Coordinate Number	Application or Claim	Owner	Diameter (inches)	Depth (feet)	Estimated annual pumpage in acre-feet																			
					1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950
(C-29-10) 6dcd-1	a 2359	Lloyd Mayer	14	235																				180
6ddc-1	C 13116	E. C. McCain	12	90																			170	130
7bbd-1	C 15658	S. D. Atkin	14	80				110	230	220	210		60	250	250		220	160	230	250	230	160	180	200
7bda-1	C 13	" " "	12	80	130	180	170	60	170	200	230		60	200	170		230	210	230	240	230	180	140	200
7ddd-1	a 2243	Russell Meyer	14	245																				510
17add-1	A 18483	M. F. Persons		200																				510
17cdd-1	A 18481	" " "		200																				650
17ddd-1	A 18482	" " "		200																				670
18add-1	A 18373	Russell Meyer	16	168																				550
18ddd-1	A 18479	" "	16	170																				260
(C-29-11) 1abd-1	C 6523	Basil Rollins	14	86	150					170	200		230	230	220	200	230	230	220	240	230	220	240	240
1ada-2	C 11579	M. K. Williams	14	58	140	120	110	140	150	110				130									150	260
1add-1	C 10290	Orin Williams	14	58	120									110	150	150	120					140	210	320
1bad-1	C 1166	Max K. Price	14	140	110	130	120	120	140	150	180	170		160	110	130	130	150	170	180	140	150	100	250
1cac-1	C 157	Doyle Syle	14	72	150	140	10	220	220	180		210	220	230	190					260	180	220	200	240
1cad-2	C 156	Doyle Syle	14	60												180	150			150	150	180	180	180
1ddd-1	A 18563	Jacob Baumback																						350
2aac-1	C 12797	Jimmy Sherwood	14	64	170	230	150	210	170	150	160	170	190	210	200		160	200	190	200	180	250	220	280
2add-1	C 2561	Lyle Applegate	16	52	120	110	110	120	130	180	130		190	170	180	190	170	190	170	200	170	130	130	160
2ddd-1		Earl Limb	12		220	240	230	220	200	200	130	120	160		150	130	170	170	160	170	170	90	110	130
11aad-1	C 5768	Alvin Jones	16	70	130	120	120	130	110	230	260				200	200	160	160	160	180		180	120	140
11aba-1	C 5770	" "	14	84									270	330		240	310	220	230	310	280	240	380	420
11acd-1	C 5769	" "	16	82			170	190	290	220	250	270	280	350	260	260	230	250	260	350	150	260	240	330
11baa-1	a 2356	Cook Brothers																						180
11cad-1	C 7541	J. L. Shepherd	18	63																			60	110
11ccd-1	C 7705	Fred Timber	14	62	130	120	180	170	150	150	190	180	220	220	180	220	180	140	180	350	260	130	210	250
11cdd-1	C 7540"R'	J. L. Shepherd																				190	290	330
11ddc-1	C 1169	Cook Brothers	16	65		260	180																220	20
11ddd-1	C 1168	" "	16	83		390	370			310	320	390	460	440	360	380	370	390	380	420	400	360	360	40
12add-1	A 17298	Jacob Baumback	14	202																	660	280	250	270
12ddd-1	A 18266	Jacob Baumback																						310
13ddd-1	A 17882	Don Olmsted	16	248																	530	290		170
14aad-1	C 2814	Ben Lewis	10	69	210	230			220	210	230	230	260	290	220	280	280	250	300	430	390	420	430	440
22add-1	C 17158	M. F. Persons	14	65	290	280		270	340	330	380	320	330	390	280	330	380	360	380	410	360	280	240	220
23cad-1	C 13119	" " "	20	70	320	350	310	280	300	270	280		320	350	320	320	340	390	340	350	380	200	270	250
27add-2	C 2619"R"	J. H. Hankins	16	118																		330	320	320
27bdd-1	C 2617	" " "	12	75				60	140								330			400	340	330	320	170
27dad-1	A 18062	" " "	15	300																		460	630	580
27dcb-1	C 2620	" " "	12	68	140	230	210	270	270	220	240			220			140			170	250	150	180	180
28aad-2	A 20102	Odell Leathers	14	203																				220
28add-2	C 10254"R"	Leland Dalton																					240	460
TOTAL NUMBER OF WELLS					68	70	69	79	83	71	62	42	56	71	68	55	76	68	78	79	83	97	104	124
TOTAL ACRE-FEET PUMPED					10,300	13,300	12,210	13,160	15,200	14,150	13,870	9,470	12,730	17,140	14,440	12,360	16,960	15,940	18,070	19,720	21,780	20,330	21,920	30,290

Coordinate Number	or Claim	Owner	Diameter (inches)	Depth (feet)	Estimated annual pumpage in acre-feet 1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950
(C-28-10) 31cad-1	C 10314	Clair Gillins	14	78	170	190		150	190	210	210			230	190				70	220	210	180	170	200
31cbd-1	C 11802	Ernest Myers	14	71												130	190		190	170	170	150	110	160
31ccd-1	C 11801	" "	22	128								250	250	310	260	300	310	340	310	230	250	240	240	210
31cdd-1	C 10315	Orin Puffer	14	78	250	290	160		240	200	190			260	190		40		210	220	200	220	210	250
31dcd-1	C 2816	" "	14	72	120	260	100	170	260	210	240				230		120	130	150	190	160	220	210	220
31dcd-2	C 2815	Orin Puffer		138													190	250	180	190	180	170	170	310
31ddc-2	a 2041	Eugene Mayer	12	195																				160
32aac-1	C 20597	Albert Berntsen	14	94																				70
32bbc-1	C 8756	Walter Yardley	14	132	170		140	160	170	220				310	320	290	270	250	290	300	290	240	270	290
32cac-1	C 305	Don Alger	14	109	210	200	230	210	200	120							90	410	410	470	510	360	320	440
32ccc-1	C 2040	Robert Ricketts	14	72	120	100	90	100	80		190													
32ccd-1	C 3837	" "	14	60	120	130	120	120	120					200	170	190	170	50	320		180	160	140	150
32cdc-1	C 1421	A. O. Williams	14	85	150	330	200	270	200	270				360	310	300	400	480	40	410	480	310	370	400
32dcc-1	C 1422	" "	14	68	180	220			250	260				330	190		260	300	310	290	320	280	250	250
32dbc-1	C 1423	" "	18	84	110	290	180	230	400	380				340	300			300	280	240		190	310	300
(C-28-11) 24daa-1	C 1317	Leo Mayer	14	58	210	330		210	200	270	290	320	370	330	280		270		290	240		200	180	190
25abd-1	C 9402	George Smith	14	77	80	200	300	250	310	220	270													
25dcd-1	A 19995	Jacob Baumback		431																				180
25ddd-1	C 3392	Kent Smith	14	73	190	160	150	210	220	220	220	310	280	260	230	230	260	240	240	250	250	30	250	240
35aad-1	C 4	W. D. Stewart	14	51																			190	270
35add-1	C 3	Lewis Stewart	14	77																		120	160	270
35ddd-1	C 3619	Mrs. W. M. Bond	14	74	200	160	170	150	140	170	180	170	160	170	150	190	160	140	150	170	160	230	230	320
36aad-1	C 7662	Gus Hooten	16	110																		20	230	240
36add-1	C 20233	George Smith	14	62	160	220	210	150	160	180														
36bac-1	C 5265	W. J. Stewart	14	72														350	280	340	280	280	240	270
36bad-1	C 6519	W. D. Stewart	14	85																		50	120	170
36bdd-1	C 2	" " "	14	77	140		160	200	140		120	180	170	170	130	190	230	170	220	240	280	220	190	360
36bba-2	C 5267	W. J. Stewart	14	66	100	270	270	240	240															
36cad-2	C 19388	Lewis Stewart	14	85					30	230	270			170	210	100		210	200	220	240	220	240	280
36cbd-1	C 10149	Eugene Meyer	14	78																			170	250
36cca-1	C 1	Eugene Meyer	14	84	70	110	120	30	60		130	160	200	180	160	190	170		170	120		170	150	230
36cdd-1	C 3691	John W. Stahl	16	90	140	100	100	120	200	160	220	240	250	270	230	270	290	470	410	470	540	460	470	550
36dcc-1	C 5143	Stanley B. Lewis	14	64	90	150	130	70	140					140	150		60		60	230	280	150	150	180
36dcd-1	C 5142	" "	14	71		180	280	180	190					250	110			200	200					
36ddd-1	C 5296	Dan Rollins	14	60				80	120	180	170	190	200	180	170	180	170	200	190	190	170	180	190	210
36ddd-2	C 5297	Dan Rollins	14	80	170	190	180	160	160	130	180	170	180	210	180	180	180	180	180	180	20	180	200	200
(C-29-10) 5bac-1	C 6839	L. D. S. Church	14	82	250	300	280	210	210	180	210	270	190	290	260	260	260		290	260		200	180	270
5bbb-1	C 10313	Alvin Jones	14	58	80	80	100	90	80											50	50	50	30	50
5cad-1	C 10285	Alden & Jack Hadley	14	84	290	220	130											240	240		240	350	290	30
5cdd-3	C 7638"R"	Guy Whitaker	12	198		200	220	100	210	200			150	260	170		180							390
6aad-1	C 17295	Alvin Jones	14	95	230	190	190	240	150	230	240		280	160	160		240		60		170	220	170	250
6abb-1	a 2042	Gael Elmer																						210
6aca-1	C 5284	" "	14	67	280	370	260	370	420	240												130	240	190
6baa-1	C 4494	Don Elmer	12	90	160	150	140	220	330	310	350		240	230	220	230	140	230	230				150	160
6bbd-1	C 13109	" "	14	130	120	150	130	170	200	150	210			110	150	230	180	120	120	130	170	130	130	140
6cdd-1	A 17927	Rosheen Lavendar	14	350																	430	10	390	450

in several observation wells at the end of each year. However, the "diversion and use" survey made by the State Engineer during 1939 provides a good check as to pumpage for that year. In that survey the total discharge of wells was computed from monthly measurements of discharge from each well. The total withdrawal of ground water for irrigation in Beaver County (practically all being from the Milford district) was computed to be 12,700 acre-feet in 1939,[34] which is approximately the same as the amount computed in the present investigation.

Summary

The natural discharge from the ground-water reservoir of the Milford district was computed to have been about 11,000 acre-feet in 1927, and is considered to have been very nearly as much in recent years. This natural discharge has been by evaporation and transpiration, by springs, and by underflow to the north.

In the past two decades the total pumpage from wells in the Milford district has ranged from about 12,000 acre-feet in 1938 to about 32,000 acre-feet in 1950. Most of the water was pumped for irrigation, and doubtless a substantial amount returned to the ground-water reservoir by deep percolation from the irrigated fields. On the other hand, in the lower parts of the Milford district the water table is shallow enough that alfalfa can obtain its water supply by subirrigation. It is not known whether the transpiration by these subirrigated crops is comparable in amount to the deep seepage from pumped irrigation water within the district. In any case, the total net ground-water discharge is considered to have ranged from about 20,000 to 40,000 acre-feet a year. The differences from year to year are accounted for chiefly by variations in annual pumpage.

BALANCE BETWEEN RECHARGE AND DISCHARGE

As pointed out for the Beryl-Enterprise district, changes in the quantity of water stored in the ground-water reservoir are shown by fluctuations of water level in wells. Figure 13 shows the hydrographs for nine wells in the Milford district. In seven of the hydrographs the most prominent fluctuations are those which recur on an annual cycle. Indeed, in most wells of the district the water levels reach a minimum during

34—Humpherys, T. H., Underground water: Utah State Eng. 22nd Bienn. Rept., p. 35, 1940.

the summer and rise to a maximum in the winter or spring. These fluctuations are caused by pumping. They are especially large in wells such as (C-28-10)19add-1, in which irrigation pumps are operated. In well (C-29-11)22ddd-1, near the fringe of the pumping district and half a mile from the nearest irrigation well, the seasonal fluctuation due to pumping is only a foot or two.

In unused wells within the pumping district, the change in water level from winter to summer may be as much as 8 feet, and even in wells beyond the area of heavy pumping the change from winter to summer may be far greater than the change from year to year. During the winter and spring the cones of depression formed by pumping gradually disappear and the water table assumes a smooth form. Changes in storage from year to year are best indicated by changes of water levels in wells as measured during these months.

If on the hydrographs of figure 13 the high points for each year are connected, the resulting lines provide a good indication of the balance between recharge and discharge for the years prior to 1950. The effects of climatic variation upon the storage in the ground-water reservoir are clearly shown by those lines. In well (C-29-10)6ddc-1 water levels during the drought of 1931-35 were more than 7 feet lower than at any time since. The subnormal precipitation of 1939 and 1940 is reflected by a dip in the hydrographs for most wells during 1940 and 1941. Conversely, the water levels in several wells were higher in 1942 and 1948, following years of heavier precipitation, than they were prior to that precipitation.

In detail the trends shown by the several hydrographs are dissimilar (fig. 13). In well (C-29-10)16ccc-1, high on the alluvial fan, and well (C-29-10)6ddc-1, close to the Beaver River channel, the water levels reached maxima during 1938 and again in 1942, and have trended downward since. This downward trend does not correlate directly with climatic variations, for there was a gradual but progressive increase in annual precipitation at Milford from 1942 to 1947. In wells (C-28-10)29cdc-1 and (C-28-11)36add-1, down the slopes of the fan to the north and west, there were maxima in 1940 and 1944, and subsequent downward trends. In well (C-28-10)19add-1, still farther north, water level trended upward until 1945 and then leveled off. From these graphs it appears that replenishment to the reservoir occurs most

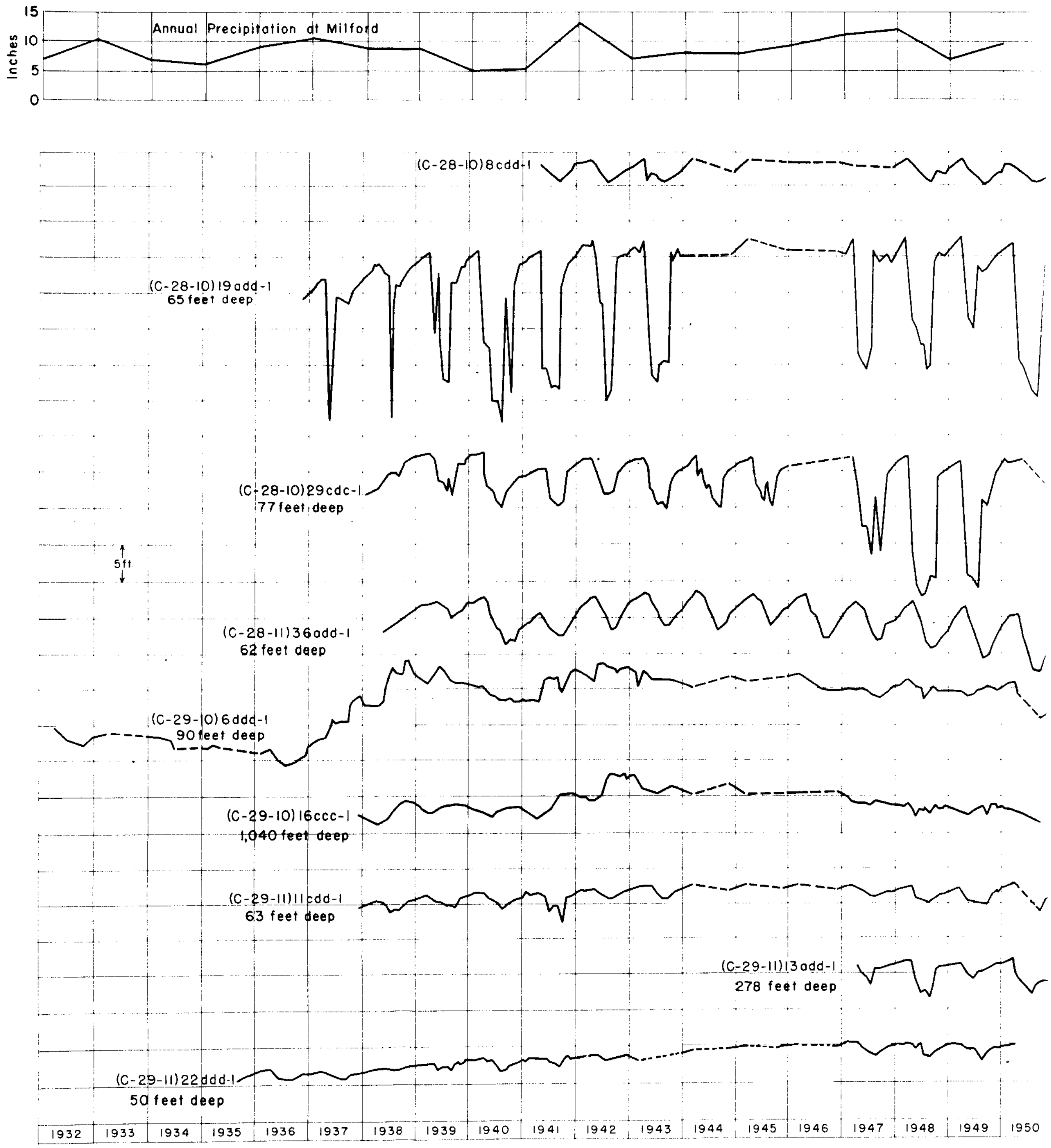


Fig. 13 - Hydrographs for nine wells in the Milford district, 1932-50.

readily in the higher and more permeable materials of the fans. Because of the slow rate of underground movement from these principal areas of recharge the water may reach the lower slopes of the alluvial fan several years later.

Wells (C-29-11)11cdd-1 and (C-29-11)22ddd-1 are in the southwest part of the pumping district. In those wells there has been no downward trend of water levels during the period of record. Rather, after the 1935 drouth the maximum annual water levels rose until 1946 and 1947, and changed very little thereafter. This upward trend is in contrast to the prevailing downward trend during the 1940's in wells farther north. It may indicate that the southern part of the Beaver River alluvial fan has been receiving a progressively higher proportion of the ground-water recharge in recent years. On the other hand, the trend of water level in well (C-29-11)11cdd-1 is not notably different from that in well (C-28-10)19add-1. The wells are respectively about 9 and 11 miles from the apex of the alluvial fan near Minersville, and both hydrographs may be indicative of a very gradual recovery from the effects of the drouth of 1931-35.

The annual changes in ground-water storage, and the chief factors responsible for those changes, are summarized in the graphs of figure 14. The upper graphs show the variations in annual runoff in and diversions from the Beaver River, which are the predominant sources of ground-water recharge in the Milford district. Three observation wells are so situated that their hydrographs show especially well the effects of recharge from surface water. They indicate increasing ground-water storage during three years of normal runoff (1936-38) following five years when runoff was far below normal. Subsequently the hydrographs reflect the deficient runoff of 1940 and the excessive runoff of 1942. Since 1942 the total runoff of the river has been about average, but the estimated diversions to the Low Line canal have trended downward. The hydrographs for all three wells have trended downward also, and this has been particularly true of well (C-28-10)33aba-1, which is near the Low Line canal. All three hydrographs suggest that the diversions to the Low Line canal are an important source of recharge.

The annual pumpage from irrigation wells is shown graphically at the bottom of figure 14. Comparison of this graph with that of canal diversions into the district shows that more water is pumped when there is a deficiency of

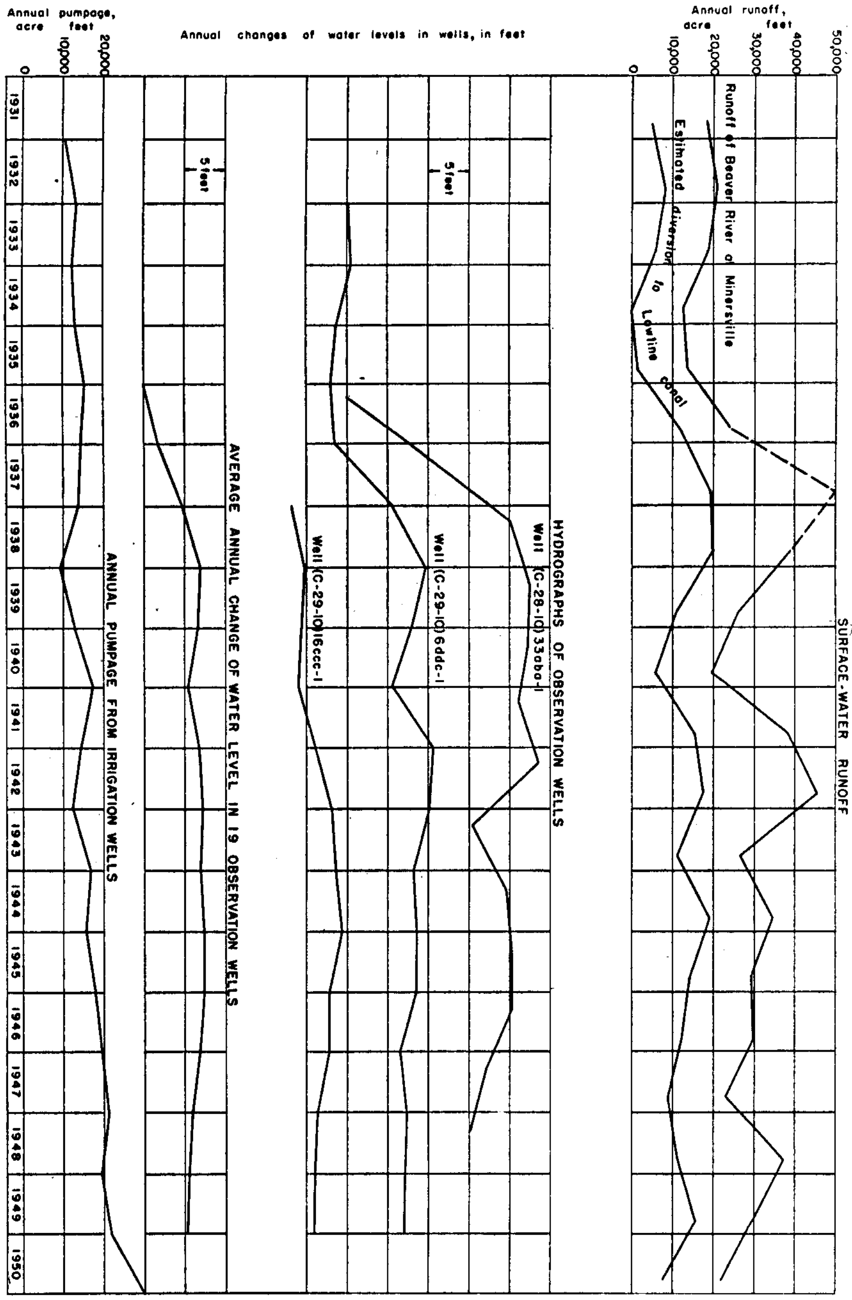


Fig. 14. Water levels in observation wells in relation to surface-water discharge and to pumping in the Milford district.

surface supplies, and less is pumped when canal supplies are plentiful. Pumpage increased in 1934 and 1935, when practically no reservoir water was available to the district. The rate of pumping decreased in the following 3 years and was least in 1938, when the acreage irrigated from the canal reached the maximum for the period of record. Decreasing surface-water supplies in 1939 and 1940 were supplemented by increased pumping, and in the following decade pumping in most years had a similar inverse relationship to canal diversions.

The graph of average annual change of water level in 19 observations wells indicates the changes in storage in the ground-water reservoir from year to year. These changes result from changes in the rates of recharge and discharge.

Because the principal method of discharge (pumping) appears to have an inverse relation to canal diversions, some correlation is to be expected between the graph of water-level changes and the graphs showing pumpage and diversions. This is seen to be the case. Following the drought, the water levels in wells rose until 1938, dropped somewhat during 1939 and 1940 as recharge decreased and pumping increased, and then rose in 1941 and 1942 in response to increased recharge and decreased pumping. From 1943 to 1946 there was little change in year-end ground-water storage, although pumping increased slightly during the four years. From 1947 to 1949 the storage decreased somewhat, probably because of further increases in pumping. The great increase in pumping during 1950, together with decreased opportunity for recharge, can be expected to cause a marked lowering of water levels in observation wells.

It must be concluded that up to 1950 there has been no progressive depletion of the ground-water reservoir by pumping in the Milford district. Prior to 1935 there had been a marked decline in water levels in wells, and that decline was viewed with alarm by many well owners. Subsequent history, however, has shown that the decline resulted not from pumping but from climatic conditions during drought years. With normal precipitation and runoff the storage in the ground-water reservoir increased substantially, even though pumping continued at rates comparable to those in the drought years.

The importance of surface-water diversions in replenishing the ground-water reservoir has long been recognized, and years ago the use of canals and ditches for artificial recharge was recommended:[35] "Opportunities are presented for artificial recharge to the ground-water reservoir in the Milford pumping district of Escalante Valley, in Beaver County, Utah. Water in excess of the storage capacity of Rockyford reservoir has heretofore been discharged down the channel of the Beaver River, occasionally in such large quantities that much of it has been wasted on the barren lands north of the town of Milford. Artificial recharge may be accomplished by diverting water into canals and ditches that traverse the gravelly alluvial slopes east and south of the main pumping district. Greater recharge to the subterranean reservoir may also be achieved by releasing water into the river channel at a rate only sufficient to permit maximum seepage from the portion of the channel south of Milford, beginning this release perhaps several weeks or even months before the peak of spring runoff is expected."

QUALITY OF GROUND WATER

An accompanying table presents chemical analyses of water from 42 wells in and near the Milford district (see p. 170) for discussion of the relation of dissolved materials to usability of water). The first three wells listed are deep artesian wells north of the Milford district; all yield waters with a relatively high concentration of dissolved mineral matter. The last well on the list is the Union Pacific Railroad well at Thermo, which yields water that is ordinary except for the high content of silica.

All the other wells are in the Milford district. The samples show a somewhat greater range in quality than do those in the Beryl-Enterprise district. The best of the waters are as good as the best of those in the Enterprise area, and some of the deep wells near Milford yield softer waters than do wells elsewhere in the valley.

On the other hand, many of the sampled waters contain excessive chloride or sulfate or total dissolved mineral matter. The most highly mineralized waters were obtained from wells less than 100 feet deep, or from deeper wells with casings perforated in shallow water-bearing zones. In general, too, the wells in the northern part of the district—in T. 28 S.—yield the more highly mineralized waters.

The specific conductances show these variations in quali-

35—Thomas, H. E., Possibility of artificial recharge to the Milford pumping district, Utah: Utah Acad. Sci., Arts and Letters, Proc., 1941, vol. 19, p. 12, 143.

ty by geographic location and by depth: all sampled waters in T. 29 S. had a specific conductance less than 1,400 micromhos; and all but one of the samples from wells more than 100 feet deep had a specific conductance less than 1,400 micromhos, regardless of location in the district. In nine wells ranging in depth from 47 to 92 feet, all in the lower parts of the Milford district, the specific conductances ranged from 1,420 to 4,730 micromhos. In these same areas, however, other shallow wells yield water of good quality.

The mineralization of the shallow ground water, as well as the spotty distribution of that mineralization, are probably caused largely by deep percolation of water applied for irrigation during the past 35 years. Water from well (C-28-10)-30bdd-1, analyzed in 1923, contained only 339 parts per million of dissolved matter. Water collected in 1950 from well (C-28-10) 30bdc-1 (1,000 feet west of well 30bdd-1) contained 2,190 parts of dissolved solids. Well (C-28-11)25abd-1 is about 1½ miles southeast of well (C-28-11)23aab-1, and 20 feet deeper. Sampled in 1950, it contained far more sulfate, chloride, and bicarbonate than the water collected from well 23aab-1 in 1927. Thus, at least in this part of the district, the mineralization of the shallow water appears to have increased in the past quarter of a century.

MAXIMUM ECONOMIC UTILIZATION OF WATER RESOURCES

Pumpage in the Milford district up to 1950 evidently has not exceeded replenishment. Thus, in contrast to the Beryl-Enterprise district, there has not yet been a progressive depletion of ground-water storage because of pumping. However, the pumping can easily be increased until it does exceed replenishment year after year. Indeed, it is possible that the pumpage in 1950, nearly 40 percent above that in 1949, resulted in some mining of ground water, similar to that which is occurring in the Beryl-Enterprise district.

The Milford district has its salt and alkali problems. Soluble minerals are accumulating in the shallow ground-water zone, chiefly in the north (lower) part of the district. In the past three decades there has been a notable increase of soluble salts in some areas. These increases are attributed, at least in part, to downward percolation of water applied for irrigation. On the other hand, some of the soluble salts of the Milford district are being disposed of by outflow to the Beaver Bottoms. A sample of water collected April 2, 1950, from the Beaver River channel at Milford contained 332 parts per million of chloride, and had a calculated hardness of 626 parts per million. Most of that water rises during the winter from springs in the trough of the valley, mainly Hay Springs. Sewage from Milford enters the channel farther downstream. If development of water resources proceeds far enough to eliminate the surface and subsurface outflow from the district, all soluble salts must then remain within the district.

The Milford district is similar to the Beryl-Enterprise district in that there is substantial natural discharge from the ground-water reservoir by evapo-transpiration, and pumping from wells has not yet resulted in salvaging very much of that natural loss. The water table is commonly within a few feet of the surface under extensive salt-grass meadows. It could be lowered by pumping, but both the shallow ground water and the soils are likely to be mineralized in the area of high water table. Salvaging of the water now wasted by native vegetation may also run into difficulties of deterioration in quality of water.

In the southeast part of the Milford district it has been a common practice to irrigate certain lands from canals only in years when there is adequate surface water, and to pump irrigation wells on those lands in years of deficient surface supplies. As a result, the ground-water reservoir is recharged by percolation from irrigation in years of plentiful surface supplies, and drawn down in time of need. Thus to a limited extent the ground-water reservoir has been utilized for hold-over storage. Similar operations in the future, to take advantage of the underground reservoir's large storage capacity, could increase the dependable yield of water resources. Flood waters that would otherwise be wasted into the Beaver Bottoms might be used for artificial recharge of the ground-water reservoir, as suggested by Thomas.

The total inflow of the Beaver River to Escalante Valley is quite likely to be less than the total quantity of water "used" from canals and wells that are supplied from that inflow. This is true because only a part of the water supplied for irrigation or domestic use is used consumptively (that is, evaporated and returned to the atmosphere); the rest returns to stream channels or to the ground-water reservoir after use, and is then available for reuse. The water may be diverted from the river for irrigation, percolate downward to recharge

CHEMICAL QUALITY OF GROUND WATER IN THE MILFORD DISTRICT[1]

Well number	Depth of well (feet)	Date of collection	Specific Conductance (Micromhos at 25° C.)	Percent Sodium	Chemical analysis, in parts per million: Total dissolved solids	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)		Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Total hardness as $CaCO_3$
(C-26-10) 7	215	1906											36	1,752			
[2] 17	215	1906			2,937	24	133	127		727		495	35	1,570		0	853
32cad-2	332	June 21, 1950	3,430	63	1,840	32	90	92		481		304	16	980		1.6	603
[3] (C-28-10) 7aad-		June 21, 1950	394	66		33				61		162	40	16	1.0		67
[2] 7dab-1	310	1904(?)			330	90	47	10	8			104	0	12			158
[4] 8bbc-1	745				261	24	14	5.7		68		173	40	15		1.0	58
17ccc-1	92	June 19, 1950	3,060	26	2,020	52	333	96		203		226	647	572		2.3	1,230
17cdc-1	60	Apr. 3, 1950	3,840									209		890			
18aca-2	450	Apr. 3, 1950	364	64		34				56		164	37	10	1.0		68
19abc-1	260	Nov. 3, 1950	328	59	219	32	14	7	45		3	148	35	9.5	.7	.1	64
19bbc-1	72	Apr. 3, 1950	320	12						9.2		128	28	26	.6		
19dcc-2	300	Apr. 2, 1950	283	30						23		130	40	11	.8		116
20cdd-1	48	Apr. 2, 1950	4,730	35		45				441		245	1,240	912	.4		1,820
21ccd-1	316	June 19, 1950	1,920	18	1,210	62	150	108		85		136	371	352		11	818
29bdd-1	60	June 21, 1950	3,520	30	2,340	52	386	99		266		365	712	640		8.1	1,370
29cdc-1	77	Apr. 2, 1950	1,150									242		163			
do	77	June 21, 1950	1,420	29	869	44	150	35		95		278	199	202		7.5	518
30adc-1	101	June 19, 1950	327	14		44				10		126	27	20			137
30bdc-1	47	June 21, 1950	3,090	32	2,190	53	354	78		261		332	829	445		9.4	1,200
[5] 30bdd-1	57	Oct. 15, 1923			339	40	62	12		18		161	57	37		Tr	204
(C-28-11) 10acd-1	227	Nov. 3, 1950	988	41	642	48	54	40	99		4.2	285	174	82	.3	.1	299
13dca-1	600	Apr. 3, 1950	446									152		30			
[5] 23aab-1	57	Oct. 15, 1927			716	44	67	26	130		9.6	193	194	145		1.2	274
25abd-1	77	Apr. 3, 1950	2,560									322	290	400	.7		
25dcd-1	431	June 20, 1950	642	18		43				26		154	100	64			264
25ddd-1	73	June 20, 1950	2,410	32	1,610	50	264	57		192		315	528	348		16	893
35ddd-1	74	Apr. 3, 1950	1,200	10						30		226	255	136	1.1		580
do	74	June 20, 1950	1,190	25	756	49	136	28		69		206	240	132			454
36baa-3	150	Apr. 3, 1950	264	7		45				4.8		130	19	10	.8		132
36bba-2	66	Apr. 3, 1950	3,060									308		455			
36cdd-1	90	Apr. 3, 1950	786									204		98			
36ddd-1	60	June 20, 1950	1,120	18	628	45	128	27		43		275	131	112		6.1	430
(C-29-10) 5cdd-1	265	Apr. 3, 1950	980									190	117	138	.3		
6baa-1	90	Apr. 4, 1950	633									198	69	65	.4		
17add-1	200	June 20, 1950	1,350	20	855	37	168	36		66		323	165	154		70	567
17ddd-1	200	June 19, 1950	1,010	13		38				29		245	119	117			428
18add-1	168	June 20, 1950	816	25		36				46		206	89	95			295
(C-29-11) 1bad-1	140	Apr. 3, 1950	484									148	49	56	.4		
2add-1	52	Apr. 3, 1950	830	19						39		190	122	108	.7		352
11aad-1	70	Apr. 3, 1950	513									156		62			
11ccd-1	62	Apr. 2, 1950	484									110	35	67	.8	27	
11ddd-1	83	Apr. 2, 1950	450	19						21		130	35	58	.4	9.2	188
12add-1	202	June 20, 1950	548	9		42				11		168	55	51			243
12ddd-1		June 20, 1950	382	14		41				12		132	35	31			162
27bad-2	192	Apr. 2, 1950	763	16						26		132	53	128	.4	5.4	292
[5] (C-30-12) 11abc-1	401	1905 (?)			689	161	32	15		57		171	4	87			142

1—Analyses by the U. S. Geological Survey unless otherwise indicated.
2—Analysis published in U. S. Geol. Survey Water-Supply Paper 217, pp. 36, 50-51, 1908.
3—Milford municipal supply, derived from wells (C-28-10)7aad-1, 478 feet deep; 7 aad-2, 468 feet deep, (perforated in various zones below 200 feet); and 7adb-1, 533 feet deep.
4—Analysis furnished by the Union Pacific Railroad Co.
5—Analysis published in U. S. Geol. Survey Water-Supply Paper 659, pp. 93-94, 1932

the ground-water reservoir, be pumped out for irrigation and return again to the ground-water reservoir by percolation, etc., until it has been "used" several times. Each nonconsumptive use, however, is likely to cause an increase in mineral constituents, and therefore a deterioration in quality, until eventually the water becomes unsuitable for further use.

In a good many years practically all the Beaver River water is diverted for use, and the bulk of the replenishment to the ground-water reservoir is therefore by "used" water. Thus ground-water development on the Beaver River alluvial fan is intimately related to surface-water development, and both types of development must be coordinated for full utilization of available water supplies. And not only are the ground water and surface water interdependent—both are clearly dependent upon the extent of utilization of water throughout the Beaver River drainage basin. The water developments in Beaver Valley are of much more importance to the inhabitants of the Milford-Minersville area than are the developments in the Beryl-Enterprise district in the south part of Escalante Valley. It has been proposed by the Yellow Mountain Irrigation Company that part of the surface water now applied to land southeast of Milford be diverted to land south and west of Minersville. This change of use of surface water if carried out might have serious effects upon the ground-water recharge to the main part of the Milford pumping district.

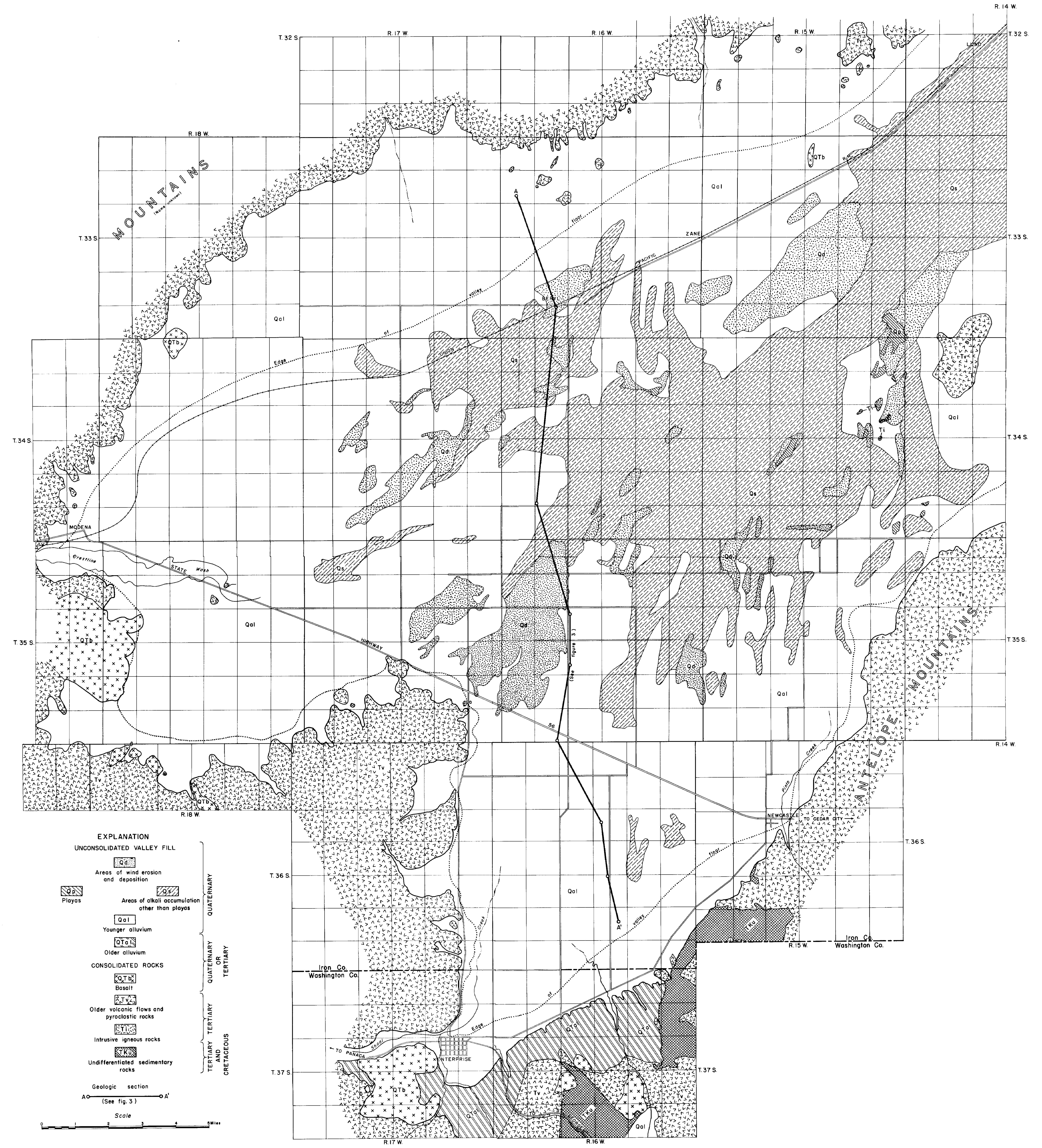
The maximum utilization of the water brought in to Escalante Valley by the Beaver River is dependent not only upon use of as much of that water as possible, but also upon reuse to the greatest possible extent as long as the water is of satisfactory quality. A detailed hydrologic study of the entire alluvial fan must be completed before a comprehensive analysis can be made of this problem.

FUTURE HYDROLOGIC INVESTIGATIONS

The current investigation has been limited to the Milford pumping district, and is by no means complete even for that area. The studies have shown that this district is only a part of a hydrologic unit that embraces the entire alluvial fan of the Beaver River. Effective utilization of the water resources requires an adequate knowledge of the hydrology of this broader area.

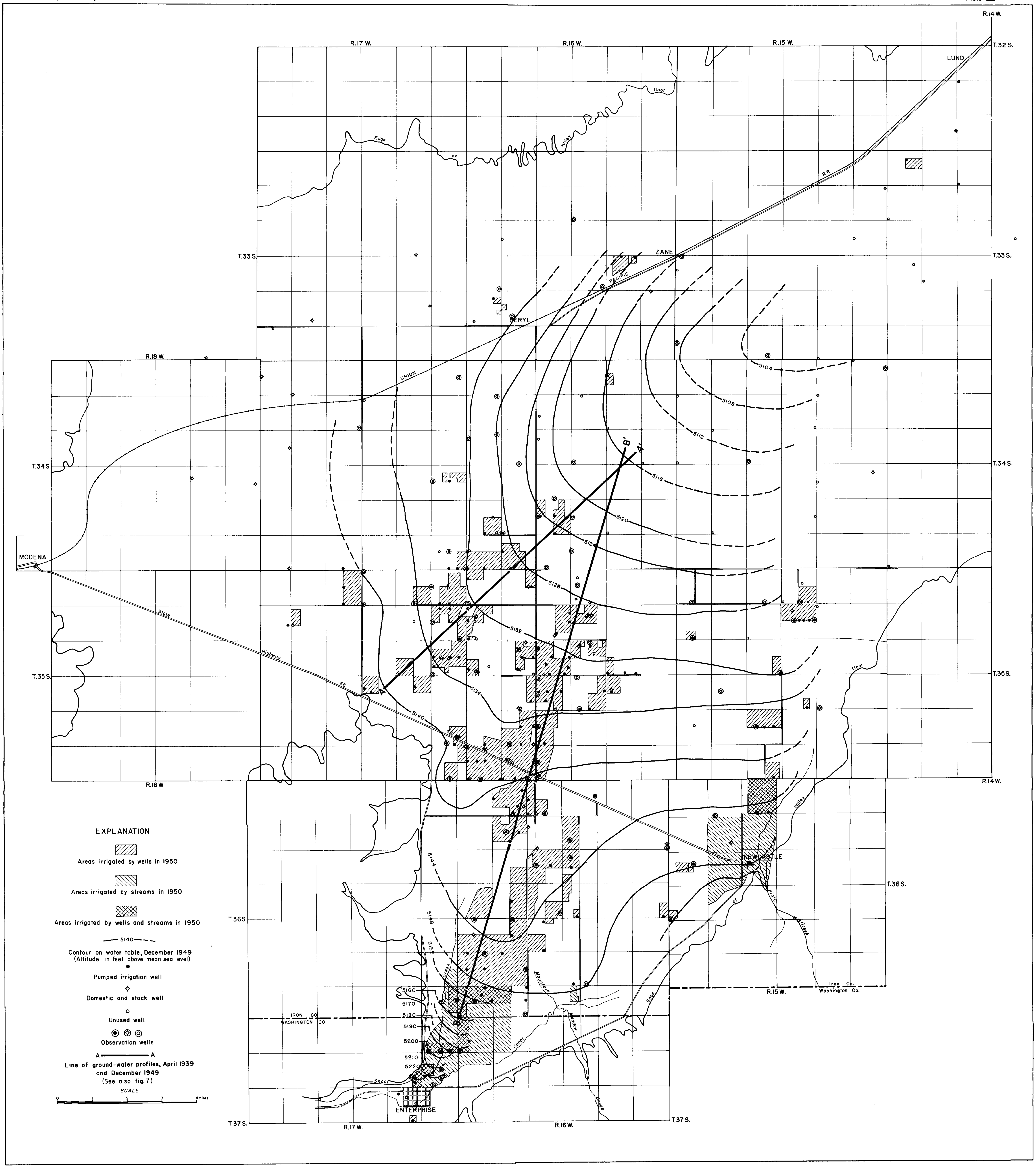
Also, more information is desirable as to the quantity of underflow down Escalante Valley into the western edge of the Milford district, and out of that district into the Beaver Bottoms.

It is evident that much more needs to be learned about the quantities of water used consumptively, whether that water comes from wells or canals. When the nonconsumptive use and disposal of water are also determined, a basis will be established for coordinated development of ground water and surface water, with maximum use and reuse of the total resources. Future investigations should be concerned with the quality as well as the quantity of water resources in the area, because the quality may limit the suitability of the water for various uses.

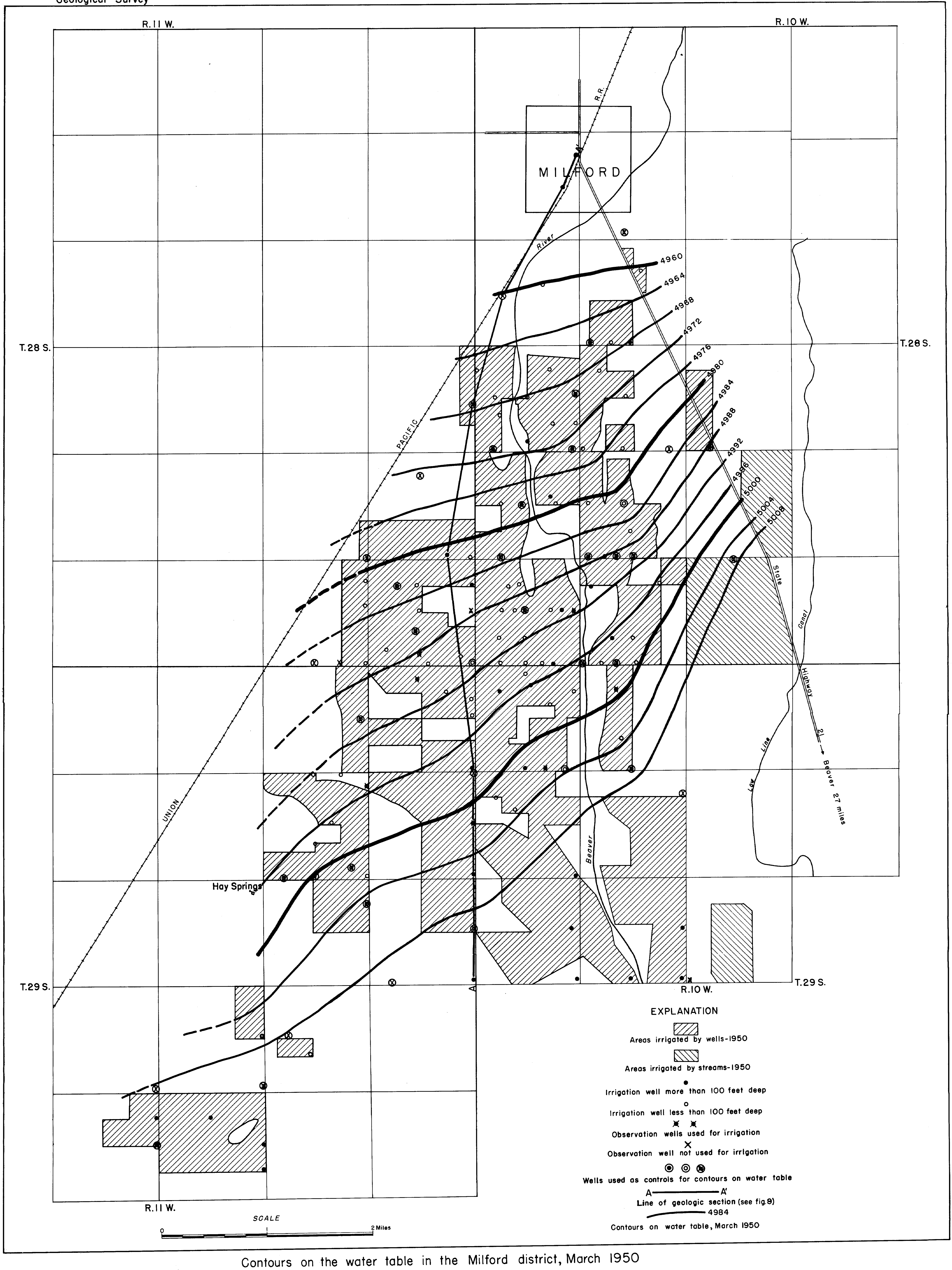


GEOLOGIC MAP OF BERYL-ENTERPRISE DISTRICT, ESCALANTE VALLEY, UTAH.

Geology by Ben E. Lofgren



IRRIGATED AREAS AND WATER-TABLE CONTOURS OF THE BERYL-ENTERPRISE DISTRICT



Contours on the water table in the Milford district, March 1950