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GEOLOGY AND GROUND-WATER RESOURCES
OF
CEDAR CITY AND PAROWAN VALLEYS, IRON COUNTY, UTAH

BY

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Prepared in cooperation with the
STATE OF UTAH
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ABSTRACT

Cedar City Valley and Parowan Valley are situated in the eastern part of Iron County, in southwestern Utah. Both valleys are traversed by United States Highway 91, which skirts the west base of the High Plateaus of Utah. The sparse population of the valleys is chiefly dependent upon agricultural products for its livelihood. The climate of the region ranges from arid to semiarid, and the agricultural products are dependent upon irrigation by surface streams and, to an increasing extent during recent years, by water pumped from wells.

Both valleys lie in the eastern part of the Great Basin. Parowan Valley is bordered on the east by the Utah High Plateaus, is about 30 miles long, and has a general northeasterly trend. Cedar City Valley lies west and south of Parowan Valley and is separated therefrom by a low range of hills; it is somewhat larger than Parowan Valley and has a more nearly north-south trend. The present drainage in both valleys is interior, to playas that occupy the lowest portions of each valley. During more humid climates in the past, drainage was established northwesterly toward the Escalante Valley, which lies beyond Cedar City Valley and has left the picturesque features known as Parowan Gap, Twentymile Gap, and Iron Springs Gap.

The rocks exposed in the region range in age from Permian to Recent. Generally the older rocks form the plateaus and mountains that border the valleys, and the most recent rocks comprise the unconsolidated materials within the valley. Permian and Triassic sediments crop out only along the base of the plateau that forms the east border of Cedar City Valley. Jurassic rocks also occur principally in that locality but there are scattered outcrops farther north. Rocks of the Cretaceous system are widespread in the mountains and plateaus that rim both valleys. Tertiary and Pleistocene rocks, mostly of volcanic origin, cap the plateaus and ranges that border the valleys and also crop out within the limits of the valleys. The region has for a long time, presumably since mid-Tertiary time, been the scene of highland erosion and lowland aggradation, and the valleys are the sites of accumulation of an unknown but undoubtedly great thickness of torrential deposits.

The alluvial fans of many of the principal streams that enter the valleys include persistent zones of coarser detritus at some depth below the surface, which are inferred to represent a period or periods when the streams had greater carrying power than now, probably a period of more humid climate. Other indications of such climate are the shore features above and beyond the limits of the present lakes in both valleys and the drainage channels already referred to as onetime outlets to the valleys. These features may well have been developed as a result of the humid climate that caused the creation of the Pleistocene Lake Bonneville elsewhere in Utah.

Post-Mesozoic folding accompanied by thrust faulting occurred in the southern part of the region, probably contemporaneously with the forming of the Virgin anticline and similar structures farther south, in Washington County. Sometime during the Tertiary period, perhaps contemporaneous with the volcanic eruptions that were prevalent during the period, andesitic intrusions in the form of laccoliths caused considerable warping of the sediments in the Iron Springs area, west of Cedar City Valley.

The outstanding structural modifications in the regions are those due to normal faulting, of which the most striking evidence is the difference in elevation between the High Plateaus and the Great Basin to the west. Normal faulting probably began early in the Tertiary period and no doubt accelerated the accumulation of debris in the valleys. The structural adjustments have continued until quite recently, as shown by scarps in the alluvium of both valleys. The physiography of the region is dominated by these faults, and the valleys are evidently down-dropped areas, or grabens, while the adjacent highland areas are horsts.

Several perennial streams rise in the highland areas and discharge into the valleys, the largest being Coal Creek, in Cedar City Valley, and Parowan Creek, in Parowan Valley. Practically the entire flow of these streams is used for irrigation.

Ground water occurs principally in the unconsolidated deposits that have accumulated in both valleys. In the consolidated rocks a small amount of water moves through previous beds and through fractures and may come to the surface as springs, chiefly in stream canyons or along the edge of the valleys. Because of their low average permeability, however, the prime function of these consolidated rocks is, practically, to limit the ground water to the unconsolidated sediments, and thus to form the boundaries to the ground-water reservoir or reservoirs.

In Cedar City Valley ground water is derived in large part from water that flows either in streams or as underflow from the canyons that drain the surrounding plateaus, hills, and mountains. Within the valley the ground water moves from the mouths of these canyons—that is, from the apexes of the alluvial fans—toward the central and lower parts of the valley, following closely the interior drainage pattern of the streams in the valleys, except that some ground water moves through the Iron Springs Gap and Twentymile Gap, which are no longer occupied by streams. A small quantity of water moves out of the valley through these gaps into Escalante Valley, but natural disposal of water in the valley is chiefly by evaporation and transpiration from areas of shallow ground water in the lower parts of the valley, particularly around Shurtz and Rush Lakes.

Some of the recent displacements along faults that cross Cedar City Valley affect the circulation of ground water. Along two of these faults, perhaps along others, ground-water dams have been created, owing to the relative impermeability of materials along the line of displacement. So far as known, the faults in the area act merely as barriers to ground-water circulation; no water is believed to be derived from deep sources along these faults.

The relative impermeability of some of the alluvial sediments gives rise to artesian conditions over a large part of Cedar City Valley. Water is most likely to occur under artesian pressure in the lower parts of the alluvial fans, where clay and silt are most common. Near the apexes of the fans, where gravel and coarse detritus predominate, ground water is commonly unconfined. The confining layers responsible for artesian pressure are not believed to be continuous over any considerable portion of the valley; more likely they are irregular and more or less lenticular in shape, as is common for beds of fluviatile origin. They do not form any major separation of the ground-water reservoir into shallow and deep zones, but appear to act as minor baffles to the free circulation of ground water.

The ground-water reservoir in Cedar City Valley has been divided into eight districts. Four of these comprise the alluvial fan of Coal Creek; their separation is based partly on natural barriers and partly on differences in occurrence of ground water, whether artesian or unconfined. The four other districts are distinguished from each other and from those on the Coal Creek fan on the basis of source of ground water.

Construction of wells in Cedar City Valley probably began soon after the arrival of settlers in 1851. Ground water was obtained first from dug wells, later from bored or jetted wells by artesian flow. By 1910 comparatively few wells had been constructed, but these were widely distributed throughout the valley. Between 1910 and 1925 there was great development of wells for artesian flow, and by 1925 a large proportion of the wells in the valley were flowing wells.

Pumping from wells for irrigation was practised very little before 1925 but began in earnest about that time. Construction of new irrigation wells was intensified particularly during the drought years of 1931 and 1934. The quantity of water pumped for irrigation increased from about 6,500 acre-feet in 1930 to 9,400 in 1938 and to more than 13,000 acre-feet in 1940. This increase was almost entirely due to increased withdrawals from the upper part of the Coal Creek fan. The present discharge from flowing wells is estimated at about 400 acre-feet a year and the discharge by natural processes at about 5,200 acre-feet a year. In the Coal Creek district, which is the principal pumping district, the pumpage from wells averaged 7,500 acre-feet a year in the 2-year period of 1938 and 1939. During that period there was a slight increase in ground-water storage, although the precipitation and runoff were slightly below normal.

The occurrence of ground water in Parowan Valley is analogous in most respects to that in Cedar City Valley. The tributary streams and canyons that drain the surrounding highlands constitute the principal sources of ground water, and it moves generally from the mouths of these canyons toward the lowest parts of the valley. The two independent topographic basins within the valley are presumably occupied by ground-water basins separated by a divide along the Summit Creek alluvial fan. Ground water north of this divide moves toward Little Salt Lake, and a very small quantity may leave the valley through Parowan Gap. Natural discharge of ground water from this northern and more important basin is almost entirely by evaporation and transpiration from the lowest parts of the area, and by discharge from numerous springs. Little is known concerning ground water in the small basin (Winn basin) at the south end of Parowan Valley, but it is presumed that movement is generally westward and that there is discharge by underflow through Winn Gap and through the unconsolidated materials at the south end of the valley into the Enoch district of Cedar City Valley.

Displacement along some of the faults that cross Parowan Valley has been so recent that scarps have been formed in the alluvium. Along at least two of these faults ground-water dams have been created, which have locally given rise to numerous springs. As in Cedar City Valley, these faults act only as barriers to circulation of ground water through the alluvial aquifers, and not as conduits for water from sources beneath the valley fill.

Ground water is obtained under artesian pressure throughout the greater part of the area of ground-water development, and about three-fourths of the wells in the valley flow during at least a part of each year. The area of artesian flow occupies the lowest part of the valley, including Little Salt Lake and a considerable area to the east and northeast. Presumably ground water is not confined under artesian conditions near the apexes of the several alluvial fans, where gravel and coarse detritus must be the dominant constituents. The great majority of wells in the valley, however, have been constructed on the middle and lower portions of the fans, where water is generally confined to some extent. According to observatoins in wells whose depths are known, the water in deeper aquifers commonly has a greater artesian pressure than that in shallower strata. The extent of the separation between aquifers could not be determined because of the common practice of perforating the casings of the deepest wells opposite both deep and shallow aquifers. It is presumed that the confining layers are generally lenticular and not of large extent, analogous to those in Cedar City Valley, and that the deeper and shallower aquifers are therefore more or less interconnected.

The amount of ground-water storage in Parowan Valley, as indicated by reports of well owners, was probably greatest at some time during the decade 1915 to 1925, and was perhaps at a minimum during 1936, owing to the deficient recharge available during the years that culminated in the drought of 1934. Generally throughout Parowan Valley the changes in ground-water storage from year to year are not at all commensurate with the wide variations in precipitation and presumably in runoff and available recharge. Fluctuations in natural discharge, as well as in discharge from flowing wells in response to the changes in recharge, are considered to be chiefly responsible for bringing the storage of ground water to a more or less comparable level each year. Withdrawals for irrigation of course cause considerable seasonal depletion in storage, but the recharge during the year has generally been sufficient to offset this loss. The considerable decline of water levels over a term of years in part of the Little Salt Lake district is exceptional for Parowan Valley, and is attributed to withdrawal of water in quantities greater than could move into the area across a barrier created by faulting. Since 1936 water levels and artesian pressures have risen somewhat each year in most wells throughout Parowan Valley, owing chiefly to increases in storage as well as pressure effects created by closing wells when not in use, in accordance with the State Engineer's program of conservation.

Ground-water development in Parowan Valley began about as early as in Cedar City Valley, but proceeded at a somewhat faster pace so that by 1910 there were more than a hundred wells in the valley. About three-quarters of the existing wells were constructed prior to 1920 and very few have been drilled since 1930. Pumping for irrigation also began early in Parowan Valley, and in 1930 the quantity pumped was about as great as that pumped in recent years—about 6,000 acre-feet.

During each of the years 1937 to 1939 the precipitation at Parowan was approximately normal, and it is presumed that runoff and recharge likewise were fairly constant. During those years the discharge from wells is estimated to have been 7,000 to 8,000 acre-feet annually, of which perhaps 1,500 acre-feet was wasted. The discharge from the valley by natural processes was of the order of 15,700 acre-feet annually, of which perhaps 5,000 acre-feet was discharged by underflow into Cedar City Valley. From these estimates it is evident that the water utilized from wells in Parowan Valley is only a minor proportion of the total ground water available, and that therefore there are excellent possibilities for further development. In this respect the conditions in Parowan Valley are in contrast to those in Cedar City Valley, where most of the ground water available in a normal year is already being utilized.

INTRODUCTION

LOCATION AND GENERAL FEATURES

Cedar City and Parowan Valleys, in the eastern part of Iron County, in southwestern Utah, are among the most important agricultural areas in southern Utah and are named [1] for the principal town and commercial center in each valley—population in 1940, Cedar City, 4,695 and Parowan, 1,519. Their location and approximate extent are shown on the index map of the State. (See pl. 1.) Both valleys are traversed by the Arrowhead Trail, United States Highway 91, from Los Angeles to Salt Lake City, and Cedar City is the terminus of a branch of the Union Pacific R. R., which connects at Lund, 33 miles northwest of Cedar City, with the main line to Salt Lake City, Utah, and Los Angeles, Calif.

PREVIOUS INVESTIGATIONS

During 1908 O. E. Meinzer, [2] of the Geological Survey, made an investigation of the ground water in Millard, Juab, and Iron Counties and discussed the development and possible utilization of ground water in Cedar City and Parowan Valleys. His conclusions concerning the water supply of both valleys have since been shown to be generally correct, and the subsequent development of ground water for irrigation has followed rather closely the recommendations that he made at the time of his visit.

In 1930 and 1931 Arthur Fife and later Lamont E. Tueller, Iron County agricultural agents, collected considerable data concerning irrigation wells and pump discharge in Cedar City and Parowan Valleys, and subsequently they made periodic measurements of water levels in several wells. These data have been of especial value for comparison with records collected during the present investigation.

PURPOSE AND SCOPE OF THE PRESENT INVESTIGATION

The investigation of the ground-water resources of Cedar City and Parowan Valleys is part of a program of research into the ground-water resources of the State of Utah. This program was begun in 1935 under a cooperative agreement, between the Geological Survey of the United States Department of the Interior and the State Engineer of Utah, which provides that the Geological Survey and the State Engineer shall contribute equally to the expenses of the investigation. The purpose of this research is (1) to determine the fluctuations of the water level in the ground-water areas of the State and (2) to determine by detailed geologic and hydrologic investigation the sources of the ground water and the amount available in selected ground-water areas. These data are being gathered in part to assist the State Engineer in his administration of the State's ground-water law [3] and to assist in the adjudication of rights to the use of ground water. A comprehensive investigation of Cedar City and Parowan Valleys was recommended by the State Engineer because of the critical ground-water problems in those areas and because of the danger of overdevelopment of the ground-water supplies.

The investigation was conducted under the supervision of Oscar E. Meinzer, geologist in charge of the Division of Ground Water of the

[1] Cedar City Valley is commonly called Cedar Valley by local residents, and was so labeled on maps of the Powell Survey. It has also been called Rush Lake Valley, notably by Meinzer in Water-Supply Paper 277. The name Cedar City Valley is used here to avoid confusion with other localities in the State, such as Rush Valley in Tooele County and Cedar Valley in Utah County.

[2] Meinzer, O. E., Ground water in Juab, Millard, and Iron Counties, Utah: U. S. Geol. Survey Water-Supply Paper 277, pp. 9-63, 138-142 [Parowan Valley], 142-149 [Cedar City Valley], 1911.

[3] Humpherys, T. H., 20th biennial report of the State Engineer to the Governor of Utah, for the biennium July 1, 1934, to June 30, 1936, pp. 15-21, 1936.

Geological Survey. General data concerning water-level fluctuations in both valleys, most of which have appeared in publications of the Geological Survey, [4] have been obtained since 1935 during the course of the State-wide cooperative investigation. The detailed investigation which forms the basis for this report was assigned to Mr. Thomas, who then spent about 2 years, beginning in July 1938, on field and office studies of the area. Mr. Taylor, in general charge of the State-wide ground-water project, was chiefly engaged on work in other areas, but he spent about 2 months in Cedar City Valley and rendered valuable assistance in the preparation of the report. The writers were ably assisted by W. Kenneth Bach, who collected and compiled much of the data concerning water-level fluctuations and who assisted in other ways.

The Utah State engineer has obtained a vast amount of data concerning ground water throughout the State, and has made freely available all information concerning the area covered by the present investigation, so that the resulting report is more detailed and conclusive than would otherwise have been possible. In particular he furnished locations and elevations of all wells in each valley, compilations of the descriptive data concerning the wells as supplied to him by the well owners, measurements of discharge of irrigation wells and computations of the quantity of water withdrawn from wells in each valley since 1938, and a large number of measurements of static level in wells. This information has been drawn upon freely in the preparation of this report, particularly in the discussion of the ground-water development in each valley.

ACKNOWLEDGMENTS

The cooperation of all the well owners of Cedar City and Parowan Valleys in permitting their wells to be used for measurements and tests was vital to the investigation and is hereby acknowledged. Particular assistance was rendered by Mr. Fernleigh Gardner and Mr. Clarence B. Skougaard, who made periodic well measurements and maintained recording gages. The writers wish to thank A. R. Barnes, Charles Corry, A. J. Decker, Carolyle Esplin, J. N. Smith, D. C. Urie, the Cottonwood Pump & Irrigation Co., and the Federal Land Bank, who gave permission to maintain recording gages on their wells. Mr. Arthur Fife and Mr. Lamont E. Tueller, Iron County agricultural agents, gave assistance and made available valuable data.

CLIMATE

The climate of southwestern Utah ranges from semiarid to arid. The areal distribution of rainfall is irregular, judging by the vegetative cover, which indicates somewhat greater precipitation on the mountain ranges than on the intervening valleys. Residents also report persistent variations in mean precipitation from place to place in the principal valleys, and it is likely these variations in areal distribution result from the positions of the mountain ranges, some parallel to, others more or less athwart the path of the prevailing southwesterly winds.

Records of the United States Weather Bureau, given below, indicate that the precipitation is greater at stations near the western edge of the Utah High Plateaus (see p. 9) than at stations farther west. At Cedar City and Parowan the annual precipitation during the 34 years prior to

[4] Taylor, G. H., and Thomas, H. E., Utah, in Water levels and artesian pressure in observation wells in the United States: in 1935, U. S. Geol. Survey Water-Supply Paper 777, pp. 228–245, 1936; in 1936, Water-Supply Paper 817, pp. 347–351, 424–438, 1937; in 1937, Water-Supply Paper 840, pp. 513–515, 565–588, 1938; in 1938, Water-Supply Paper 845, pp. 556–561, 582–618, 1939; in 1939, Water-Supply Paper 886, pp. 800–822, 832–841, 1940.

1940 has averaged, respectively, 13.10 and 12.90 inches, while at Modena, in western Iron County, over the same period the mean annual rainfall has been 11.04 inches. The precipitation is commonly considerably greater upon the plateau than at stations in the valleys. Thus the annual precipitation at Bryce Canyon, on the plateau about 40 miles southeast of Parowan at an elevation of 8,000 feet, has averaged 18.53 inches during the past 7 years, while the average rainfall at Parowan during the same period was only 10.47 inches.

Annual precipitation at three stations in Iron County, Utah

[Records from United States Weather Bureau]

Year	Station [1]			Year	Station		
	Parowan	Modena	Cedar City		Parowan	Modena	Cedar City
1891	14.24			1916	16.30	16.67	18.19
1892	11.00			1917	13.40	8.41	11.91
1893	12.80			1918	14.20	10.48	11.60
1894	12.97			1919	[2] 13.14	10.45	11.07
1895	12.07			1920	15.33	12.25	[2] 16.6
1896	9.17			1921	17.01	14.57	[2] 17.0
1897	18.47			1922	[2] 12.4	11.57	15.66
1898	13.82			1923	12.82	9.96	13.63
1899	10.92			1924	12.28	7.54	13.65
1900	7.04		8.44	1925	13.76	16.27	16.71
1901	11.05	9.24		1926	10.45	7.64	9.17
1902	9.02	5.09		1927	15.30	13.35	16.22
1903	11.89	6.93		1928	10.76	6 95	11.54
1904	11.32	9.83		1929	10.91	7.38	12.85
1905	13.47	12.39		1930	10.69	11.31	13.36
1906	20.87	19.08	14.70	1931	8.50	8.66	12.80
1907	13.73	12.80	16.16	1932	12.63	9.40	15.40
1908	11.80	16.62	13.73	1933	8.11	8.60	8.82
1909	15.31	11.49	[2] 12.5	1934	8.07	6.80	7.62
1910	13.72	9.50	11.77	1935	10.42	9.51	10.95
1911	12.04	10.46	13.68	1936	12.60	11.44	13.60
1912	12.75	10.07	12.98	1937	[2] 12.60	9.97	11.04
1913	14.19	8.51	10.10	1938	12.23	15.20	14.38
1914	17.01	10.55	10 63	1939	11.41	8.83	10.30
1915	11.93	13.00	14.04				
				Normal	[3] 12.90	[3] 11.04	[3] 13.10

[1] Elevations above sea level: Parowan, 5,970 feet; Cedar City, 5,805 feet; Modena, 5,460 feet.
[2] Estimated by Geological Survey.
[3] For period 1906 to 1939, inclusive.

The precipitation at each station varies greatly from year to year, as shown in the above table. At Parowan the rainfall has ranged between 6.80 and 20.87 inches during the period of record, and at Modena between 5.09 and 19.08 inches. For the most part this variation is regional, but there also are some prominent local variations, as for instance in 1932, when the rainfall at Parowan was about normal, that at Cedar City more than 2 inches above normal, and that at Modena nearly 2 inches below normal.

The precipitation received as snow on the higher altitudes tributary to the adjacent valleys probably is an important factor in the amount of water available to recharge the ground water in the valleys. There are no records of the annual precipitation at these higher altitudes within the area covered by this report, and the only available information concerning precipitation there is obtained from snow surveys made on numerous courses throughout the State for the purpose of forecasting runoff available for irrigation. The records for three snow courses south and east of Cedar City are presented in the table below.

Snow cover near Cedar City, Utah [1]

[Measured in inches, April 1 of each year]

Date	Snow cover at —		
	Cedar Breaks 59 [2]	Co-op Flat 60 [3]	Webster Flat 61 [4]
1927	....	18.3	14.4
1928	....	15.4	12.0
1929	....	15.6	12.1
1930	....	11.8	9.6
1931	....	6.7	8.3
1932	....	22.7	28.7
1933	....	13.7	13.6
1934	....	7.4	8.5
1935	23.1	18.1	18.0
1936	24.3	16.8	18.7
1937	41.2	31.0	30.0
1938	29.1	24.2	27.6
1939	18.6	13.2	14.0
1940	15.2	10.9	11.0

[1] Records from Utah Cooperative Snow Surveys, in which the following State and Federal agencies cooperate: Utah State Agricultural Experiment Station, United States Weather Bureau, Utah State Engineer, United States Forest Service, and Division of Agricultural Engineering of the United States Soil Conservation Service.
[2] Altitude, 10,200 feet; location, sec. 12, 13, T. 37 S., R. 9 W.
[3] Altitude, 9,530 feet; location, sec. 18, T. 37 S., R. 10 W.
[4] Altitude, 9,200 feet; location, sec. 20, T. 37 S., R. 9 W.

The records of precipitation in Iron County are shown graphically in figure 1. In the upper diagram the average departure from normal precipitation has been obtained by averaging the annual departure from the normal precipitation at each of the Iron County stations, using the 1906–39 mean—13.10 inches at Cedar City, 12.90 inches at Parowan, and 11.04 inches at Modena. It is assumed that the resulting curve is more nearly representative of the conditions of precipitation throughout the area than is a curve based on the records from any one station.

The precipitation records are presented in another form on the lower half of figure 1. Curves showing the cumulative departure from normal precipitation may be especially valuable in discussions of ground-water conditions, because they portray especially the long-term deficiencies or excesses of precipitation, and because the storage in ground-water reservoirs, as in surface reservoirs, may well reflect these long-term deficiencies or excesses. In the graph on figure 1, periods of abnormal rainfall are indicated by a rising trend, and periods of subnormal precipitation by a declining trend. Records from Parowan prior to 1906 show that the cumulative departure below normal precipitation was about 14 inches from 1899 to 1904, inclusive. Each of the 6 years had less than normal precipitation, and the deficiency, as shown by other records, was Statewide.

During the years 1898 to 1904 and from 1928 to 1935 precipitation over the region was ordinarily less than normal. From 1905 to 1922, precipitation was generally above normal, except during 1910–14 and 1917–19, and during the years 1891–98, 1923–27, and 1936–39 the precipitation was approximately normal.

Precipitation is distributed rather evenly throughout the year, and this distribution is fairly consistent at the several stations. Commonly, less than 4 percent of the annual precipitation falls in June, the driest month, while 11 to 13 percent falls in each of the wettest months, usually August and March. During July and August rain commonly falls in the form of afternoon showers or cloudbursts, similar to those occurring in Arizona and New Mexico. Considered from the standpoint of the farmers

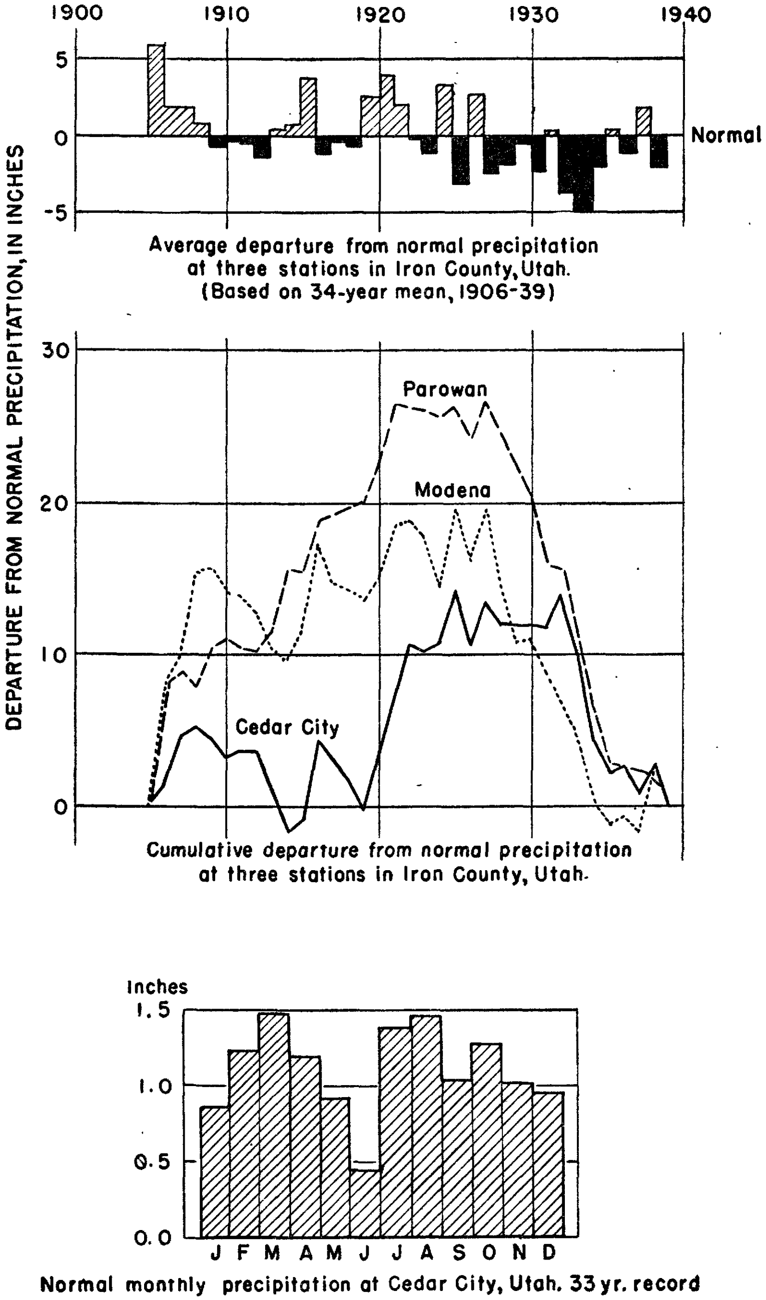

FIGURE 1.—Average and cumulative departure from normal yearly precipitation at three stations in Iron County, and normal monthly precipitation at Cedar City, Utah.

of the region, the seasonal distribution of rainfall is about as favorable as could be desired—about 50 percent falls during the 6 months from October to March, and a good proportion of this accumulates as snow on the higher parts of each watershed; only 20 percent falls during the months from April to June, the period of greatest runoff from melting snow; and 30 percent falls during the latter half of the irrigation season, when surface water supplies are lowest.

The growing season is ordinarily from about the first week in May to the first week in October, but killing frosts have been reported as late as July 3 and as early as September 5. Throughout the year the highest daily temperatures at Modena approximate those at Salt Lake City, but the average daily range at Modena is about 10° greater, and the nights are correspondingly cooler. At Modena the average wind velocity (10.3 miles an hour) is high, and the relative humidity during the day (17 to 27 percent in summer months) is low, so that opportunity for evaporation in the area probably is above average.

PHYSIOGRAPHY

GENERAL FEATURES

Southwestern Utah comprises parts of two physiographic sections as delimited by Fenneman:[5] The Great Basin of the Basin and Range province, and the Utah High Plateaus of the Colorado Plateau province. By far the greater part of Iron County is located in the Great Basin; Parowan and Cedar City Valleys are entirely within this section, and their eastern boundaries constitute the dividing line between the Great Basin and the High Plateaus to the east. The High Plateaus section, although it is beyond the limits of the ground-water areas considered here, includes the drainage basins of nearly all the perennial streams entering these valleys and is therefore of prime importance as a source of water for the valleys. The principal physiographic features of the area described in this report are shown in plate 2.

CEDAR CITY AND PAROWAN VALLEYS

The Great Basin includes a number of more or less parallel, isolated mountain ranges separated by basinlike intermontane areas, which are, characteristically, sites of tremendous aggradation. The streams issuing from canyons in the mountains become sluggish as they reach these intermontane areas, their waters disappear by evaporation or downwrad percolation, and the sediments which they carry are deposited to form extensive, gently sloping alluvial fans. Adjacent fans merge with each other to form broad, smooth, alluvial slopes, which everywhere surround the mountain ranges. The alluvial slopes of neighboring ranges extend toward each other, and the base of one may nearly touch the base of the other. In many valleys the central part consists of a nearly level plain, the lowest depressions of which may be occupied by swamps, lakes, or dry alkali flats. These intermontane areas thus become topographic basins in which alluvial and playa deposits of considerable depth are the dominant feature. Cedar City and Parowan Valleys are basins of this type. According to common usage in this region, a "valley" includes the entire area between two ranges, and the term is so used in the titles of Cedar City and Parowan Valleys. The areas of these valleys would be

[5] Fenneman, N. M., Physiographic divisions of the United States, 3d ed.: Assoc. Am. Geographers Annals, vol. 18, map, December 1928.

approximately coextensive with the area of Quaternary alluvial deposits. (See pl. 3.)

Cedar City Valley includes a peripheral area consisting of broad, moderately steep alluvial slopes, which are chiefly the work of the streams that enter the valley, and a central valley floor or bottom, which has a lower, more uniform gradient and which probably represents a grade established by the larger streams of the valley, especially Coal Creek. Two small lakes, Shurtz and Rush Lakes, are situated upon this valley floor, the plain surface of which is otherwise interrupted only by a few sand dunes and by small indistinct channels used only in time of flood. The altitude of the valley floor ranges from about 5,275 feet above sea level at the northern outlet of the valley to about 5,800 feet at Cedar City.

Parowan Valley likewise consists of a peripheral area of alluvial cones and fans and a comparatively flat valley floor. However, since relatively small amounts of rock waste were brought into the valley from the west, the alluvial slope on the east side comprises most of the valley, and Little Salt Lake, which occupies the lowest depression, lies close to the west border. The floor of Parowan Valley is somewhat higher than that of Cedar City Valley, ranging from about 5,690 feet at Little Salt Lake to more than 6,100 feet near the town of Summit.

HIGH PLATEAUS AND MOUNTAINS

The High Plateaus of Utah consist for the most part of nearly horizontal rock strata, which have been lifted to altitudes several thousand feet above the Great Basin. The boundary between the two provinces is commonly an escarpment or series of escarpments along which the rock strata may be inclined at steeper angles than is common throughout the main body of the High Plateaus section. Along the eastern edge of Parowan Valley there is a scarp which is continuous except where breached by the narrow canyons of the streams entering the valley. This scarp rises about 1,000 feet above the valley floor opposite the town of Paragonah, and becomes higher to the south. Between the towns of Parowan and Cedar City the High Plateau is more than 2,000 feet above the valleys, and the topography along its broken western edge is extremely rugged. South of Cedar City the western boundary is again a bold escarpment that rises more than 2,000 feet above the valley.

The High Plateaus comprise numerous structural blocks at different elevations, ordinarily with a gentle easterly slope. East of Cedar City Valley the Kolob Plateau reaches altitudes of more than 10,000 feet above sea level and slopes gently southeastward toward the Virgin River drainage basin. Northeast of that plateau is the higher Markagunt Plateau, which lies east of Parowan Valley and which culminates in Brian Head, altitude 11,315 feet above sea level, the highest point in Iron County.

Cedar City and Parowan Valleys are bounded on their north and west sides by mountain ranges and low hills of the Great Basin and are shut in at the north by low ridges and hills of volcanic origin. The two valleys are separated by the Black Mountains, occupying an area 5 or 6 miles wide at the north end of Cedar City Valley, with several peaks that rise more than 7,500 feet above sea level. The Red Hills, the portion of this range west of the town of Parowan, is about 3 miles wide and has a crest about 7,000 feet above sea level. Still farther south, opposite the settlement of Enoch in Cedar City Valley, this highland dwindles to a low ridge, which is separated from the end of the High Plateaus section by a belt of alluvial sediments less than a mile wide. This belt is continuous with that of the southern part of Parowan Valley, but it forms a bench standing about 250 feet above the level of Cedar City Valley. (See p. 34.)

The New Harmony and the Iron Mountains, whose peaks are as much as 8,000 feet above sea level, bound the southern part of Cedar City Valley on its west side, but these mountains continue only a short distance north of the settlement of Iron Springs, and a low ridge of volcanic rock known as the Sulphur Divide separates Cedar City Valley from the Escalante Valley in T. 34 S., R. 12 W. (See pl. 3.) Still farther north, for a distance of about 3 miles in T. 33 S., R. 12 W., these volcanic rocks appear only in scattered outcrops, and the west border of Cedar City Valley consists of alluvial materials whose western slope comprises a broad alluvial fan extending out into the Escalante Valley. These alluvial sediments appear to represent the accumulations of streams which flowed westward from Cedar City Valley into Escalante Valley, and the broad gap in the outcrop of the volcanic rocks in T. 33 S., R. 12 W., may thus represent an outlet for Cedar City Valley that antedates Twentymile Gap, described below.

From Cedar City southward the valley has two branches of quite unequal size—the east fork, for the most part less than a mile wide, extending southwestward for 7 or 8 miles, and the west and main branch, 4 to 7 miles wide, extending southward beyond the limit of the area. At its north end near Cedar City, the intervening upland rises about 300 feet above the surrounding alluvial plain. It extends southward with an average width of about 2 miles, except opposite Hamiltons Fort where Shurtz Creek has cut through the upland and formed a valley plain joining the two branches of the valley. The upland, which south of Hamiltons Fort is 400 to 500 feet above the adjacent alluvial material of the valley, extends southward to a point about 2 miles northeast of the village of Kanarraville, where it abuts against a salient of the west edge of the plateau.

Several hills and ridges in each valley are entirely surrounded by alluvial deposits. All are of small areal extent, and practically all lie close to the borders of the valleys; quite clearly they were once parts of the bordering ranges from which they recently have been separated by the enveloping sheet of alluvium.

DRAINAGE

Cedar City and Parowan Valleys do not constitute drainage ways in the sense ordinarily intended by the term "valley." Instead each includes several independent drainage systems whose general trend is northwesterly and therefore across the major northeastward-trending structural features. The several streams that drain the High Plateaus flow in narrow, deeply-incised canyons, and the intervening divides range from broad uplands to sharp ridges. Where these streams cut across Parowan and Cedar City Valleys they are separated by low inconspicuous divides, which are themselves the products of stream deposition. Mountains, ridges, and hills border both valleys on their west sides, and also are conspicuous within the limits of Cedar City Valley. The northwestward-trending streams of the region have either cut narrow channels across these obstacles or have developed devious courses around them.

Parowan Creek, which enters Parowan Valley at the town of Parowan, and all the streams entering the valley farther north, of which the largest are Red and Little Creeks, discharge naturally into Little Salt Lake. Winn Wash and ephemeral drains farther south enter an independent drainage basin in the southern end of Parowan Valley. Drainage from this independent basin is through Winn Gap, in the west wall of the valley that empties into Rush Lake in Cedar City Valley. The two drainage basins in Parowan Valley are separated by a low divide of alluvial materials, deposited chiefly by Summit Creek, and this stream might discharge naturally into either basin, depending on whether Summit Creek flowed over the northern or the southwestern part of its fan. The flow of all streams in Parowan Valley is ordinarily diverted near the mouths of the respective canyons for irrigation and stock watering; discharge down the natural channels occurs principally during periods of extraordinary runoff from melting snow or cloudbursts.

Coal Creek, the principal stream entering Cedar City Valley, has been a dominant factor in the development of the present drainage system in that valley. The creek has built a broad alluvial fan that extends entirely across the valley and abuts against the west border near Iron Springs. Thus the alluvial fan of Coal Creek forms the low divide between the drainage basin containing Shurtz Lake and the rest of Cedar City Valley, and Coal Creek by its own deposition appears to have originated the independent drainage basin that contains Shurtz Lake. The southwest part of the Coal Creek fan, served by the Woodbury Canal, drains toward Shurtz Lake; the northwest part of the fan slopes toward Iron Springs Gap and thence northwestward toward the Escalante Valley. The present natural channels of the creek, however, extend northward along the eastern half of the Coal Creek fan and along the fairly well graded floor of Cedar City Valley, itself a product principally of aggradation by the waters of Coal Creek, and thence toward the outlet known as Twentymile Gap (pl. 4, A), which opens into the Escalante Valley. In recent years the flow in these natural channels has not extended more than 6 or 8 miles north of Cedar City, even during floods.

Shurtz Creek, the next permanent stream south of Coal Creek, discharges during floods into Shurtz Lake. Queatchupah Creek and Leach Creek, which drain the New Harmony Mountains that border Cedar City Valley on the southwest, would also discharge naturally into this lake.

Kanarra Creek and other streams that enter Cedar City Valley south of Kanarraville are tributaries of Ash Creek, which drains southward into the Virgin River. The divide between these streams and those tributary to Shurtz Lake is quite inconspicuous and not readily ascertained without detailed topographic maps. The shape of the Kanarra Creek fan suggests that it may have been built when the stream was tributary to Shurtz Lake, and it is likely that Kanarra Creek and probably other streams farther south may once have drained northward toward Shurtz Lake and that their present inclusion in the Virgin River drainage basin is a result of recent piracy. Doubtless this piracy is still continuing, because of the much steeper gradient of Ash Creek, and a much larger part of Cedar City Valley may eventually be a part of the Virgin River drainage basin.

Rush Lake occupies the bottom of a relatively large interior drainage basin in the northern part of Cedar City Valley. It receives drainage from the hills that border the north end of that valley and from the south end of Parowan Valley through Winn Gap. Perhaps also some water drains from the Cedar City Valley floor, which slopes gently northward toward Rush Lake.

About a mile north of the settlement of Enoch a small playa receives the excess runoff from a portion of the range that separates Cedar City Valley from Parowan Valley. Another small interior drainage basin, Bolly Basin, is located in the foothills that form the west edge of the plateau about 2 miles east of Enoch, and similar features are found elsewhere in the region. Some of these small basins are described in more detail in discussion of the structural modifications which brought them about. (See p. 49.)

The several interior drainage basins that now comprise Cedar City Valley and Parowan Valley were formerly parts of an integrated drainage system that was tributary to the Escalante Valley and thence to the Sevier Desert. The present lake levels are only a very few feet below the point of outflow for each basin, and it is likely that outflow ceased in comparatively recent times because of gradual dessication in an increasingly arid climate. Thus, Little Salt Lake in Parowan Valley has reached a level about 12 feet higher than at present, as shown by an indistinct strand line, at which time the water would have been above the outlet to the valley known as Parowan Gap, and there would have been overflow through the gap into Cedar City Valley above Rush Lake. That lake also had a higher level and extended as far northward as the lower end of Parowan Gap, as indicated by a delta formed at the mouth of the small canyon just south of Parowan Gap. (See pl. 4, B.) The surface of the delta has an altitude of about 5,520 feet above sea level, which is about 130 feet above the present level of Rush Lake and 150 feet above the level at which water would overflow from Cedar City Valley into the Escalante Valley across the broad alluvial fan north of Sulphur Divide. (See p. 11.) This delta and minor shore features farther south are thus higher than the col which separates Cedar City Valley from the Escalante Valley, in which the Pleistocene Lake Bonneville is known to have reached a level not greater than 5,200 feet above sea level. They therefore indicate that structural adjustments have occurred since Rush Lake attained its highest stage. (See p. 64.) At the time of its maximum extent Rush Lake was doubtless high enough to cover a broad area in the northern part of Cedar City Valley and may well have overflowed into Escalante Valley.

Finally, there are indistinct strand lines, particularly on the west side, about 20 feet above the present level of Shurtz Lake. When this lake reached its highest stage, approximately 5,470 feet above sea level, it evidently overflowed to the north through Iron Springs Gap and discharged into the Escalante Valley.

In a climate humid enough to produce outflow from these three lakes, Coal Creek also undoubtedly had excess runoff, which discharged either northward into the predecessor of Rush Lake or northwestward through Iron Springs Gap, in either case draining into the Escalante Valley.

Along the western border of Cedar City Valley, just east of the outlet through Iron Springs Gap, and covering an area considerably less than a square mile, is a somewhat dissected gravel terrace, shown in plate 3 where it appears in light color in the center foreground. Along its western edge this terrace rises about 50 feet above the adjacent valley floor, while its eastern edge is only 4 or 5 feet higher than the valley floor. Thus the surface of the gravel terrace has a definite easterly slope. In its composition as well as in its surface slope this gravel appears to be similar to the eastward-sloping plain of materials that borders Cedar City Valley both north and south of Iron Springs Gap. The terrace is believed to be a remnant of a once-continuous alluvial plain that bordered the valley on its west side. The development of the outlet through Iron Springs Gap involved the dissection of some of these alluvial deposits, and this gravel now remains as a remnant, isolated from the rest of the alluvial plain.

The lowest point in the divide that Coal Creek has constructed across the valley about 3 miles northeast of this terrace is about 30 feet above the valley floor adjacent to the terrace. If Shurtz Lake today were to rise because of greatly increased inflow, the outlet at the north end of Cedar City Valley would be closed to it, and it would overflow instead through Iron Springs Gap. Presumably, during the time of the ancient larger predecessors of Little Salt Lake and Rush Lake, the alluvial fan of Coal Creek similarly prevented outflow of Shurtz Lake through the north end of the valley, and hence the overflow from this lake developed the outlet through Iron Springs Gap.

According to the reconnaissance maps of the Powell and Wheeler surveys [6] the drainage tributary to Twentymile and Iron Springs gaps is about 1,100 square miles, which would include all the area of the present drainage basins in Cedar City and Parowan Valleys. The drainage basin of Parowan Valley alone has about half this area. This drainage pattern tributary to the Escalante Valley would in all likelihood be reestablished during a period of more humid climate.

GEOLOGY

PREVIOUS GEOLOGIC INVESTIGATIONS

Descriptions of the geology of southwestern Utah, particularly by the geologists of the Powell and Wheeler surveys, appeared as early as 1875. Most of the publications of the 19th century were the product of reconnaissances covering wide areas, and the maps and descriptions were necessarily quite generalized. Especially noteworthy among those early reports were Dutton's report on the High Plateaus, for descriptions of regional physiography and stratigraphy; and Gilbert's monograph on Lake Bonneville, for Pleistocene history.

Detailed geologic studies of the Hurricane fault were made in 1903 by Huntington and Goldthwait. In 1906 Leith and Harder completed a detailed investigation of the Iron Springs district, which lies along the west side of Cedar City Valley. During 1906 and 1907 Lee and Richardson made a reconnaissance of the coal fields of southwestern Utah. In 1920 a geologic map of the State of Utah was compiled by Butler, based upon published and unpublished data available at the time.

Since 1920 very little geologic work has been done within the area covered by this report. In adjacent areas there has been considerable study of the stratigraphy, particularly by Reeside, Bassler, Baker, Dane, and Gregory; and summaries have been published by Baker,

[6] Beaver, Kanab, and St. George sheets, Utah: U. S. Geol. Survey topographic atlas, 1885–1891.

Dane, and Reeside of the present status of correlations of Permian and Jurassic rocks over a wide area.

The geologic structure of the St. George Basin, in the southwest corner of Utah, has been the subject of reports by Reeside and Bassler and, recently, Dobbin. Gardner in 1941 was completing a more detailed study of the area, having already prepared a preliminary report on the structure along the Hurricane fault zone.

The following list includes the more important geologic reports on the eastern part of Iron County and several publications relating to adjacent regions.

ANNOTATED LIST OF GEOLOGIC REPORTS

1875

Gilbert, G. K., Report on the geology of portions of Nevada, Utah, California, and Arizona, examined in the years 1871 and 1872, U. S. Geog. and Geol. Surveys W. 100th Mer. Rept., vol. 3, pp. 17-187. Reconnaissance of an area covering several States.

Howell, E. E., Report on the geology of portions of Utah, Nevada, Arizona, and New Mexico, examined in 1872-73, U. S. Geog. and Geol. Surveys W. 100th Mer. Rept., vol. 3, pp. 227-301. Reconnaissance of basin ranges and high plateaus.

1879

Powell, J. W., Report on the lands of the arid region of the United States, with a more detailed account of the lands of Utah, U. S. Geog. and Geol. Survey Rocky Mtn. Region Rept., 195 pp., especially p. 149. Reconnaissance survey of the State.

1880

Dutton, C. E., Report on the geology of the high plateaus of Utah, U. S. Geog. and Geol. Survey Rocky Mtn. Region Rept., 307 pp., especially pp. 188-210. Comprehensive report on regional geology and physiography.

1882

Dutton, C. E., Tertiary history of the Grand Canyon district: U. S. Geol. Survey Mon. 2, 264 pp., especially pp. 112-115. Reconnaissance chiefly of area to the south, but with reference to southern Utah.

1890

Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Mon. 1, 438 pp., especially pp. 362-369. Pleistocene history of a large portion of western Utah, including Escalante Valley, which lies just west and north of Cedar City Valley.

1903

Davis, W. M., An excursion to the plateau province of Utah and Arizona: Harvard Coll. Mus. Comp. Zoology Bull. 42, pp. 1-50. Description of physiography developed by erosion along Sevier and Hurricane faults.

Huntington, Ellsworth, and Goldthwait, J. W., The Hurricane fault in southwestern Utah, Jour. Geology, vol. 11, pp. 46-63. Preliminary report describing sequence of events in Toquerville district.

1904

Huntington, Ellsworth, and Goldthwait, J. W., The Hurricane fault in the Toquerville district, Utah, Harvard Coll. Mus. Comp. Zoology Bull. 42, pp. 199-259. Structual history of area along Hurricane fault.

1907

Lee, W. T., The Iron County coal field, Utah: in U. S. Geol. Survey Bull. 316-E, pp. 359-375. Reconnaissance along east border of Cedar City Valley.

1908

Leith, C. K., and Harder, E. C., The iron ores of the Iron Springs district, southern Utah: U. S. Geol. Survey Bull. 338. Detailed geologic investigation along west border of Cedar City Valley.

1909

Richardson, G. B., The Harmony, Colob, and Kanab coal fields, southern Utah: in U. S. Geol. Survey Bull. 341–C, pp. 379–400. Reconnaissance covering area south and east from Cedar City Valley.

1917

Gregory, H. E., Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93. Reconnaissance of plateau country in southeastern Utah and adjacent States.

1920

Butler, B. S., and others, The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, 672 pp. (especially bibliography, pp. 38–57; geologic map of Utah, pl. 4). Compilation of results of field work by authors and others throughout mining districts of the State.

Stone, R. W., and others, Gypsum deposits of the United States: U. S. Geol. Survey Bull. 697, pp. 270–271. Compilation includes data on deposits near Cedar City.

1921

Reeside, J. B., Jr., and Bassler, Harvey, Phases of the Carboniferous and Triassic of southwestern Utah: abstract in Washington Acad. Sci. Jour. vol. 11, pp. 445–446. Examples of lateral variations in stratigraphy.

Bassler, Harvey, and Reeside, J. B., Jr., Oil prospects in Washington County, Utah: U. S. Geol. Survey Bull. 726–C, pp. 87–107. Reconnaissance over an area 20 to 40 miles south and southwest of Cedar City Valley.

1922

Reeside, J. B., Jr., and Bassler, Harvey, Stratigraphic sections in southwestern Utah and northwestern Arizona: U. S. Geol. Survey Prof. Paper 129–D, pp. 53–77. Stratigraphic sections in Utah 20 to 40 miles south and southwest of Cedar City Valley.

1926

MacVichie, Duncan, Iron fields of the Iron Springs and Pinto mining districts, Iron County, Utah: Am. Inst. Min. Eng. Trans. vol. 74, pp. 163–173. Developments since publication of Leith and Harder's report.

1928

Gilluly, James, and Reeside, J. B., Jr., Sedimentary rocks of the San Rafael Swell and some adjacent districts in eastern Utah: U. S. Geol. Survey Prof. Paper 150–D, pp. 61–110.

1931

Gregory, H. E., and Moore, R. C., The Kaiparowits region, Utah and Arizona: U. S. Geol. Survey Prof. Paper 164, p. 69. Reconnaissance of an area 20 to 100 miles east and southeast of Parowan Valley.

1933

Gregory, H. E., Colorado Plateau region: Internat. Geol. Cong. Guidebook 18, pp. 19–20.

1936

Baker, A. A., Dane, C. H., and Reeside, J. B., Jr., Correlation of the Jurassic formations of parts of Utah, Arizona, New Mexico, and Colorado: U. S. Geol. Survey Prof. Paper 183.

Gregory, H. E., and Evans, R. T., Zion National Park: U. S. Geol. Survey topographic map of Zion National Park, Utah. Descriptive text on back of map of an area 20 to 40 miles south of Cedar City.

Hewett, D. F., and others, Mineral resources of the region around Boulder Dam: U. S. Geol. Survey Bull. 871, 197 pp., especially pp. 75–76, 80, 182. An appraisal of resources within a 200-mile radius of Boulder Dam, near Las Vegas, Nev.

1939

Bartram, John G., Summary of Rocky Mountain Geology: Am. Assoc. Petroleum Geologists Bull. vol. 23, pp. 1131–52. Historical summary of wide area.

Callaghan, Eugene, Volcanic sequence in the Marysvale region in southwest-central Utah: Am. Geophys. Union Trans., Twentieth Annual Meeting, pp. 438–452. Description of the Tertiary volcanic sequence in an area which lies 25 to 60 miles northeast of Parowan Valley.

Dobbin, C. E., Geologic structure of the St. George district, Washington County, Utah: Am. Assoc. Petroleum Geologists Bull. vol. 23, pp. 121–144. Detailed reconnaissance of an area which lies 10 to 50 miles south and southwest of Cedar City Valley.

1941

Gardner, Louis S., The Hurricane fault in southwestern Utah and northwestern Arizona: Am. Jour. Sci. vol. 239, pp. 241-260. Preliminary paper resulting from a detailed study of an area south of Cedar City Valley.

Wells, F. G., Iron ore deposits of the Bull Valley district, Washington County, Utah: U. S. Dept. Interior Information Service Press Notice 152284, 4 pp. and geologic map, July 29, 1941. Economic geology of a small area 40 miles southwest of Cedar City.

PURPOSE AND SCOPE OF GEOLOGIC WORK

The geologic work during the present investigation comprised especially the studies that were essential to the understanding and interpretation of problems relating to ground water. Practically all the ground water now used in Cedar City and Parowan Valleys is derived from the unconsolidated sediments that make up the alluvial basins. The consolidated rocks making up the mountain ranges and plateaus form the relatively impervious boundaries of the ground-water reservoirs. The investigation therefore involved a detailed study of the unconsolidated deposits and a reconnaissance of the consolidated rocks, considering especially the water-bearing properties. Because the geologic structure of southwestern Utah has undergone modifications during comparatively recent times, particularly by faulting, and because the alluvial sediments have been involved in this faulting, with considerable effect upon groundwater circulation, the areal geologic mapping was extended beyond the borders of each valley sufficiently to delineate the geologic structure. Thus the geologic map (pl. 3) covers most of the eastern half of Iron County.

The geologic map is based upon township plats of the United States General Land Office and upon aerial-survey mosaics of the Soil Conservation Service that were made available after the completion of field work. Stream courses and culture, as shown, are obtained from these mosaics. Geologic mapping was accomplished by speedometer-and-compass or pacing-and-compass traverses, using the unmodified township plats as a base. In the Iron Springs district no geologic work was done during the investigation, and the geologic map for this area is from Leith and Harder, [7] with some modifications, chiefly of the boundary of the Quaternary alluvium.

Gardner has recently completed a detailed geologic investigation of the St. George Basin, and has extended his geologic mapping along the west front of the plateau as far north as Cedar City. For this area south of Cedar City, therefore, the geologic formations are not shown on plate 3, although some of the principal structural features are shown. Quite likely these will be modified by Gardner's more detailed study. The description of the stratigraphic sequence in this part of the area is thus based on a rather small amount of geologic work, and is presented only as a basis for the structural interpretations which follow.

STRATIGRAPHY

GENERAL RELATIONS

The oldest rocks exposed in eastern Iron County are of Carboniferous age. The geologic history of this region prior to the deposition of these rocks is probably similar to that in Washington County, where the section includes rocks of pre-Cambrian age. The history of that area

[7] Leith, C. K., and Harder, E. C., The iron ores of the Iron Springs district, southern Utah: U. S. Geol Survey Bull. 338, pl. 2, 1908.

has been outlined by Dobbin.[8] The Carboniferous period in Iron County is represented by marine limestones, indicating an invasion of the area by a marine sea. The end of the Paleozoic era was marked by a moderate emergence of the land and some erosion of the Permian Kaibab limestone.

During the Triassic period the area received sediments of continental origin, except for a short resubmergence during the early part of the period while the marine Virgin limestone member of the Moenkopi formation was being deposited. The deposition of the Triassic succession was interrupted several times by erosion, as is shown by minor unconformities in the sequence, and the deposition of the Navajo sandstone, probably during the Jurassic period, followed that of the Upper Triassic Chinle formation without apparent interruption. During Upper Triassic time the area was resubmerged while the Carmel formation of the San Rafael group was being laid down. It again emerged, and gypsum and other sediments of continental origin, equivalent to the upper part of the San Rafael group, were deposited. After a break in sedimentation the area was submerged for the last time during the Upper Cretaceous epoch, and marine sandstones, with a lesser amount of shale and limestone, were deposited. Sometime after the Cretaceous deposition the area was raised, and the sediments were locally folded and faulted.

The orogenic movements that followed Upper Cretaceous sedimentation may have been completed during the Cretaceous or they may have extended into the Tertiary period, after which the lacustrine Wasatch formation, of Eocene age, was deposited over the area. Acidic lava and ejectamenta were then distributed over a large part of southern Utah by volcanic eruptions on a grand scale, which probably occurred during the latter part of the Tertiary period. Later, probably during the Quaternary period, basalt was erupted, but on a less extensive scale than during the Tertiary eruptions, at least in Iron County. Ever since the conclusion of Wasatch deposition, probably throughout the periods of volcanic disturbance as well as during the quiescent intervals, the area has had an arid cycle of highland erosion and lowland deposition, and the principal valleys are now filled to unknown depths by torrential and playa deposits accumulated during this long interval of geologic time. Intermittently, also, during this time, the area has been subjected to faulting and other crustal disturbances, which are discussed in more detail in the chapter on geologic structure. (See p. 62.)

In their relation to ground water, the rocks of the area might logically be grouped in two divisions: the consolidated rocks, including sediments of Permian to Eocene age, and effusives of Tertiary and Quaternary age—all of minor importance as sources of ground water; and the unconsolidated sediments, which are the prime source of water. Instead of the traditional separation into groups of sedimentary and igneous rocks, the following discussion of the stratigraphy presents all the rocks, including the Tertiary and Quaternary effusives, in sequence according to age; thus, all the consolidated rocks are considered first, prior to the discussion of the unconsolidated deposits.

The stratigraphy of the eastern part of Iron County is summarized in the accompanying chart:

[8] Dobbin, C. E., Geologic structure of the St. George district, Washington County, Utah: Am. Assoc. Petroleum Geologists Bull. vol. 23, pp. 121-122, 1939.

Stratigraphy of the eastern part of Iron County, Utah

[Generalized section [1]]

Geologic age: System	Geologic age: Series	Group or formation and symbol on plate 3	Thickness (feet)	General character	Water-bearing properties
Quaternary.	Pleistocene and Recent.	Alluvium (Qal)	0 - 960+	Boulders, gravel, sand, and silt in present stream channels and beneath alluvial fans and flood plains.	Sand and coarser materials highly permeable; constitute principal source of ground water in both valleys.
		Landslide breccia (Qlb)		Breccia and rubble on slopes, derived from rocks on adjacent precipitous escarpments by landslides.	Impervious.
		Dune sand (Qds)	0 - 30	Sand dunes, chiefly on the floors of the valleys, especially along the margins of ancient or modern lakes.	Permeable, but thin and unimportant as a source of ground water.
		Lake deposits (Qld)	0 - 50	Clay, silt, sand, and chemical deposits on playas; also lacustrine and fluviatile gravel, sand, and silt located above present lake levels and deposited in bodies of water believed to be contemporaneous with Lake Bonneville.	Includes some permeable material, but present lake flats are relatively impervious.
	Pleistocene (?).	Fanglomerate (Qf)	0 - 500+	Water-worn cobbles, gravel, and sand on upland plains and ridges well above present sites of alluviation.	Comparable to Qal, but may be cut off by faulting from principal sources of ground water.
?	?	Basalt (QTb)	0 - 800	Basalt in rather thin flows, some probably as young as late Pleistocene, some perhaps late Pliocene in age.	Moderately permeable scoriaceous material and many fractures, which are sources of several springs.
Tertiary.	Pliocene (?). ? Miocene (?).	Unconformity. Acidic volcanic rocks (Tv)	1,700-2,500	Rhyolite and latite flows and associated tuffs and breccias. At the base, as much as 300 feet of stratified tuff and volcanic ash.	Pyroclastics generally impervious; flows commonly dense with some ground water in fractures, which gives rise to some springs.
		Intrusive andesite (Ta)	1,600+	Porphyritic biotite andesite intruded in the form of laccoliths into Paleozoic and Mesozoic sediments.	Comparable to flows of Tv.
	Eocene.	Unconformity. Wasatch formation (Tw)	0 - 1,000	Pink, white, and variegated shale, calcareous sandstone and limestone, with generally a coarse, well-cemented basal conglomerate as much as 500 feet thick.	Basal conglomerate presumably permeable where not too well cemented; rest of formation relatively impervious.
Cretaceous.	Upper Cretaceous.	Unconformity. Undifferentiated (Ku)	2,700±	Brown and yellow sandstone in irregular medium to massive beds; some coal beds as much as 9 feet thick; in lower part a greenish-gray soft shale more than 400 feet thick. (Probably equivalent of Tropic shale.)	Many permeable zones, particularly at coal horizons but also in coarser sandstone, which are a major source of springs in the area.
Jurassic.	Upper Jurassic.	Unconformity. San Rafael group: Undifferentiated (Jsr)	800±	Reddish-brown sandstone and shale in alternating beds; white gypsum in massive beds (may represent Curtis formation); red-brown sandstone and shale (resembles Entrada sandstone); greenish-gray fissile limestone and shale (equivalent to the Carmel formation).	Generally impervious. Formation yields water of very poor quality.
Jurassic (?).		Glen Canyon group: Navajo sandstone (Jn).	1,100±	Cross-bedded medium sandstone in massive beds; dominantly orange red, but locally white in upper part, sometimes yellow or buff.	Moderately permeable sandstone, giving rise to several springs along fractures.
Triassic.	Upper Triassic.	Chinle formation (Ŧc)	1,900±	Vermilion, pink, white, and purple sandstone; dark red, pink, and variegated calcareous shale, some shaly sandstone in upper part.	Generally impervious, but with zones of presumably permeable sandstone.
		Shinarump conglomerate (Ŧs)	0 - 100	White to greenish-gray coarse cross-bedded sandstone in massive beds; conglomeratic in part, with pebbles up to 2 inches in diameter.	Generally impervious except along fractures.
	Lower Triassic.	Unconformity. Moenkopi formation (Ŧm).	1,200±	Chocolate-brown to gray sandy shale, some thin-bedded hard limestone in lower part.	Impervious.
Carboniferous	Permian.	Unconformity. Kaibab limestone (Ck)	900±	Yellowish massive limestone, somewhat dolomitic.	Yields no water in Cedar City area.

[1] Dotted lines are used to separate formations that are considered to be contemporaneous, at least in part.

CARBONIFEROUS SYSTEM

PERMIAN SERIES

KAIBAB LIMESTONE

The Kaibab limestone, of Permian age, crops out along the base of the Kolob Plateau in the southern part of Cedar City Valley. It underlies the Moenkopi formation of Triassic age with slight disconformity, indicating some erosion of the upper surface of the Kaibab limestone. The lower part of the Kaibab limestone is not exposed in the area, having been displaced by a fault that extends along the base of the plateau. About 10 miles south of the area mapped, however, Dobbin [9] shows the Kaibab to be underlain by a pale yellow sandstone of Permian age, and gives the thickness of the Kaibab limestone in Washington County as roughly 900 feet.

The Kaibab limestone in the Cedar City area is a light gray to buff massive limestone, ordinarily finely crystalline and nonfossiliferous. It is far more resistant to erosion than the overlying shales of the Moenkopi, and forms a low ridge along the edge of the valley, east of which the Moenkopi shales have been extensively eroded to form badlands. The Kaibab yields no water in the Cedar City area, but water moving as underflow down some of the small canyons south of Cedar City is forced to the surface where those canyons cross the outcrop of that limestone.

TRIASSIC SYSTEM

Rocks of the Triassic system are exposed only along the western base of the Kolob Plateau from Cedar City southward. Throughout this outcrop belt the formations have been folded, and all beds now dip at high angles and are overturned in places. Because of faulting, certain beds are repeated and others are no doubt missing, and the determination of the stratigraphic sequence and of the thickness of the formations therefore is a complex problem.

The Triassic system in this area includes the Lower Triassic Moenkopi formation, the Shinarump conglomerate, and the Chinle formation of Upper Triassic age.

LOWER TRIASSIC SERIES

MOENKOPI FORMATION

The Moenkopi formation comprises a thick series of sandy shales which are dominantly a chocolate brown, with a lesser amount of light-gray shale and, in the lower part, thin-bedded gray limestone. The formation rests unconformably upon the Kaibab limestone in the southernmost part of the area; from Shurtz Creek northward to Cedar City, however, the Kaibab is absent, and the Moenkopi forms the base of the plateau.

Some fossils were collected from a gray limestone, probably the Virgin limestone member, of the Moenkopi formation, near the base of the Kolob Plateau in the SE¼NW¼ sec. 25, T. 37 S., R. 12 W. These fossils were examined by J. B. Reeside, Jr., who made the following identifications:

Isocrinus ? sp.
Pugnoides cf. P. triassicus Girty.
Terebratula ? sp.
Pelecypoda, not determined.
Gastropoda, not determined.

The upper part of the Moenkopi formation (Tr m) is exposed at the mouth of Coal Creek Canyon, and is described with other Triassic and

[9] Dobbin, C. E., Geology of the St. George district, Washington County, Utah: Am. Assoc. Petroleum Geologists Bull. vol. 23, pp. 124-126, 1939.

Jurassic rocks in the following section, computed from a traverse across beds dipping 42° to 70° in an easterly direction. In this section the upper 670 feet of the Moenkopi and the entire thickness of the overlying Shinarump conglomerate have been repeated by a fault that follows the strike of the beds. (See p. 61.)

Section in lower part of Coal Creek Canyon, from NE¼ sec. 14, T. 36 S., R. 10 W., to NW¼ sec. 18, T. 36 S., R. 9 W.

	Feet
Jurassic system.	
San Rafael group.	
Equivalent of Carmel formation.	
32. Limestone, dark gray, dense, fissile, hard, forms ledge.	
Glen Canyon group.	
Navajo sandstone.	
31. Medium sandstone, vermilion, even-grained, cross-bedded, massive, hard; forms ridge	1,100
Triassic system.	
Chinle formation.	
30. Medium sandstone, pink and white, in thin beds, alternating with darker red shale in beds 2 inches to 1 foot thick	205
29. Medium sandstone, pink, massive; forms ledge	5
28. Sandstone, shaly, dark red, weak, covered in part; forms valley	215
27. Medium sandstone, pink, banded, cross-bedded, resistant; forms ledge	230
26. Medium sandstone, vermilion, even-grained, cross-bedded, massive, hard, resembling number 31; a thin bed of darker red shaly sandstone near the middle; forms ridge crest	115
25. Shale, dark red to purple, and sandstone, banded, pink and white, in alternating beds; mostly covered by talus from number 26	420
24. Sandstone, pink, massive, hard; forms low hogback	25
23. Sandstone, shaly, purplish-pink, thin-bedded; mostly covered	35
22. Sandstone, pink, massive, hard, with beds of dark red shale 2 inches to 4 feet thick; shale beds more numerous toward base	165
21. Medium sandstone, vermilion, massive	10
20. Shale, dark red, in beds as much as 5 feet thick, alternating with pink sandstone in beds 6 inches to 3 feet thick	200
19. Medium sandstone, vermilion, massive, forms hogback	40
18. Shale, pink to vermilion	30
17. Shale, gray	10
16. Shale, purple to maroon	225
15. Shale, light greenish-gray	20
Total Chinle formation	1,950
Shinarump conglomerate.	
14. Coarse sandstone, white to greenish, cross-bedded, massive; forms ridge	25
13. Conglomerate, sandy, greenish-white, pebbles as large as ¼-inch diameter	20
Total Shinarump conglomerate	45
Moenkopi formation.	
Upper member.	
12. Shale, sandy, chocolate-brown upon weathering, purplish on fresh exposures	300
Schnabkaib shale member.	
11. Shale, predominantly gray, some brown beds, gypsiferous	310
Middle member.	
10. Shale, dark red to purple	60
Partial Moenkopi formation	670

Fault contact.	
Shinarump conglomerate.	
9. Coarse sandstone, conglomerate, white to greenish, cross-bedded, with pebbles to ¼-inch in diameter....	75
Moenkopi formation.	
Upper member.	
8. Shale, sandy, chocolate brown (equivalent to member 12)........	255
Schnabkaib shale member.	
7. Shale, light gray, few brown beds, gypsiferous (equivalent to member 11)........	320
Middle member.	
6. Shale, chocolate brown, few gray beds (equivalent to member 10 in part)........	125
Virgin limestone member.	
5. Limestone, gray, in beds 2 to 8 inches thick, alternating with thin beds of green-gray gypsiferous shale.......	30
4. Shale, sandy, red-brown........	66
3. Limestone, sandy, light gray, weathering buff, crystalline, massive beds; some beds of brown to gray shale and sandstone, soft, easily eroded........	34
2. Shale, predominantly gray, some chocolate brown.....	40
1. Limestone, gray, in thin to massive beds........	20
Partial Moenkopi formation........	830
Section abuts against Quaternary alluvium of the valley floor.	

In the above section the members of the Moenkopi formation are believed to correlate with those described by Reeside and Bassler [10] in their classification of geologic formations in southwestern Utah. No attempt was made to differentiate the individual members of the Moenkopi formation in the areal geologic mapping. (See pl. 3.) Throughout their area Reeside and Bassler found the Moenkopi to range from 1,775 to 2,650 feet in thickness. The individual members of the formation in the Coal Creek section are generally somewhat thinner than those in the sections measured by Reeside and Bassler. Assuming that the lowest member of the section is the base of the Virgin limestone, and estimating approximately 370 feet thickness for the missing lower shale member, the total thickness of the Moenkopi formation would be about 1,200 feet. The formation was once considered to be of Permian age but has more recently been accepted as Lower Triassic in age. [11] The Moenkopi yields no water in the Cedar City area. The greater part of the formation is practically impervious, and it is likely that any water encountered in the thin sandy zones would be of poor quality because of the gypsum content of the formation.

UPPER TRIASSIC SERIES

SHINARUMP CONGLOMERATE

The Shinarump conglomerate in most exposures in this area is a coarse cross-bedded gray sandstone made up of a fairly well-cemented clear quartz sand with a few pebbles. In most outcrops these pebbles do not exceed one-fourth inch in diameter, but in certain exposures they are as large as 2 inches. Locally the middle part of the formation is a shaly sandstone. Fossil wood, reported by Gregory [12] to be characteristic of the formation in many localities, was found in a few exposures. In Iron County the Shinarump ranges up to 100 feet in thickness.

The Shinarump conglomerate rests disconformably upon the Moenkopi

[10] Reeside, J. B., Jr., and Bassler, Harvey, Stratigraphic sections in southwestern Utah and northwestern Arizona: U. S. Geol. Survey Prof. Paper 129-D, p. 55, 1922.

[11] Reeside, J. B. Jr., and Bassler, Harvey, op. cit. pp. 67-68.

[12] Gregory, H. E., The Shinarump conglomerate: Am. Jour. Sci. 4th ser., vol. 35, pp. 424-438, 1913.

formation, but there is no noticeable break between it and the overlying Chinle formation. The Shinarump is in places harder and more resistant to erosion than the soft shales and sandstones that lie above and below it, and hence it forms discontinuous hogbacks throughout its belt of outcrop along the edge of the plateau. Locally, however, it is quite thin and no more resistant than adjacent beds of the Moenkopi and Chinle formations, so that its outcrop forms no hogback and on steep slopes may be entirely covered by talus from higher outcrops. In many places the outcrop of the Shinarump has been repeated by strike faulting, and appears in two or, locally, three more or less parallel hogbacks one-eighth to one-quarter of a mile apart.

The characteristics of the Shinarump conglomerate in Iron County appear to be persistent over an extensive area. Gregory and Moore [13] note that in New Mexico, Arizona, Utah, and Nevada the exposures of the Shinarump conglomerate are remarkably alike; the beds exhibit the same range in thickness, texture, and composition, and at nearly all places form resistant benches between series of friable shales. The age of the Shinarump conglomerate is determined chiefly by its stratigraphic position between the Lower Triassic Moenkopi formation and the Upper Triassic Chinle formation.

The Shinarump conglomerate yields no appreciable amount of water in the Cedar City area. Although the sediments are well sorted and of fairly uniform texture, the porosity of the formation is believed to be low, particularly in the more resistant beds, because of rather thorough cementation.

CHINLE FORMATION

The Chinle formation comprises a thick series of brightly colored, dominantly red, sandstones and shales, which lie conformably upon the Shinarump conglomerate. This formation commonly forms the lower part of the "Vermilion Cliffs" in southwestern Utah. Fossil wood is common in the lower part of the formation, and has formed the Petrified Forest in northern Arizona, where it is especially plentiful.

The Chinle formation is exposed in Coal Creek Canyon, and appears in the section on page 20. The shale beds at the base (beds 15 to 18 in the section, aggregating 285 feet in thickness) were observed in other canyons farther south, and may be persistent over a larger area in southwestern Utah, for Reeside and Bassler in their section 3 miles north of Virgin City [14] record a thickness of 260 feet of "variegated 'gumbo' clay shale." The upper limit of the Chinle formation is taken arbitrarily as the top of the uppermost shaly beds, member 30 in the Coal Creek Canyon section. The measured thickness of the formation in Coal Creek Canyon is 1,950 feet.

Much of this formation consists of shales and "marls" of low permeability, but it also includes beds of rather well-sorted sandstone that might well contain water of good quality.

JURASSIC (?) SYSTEM

GLEN CANYON GROUP

The Glen Canyon group, as defined by Gregory and Moore, [15] includes the Wingate sandstone, the Kayenta (formerly the Todilto) formation, and the Navajo sandstone. Of these only the Navajo appears to be

[13] Gregory, H. E., and Moore, R. C., The Kaiparowits region, a geographic and geologic reconnaissance of parts of Utah and Arizona: U. S. Geol. Survey Prof. Paper 164, pp. 52–53, 1931.

[14] Reeside, J. B., Jr., and Bassler, Harvey, op. cit., p. 73.

[15] Gregory, H. E., and Moore, R. C., op. cit., pp. 61–62, 1931.

present in Iron County. According to Gregory,[16] the Wingate sandstone is thickest in the vicinity of the San Rafael Swell in southeastern Utah, and extends westward as far as Zion National Park in south-central Utah. The Kayenta formation likewise is reported[17] to attain its maximum thickness near the San Rafael Swell and to thin to the southwest; it is absent in the St. George Basin,[18] and its presence in Zion Canyon[19] is questioned.

Although there are no strata in Iron County identifiable as Wingate sandstone or Kayenta formation, neither is there any perceptible stratigraphic break between the beds of the Triassic Chinle formation and those of the overlying Navajo sandstone of the Glen Canyon group. Between the shaly sandstones and sandy shales that are typical of the Chinle formation and the massive beds that are clearly identifiable as Navajo sandstone, there is a transition zone several hundred feet thick which might doubtfully be included in either formation. This transition zone, represented in the Coal Creek Canyon section by beds 26 to 30, is here assigned to the Chinle formation. Although the lower strata (bed 26 and much of bed 27 in Coal Creek Canyon) are quite similar in lithology to the typical Navajo sandstone, the intervening shaly beds are not acceptable as part of that formation, which is a well-defined lithologic unit. As identified in Coal Creek Caynon, the Chinle formation is somewhat thicker, and the Navajo sandstone thinner, than in other sections in southern Utah.[20]

The strata identified as Chinle formation and Navajo sandstone in this and other sections in southwestern Utah are probably not closely equivalent in age to the formations so named farther east. The apparent absence of a stratigraphic break in southwestern Utah suggests that deposition may have been continuous from one formation to the other, and hence these formations as mapped may represent time intervals considerably greater than the time required for the deposition of the Chinle formation and of the Navajo sandstone farther east, where the Wingate sandstone and Kayenta formation are represented. Whether the Chinle deposition continued somewhat longer in this area than farther east, or the Navajo sedimentation began earlier, or both, is a regional problem that is not answered here.

NAVAJO SANDSTONE

The Navajo sandstone is predominantly a cross-bedded medium sandstone, in massive beds that are resistant to erosion and hence form prominent hogbacks or ridges in the area covered by this report. It is exposed along the western edge of the Kolob Plateau from Cedar City southward, where it appears in sequence east of the outcrops of the Chinle formation. It is here a brilliant orange red throughout its entire thickness; near the south edge of the area, however, the upper part is composed of a variable thickness of white cross-bedded sandstone similar to the upper part of the Navajo sandstone in Zion Canyon. The Navajo sandstone also crops out in secs. 1 and 12, T. 37 S., R. 12 W., along the western edge of the upland area that divides Cedar City Valley south of Hamiltons

[16] Idem, p. 62, and personal communication.

[17] Baker, A. A., Dane, C. H., and Reeside, J. B., Jr., Correlation of the Jurassic formations of parts of Utah, Arizona, New Mexico, and Colorado: U. S. Geol. Survey Prof. Paper 183, p. 32, 1936.

[18] Dobbin, C. E., Geology of the St. George district, Washington County, Utah: Am. Assoc. Petroleum Geologists Bull., vol. 23, pp. 121-144, 1939.

[19] Gregory, H. E., and Evans, R. T., Zion National Park: U. S. Geol. Survey topographic map, text on back, 1936. Baker, A. A., Dane, C. H., and Reeside, J. B., Jr., op. cit. p. 32.

[20] Gregory, H. E., and Evans, R. T., op. cit. Reeside, J. B., Jr., and Bassler, Harvey, op. cit., pp. 54-55. Dobbin, C. E., op. cit., p. 124. Baker, A. A., Dane, C. H., and Reeside, J. B., Jr., op. cit., p. 22.

Fort (p. 11), where it is predominantly buff to yellow in color. Here the sandstone is overlain unconformably by beds of Tertiary age, and the base is covered by Tertiary volcanic rocks. The part of the formation exposed is not known, but the color suggests that the outcrop may represent the upper part.

The northernmost outcrop ascribed to the Navajo sandstone is in secs. 21, 28, 32, and 33, T. 33 S., R. 10 W., where it forms the prominent hogback through which Hieroglyph Canyon has been cut. (See pl. 5, A.) This hogback is composed of a cross-bedded standstone, ordinarily white, more rarely yellow and buff. The sandstone of this outcrop is in fault contact with sediments of the Wasatch formation on the east and with the alluvium of Cedar City Valley on the west. The thickness of sandstone exposed in Hieroglyph Canyon, about 650 feet, is doubtfully called Navajo sandstone, because it is similar in color and lithologic features to the upper part of that formation in other parts of the area.

The Navajo sandstone throughout the area appears to be highly permeable, for it is made up principally of very well-sorted fine sand that is only loosely cemented by calcium carbonate. It is an important aquifer throughout the plateau country, and gives rise to several springs in the area tributary to Cedar City Valley.

JURASSIC SYSTEM

SAN RAFAEL GROUP

Above the Navajo sandstone in eastern Iron County there is a succession of limestones, shales, sandstones, and gypsum which comprise the Upper Jurassic San Rafael group. In its type locality in eastern Utah [21] the San Rafael group consists of marine deposits, which are divisible into four formations: The Carmel formation, the Entrada sandstone, the Curtis formation, and the Summerville formation. In southwestern Utah, according to tentative correlations by Baker, Dane, and Reeside, [22] the Carmel formation includes red shale and sandstone overlain by limestone and limy shale, with a total thickness of as much as 480 feet; the Entrada sandstone consists of an earthy red sandstone or sandy shale as much as 700 feet thick; and the Curtis formation includes a basal gypsum bed, succeeded by reddish and gray sandy shales, with a total thickness as great as 350 feet. The Summerville formation probably is not represented in Southwestern Utah.

In eastern Iron County the San Rafael group is exposed along the western margin of the Kolob Plateau as far north as Fidlers Canyon in sec. 5, T. 36 S., R. 10 W. In Coal Creek Canyon it is a confusing array of faulted, folded, squeezed, and warped beds of limestone, shale, sandstone, and gypsum of some economic importance. (See pl. 5, B.) Just below the plateau, however, along the northwest slope of "A" Mountain, the San Rafael group outcrops in nearly horizontal beds. The following section was measured by Gardner [23], who has kindly premitted its inclusion here.

[21] Gilluly, James, and Reeside, J. B., Jr., Sedimentary rocks of the San Rafael Swell and some adjacent areas in eastern Utah: U. S. Geol. Survey Prof. Paper 150-D, p. 73, 1928.
[22] Baker, A. A., Dane, C. H., and Reeside, J. B., Jr., op. cit., pp. 22-24.
[23] Gardner, L. S., personal communication.

A. TWENTYMILE GAP.

View from the south.

B. DELTA AT MOUTH OF GULLY ABOUT A MILE SOUTH OF HIEROGLYPH CANYON, IN CEDAR CITY VALLEY.

View from the west.

A. HIEROGLYPH CANYON AND CEDAR CITY VALLEY BEYOND.

View from the east. Jn, Navajo sandstone (?); Ku, undifferentiated Cretaceous rocks; Tew, Wasatch formation; Tmv, acidic volcanic rocks.

B. SAN RAFAEL GROUP EXPOSED ALONG THE NORTH SLOPE OF COAL CREEK CANYON.

Jcl, Carmel formation; Je, red sandy shale, possibly equivalent to the Entrada formation; Jcr, gypsum, probably equivalent to the Curtis formation; Ku, undifferentiated Cretaceous rocks.

Section of the San Rafael group 1½ miles southeast of Cedar City, in sec. 24, T. 36 S., R. 11 W.

[Section by L. S. Gardner]

	Feet
Cretaceous strata:	
San Rafael group:	
7. Red soft gypsiferous mudstone in layers up to 2 feet thick, alternating with more resistant though quite soft red massive impure sandstone with some lenses of angular pebbles	212
6. Pale lavender to gray nonresistant massive sandstone and mudstone, poorly exposed	28
5. Alternating soft red sandstone and mudstone, poorly exposed	77
4. Thin-bedded, pale greenish-gray, brittle impure limestone, with many ripple marks and some cross bedding	29
3. Massive resistant white alabaster gypsum in one great bed	101
2. Red shale and sandstone, with resistant sandstone predominating in middle part	127
1. Massive resistant brittle thin-bedded pale greenish-gray limestone. Base not exposed	162
Fault.	
Total thickness exposed	736

In this section the basal member of the San Rafael group is a marine limestone, apparently equivalent to the Carmel formation. The red sandstone and shale of the next higher member bear some resemblance to the Entrada sandstone in other regions, and the massive gypsum bed and overlying members may be equivalent to the Curtis formation. In the areal geologic mapping for plate 3 the San Rafael group is mapped as a unit and the component formations are not differentiated.

The limestone apparently equivalent to the Carmel is locally fossiliferous in eastern Iron County. A collection made about 2 miles north of Cedar City was identified by J. B. Reeside, Jr., as a Carmel fauna.

18212. NE¼NE¼ sec. 2, T. 36 S., R. 11 W.
Nucula n. sp.
Ostrea sp.
Trigonia montanensis Meek.
Camponectes extenuatus Meek and Hayden.
Lima n. sp.

In the Iron Springs district a dense bluish-gray limestone outcrops adjacent to the areas of laccolithic andesite. (See p. 30.) The distribution, character, and metamorphic changes of this limestone are described in detail by Leith and Harder, [24] who named it the Homestake limestone and considered it to be of doubtful Pennsylvanian age. Recently, J. B. Reeside, Jr., has identified fossils collected from this limestone in the SE¼NW¼ sec. 21, T. 35 S., R. 12 W., as *Camponectes* cf. *C. stygius* White, and he concludes that the limestone is Jurassic in age, probably of the Carmel formation. Because of this identification and because, as Leith and Harder note, [25] the Homestake limestone is overlain, apparently conformably, by the Pinto sandstone of Cretaceous age, the limestone is tentatively assumed to be a part of the San Rafael group and is so mapped on plate 3. Wells, in a recent report, [26] notes that the iron ores of the Bull Valley district, about 20 miles southwest of Iron Springs, are in the Carmel formation, which is overlain by the Pinto sandstone in a section apparently analogous to that of the Iron Springs district.

The San Rafael group includes a large proportion of shales and shaly

[24] Leith, C. K., and Harder, E. C., The iron ores of the Iron Springs district, southern Utah: U. S. Geol. Survey Bull. 338, pp. 24–37, 1908.

[25] Idem, p. 37.

[26] Wells, F. G., Iron ore deposits of the Bull Valley district, Washington County, Utah: U. S. Dept. Interior Information Service Press Notice 152284, p. 1, July 29, 1941

beds whose permeability is presumably low, as well as certain sandstone zones that might be expected to have at least a moderate permeability. There also are considerable thicknesses of soluble rocks, particularly limestone and gypsum, which are being dissolved by water in streams crossing the outcrops, as shown by the increase in content of alkaline earths and sulfates in water collected from these streams. Circulation of ground water through these soluble rocks would presumably tend to increase the porosity of the formations, but this process probably is restricted by the limited amount of precipitation on the outcrop under present conditions of aridity. Ground water obtained from beds of the San Rafael group is of very poor quality, judging by the water obtained from a well in Coal Creek Canyon that was deemed unfit for municipal use by Cedar City.

CRETACEOUS SYSTEM

The rocks of the Cretaceous system which are exposed over extensive areas in the eastern part of Iron County, comprise a thick series of massive to thin-bedded sandstones with some shale and workable coal. They underlie a large portion of the Kolob Plateau, particularly in the Coal Creek drainage basin, and are exposed on this plateau from the south limit of the area north as far as the town of Paragonah, in Parowan Valley. They appear in Parowan Gap and for several miles to the north and south along the range that separates Parowan Valley from Cedar City Valley. In the Iron Springs district Leith and Harder [27] show areas to be underlain by the Pinto sandstone of Cretaceous age in Iron Springs Gap and in the hills west and north of the gap.

Gregory and Moore [28] divide the rocks of the Cretaceous system in the Kaiparowits region into five formations: The Dakota (?) sandstone, 0–100 feet thick; the Tropic shale (soft, bluish drab), 550–1,450 feet thick; the Straight Cliffs sandstone (buff, coal bearing), 900–1,200 feet thick; the Wahweap sandstone (gray, massive), 1,100–1,300 feet thick; and the Kaiparowits formation (drab, soft, sandy shale), 2,200 feet thick. In the area considered in this report, a conglomeratic sandstone locally rests upon the uppermost members of the San Rafael group and may be roughly equivalent to the Dakota (?) sandstone. A grayish shale is exposed above this conglomeratic zone in Coal Creek Canyon, and probably the same shale makes up the lower portion of the section of the Cretaceous rocks in Fidlers Canyon, given below; these beds of shale are probably equivalent to the Tropic shale in the Kaiparowits region. Resting upon this shale is a series of massive sandstones which aggregates more than 2,000 feet in thickness, and which probably corresponds to the Straight Cliffs and Wahweap sandstones of the Kaiparowits region.

Section in Fidlers Canyon, from the SE¼ sec. 25, T. 35 S., R. 10 W., to the SE¼ sec. 31, T. 35 S., R. 9 W.

	Feet
Wasatch formation:	
Basal conglomerate, pink, with cobbles up to 6 inches in diameter.	
Upper Cretaceous, undifferentiated:	
Sandstone, coarse to fine, dirty brown to buff; in massive to thin beds, some white, cross-bedded; covered in part	850
Conglomerate, gray pebbles to 3 inches in diameter	5
Sandstone, coarse to fine, light brown; covered in part	630
Limestone, sandy, gray, fossiliferous	3
Sandstone, calcareous, buff, fossiliferous	4

[27] Leith, C. K., and Harder, E. C., op. cit., pp. 37–38, pl. 2, 1908.

[28] Gregory, H. E., and Moore, R. C., The Kaiparowits region, a geographic and geologic reconnaissance of parts of Utah and Arizona: U. S. Geol. Survey Prof. Paper 164, pp. 36–37, 88–113, 1931.

Upper Cretaceous, undifferentiated—Continued.	Feet
Sandstone, light brown, some small pebbles in thin discontinuous beds	80
Shale, calcareous, dark gray, thin-bedded, fossiliferous in part	50
Sandstone, buff, massive, hard	50
Shale, calcareous, fossiliferous	40
Sandstone, yellow, somewhat fossiliferous	15
Shale, calcareous, gray, thin-bedded, fossiliferous	15
Limestone, fossiliferous	5
Sandstone, gray, hard	15
Sandstone, buff, massive	20
Shale, calcareous, thin-bedded, fossiliferous; alternating beds of sandstone up to 12 inches	15
Sandstone, yellow, massive	215
Shale, calcareous, dark gray, fossiliferous	40
Coal or bone	2 to 7
Sandstone, yellow, massive	40
Sandstone, gray, thin-bedded, shaly, fossiliferous	15
Bone, partings of coal up to 4 inches	10
Shale, greenish-gray to yellow; some sandstone in beds up to 2 feet thick	160
Sandstone, yellow, massive	10
Top of Tropic shale ?	
Shale, greenish-gray	295
Sandstone, yellow, massive	5
Shale, greenish-gray	100
Thickness of Cretaceous system exposed	2,700±
Fault contact with San Rafael group of Jurassic system.	

Fossils collected from the thin limestone and sandstone beds of this section about 1,500 to 1,700 feet below the base of the Wasatch formation were examined by J. B. Reeside, Jr., and referred to the lower part of the Upper Cretaceous series.

18214. NW¼SE¼ sec. 30, T. 35 S., R. 10 W.
Ostrea soleniscus Meek.
Cyrena securis Meek.
Curbula nematophora Meek.
Turbonilla coalvillensis Meek.

The section in Parowan Gap, below, is evidently limited to these sandstone beds. The lower 800 feet of this sandstone contains coal in beds up to 9 feet thick, [29] which has been prospected in numerous places along the outcrop, particularly along the edge of the Kolob Plateau. This coal is mined for use within the county at the MacFarlane ("Hot Coal") mine, in Coal Creek Canyon, in the NW¼ sec. 36, T. 36 S., R. 10 W.; and at the Graff ("Kleen Coal") mine, along the west edge of the Kolob Plateau, in the SW¼ sec. 21, T. 37 S., R. 11 W.

Section in Parowan Gap, in the S½ sec. 27, T. 33 S., R. 10 W.

Wasatch formation:	Feet
Coarse conglomerate N-S. 40°E.	
Fault contact.	
Upper Cretaceous undifferentiated rocks:	
Sandstone, coarse to fine, brown to yellowish-buff, hard, in massive to thin beds	1,080
Sandstone, white, massive	15
Sandstone, coarse to fine, brown to buff, soft	450
Sandstone, dark brown to buff	90
Sandstone, buff, massive	15
Sandstone, brown to yellow, in hard and soft beds	90
Sandstone, buff, massive	15
Shale, calcareous, "oyster beds"	5
Sandstone	10
Bone and clay, with six 1-inch layers of coal	6

[29] Lee, W. T., Iron County coal field, Utah: Geol. Survey Bull. 316–E, pp. 367–374, 1907. Richardson, G. B., Harmony, Colob, and Kanab coal fields, Utah: Geol. Survey Bull. 341–C, pp. 384–392, 1909.

Upper Cretaceous undifferentiated rocks—Continued.	
Sandstone, brown to yellow, in massive to thin beds	340
Shale, calcareous, "oyster beds"	4
Sandstone, brown to buff, alternating hard and soft beds, N. 35° E., 72° NW	280
Thickness of Cretaceous rocks exposed	2,400
Fault contact.	
Upper Cretaceous undifferentiated rocks:	
Sandstone, brown, N. 15° E., 20° SE.	

In the Iron Springs district the main body of the Pinto sandstone appears to correspond with these sandstones, whose average thickness is reported by Leith and Harder [30] as considerably more than 1,000 feet and may be as much as 3,500 feet. Below the Cretaceous sandstone are beds of shale, variegated sandstone, brecciated limestone, and conglomerate aggregating 150 to 250 feet in thickness. These beds may correspond in part with the Tropic shale, in part more nearly to members of the San Rafael group.

The sandstones are overlain unconformably by rocks of Tertiary age; there appear to be no shale beds corresponding to the Kaiparowits formation of the Kaiparowits region. [31] In the areal mapping for plate 3, no differentiation of the Cretaceous rocks into formations was attempted, and the system was mapped as a unit.

The Cretaceous system includes a number of highly permeable zones as well as considerable thicknesses of relatively impervious strata. Numerous springs originate in the permeable beds, particularly along coal beds, and constitute an important source of water in streams during periods of low flow. The water from these springs is of excellent quality, as shown by analyses on page 111. The culinary water used by Cedar City is derived from several springs rising along outcrops of Cretaceous sandstone, and is generally superior to the water obtained from wells drilled in the alluvium of Cedar City Valley.

TERTIARY SYSTEM

EOCENE SERIES

WASATCH FORMATION

Beds of early Tertiary (probably Eocene) age, which rest unconformably upon Cretaceous and in a few places older strata in eastern Iron County, ordinarily include a basal conglomerate and overlying limestone, shale, and calcareous sandstone, all commonly of a pink color that contrasts strikingly with the drab beds of the underlying Cretaceous rocks. These strata form the brilliant Pink Cliffs of southwestern Utah and are assigned by common usage to the Wasatch formation, although exact correlation with known beds of that formation has not been established.

The Wasatch formation covers extensive areas on the Kolob Plateau and on the higher Markagunt Plateau farther east. Along the steep slopes that border the plateau, the rapid erosion of the soft beds of the formation has given rise to picturesque sculpture, such as is seen in Cedar Breaks National Monument, near the headwaters of Coal Creek, and farther east, in Bryce Canyon National Park. The Wasatch formation also appears in discontinuous outcrops along the western edge of the Kolob Plateau from Cedar City northward nearly to the north end of Parowan Valley. Farther west, it is exposed over extensive areas,

[30] Leith, C. K., and Harder, E. C., op. cit. pp. 38–41.
[31] Gregory, H. E., and Moore, R. C., op. cit., pp. 106–108.

locally called the Red Hills, in the range that separates Cedar City Valley and Parowan Valley, and is also exposed in the northwest part of Cedar City Valley, 6 or 7 miles south of Twentymile Gap. Farther south in Cedar City Valley, the Wasatch formation is found in the Iron Springs district, where Leith and Harder [32] have mapped it as the Claron limestone, and its outcrop forms the west border of Cedar City Valley in the vicinity of the settlement of Kanarraville. The Wasatch formation also appears along the west edge of the upland area south of the settlement of Hamiltons Fort, where it rests unconformably upon the Jurassic (?) Navajo sandstone.

The beds of the Wasatch formation vary greatly in composition, texture, and color, but include predominantly mottled gray to pink fresh-water limestone and red sandstone and shales; upon weathering the rocks commonly develop more brilliant shades of pink to red or even purple. These beds generally rest upon a thick basal conglomerate, which is made up of pebbles and boulders of quartzite and some dense igneous rocks, having diameters as large as 12 inches. The formation is generally considered to be lacustrine in origin. Typical sections of the beds of the Wasatch formation follow.

Section of the Wasatch formation near Paragonah, in the SE¼ sec. 27, T. 33 S., R. 8 W.

	Feet	
Wasatch formation:		
Shale and limestone, sandy, light red	300+	
Coarse conglomerate, gray, boulders up to 12 inches	250	Basal cong.= 480 feet
Sandstone, yellow, cross-bedded	100	
Coarse conglomerate, gray	30	
Sandstone, yellow, cross-bedded	70	
Conglomerate	30	
Thickness of Wasatch formation exposed	780+	
Cretaceous system.		

Section of the Wasatch formation in the NE¼ sec. 5, T. 35 S., R. 8 W.

	Feet	
Wasatch formation:		
Limestone and sandy shale, light red	400+	
Conglomerate, white to gray, pebbles to 6 inches	150	Basal cong.= 540 feet
Medium sandstone, white to yellow, cross-bedded	260	
Conglomerate, white to gray, pebbles to 6 inches	130	
Thickness of Wasatch formation exposed	940+	
Cretaceous system:		
Sandstone, brown and yellow.		

Immediately east of the Hieroglyph Canyon are outcrops of gray, mottled, and cream-colored limestone and shale that bear little resemblance to the beds of the Wasatch formation elsewhere in Iron County. Locally the limestone beds in this area show peculiar markings that are generally considered to be of algal origin. According to Reeside, these algal forms are abundant only in the Wasatch formation, and the material is so mapped on plate 3.

Ordinarily the Wasatch formation rests unconformably upon rocks of Cretaceous age; exceptionally it rests directly on Jurassic or older rocks. In parts of the area the unconformity between the Wasatch and older rocks is angular. Elsewhere the contact is an uneven erosion surface upon which the basal conglomerate of the Wasatch was deposited, and it is likely that the original thickness varied from place to place. Today the Wasatch formation for the most part is not covered by younger rocks, and it has been exposed to erosion probably since Tertiary time; where

[32] Leith, C. K., and Harder, E. C., op. cit., pl. 2, pp. 41–43.

the Wasatch has been covered by Tertiary volcanic flows, the upper part may have been removed before the later Tertiary volcanics were laid down. Hence the original thickness may have been considerably greater than that in present exposures. Measured sections of the Wasatch indicate an average thickness approaching 1,000 feet. Leith and Harder [33] indicate a similar thickness of the equivalent Claron limestone in the Iron Springs district. In other parts of southern Utah the measured thickness of the Wasatch formation is roughly comparable. The thickness of the formation is about 1,300 feet in Bryce Canyon [34] and about 1,500 feet near Diamond Valley, about 12 miles north of St. George, [35] where its beds are predominantly sandstone.

Relatively impervious beds of limestone and shale are predominant in the Wasatch formation, but the basal conglomerate may be fairly permeable, particularly in areas where it is weakly cemented. The less permeable materials are exposed over a large part of the principal areas of outcrop of the formation, which are located chiefly on the plateaus east of Cedar City and Parowan Valleys. Where the permeable materials are exposed there is doubtless seepage of water into the formation, the water moving downward and perhaps reappearing in springs or seeps at lower elevations.

MIOCENE (?) SERIES

INTRUSIVE ANDESITE

Intrusive andesite has been described by Leith and Harder [36] as forming "laccoliths intruded into the Paleozoic and to a less extent into Mesozoic rocks after the deposition of Tertiary sediments. *** The laccoliths are exposed in three main areas forming the cores of the principal mountains of the [Iron Springs] district—the Three Peaks and Granite Mountain in the northeastern and Iron Mountain in the southwestern part." The Three Peaks outcrop comprises an area 1 to 2 miles wide which borders the west edge of Cedar City Valley from Iron Springs Gap northward about 5 miles. The Granite Mountain exposure is about 2 miles southwest of Iron Springs. These laccoliths are considered by Leith and Harder to be of Miocene age. The rock is prevailingly dense, and ground water in the formation would be limited to fractures, which are fairly common throughout the andesite. [37]

EXTRUSIVE ACIDIC ROCKS

Resting upon the Wasatch formation and more rarely upon older rocks is a thick series of acidic volcanic rocks, including probably rhyolite, trachyte, latite, dacite, andesite, and associated pyroclastics, which form a series estimated by Leith and Harder to be 1,700 to 2,500 feet thick in the Iron Springs district. [38] In the area considered in this report this volcanic series has been mapped as a unit, and the several rock types have not been differentiated.

The Tertiary acidic extrusive rocks are widespread in the ranges and plateaus bordering Cedar City Valley and Parowan Valley, especially in areas adjacent to the outcrops of the Wasatch formation. They cover the surface of large blocks of the Kolob Plateau and the higher Markagunt Plateau, where they form several of the highest peaks, including Brian Head, the highest peak in the area. Along the west side of the

[33] Leith, C. K., and Harder, E. C., op. cit., p. 43.
[34] Gregory, H. E., and Moore, R. C., op. cit., p. 115.
[35] Reeside, J. B., Jr., and Bassler, Harvey, op. cit., p. 65.
[36] Leith, C. K., and Harder, E. C., op. cit., p. 46.
[37] Idem, pp. 19–20.
[38] Leith, C. K., and Harder, E. C., op. cit., p. 50.

Kolob Plateau they are exposed in an extensive area from the settlement of Enoch in Cedar City Valley northeastward along the south edge of Parowan Valley and also appear along the edge of the plateau north of Paragonah, beyond the limit of outcrop of the Wasatch formation. In the range that separates Cedar City Valley from Parowan Valley these volcanic rocks are exposed in a broad belt north of the Wasatch formation, a belt that continues westward into the dissected area bordering the north end of Cedar City Valley. The Tertiary acidic effusives form the west border of Cedar City Valley from Twentymile Gap southward into the Iron Springs district and also border the valley throughout most of the distance between Iron Springs Gap and the south limit of the area. Finally, the Tertiary acidic extrusives are exposed in the western part of the upland area that separates the two branches of Cedar City Valley between Cedar City and Kanarraville, where they rest in part upon eroded surfaces of the tilted Navajo sandstone.

In the Marysvale region, about 25 to 60 miles northeast of Parowan Valley, Callaghan [39] has distinguished three groups of volcanic rocks: an earlier Tertiary group of latitic breccias, tuffs, and flows; a later Tertiary group of rhyolites, quartz latites, latites, and tuffs; and scattered thin-basalt flows of late Pliocene or early Pleistocene age. The acidic volcanic rocks exposed in eastern Iron County appear to be lithologically similar to the rocks in the first two of these groups, and may be roughly equivalent in age. Leith and Harder [40] consider the volcanic series in the Iron Springs district to be upper Miocene.

The lower part of the series consists chiefly of ash, tuff, and volcanic breccia, commonly white to light gray in color. These pyroclastics are encountered southeast of Parowan, where the volcanic series rests upon the Wasatch formation, and were observed in other parts of the area. Callaghan found a similar predominance of "latitic and andesitic tuffs and breccias with scarcely 10 per cent of flows" in the lower part of his "Bullion Canyon volcanics," which constitute the oldest rocks of the earlier Tertiary group. Similar deposits of volcanic detritus are no doubt commonplace as forerunners of volcanic activity.

The pyroclastic rocks in this volcanic series are generally rather fine grained and poorly sorted, and are presumed to be relatively impervious. The lavas are characteristically dense and probably likewise impervious, except along the numerous fractures which were observed at all outcrops and which doubtless are the principal means of ground-water movement in the formation. Several springs, particularly along the south edge of Parowan Valley, rise from outcrops of the volcanic rocks.

QUATERNARY SYSTEM

PLEISTOCENE (?) SERIES

BASALT

Flows of basalt, generally less than 100 feet thick, occur in several places throughout the region. On the Kolob Plateau basalt covers an area of several square miles in the drainage basins of Shurtz Creek and the South Fork of Coal Creek, where it rests upon beds of the Cretaceous and Jurassic systems. Just west of this area, discontinuous outcrops of the basalt are found resting upon Triassic rocks along the steep west edge of the plateau. Along the Kanarra Mountain road, in sec. 20, T. 37 S.,

[39] Callaghan, Eugene, Volcanic sequence in the Marysvale region in south-central Utah: Am. Geophys. Union Trans. of 1939, part III, pp. 438–452, August 1939.

[40] Leith, C. K., and Harder, E. C., op. cit., p. 21.

R. 11 W., the basalt rests upon a surface sloping northwestward about 600 feet to the mile. Elsewhere along the front of the plateau, particularly in secs. 33, 34, and 35, T. 36 S., R. 11 W., the basalt appears to have been broken by several faults which have displaced it downward to the west. Still farther west, the basalt covers considerable parts of the upland that separates the two branches of the valley from Cedar City southward. Individual flows in this area have a gentle westward dip, but toward the south end of the upland the flows are inclined at angles of 6° to 10°.

These several outcrops may be remnants of a once continuous sheet of basalt that covered most of an area 10 miles or more in diameter. The present range in altitude of the basalt—from the valley floor, at about 6,000 feet above sea level, to the summit of the plateau, at more than 9,000 feet above sea level—is apparently due partly to the original surface over which the basalt flowed, and partly to subsequent faulting, which has raised the eastern (plateau) part still higher since the time of the extrusion. The vent or vents from which the basalt was extruded were not found; it is assumed from the westward slope negotiated by the flow at the front of the plateau that some of the vents at least must have been farther east, on the plateau.

At the south end of Parowan Valley, between the settlements of Enoch and Summit, there are several outcrops of basalt in an area about 4 miles in diameter, extending along both the south and west sides of Parowan Valley. These outcrops may likewise be remnants of a once continuous sheet, but their source is unknown. The flows exposed along the north side of Winn Wash have a northwesterly dip of about 10°.

East of Rush Lake basalt is exposed over an area 3 to 5 miles long and about 2½ miles wide, in the range that separates Cedar City Valley from Parowan Valley. Three cinder cones (pl. 6, A), alined in a direction N. 30° E. down the center of this area, are evidently the vents from which the flows issued, for the flows slope away from these cones in all directions. Except in the immediate vicinity of these cones, the present inclination of the flows is ordinarily 4° or 5°. West of Rush Lake, in sec. 11, T. 34 S., R. 11 W., a small outcrop of basalt projects only a few feet above the floor of Cedar City Valley and may have had the same source.

Just south of Paragonah a basalt flow covers an area of about a square mile along the edge of Parowan Valley (pl. 6, B). This flow can be traced southeastward up a narrow channel to a cinder cone in the southern part of sec. 15, T. 34 S., R. 8 W., which was apparently the source of the basalt. The channel is evidently a stream valley that was cut into Cretaceous and Eocene rocks before the extrusion. Its mouth is now about 500 feet above the adjacent valley floor. (See p. 62.) A small outcrop of basalt was also found in the hills about 2 miles south of Parowan; no vent was observed, but it is likely that the outcrop represents a small flow having a source in the immediate vicinity.

Basalt is exposed in a broad belt rimming the north end of Parowan Valley. This belt continues westward north of the outcrop belt of the Tertiary acidic extrusive rocks, which presumably underlie the basalt throughout this area. Basalt is exposed near the north end of Cedar City Valley, in secs. 24 and 25, T. 32 S., R. 10 W., and a few miles east of Twentymile Gap, in sec. 7, T. 33 S., R. 11 W. Elsewhere its outcrop is beyond the limit of the area mapped, but the basalt float brought into Cedar City Valley attests its presence in abundance in the hills farther north.

Along the west margin of Parowan Valley, north of Little Salt Lake, there are several small hills of basalt. These appear to be outliers, separated from the main mass by the outcrop of Tertiary acidic volcanic rocks, 2 to 5 miles wide. Their presence is indicative that these Tertiary rocks were once covered to a much greater extent than now by the basalt flows, which have since been removed from considerable areas by erosion.

The basalt is commonly scoriaceous, less commonly a dense black mass with occasional small phenocrysts of olivine. The flows generally show very little evidence of erosion, and locally exhibit a ropy pahoehoe type of lava, which looks as if it might still be cooling, so fresh is the surface. The flows in eastern Iron County are probably roughly contemporaneous with basalt flows in the Marysvale region, which Callaghan [41] found to be associated with the late Pliocene and early Pleistocene Sevier River formation, and with those farther south in Washington County, which Dobbin [42] suggests are Quaternary in age. The flows appear to have continued for a considerable time, and their history is intimately bound up with the faulting, erosion, and drainage changes that took place in the Quaternary, and possibly also in the later Tertiary period. (See p. 63.)

The basalt is probably one of the most permeable of the consolidated rocks in the Cedar City area. The scoriaceous zones may be highly permeable, and the fractures that have formed everywhere as a result of cooling afford ready means for ground-water circulation. A large spring along the east edge of Rush Lake in Cedar City Valley probably derives water from the adjacent basalt, and many springs in the plateau likewise are along outcrops of the lava.

FANGLOMERATE TERRACES

Poorly sorted deposits of unconsolidated or very slightly consolidated materials are found at altitudes considerably higher than the deposits of the present streams. These deposits, which include sand, gravel, boulders, and blocks as large as 5 feet in diameter, with all degrees of rounding, are quite similar to the materials making up the present alluvial fans of the several streams that enter Cedar City and Parowan Valleys. The areas in which these deposits occur have been dissected considerably by erosion, particularly along their margins. The summits and ridge crests, however, appear to define a graded plain comparable to those developed by aggradation of the present streams in the region. This plain is herein referred to as a "fanglomerate terrace."

The largest fanglomerate terrace in the area is on the uplands that extend southward from the Cedar City stockyards to Hamiltons Fort and from there southward nearly to Kanarraville. (See pl. 4, B.) Most of these areas are considerably dissected and consist principally of narrow ridges and steep-sided valleys. Viewed from distant vantage points along the west side of Cedar City Valley, however, it is evident that there is a rough accordance of the summits and ridge crests of these uplands. These ridge crests are about 300 feet above the valley floor near Cedar City and rise somewhat higher above the valley farther south, the difference being nearly 500 feet at the south end of the upland

[41] Callaghan, Eugene, op. cit., p. 450.

[42] Dobbin, C. E., Geology of the St. George district, Washington County, Utah: Am. Assoc. Petroleum Geologists, vol. 23, p. 125, 1939.

area. Most of the crests are parts of a fanglomerate terrace, although locally volcanic rocks of Tertiary and Quaternary age project above the fanglomerate. The fan deposits are made up of rocks derived from the Mesozoic and Tertiary rocks exposed in the vicinity and in the plateau to the east, and in most places boulders and blocks derived from the Wasatch formation, Cretaceous sandstones, and older formations are readily recognized. Materials derived from the volcanic rocks of the region are generally quite common, as they are in present stream gravels, presumably because these rocks are hard and best able to resist the demolishing forces of stream action. Locally the fanglomerate may have an exceptionally high proportion of basalt or of fragments of the Tertiary acidic extrusive rocks. Generally where this occurs, nearby outcrops of these volcanic rocks offer evidence of a local source for the fragments. In other places no outcrops are visible, and the concentration of volcanic debris may indicate that a source is nearby but buried by the fanglomerate. The gravel in these upland areas rests in part upon rocks of Jurassic and Tertiary age exposed along the west margin of the upland. Locally the gravel also covers flows of the basalt and, on the other hand, some of the gravel is covered by the basalt flows. Indeed, just southwest of Cedar City, in sec. 15, T. 36 S., R. 11 W., the fanglomerate lies beneath, beyond, and above the end of a basalt flow some 50 feet thick. The fanglomerate is therefore regarded as roughly contemporaneous with the basalt, the deposition having perhaps been initiated before the beginning of volcanic activity and having continued throughout the activity and perhaps for some time thereafter.

About a mile east of Enoch and thence northward for about 3 miles there is a fanglomerate terrace that rises 250 feet above the valley floor north of Enoch. (See pl. 6, C.) The fanglomerate rests upon eastward-dipping beds of the Wasatch formation. The gravel includes a large proportion of volcanic rocks, perhaps derived from the basalt that crops out east of the terrace and from the acid volcanic rocks bordering the fanglomerate to the southwest. A little more than a mile west of this terrace and extending southwestward for about 3 miles from the SE¼ sec. 24, T. 34 S., R. 11 W., there is a discontinuous low gravel-capped ridge, the north end of which nearly meets the south end of the basalt that borders Rush Lake. There it rises about 130 feet above the valley floor. The ridge, which dwindles in height and width to the south and is breached in three places by small stream channels, is about 30 feet high and 400 feet wide near its south end. It is made up of sand, silt, gravel, and boulders as large as 8 inches in diameter, a composition similar to that of the alluvium of Cedar City Valley as exposed in pits nearby. Blocks of basalt and of acidic volcanic rocks are included. This gravel ridge, like the fanglomerate terraces elsewhere in the valley, is believed to represent alluvial material that has been raised above the rest of the valley floor by faulting. (See p. 51.)

Near the mouth of Coal Creek Canyon, about 200 feet above the present stream bed, small poorly consolidated deposits of alluvial gravel and boulders up to 5 feet in diameter rest upon the upturned strata of the Moenkopi formation and the Shinarump conglomerate. Scattered boulders and blocks of the Tertiary volcanic rocks in the vicinity, particularly those in gullies cut into the Triassic strata, indicate that these gravel deposits have formerly been more widespread. A rather hasty search was made for similar deposits farther upstream, and although none were found, they might well be. These deposits are evidently remnants of a fanglomerate deposited by Coal Creek when the canyon mouth was several hundred feet higher than it is today.

Fanglomerate is exposed on the summit and west side of the low hill along the east edge of United States Highway 91, about a mile north of Cedar City. (See pl. 7, A.) Steeply dipping beds of the Chinle formation crop out along the east margin of this hill. The fanglomerate contains huge blocks and boulders of the Tertiary acidic volcanic rocks, suggesting that these rocks are in place nearby, although apparently they do not crop out. The fanglomerate here is nearly 250 feet above the valley floor. Along the east edge of Cedar City Valley north of this hill, as well as in other parts of the area, there may be fanglomerates, other than those shown on the map, which have been elevated some distance above present alluvial deposits but which were not distinguished from them.

The gravels that make up the forms described herein as fanglomerate terraces are all most certainly of alluvial origin, and are thus quite similar in texture, lithology, and other characteristics to the materials described as Quaternary alluvium. (See p. 37.) It may well be asked just what the distinction is between the fanglomerate and the alluvium. It should be pointed out that southwestern Utah has been a site of upland erosion and lowland alluviation ever since the end of deposition of the Eocene Wasatch formation. Deposition of stream-borne sediments has continued throughout most of the Tertiary and all of the Quaternary. Thus, throughout the times of intense volcanic activity and periods of great structural modification as well as during more quiescent intervals, alluviation has gone on, perhaps at widely varying rates, but probably not completely interrupted at any time. This accumulation of alluvial material thus spans a broad period of geologic history, beginning in the early Tertiary and continuing vigorously today. The fanglomerates forming the terraces described above represent accumulations in areas that are no longer places of deposition, because of structural adjustments that have occurred since the deposition of the fanglomerate. It has been noted that some of these gravels were being deposited during the time of basalt eruption, and the fanglomerates are tentatively assumed to be of Pleistocene age, more or less contemporaneous with the basalt eruptions.

The fanglomerates are similar in texture and degree of sorting to recent alluvial deposits at comparable distances from the mouths of the stream canyons, and their water-bearing properties are considered to be analogous to those of the alluvium described below.

PLEISTOCENE AND RECENT SERIES

LAKE DEPOSITS

Recent lacustrine sediments occur in both Parowan Valley and Cedar City Valley, and represent accumulations in the lakes in the two valleys —Shurtz and Rush Lakes in Cedar City Valley and Little Salt Lake in Parowan Valley. These lakes are playa lakes, common to the Great Basin. They receive inflow during only a part of the year; during the rest of the time the water is evaporated so that the lakes occupy only a small part of the flat, and during dry years may disappear entirely as they did in 1935. The lake flats are made up of the clay, silt, and sand brought in when the water is replenished, as well as of salts resulting from dessication. These materials are relatively impervious, and serve to impede downward seepage from the lake to the zone of saturation when ground-water levels are low, and thus over large areas of these undrained depressions the loss of water is due to evaporation.

Beyond the limits of the present beds of Little Salt Lake, Rush Lake, and Shurtz Lake there are some deposits that appear to be lacustrine in origin and suggest that the lakes formerly had greater depth and areal extent. These deposits are of insignificant areal extent but are of value in showing the height of former lake levels. Along the west edge of Little Salt Lake in Parowan Valley there is a faint strand line about 12 feet above the west edge of the lake flat. This strand line is above the level at which water would overflow from Little Salt Lake through Parowan Gap, and the strand line therefore marks a shore line of the lake during an epoch when Parowan Valley was tributary to Cedar City Valley. The present lake bed is very slightly lower than the floor of the gap at its upper end, and ditches have been dug to divert the flow of several springs into the upper end of the gap, where it is used by stock. A similar strand line can be discerned west of Shurtz Lake in Cedar City Valley, about 20 feet above the present lake level. This strand line is at approximately the altitude, 5,470 feet above sea level, at which Shurtz Lake would overflow through Iron Springs Gap.

A small stream that enters Cedar City Valley in the NW¼ sec. 33, T. 33 S., R. 10 W., has built what appears to be a small delta at the mouth of its canyon. (See pl. 5, B.) This delta is roughly of semicircular form and has a nearly flat surface quite dissimilar to the alluvial fans that are built by streams under conditions of subaerial deposition. It is considered to have been formed in a lake that extended over an area considerably greater than that of the present Rush Lake.

The age of the ancient predecessors to the present lakes in Cedar City and Parowan Valleys is not known. It is inferred, however, that they may have been developed during a glacial stage of the Pleistocene—probably equivalent to that which gave rise to Lake Bonneville—when, according to abundant evidence over the continent, the climate was considerably more humid than now.

DUNE SAND

Sand has been formed into dunes at several places in Cedar City and Parowan Valleys. There are rather large areas covered by dune sand in the vicinity of Shurtz Lake, particularly along its east border. Sand dunes also are common west and south of Rush Lake, and along the east side of Little Salt Lake. Elsewhere in Cedar City and Parowan Valleys there are small areas covered by sand dunes, some of which may not be included on the geologic map. The material of these dunes is highly permeable, and readily absorbs the water that falls as precipitation.

LANDSLIDE BRECCIAS

Breccias produced by landslides are fairly common in southwestern Utah, particularly along such bold escarpments as those marking the west edge of the High Plateaus. The most prominent landslide in the region is about 2 miles south of Cedar City, where an area about 2 miles long and as much as half a mile wide is covered by a breccia consisting chiefly of blocks and rubble derived from the Cretaceous sandstone that caps the plateau farther east. The material of the breccia is well exposed south from Cedar City along the road that makes use of the favorable gradient to the top of the plateau. The breccia, which has been deposited upon strata of Triassic and Jurassic age, has interrupted the drainage of one of the smaller streams, so that a small pond, Greens Lake, is formed about

2,000 feet above the base of the plateau. About a mile farther south another landslide, which has extended to the floor of the valley, comprises chiefly fragments of basalt similar to that which caps the plateau east of that landslide area.

Landslide breccias of this sort may be identified elsewhere along the margin of the plateau, most of them covering too small an area to be shown on the geologic map. Doubtless landslides have occurred throughout the period since the bold escarpments were first formed, but where the breccia can be identified it must of necessity have been rather recent in origin, for it forms only along steep slopes where gradational processes are exceptionally active and where the products of a landslide quickly lose their identity. The interruption of drainage by the landslide south of Cedar City, which can be only temporary on so steep a slope, is itself an indication of the recency of the landslide. The materials are unsorted and generally impervious.

ALLUVIUM

Cedar City and Parowan Valleys are lowland areas in which great thicknesses of debris are accumulating as a result of great erosional activity in the adjacent highlands. A minor amount of this debris has been re-sorted in ancient or modern lakes situated on the lowest part of the valley floor, and a smaller amount has been modified by wind action, but the great bulk of the material has been deposited directly by streams, forming alluvial cones, fans, and piedmont plains along the borders of the valleys and the comparatively level alluvial plain that makes up the valley floor; hence alluvium constitutes the major part of the valley fill. These deposits include many highly permeable beds that constitute the principal source of ground water in both Cedar City and Parowan Valleys.

The unconsolidated materials that form the upper part of the valley fill are exposed in shallow pits, road cuts, and banks of stream channels. The materials forming the upper part of the Coal Creek fan, as seen in several places in and about Cedar City, include poorly sorted sand, gravel, and subrounded boulders as much as 5 feet across buried under a soil layer that is rarely more than 3 or 4 feet thick. The debris in the channels of Coal Creek in Cedar City (pl. 7, *B*) is of comparable coarseness, and cobbles or boulders several inches in diameter may be transported as much as 3 miles from the mouth of the canyon. At lower elevations the surficial material of the fan is prevailingly finer, and silt and fine sand are the most common materials north of the midvalley road, about 7 miles from the mouth of the canyon. On each of the alluvial fans and cones in Cedar City and Parowan Valleys, there is a comparable gradation in size of material, from coarse gravel and boulders at the apex to fine stuff lower on the fan. Deposition of these alluvial materials is highly irregular, however, for coarse detritus may be transported several miles down the slopes of the fan by a stream at flood stage, and silt and clay may be left near the apex during the decline from the flood stage. Because of continual changes in stream-carrying power as well as in the positions of stream channels, the alluvial gravel, sand, and silt are characteristically deposited in discontinuous lenticular beds of variable thickness and areal extent.

The aggradation that has resulted in these alluvial deposits is continuing today, and the upper surfaces of the fans and plains are obviously quite recent. Similar aggradational processes have been going on throughout the Quaternary and during most of the Tertiary, probably ever since the deposition of the Wasatch formation of Eocene age, and the total thickness of alluvium in the valleys would thus include sediments of all ages from early Tertiary to Recent. Alluvium of Tertiary age would doubtless be buried to considerable depths by more recent accumulations, but might be encountered in deep wells.

The central parts of Cedar City and Parowan Valleys have been graded to comparatively level plains, chiefly by the action of the principal streams. This valley floor is particularly well marked in Cedar City Valley, having been developed chiefly by Coal Creek. On the geologic map (pl. 3) the limit of the valley floor in Cedar City Valley is marked by a dotted line. Throughout much of the area this boundary is distinct and is marked by a sharp change in slope between the valley floor and the steeper fans and cones adjacent to it; elsewhere the valley floor grades imperceptibly into the steeper alluvial slopes that border the valley, and the boundary is an arbitrary one. This boundary is not based upon any difference in geologic age, for the material of the steeply sloping fans may be as recent as that forming the valley floor. Rather, the boundary is a topographic one, separating the well-graded central valley floor from the steeply sloping piles of poorly sorted torrential deposits. It happens also to be a sort of economic boundary, for the development of ground water is practically limited to the area of the valley floor. Under the steep alluvial slopes that border the valley floor the water table may be very little higher than under the valley floor; consequently water is likely to be encountered at such great depth below the land surface that the pumping lift makes its use uneconomic.

The central part of Parowan Valley is analogous to that of Cedar City Valley, having similarly been formed largely by the action of the principal streams. It is by no means as evenly graded as the floor of Cedar City Valley, partly because several of the contributing streams in Parowan Valley are of comparable magnitude, and no one stream has the outstanding position that Coal Creek holds in Cedar City Valley; and partly because recent faulting and the action of wind to form sand dunes have produced minor irregularities. Thus the central part of the valley could hardly be termed a valley floor in the sense used in Cedar City Valley.

GEOLOGIC DATA DERIVED FROM WELLS

Practically all the wells in eastern Iron County have been drilled or dug in the alluvium that makes up the valley fill in Cedar City and Parowan Valleys. Most of the available information concerning the depth, nature, and composition of the alluvium is derived from these wells. None is known to have encountered bedrock, and hence the depths reported for the deeper wells constitute a minimum estimate of the thickness of the unconsolidated deposits at the well site. The nature and composition of the materials is indicated in well logs kept by the drillers and also, to some extent, in chemical analyses of water obtained from wells.

DATA FROM WELL LOGS

In most of the drillers' logs gravel, sand, and clay are commonly distinguished, but the very poor sorting characteristic of these unconsolidated sediments where they are exposed in shallow trenches and pits may be presumed to be likewise characteristic at the depths encountered in wells, so that these terms as used would signify merely the driller's opinion of the predominant texture being penetrated. Even so, the terms are loosely used, and one man's "clay" may be another man's "sand" or "clay and gravel." Furthermore, a large proportion of the wells in Iron County, including practically all that have a diameter of less than 8 inches, have been jetted, and the driller's record for these wells is likely to be exceedingly inaccurate.

Most of the data concerning wells in both Cedar City and Parowan Valleys has been obtained from notices of claims to underground waters filed with the Utah State engineer. In these notices well owners are required to set forth details of well construction and equipment, history of development, use of water, and other information which might assist in establishing their right to appropriate water according to the provisions of the Underground Water Law of March 1935. Because most of the wells were constructed before these notices of claims were filed, the information set forth on the claims has been dependent in large part upon memories of owners, tenants, or drillers, and may be inaccurate or incomplete, especially for the older wells. Thus, in Cedar City Valley about 350 wells are listed by the State engineer, of which the depths are reported for about 300 and well logs are available for about 60. Information is more fragmentary in Parowan Valley, where about 400 wells are known, but the depths of only 210 are reported (many of these in round figures that suggest approximations), and logs are available for only 15 wells.

CEDAR CITY VALLEY

The great majority of wells in Cedar City Valley are constructed on the alluvial fan of Coal Creek, and at least half the wells in the valley are located in T. 35 S., R. 11 W. Most of the other wells are located on the alluvial fans of the other principal tributaries to the valley, especially Queatchupah, Kanarra, and Shurtz Creeks. No wells are known to have been constructed on the present beds of Shurtz and Rush Lakes, and no logs are available for wells drilled in the vicinities of these lakes, which might have penetrated lacustrine or playa deposits in ancient and perhaps larger predecessors of these lakes. Thus the available information applies chiefly to the alluvial deposits in the valley, particularly to those that make up the larger alluvial fans.

The deepest well in the valley—well (C–34–11)20ddd1— [43] penetrated unconsolidated sediments to a reported depth of 960 feet in the north-central part of the valley. No log is available for this well, but bedrock was not reported, and it appears that the valley fill in the vicinity of the well has a thickness greater than the 960 feet penetrated by the well. Three wells in the valley are reported to be 500 to 600 feet deep, and these penetrated only unconsolidated sediments.

Logs for 10 wells in Cedar City Valley and one well in Iron Springs Gap are presented below. These selected logs are typical of the best of the 60 available logs for wells in Cedar City Valley.

[43] The well number indicates the location of the well with reference to land subdivision, according to a system adopted by the Utah State engineer, and described in his Twentieth Biennial Report, page 87, 1936. Briefly, the State is divided into four quadrants by the Salt Lake base and meridian, and, according to the well-numbering system, these quadrants are designated by capital letters, A for the northeast quadrant, representing townships north, 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 one of these letters, a figure showing township, and a figure showing range. Thus, in the number of the well here cited, the portion within parentheses indicates that the well is in T. 34 S., R. 11 W. The number following the parentheses designates the section, and the lower-case letters following the section number give the location of the well within the section, the first letter indicated the quarter section (the letters a, b, c, d representing respectively the northeast, northwest, southwest, and southeast quarters, as before), and succeeding letters showing location within the quarter section down to a 10-acre tract. The final number merely designates the particular well within the 10-acre tract. Thus, number (C-34-11) 20ddd1 represents well 1 in the SE¼SE¼SE¼ sec. 20, T. 34 S., R. 11 W.

Well (C-35-11)27cdd1. State claim 8182. Grant Hunter and others, owners

[Drilled 147 feet deep for the Drought Relief Administration in June 1934 by R. L. Halterman. One of the highest irrigation pump wells in the Coal Creek district.]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Soil and clay	19	19	Gravel, loose	1	100
Gravel, small boulders, clay, mixed	38	57	Gravel, boulders, clay, mixed	15	115
Gravel	3	60	Gravel, loose	3	118
Gravel, boulders, clay, mixed	10	70	Gravel, coarse, clay, mixed	9	127
Gravel, coarse, loose	5	75	Gravel, fine sand	5	132
Gravel, coarse, clay, mixed	6	81	Gravel, coarse, clay, mixed	7	139
Gravel, fine, and clay	3	84	Gravel, loose	1	140
Gravel, boulders, clay, mixed	15	99	Gravel, clay, mixed	3	143
			Gravel, medium, loose	4	147

Well (C-35-11)10cdd1. State claim 6740. Federal Land Bank of Berkeley, owner

[Drilled 499 feet deep in April 1923 by R. L. Halterman. Domestic and stock well on the northern part of the Coal Creek alluvial fan, in the Midvalley district.]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Sand and clay	73	73	Sand and clay	11	337
Gravel	18	91	Gravel (flow 25 g.p.m.)	10	347
Sand and clay	111	202	Clay	15	362
Gravel (artesian flow 3 g.p.m.)	25	207	Gravel (flow 5 g.p.m.)	4	366
Clay and gravel	25	232	Sand and clay	50	416
Gravel (flow 20 g.p.m.)	11	243	Gravel (flow 10 g.p.m.)	10	426
Sand, clay, and gravel	50	293	Clay	8	434
Gravel (flow 50 g.p.m.)	9	302	Gravel (flow 8 g.p.m.)	5	439
Clay and gravel	21	323	Clay, sand, and gravel	60	499
Gravel (flow 12 g.p.m.)	3	306			

Well (C-36-12)12dba1. State claim 15411. Branch Agricultural College, owner

[Drilled 600 feet deep in July 1925 by S. A. Halterman. Irrigation pump well on the western part of the Coal Creek alluvial fan, in the Iron Springs district.]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Sand and clay	7	7	Clay	4	285
Sand, fine	2	9	Sand, fine	3	288
Clay	18	27	Clay	23	311
Sand, fine, surface water	3	30	Sand, gravel, and cobble rock	31	342
Clay	24	54	Clay	3	345
Sand, fine	5	59	Sand, gravel, and cobble rock	26	371
Clay	30	89	Clay	3	374
Sand, fine	10	99	Sand, fine	4	378
Clay	11	110	Clay	3	381
Sand, coarse	4	114	Sand, fine	5	386
Clay	6	120	Clay	2	388
Sand, fine	7	127	Sand, fine	3	391
Clay	3	130	Clay	6	397
Sand, fine	5	135	Sand, fine	7	404
Clay	4	139	Clay	3	407
Sand, fine	2	141	Sand, gravel, and cobble rock	24	431
Clay	3	144	Sand, fine	3	434
Sand, fine	8	152	Cobble rock	11	445
Clay	18	170	Clay	30	475
Sand, fine	3	173	Sand, gravel, and cobble rock	21	496
Clay	2	175	Sand, fine	5	501
Sand, fine	3	178	Gravel	4	505
Clay	3	181	Clay	3	508
Sand, fine	6	187	Sand, fine	14	522
Clay	19	206	Clay	3	525
Sand, fine (flow 5 gal. per min.)	5	211	Gravel	2	527
Clay	3	214	Clay	2	529
Sand, coarse	4	218	Sand, fine	1	530
Clay	3	221	Clay	7	537
Sand, fine	3	224	Sand, fine	5	542
Clay	16	240	Clay	7	549
Sand, fine	2	242	Gravel	7	556
Clay	10	252	Clay	3	559
Sand, fine	8	260	Sand, fine	2	561
Clay	5	265	Sand and cobble rock	4	565
Sand, fine	3	268	Clay	9	574
Clay	8	276	Sand, fine	11	585
Sand and gravel	5	281	Clay	6	591
			Sand and gravel	9	600

Well (C-33-11)30ddd1. State claim 6005. G. P. Stapley, owner

[Drilled 250 feet deep in 1930 by Fred Perry. Unused well drilled for irrigation near the north end of Cedar City Valley, about midway between Rush Lake and Twenty mile Gap.]

	Thickness (feet)	Depth (feet)
Sand and clay, caving	55	55
Gravel, water-bearing	5	60
Sand and clay	40	100
Sand and clay, some water-bearing strata	150	250

Well (C-35-12)34dcd1. State claim 4873. R. J. and W. M. Shay, owners

[Drilled 120 feet deep about 1925 by Guy Odin. Log from records of Arthur Fife. Irrigation pump well on western part of Coal Creek alluvial fan, in the Iron Springs district.]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Sand and clay	14	14	Gravel and sand	24	87
Clay	34	48	Clay	6	93
Sand	5	53	Gravel	4	97
Sand and gravel	4	57	Clay	3	100
Clay	3	60	Coarse gravel	8	108
Boulders	3	63			

Well (C-35-12)18ddd1. State claim 4258. Los Angeles & Salt Lake Railroad, owner

[Drilled 282 feet deep in March 1924 by Roscoe Moss. Railroad well at Iron Springs station, in Iron Springs Gap.]

	Thickness (feet)	Depth (feet)
Quaternary alluvium:		
Soil (water at 11 feet)	22	22
Gravel, water-bearing	2	24
Clay, red	2	26
Undifferentiated Cretaceous (?):		
Rock	45	71
Sandstone	17	88
Conglomerate	69	157
Sandstone	123	280
Rock, hard	2	282

Well (C-35-11)13ddb2. State claim 8178. Union Field Irrigation Co., owner

Drilled 166 feet deep for the Drought Relief Administration in July 1934 by C. N. Quinn. Irrigation pump well in the Enoch district.]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Soil	9	9	Boulders	3	73
Clay	31	40	Gravel and clay	31	104
Boulders	15	55	Gravel, water-bearing	10	114
Gravel, water-bearing	10	65	Clay	2	116
Clay	5	70	Gravel, water-bearing	50	166

Well (C-36-11)31ada1. State claim 8179. Village of Hamiltons Fort, owner

[Drilled 210 feet deep for the Drought Relief Administration in November 1934 by E. H. Douglas. Culinary pump well on the Shurtz Creek alluvial fan.]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Clay	16	16	Gravel and rock	14	116
Gravel and rock	12	28	Clay	29	145
Clay	17	45	Gravel and rock	27	172
Gravel and rock	40	85	Gravel, water-bearing	20	192
Clay	17	102	Clay	18	210

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Well (C-36-12)36daa1. Drought Relief Administration, owner

Drilled 308 feet deep in August 1934 by Harry Stonehill. Unused well drilled for irrigation on the Shurtz Creek alluvial fan.]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Soil	24	24	Clay	8	204
Gravel	2	26	Gravel	2	206
Gravel and clay	39	65	Clay	12	218
Clay, water at 107 feet	43	108	Gravel, some clay, water-bearing	17	235
Gravel	5	113	Clay, yellow, hard	23	258
Clay	17	130	Gravel and sand	24	282
Gravel, some clay	20	150	Clay	26	308
Clay	40	190			
Gravel	6	196			

Well (C-37-12)4bcb1. State claim 13749. F. A. Palmer, owner

[Drilled 208 feet deep in July 1929 by Fred Perry. Unused flowing well drilled for irrigation, on the Queatchupah Creek alluvial fan.]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Clay	46	46	Clay, sand, and gravel	23	121
Gravel	3	49	Gravel	8	129
Clay, blue	14	63	Clay	28	157
Gravel	2	65	Gravel	2	159
Clay and sand	25	90	Clay	41	200
Gravel	8	98	Gravel	8	208

Well (C-37-12)34abb1. State claims 1646 and 8184. Kanarra Field Irrigation & Reservoir Co., owner

[Drilled 190 feet deep for the Drought Relief Administration in August 1934 by C. N. Quinn. Irrigation pump well on the Kanarra Creek alluvial fan.]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Soil	18	18	Clay	6	96
Sand and clay	30	48	Gravel	58	154
Gravel	8	52	Clay	2	156
Clay	12	64	Gravel, coarse	34	190
Gravel	26	90			

The drillers' logs for several of the wells in Cedar City Valley form the basis for the profiles that comprise figures 2 and 3. In these profiles the logs are shown graphically in their proper relation to sea-level, and the distance between the well sections on the graph is proportional to the distance between wells. The wells represented by the sections of figure 2 are approximately on a line trending S. 60° E. along the alluvial fan of Coal Creek; well 27adc1, on the right, is highest, and the others are progressively farther from the apex of the fan. In alluvial sediments such as those encountered on this fan, where irregular lenticular deposition is the rule rather than the exception, close correlation of the individual strata reported in the several wells would be a questionable undertaking. Each well section in this profile, however, contains a zone in which coarser sediments predominate. This zone is thickest in the wells nearest to the head of the fan, and becomes thinner to the northwest. It is within 20 to 40 feet of the surface in the higher wells, and more than 60 feet below the surface in the wells farthest from the source of the material. In figure 3, comprising a profile parallel to and about 2½ miles north of that shown in figure 2, the sediments in all wells are of prevailingly finer texture (except well 13ddb2, which is within a quarter of a mile of the edge of the valley floor and probably includes sediments from the adjacent foothills) as might be expected in wells farther out on the Coal Creek fan.

In these wells, likewise, there is a zone of coarser sediments, generally thinner than in the wells included in figure 2, and 70 to 90 feet below the surface.

Practically all the available logs for wells in Ts. 35 and 36 S., R.11 W., show a similar sequence of finer sediments immediately beneath the surface and a zone of coarser material below. The thickness of these fine sediments and of the underlying coarser materials as found in the well logs is shown in plate 8. The gravel deposits are evidently thickest in wells nearest to the head of the Coal Creek alluvial fan, and in these wells the gravel is encountered within 10 or 15 feet of the surface. In the wells farther down the slopes of the fan, the gravel zone becomes progressively thinner and farther below the surface. On the upper part of the Coal Creek fan, above the limit of the area where wells have been drilled for irrigation, the creek is depositing coarse gravel in its channel. Shallow excavations and pits in this area indicate that coarse deposits lie very close to the surface, and the finer sediments that underlie the surface farther down the fan are very thin or absent on the upper part. Thus it appears that the head of the fan is and has been the site of deposition of the coarsest detritus that has been brought down the canyon. The finer sediments that underlie the surface of the lower part of the fan, including the area where wells are pumped for irrigation, are contemporaneous with the upper part of these gravels and were likely deposited under conditions approximating those today.

The zone of coarse materials that underlies these finer sediments throughout most of the pumping district is indicative that the deposition of coarse detritus has in the past extended much farther down the slopes

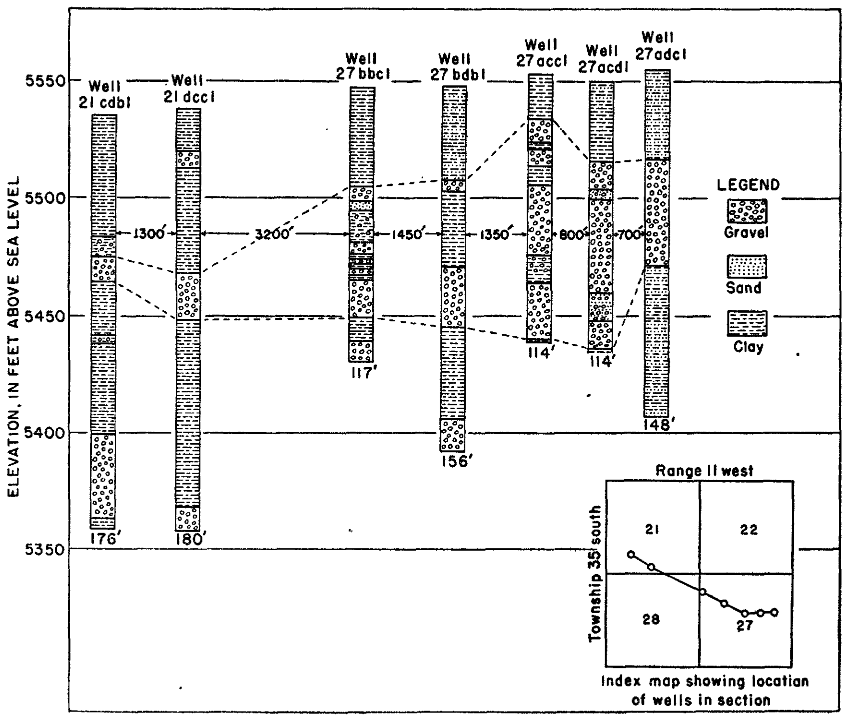

FIGURE 2.—Logs of seven wells in Cedar City Valley and suggested correlations of the coarser sediments.

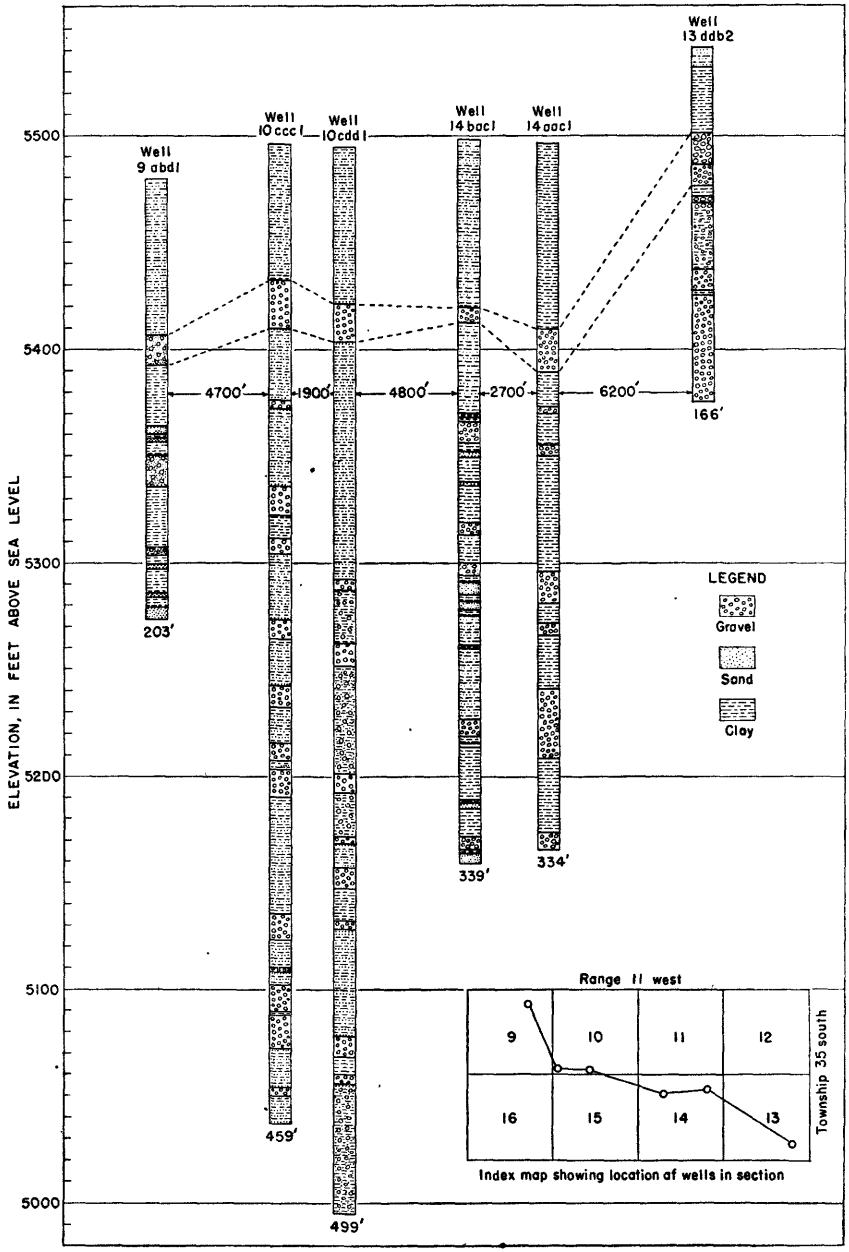

FIGURE 3.—Logs of six wells in Cedar City Valley and suggested correlations of the coarser sediments.

of the fan than at present, at a time when Coal Creek must have had considerably greater carrying power and presumably much larger volume than it has today. Because larger streams with great carrying power are generally characteristic of the glacial stages of the Pleistocene, which in Utah culminated in Lake Bonneville, it is inferred that these coarse gravels may be correlated with Lake Bonneville sediments in other parts of Utah. That other streams entering the valley formerly had greater capacity than today is suggested in logs for wells located on the fans of Queatchupah Creek and Shurtz Creek. (See p. 42.) In both these wells thick gravel deposits were encountered at depths of about 40 feet.

Wells on the western part of the Coal Creek alluvial fan, particularly in T. 36 S., R. 12 W., commonly have not penetrated thick gravel deposits at depths comparable to the gravel encountered in wells on the fan farther east. In plate 9 the logs of several of these wells on the western part of the fan, and those of several others farther east, are graphically portrayed. The logs for the wells forming the easternmost profile (B – B') show the gravel zone that has been described above to be encountered at depths ranging from 33 feet in well (C-36-11)8cab1 to 73 feet in well (C-35-11)9abd1. By contrast, in six of the wells forming profile A – A' the gravel strata encountered in the first 200 feet of drilling totaled 10 feet or less, and finer sediments predominated to depths ranging from 240 to 350 feet. Coarse detritus reached the area in the past, however, as shown by considerable thicknesses of gravel encountered in wells drilled more than 300 feet deep. The thickness of these coarse materials is comparable to that encountered in wells farther east, but the depth to these gravels is more than 200 feet greater. It is suggested that these gravels found at considerable depth on the western part of the fan may be approximately contemporaneous with the coarse detritus at shallower depths under the fan farther east, and that the present difference in depth below the surface is due to displacement along the Stockyards fault. (See p. 59.)

During 1935 the Drought Relief Administration prospected for water on the broad alluvial plain that rises from the Cedar City Valley floor north from Rush Lake, and the well site is about 3 miles from the valley floor. The well was drilled to a depth of 910 feet, but it failed to encounter water sufficient for stock and was abandoned. So far as known, this is the only attempt to develop water at some distance from the valley floor; all other wells are located either on the valley floor or within a few hundred yards of it. The driller's log for this well follows.

Well (C-35-11)15bbb1. Drought Relief Administration, owner

[Drilled 910 feet deep in January 1935 by R. L. Halterman. Unused stock well on the alluvial plain about 5 miles northwest of Rush Lake.]

	Thickness (feet)	Depth (feet)
Quaternary alluvium:		
Sand, clay, and fine gravel	54	54
Undifferentiated Quaternary and possibly Tertiary sediments, including the Wasatch formation in part:		
Clay, pink and brown	246	300
Clay, gray, with red layers	53	353
Clay, dark gray	59	412
Shale, gray	1	413
Clay	83	496
Sand, water-bearing	2	498
Clay, various colors	412	910

PAROWAN VALLEY

The wells constructed for water in Parowan Valley are distributed rather widely over the valley floor. Most of these wells are jetted artesian wells, however, and little information is available concerning them. Of nearly 400 known wells in the valley, the depth is reported for only 210, and in many of these the depth reported is only an approximation. The deepest well is said to be 740 feet deep, and 26 wells are reported to be more than 500 feet deep. All these deep wells were constructed in Ts. 33 and 34 S., R. 9 W., and are presumed to have penetrated only unconsolidated deposits; thus the valley fill in the center of the valley is no doubt more than 500 feet thick.

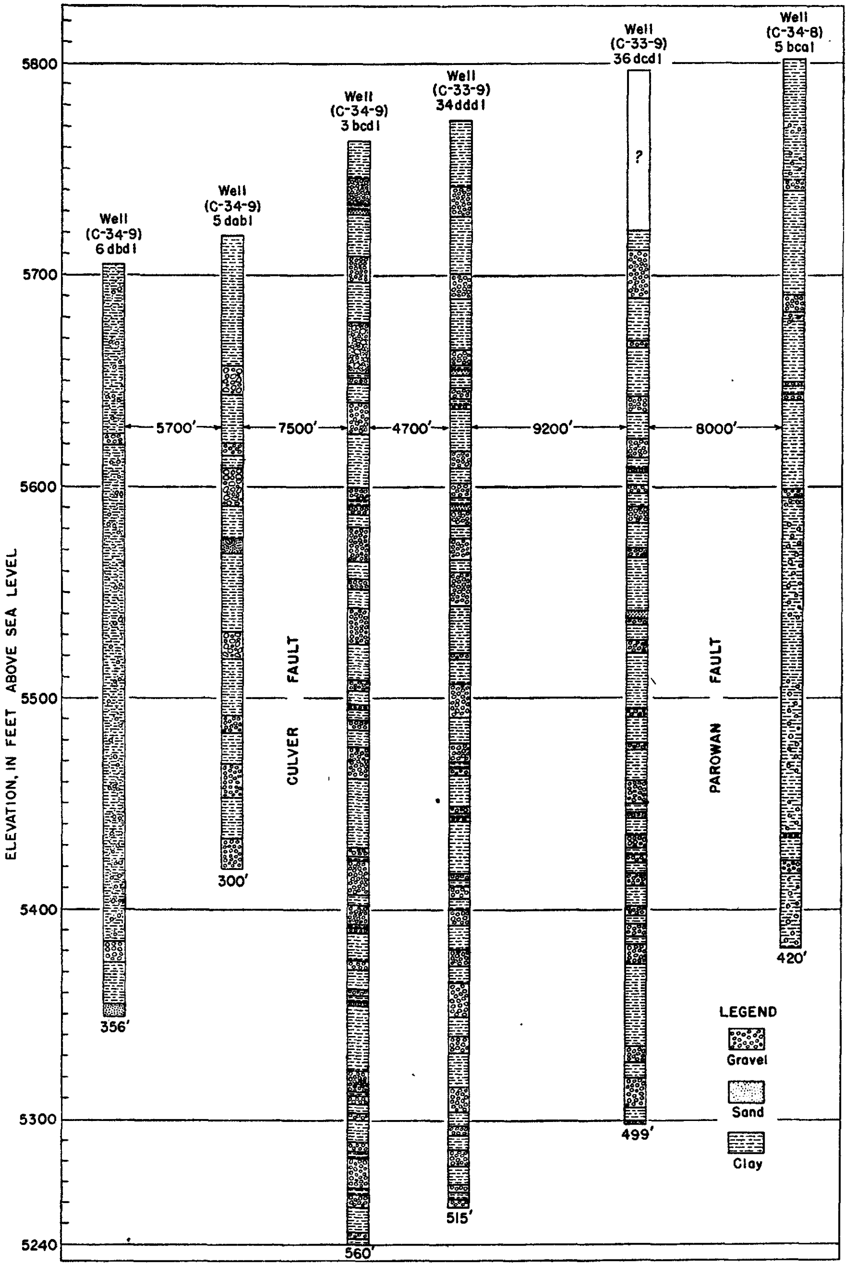

FIGURE 4.—Logs of six wells in Parowan Valley that are located near the east-west line that forms the south boundary of T. 33 S.

Logs are available for only 15 wells in Parowan Valley, most of which are in the pumping district northwest of the town of Parowan. Three typical logs are presented below. These and three other logs also are shown graphically in figure 4. Two recent faults cross the line of this profile. (See pp. 60.) The logs show no clear basis for correlation of strata on opposite sides of these faults; hence the displacement along these faults since the deposition of the beds shown in the well logs could not be determined. For the three wells located between the Culver and Parowan faults an attempt at correlation of beds has been made, based on the assumption that the form of the Parowan Creek fan has not varied greatly during its accumulation, and that the beds therefore would be more or less parallel to the present surface. The result, shown on figure 4, appears at least to be plausible.

Well (C-34-8)5bca1. Drought Relief Administration, owner

[Drilled 420 feet deep in October 1934 by R. L. Halterman. Unused irrigation well near the south end of the Red Creek alluvial fan, 2 miles east of the area where wells are pumped for irrigation.]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Clay	30	30	Gravel	4	207
Clay and gravel	6	36	Clay and gravel	5	212
Clay	7	43	Clay	6	218
Clay and gravel	14	57	Clay and gravel	49	267
Gravel	5	62	Clay	25	292
Clay	49	111	Clay and gravel	46	338
Gravel	8	119	Clay	12	350
Clay and gravel	7	126	Clay and gravel	16	366
Clay	26	152	Gravel	2	368
Gravel	2	154	Clay	11	379
Clay	4	158	Gravel	6	385
Gravel	3	161	Clay and gravel	35	420
Clay	42	203	Gravel	....	....

Well (C-34-9)3bcd1. State claim 920. S. A. Halterman, owner

[Drilled 560 feet deep in May 1926 by the owner. Irrigation pump well near the center of the irrigation pumping district.]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Clay	17	17	Gravel and sand (small flow)	15	301
Gravel and sand, some clay	12	29	Clay	33	334
Clay	3	32	Gravel and sand (small flow)	4	338
Sand	2	34	Clay	2	340
Clay	20	54	Gravel and sand (small flow)	16	356
Gravel and sand (flow 3 gal. per min.)	12	66	Clay	5	361
Clay	19	85	Gravel and sand (small flow)	9	370
Boulders, gravel, and sand (flow 3 gal. per min.)	24	109	Clay	2	372
Clay	2	111	Gravel	2	374
Gravel (flow 8 g. p. m.)	3	114	Clay	13	387
Clay	9	123	Gravel and sand (small flow)	5	392
Gravel and sand (small flow)	15	138	Clay	9	401
Clay	25	163	Gravel and sand	3	404
Gravel and sand, cemented	6	169	Clay	3	407
Clay	3	172	Gravel and sand	2	409
Gravel and sand	4	176	Clay	31	440
Clay	6	182	Gravel and sand (small flow)	10	450
Gravel and sand (small flow)	16	198	Clay	2	452
Clay	8	206	Gravel and sand	4	456
Gravel and sand (small flow)	5	211	Clay	4	460
Clay	9	220	Gravel and sand	3	463
Gravel and sand	17	237	Clay	11	474
Clay	17	254	Gravel and sand	4	478
Gravel and sand (small flow)	5	259	Clay	3	481
Clay	7	266	Gravel and sand (water)	15	496
Gravel	2	268	Clay	3	499
Clay	5	273	Gravel and sand	6	505
Gravel and sand	5	278	Hardpan	12	517
Clay	8	286	Gravel and sand	3	520
			Clay	37	557
			Gravel and sand	3	560

Well (C-34-9)5dab1. State claim 5088. J. C. Robinson, owner

[Jetted 300 feet deep in 1918. Stock well near the west edge of the irrigation pumping district.]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Clay	61	61	Clay	37	187
Gravel, coarse	14	75	Gravel, coarse	13	200
Clay	23	98	Clay	27	227
Gravel	6	104	Gravel	8	235
Clay	6	110	Clay	15	250
Gravel, coarse	18	128	Gravel	16	266
Clay	15	143	Clay	19	285
Sand	7	150	Gravel	15	300

DATA FROM CHEMICAL ANALYSES OF WATER IN WELLS

Throughout the Great Basin and other arid regions in the southwestern United States the accumulation of chemical deposits by dessication and evaporation is a common geologic phenomenon. Such evaporites are accumulating at the present time in playas on the floors of Cedar City and Parowan Valleys. None of the available logs for wells in these valleys shows the presence of recognizable beds of these chemical deposits. Our only clues concerning the existence of evaporites in the great thickness of unconsolidated sediments that has filled these valleys, therefore, are obtained from chemical analyses of the water that moves within these sediments and is subsequently discharged from wells or springs.

Chemical analyses of water from numerous wells in Cedar City and Parowan Valleys, presented elsewhere in this report (pp. 106, 173), serve to substantiate some of the conclusions regarding the sources and movements of ground water. The discussion here is limited to indications as to the composition and origin of the sediments under the valley floor, which are obtained especially from the analyses of the chloride content of the water in wells. The chloride content of the streams that enter the valleys is extremely low, ordinarily considerably lower than that of water in wells. Presumably, therefore, the chloride content of ground water has been increased by dissolving certain salts as it passes through the unconsolidated sediments, and it may be inferred that these soluble salts have accumulated among the unconsolidated deposits because of evaporation.

In comparison with other areas in the Great Basin [44] the amount of chloride dissolved in the ground water in Cedar City and Parawon Valleys is low and thus, inferentially, chemical deposits due to aridity have not been a significant item in the accumulation of the great amounts of unconsolidated material in the two valleys. In Parowan Valley the chloride in ground water is generally less than 60 parts per million, and in nine wells and three springs less than half a mile from Little Salt Lake the chloride content ranges from 10 to 40 parts per million. The analyses of chloride content provide no basis for differentiation according to depth. In all these analyses there is no evidence to show that, during the accumulation of unconsolidated materials in Parowan Valley, there ever was an undrained basin, similar to that now occupied by Little Salt Lake, in which playa deposits formerly were accumulated.

In Cedar City Valley the percentage of chlorides in ground water is likewise quite low, except in certain shallow wells. The chloride content in wells on both sides of Shurtz Lake ranges from 5 to 20 parts per million,

[44] Taylor, G. H., and Leggette, R. M., Ground water in the Jordan River Valley, Utah: U. S. Geol. Survey Water-Supply Paper (in preparation). As shown in figure 10, the chloride content in wells throughout the lower, western half of the Jordan River Valley ordinarily exceeds 100 p. p. m., and over an extensive area it exceeds 300 p. p. m. and may run as high as 15,000 p. p. m.

A. CINDER CONE IN SEC. 17, T. 34 S., R. 10 W.

B. BASALT (QTb) IN CHANNEL AND ON THE VALLEY FLOOR SOUTH OF PARAGONAH.

C. SCARP OF THE ENOCH FAULT NORTHEAST OF THE VILLAGE OF ENOCH.

Fanglomerate terrace, clearly marked by shadows, is beyond the fault scarp. View southeastward toward the Kolob Plateau.

A. FANGLOMERATE EXPOSED IN ROAD CUT ALONG HIGHWAY ABOUT A MILE NORTH OF CEDAR CITY.

B. CHANNEL OF COAL CREEK AT APEX OF ALLUVIAL FAN.

offering no evidence of significant chemical deposits beneath the surface in that area, at least within the depths penetrated by wells. In the vicinity of Rush Lake the wells sampled show less than 100 parts per million of chloride, but very few wells have been drilled in that area, and the results are inconclusive as to the presence of evaporites among the unconsolidated materials beneath the surface.

STRUCTURE

Cedar City and Parowan Valleys lie entirely within the Basin and Range physiographic province, and their eastern margins constitute the west border of the Colorado Plateaus province. In respect to geologic structure, however, these valleys and the surrounding highlands occupy a transition zone between the two provinces, and the structural features in the region are in many respects similar to those in the Plateau province rather than to those in the Basin and Range province farther west. The major structural features of the Plateau province are the great tabular blocks that are raised to different elevations by normal faulting, and the rock strata included in these fault blocks have a gentle eastward dip that is primarily the result of tilting accompanying the faulting. The structure of Parowan Valley particularly is similar to that of the plateau farther east, and the strata bordering the valley on all sides have a comparable gentle eastward inclination; the structural units in the vicinity of the valley are exceptional chiefly because their altitude is far below that of the units of the plateau, and the lowest segments, under the floor of the valley, have been the scene of extensive deposition.

FOLDING

In many places in eastern Iron County, especially around the borders of Cedar City Valley, rock strata are steeply inclined and locally overturned. From Cedar City southward along the western base of the Kolob Plateau the Mesozoic and late Paleozoic strata form a sharp flexure, which is exposed in cross section along each of the canyons that drain the western edge of the plateau. Southeast of Kanarraville, near the south end of Cedar City Valley, overturned beds of the Kaibab limestone of Permian age crop out along the base of the plateau. The overlying Triassic strata are similarly overturned, but in the belt of outcrop of Navajo sandstone the inclination of the strata ranges from vertical through progressively gentler easterly dips until in the eastern part the upper Navajo is nearly horizontal. The overlying San Rafael group and Cretaceous strata similarly are gently inclined eastward.

In the drainage basin of Shurtz Creek the strata of the Chinle formation and Navajo sandstone have a northeasterly trend and are generally inclined steeply southeastward. The upper members of the San Rafael group and the overlying Cretaceous strata have progressively less inclination, and on the surface of the plateau they dip eastward at angles ordinarily less than 5°. The Lower Triassic Moenkopi strata, which appear along the western base of the plateau, likewise dip eastward at angles commonly not exceeding 15°, so that the regional structure here has the shape of a broad "S" curve.

In Coal Creek Canyon opposite Cedar City, the Triassic and some of the Jurassic strata have a northward strike and an easterly dip of 40° to 60°; farther east the members of the San Rafael group are folded, warped, and faulted in complex fashion; still farther east, the Cretaceous sandstone strata exhibit the gentle eastward dip that is characteristic of much of the Plateau country.

North of Coal Creek the outcrop belts of the Mesozoic strata veer northwestward and are cut off abruptly about 2 miles north of Cedar City by a fault that borders the valley. Here the strata involved in the flexure include Cretaceous as well as older Mesozoic formations, but not the Wasatch formation of Eocene age. The flexure continues southward beyond the limit of Cedar City Valley. It is roughly parallel to the Virgin anticline and other folds that have been described by Dobbin [45] and by Gardner. [46] The flexure observed from Cedar City southward probably represents the east limb of an asymmetrical anticline that was formed during the Laramide revolution, in late Cretaceous or early Eocene time, and that has been broken by one or more branches of the Hurricane fault. (See p. 51.) From the overturned strata that form this east limb in many places it is inferred that the compressive stresses responsible for the folding originated to the west.

Along the west margin of the upland south of Hamiltons Fort the Navajo sandstone is exposed in a narrow belt in which the beds dip about 30° southwestward. This small outcrop of Navajo sandstone may be a part of the western limb of the anticline whose east side is so prominently exposed along the edge of the plateau to the east.

Steeply inclined strata of Jurassic and Cretaceous age crop out in the range that separates Cedar City Valley from Parowan Valley, and are well exposed in Parowan Gap. Along the east edge of the northern part of Cedar City Valley the Navajo sandstone forms a prominent hogback about 2 miles long. Near the north end of this hogback the stream that once flowed through Parowan Gap has cut a canyon 400 feet deep, known as Hieroglyph Canyon because of the prehistoric markings carved upon the sandstone walls.

Less than a mile east of Hieroglyph Canyon the walls of Parowan Gap are formed of Cretaceous strata, which dip steeply westward. Farther east these steeply inclined strata are in fault contact with Cretaceous strata that dip gently eastward and that are exposed for a distance of more than a mile in the eastern part of Parowan Gap. High above the floor of Parowan Gap these gently inclined Cretaceous strata, as well as the nearly vertical Cretaceous beds farther west, are seen to be overlain by the basal conglomerate of the Wasatch formation (pl. 10, A) in nearly horizontal beds, and the folding and faulting are therefore dated as post-Cretaceous and pre-Wasatch, approximately the time of the Laramide revolution.

North of Parowan Gap the steeply inclined Cretaceous strata are for the most part concealed by the Wasatch formation, but there are scattered exposures in canyons and gullies at least as far as 2 miles north of the gap. South of the gap, likewise, the upturned Cretaceous rocks are mostly covered by the Wasatch formation, but they are exposed over a small area in secs. 3 and 4, T. 34 S., R. 10 W. South of these outcrops the upturned Cretaceous rocks are buried under the extensive basalt flows, which also cover the hogback of Navajo sandstone farther west.

The belt of steeply inclined Jurassic and Cretaceous strata exposed in Parowan Gap includes the only rocks in the northern part of the area that have been subjected to compressive stresses similar to those that produced the intense folding along the west edge of the Kolob Plateau from Cedar City southward. East of this belt the strata have a gentle easterly

[45] Dobbin, C. E., Geologic structure of the St. George district, Washington County, Utah: Am. Assoc. Petroleum Geologists Bull. vol. 23, p. 126, fig. 2, 1939.

[46] Gardner, L. S., Hurricane fault in southwestern Utah and northwestern Arizona: Am. Jour. Sci. vol. 239, p. 250, 1941.

inclination comparable to that of strata east of the folding on the Kolob Plateau. Possibly, then, this belt represents a northerly extension of the same fold as that which forms the west edge of the plateau south of Cedar City. Between this belt near Parowan Gap and the main folded mass near Cedar City, a distance of about 12 miles, the Mesozoic rocks are buried under an extensive cover of Quaternary basalt flows and alluvium, which prevents the tracing of this structural feature; and complex faulting subsequent to the period of folding makes correlation uncertain.

WARPING DUE TO INTRUSION

In the Iron Springs district the dominating geological features are three large andesitic masses, around which the sedimentary formations dip outward asymmetrically, very steeply at the contact, less steeply farther away. The structural features in this region are described in detail by Leith and Harder. [47] During the investigation covered by this report, practically no detailed geologic work was done in the Iron Springs district.

FAULTING

Faults constitute the dominant structural features throughout the eastern part of Iron County. They are common throughout the area, and have displacements ranging from a few feet to several thousand feet. The major physiographic features of the region have been produced chiefly by displacements along the larger faults, and even the minor faults find common topographic expression in escarpments or in the alinement of stream courses. Most of the faults observed appear to be high-angle normal faults, and the trace is generally fairly straight. Thrust faulting is also believed to have occurred, particularly in areas of intense folding.

In the geologic mapping, efforts were directed particularly toward locating the faults in the ranges and hills immediately adjacent to Cedar City and Parowan Valleys, especially those faults whose trend indicated that they might continue under the valleys. In this search use was made of aerial photographs taken for the Soil Conservation Service, United States Department of Agriculture. On these photographs the evidence of faults is in many places strikingly recorded. Nevertheless, it is probable that many of the minor faults and perhaps some of the major faults in the area have been missed.

HURRICANE FAULT ZONE

The master displacement which separates the High Plateaus of Utah from the Great Basin farther west is one of the most striking geologic features in the western United States, and was noted by the earliest geologists who visited the region. In 1903 Huntington and Goldthwait [48] described some of the structural and physiographic details along this displacement in the region beyond the south limit of the area covered in this report. Recently Gardner completed the detailed geologic mapping of the St. George basin in Washington County, Utah, including the area visited by Huntington and Goldthwait, and prepared a short preliminary report on the Hurricane fault in that area. [49] He stated [50] that the Hurricane fault in Washington County was not a simple, continuous fracture but

[47] Leith, C. K., and Harder, E. C., The iron ores of the Iron Spring district, Southern Utah: U. S. Geol. Survey Bull. 338, pp. 16-65, 1908.

[48] Huntington, Ellsworth, and Goldthwait, J. W., The Hurricane fault in southwestern Utah: Jour. Geology, vol. 11, pp. 46-63, 1903; The Hurricane fault in the Toquerville district, Utah: Harvard Coll. Mus. Comp. Zoology Bull. 42, pp. 199-259, 1904.

[49] Gardner, L. S., The Hurricane fault in southwestern Utah and northwestern Arizona: Am. Jour. Sci. vol. 239, pp. 241-260, 1941.

[50] Idem, p. 247.

that it comprised a zone of displacement that might be as much as 5 miles wide.

In Iron County the displacements that have raised the plateaus high above the Great Basin occupy a zone that is several miles wide at the southern limit of the area near Kanarraville and that increases in width northward. This zone is spoken of here as the Hurricane fault zone and embraces several structural units separated by major normal faults trending northward to northeastward.

FAULTED MARGIN OF THE MARKAGUNT PLATEAU

A bold, fairly straight escarpment forms the east border of Parowan Valley for several miles north of Paragonah. South of that town the valley is bordered by lower hills and ridges, behind which this same escarpment towers strikingly east and south of Parowan. The scarp is readily identified as a fault scarp, along which, in the vicinity of Paragonah, Cretaceous rocks are exposed on the upthrown (east) side, and outcrops of the Wasatch formation or alluvium of the valley floor appear on the downthrown side. The escarpment rises more than 1,500 feet above the valley and may have been higher immediately after the faulting. The downthrown block was dropped an indeterminate amount below the present valley floor, and the total displacement is therefore unknown, but it can safely be estimated as considerably greater than the present height of the escarpment. This displacement evidently occurred principally along one or two fairly clean fractures. Where the break is along a double line, slivers of the Wasatch formation are likely to occupy an intermediate position between the two main fault blocks. Such slivers border the valley floor east and southeast of Paragonah and are in contact with approximately horizontal Cretaceous sandstone to the east, and the fault plane that forms the contact appears in rather poor exposures to dip about 70° to westward.

Just south of Paragonah the east border of Parowan Valley consists of a rather low escarpment likewise formed by faulting. This fault continues northward from Paragonah, buried under alluvial materials of the valley for a distance of several miles at least. Southward one branch of the fault can be traced away from the valley border and southwestward across Parowan Creek Canyon to a probable junction with the major fault described above, about 3 miles southwest of Parowan. (See pl. 10, B.) Another branch forms the south wall of the valley at Parowan and appears to continue southwestward along United States Highway 91, intercepting or crossing several faults that have a more nearly northward trend.

The east wall of Parowan Valley is formed throughout most of its length by one or another of these three faults, which together occupy a zone not over 2 miles wide. This zone has commonly been considered to mark the continuation of the Hurricane fault, which has been mapped only as far north as the south end of Cedar City Valley.[51] From the geologic map (pl. 3), however, it appears that this narrow zone is only a small portion of the complex comprising the Hurricane fault zone, although it is admittedly a zone where major displacements have occurred.

At a greater distance east of Parowan Valley the sediments that underlie the plateau are broken along several faults that are approximately parallel to the faults along the margin of the valley and that are ½ mile to 2 miles apart in the area covered by the geologic map. The displace-

[51] Huntington and Goldthwait, op. cit., p. 460.

ments along these faults appear to have been rather large, as evidenced principally by present escarpments several hundred feet high.

PAROWAN VALLEY GRABEN

Most of the west border of Parowan Valley, like the east border, is formed by fault scarps, but these scarps are generally lower and less imposing than those on the east side of the valley. Northwest of the town of Summit the escarpment rises more than 1,000 feet above the valley, but its upper part is considerably eroded. The fault plane was observed in one exposure to dip eastward between 65° and 70° and to trend N. 25° E., parallel to the wall of the valley. Farther north, in sec. 22, T. 34 S., R. 10 W., the fault forks, the east branch continuing northeastward, largely concealed under alluvial and lacustrine sediments, and the west branch veering northward toward Parowan Gap and thence northeastward again. Near Parowan Gap the west branch divides and outlines a sliver of the Wasatch formation 2½ miles long and as much as 1,000 feet wide, which lies between the upthrown and downthrown blocks. North of Little Salt Lake the west edge of the valley generally abuts against an upfaulted block of the Tertiary acidic effusive rocks. Several outliers of basalt projecting above the floor east of this fault line probably represent portions of a block which rests between branches of the fault that follows the west edge of the valley. Thus, the western edge of Parowan Valley is defined by one or another of several faults occupying a zone not more than 2 miles wide and similar to the zone of faulting along the east edge of the valley, except that on the west side there is a downward displacement to the east.

These faults follow the edge of Parowan Valley only as far south as the north limit of township 35 south. From this line they continue southward across secs. 4 and 9, T. 35 S., R. 10 W., where they are for the most part buried under alluvium, and may be traced on southward through the rugged area southeast of Enoch. A small basin in the southeast quarter of section 9 apparently owes its origin to displacement along one of these faults. At the present time this basin, locally called Bolly Basin, has no outlet to Parowan Valley, and runoff from the hills to the south and east collects in a small pond on the floor of the basin and then gradually disappears by seepage and evaporation.

The Parowan Valley graben comprises the down-dropped blocks that are included between these faults, and thus has a width equal to that of Parowan Valley. Although faults that border the valley were not traced northward beyond its limits, it is likely that the graben structure continues northward and that the comparatively gentle grade of United States Highway 91 toward Beaver is made, at least in part, upon relatively low areas that form the northward continuation of the graben.

The graben structure likewise continues southward beyond the limit of Parowan Valley. In the drainage basins of Summit Creek and Winn Wash, T. 35 S., R. 10 W., the down-dropped graben blocks are capped by Tertiary and Quaternary volcanic rocks, and the adjacent uplifted units expose chiefly rocks of Cretaceous age. The faults that outline the graben are believed to cross Coal Creek Canyon respectively in the west part of sec. 17, T. 36 S., R. 10 W., and at Maple Creek Canyon, sec. 22, T. 36 S., R. 10 W., but the faults were not mapped in those areas. The displacement along these faults apparently decreases to the southward, and the graben structure thus becomes fainter and less distinct in that direction.

The Parowan Valley graben includes several roughly parallel blocks separated by faults of comparatively small displacement, which trend northeastward parallel to the length of the valley. The fault blocks appear at the surface at the north end of the valley, where the differential elevations produced by the faulting are believed to be largely preserved in the present topography. South of Parowan Valley several more or less parallel faults are intercepted or crossed by the fault that forms the south edge of the valley near Parowan. Between these extremities of the valley the faults traverse alluvial sediments for a distance of more than 20 miles. The traces of these faults in the alluvium are shown in part by scarps that have resulted from recent faulting, in part by springs whose alinement suggests structural control, and in part by evidence based on studies of ground-water movement.

The movement along certain faults in Parowan Valley has been so recent, or subsequent aggradation has been so slight, that the trace of the fault has been preserved in the unconsolidated sediments. Fault scarps in alluvium are more likely to be preserved in the western part of the valley, where the rate of accumulation of debris has been much slower than along the east side. In sec. 16, T. 32 S., R. 8 W., a fault trending N. 20° E. is indicated by a scarp about 25 feet high. (See pl. 11, A.) Recent movement along one of the faults forming the west border of Parowan Valley is indicated by a scarp about 40 feet high, easily recognized in the alluvial slope west of Little Salt Lake. (See pl. 11, B.) The alinement of certain ridges and knolls on the floor of Parowan Valley is also suggestive of structural control, and may be due at least in part to recent faulting.

Alinement of springs in certain parts of Parowan Valley further suggests the structural pattern underlying the floor of the valley. About 4 miles north of Paragonah, in secs. 8 and 17, T. 33 S., R. 8 W., there are more than 20 orifices of springs on the floor of the valley, most of which are located approximately along a line trending N. 20° E. across the two sections. The ground water discharged at these springs has doubtless been prevented from moving farther westward through the alluvium by a barrier that is probably parallel with the line of springs. Displacement of aquifers by faulting, even though the displacement totals only a few feet, may be sufficient to hinder circulation of ground water through its accustomed channels, and overflow at the surface through springs may result. In this particular area the alinement of springs suggests not only the presence of a fault that has broken the alluvial aquifiers but also the trend of the fault.

Other indications of faulting of the alluvium of Parowan Valley, as deduced from circulation of ground water in the valley, will be discussed later in this report.

RED HILLS HORST

The range between Cedar City Valley and Parowan Valley includes several structural units, of which the easternmost is an uplifted block here referred to as the Red Hills horst. It lies adjacent to the Parowan Valley graben and is separated therefrom by the fault zone that marks the west edge of Parowan Valley. The western edge of the Red Hills horst is formed by a normal fault that passes through the settlement of Enoch. From the south end of the Red Hills near Enoch, as far north as Parowan Gap, the width of the Red Hills horst averages 2 miles. North from the gap the horst appears to increase in width, but the structural features were not traced through the outcrops of volcanic rock that cover the horst toward the north end of Parowan Valley.

Beyond the south end of Parowan Valley the Red Hills horst is poorly defined. Apparently the structural unit is bounded by faults of no great displacement, and it is believed that as the Parowan Valley graben structure fades out to the southward, the Red Hills horst merges into the typical fault-block structure that underlies the Kolob Plateau to the east.

The Red Hills horst embraces all the higher ridges and peaks that are included in the Red Hills and in the Black Mountains farther north, many of which are more than 2,000 feet above the present floor of Parowan Valley. The present topography is suggestive that the Red Hills horst is probably the highest structural unit west of the plateaus. Furthermore, a very rough comparison of the position of stratigraphic units in the Red Hills horst and at the base of the Markagunt Plateau east of Parowan Valley indicates that, although the Parowan Valley graben may have been dropped many thousands of feet, the faulting on the west side of the graben has been of a magnitude comparable to that on the east side, and hence the movement of the Red Hills horst relative to the main plateau block has not been great. Thus, the base of the Wasatch formation near the east end of Parowan Gap is about 5,850 feet above sea level. Along the margin of the plateau near Paragonah, 10 miles to the east, the same contact is about 6,650 feet above sea level. The strata near Parowan Gap dip about 5° eastward, and those along the west margin of the plateau dip westward about the same amount. The difference in the displacement on the east and west sides of the Parowan Valley graben would be only the amount of the present difference of altitude, roughly 800 feet, if the strata of the involved blocks are approximately horizontal. These comparisons of course are only approximate, because the attitude of the strata concealed under Parowan Valley is unknown and because the horizon chosen for comparison, the Cretaceous-Eocene contact, is admittedly a rough and irregular surface. They serve to indicate, however, that the structure of Parowan Valley involves two relatively high units with a down-dropped block between, rather than a single high unit (the plateau), a zone of huge displacement, and a much lower unit or group of units comprising a part of the Great Basin.

ENOCH GRABEN

The Enoch graben comprises a depressed block 1 to 2 miles wide lying immediately west of the Red Hills horst. The structural unit is most conspicuously shown in the area covered by basalt flows east of Rush Lake, where both its east and west edges are bold, inward-facing escarpments. Three cinder cones, presumed to have spewed forth the basalt, are alined approximately along the center of the graben area, and lead to the suggestion that the dropping of the graben may have occurred contemporaneously with the basalt extrusion.

North of the area of basalt flows the Enoch graben comprises a belt of Tertiary sediments and volcanic rocks, across which even minor streams have cut rather broad valleys, suggesting that throughout the development of these stream courses the graben has been a depressed area. Still farther north the graben is composed of soft Eocene sediments which crop out along the eastern edge of Cedar City Valley and which have in part been reduced to the level of the valley.

The surface of the Enoch graben south of the basalt flows for about 3 miles is graded approximately to the level of the floor of Cedar City Valley and is separated therefrom by a discontinuous gravel ridge. Beyond the end of this gravel ridge the alluvium on the graben is continuous with that in Cedar City Valley farther west. Still farther south the graben area includes the rather narrow branch of Cedar City Valley that extends southward from Cedar City. (See p. 11.) The alinement of this valley, at right angles to the courses of the principal streams and parallel to the principal faults, indicates clearly that the valley owes its origin to the regional structure. Escarpments indicating recent faults of small displacement can be identified in the foothills east of this branch valley, and throughout much of its length the eastern margin is rather straight, suggesting that the valley is bounded by normal faults on this side. Near the mouth of Coal Creek, however, the east margin of the valley fill extends nearly a mile farther east than the presumed trace of the edge of the graben, probably because of rapid erosion by Coal Creek of the soft Moenkopi shales that crop out on the raised block.

The west edge of the Enoch graben south of Cedar City may be formed in part by faults that follow roughly the west edge of the valley fill, and probably also by faults that traverse the upland west and southwest of Cedar City. These latter faults are indicated by escarpments and by alinement of stream courses parallel to the direction of known faults. The Enoch graben ranges in width from about a mile to 1½ miles. It extends south as far as the prominent east-west fault that trends eastward up Muries Creek, which enters the main branch of Cedar City Valley about 2 miles north of Kanarraville, and no trace of the graben is shown in the structure south of this fault. Perhaps significant is the great extent of the basalt flows in the vicinity of the south end of this graben. Conceivably the graben structure here may be due at least in part, as it appears to be farther north, to relaxational movements made necessary by volcanic extrusions.

HAMILTONS FORT HORST

The Hamiltons Fort horst includes principally the uplands that lie north and south of the settlement of Hamiltons Fort. It is bounded on the east by the Enoch graben and on the west by the zone of faulting that occurs along the edge of the uplands. It is terminated at the south by the same curved eastward-trending fault that forms the south end of the Enoch graben. In these uplands the horst is ordinarily about 2 to 2½ miles wide. The raising of this block with respect to the adjacent Enoch graben must have been exceedingly slow, because not only Shurtz Creek but two very small streams farther north have been able to maintain their channels across the horst. North of Cedar City for about 7 miles the structural unit is not expressed in the topography, for it is buried under the extensive alluvial sediments that form the Cedar City valley floor. Farther north there are uplifted units that appear to comprise the northward continuation of the Hamiltons Fort horst, or at least its eastern part. About 1½ miles northwest of Enoch a narrow gravel ridge projects about 30 feet above the valley floor; the materials of this ridge are in all respects similar to those of the surrounding alluvial plain, as exposed in nearby pits, and the development of the ridge is ascribed to faulting of alluvial sediments. This ridge extends northward, broken in several places by drainage ways, and becomes somewhat broader and higher, so that it is about 2,000 feet wide and 150 feet higher than the adjacent valley floor about 2 miles southeast of Rush Lake. Farther north the uplifted block includes the basalt flows that border Cedar City Valley east of Rush Lake. The uppermost flows are as much as 300 feet above the valley floor at the lake, and the block is bounded on both sides by steep escarpments. Northeast of Rush Lake the horst again dwindles in width, and is only about 1,000 feet wide at the west end of Parowan Gap, where Hieroglyph Canyon has been cut into the Navajo sandstone that makes up the uplifted block. A few hundred yards north of Hieroglyph Canyon, the faults that outline the block of Navajo sandstone converge.

This block east of Rush Lake is considerably narrower than the horst in the vicinity of Hamiltons Fort. The west edge of the block may be formed by a fault that trends southwesterly across the Coal Creek fan and thence across the middle of the uplands near Cedar City, where it has left a prominent scarp in secs. 9 and 16, T. 36 S., R. 11 W.

The fault that forms the west margin of the Hamiltons Fort horst is the westernmost of the branches that can be traced southward into the Hurricane fault as described by Huntington and Goldthwait and others. It therefore is taken as the western limit of what has here been called the "Hurricane fault zone." North of the western edge of the upland near Cedar City the fault is concealed beneath Recent alluvial sediments. Its trace continues through the valley fill, as indicated by hydrologic studies (p. 88), trending N. 18° E. across the Coal Creek fan and probably somewhat more northerly in the vicinity of Rush Lake. A small outcrop of basalt that rises a few feet above the valley floor in sec. 11, T. 34 S., R. 11 W., may possibly be on the upthrown block east of the fault. The total displacement along this westernmost fault of the Hurricane fault zone cannot be determined because the downthrown block has everywhere been buried beneath unconsolidated materials. Faulting since the time of basalt extrusions is indicated by outcrops in secs. 1 and 12, T. 37 S., R. 12 W., where two outliers of what appears once to have been a continuous basalt flow suggest a displacement of 500 feet. The lower of these two outliers is now more than 200 feet above the valley floor, and it is likely that there has been further displacement along faults located west of the outlier. The post-basalt faulting at this point appears to have been sufficient at least to account for the present difference in elevation between the upland and the valley floor, approximately 700 feet. Farther north the upland is lower with respect to the valley floor, probably because the amount of displacement diminishes to the north. According to logs of wells on the Coal Creek alluvial fan, there has been a displacement of about 250 feet in the coarse alluvial sediments that are inferred to be approximately contemporaneous with Lake Bonneville. West of Rush Lake a small outlier of basalt is only a few feet above the alluvium, and, as far as the topographic evidence goes, any recent displacement along the fault must have been slight. Thus, according to available evidence, the western margin of the Hamiltons Fort horst is formed by a fault having a displacement of several hundred feet where it branches from the main Hurricane fault, and progressively less displacment to the north, so that beyond Rush Lake it may disappear entirely.

TOTAL DISPLACEMENT IN THE HURRICANE FAULT ZONE

Inasmuch as the Hurricane fault zone is several miles in width and comprises a number of branches along each of which there may be displacement of hundreds or thousands of feet, only the roughest estimates could be made as to the total amount of displacement involved. Undoubtedly the total displacement is greater than the present difference of elevation between Cedar City Valley and the plateau, 3,000 feet, because there has been a tremendous amount of aggradation in the valleys, and an equally great amount of erosion from the uplands. A rough estimate of the total displacement may be made near the south end of Cedar City Valley, where the Hurricane fault zone is narrowest.

A huge displacement along a single break is indicated along the canyon of Muries Creek in sec. 24, T. 37 S., R. 12 W., where the Kaibab limestone on the main Kolob Plateau block is within a quarter of a mile of the Wasatch formation at the south end of the relatively down-dropped Hamiltons Fort horst. The stratigraphic interval between these formations resting on opposite sides of the fault is more than 8,000 feet. Unfortunately the Kaibab limestone is overturned, and the stratigraphic interval does not afford a close estimate of the displacement along the fault, for continued erosion along the front of the plateau will tend to reduce the stratigraphic interval between formations on opposite sides of the fault. The figure, 8,000 feet, may be considerably greater than the true displacement along the fault, because of folding; certainly the displacement of the fault does not exceed this figure.

The displacement along the front of the plateau at Kanarraville includes the movement along the east-west fault just discussed, plus the movement along the fault that forms the west boundary of the Hamiltons Fort horst—a total displacement probably somewhat less than 9,000 feet. This figure includes only the displacement along the base of the plateau; displacement along other faults farther east within the Hurricane fault zone may increase the total displacement considerably.

FAULTING WEST OF THE HURRICANE FAULT ZONE

The Great Basin lies west of the Hurricane fault zone and includes a vast area in which faulting has had a dominant role in the development of the present land forms. The faulting in the vicinity of Cedar City Valley is therefore by no means limited to the Hurricane fault zone even though this zone may include the major displacements of the area.

IRON SPRINGS GRABEN

The Iron Springs graben includes the depressed block between the Hamiltons Fort horst and the raised blocks that are encountered in the mountainous areas west of Cedar City Valley. Its east margin is the fault that forms the west boundary of the Hurricane fault zone, and thus becomes less distinct from the Hamiltons Fort horst northward, as the displacement along this fault decreases. The west boundary is a normal fault that forms a low but fairly distinct escarpment along the west edge of the valley floor near Kanarraville. It is concealed under alluvium for several miles opposite Shurtz Lake, but its trace is fairly well defined by several seeps, which suggest that the fault zone acts as a ground-water barrier. Farther north the fault line appears to follow the west edge of the valley floor, and where it crosses the valley floor west of Rush Lake, a spring is indicative of the impeded circulation of ground water across the fault zone.

FAULT BLOCKS WEST OF CEDAR CITY VALLEY

Leith and Harder have mapped several faults in the southern part of the Iron Springs district, [52] as shown by the fault lines on plate 3. Most of the faults in this area are normal faults trending northeasterly, and the upthrow side is generally to the west. Farther north, in T. 35 S., R. 12 W., the east boundary of the andesitic mass that forms the Three Peaks is so straight that a fault line is suggested, although Leith and Harder have not mapped it as such, stating, however, that "fault scarps are

[52] Leith, C. K., and Harder, E. C., The iron ores of the Iron Springs district, southern Utah: U. S. Geol. Survey Bull. 338, pl. 2, 1908.

common. Streams or canyons follow faults and joints, especially the former, so prevailingly that in the mapping faults were looked for whenever a canyon was encountered. Faults have been mapped only where they could be actually proved to exist by the relations of the rock formations; otherwise they are not shown on the map, even where their absence or abrupt termination looks structurally improbable. It is certain that many have been missed." [53]

North of the Iron Springs district the physiography likewise appears to be dominantly controlled by faulting. Thus the volcanic mass known as Sulphur Divide, that separates the Escalante Valley from Cedar City Valley, is evidently a typical fault block of the Basin and Range type, in which the pyroclastics are tilted eastward toward Cedar City Valley at angles up to 15°. Similar tilting coincident with block faulting farther north may have been responsible both for the abandonment of the alluvial fan in the western half of T. 33 S., R. 12 W. and the development of the outlet at Twentymile Gap (pl. 4, A).

Between the Sulphur Divide and the west edge of the Iron Springs graben there is a wide area, chiefly of volcanic outcrops, in which faulting has undoubtedly been of great importance. As far as ground water is concerned, however, the area plays a very unimportant rôle, and the structure was not studied in any detail.

DESIGNATION OF FAULTS THAT CROSS THE GROUND-WATER BASINS

For convenience in discussion of ground-water hydrology as it relates to geologic structure, certain faults that cross the alluvium in Cedar City and Parowan Valleys are designated below by name. These faults are by no means the faults of greatest displacement in the area; instead they may be relatively minor breaks, with displacements of less than a hundred feet. However, if such a minor fault has displaced the beds sufficiently to interrupt the flow of water through an aquifer, that fault is of importance to ground-water circulation. The effects of these faults upon ground-water movements are described in detail on pp. 88, 155.

Faults that cross the Cedar Valley ground-water basin include the following:

1. The Junction fault forms the west boundary of the Iron Springs graben. It passes under the junction of the Newcastle and Pinto roads about 5 miles west of Cedar City, and takes its name from that junction. For 2 or 3 miles north of that junction the trace of the fault is indicated by several areas of ground-water seepage in which willows grow in some profusion. Farther north and also near the south end of Cedar City Valley the Junction fault marks the west edge of the valley floor.

2. The Stockyards fault forms the west boundary of the Hamiltons Fort horst. It receives its name from the stockyards that have been built near the northwest tip of the upland west of Cedar City, although the trace of the fault lies nearly three-quarters of a mile west of the stockyards.

3. The Bulldog fault occurs within the Hamiltons Fort horst. It is so named because it traverses the Bulldog irrigation district in and adjacent to sec. 27, T. 35 S., R. 11 W. This fault forms a prominent scarp in the uplands west of Cedar City. Its trend across this upland and across the Coal Creek alluvial fan farther north suggests that it may form the west margin of the high portion of the Hamiltons Fort horst that lies east of Rush Lake.

[53] Leith and Harder, op. cit., p. 18.

4. The West Enoch fault forms the west border of the Enoch graben. It is concealed under the Coal Creek alluvial fan but is expressed in the topography north of Enoch and south of Cedar City.

5. The Enoch fault forms the east margin of the Enoch graben. It has left a prominent escarpment from Enoch northward, along which several springs rise. The trace of the fault is alternately exposed in the bedrock east of the valley and concealed under the alluvium of the several fans that border the valley.

In Parowan Valley the following five faults are designated:

1. The Paragonah fault forms the east border of Parowan Valley just south of the town of Paragonah. The trace of this fault traverses the town from which it receives its name and continues northeastward through alluvial sediments.

2. The Parowan fault branches from the east edge of the valley just south of the town of Parowan, passes through the town, and continues northeastward. For several miles in T. 33 S., R. 8 W. the trace of this fault is indicated by springs, particularly in sections 8 and 17. At the north end of Parowan Valley the fault has formed a prominent escarpment along the west side of Fremont Wash, just west of the highway in secs. 30 and 19, T. 31 S., R. 7 W. The displacement along this fault has been downward toward the east, and that along the Paragonah fault downward toward the west. Thus the area between these two faults appears to be the lowest block in the Parowan Valley graben.

3. The Summit Creek fault has a trace across Parowan Valley northeastward from a point a few hundred yards east of the mouth of Summit Creek Canyon. A low, eroded escarpment in section 33 and springs in the NE¼ sec. 21 mark the trace of this fault across the southern part of T. 33 S., R. 9 W. Farther north it joins the Little Salt Lake fault and eventually merges with the fault that forms the west edge of Parowan Valley in T. 32 S., R. 9 W.

4. The Culver fault branches from the Summit Creek fault, in sec. 8, T. 34 S., R. 9 W., and traverses the old Culver ranch, [54] from which the fault receives its name. This fault is of preeminent importance in the circulation of ground water in Parowan Valley, and marks the west edge of the area of most intensive development of ground water. Displacement along the Culver fault has been so recent that a conspicuous scarp is found in the valley fill in T. 32 S., R. 8 W., described on page 54 and pictured in plate 11, A.

5. The Little Salt Lake fault evidently branches from the Summit Creek fault in sec. 10, T. 33 S., R. 9 W., and has a more southwesterly trend. Recent movement along this fault has also produced an escarpment in the alluvium west of the lake bed. (See p. 54 and pl. 11, B.) Farther south the trace of this fault is marked by springs in the SE¼ sec. 20, T. 33 S., R. 9 W. and by a low escarpment in sec. 6, T. 34 S., R. 9 W. Still farther south the Little Salt Lake fault merges with the fault that forms the west border of Parowan Valley.

THRUST FAULTS

In a region where compressive stresses have been great enough to produce the steep, locally overturned folds described above, some thrust faulting—likewise the product of compression—might be expected.

[54] Meinzer, O. E., Ground water in Juab, Millard, and Iron Counties, Utah: Geol. Survey Water-Supply Paper 277, p. 141, 1911.

The only indications of thrust faults in the area were found in the belt of steeply inclined strata that already has been described.

In the area east and southeast of Cedar City the Triassic Shinarump conglomerate has been repeated by faulting. The two bands of the conglomerate are separated by a belt of the underlying Moenkopi formation, which is rather consistently 600 to 800 feet wide. Clearly this repetition is caused by a strike fault, and evidently the fault plane is very nearly parallel to the bedding, for the interval between the two outcrops is about the same in the canyons as on the intervening ridges. The repetition of the Shinarump outcrop is believed to have been caused by the overriding at a very low angle, or overthrusting, of rigid layers of the Shinarump upon the easily crumpled Moenkopi formation during the early stages of folding, while the massive Jurassic and Cretaceous sandstones were arching above.

About a mile east of Cedar City the Navajo sandstone forms a prominent hogback, the eastern margin of which is marked by a fault that extends with curving trace both north and south from Coal Creek Canyon. The upthrow side is to the west. The fault appears to be a thrust fault that has resulted from compressive stresses originating farther west; presumably this fault is approximately contemporaneous with the folding.

In Parowan Gap intensely folded Cretaceous strata are in fault contact with nearly horizontal Cretaceous rocks. The overlying Wasatch formation was not affected by either faulting or intense folding. The faulting therefore occurred before the Eocene deposition and may have occurred during or very shortly after the folding. The fault plane was not located in the area, and the fault is not known with certainty to be a thrust fault. Possibly it may be a continuation of the fault near Cedar City which forms the east boundary of the steeply-inclined Jurassic and Triassic strata.

Doubtless many other faults have been developed in the steeply-inclined strata that crop out from Cedar City southward, as well as in the area adjacent to Parowan Gap. Structural studies of these strata were not detailed enough, however, to identify and locate these faults.

TILTING DUE TO FAULTING

In many parts of eastern Iron County the strata are inclined as a result of faulting. Particularly is this true west of Cedar City Valley, where block faulting has been accomplished in part by rotation of the blocks, leaving the strata inclined at angles up to 20°. On a much smaller scale, movements along two closely spaced faults may cause rotation of the enclosed unit so that the rock strata dip steeply. The small slivers of bedrock that occur between adjacent faults along the margins of Parowan Valley include strata dipping at angles as high as 60°.

In the Hurricane fault zone and in the plateau section farther east the attitude of the strata is ordinarily very little disturbed by faulting, and the rocks are horizontal or dip gently to the east. The eastward dip of the strata in several of the plateau blocks is of particular significance, because it determines the direction of movement of ground water through the permeable zones of the consolidated rocks. The Cretaceous sandstones, the Wasatch basal conglomerate, and the Tertiary and Quaternary effusives include permeable zones that may conduct appreciable quantities of water eastward from the drainage areas tributary to Cedar City and Parowan Valleys into the headwaters of the Sevier River.

Locally within the Hurricane fault zone structural adjustments are evidently accomplished by rotation and displacement of the sort typical of block faulting. The west edge of the Kolob Plateau near the mouth of Fidlers Canyon, about 3 miles northeast of Cedar City, provides an example of this sort of tilting. Here the Cretaceous sandstones and overlying Wasatch formation dip northwestward at angles of 30° to 35°, and the west edge of the plateau over a considerable area is formed by a dip slope on resistant Cretaceous sandstone ledges.

SEQUENCE OF DIASTROPHIC EVENTS

The folding, faulting, and other structural changes that have been described have taken place during a relatively long period of geologic time. The following paragraphs offer a brief summary of the sequence of these events, together with the evidence upon which this sequence is based.

POST-MESOZOIC FOLDING AND FAULTING

The Upper Cretaceous rocks are evidently included in the folded strata east of Cedar City and are certainly involved in the folding east of Rush Lake. In both areas the Wasatch formation of Eocene age is clearly not involved, and the folding can be dated as post-Cretaceous, pre-Wasatch. The thrust faults that have been observed in the area probably occurred during the time of folding. Both the faults and the folds appear to have resulted from intense compressional forces that originated farther west.

MID-TERTIARY INTRUSION AND WARPING

The laccolithic intrusions in the Iron Springs district are ascribed by Leith and Harder to the lower Miocene, following the deposition of the Wasatch formation, which was subjected to warping, and preceding the late Miocene volcanic extrusions.

LATER TERTIARY FAULTING

The latter part of the Tertiary period included vast eruptions of acidic lava and was a time when extensive adjustments might be expected. Evidence that such adjustments occurred is rather limited, perhaps because the succeeding event, the eruption of Pleistocene (?) basalt lava, occurred over a rather small part of eastern Iron County.

The Markagunt and Kolob Plateaus had evidently been raised high above the adjacent Parowan and Cedar City Valleys prior to the basaltic eruptions, and therefore presumably during the Tertiary, and it follows that some faulting must have occurred along the east margins of these valleys during the Tertiary period. Movement along the faults along the east margin of Parowan Valley can be dated with respect to the flow of basalt just south of Paragonah. This basalt appears to have originated from a vent on the plateau and to have flowed northward down a narrow canyon to its mouth near Paragonah, whence the flow spread out fanwise over an area slightly greater than a square mile. The canyon down which the lava flowed has a gradient comparable to that of other canyons along the edge of the plateau, and its mouth is less than 500 feet above Parowan Valley; in all respects it appears to have developed since the plateau achieved approximately its present elevation with respect to the valley, and therefore is later than the major displacement along the east edge of the valley. This major displacement thus antedates the basalt extrusion.

Farther south the flows exposed along the north side of Winn Wash have a northwesterly dip of about 10°. This inclination may have resulted from flow over an initially steep slope, implying that here too the plateau front existed prior to the basalt extrusion, or it may have been caused by tilting coincident with faulting after the extrusion.

The extensive basalt flows near the south end of the Enoch graben and on the west margin of the plateau have evidently come to rest upon an originally rugged surface (see p. 31), indicating that the plateau block has been raised high above the valley block before the basalt extrusion, presumably during the Tertiary period. These flows have since been extensively faulted, and the plateau has been lifted still farther above the valley floor.

From the foregoing instances it appears that displacements along at least some of the major faults occurred in the Tertiary period. It is presumed that adjustments likewise may have occurred along other faults in the area but that these earlier movements are generally indistinguishable from the more recent displacements.

QUATERNARY FAULTING

Faulting during the Quaternary period has produced many of the most striking structural and topographic features in the region, and displacement has occurred during the Quaternary along a large proportion of the major faults in the area. Some of these movements may be dated with respect to the basalt eruptions, others are related to the lakes and drainage changes of probable Pleistocene age, and still others are so recent that they have left scarps in the alluvium of the valleys.

Along several of the faults where Tertiary displacement has been inferred, there is evidence of further movement during the Quaternary. For instance, the basalt flow just south of Paragonah has been described as later than the main displacement on the east side of Parowan Valley. Along the fault that forms the edge of the valley farther north, however, this basalt flow is displaced about 400 feet downward on the west. Postbasalt faulting is also suggested by the straight, scarplike west edge of the outcrop of basalt in the valley just south of Paragonah. Thus the displacements along the east side of Parowan Valley appear to have occurred both before and after the eruption of basalt, which is supposed to have taken place chiefly during Pleistocene time.

Along the west edge of the Kolob Plateau, south of Cedar City, the evidence of faulting subsequent to the basalt flows is less certain, for the basalt along the west front of the plateau has been removed by erosion except for two or three outliers. The slope on which these outliers rest, however, is not nearly so steep as the plateau front, and it is inferred that there has been faulting subsequent to the extrusion of basalt, which has raised the plateau still higher above the valley.

Along the western margin of Parowan Valley several outliers of basalt lie adjacent to the Tertiary acidic extrusives, presumably because of postbasalt faulting. At least some of the movement along the Enoch and West Enoch faults, which bound the Enoch graben, has been subsequent to the extrusion of basalt, for these faults have displaced the lava east of Rush Lake. The fault pattern in this area resembles roughly that of a caldera, suggesting that the faulting has resulted from the extrusion of great amounts of basalt from the area of the Enoch graben, and therefore that the faulting occurred very shortly after the basalt was erupted.

Pleistocene displacements are inferred along several of the normal faults west of the West Enoch fault. The evidence for such movement along individual faults may be rather slight, but the accumulated data indicate that a great amount of faulting occurred during the early part of the Quaternary period.

Along the Bulldog fault and its northerly projection there are several indications of rather recent displacement. The small delta south of Hieroglyph Canyon and the small terrace and gravel deposits farther south appear to be relics of an ancient (Pleistocene?) predecessor of Rush Lake. These deposits are now about 5,500 feet above sea level, at which altitude no other shore features have been found. Although without supporting evidence there is the possibility that displacement along the Bulldog fault may have raised these shore features somewhat with respect to the present lake bed. The tortuous Hieroglyph Canyon, which is much narrower and evidently younger than the rest of Parowan Gap, and the fault scarp in unconsolidated materials of the uplands west of Cedar City are other indications of recent movement along the Bulldog fault.

Along the Stockyards fault, which forms the west edge of the Hamiltons Fort horst, the displacement of the coarse gravels of presumed Pleistocene age has been described. Faults farther west in Cedar City Valley displace principally the Tertiary volcanic rocks, and the age of the faulting cannot be determined within close limits. Displacement along these faults is believed to be partly responsible for the present drainage outlets known as Iron Springs Gap and Twentymile Gap and thus roughly contemporaneous with the development of these outlets, probably during the Pleistocene. (See p. 13.)

Recent faulting in the western part of Parowan Valley, and the escarpments in alluvium resulting therefrom, have already been described. (See p. 54.)

SURFACE WATER

The streams that enter Cedar City and Parowan Valleys have already been mentioned in the discussion of the physiography. (See p. 11.) For several decades after the first settlers arrived in these valleys in 1851, these streams constituted the only source of water for irrigation, and at present a large proportion of the cultivated land is irrigated by surface water. Considering the importance of this water to the communities in the two valleys, the records that have been and are being made of the discharge from streams are poor and inadequate. Coal Creek is the only stream in the area for which continuous records of the discharge have been kept over a period of a year or more. The records available for Parowan Creek are limited to the irrigation seasons of 1938 and later years, while the discharge from other streams is shown only by a few miscellaneous measurements made in recent years, which shed little light on the total annual flow.

In each of the streams of the region there is an annual freshet caused by the melting snow, which accounts for a large proportion of the runoff of the stream. The peak of the freshet ordinarily occurs in May but may be as early as April or may extend into June. During the rest of the year the flow is small and nearly constant, except for flash floods due to cloudbursts in the late summer, when there may be a tremendous discharge for a few hours, after which the flow returns to normal. The curve showing daily discharge of Coal Creek (fig. 5), is typical of the streams that drain the High Plateaus in southwestern Utah.

A. WASATCH FORMATION RESTING UPON FOLDED AND FAULTED CRETACEOUS SANDSTONES IN PAROWAN GAP.

Ku, Undifferentiated Cretaceous rocks; Tew, Wasatch formation.

B. ESCARPMENTS FORMED BY TWO BRANCHES OF THE HURRICANE FAULT.

View south from the mouth of Dry Fork of Parowan Creek, near Parowan. Ku, Undifferentiated Cretaceous rocks; Tew, Wasatch formation; Tmv, acidic volcanic rocks.

A. FAULT SCARP IN ALLUVIUM ALONG WEST SIDE OF PAROWAN VALLEY.

Base of scarp indicated by dashed line. Scarp is generally about 25 feet high. Black Mountains in the distant center.

B. FAULT SCARP IN ALLUVIUM WEST OF LITTLE SALT LAKE (LINE A–B).

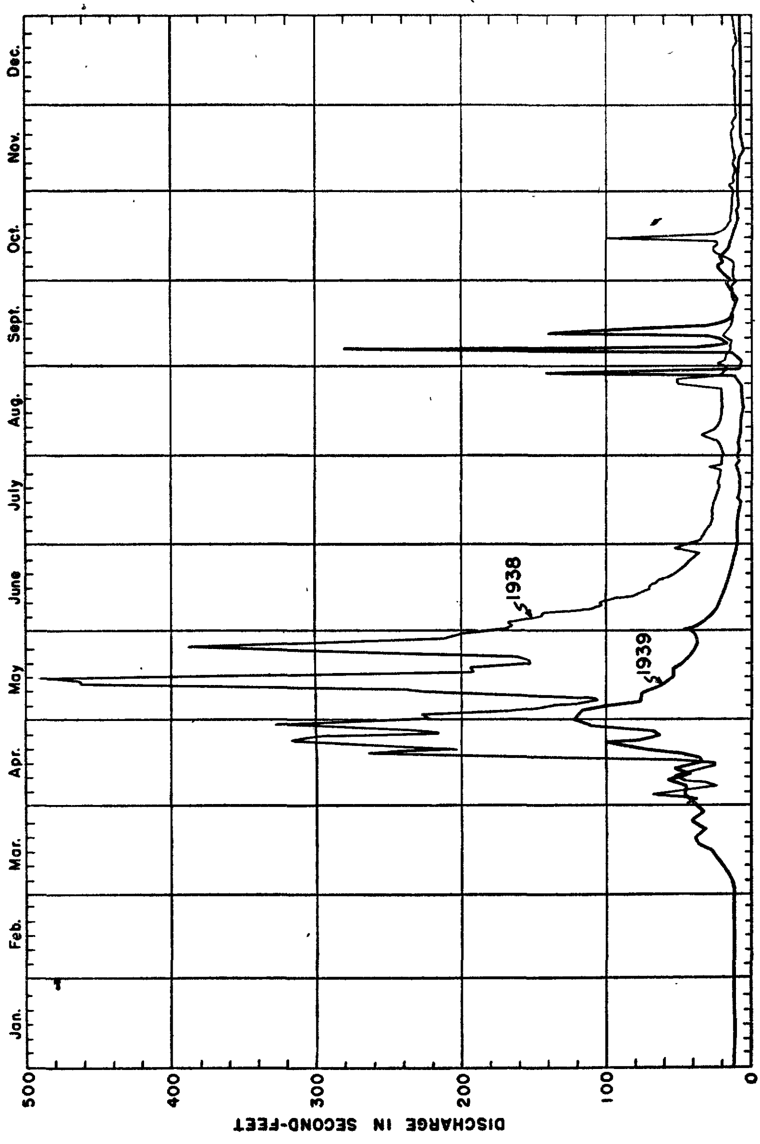

FIGURE 5.—Discharge of Coal Creek near Cedar City, in second-feet, and distribution for irrigation, 1938-39.

COAL CREEK

AVAILABLE RECORDS

The Geological Survey has maintained a gaging station on Coal Creek near Cedar City between May 1915 and November 1919 and since May 1935. [56] The gaging station since May 1935 has been located in NE¼ sec. 13, T. 36 S., R. 11 W., at the flood-control dam 1½ miles southeast of Cedar City. The drainage area above the gaging station is about 92 square miles. Since April 1939, records have been obtained

[56] Surface water supply of the United States: in 1915, U. S. Geol. Survey Water-Supply Paper 410, p. 113. 1918; in 1916, Water Supply Paper 440, p. 196, 1919; in 1917, Water Supply Paper 460, p. 154, 1921; in 1918, Water Supply Paper 480, p. 141, 1922; in 1919, Water Supply Paper 510, p. 171, 1923; in 1936, Water Supply Paper 810, p. 49, 1938; in 1937, Water Supply Paper 830, p. 52, 1938; in 1938, Water Supply Paper 860, p. 57, 1939; in 1939, Water Supply Paper 880, p. 71, 1941; in 1940, Water Supply Paper 900, p. 76, 1941.

from a continuous water-stage recorder; prior to that time they were taken from a staff gage ordinarily read once daily. Records for the period 1915 to 1919 were obtained at a gaging station about half a mile downstream from the present station. All available records have been collected for the period 1920 to 1935, but the record is incomplete for all but 3 of those years. From 1920 to 1925 the records were obtained from a gaging station 3 miles east of Cedar City, and from 1925 to 1934 the stream was gaged at various places in town. [57] All stations except those in town are above diversions for irrigation; those in town were used in conjunction with stations on the several canal diversions, and the total discharge from the creek is reported.

The observed discharge of Coal Creek has ranged from about 2,900 second-feet on July 9, 1936 (gage height 6.4 feet), to 4 second-feet on December 15, 1935. During the period for which records are available, the greatest annual runoff was estimated about 74,000 acre-feet, during the hydrographic year ended September 30, 1922, and the least runoff was 9,900 acre-feet, in the year ended September 30, 1934. The table below shows available records of the monthly and annual runoff from Coal Creek, together with estimates of the runoff for years in which records are incomplete, but not for years in which records are lacking. These estimates are based on studies of climatological data for the area, and on comparisons with runoff of other streams in southwestern Utah, particularly the North Fork of the Virgin River near Springdale (records available since 1926), and the Beaver River near Beaver (records available since 1915).

During the 18 years prior to 1940 for which records or estimates have been made, the annual runoff of Coal Creek has averaged about 32,000 acre-feet. The precipitation at Cedar City during the same periods has averaged 12.9 inches a year, which happens to coincide with the normal established during the 34 years of precipitation records there, covering the period from 1906 to 1939 inclusive.

[57] Arthur Fife, personal communication.

Runoff, in acre-feet, of Coal Creek near Cedar City, Utah

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Hydrographic year
1915									[1] 8,670	[1] 5,780	[1] 1,170	[1] 747	
1916	[1] 460	[1] 500	[1] 475	[1] 780	[1] 1,040	[1] 2,580	[1] 9,500	[1] 16,000	[1] 6,130	[1] 1,800	[2] 2,400	[1] 2,630	[2,1] 44,300
1917	[1] 2,210	[1] 1,110	[1] 889	[1] 742	[1] 747	[1] 1,340	[1] 3,780	[1] 10,900	[1] 9,090	[1] 2,400	[1] 1,690	[1] 1,066	[1] 36,000
1918	[1] 992	[1] 990	[1] 859	[1] 1,060	[1] 904	[1] 1,870	[1] 4,260	[1] 8,760	[1] 3,600	[1] 1,700	[2] 1,100	[1] 843	[2,1] 26,900
1919	[1] 1,070	[1] 983	[1] 1,020	[1] 837	[1] 866	[1] 1,240	[1] 5,430	[1] 6,190	[1] 1,110	[1] 1,080	[1] 882	[1] 2,290	[1] 23,000
1919–20	[1] 1,110	[1] 941	[2] 900	[2] 900	[3] 1,060	[3] 1,180	[3] 1,830	[3] 36,900	[3] 7,050	[3] 2,390	[3] 2,000	[3] 1,400	[2] 57,700
1920–21													
1921–22							[2] 3,200	[3] 33,300	[3] 23,500	[3] 3,150	[3] 2,370	[3] 1,680	[2] 74,000
1922–23	[3] 1,380	[3] 1,300	[3] 1,320	[3] 883	[3] 894	[3] 1,270	[3] 3,730	[3] 16,700	[3] 6,070	[3] 2,380	[3] 1,120	[3] 925	38,000
1923–24	[3] 961	[3] 890	[3] 982	[3] 899	[3] 955	[3] 1,210	[3] 5,460	[3] 15,600	[3] 3,850	[3] 1,540	[3] 1,000	[3] 910	34,300
1924–25	[3] 870	[3] 900	[3] 895	[3] 855	[3] 890	[3] 1,510	[3] 5,380	[3] 8,480	[3] 4,160	[3] 1,230	[3] 978	[2] 950	[2] 27,100
1925–26	[3] 899	[3] 870	[3] 816	[3] 1,020	[3] 1,210	[3] 1,650	[3] 10,700	[3] 11,600	[3] 2,920	[3] 989	[3] 699	[3] 495	33,900
1926–27	[3] 519	[3] 465	[3] 449										
1927–28													
1928–29													
1929–30							[3] 9,720	[3] 9,200	[3] 3,820	[3] 2,280	[3] 1,570	[3] 989	[2] 33,400
1930–31	[3] 1,180	[3] 1,050	[3] 995	[2] 950	[2] 930	[2] 1,200	[2] 3,200	[4] 1,810	[4] 740	[4] 1,720	[4] 1,080	[4] 425	[2] 15,300
1931–32													
1932–33													
1933–34						[2,5] 809	[5] 1,980	[5] 1,500	[5] 684	[5] 637	[2] 690	[2] 655	[2] 9,900
1934–35								[2] 12,000	5,960	1,730	2,020	605	[2] 30,000
1935–36	557	694	615	492	690	1,130	4,400	4,960	1,340	3,640	1,300	448	20,300
1936–37	615	595	615	676	666	1,110	3,760	20,100	4,970	1,850	922	1,190	37,100
1937–38	[2] 800	[2] 750	[2] 700	[2] 750	[2] 800	[2] 2,500	8,380	14,600	5,050	1,620	1,570	914	[2] 38,400
1938–39	1,210	781	720	738	666	1,540	3,430	3,940	1,210	565	762	1,860	17,400
1939–40	912	520	492	430	434	1,220	4,560	4,560	1,000	502	734	1,770	17,130

[1] 6 to 7 second-feet diversion for power above gaging station; reported constant, estimated 400 acre-feet per month, included in figure.
[2] Estimated.
[3] From records of Arthur Fife.
[4] From records of T. R. Collier.
[5] From records of Leland Perry.

Records for Coal Creek are missing for 7 nonsuccessive years since 1915, but those from the Beaver River near Beaver are available for the entire period, and those for the North Fork of the Virgin River near Springdale begin in 1926. Snow surveys since 1927 also provide a basis for comparison of snow cover on the Coal Creek drainage basin just prior to the annual spring freshet. None of these records provide an accurate means of estimating runoff during the years when the discharge records were not kept. However, to have a basis for comparison with records of ground-water levels, which began in 1932, the snow surveys and runoff from nearby streams are used for making rough estimates of Coal Creek discharge since that year. The estimates for the hydrographic years 1932 and 1933, which may be as much as 25 percent in error, are respectively 36,000 and 23,000 acre-feet. Using these estimates, the mean annual runoff from Coal Creek between October 1931 and October 1939, has been about 26,500 acre-feet; during the 8-year period the total deficiency below normal runoff is estimated to be about 45,000 acre-feet.

PAROWAN CREEK

The discharge of Parowan Creek has been measured periodically by the Utah State Engineer since January 1938, and the runoff has been determined for the summer months in recent years, based on daily readings of a staff gage located below the power house in the SE¼ sec. 24, T. 34 S., R. 9 W. The records of runoff are shown in the table below.

Runoff, in acre-feet, of Parowan Creek near Parowan, Utah

[From records of the Utah State Engineer]

	April	May	June	July	August
1938		2,138	1,844	1,623	1,274
1939	1,256	1,424	1,173	1,012	907
1940	817	1,599	1,216	1,123	994

Miscellaneous measurements of Parowan Creek indicate that the discharge between September and March ordinarily ranges from about 9 to 15 second-feet, and the runoff during these months probably ranges between 500 and 900 acre-feet per month.

From this scanty information the annual runoff of Parowan Creek appears to be considerably less than that of Coal Creek, although the drainage basins of the two streams are very nearly of the same size. The runoff of Parowan Creek is much more evenly distributed throughout the year, however, and the flow during the later part of the summer may be larger than that of Coal Creek.

MINOR STREAMS

Measurements of the discharge of several of the minor streams have been made by the Utah State Engineer. These measurements are shown in the table below. Fluctuations in the rate of discharge during the months of May and June are probably due to diurnal fluctuations in the runoff from melting snow.

Discharge of minor streams

Stream	Drainage area above mouth of canyon (square miles)	Measurements of discharge	
		Date	Discharge (second-feet)
Cedar City Valley:			
Shurtz Creek	20±	Oct. 22, 1939	[1] 0.77
Parowan Valley:			
Red Creek	30±	Jan. 14, 1938	4.74
		Mar. 9	3.73
		Apr. 22	7.57
		May 7	7.18
		May 25	9.70
		June 8	12.68
		Sept. 14	2.0
		Mar. 28, 1939	4.67
		Apr. 7	9.43
		May 31	13.84
		Aug. 12	5.34
		Nov. 14	4.25
		Mar. 6, 1940	3.98
		Apr. 5	5.41
		Apr. 28	9.43
		May 20	12.93
Little Creek	45±	Apr. 22, 1938	7.19
		May 7	7.17
		May 25	5.90
		June 8	3.86
		Sept. 14	3.0
		Mar. 28, 1939	4.37
		May 7	8.81
		May 29	3.47
		Apr. 5, 1940	3.77
		Apr. 28	4.92
		May 20	1.73

[1] By U. S. Geological Survey.

GROUND WATER IN CEDAR CITY VALLEY

GENERAL RELATIONS

Ground water in Cedar City Valley is obtained principally from the alluvium that underlies the valley floor. Water from wells is derived almost entirely from this source, and water in quantities sufficient for irrigation is obtained from the coarser alluvial sediments. Most of the springs likewise originate in the alluvium, and it is not certain that any springs within the limits of the valley derive water from the consolidated rocks. Certainly the quantity of ground water derived from all other sources is insignificant compared to that obtained from the alluvium.

Beyond the limits of the Cedar City Valley floor unconsolidated materials cover a rather extensive area. These deposits include the alluvial cones and fans of the smaller streams, more or less contemporaneous with the alluvium of the valley floor, but deposited on steep slopes that may rise several hundred feet above the adjacent floor (see p. 38 and pl. 3); they also include the fanglomerates that now stand well above the sites of present stream deposition by reason of faulting since their deposition (pp. 33 to 35). These unconsolidated materials are at levels a few feet to several hundred feet above the valley floor. The quantity of ground water developed from them is very small, practically all from wells located within a few hundred yards of the edge of the valley floor. Few attempts have been made to obtain water from the deposits at greater distance from the valley floor, and these have been unsuccessful. For instance, well (C-33-11)15bbb1,[58] drilled 910 feet deep in the northern part of Cedar City Valley, penetrated great thicknesses of impermeable material

[58] See p. 39 for explanation of well-numbering system.

and was abandoned (p. 45); and well (C-36-11)22adc1 was drilled 350 feet deep south of Cedar City but encountered no water. Generally it appears that these unconsolidated materials are not likely ever to be important sources of ground water, principally because the water is so far beneath the surface.

The consolidated rocks that border Cedar City Valley, ranging from the Permian Kaibab limestone to Pleistocene basalt, likewise are unimportant as sources of ground water in the valley. Indeed, because the permeability of these rocks is ordinarily far lower than that of the valley fill, the bedrock acts as barriers to ground-water movement and thus forms boundaries to the ground-water reservoir.

Indirectly the rock strata influence the ground-water supplies in Cedar City Valley because of their control of ground-water circulation in the plateaus and mountains surrounding the valley. East of the valley, particularly, a considerable quantity of the water that falls as rain or snow evidently seeps into the ground and moves eastward down dip, for along the west sides of the canyons that cut into the plateau there are numerous springs. The effect of this eastward migration of ground water is to transfer to the Coal Creek drainage some of the water falling on the drainage basins of the minor streams that drain the west slope of the plateau; and farther east there may well be appreciable losses from the Coal Creek drainage basin by movement of water toward Mammoth Creek and other tributaries to the Sevier River. Thus some of the water that falls on the drainage basin tributary to Cedar City Valley is probably transferred out of the basin by movement down the dip of the rock strata. This water, however, could not conceivably be diverted to the basin; it is entirely unavailable to the valley's sources of ground water (see p. 98) and is beyond the scope of this report. This brief discussion is indicative that problems of ground-water resources in Cedar City Valley are problems that relate almost exclusively to the water in the valley fill.

WATER IN THE VALLEY FILL

Beneath the surface of the earth there is in most places a zone, called the zone of saturation,[59] in which all the interstices between the rock particles are filled with water under hydrostatic pressure. The water in this zone is called ground water, and its upper surface is known as the water table, except where that surface is formed by an impermeable body. The location of the source of the ground water, as well as its direction of movement and discharge from the area under consideration, may be indicated by maps showing contours of the water table, for ground water, like surface water, tends to move in the direction of maximum slope, which is at right angles to the ground-water contours. The zone of saturation is reached by all wells, and its upper surface is located at the depth where water is first encountered in the well. Commonly water is confined beneath strata of low permeability under sufficient pressure to rise above the zone of saturation, and is said to be artesian; more rarely the water beneath a relatively impermeable stratum may have a pressure head insufficient to reach the top of the zone of saturation, in which case it is said to have subnormal head. For these aquifers, maps may be constructed showing piezometric surfaces, which are determined by the static level of water in the aquifer. These maps are comparable to those showing contours of the water table where the water is not confined beneath

[59] For definitions of terms used in ground-water hydrology see Meinzer, O. E., Outline of ground-water hydrology, with definitions: U. S. Geol. Survey Water-Supply Paper 494, 1923.

impermeable beds, and may be equally valuable in determining the source and movement of ground water.

In Cedar City Valley, as has been pointed out, ground water occurs principally in the alluvium, and the ground-water reservoir is for all practical purposes limited to the valley fill. Characteristically here as elsewhere, the alluvial sediments comprise discontinuous, lenticular, and commonly elongated bodies of sand, clay, gravel, and boulders which exhibit varying degrees of sorting. Thus the valley fill is a markedly heterogeneous assortment of unconsolidated materials; and the finer materials, including clay, silt, and even the finer grades of sand, tend to retard the movement of ground water that has been circulating through coarser and more permeable materials. All the ground water in the valley, whether confined or not, is attributed to a common reservoir in which the confining layers are construed as baffles that undoubtedly have a pronounced local effect on the circulation of water, but which are not continuous enough to form major separations in the ground-water reservoir. It should be pointed out that the valley fill is comparable to alluvium in other parts of the United States, except that alluvial sediments in these intermontane areas are undoubtedly coarser than would be the sediments along streams of low gradient. The clay, silt, and fine-sand layers are more effective in developing artesian pressure head than similar sediments would be elsewhere, because of the steeper slopes of the land surface, the confining layers, and the upper surface of the zone of saturation. Thus the surface of the Coal Creek fan in the central pumping district slopes to north and west 25 to 40 feet in a mile, and at Cedar City it has a gradient of nearly 100 feet to the mile.

Obviously, in materials as heterogeneous as the valley fill, the upper surface of the zone of saturation is partly in coarse sediments, where the water table is unconfined, and partly within or beneath less permeable materials which tend to confine the water under some artesian head. A water table, as defined, can be charted only over limited discontinuous areas in Cedar City Valley, and a regional water table in the valley as a whole does not exist. Water-table conditions are most nearly approached in that part of the Coal Creek fan above the 5,540-foot contour, including secs. 27 and 28, the SE¼ sec. 29, and the eastern part of sec. 32, T. 35 S., R. 11 W., nearly all of secs. 5 and 8, T. 36 S., R. 11 W., and higher parts of the fan. At lower altitudes on the alluvial fan the valley fill includes a progressively higher proportion of fine materials that act as confining layers, and artesian conditions become more common. On the alluvial fans of the smaller streams that enter Cedar City Valley there are similar artesian conditions, particularly on the lower parts of the fans, where flowing wells have been developed from aquifers within 50 feet of the land surface.

On the alluvial fans in Cedar City Valley, as in other intermontane valleys in Utah, there is commonly a zone in which wells of a certain depth achieve a maximum differential head in comparison with the water table or normal-pressure surface. This zone is ordinarily intermediate in position between the apex of the fan, where the coarsest debris is dropped, and the lowest part of the fan, toward which the finest sediments are carried. Above this zone of optimum artesian conditions, the confining layers that give rise to artesian pressure become discontinuous and thinner, and the alluvial materials, although they still range widely in size of particle, become progressively coarser. Near the apex of the fan there is likely to be free circulation of ground water, practically no differential pressure head in wells of different depths, and therefore essentially water-table conditions. Below the zone where artesian pressures are highest the coarser layers that form the aquifers evidently become discontinuous and thinner, the proportion of fine materials increases, the surface gradient commonly decreases, and there is little movement of ground water.

Fluctuations of the water table or of artesian pressure are caused chiefly by irregularities in the rates at which water is taken into or discharged from the zone of saturation. These fluctuations are observable in wells, where they cause changes in the position of the water level. Because fluctuations in wells afford the basis for determining many of the factors that affect ground water in the valley, they are discussed in some detail before the source, movement, and disposal of the water are considered.

FLUCTUATIONS OF GROUND-WATER LEVEL

CAUSES OF FLUCTUATIONS

The level at which water stands in wells in Cedar City Valley, or, in flowing wells, the level to which it would rise in an open pipe if the flow were stopped, rises or falls in response to changes in the hydrostatic pressure or head of the ground water. The major changes in head are ascribed to (1) pumping from wells; (2) discharge from flowing wells; (3) discharge by transpiration and evaporation; and (4) infiltration of water from rainfall, from irrigated lands, or from stream channels or irrigation ditches. In addition, minor fluctuations may occur as a result of other causes.

Fluctuations of the static level in a well during a period of hours, weeks, or years may be represented graphically. These hydrographs will show the composite effect of all the forces that tend to change the level of the ground water. By selection of particular wells, however, or of records for particular periods, the hydrographs may show one predominant force which is causing fluctuations of the water level.

Information concerning these fluctuations is based upon data collected from observation wells—detailed data are obtained from recording gages which provide continuous records of the position of the water level in a well, while records from other wells are based upon weekly, monthly, or less frequent periodic measurements of the position of the water level. These records are published annually. [60]

FLUCTUATIONS RELATED TO PUMPING FROM WELLS

During the past few years some 50 to 60 wells have been pumped for irrigation in Cedar City Valley. Many irrigators use ground water to supplement surface-water supplies, so that during years of normal or abnormal runoff several of the pumps may be started late in June or in July, and a few wells equipped for irrigation may stand idle the entire season. During dry years, on the other hand, pumping from wells for irrigation is likely to start early in April and continue for 5 or 6 months. Ordinarily the pumps are operated continuously during the irrigation season, but many wells are pumped intermittently near the beginning and end of the season, and some are used for stock watering throughout the winter.

Figure 6 shows fluctuations of ground-water level caused by intermittent pumping in two irrigation wells, as recorded in nearby observation wells equipped with automatic gages. During the period represented very few of the irrigation pumps were operating, and the static level at the ob-

[60] Taylor, G. H., and Thomas, H. E., Utah, in Water levels and artesian pressure in observation wells in the United States: in 1935, U. S. Geol. Survey Water-Supply Paper 777, pp. 244-245, 1936; in 1936, Water-Supply Paper 817, pp. 428-438, 1937; in 1937, Water-Supply Paper 840, pp. 570-588, 1938; in 1938, Water-Supply Paper 845, pp. 590-618, 1939; in 1939, Water-Supply Paper 886, pp. 800-822, 1940.

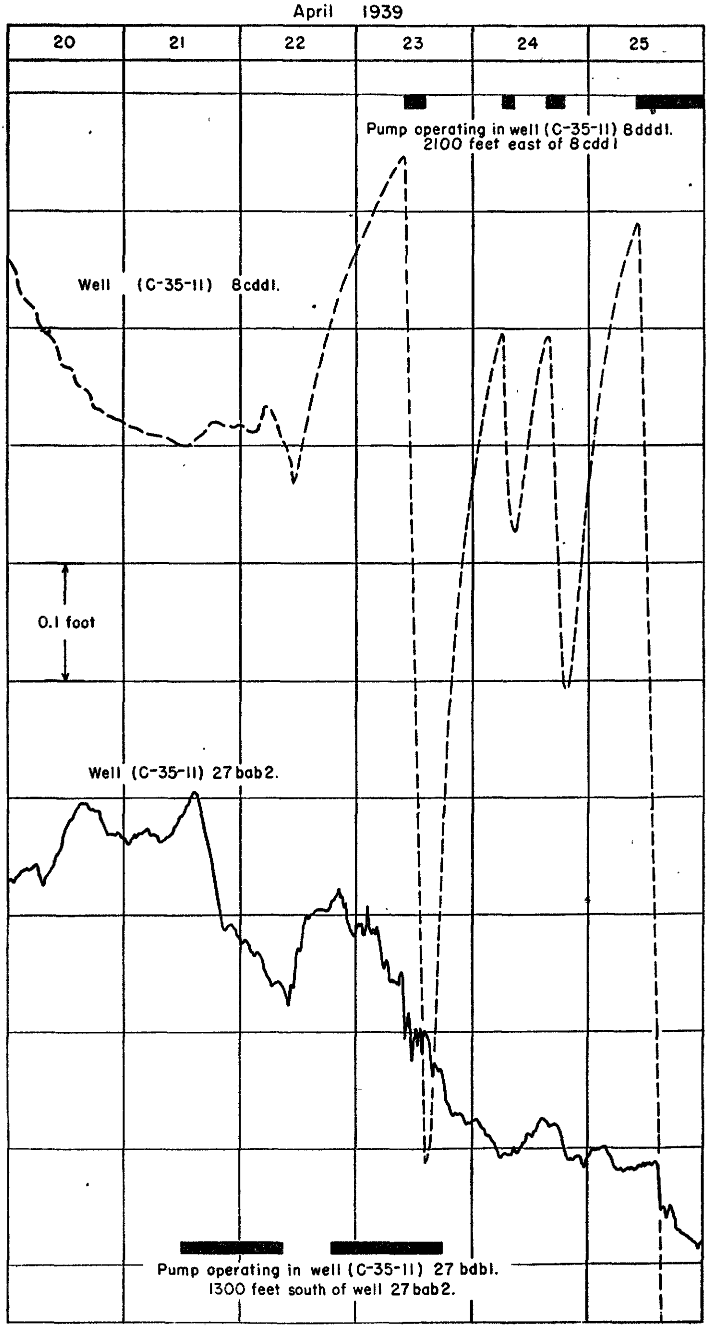

FIGURE 6.—Hydrographs of two wells in Cedar City Valley showing fluctuations caused by pumping in nearby irrigation wells.

servation wells appears to have been affected principally by the pumping from the two wells whose periods of operation are shown on the diagram.

Well (C-35-11)8cdd1 is located near the north end of the area in which wells are pumped for irrigation. Pumping in well (C-35-11)8ddd1, 2,100 feet east, causes the static level in the observation well to drop rapidly, beginning almost immediately after pumping starts. Upon cessation of pumping the static level in the observation well begins to rise almost immediately. Pumping about 110 gallons a minute for 4½ hours on April 23 caused the static level in well (C-35-11)8cdd1 to drop 0.86 foot.

Well (C-35-11)27bab2 is located on the Coal Creek alluvial fan in a district of intensive pumping for irrigation. Pumping from well (C-35-11)27bdb1, only 1,300 feet distant, on April 21 and again on April 22, was followed, after an interval of 1½ to 2 hours, by a decline in the static level in the observation well, and when pumping ceased the level began to rise after a corresponding interval. Pumping about 550 gallons a minute for 21 hours, April 21-22, caused a decline of water level in the observation well of about 0.1 foot, which is superimposed upon a declining trend created by beginning of operation of other more distant irrigation pumps. The effect of pumping from well (C-35-11)27bdb1 during the later period, April 22-23, cannot be certainly discriminated from this regional interference but is suggested by the greater rate of decline of water level in the observation well during the period of pumping.

The striking contrast in the interference measured in the observation wells during pumping is taken to indicate the different conditions under which ground water occurs in different parts of the Coal Creek alluvial fan. In the vicinity of well (C-35-11)27bab2 ground water is derived from highly permeable materials, and the decline of the water level in this well is believed to have resulted largely from unwatering of these materials as water was taken from storage in the cone of depression around the pumped well. In the wells farther north, however, ground water is commonly confined under artesian pressure; the large fluctuations of the water level in well (C-35-11)8cdd1 represent losses in head of these aquifers during pumping.

Changes in head in artesian wells during pumping for irrigation are also shown in figure 7. The wells whose hydrographs are shown are more than a mile north of the limit of the area of pumping for irrigation. The decline of water levels in spring and corresponding rise in fall are primarily the result of pumping in the vicinity. Three irrigation wells are within 2 miles of wells (C-35-11)4dda1 and (C-35-11)4dda2, and the withdrawal from each may affect the water level in one or both observation wells, although it is likely that the nearest one, well (C-35-11)10ccc1, about 1.2 miles to the south, drilled 459 feet deep, and ordinarily pumped at about 200 gallons a minute, may have the greatest effect. Well (C-35-11)4dda1 is reported to be 267 feet deep, and probably shows the head on a single aquifer encountered at the bottom of the well. Well (C-35-11)4dda2 has a measured depth of 144 feet, and thus shows the head on a shallower aquifer. During winter and spring the static level in the deeper well rises more than 6 feet higher than that in the shallow well, and during the pumping season the head of the deeper aquifer declines more than that of the shallow aquifer, indicating that irrigation pumping affects the deeper aquifer more. Even during the pumping season, however, the deeper aquifer has greater artesian head than the shallow aquifer.

Wells (C-35-11)4bbd1 and (C-35-11)4bbd2 are about a mile northwest of these observation wells and hence still farther from any irrigation wells.

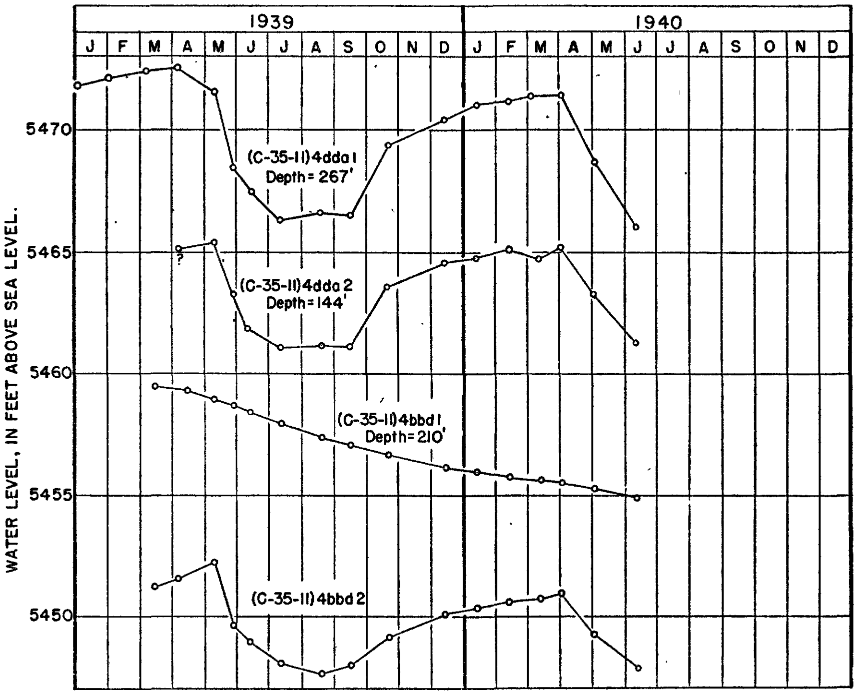

FIGURE 7.—Hydrographs of adjacent deep and shallow wells showing effects of pumping for irrigation.

Well (C-35-11)4bbd1 is reported to be 210 feet deep, and (C-35-11)4bbd2 is apparently shallow. Here, as before, the deeper aquifer has the higher artesian head. In these wells, however, it is the shallow aquifer that shows the greatest fluctuations in head during the pumping season.

The hydrographs in plate 12 show the position of water level with respect to sea level in six wells on the Coal Creek fan during the years 1938 and 1939. The uppermost hydrographs thus represent the highest wells on the fan. In the upper three wells the water level declines throughout the pumping season, rapidly at first, more slowly as the season progresses. After pumping is ended there is a corresponding recovery. These hydrographs clearly reflect the difference in the period of regional pumping during the 2 years. In 1938 many pumps did not begin operating until mid-June or even July, whereas during 1939 general pumping started during the last of April and early in May and ceased early in September.

The lower three wells are in areas where most of the developed ground water is under artesian head. Based on casual observations during periodic visits, well (C-35-11)21bac1 appears to lie within the area of influence of irrigation wells (C-35-11)16acd1 and (C-35-11)10ccc1, and the decline in head during the pumping season, ordinarily amounting to 8 to 12 feet, appears to be due predominantly to pumping from these wells. Well (C-35-11)8cdd1 is within the area of influence of well (C-35-11)8ddd1, as shown in figure 6, and the hydrograph shows the fluctuations in head caused by the intermittent pumping from that well. Although well (C-35-11)17dcd1 is more than a mile distant from the nearest irrigation well, its head declines during the pumping season. The fluctuations, however, are much less in amplitude than are those in the other wells the hydrographs of which are shown.

Fluctuations of head between 1931 and 1940 in a well high on the Coal Creek alluvial fan are shown in figure 8. Well (C-35-11)33aac1 is an irrigation pump well which has been used each season, so far as known, except during 1935. Each year the head rises at some time during spring, and then declines several feet by September or October, near the end of the pumping season. The decline during the pumping season is quite evidently caused by pumping, for the time of its beginning each year coincides with the start of pumping in the vicinity of the well. The seasonal fluctuation has ranged from 3 feet in 1932 to more than 12 feet in 1934, primarily because of regional pumping rather than of withdrawals from the observation well, for the decline during 1935, when the well was not pumped, amounted to 5½ feet, a greater decline than was measured in 1932 and nearly as much as during the other seasons when the well was used.

In figure 8 the fluctuations due to pumping are very prominent, and seem to mask all others. The detailed hydrographs of this well, however, indicate quite clearly that there are other factors influencing the water level in the well, and even in figure 8 an accelerated rise in May of 1937 and 1938 is suggestive of the effect of recharge from surface water. (See p. 77.) The graph thus represents the changes of water level in response to several forces acting upon it.

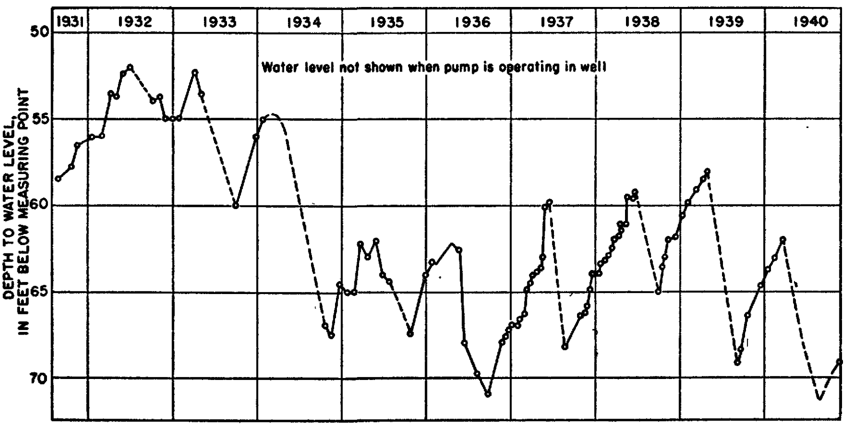

FIGURE 8.—Hydrograph of well (C-35-11) 33aac1, 1931–40.

FLUCTUATIONS RELATED TO DISCHARGE FROM FLOWING WELLS

Discharge from flowing wells causes fluctuations of the same type as those due to pumping, and presumably, inasmuch as the flowing wells are located in areas of artesian pressure, the fluctuations would be of the type shown in well (C-35-11)8cdd1 (pl. 12 and fig. 6), caused by changes of head. The records obtained during the present investigation were inadequate to show these fluctuations, because the discharge from flowing wells is very small compared to that of the pumped irrigation wells, and because most of the flowing wells in Cedar City Valley continue to flow throughout the year and afford no opportunity to compare the static level of nearby wells under varying conditions of withdrawal of ground water by artesian flow.

In measuring head of flowing wells it is the customary practice of the Geological Survey, and also that of the Utah State Engineer, to close the well for 10 minutes prior to the measurement. Assuming that the recovery in the well is about the same during each 10-minute period, a series of measurements of head taken in this way are presumed to indicate the trend of the water-level fluctuations, although the 10 minutes may not be sufficient time to permit complete recovery. Well (C-37-12)3ddd1 was found flowing prior to each measurement between January and September 1939. During this period the measurements indicate a rise until April and May, and then a decline until September, amounting to about 0.5 foot. The well was closed prior to December, and succeeding measurements in December, January, and March show the static level to be 1.5 to 2.2 feet higher than indicated by the measurement of September 1939. The head during the winter perhaps represents further recovery than occurs during the standard 10 minutes, but its higher position is partly due to the salutary effect of conservation of water resulting from closing the well. In the few other flowing wells that have been closed part of the time there is likewise a substantial increase in head above that attained when the well is found flowing.

FLUCTUATIONS RELATED TO RECHARGE FROM SURFACE WATER

Fluctuations in many wells throughout Cedar City Valley are approximately contemporaneous with fluctuations in stream discharge, and are therefore indicative that the streams contribute to the ground water stored in the valley. On the Coal Creek alluvial fan the period of maximum stream flow, ordinarily in April, May, or June, may coincide with the early part of the pumping season, and in many wells the fluctuations caused by this pumping are so great as to conceal any possible effects of recharge from streams. The effects of recharge from stream flow on this fan are therefore shown particularly (1) during years when the pumping season begins late, after the peak of stream discharge has passed, and (2) in wells outside of the pumping district but near areas irrigated from Coal Creek.

In the hydrograph of well (C-35-11)27acc1 (pl. 12) the effect of recharge from surface water is shown during June 1938, prior to the pumping season. The static level in this well rose slowly throughout the first 4 months of the year, and somewhat more rapidly in May, during the peak of the spring runoff. During the second week in June the static level rose 1.6 feet. A parallel rise in the nearby well (C-35-11)27bab2 and in other wells in the pumping district is suggestive of a rapid increase in storage, and inferentially of recharge from surface water. Unfortunately the details of this recharge are not available, for the distribution among the several ditches near the wells was not recorded during the period. Ditches of the Northwest Field serve the area near the wells, and ditches of the North Field as well as of the Coal Creek Irrigation Co. are within half a mile. These ditches were all in use during the latter part of May and the first half of June, and probably contributed to ground-water storage during that time. The effect of recharge from surface water is not shown in the hydrographs for 1939; during that year the pumping season began late in April, and the spring runoff occurred chiefly in May.

Hydrographs of four wells near the east edge of the Coal Creek alluvial fan are shown in figure 9. Well (C-35-11)27aca1 is at the eastern edge of a heavily pumped area and obviously within the area influenced by this pumping. The other wells were not greatly affected by irrigation pumping during 1938, but well (C-35-11)14dab1 was within the area of influence of well (C-35-11)14aac1, operated during 1939. Minor irregularities in the graph for well (C-35-11)22acb1 are probably caused by the intermittent operation of an automatic pressure pump in the well. The wells are located in areas irrigated chiefly by surface water from the Northwest Field, North Field, and Union Field ditches. Details of the irrigation in the immediate vicinity of the wells during 1938 and 1939 are not known, but the flow of Coal Creek was above 100 second-feet throughout the periods April 18 to June 10, 1938, and April 28 to May 5, 1939; during these periods the ditches mentioned were presumably filled approximately to capacity, and flood water was available to Coal Creek Irrigation Co. for distribution over the entire fan.

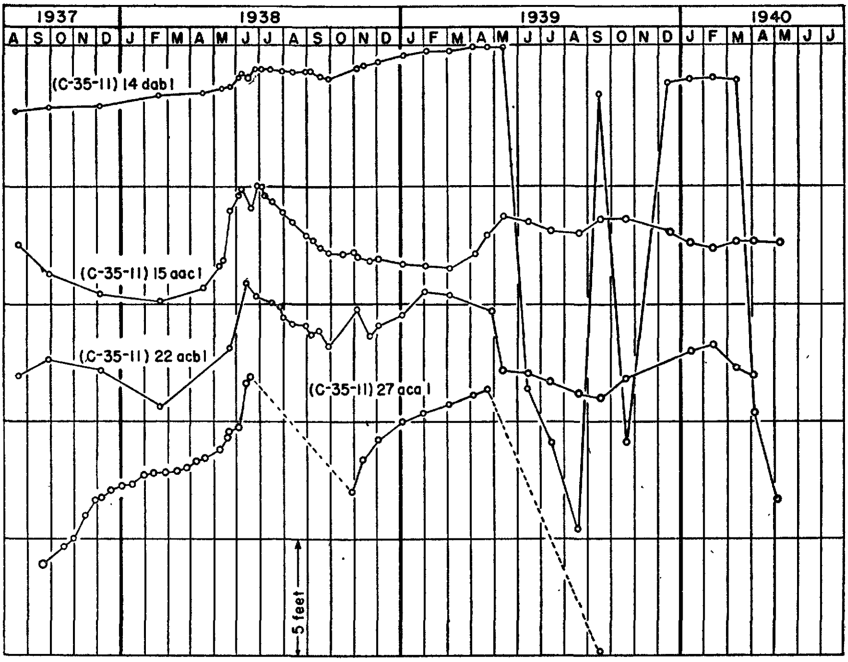

FIGURE 9.—Hydrographs of four wells near the eastern margin of the Coal Creek alluvial fan.

In each of the four wells there was a gradual rise in head during the spring of 1938, accelerated late in May and early in June, until a maximum stage was reached in June. This spring rise ranged from 1 foot in well (C-35-11)14dab1 to more than 4 feet in well (C-35-11)15aac1. The double maxima achieved in each of these wells during June 1938 suggests that there were two separate periods of irrigation near the wells during the time of greatest runoff. After the June maximum there was a sharp decline of the head in well (C-35-11)27aca1 because of pumping, a more gradual drop in the other wells, continuing until September in two of the wells and until March 1939 in well (C-35-11)15aac1. During 1939 only the last-mentioned well exhibited any appreciable effect of spring recharge, and during both years the record from this well appears to show the effects of ground-water recharge from surface water, to the exclusion of fluctuations from other causes. Conceivably, the fluctuations in this well may resemble the fluctuations of water level in the alluvial fan under natural conditions, before the development of the ground-water basin.

Figure 10 comprises hydrographs of five wells on the alluvial fans of minor streams that enter Cedar City Valley. The hydrographs represent well (C-33-10)31adb1, on the Spanish Treasure Wash alluvial fan; well

(C-36-12)26cbb1, on the Shurtz Creek fan; well (C-37-12)11dbc1, on the Muries Creek fan; well (C-38-12)3bcb1, on the Spring Creek fan (south of Kanarraville); and well (C-36-12)33dbc1, on the Queatchupah Creek fan. These wells are remote from wells of large seasonal withdrawal. Their seasonal fluctuations of water level are small compared to those in areas of greater development. The highest static level during the year is normally reached in May, June, or July, presumably soon after the peak flow of the streams that discharge over these fans. The small amount of rise during 1939 is indicative that the recharge by this spring runoff was small, but it should be recalled that wells on the Coal Creek fan likewise showed little effect of recharge that year and that runoff in 1939 was far below normal. During a year when the runoff from minor streams is normal, greater increase in ground-water storage might be expected.

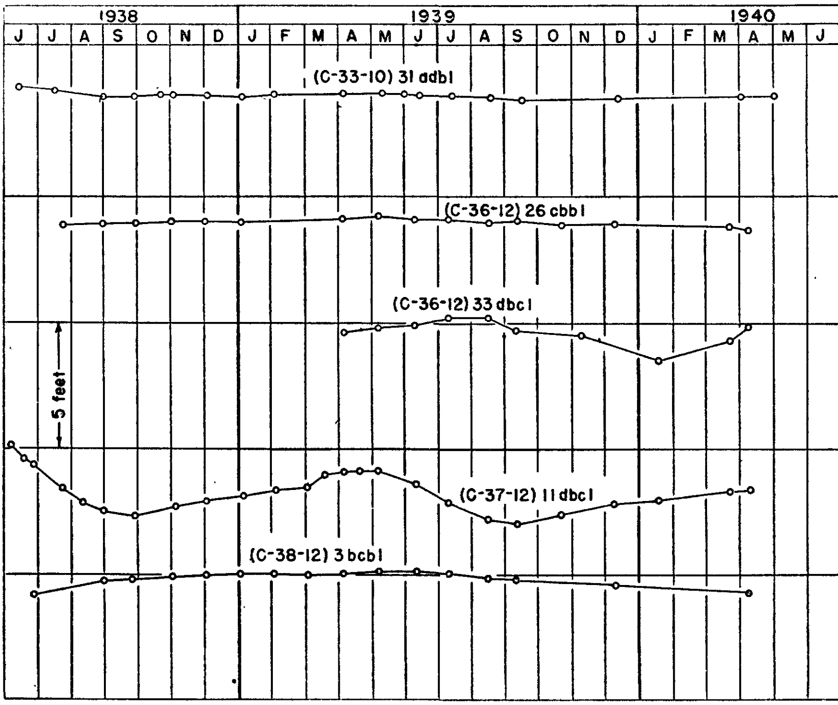

FIGURE 10.—Hydrographs of five wells outside of main pumping area in Cedar City Valley.

FLUCTUATIONS RELATED TO EVAPORATION AND TRANSPIRATION

Considerable water may be lost from a ground-water reservoir by evaporation from the soil or by transpiration from plants. This loss is obviously limited to areas where water is close enough to the surface to be evaporated directly from the capillary fringe above the water table or to be absorbed through the roots and transpired from the leaves of plants. In describing his experiments near Milford, Utah, White [61] remarks that evaporation from soil is comparatively high where the depth to water is less than a foot, comparatively low where the depth to water is more than 2 feet, and presumably nil where the water table is at a depth of 8 feet or more. Transpiration from the zone of saturation most commonly oc-

[61] White, W. N., A method of estimating ground-water supplies based on discharge by plants and evaporation from soil—results of investigations in Escalante Valley, Utah: U. S. Geol. Survey Water-Supply Paper 659-A, pp. 77–81, 1932.

curs where the water table is within 15 feet of the surface, but plants dependent on ground water may grow where the depth to water is as much as 25 feet. In Cedar City Valley there are three principal areas where the water table is less than 15 feet below the surface (p. 94)—in the vicinity of Shurtz Lake, in the vicinity of Rush Lake, and in an area north and west of Enoch.

Evaporation and transpiration may cause fluctuations of the water level in wells because they cause a fluctuating draft upon the ground-water reservoir. White [62] has shown that the water table is likely to go down during the day, when transpiration and evaporation are greatest, and then rise during the night. Likewise there is a seasonal fluctuation, because the draft on ground water by evaporation and transpiration is greatest during the summer and practically nil during the winter. The daily fluctuations of water level in a shallow well dug in the north part of Rush Lake bed are shown in figure 11, during a period when the water level is 3 feet or more below the land surface. The fluctuations of water

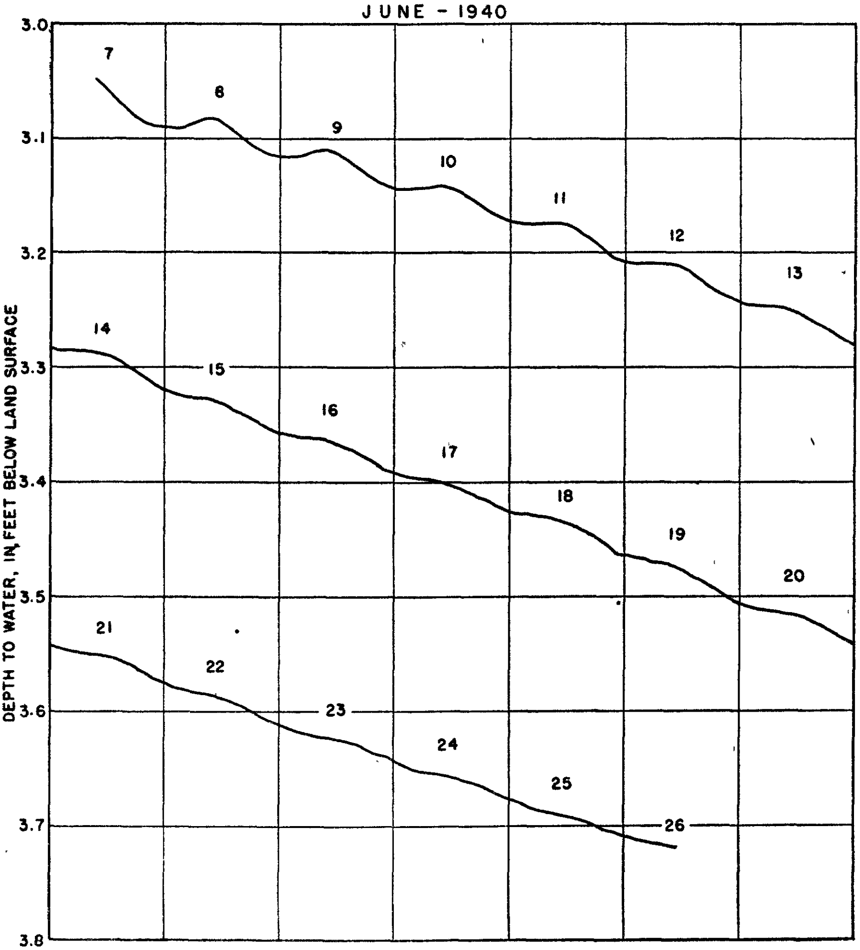

FIGURE 11.—Hydrograph showing daily fluctuations and general downward trend of water level in well (C-34-11)2bbd1.

[62] White, op. cit., pp. 23–24.

level in the well are probably caused principally by ground-water draft by saltgrass near the well, but there may also be some loss by evaporation. The gradual diminution of fluctuations as depth to the water table increases are clearly shown in the diagram.

Seasonal fluctuations in this and in three other wells near Rush Lake are shown in figure 12. In these wells the greatest seasonal fluctuation, nearly 3½ feet, occurred in well (C-34-11)2dda1, the diurnal fluctuations of which have already been described. (See p. 80.) In the other wells the seasonal fluctuation ranged from 0.7 foot to 2.0 feet. For contrast the water level in well (C-34-11)13bab1 fluctuates less than 0.5 foot annually. This well is a flowing well near (C-34-11)13bab2; its depth is unknown, but it undoubtedly taps an aquifer that is entirely beyond the reach of the effects of evaporation or transpiration.

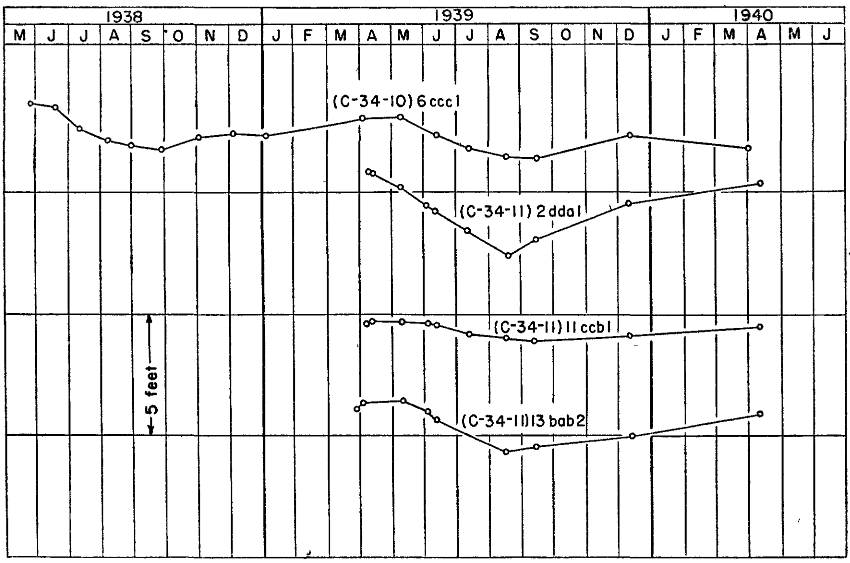

Figure 12.—Hydrographs of four shallow wells near Rush Lake showing effects of evaporation and transpiration.

Comparable records are not available to show the effects of transpiration and evaporation in the other principal areas where ground water is at shallow depths. In the vicinity of Shurtz Lake the conditions are particularly analogous to those near Rush Lake. Both are playas, and hence are likely to be more or less filled with water each year. In Rush Lake this water is continuous with the ground-water body, and the lake surface appears to be continuous with the water table. Shurtz Lake likewise appears to be continuous with a shallow ground-water body, for the sediments beneath and adjacent to the lake are reported to be saturated below the lake level. In both areas, then, it is inferred that the effect of evaporation during the hot summer months of each year is to lower the free-water surface of the lake and subsequently to lower the position of the water table in the sediments under the lake bed, no doubt at a diminishing rate as the depth to water below the land surface increases. Lowering of the water table undoubtedly extends beyond the limits of the lake bed, for water is at shallow depth over a large area, much of which has some vegetative cover, and is probably withdrawn by transpiration as well as by evaporation.

Transpiration and, less likely, evaporation may also cause some fluctuations of the water level in wells in the area north and west of Enoch where, however, several irrigation wells, each with a wide area of influence, tend to lower water levels during the summer below the zone where evaporation and transpiration are most effective.

MINOR FLUCTUATIONS

Many fluctuations of the water level in wells that reach artesian aquifers are caused by changes of pressure upon the water in the aquifer. These changes in pressure may cause the water level to fluctuate momentarily or through periods of a few hours or days. Such fluctuations are of minor importance to the ground-water user, because they do not represent changes in ground-water storage. Minor fluctuations in wells in Cedar City Valley are caused by changes in barometric pressure and by seismic waves of compressional type.

The effect of variation in barometric pressure upon water levels in wells is suggested by figure 13, which compares the hydrographs of three wells with the barograph at Modena. The barograph is plotted in inverted position for better comparision with ground-water levels, because an increase in barometric pressure would tend to depress the water level in wells. The barometric pressure has been represented in terms of feet of water and plotted to a scale one-fifth of that used to show the fluctuations of the water level in the wells. During the 10-day period represented in the diagram the barograph records a succession of cyclonic storms, shown by barometric "lows" on January 22 and 28 and "highs" on January 24 to 25 and 29. The three hydrographs show varying degrees of response to these major changes in barometric pressure. The hydrograph of well (C-35-11)27bab2 nearly parallels the inverted barograph, although there is a slight convergence during the 10 days because of the steady rise of the water level which is characteristic of this well during the winter (pl. 12). Thus, the amplitude of the water-level fluctuations is roughly 20 percent of the corresponding major barometric fluctuations during this period. Barometric changes have somewhat less effect on the water level in well (C-35-11)8cdd1 and barely perceptible effect in well (C-36-11)18aba2, where, however, they are reflected by very slight bulges and sags in the hydrograph.

The water levels in the wells respond in greater degree to the slight diurnal changes in barometric pressure induced by solar heating of the atmosphere than to the major changes described above. These fluctuations occur about midday and appear on the barograph as small dimples, of which those on January 24, 27, and 29, shown in figure 13, are perhaps most readily discernible. These dimples are evident even in well (C-36-11) 18aba2. In well (C-35-11)27bab2 they are much more marked than shown in the barograph at its reduced scale; the barograph is therefore reproduced for January 25-26, in dotted line just above the hydrograph for the well, on the same scale as that of the hydrograph. Here it is evident that the water surface in the well is as sensitive as the barograph to minute changes in barometric pressures; indeed, the minor oscillations in water levels are considered to be due entirely to variations in pressure, and the water surface is thus inferred to be even more sensitive than the barograph to these small changes. As an explanation for the varying degree of response of the water level in this well to fluctuations of the barometer, the suggestion is made that a change in barometric pressure causes an immediate, equivalent change in the water level in the well. More gradually this change in transmitted to the water in the

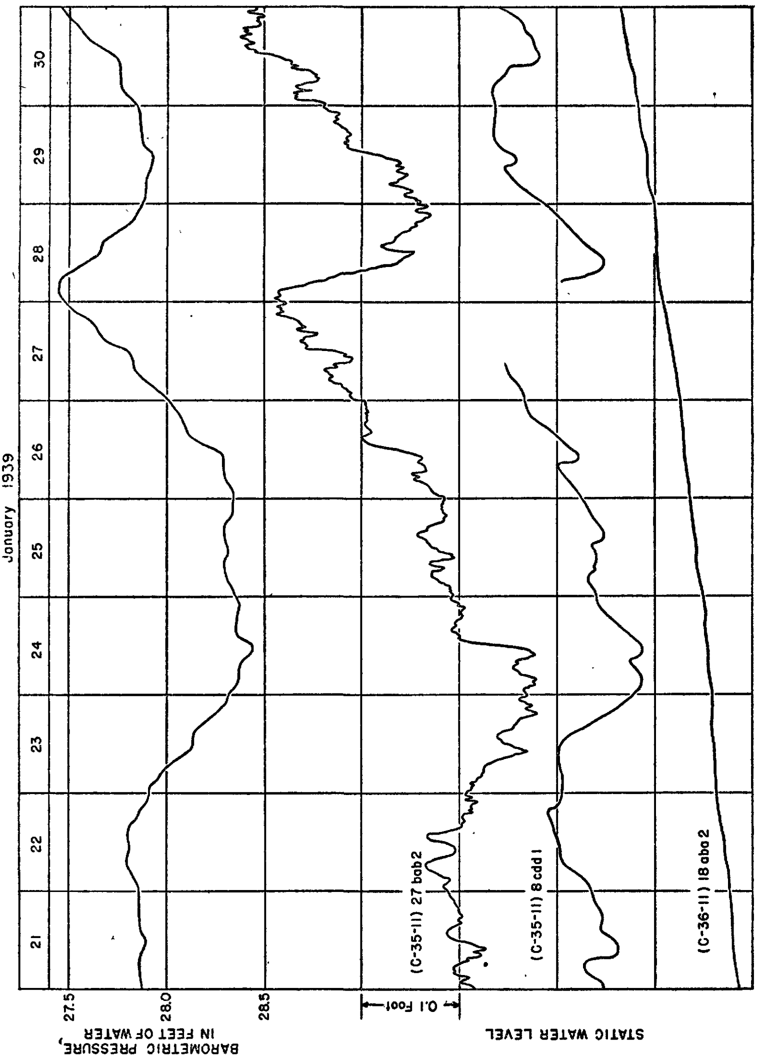

FIGURE 13.—Hydrographs of three wells in Cedar City Valley and barograph at Modena during part of January 1939.

aquifer also, in part through the water in the well, perhaps also to a small extent through the overburden. As the pressures in well and in aquifer become equalized again, the effect first noticed in the well would be offset by a gradual return of the water level to approximately its original position, were it not for subsequent barometric fluctuations. Thus each change in pressure is reflected immediately but is dissipated gradually, and the larger but less sharp barometric fluctuations induced by cyclonic storms produce a smaller degree of response in the well. The hydrographs give evidence of this lessened effect over a longer period of time. The rising barometer on January 28 has caused a much greater degree of response in the wells than the equivalent but slower rise of January 22–24.

Fluctuations due to barometric cycles were observed in each of the seven wells in which water-stage recorders have been maintained in

Cedar City Valley, and it is inferred that they are equally common in the other wells in the area. In one well the range in water level due to barometric cycles has been shown to exceed 0.2 foot, and it is inferred that from that cause alone a single measurement of water level may deviate several tenths of a foot from the mean water level established over a period of several days. Thus in areas where the yearly range in ground-water level is small, the deviations caused by barometric pressure might introduce an appreciable percentage error into an estimate of the yearly change in ground-water storage. In areas where important ground-water developments have been made, however, the fluctuations due to barometric changes are small compared with those due to other forces.

Fluctuations due to earthquakes have been recorded in wells in Cedar City Valley and in other parts of Utah. [63] The short, sharp fluctuations shown in the hydrographs of figure 13 on January 24 are of the type commonly caused by earthquakes, in which the water level moves rapidly up and down in response to the compressional and dilatational stresses of seismic waves. Simultaneous fluctuations were recorded in a well in Parowan Valley, but not in any other wells in Utah. No contemporary seismic disturbances were recorded at the seismograph stations in Salt Lake City, Utah, Tucson, Ariz., or Pasadena, Calif., and it is inferred that the fluctuations on January 24 must have resulted from a slight local shock.

LONG-TERM FLUCTUATIONS

For most of the observation wells in Cedar City Valley the records of water-level fluctuations were begun in 1935 or thereafter, under the present cooperative investigation of the Federal Geological Survey and the Utah State Engineer. Prior to this investigation periodic measurements were made by Lamont E. Tueller, Iron County agricultural agent, in several of the irrigation pump wells. Records for those wells begin in 1931 or 1932, and constitute the longest records available in the area. The hydrograph for well (C-35-11)33aac1 has been presented in figure 8. If the points representing the highest water level in the well each year be connected in this diagram, the resulting curve indicates the major trend of the water level over the 8-year period 1932 to 1940—downward during all years except 1936–39, and slightly upward during those years. The changes in high water level in this and 11 other wells are shown in figure 14. Reproduced also on this diagram is the correlative part of the curve showing cumulative departure from normal precipitation in Cedar City. (See fig. 1.) The ultimate source of practically all ground water is precipitation, and there is commonly some correlation between the graphs showing changes in storage in a ground-water reservoir and the cumulative departure from normal precipitation, for both are measures of the accumulated excesses or deficiencies in moisture during past years, as well as the conditions during the year under consideration. In figure 14 the scale used for the cumulative-departure curve was selected with a view to emphasizing the correlation between it and the changes in ground-water levels, and the resulting curve is rather strikingly parallel to several of the well hydrographs. Rising trends in the cumulative-departure curve, due to more than normal rainfall in 1932, 1936, and 1938, are reflected by rising water levels in many wells, and the implication is that the ground-water basin, insofar as it is represented by these wells, has not been seriously overdeveloped.

[63] Thomas, H. E., Fluctuations of ground-water levels during the earthquakes of November 10, 1938, and January 24, 1939: Seismol. Soc. America Bull. vol. 30, pp. 93–97, 1904.

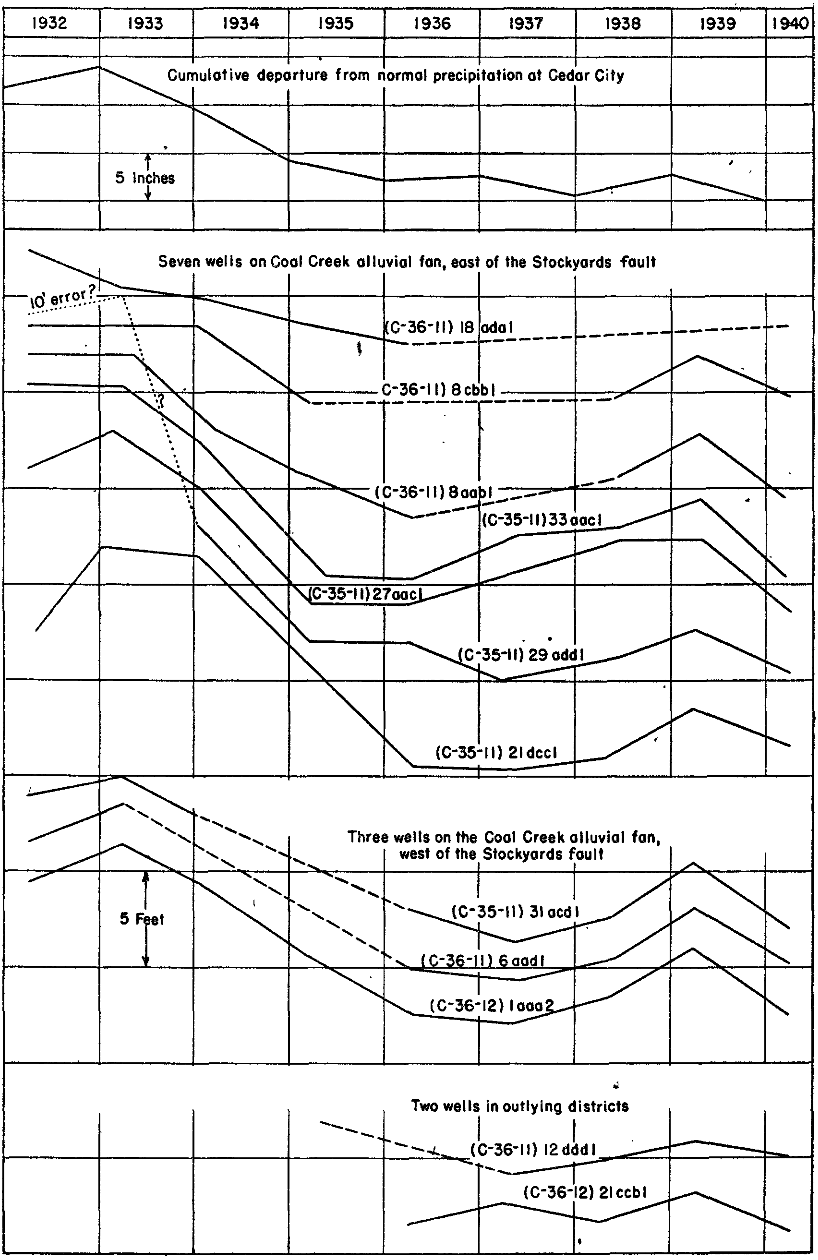

FIGURE 14.—Hydrographs showing approximate high-water levels each year in 12 wells in Cedar City Valley, 1932–40.

During the 8-year period the trend of the water level has been downward in each well, and the net change has ranged from 3½ feet in well (C-36-11)8cbb1 to a doubtful 18½ feet in well (C-35-11)29addl.[64] Seven of the wells are located on the Coal Creek alluvial fan east of the Stockyards fault and are grouped in the figure. The long-term decline is least in wells (C-36-11)8cbb1 and (C-36-11)18adal, near the south end of the pumping district. In well (C-35-11)33aacl, the highest well on the Coal Creek fan included in the diagram, the net decline from 1932 to 1940 was about 8½ feet. During the 8-year period the accumulated deficiency in precipitation at Cedar City amounted to nearly 12 inches.

Three other wells are located on the Coal Creek fan, but on the west side of the Stockyards fault, and they are likewise grouped. The long-term fluctuations in these three wells are about as great as those in the central part of the pumping district east of the fault. The two hydrographs near the bottom of the diagram represent wells not on the Coal Creek fan but in other parts of Cedar City Valley—well (C-35-11) 12ddd1 in the vicinity of Enoch, and well (C-36-12)21ccb1 on the Queatchupah Creek fan. The records for these wells extend over only a part of the interval covered by the other hydrographs in the diagram. They serve to show that the changes in water levels in these outlying districts also correlate roughly with climatological data.

All but one of the hydrographs of figure 14 represent irrigation pump wells; the exception, well (C-36-12)21ccb1, is a flowing irrigation well. The water-level fluctuations in these wells are thus representative of the areas where the principal ground-water developments have occurred and include in marked degree the effects of pumping. Nevertheless, the hydrographs show not only those effects but also the resultant of all the forces that influence the position of water level in wells. The close correlation of these water-level fluctuations with climatic cycles is indicative that the developments of ground water have not displaced the natural forces as the dominant factor controlling ground-water storage.

REGIONAL NORMAL-PRESSURE SURFACE

The regional normal-pressure surface shown on plates 31 and 14 is based on data obtained from wells of several classifications. On the upper part of the Coal Creek fan, roughly above 5,540 feet above sea level, both deep and shallow wells define a common piezometric surface; the water in these wells is evidently unconfined, and this piezometric surface thus coincides with the water table. Many shallow dug wells and boreholes—some constructed especially for water-level observations—are distributed over Cedar City Valley; most of these penetrate barely to the zone of saturation, and likewise define the water table. Throughout much of the valley the ground water is confined under artesian pressure; in some of these areas the confining layer may well be thin and discontinuous, and when penetrated may cause the water to rise to approximately the same piezometric surface as that defined by nearby water-table wells. All these wells would define a normal-pressure surface, which would be the same as the water table but would extend into areas where water is confined. Finally, there are several areas in Cedar City Valley in which practically all wells reach water that is under artesian head. The Queatchupah Creek alluvial fan is an area of this kind, as are also certain parts of the lower

[64] The positions of the water level in these wells prior to 1936 are based on readings of air gages, which may be several feet in error. Included in the 18½-foot net decline in this well is a recorded drop of 12 feet between 1933 and 1934. By contrast, the water level in well (C-35-11)29dcd1, half a mile south, declined only 1 foot between 1933 and 1934, and in the same year the decline in the other wells ranged from 0 to 4 feet. Quite possibly the air gage in well (C-35-11)29addl was as much as 10 feet in error prior to 1934.

Coal Creek alluvial fan. In these areas where data concerning the normal-pressure surface are lacking the wells having the lowest pressure head, ordinarily the shallower wells, were used to define a piezometric surface that is certainly above normal but that is probably not far above the normal-pressure surface for the district. In the areas where wells are lacking or where the wells used are likely to be slightly artesian the contours are dotted.

RECORDS FOR THE PERIOD 1936-40

FORM OF THE NORMAL-PRESSURE SURFACE, APRIL 1940

The map showing contours of the normal-pressure surface in April 1940 (pl. 13) is based upon measurements of the water level in more than 185 wells and boreholes in Cedar City Valley. Most of the measurements were made within a few days of the first of April; locally, however, irrigation pumps were started before that date, and in those areas the map is based upon measurements made in March. The period represented by the map is thus prior to the beginning of pumping, and also prior to the peak of the spring runoff occasioned by melting snow.

The general form of the normal-pressure surface is similar to that of the land surface. The broadly convex form of the Coal Creek alluvial fan, the similar but smaller fans of the minor streams, the slope northward toward Rush Lake and thence northwestward through Twentymile Gap, the slope northwestward through Iron Springs Gap, the depression in which Shurtz Lake is situated, the low, almost imperceptible, divide north of Kanarraville, and the slope southward in the vicinity of Kanarraville—all are reflected on the normal-pressure surface.

On the other hand, the gradient of the normal-pressure surface is ordinarily not equivalent or even proportional to the slope of the land surface throughout the valley. For instance, Coal Creek has a typical alluvial fan, steepest at the mouth of the canyon, where its gradient exceeds 100 feet to the mile, and becoming progressively less steep farther from the canyon, so that its slope is only about 15 feet to the mile near Rush Lake and beyond. The normal-pressure surface has very little slope in the immediate vicinity of Twentymile Gap, and slopes about 20 feet to the mile between the Gap and Rush Lake, where again it has a nearly flat surface. Southward up the Coal Creek fan there is a gradual increase in gradient to about 25 feet to the mile west of Enoch. Farther south, on that part of the fan where most of the pumped irrigation wells are located, the water table is again a nearly flat surface, with a gradient as low as 5 feet to the mile. Above this ground-water terrace that covers the central pumping district, the gradient of the water table again increases, as indicated by well (C-36-11)10bcc1. The position of the water table under Cedar City is not known from wells, but there is undoubtedly a steep gradient near the mouth of the canyon, which is about 300 feet higher than the water level in the highest well, 2 miles to the west.

The ground-water contours are drawn only for the area of the valley floor, because the wells are limited almost entirely to this area, and information is lacking as to the position of the water table in the unconsolidated sediments bordering the valley floor. The upper surface of the ground-water body in these unconsolidated sediments probably slopes toward the valley floor. Such a slope is known to exist under the fans of the principal streams that enter the valley, and the smaller fans that make up the rest of these unconsolidated deposits are analogous.

Along the narrow northern outlet of Cedar City Valley the ground water is lowest in the center of the valley and is inferred to move in from the materials along the valley border. South of Rush Lake the valley floor is 4 or 5 miles wide; here the ground-water contours outline the ground-water fan developed by Coal Creek and have a trace convex to northward across the valley floor. It is inferred that the water table, or other piezometric surface, rises westward under the unconsolidated materials bordering the west side of the valley, with a gradient presumably much more gentle than that of the land surface, and that groundwater in small quantities moves toward the valley floor from these unconsolidated materials. At some altitude below 5,470 feet the groundwater contours are inferred to turn northward or northwestward beyond the edge of the valley floor and west of the Midvalley district. Similarly the ground-water contours are inferred to turn westward or northwestward along the north side of the Iron Springs outlet. The ground-water saddle or divide thus created separates the water moving toward Iron Springs Gap from that moving toward Twentymile Gap and is probably located in the northeast quarter of T. 35 S., R. 12 W. The ground-water contours in the north half of T. 36 S., R. 12 W., indicate a low groundwater divide extending approximately east and west through section 3 or 10. This divide serves to prevent ground-water drainage from Shurtz Lake northward to Iron Springs Gap. Thus the area surrounding Shurtz Lake is a closed ground-water basin.

Striking features of the normal-pressure surface are the ground-water dams indicated along the West Enoch and Stockyards faults. The existence of these dams was suggested by the great difference in the nonpumping levels of wells only a few hundred yards apart, but the number of observation wells used during 1939 was inadequate for conclusive evidence. Accordingly, in April 1940 all available wells in the vicinity of the fault traces were used for contouring the water surface. The dam along the West Enoch fault is clearly shown in the resulting map, ranging from about 8 to more than 20 feet in height; and all contours 5,510 feet and lower in elevation appear to be deflected along the fault. Along the Bulldog fault and the Junction fault farther west, the control is inadequate to determine whether or not ground-water circulation is influenced.

A ground-water dam along the Stockyards fault is indicated particularly by the 5,480-, 5,490-, and 5,500-foot contours. Farther north there is an insufficient number of wells to show how far this dam extends. In the central pumping district the 5,510-foot contour is pinched together somewhat along the line of the fault, perhaps because the fault zone includes relatively impermeable materials that are not as quickly saturated during the nonpumping season as are the sediments farther from the fault.

SUBDIVISIONS OF THE GROUND-WATER RESERVOIR

The ground-water reservoir, as discussed in this report, includes the entire body of ground water that lies within Cedar City Valley. Just as that valley includes parts of three independent drainage basins, so does the ground-water reservoir under it include portions of three independent ground-water basins, roughly coextensive with the topographic basins. Ground water enters this reservoir from a number of sources (see p. 98), moves down gradients that vary considerably in different parts of the area, and leaves the reservoir by any one of three outlets. Before considering in detail the conditions of ground-water occurrence, it is desirable to subdivide the reservoir into homogeneous units. The normal-pressure surface shown in plate 13 provides a basis for subdivision into units very much as a topographic map might be used for delineation of physiographic features. The boundaries of these subdivisions of the ground-water reservoir follow prominent features of the normal-pressure surface, including the limits of the alluvial fans of the principal streams, the ground-water divides between the Virgin River, Shurtz Lake and Rush Lake drainage basins, the faults that form ground-water dams, and the locations of abrupt changes in slope of the water surface; as far as possible these boundaries are stylized along section lines. The eight subdivisions shown on plate 13 are merely outlined here; the source, movement, and disposal of ground water in them are discussed later. (See p. 102.) The subdivisions are limited to the valley floor, because there are no available data concerning the ground-water body beyond the edge of the valley floor.

The Coal Creek alluvial fan includes four principal ground-water subdivisions. The Coal Creek district includes the upper part of the fan, in which ground water is not confined under appreciable artesian pressure and the water table has very low gradient. The Iron Springs district embraces the western part of the fan; it is separated from the Coal Creek district by the Stockyards fault. North of these two districts and bounded arbitrarily by the center of T. 35 S., is the Midvalley district, in which ground water is commonly under artesian pressure and the piezometric surfaces have relatively high gradient. The Stockyards fault traverses the center of the district, but ground-water conditions east and west of the fault appear to be similar enough to warrant their inclusion in a single unit. Still farther north, and separated from the Midvalley district along an arbitrary boundary that follows the center of T. 34 S., is the Rush Lake district, which embraces the lake bed and vicinity and the northern outlet to the valley.

Four other ground-water districts lie beyond the margins of the Coal Creek fan. The Enoch district is separated from the Midvalley and Coal Creek districts by the West Enoch fault. The Hamiltons Fort district, including chiefly the Shurtz Creek alluvial fan, lies south of the Iron Springs district, the boundary following the center of T. 36 S. The Queatchupah district, embracing especially the Queatchupah Creek alluvial fan, lies west of the Hamiltons Fort district, from which it is separated along the center of T. 36 S. and T. 37 S. The Kanarraville district, embracing the alluvial fans of Kanarra Creek, Muries Creek, and minor streams from the west side of the valley, lies south of the south boundary of secs. 8 to 12, T. 37 S., R. 12 W., which is roughly the position of the ground-water divide between Shurtz Lake and tributaries of the Virgin River.

SEASONAL CHANGES, 1939

The position and form of the normal-pressure surface are changing constantly in response to the forces that induce fluctuations of the static level in wells. The fluctuations induced by pumping for irrigation are especially prominent, and in a majority of the observation wells in the valley the water level is highest before pumping begins and lowest near the end of the pumping season. Plate 14 shows the positions of the normal-pressure surface in April and in September, immediately before and after the irrigation pumping season, and thus represents approximately the high and low-water surfaces during the year throughout most of the valley. The contours for April 1939 show a ground-water surface very similar in form but somewhat higher than that in April 1940 (pl. 13), particularly on the Coal Creek fan.

In September the principal changes in positions of the contours are of course in the pumping districts. The ground-water terrace, which was noted over the central part of the pumping district in April 1940 and which was about as marked in April 1939, has become so broad as to include practically the entire central pumping area. The flatness of this water surface is not adequately shown by the contours, and is better illustrated by the water levels in wells. At the close of the 1939 pumping season the water level in practically all observation wells in an area of more than 10 square miles ranged between 5,503 and 5,509 feet above sea level. It is inferred that there was a corresponding steepening of the water table in that part of the fan above the pumping district, but no data are available for that area.

The ground-water dam along the Stockyards fault, noted in April 1940, is shown also by the contours for April 1939. By September the steep slope of the water surface along the Stockyards fault has practically disappeared, chiefly because of the pumping in two wells less than half a mile east of the fault—wells (C-35-11)16bac1 and (C-35-11)10ccc1. The ground-water dam along the West Enoch fault is nearly as prominent in September as in April, probably because the pumping in the Enoch district is chiefly from pumps located more than a mile east of the fault.

The decline of ground-water levels in the central part of Cedar City Valley during the 1939 pumping season is shown on plate 15. Water levels declined more than 10 feet in three principal areas. One of these areas is principally in secs. 27 and 33, T. 35 S., R. 11 W. Fifteen irrigation wells are in these two sections, practically all within the area where the decline exceeded 10 feet. Another area farther southwest lies across the Stockyards fault. Thirteen wells are located east of the fault, in secs. 5 and 8, T. 36 S., R. 11 W. Only four irrigation wells—(C-35-11)31acb1, (C-35-11)31ccd1, (C-36-12)1aaa2, and (C-36-12)12dba1—are located in the portion of the area west of the fault, yet the decline is practically as great as the lowering caused by the 13 wells east of the fault.

The third area where the decline during the 1939 pumping season exceeded 10 feet is along the Midvalley road west of Enoch. Only three irrigation wells are in that part of the valley, yet the ground-water surface has been lowered over an area covering several square miles around those wells, and the amount of the lowering is at least as great as on the higher parts of the fan, where ground-water withdrawals are several times as great. In this area the fluctuations of ground-water level are inferred to be due primarily to changes in artesian pressure head, and the decline over a wide area is due to withdrawal from artesian aquifers.

Ground-water levels were lowered appreciably between April and September 1939 in several areas in Cedar City Valley beyond the limits of the Coal Creek alluvial fan. The decline caused by pumping in the Enoch district is shown in plates 14 and 15. Significant declines of the water level in T. 37 S., R. 12 W., are evidently caused by pumping from wells (C-37-12)23acb1 and (C-37-12)34abb1. In the vicinity of Rush Lake the ground-water surface has evidently been lowered because of evaporation from the lake and its environs. (See fig. 12.)

The longitudinal profile of the Coal Creek fan presented in plate 16 shows the normal-pressure surface at three periods in 1939—during April, when the water level was highest; in September, at the end of the pumping season; and in December, after several months of recovery from the effect of pumping. These profiles show the relatively low gradient of the water table in the Coal Creek district, flatter in September than in April; the increased gradient in the Midvalley district (center of the profile) where artesian wells are common; and the gentler slope under the Rush Lake district, farther north.

ANNUAL CHANGES, 1936–39

As shown in plate 13, the normal-pressure surface in April 1939 was very similar to that in April 1940. Sketch maps, based on a smaller number of observation wells and prepared for December 1937 and December 1938, indicated that the normal-pressure surface at those times was likewise of similar pattern. It is inferred that throughout the nonpumping season of each year the normal-pressure surface has the same broad general features. Changes from year to year are typified by the maps of plate 13—practically no change in many parts of the valley, and considerable change in other areas, particularly those most heavily pumped for irrigation. Prior to 1939 the number of observation wells was inadequate for detailed maps of the normal-pressure surface, and comparisons of the storage within the ground-water reservoir, which governs the position of the normal-pressure surface, must be based upon the changes in the water level in observation wells and upon averages drawn from these changes.

During 1936, the first year of the cooperative investigation of Utah's ground-water resources, only nine observation wells were established in Cedar City Valley, and estimates of the change in position of the water table and piezometric surfaces during that year are necessarily based on those wells. In later years the number of observation wells was increased; thus, during 1938 and 1939 the position of the nonpumping water level was determined periodically in 32 key wells and was used in a large number of other wells to check the changes shown by the key wells. There is a wide range in the amount of annual change in the water level in these key wells, but the greatest differences are usually between wells in different subdivisions of the ground-water reservoir. For wells within a single district the annual changes recorded are in better agreement, although there is considerable range even within the individual districts, as shown in the table on p. 92.

The table shows the changes during the years 1937 and 1938, when water levels rose in practically all the key wells, and the years 1936, 1939, and 1940, when water levels declined in nearly all wells. The districts in which the greatest annual fluctuations have been observed are the districts where there is pumping for irrigation. In the relatively undeveloped areas—Rush Lake, Hamiltons Fort, and Queatchupah districts—the annual changes are ordinarily in the same direction but smaller in amount. Within the irrigation-pumping districts the wells showing the greatest annual change are near irrigation wells (eight of the observation wells are irrigation wells), and the wells showing little change from year to year are remote from irrigation wells. It is to be noted that the wells in which the nonpumping level declined most in 1936, 1939, and 1940 had correspondingly large increases in 1937 and 1938.

During 1938 and 1939 about 70 wells were used for periodic measurements of the water level throughout the valley; hence in each ground-water district there were two or three times as many wells as were used in compiling the table on p. 92. The 32 key wells were selected from this large group so as to provide a fairly even areal distribution in each district, and some distribution in depth. Wells in the midst of heavily pumped areas were balanced by others remote from irrigation wells, so that the average net change in the key wells selected was about equal to the average change in the much larger number of wells observed in that district dur-

Net change of water level in observation wells in Cedar City Valley

[Based on measurements or interpolations of water level about December 3 of each year]

Ground-water district	Well number	Depth of well (feet)	Rise (+) or fall (-) of water level, in feet, during —				
			1936	1937	1938	1939	1940
Rush Lake	(C-33-11)30ddd1	250	....	....	....	0.0	-0.1
	(C-34-10)6ccc1	14	....	....	....	-.1	-.7
	(C-34-11)9cdc1	61	....	....	....	-.1	-.2
Midvalley	(C-34-11)29bad1	56	....	....	-0.3	-.3	-.2
	36cbc2	195	....	....	.0	-.2	-.6
	(C-35-11)4dda1	267	....	....	+1.1	-.7	-2.9
	8cdd1	130	[1] -1.0	....	+1.2	-1.2	-2.1
	15aac1	300	....	[2] +0.5	+1.4	+1.1	-1.7
Enoch	(C-34-10)31cbc1	109	....	....	....	+.1	-.5
	(C-35-10)18cbb1	112	....	....	+2.2	+.3	-3.5
	(C-35-11)1cdc1	217	....	....	+.6	+.6	-.6
	14dab1	160	....	....	+1.8	-.9	-2.8
Coal Creek	(C-35-11)21dcc1	180	-2.4	+2.0	+2.6	-2.4	-3.0
	27acc1	113	-1.5	+3.8	+2.5	-3.7	-4.3
	32cdd1	75	....	....	+2.8	-2.0	-1.6
	33aac1	138	-2.2	+3.1	+3.0	-3.4	-4.0
	(C-36-11)8aab1	103	-1.8	+1.6	+4.0	-2.4	-2.7
	18aba2	200	....	+1.7	+3.4	-1.4	-2.4
Iron Springs	(C-35-11)29abd2	120	....	....	+1.9	-1.7	-2.9
	31acd1	248	-.3	+1.3	+3.0	-2.1	-3.2
	(C-35-12)34dcd1	120	....	+.2	+.1	-.1	-.7
	(C-36-12)1aaa2	366	-1.7	+1.7	+2.5	-1.8	-2.1
	12dba1	600	....	+1.4	+2.0	-1.4	-2.0
	14bbd1	200	-.1	+.5	+.7	+.2	-.3
Hamiltons Fort	(C-36-12)26cbb1	113	....	....	....	-.1	-.5
	(C-37-12)11dbc1	24	....	....	....	-.2	-.7
Queatchupah	(C-36-12)20ddc1	....	....	[3] +.2	[3] +.2	[3] -.6	[3] -.2
	28ccc1	140	....	....	....	-.6	-.6
	(C-37-12)9baa1	90	....	....	....	-.5	-.2
Kanarraville	(C-37-12)23acb1	250	+.3	+1.0	+1.3	-2.5	-3.2
	34abb1	190	-1.4	+3.6	+3.7	-1.6	-4.9
	(C-38-12)3bcb1	210	....	....	....	-.3	-1.1

[1] Estimated from record of adjacent well, (C-35-11)9ccc2.
[2] Estimated from record of adjacent well, (C-35-11)10dbd3.
[3] Estimated from record of adjacent well, (C-36-12)21ccbl.

ing 1938 and 1939. Other conditions being equal, the wells chosen were those with longest records of nonpumping-level observations, and those most likely to be accessible for further observations. Ordinarily, the greater the number of key wells used, consideration being given to representative areal distribution and depth, the more exact the averages will be. For economic reasons, the number of key wells has here been limited to as small a number as possible to yield what is believed will be reliable results. Continuation of observations in these key wells, perhaps no oftener than once a year, probably will provide data sufficient for estimating the changes in ground-water storage from year to year. Additions to or changes in the list of wells given above will likely lower the value of the data for comparative purposes, because the net changes computed for a district would be raised or lowered, depending on whether the new wells are adjacent to or remote from areas of heavy pumping. During the past 4 years the comparisons of water level have been made in December, because ground-water conditions are fairly well stabilized then. These conditions continue fairly stable from December until April, or whenever the pumping season starts, and during this entire period there is in most wells a gradual, fairly uniform rise in the water level. Any month between December and April, before pumping begins, is thus a satisfactory time for ground-water inventory. December was selected because of the ominous possibilities in the weather of January, February, and March and because of the unpredictability of the beginning of the pumping season, which may start as early as the latter part of March.

The estimates given below of the average change in ground-water levels in each of the districts in Cedar City Valley are based on the figures shown in the table on p. 92.

Change of water levels in ground-water districts, Cedar City Valley

Ground-water district	Estimated average rise (+) or fall (-), in feet, during —				
	1936	1937	1938	1939	1940
Rush Lake	....	....	....	-0.1	-0.3
Midvalley	....	....	+0.7	-.2	-1.5
Enoch	....	....	+1.5	.0	-1.8
Coal Creek	-2.0	+2.4	+3.0	-2.6	-3.0
Iron Springs	-.7	+1.0	+1.7	-1.2	-1.9
Hamiltons Fort	....	....	....	-.1	-.6
Queatchupah	....	....	....	-.6	-.3
Kanarraville	....	+2.3	+2.5	-1.5	-3.3
Cedar City Valley	-1.2	+1.6	+1.8	-0.9	-1.8

RECESSION PRIOR TO 1936

The normal-pressure surface in September 1936 reached the lowest level recorded during the 4 years of the present investigation. The water levels in observation wells of the Iron County Agricultural Agent were quite generally lower during that month than at any time since observations were begun in 1931 or 1932. In those wells, as shown by figure 14, the highest levels recorded during 1936 or 1937 (before and after the low levels reached in September 1936) were lower than during any other year of the decade 1931-40.

The county agent's observation wells include several that have been selected as key wells for Cedar City Valley—three in the Coal Creek district and two in the Iron Springs district. The average net changes of water level in the three wells in the Coal Creek district (based on interpolations in December each year) are, as follows: 1932, +3.3 feet; 1933, -2.0 feet; 1934, -7.0 feet; 1935, -2.0 feet; 1936, -2.0 feet; 1937, +3.0 feet; 1938, +2.7 feet; 1939, -3.2 feet; 1940, -3.8 feet—a net decline during the 9-year period of about 11 feet. In the Iron Springs district the average of the changes in two wells was: 1932, +3.0 feet; 1933, -1.0 feet; 1934, -5.0 feet; 1935, -2.7 feet; 1936, -1.0 foot; 1937, +1.5 feet; 1938, +2.8 feet; 1939, -2.0 feet; and 1940, -2.6 feet—a decline of about 7 feet in 9 years. From 1936 to 1939 these averages are in fair agreement with those computed from the group of key wells in each district (p. 92), and presumably for the earlier years likewise these few wells would have been fairly representative for the two districts.

The only indications of the position of the normal-pressure surface or of other piezometric surfaces prior to 1932 are based on reports of residents, particularly the information that has been filed by well owners to support their claims to the right to use ground water. Specific information was required of the owners as to the date of construction of each well and the position of the water level when the well was completed. These data, shown in underground water claims filed with the State engineer, include many statements of doubtful accuracy, but there is much that seems credible. According to information taken from these claims, the area of artesian flow has at some time during the past 40 years extended nearly to the 5,540-foot contour on the Coal Creek alluvial fan. (See p. 128.) Comparison of the reported water levels in and dates of construction of adjacent wells indicates that since the beginning of ground-water development about 50 years ago, water levels were probably highest—and ground-water storage therefore greatest—at some time during the decade between 1915 and 1925, during which there was a considerable accumulated excess of precipitation. (See fig. 1.) Data relating to wells constructed during this decade form the basis for the "reported high water levels" shown in the profile of plate 16. These high-water levels in the Coal Creek pumping district are shown to be more than 30 feet above the low levels recorded in September 1936.

The residents of Cedar City Valley are practically unanimous in reporting that, after the drought of 1934, the water levels in wells reached the lowest point in history, and that these low levels were the culmination of a long period when the trend of levels was prevailingly downward. These reports are supported by the evidence presented in figure 14, which shows the correlation between water-level trends and climatic cycles, and in figure 1, which shows a great accumulated deficiency due to 8 years of subnormal precipitation in the 10-year period 1927-36.

On the other hand, it is probable that ground-water storage in the valley has decreased during previous drought cycles very much as it did during the 10-year period 1927-36. The years 1899 to 1904 were notably deficient in precipitation, as shown by the records at Parowan and other Weather Bureau stations in Utah, and the effect of this drought cycle has been noted in other ground-water areas in the State. [65] The effect on ground-water levels of this early period of rainfall deficiency is indicated in a well described by Meinzer [66] as "Webster's well." He states that "when the well was completed the water remained at a depth of 7 feet, and for 7 years it had to be pumped in order to bring it to the surface, but in July 1907, it began to overflow, and from that time until October 1908, when the investigation was made, it overflowed continuously. This interesting rise in the head of the water is probably to be correlated with increase in rainfall." The Webster well probably is the well now numbered (C-35-11)14dab1, in which the water level during the past 3 years has ranged from 3.7 feet below the surface in August 1937 to 1.0 foot in April 1939. Judging by nonpumping levels in other wells, the depth to water in this well was probably lower in 1935 and 1936 than in 1937 but perhaps not a great deal below the level reached soon after the well was drilled in 1900.

RELATION TO SURFACE-WATER BODIES

The normal-pressure surface in Cedar City Valley appears to be continuous with the water surface of Rush Lake, and when the lake bed is dry it evidently continues beneath it at depths of from a few inches to a few feet. This continuity is indicated by the positions of the water level in shallow boreholes located on or near the lake bed. The fluctuations of the level in these boreholes are evidently caused chiefly by evaporation from the lake surface and from evaporation and transpiration of ground water at shallow depths near the lake. Thus Rush Lake appears to be within the zone of saturation, and loss of water from its surface by evaporation constitutes loss from the ground-water reservoir.

[65] Taylor, G. H., and Thomas, H. E., Artesian-water levels and interference between artesian wells in the vicinity of Lehi, Utah; U. S. Geol. Survey Water-Supply Paper 836-C, pp. 112-114, 1939.

[66] Meinzer, O. E., Ground water in Juab, Millard, and Iron Counties, Utah: U. S. Geol. Survey Water-Supply Paper 277, pp. 145-146, 1911.

In the vicinity of Shurtz Lake, according to residents of the valley, the zone of saturation is likewise at shallow depths. The lake bed was dry in April 1940, but water, probably the zone of saturation, was found within a few inches of the surface, and the relation of the lake to the zone of saturation appeared to be analogous to that of Rush Lake. As in Rush Lake, evaporation there probably represents loss from the ground-water reservoir.

The streams of Cedar City Valley are believed to be generally separated from the zone of saturation after they enter the valley. There is considerable evidence that this is true of Coal Creek, for the water levels in several wells adjacent to one or another of the channels define a water table no higher than that shown by wells distant from these channels. Furthermore, the channels of the creek in the upper part of the fan are more than 50 feet and may be as much as 200 feet above the water table, and these channels are dry during the greater part of each year. Thus it is not likely a permanent water-table ridge is maintained under them.

Minor streams entering the valley are likely to be even higher above the main ground-water body, because of the greater slopes of their fans, and they are believed to be likewise separated from the zone of saturation. Finally, the ditches and canals diverting from these streams are judged from tests of seepage losses to be rather thoroughly silted up, so that at least over a good part of their courses they are likely not to be continuous with the water table.

The ground-water terrace under the Coal Creek ground-water district has been described. (See p. 87.) This ground-water terrace is more nearly level and covers a more extensive area at the end than at the beginning of the pumping season, and it is apparent that pumping has been primarily responsible for the enlargement of the terrace. It might be presumed that the flatness of the water table in April results from incomplete recovery from the effects of the previous pumping season, and that the recovery is interrupted each year by renewed pumping, so that the ground-water terrace might be traced ultimately to the development of ground water for irrigation.

On the other hand, similar ground-water terraces have been noted on alluvial fans elsewhere in Utah. On some of these fans there has been practically no ground-water development, and the flatness cannot have been caused by pumping. At the south end of the Escalante Valley near the town of Enterprise, in southwestern Utah, the water table has a lesser gradient than in the lower areas farther north, [67] although the great majority of irrigation wells are in these lower areas. East of Clearfield, in northern Utah, under the terrace formed during the Provo stage of Lake Bonneville, the water table evidently has a flatter gradient than under the area farther west, although there are no ground-water withdrawals on the bench, and although there are several flowing wells and pumped wells in the area to the west. [68] In both areas the streams that are presumed to be the chief agencies responsible for recharging the ground-water reservoir are small in comparison with the probable size of the reservoir. In areas where the quantity of water available for recharge is great compared to the size of the ground-water reservoir, as in Ogden Valley, [69] the slope of the water table under the alluvial fan is likely to conform

[67] Unpublished data.

[68] Unpublished data.

[69] Leggette, R. M., and Taylor, G. H., Geology and ground-water resources of Ogden Valley, Utah: Geol. Survey Water-Supply Paper 796-D, p. 121, 1937.

more closely to the progressively increasing slope of the surface of the fan; in these fans, however, there is likely to be rejected recharge, shown by springs near the upper limits of confining layers for artesian aquifers. The conditions in Cedar City Valley are comparable with the Escalante Valley rather than with any area that is blessed with an abundance of surface water.

Under the Coal Creek fan the reported high-water levels shown on figure 22, based on admittedly sketchy information, define a water surface more or less parallel to that which has existed in recent years. On this insecure basis it is tentatively suggested that, although pumping may have augmented the flatness of the water table near the pumping area, there may well have been under natural conditions a very steeply sloping water table at the mouth of Coal Creek Canyon and a relatively flat water table for some distance beyond in which ground water moved through permeable materials; still lower on the fan, where the proportion of impermeable sediments is greater, the water surface probably has always had an increased slope consistent with the greater hydrostatic head required for movement.

PIEZOMETRIC SURFACES FOR CONFINED WATER IN DEEP AQUIFERS

ARTESIAN-PRESSURE SURFACES

In Cedar City Valley the piezometric surface for water confined in deep aquifers is commonly considerably higher than the normal-pressure surface. The artesian aquifers are ordinarily discontinuous and are distributed irregularly in depth as well as laterally throughout the valley fill. The deeper wells may penetrate several of these aquifers, each having a different pressure head. This differential head is clearly shown in pairs of adjacent deep and shallow wells, and the table below shows the differences in pressure head in nine pairs of wells. During April 1940, when ground-water conditions were presumably fairly stable, the differential head in observed pairs of wells on the Coal Creek fan ranged from 1.6 to 7.4 feet. On the Queatchupah Creek fan even greater differential pressures were observed in adjacent deep and shallow flowing wells. The differential head of the previous September had been even greater in the Rush Lake district, perhaps as a result of lowering of the shallow-water surface by evaporation and transpiration during the summer. Elsewhere the differential head increased in certain pairs of wells and decreased in others, no doubt reflecting differences in the effects of pumping, which in some areas probably withdrew from deep aquifers, in other areas from shallow strata.

For several reasons the available data concerning water levels in Cedar City Valley are inadequate for the construction of isopiestic lines on individual piezometric surfaces. The information derived from wells is not sufficient to show the location and extent of aquifers, or even to indicate that certain wells tap a common aquifer and therefore may be used to define the piezometric surface for that aquifer. On the other hand, the water levels in deep wells do not define a smooth, regular surface but suggest instead that they represent a number of piezometric surfaces. The profile of plate 16, based on three artesian wells, shows marked irregularity; this suggests that the three wells do not tap a common aquifer and therefore do not define a common piezometric surface.

Pairs of deep and shallow wells in Cedar City Valley, showing differential head of piezometric surfaces above the normal-pressure surface

Well number	Depth (feet)	Distance between wells (feet)	Differential head (feet)		Ground-water district
			Apr. 1-10, 1940	Sept. 10-15, 1939	
(C-34-11)3ccb1	519	50	+5.0	+6.2	Rush Lake.
3ccb2	6				
13bab1	....	25	+7.4	+8.4	Rush Lake.
13bab2	9				
(C-35-11)4bbd1	210	4	+4.6	+9.1	Midvalley.
4bbd2	21+				
4cad1	....	Concentric	+6.6	....	Midvalley.
4cad2	....				
4dda1	267	1	+6.2	+5.3	Midvalley
4dda2	144				
13cac2	121	3	+1.8	....	Enoch.
13cac1	65				
30caa2	[1] 200	25	+1.6	+.8	Iron Springs.
30caa1	[1] 180				
(C-36-12)21ccb1	180	470	+9.4	....	Queatchupah.
21ccb2	50				

[1] Well casing probably perforated through all permeable strata.

In many wells, particularly in those drilled for irrigation, the casing is perforated opposite several of the more permeable strata, and the water level in the well indicates not a single piezometric surface but a level achieved by the mingling of waters from several aquifers. And in several wells the level cannot be classified at all, because details as to depth of perforations are unknown or because it is not known whether the casing is perforated. Finally, several deep wells, including two of the reportedly deepest in the valley, wells (C-34-11)20ddd1 and (C-35-11)10ccc1, discharge into pits where the artesian water mingles with shallow water, so that the pressure head of the deep aquifers cannot be ascertained.

Although the piezometric surfaces cannot be mapped satisfactorily, the general forms of these surfaces may be suggested roughly in comparison with the normal-pressure surface. The normal-pressure surface is compared with the highest piezometric surface, defined ordinarily by the deepest wells in an area; other artesian-pressure surfaces, of which there may be several, will of course be intermediate between this highest surface and the normal-pressure surface. On the upper part of the Coal Creek alluvial fan the water levels in deep and shallow wells alike appear to define a common piezometric surface—the water table. Farther from the apex of the fan there is likely to be progressively greater divergence between the water levels in shallow wells and adjacent deep wells; in other words, the artesian-pressure surface is similar in form to the normal-pressure surface, but flatter, and the two surfaces diverge slightly. This divergence continues only part way down the fan, perhaps to the north boundary of T. 35 S. Farther north, according to the meager data available, the artesian-pressure surfaces appear to be roughly parallel to the normal-pressure surface.

SUBNORMAL-PRESSURE SURFACES

The water level in deep well (C-36-12)12dba1 is persistently lower than the normal-pressure surface as defined by nearby shallower wells. This is an irrigation well, and the differential head is greater at the close of the pumping season than at the beginning. Thus the subnormal pressure may be due, at least in part, to withdrawal of water from the deep aquifers tapped by the well. The log of this well appears on page 40; the casing was originally perforated only opposite the deeper strata, below 500 feet, but was subsequently reperforated between 200 and 600 feet. [70]

The subnormal pressure head of the deep aquifers in this well cannot be ascribed entirely to pumping, however, for it was noticed during the construction of the well. According to the driller's log, a stratum of fine sand at a depth of 206 to 211 feet yielded a flow of 5 gallons a minute at the surface. The water-bearing beds below this depth had a lower pressure head, and when the well was finished the level for the deep aquifers was below the land surface. This well is west of the Stockyards fault, and it has been suggested (p. 45) that the coarser sediments encountered at depths below 276 feet may once have been continuous with the shallower gravels east of the fault and may have been dropped to their present position by faulting. Plausibly this faulting may have impeded recharge to the gravel by cutting off the original source of supply. The present differential head between deep and shallow aquifers indicates that water may be moving downward into these deep gravels.

A subnormal-pressure surface was encountered in well (C-34-11)3ccb1, near the north end of Cedar City Valley, according to the record of the owner, Mr. H. L. Adams. It is reported that when the well had been jetted to a depth of 80 feet, the depth to water was 2.85 feet below the surface; presumably this static level defined the approximate position of the normal-pressure surface. Water from aquifers at depths of 211 to 285 feet below the surface was apparently under slight artesian pressure, for the water level rose to 1.0 foot below the surface. Still higher artesian pressure was encountered in an aquifer at a depth of 307 to 330 feet, and the well flowed 15 gallons a minute. An aquifer at depth of 365 feet evidently had subnormal-pressure head, for the water level remained 4.5 feet below the land surface and nearly 2 feet below the normal-pressure surface. At greater depths other aquifers were encountered, some with artesian-pressure head.

Drillers' records are inadequate to show whether subnormal-pressure surfaces are at all common in the area. It is quite possible, however, that subnormal-pressure surfaces exist for other deep aquifers in Cedar City Valley, particularly if those aquifers have been displaced by faulting.

SOURCES OF GROUND WATER

Many of the sources from which the ground-water reservoir of Cedar City Valley receives replenishment have been mentioned or suggested in the foregoing discussion. The ultimate source of all or nearly all of the ground water is precipitation over the drainage basin, and additions to the ground-water body may be made either by direct penetration of the rainfall within the limits of the valley or by seepage from streams which drain the mountainous areas bordering the valley; and this seepage may occur in the alluvium within the canyon itself or along the natural channels or diversion ditches below the mouth of the canyon. Penetration of excess irrigation water from areas irrigated by these streams is closely allied with loss from the stream channels, and the data collected in Cedar City Valley were not adequate to discriminate the recharge derived from the two sources. Faults are believed to be of no importance as sources of ground water, although many springs in Cedar City Valley ar

[70] Iron County Record, Oct. 8, 1926.

located along or near fault lines, and the comparatively recent structural adjustments in the area have undoubtedly had some bearing on the circulation of ground water.

SEEPAGE FROM STREAMS

The streams entering Cedar City Valley ordinarily lose water rapidly after they leave the mountains. Part of this loss no doubt is due to evaporation, but a large proportion is due to seepage into the coarse materials of the stream bed. Commonly the flow of smaller streams disappears into the ground within a few hundred feet of the mouth of the canyon. Considerable seepage also may occur above the mouths of the canyons in the narrow belt of alluvium that forms the floor of the canyon. Well (C-36-10) 21caa1, drilled in the canyon of Coal Creek about 4 miles upstream from the mouth, penetrated 110 feet of alluvial sediments. The canyon floor is about 700 feet wide in the vicinity of the well. The water level in the well indicates a steep slope away from the stream channel, and it is likely that there is seepage from the stream into the alluvial sediments in the canyon. Some of this lost water may be forced to the surface farther downstream, where the canyon is cut through resistant rocks, but probably seeps away again as the canyon widens out below the resistant outcrops and continues downstream as underflow beneath the floor of the canyon. It is likely that the canyons of all the streams entering Cedar City Valley serve similarly as underflow conduits. In the alluvium of Coal Creek there is a fluctuation of the water table corresponding to the cycle of stream runoff, high in the spring and low in the fall, as shown in well (C-36-10)21caa1; obviously this fluctuation reflects the rate of seepage from the stream channel.

Much of the area surrounding Cedar City Valley is drained by small canyons in which there may be runoff for only a few days or weeks each year, or, in some canyons, no runoff for several years. This runoff ordinarily seeps into the ground soon after it enters the valley, making a rather small contribution to the ground-water reservoir. In these smaller canyons probably the greater part of the water moves as underflow through the alluvium in the bottom of the canyon until it enters the ground-water reservoir in the valley.

The rate of seepage from streams that enter Cedar City Valley would be greatest as the stream flows over the upper part of its alluvial fan, where sediments are ordinarily coarsest and most permeable, unless the stream is insulated from these sediments by silt or clay deposited in its channels. Comparison in September 1939 of the discharge of Coal Creek at the gaging station in the canyon and at the heads of the principal diversion ditches in Cedar City did not show any appreciable loss in this distance of about 2¼ miles as the stream flows, possibly because the runoff from cloudbursts a few days earlier had left a generous coating of silt and clay over the bed of the stream, and possibly also because the hard rocks which outcrop below the gaging station may have brought water to the surface that was not measured at the gaging station. Rises of the water table in the highest part of the fan tapped by wells are correlated with the high spring runoff in the creek, when seepage might be presumed to be greatest, and seem to justify the conclusion that there is appreciable recharge to the ground-water body at this time. In many wells located on the fans of the smaller streams entering Cedar City Valley the water level likewise rises soon after the time of maximum runoff in the spring, presumably due to recharge occasioned by seepage during this runoff.

From streams that have a summer flow sufficient for irrigation the water is ordinarily diverted near the apex of the alluvial fan, and the natural stream channels lower on the fan are likely to be dry most of the year. Commonly such channels, particularly those of Coal Creek but also those of the smaller streams, have beds of coarse material, and seepage loss is believed to be considerable when the channel is used.

The irrigation ditches and canals ordinarily are constructed with lesser gradient than the main channels, and diversion works are built so that the flow in the ditches is fairly constant, regardless of great variations in discharge of the main stream. The beds of the ditches are therefore likely to become more or less insulated by silt deposition, and loss by seepage from the older ditches may be low. Measurements of the flow in several ditches that serve primary rights near Cedar City have indicated that loss by seepage is inappreciable.

Each of the streams that enter the valley may lose water to the ground-water body, and several canyons that contain streams only in their upper reaches may likewise contribute to the ground water. Thus the sources from which ground water is obtained are as numerous as the streams themselves. The relative importance of these sources is most clearly indicated on the maps showing contours of the normal-pressure surface (pls. 13 and 14). Coal Creek is clearly the predominant source, for the water moves approximately in the direction of slope of the land surface, northward down the valley, northwestward toward Iron Springs, southwestward toward Shurtz Lake. Other important sources indicated by this map are Shurtz, Queatchupah, possibly Leach's, and Kanarra Creeks, and the Spanish Treasure Wash. Another important source is evidently east of the Enoch district, from which water moves westward toward the center of the valley. Movement of water throughout practically the entire reservoir is evidently outward from these principal sources. Water entering the valley from minor ephemeral drains is apparently of very small quantity compared with that from these major sources and has no discernible effect on the upper surface of the ground-water body as depicted by contours, except possibly along the narrow outlet toward Twentymile Gap.

Both the confined and unconfined waters of the valley are recharged by seepage from these several streams, for the distinctions between deep and shallow water disappear in the upper parts of the ground-water reservoir, where the seepage loss probably is greatest in amount. Quantitative measure of the water derived from seepage is manifestly impracticable, because of the many and varied sources of this water.

RECHARGE FROM IRRIGATION WATER

When water is applied for irrigation in sufficient amounts that some penetrates below the root zone, the excess may continue downward to the zone of saturation. This recharge may be derived from water diverted from streams or pumped from wells.

The irrigated lands supplied by streams are commonly distributed rather widely over the alluvial fans of the respective streams, and irrigation in many instances requires unduly long and uneconomical canals. On the Coal Creek fan some land is irrigated near the head of the fan, around Cedar City, but some water is diverted as much as 5 miles from the mouth of the canyon. The fluctuations of water levels in the areas irrigated from some of these longer ditches have been discussed. (See p. 77.) It is presumed that these fluctuations result largely from seepage of excess irrigation water, because the ditches appear to be rather thoroughly insulated from the ground-water body. On the Shurtz Creek and Queatchupah Creek fans practically all the water is diverted to areas rather far down the slopes of the fans. The position of the irrigated area on the fan may determine what proportion of the water may join the ground-water body—on the highest parts of the fan the soil is likely to be more permeable, downward penetration of water more rapid, and the proportion that migrates to the zone of saturation greater. Water from these higher areas joins the ground-water reservoir and may then move through either the deep or the shallow aquifers. On the other hand, the irrigated lands farther down on the fan commonly lie above artesian aquifers, but are separated therefrom by confining layers. Most of the stream-irrigated lands on the Shurtz Creek and Queatchupah Creek fans and in the Mid-valley district on the Coal Creek fan are in that position; excess water from irrigation cannot reach the artesian aquifers but moves into the saturated zone above the confining layers.

The return seepage of irrigation water pumped from wells is probably small in comparison with the total amount of water pumped, and its effect on the position of the water table would doubtless be an unmeasureable amount of retardation of the decline that is caused by pumping.

PENETRATION OF PRECIPITATION

Water from precipitation may reach the zone of saturation under the same conditions as water from irrigation—the soil-moisture deficiency must first be satisfied, and then any excess that escapes from the root zone will migrate to the zone of saturation. Rarely are these conditions satisfied during storms in the summer, for the cloudbursts and heaviest storms are usually of such short duration that the soil is left dry below a depth of a few inches. Occasionally but not usually, at least during the past 5 years, winter storms result in the accumulation of snow several inches deep over the valley. When this snow melts there may well be additions to the ground-water reservoir by deep penetration.

As was true of water on irrigated lands, the opportunity for penetration of rainfall would be greatest in the permeable materials of the upper parts of the fans, and recharge to the deep confined aquifers could occur only in these areas. Penetration of rainfall in the lower parts of the fans would add increments to the zone of saturation above the confining layers.

WATER RISING ALONG FAULTS

Numerous springs rise just west of the Enoch fault near the settlement of Enoch, and four or five others appear along the West Enoch fault. (See pl. 3.) Several seeps are to be found where the Junction fault cuts across the Coal Creek fan near Iron Springs, and far to the north, near Rush Lake, a spring occurs along the same fault. To this extent in Cedar City Valley springs "arise" along faults. The origin of the springs along the West Enoch fault is clearly indicated on plate 13, which shows a ground-water dam along the fault. The water from the springs has the same temperature and general characteristics as that derived from artesian aquifers farther east. The fault has evidently cut across the aquifers, and thus represents a barrier to ground-water circulation rather than a source of new water in the valley. The springs along the Junction fault are believed to have originated from similar conditions.

The water of the Enoch springs, rising along and near the Enoch fault, has a quality and temperature similar to that of the water in the adjacent ground-water reservoir under the valley. The source of this water appears to be the considerable volume of unconsolidated materials that crop out east of the fault and in the southern part of Parowan Valley. (See p. 169.) The spring along the fault just east of Rush Lake is considered likewise to be derived not from deep sources along the fault but from ground water at rather shallow depths—perhaps moving through porous basalt from areas farther east.

Many springs rise in higher areas bordering Cedar City Valley, particularly in the plateaus east of the valley. None of these springs is thermal. Many are located along faults, and may have been originated by the displacement of a permeable stratum along the fault.

MOVEMENT AND DISPOSAL OF GROUND WATER

GENERAL RELATIONS IN CEDAR CITY VALLEY

The movement of ground water follows closely the drainage pattern of Cedar City Valley. The three independent drainage basins within the valley are occupied by independent ground-water basins, separated by low ground-water divides, and drained by underflow beneath the channels that form the outlets to the separate topographic basins at Twentymile Gap, Iron Springs Gap, and Kanarraville. Movement of the ground water, like the surface water, is generally from the mouths of the canyons that empty into Cedar City Valley, down the slopes of the alluvial fans and toward one or another of these three outlets. Natural disposal of the ground water is not limited to these outlets, however. Still analogous with surface drainage, some ground water is discharged by evaporation from the vicinity of the Shurtz Lake and Rush Lake playas, and from an area northwest of Enoch, where ground water is at shallow depths.

MOVEMENT AND DISPOSAL IN SUBDIVISIONS OF THE GROUND-WATER RESERVOIR

Coal Creek district.—Ground water in the Coal Creek district moves northward and northwestward from the apex of the Coal Creek fan at Cedar City, and presumably also in minor quantities from the mouths of the canyons of minor tributaries, particularly Fidlers Creek. It leaves the district by movement into the Midvalley district to the north and into the Iron Springs district that lies west of the Stockyards fault. Movement of ground water is apparently impeded in the vicinity of this fault, but a considerable quantity nevertheless enters the Iron Springs district, as shown most clearly by the recovery in that district following each pumping season.

Iron Springs district.—Water in the Iron Springs district moves southwestward toward Shurtz Lake and westward toward Iron Springs Gap. Because the arbitrary north boundary of this district does not exactly coincide with the ground-water divide north and east of Iron Springs Gap there is also movement northward into the Midvalley district from a small area. Several seeps situated along the trace of the Junction fault, and marked by clumps of willows, probably represent places where the westward movement of water is impeded by the faulting. Discharge there is limited primarily to the transpiration of the willows. The water moving toward Shurtz Lake enters an interior basin from which there is evidently no outlet, either for surface or ground water, and discharge is chiefly by evaporation and transpiration of shallow water from the lake bed and vicinity. Water discharged from the Shurtz Lake basin includes much that is derived from the Queatchupah and Hamiltons Fort districts, and its disposal is considered more fully under those districts. (See pp. 105-106.)

Water moving toward Iron Springs leaves the district and Cedar City Valley through Iron Springs Gap and enters the Escalante Valley farther west. The Iron Springs, located in the NE¼ sec. 28, T. 35 S., R. 12 W., originate where Cretaceous strata underlying the alluvium in the Gap force some of this ground water to the surface. The springs rise in a seepage area several hundred feet long in the Gap. Flow from the upper part of this area ranges from about 45 gallons a minute during April to about 25 gallons in July and August. The total flow from the springs could not be measured but is believed not to exceed 0.5 second-foot.

The amount of underflow through Iron Springs Gap is dependent upon the cross-sectional area, the hydraulic gradient, and the permeability of the water-bearing materials within the Gap. The rock barrier that gives rise to the Iron Springs, the presence of other outcrops along the floor of the Gap, and the log of well (C-35-12)18ddd1 (p. 41) showing consolidated rock in the Gap within 26 feet of the surface—all are indications that the alluvial fill in the Gap is thin. At the springs, therefore, where the width of the gap is 1,600 feet, estimating an average depth of 25 feet below the spring outlets in the bottom of a channel cut into the floor of the gap, probably 40,000 square feet is a generous estimate of the cross-sectional area of alluvium. The slope of the normal-pressure surface through the gap is about 25 feet in a mile, so that the hydraulic gradient is roughly 0.5 percent. No tests were made of the permeability of any of the alluvial materials in the gap, but the alluvium exposed in cut banks is dominantly very fine sand and silt, that is, its particles ordinarily have a diameter of less than 0.1 mm. In all probability the deeper strata of the alluvial fill have a larger proportion of coarse materials than the beds at the surface, for the development of the gap by erosion of Tertiary and older rocks would necessarily require streams of greater volume and velocity than those of today. The log of well (C-35-12) 18ddd1, however, shows material similar to that on the surface, down to a depth of 22 feet, and only 2 feet of gravel in the entire section. Accordingly it is considered that the average coefficient of permeability [71] for the entire thickness of saturated alluvium is not greater than 100. Using a coefficient of 100, with cross section of 40,000 square feet and hydraulic gradient of 0.5 percent, the estimated underflow is 20,000 gallons a day, or about 14 gallons a minute. An underflow of 0.1 second-foot would require that the materials in the gap have a coefficient of permeability greater than 300, which is ordinarily true only of well-sorted sand or gravel. Accordingly, the discharge through Iron Springs Gap, by springs and underflow, is believed to average not over 0.6 second-foot, or about 500 acre-feet a year.

Enoch district.—Ground water in the Enoch district moves principally westward from the unconsolidated deposits that lie east of Cedar City Valley, and from the south end of Parowan Valley. Many springs arise along the east edge of the valley floor near Enoch. Two of the largest of these discharged respectively 270 and 170 gallons a minute during the summer of 1939, and the total discharge from all the springs at Enoch is estimated to be about 4 or 5 second-feet. Most of the water from these springs is used for irrigation and for stock, some is lost by evaporation and transpiration, and no doubt some seeps into the ground and returns to the ground-water reservoir within the Enoch district.

[71] The rate of flow, in gallons a day, through a square foot of cross section, under a hydraulic gradient of 100 percent, at a temperature of 60°F.

Ground water moves from the Enoch district over the ground-water dam along the West Enoch fault and enters the Midvalley district farther west. In the northern part of the Enoch district this ground-water dam causes several small springs, from which the total discharge is probably less than one-half second-foot. Most of this discharge collects in pools for stock and is lost by evaporation.

Besides the discharge by springs within the Enoch district, there is undoubtedly some loss of ground water from the district by transpiration and perhaps by evaporation, for the depth to water in a part of the district is less than 10 feet. It is estimated that this area of shallow ground water covers about 1,600 acres. Some of the area is bare, some is meadowland similar to that for which White [72] estimated an average annual loss by transpiration and evaporation of 1 acre-foot per acre, and some is covered with greasewood and other plants using a smaller quantity of ground water. The total annual discharge by transpiration and evaporation and by the springs along the lower western edge of the Enoch district is estimated to be about 1,000 acre-feet. This estimate does not include possible wastage from the springs along the east side of the district.

Midvalley district.—Ground water from the Enoch district and from parts of the Coal Creek and Iron Springs districts moves northward through the Midvalley district and into the Rush Lake district. There are no springs in the Midvalley district and the zone of saturation is far enough below the surface, particularly during the summer, that there is probably little loss by transpiration.

Presumably, ground water in the Midvalley district has been much closer to the surface in decades prior to 1930 than in recent years, for residents of the area report water to have been "struck in every post hole" in bygone days. Under such conditions there would no doubt have been considerable discharge of ground water from the district by transpiration and evaporation.

Rush Lake district.—In the Rush Lake district ground water moves northward from the Midvalley district toward Rush Lake and also southwestward toward the lake by underflow through the Spanish Treasure Wash. Some water, probably moving in part from the vicinity of Rush Lake, and partly from the Midvalley district, moves northwestward through Twentymile Gap, where it leaves Cedar City Valley and enters the Escalante Valley.

The discharge through Twentymile Gap is undoubtedly small. The depth to water in the gap is more than 25 feet, and the width of the valley floor, between outcrops of volcanic rock, is only 800 feet. If the alluvium had an average depth of 125 feet in the gap, the cross-sectional area of the saturated zone would be about 80,000 square feet. The alluvium in this part of Cedar City Valley is predominantly of fine texture, as is shown by the log of well (C–33–11)30ddd1 (p. 41), and the average coefficient of permeability of the saturated materials is probably considerably less than 100. Assuming a cross-sectional area of 80,000 square feet with a coefficient of permeability of 100, the discharge by underflow through Twentymile Gap, under the existing hydraulic gradient of 10 feet in a mile, would be less than 15 gallons a minute, or 20 acre-feet a year.

The depth to the water table or normal-pressure surface is indicated

[72] White, W. N., A method of estimating ground-water supplies, based on discharge by plants and evaporation from soil—results of investigations in Escalante Valley, Utah: Geol. Survey Water-Supply Paper 659-A, p. 86, 1932.

in plate 17. The area of the bed of Rush Lake is about 500 acres. In years of more than normal precipitation a major part of this surface may be covered with water, and water may be within a foot of the surface throughout the summer. In these years the quantity of water evaporated would reach a maximum. According to records of the United States Weather Bureau, evaporation from land pans in Utah ranges from 50 to 60 inches during the season April to November. White's [73] experiments indicate evaporation from these land pans is about 1.5 times the amount that would be evaporated from a free water surface. If the entire bed of Rush Lake were covered with water throughout the season from April to November, the quantity evaporated would probably amount to about 1,500 acre-feet. Part of this water is undoubtedly derived from surface runoff, and therefore the amount lost from the ground-water reservoir by evaporation would be only a fraction of that amount. As the water on the lake bed evaporates, and the zone of saturation drops below the land surface, the rate of evaporation diminishes rapidly. Experiments by White [74] indicate that when the water table is a foot below the land surface, the evaporation may be less than 30 percent of that from a free water surface; and when the depth to the water table is more than 2 feet, evaporation is likely to be less than 15 percent of the free water surface. Accordingly, the evaporation from the area occupied by the bed of Rush Lake in a normal year is probably about 500 acre-feet, and in years of low ground-water levels it may be considerably less.

Beyond the margins of Rush Lake there is an area of about 3,500 acres in which the depth to the zone of saturation is less than 10 feet and in which transpiration may occur. Much of this area has a vegetative cover that includes such ground-water plants as rabbitbrush and greasebush which, under similar conditions in the Escalante Valley, are estimated to transpire about 2½ acre-inches of water per acre. [75] On this basis the total annual discharge by transpiration over the 3,500 acres would be about 700 acre-feet. The total ground-water discharge from the Rush Lake district by evaporation, transpiration, and underflow through Twentymile Gap is thus estimated to be about 1,200 acre-feet.

Queatchupah district.—Ground water moves eastward in the alluvial fans of Queatchupah and Leachs Creeks and certain other smaller streams. A very small quantity of water is discharged by Eightmile and Mud Springs, and the rest moves into the undrained depression occupied by Shurtz Lake, where it is discharged by evaporation and transpiration.

The bed of Shurtz Lake covers an area of about 600 acres. Estimated on the same basis as for Rush Lake, the evaporation from the lake if covered by water throughout the year probably would be about 1,800 acre-feet, and under normal playa conditions it would more likely be about half that figure. A large proportion of the water that collects in Shurtz Lake probably is storm water from surface streams, and therefore the quantity lost from the ground-water reservoir would be only a small proportion of the total evaporated, perhaps about 500 acre-feet a year.

Beyond the edges of the lake bed and adjacent sand dunes is an area of about 12,000 acres in which ground water commonly occurs under sufficient artesian pressure to produce flowing wells. The position of the water table is not accurately known, but it probably is within 10 feet of the surface over much of the area. The loss by transpiration in the

[73] White, W. N., op. cit., p. 76.
[74] White, W. N., op. cit., p. 80.
[75] White, W. N., op. cit., p. 87.

area is estimated to be about 1,500 acre-feet, and the total annual ground-water discharge from the vicinity of Shurtz Lake is considered to average about 2,000 acre-feet. This water is derived not only from the Queatchupah district but also in part from the Iron Springs and Hamiltons Fort districts.

Hamiltons Fort district.—Water in the Hamiltons Fort district moves westward down the slopes of the Shurtz Creek alluvial fan toward Shurtz Lake. Its discharge from that area has been included in the estimate given above.

Kanarraville district.—Ground water in the Kanarraville district moves toward the center of the valley through the alluvial fans of Kanarra and Muries Creeks on the east side of the valley and through alluvial sediments of smaller unnamed streams on the west side. The motion of ground water in the center of the valley is southward out of the area from a divide near the south edge of secs. 10 and 11, T. 37 S., R. 12 W. No estimates have been made of this underflow but, judging by the small size of the drainage basin, it is certainly not large.

Summary.—It is evident that there is loss from the ground-water reservoir of Cedar City Valley by natural discharge from several of the ground-water districts. A small part of this natural discharge is through the outlets at Twentymile Gap, Iron Springs Gap, and near Kanarraville; a much larger amount is lost by evaporation and transpiration where the water table is near the surface. The districts from which there is natural discharge of ground water, and the estimated average amount of this discharge, are summarized below.

Estimated annual natural discharge, in acre-feet, from ground-water districts in Cedar City Valley, during recent years

	Acre-fee
Rush Lake	1,200'
Enoch	1,000
Iron Springs (through Iron Springs Gap)	500
Queatchupah, Hamiltons Fort, and Iron Springs (Shurtz Lake)	2,000
Kanarraville	Small; not estimated
Total	4,700

CHEMICAL CONSTITUENTS OF THE GROUND WATER

CHEMICAL ANALYSES

Samples of water from 56 wells, 2 springs, and 4 streams in Cedar City Valley were collected and analyzed in the laboratory of the Geological Survey at Washington, D. C., for total hardness, alkalinity (bicarbonate), sulfate, chloride, and nitrate. In addition, field determinations of chloride were made on samples from 110 wells, including most of those from which samples were collected for partial analysis.

The results of the 62 partial analyses are given below, and the results of field determinations of chlorides in the water of 57 other wells appear in a supplementary table. (See p. 109.) The wells are grouped in these tables according to the source from which the water is derived. Inasmuch as the subdivisions of the ground-water reservoir are also determined in large part by the sources of the water, the wells are listed by ground-water districts, except that wells on the Fidlers Creek alluvial fan are distinguished here, although the fan was not deemed of sufficient size or importance to be defined as a separate ground-water district. As has been pointed out (p. 102), small quantities of ground water may enter Cedar City Valley from minor drains and tributaries other than the sources under which the wells are grouped, and thus some wells, particularly those near the edge of the valley floor, may receive a portion of their supply from a source other than indicated in the table. Even these wells, however, probably derive a major part of their supply from Coal Creek and other larger streams, as indicated by the direction of movement of ground water in the valley. (See pls. 13 and 20.)

Partial analyses of water collected in Cedar City Valley

[M. D. Foster and G. J. Petretic, analysts. Chemical constituents shown in parts per million]

No. on plate 17	Well number	Depth of well (feet)	Total hardness as $CaCO_3$	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)
	Enoch alluvial plain, Enoch district						
1	Enoch Springs	....	190	208	32	12	2.8
2	(C-34-11)36adc1	200	198	242	34	13	.9
3	(C-35-10)7cad1	101	228	232	40	13	4.2
4	(C-35-11)1acc1	150	194	200	28	12	2.5
5	1ccd2	156	228	235	26	10	2.7
6	12ddd1	250	249	246	32	21	....
7	13ddb2	166	228	186	50	26	....
8	14aac1	334	222	200	36	15	....
	Fidlers Creek alluvial fan, Enoch and Coal Creek districts						
9	(C-35-11)14ddd3	158	712	361	200	86	125
10	23bdc1	100	1,365	244	600	237	260
11	26bbb1	140	1,170	312	520	172	144
	Coal Creek alluvial fan, Coal Creek district						
12	Coal Creek [1]	....	276	204	120	3	....
13	(C-35-11)21dcc1	180	578	191	280	17	10
14	22acb1	227	351	178	240	11	....
15	22dcc1	61	712	306	400	36	17
16	27aca1	108	765	443	300	33	56
17	27acc1	113	765	188	480	16	13
18	27adc1	148	615	424	180	17	44
19	27dcd1	150	728	227	600	13	....
20	32aca1	175	630	290	260	13	11
21	33aac1	138	818	157	800	17	16
22	(C-36-11) 5baa1	132	825	193	640	21	10
23	8aab1	103	825	246	600	58	58
24	8cab1	200	1,125	398	640	45	18
25	8cbb1	60	1,365	338	960	67	21
26	10bcc1	195	1,500	300	880	25	8.5
27	18ada1	230	960	224	640	84	29
	Coal Creek alluvial fan, Iron Springs district						
28	Iron Springs	....	405	301	125	35	0.0
29	(C-35-11)19bda1	175	288	202	120	7	.0
30	29abd1	100	468	290	240	10	4.7
31	31acd1	248	435	294	120	12	....
32	(C-35-12)25ddd1	....	698	240	440	24	1.7
33	(C-36-11) 7baa1	167	585	166	280	25	12
34	(C-36-12) 1aaa2	366	261	175	120	5	.5
35	9aaa1	257	288	182	120	6	.8
36	10ada1	389	288	189	125	6	1.0
37	12dac1	200	255	152	150	6	.8

Partial analyses of water collected in Cedar City Valley—Continued

Coal Creek alluvial fan, Midvalley district

No. on plate 17	Well number	Depth of well (feet)	Total hardness as $CaCO_3$	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)
38	(C-34-11)29ddd1	....	252	157	95	8	0.0
39	36cbc1	60	472	444	100	33	.0
40	(C-35-11) 2ddd1	40	1,470	335	560	419	.0
41	8ddd1	178	279	149	130	6	.9
42	9add1	151	412	163	210	12	1.3
43	10dbd1	90	532	270	270	12	22
44	15aab1	266	435	222	220	10	....
45	15dba1	84	585	278	280	30	49
46	16dba1	104	450	189	210	12	13
47	17dad1	270	412	249	130	9	8

Coal Creek alluvial fan, Rush Lake district

No. on plate 17	Well number	Depth of well (feet)	Total hardness as $CaCO_3$	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)
48	(C-33-11)29ccb1	72	264	250	360	90	1.0
49	30bca1	60	750	212	800	151	.0
50	(C-34-11)13bab1	200+	312	256	120	96	1.2

Shurtz Creek alluvial fan, Hamiltons Fort district

No. on plate 17	Well number	Depth of well (feet)	Total hardness as $CaCO_3$	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)
51	Shurtz Creek [2]	....	1,200	126	1,050	24	1.0
52	(C-36-11)31ada1	210	585	230	360	15	11
53	(C-36-12)23ddd1	70	330	163	210	10	3.5
54	26cbb1	113	285	149	180	8	.0
55	(C-37-12) 3ddd1	230	518	145	720	7	....
56	11cbb1	90	184	163	140	8	1.3

Kanarra Creek alluvial fan, Kanarraville district

No. on plate 17	Well number	Depth of well (feet)	Total hardness as $CaCO_3$	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)
57	Kanarra Creek [2]	....	249	204	54	6	3.9
58	(C-37-12)23acb1	250	216	148	120	11	....

Queatchupah Creek alluvial fan, Queatchupah district

No. on plate 17	Well number	Depth of well (feet)	Total hardness as $CaCO_3$	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)
59	Queatchupah Creek [2]	....	78	138	3	7	0.0
60	(C-36-12)21ccb1	180	129	152	15	8	....
61	33dbc1	....	112	151	7	7	.5
62	(C-37-12) 9baa1	90	114	123	13	22	1.1

[1] Sample collected Sept. 29, 1939.
[2] Sample collected March 20, 1940.

Chloride in well water in Cedar City Valley

[Field determinations]

Well number	Depth (feet)	Chloride (parts per million)
Enoch District		
(C-34-10)31cbc1	109	10
(C-35-10) 7cdd1	70	10
18cba1	....	50
12ccc1	228	10
Fidlers Creek alluvial fan		
(C-35-11)23abb1	96	165
Coal Creek district		
(C-35-11)21abb1	131	10
22dac1	82	40
27aba1	75	80
27acd1	114	10
27bab2	150	5
27bbc1	117	5
27bdb1	156	5
27cdd1	147	5
27dbb1	99	10
28aac1	93	10
28dbc1	100	10
29dcd2	200	5
32add1	89	5
32cdd1	75	30
33cdd1	116	10
(C-36-11) 5cab1	230	25
5dcc1	150	10
Iron Springs district		
(C-35-11)30acd1	150	5
32ccd1	287	15
(C-35-12)13dad1	78	200
34dcd2	230	25
(C-36-11) 6aad1	260	35
(C-36-12) 1bbb1	190	5
3bba1	18	10
3cba1	78	10
9dcb1	....	5
12dba1	600	10
13ada1	14	40
16bcc1	125	5
Midvalley district		
(C-34-11)20dba1	260	60
33dac2	312	25
(C-35-11) 5aab1	110	10
10ccc1	459	10
10ddc1	305	10
11dcc1	292	10
14bac2	230	10
15aba1	165	15
15adc1	300	20
16acd1	268	5
Rush Lake district		
(C-33-10)16dac1	118	40
(C-33-11)31aad1	....	120
33dbb1	25	55
(C-33-12)11aaa1	60	80
(C-34-10) 6ccc1	14	135
(C-34-11) 3ccb1	519	30
Hamiltons Fort district		
(C-37-12) 3ccc1	150	25
10aca1	63	10
10bbc1	75	15
Kanarraville District		
(C-37-12)14baa1	88	5
34abb1	190	5
Queatchupah District		
(C-36-12)28ccc1	140	5
(C-37-12) 5aad3	185	5

Margaret D. Foster, who made the analyses, writes the following description of ground water in Cedar City Valley:

In chemical character the waters of the area appear to be either calcium-bicarbonate or calcium-sulfate waters or a mixture of the two. As a rule, the calcium-bicarbonate waters examined are only moderately mineralized in contrast to the calcium-sulfate waters, which are highly mineralized. Those of intermediate character also are intermediate in mineral content. The calcium-sulfate and intermediate-type waters appear to be calcium-bicarbonate waters to which more or less calcium sulfate has been added and are, for the most part, comparable in bicarbonate content with the calcium-bicarbonate waters.

QUALITY OF WATER FOR DOMESTIC AND IRRIGATION USE

Although the partial analyses give some indication as to the fitness of the water for domestic use, for stock watering, and for irrigation—the three principal uses to which water is put in Cedar City Valley—they do not show the sanitary condition of the waters.

Hardness, caused chiefly by salts of calcium and magnesium, represents the soap-consuming power of the water. Water with a hardness of less than 50 parts per million is generally rated as soft. If the hardness is between 50 and 150 parts per million it does not interfere with the use of water for most purposes, although the compounds that cause hardness are deposited as scale on kettles and boilers when the water is heated. Where the hardness is above 150 parts per million it is generally profitable to soften the water for household use to avoid excessive use of soap. The water in Cedar City Valley is generally hard or very hard; only in the Queatchupah district is the hardness of sampled water less than 150 parts per million, and elsewhere in the valley it ranges from 184 to 1,500 parts. More than half the sampled waters have a hardness in excess of 400 parts per million.

Sulfate itself has little effect on the general use of water, but certain sulfates, if present in sufficient amount, may impart a bitter taste to the water. Hardness due to sulfate of calcium or magnesium may increase the cost of softening, and it makes the scale formed in boilers much more troublesome. Chloride likewise has little effect on the suitability of water for ordinary use unless there is enough to give a "salty" taste—ordinarily more than 500 parts per million. The chloride content of the well waters in Cedar City Valley is generally low, only one of the wells sampled having more than 300 parts. In about 90 percent of the sampled waters the chloride amounts to less than 100 parts per million.

Nitrate in excess of a few parts per million in shallow waters is ordinarily taken as an indication of pollution, as nitrate is a final oxidation product of nitrogenous organic matter. Most of the waters high in nitrate in Cedar City Valley, however, are from drilled wells more than 100 feet deep and it is therefore probable that in these waters the nitrate is due to accumulation of soluble salts in the valley fill rather than to pollution, particularly in view of the fact that high nitrate in these waters is often associated with high sulfate and hardness.

The total dissolved mineral content of ground water in Cedar City Valley is estimated to range from about 150 parts per million in the Queatchupah district to more than 1,700 parts per million in certain wells on the Coal Creek alluvial fan. In 13 of the 56 well waters sampled for partial analysis the total dissolved solids is estimated to exceed 1,000 parts per million. In all 13 wells the sulfate content is greater than 500 parts, in two of them the nitrate exceeds 100 parts, and in four the chloride content is greater than 150 parts per million. Such highly mineralized waters are likely to contain enough of certain constituents to produce a noticeable taste, and several of these wells are not very satisfactory for domestic use because of the disagreeable taste of the water. Nevertheless, some of the most highly mineralized water is being used for domestic purposes. None of the water encountered in the valley was so highly mineralized as to be unfit for stock watering or irrigation.

Most of the wells yielding highly mineralized water are on the upper part of the Coal Creek fan in the Coal Creek district and on the adjacent Fidlers Creek fan. In the 15 well waters sampled in the Coal Creek district the total dissolved solids is estimated to range from about 500 to more than 1,700 parts per million, with an average of perhaps 1,000 parts. Several wells in other parts of Cedar City Valley, of which well (C-37-12)3ddd1 is an example, yield water that is highly mineralized in contrast to other wells in the vicinity. The total mineral content is relatively low (estimated less than 300 parts per million) in all sampled waters in the Queatchupah and Enoch districts.

Wells and springs within Cedar City Valley constitute only a minor source of water for domestic use. The great majority of the inhabitants of the valley dwell in Cedar City and thus are dependent on the municipal system for their domestic supply. Cedar City obtains water by pipe lines from several springs, which rise along the west front of the Kolob Plateau from the Cretaceous sandstones, particularly in the vicinity of coal outcrops. The following analyses made for the Utah State Board of Health show that the municipal supply of Cedar City is generally superior in quality to the ground water obtained throughout the valley.

Analyses of water from public supply of Cedar City, Utah

[Analyzed by M. Elmer Christensen, State Board of Health. Parts per million]

	1	2
Silica (SiO_2)	16.0	18.0
Iron (Fe)	.0	Trace
Calcium (Ca)	39.3	36.8
Magnesium (Mg)	8.7	8.2
Sodium and Potassium (Na+K)	5.2	7.8
Sulfate (SO_4)	7.8	8.1
Chloride (Cl)	6.0	6.0
Nitrate (NO_2)	Trace	.0
Total dissolved solids	166	165
Total hardness as $CaCO_3$	134	126

1. Sample from spring area at head of Shurtz Creek in sec. 24, T. 36 S., R. 11 W. Altitude, 8,623 feet. Cretaceous sandstone and coal. Discharge, estimated 1-½ to 2 second-feet, now included in Cedar City system. Oct. 11, 1938.
2. Sample from tap on Cedar City system, which obtains water from the following springs: Cluff, Chatterly, Right Hand Canyon, and the head of Shurtz Creek (analysis 1). Nov. 29, 1940.

CHEMICAL CONSTITUENTS IN RELATION TO GEOLOGY

The quantity of soluble mineral constituents in the strata of the alluvial fans, the amount available for solution by ground water, might be expected to depend somewhat upon the climatic conditions that prevailed at the time of deposition of these strata. The Recent alluvial deposits in the Basin and Range Province are generally considered to have accumulated under conditions of progressively increasing aridity since the humid cycles of Pleistocene glaciation. Evidences of increasing aridity in Cedar City Valley have been discussed in the chapter on geology (p. 14)—the abandonment of once-used outlets at Iron Springs Gap and Twentymile Gap; the gradual dessication and accumulation of evaporites in playas located on the valley floor; and the prevalence of thick strata of gravel at some depth below the surfaces of the present fans, suggesting that the streams formerly had greater carrying power and presumably greater volume than now. As a result of such a cycle of increasing aridity it might be expected that the proportion of soluble salts would be greater in upper layers of the fans and hence that in general the waters from shallow wells might be more highly mineralized than those from deeper wells. Comparison of four pairs of adjacent deep and shallow wells (that is, located within half a mile of each other) shows that in every case the shallow well yields water of higher mineral content: wells (C–35–11) 15aab1 and 15dba1, (C–35–11)22acb1 and 22dcc1, (C–35–11)27aca1 and 27adc1, and (C–36–11)8cab1 and 8cbb1. The indications in these analyses are confirmed by the experience of well owners, who are generally agreed that the "surface" water is the poorest. These differences, of course, need not be altogether due to original content of soluble salts in the aquifers. Where the water table is close to the surface, as near Rush and Shurtz Lakes, the mineral content at shallow depths may be increased by the annual fluctuations of the water table through a zone in which soluble salts accumulate as water is evaporated. In other areas, where perhaps water from rainfall or irrigation percolates downward to the zone of saturation, there may be leaching in the zone of aeration, and a corresponding enrichment in the upper part of the zone of saturation.

There is a close relationship between the chemical constituents of the ground water and the geologic formations cropping out in the drainage basin that constitutes the source of this ground water, for these geologic formations have been the source not only of the materials found in solution in the water of streams but also of the great alluvial deposits through which the ground water moves and from which it is obtained through wells. These relationships within the several drainage basins of the larger streams are discussed in subsequent paragraphs. In general it appears that the distribution of mineral constituents in the sampled ground water can be satisfactorily explained on the basis of the principles of occurrence of ground water that have already been brought out, and therefore this distribution tends to substantiate the conclusions that have been presented as to source and movement of ground water in the valley. (See p. 102.)

Coal Creek drainage basin.—Several of the formations that crop out in the Coal Creek drainage basin contain relatively soluble materials. Beds of limestone occur in the upper part of the basin, both in the Wasatch formation and in the Cretaceous rocks. In the lower part of the canyon, within 5 miles of Cedar City, the stream crosses Jurassic and Triassic formations that include considerable thicknesses of gypsum as well as of limestone. In this lower part of the canyon, the stream is generally separated from the rock outcrops by a belt of alluvial material, and the dissolving and carrying of soluble constituents is likely to occur chiefly when there is runoff from the minor drains that cross the outcrop area. Boulders and fragments of gypsum and limestone within the Coal Creek channel suggest that the solution and transportation of mineral matter probably occur continuously, though the rate may vary from season to season. Analysis of a sample collected during the annual low stage of Coal Creek indicated that the stream water was moderately hard and was moderately high in bicarbonate and sulfate. Assuming that the hardness is due chiefly to calcium, these are the mineral constituents that would be dissolved from gypsum and limestone.

Wells on the upper part of the fan in the Coal Creek district quite generally yield water that is very hard and that is very high in sulfate and moderately high in bicarbonate. The well waters are all more highly mineralized than the stream water collected for analysis, suggesting that mineralization increases as water moves through the alluvial materials forming the upper part of the fan. It is also possible that the stream water is at times more highly mineralized than on the date sampled.

Lower on the Coal Creek fan, both in the Iron Springs district to the west and in the Midvalley district to the north, the sampled well waters are generally less mineralized than those in the Coal Creek district, largely because of a lower content of calcium sulfate. A suggested explanation for this apparent decrease in mineralization outward from the head of the fan is that the strata encountered at depths of, say, 100 to 150 feet toward the head of the alluvial fan would be contemporaneous with materials at somewhat lesser depths in the Midvalley and Iron Springs districts, because of the more rapid rate of accumulation of coarse detritus. The sampled wells in the Iron Springs district especially, but also in the Midvalley district, are commonly deeper rather than shallower than those in the Coal Creek district. Every one of the sampled wells in these districts, the water of which is conspicuously less mineralized than waters in the Coal Creek district, is more than 175 feet deep, whereas most of the wells in the Coal Creek district are of less than that depth. Furthermore, the shallowest wells on the lower parts of the fan yield water with a mineral content about ⅔ as high as the average in the Coal Creek district. Thus it appears that most of the sampled wells on the lower part of the fan yield water from strata that are older than the aquifers serving the Coal Creek district. If deposition has occurred during a cycle of increasing aridity, these older strata, and therefore the water yielded by them, might be expected to contain a smaller proportion of soluble salts.

The three wells sampled in the Rush Lake district have a calcium, sulfate, and bicarbonate content comparable to that of wells farther south. In those wells sodium and chloride are also present in amounts appreciably greater than in most other waters in the valley. The concentration of salts (sulfates and chlorides) on the Rush Lake playa is a conspicuous feature of deposition in the district today, and it is quite likely that the concentration began in this lowest part of the valley long ago and continued on a larger scale as the climate became more and more arid.

Fidlers Creek drainage basin.—The Fidlers Creek drainage basin, which is very small, includes chiefly outcrops of Cretaceous sandstones. For nearly a mile of its course, however, the creek flows directly over soft outcrops of the San Rafael group, in which it has cut a narrow gorge. No sample of this water was analyzed, but it is so highly mineralized that the taste is somewhat bitter and disagreeable. The ground water in the Fidlers Creek fan is likewise highly mineralized, and several wells yield water of an unpleasant taste. The waters in the sampled wells are similar to those of the Coal Creek fan in their high content of calcium and sulfate and moderate content of bicarbonate; in contrast to the Coal Creek fan, however, these waters also have a considerable quantity of chloride and of nitrate.

Enoch district.—The Enoch district obtains water from the west front of the plateau along the south edge of Parowan Valley. Rock formations outcropping in this area include the Tertiary and Quaternary volcanic rocks and the Cretaceous sediments. None of the gypsiferous strata of lower Mesozoic age crop out in the drainage basin. The ground water in the Enoch district, whether from wells or springs, is a calcium bicarbonate water in which the total of mineral constituents is moderate and in which the low content of sulfate is in striking contrast to the waters found in the Fidlers Creek fan to the south or in the Midvalley district across the West Enoch fault to the west.

Shurtz Creek drainage basin.—The Shurtz Creek drainage basin is comprised very largely of the rock formations of Jurassic and Triassic age, among which the San Rafael group and the Moenkopi formation in particular are likely to have considerable thicknesses of soluble rock material. The composition of Shurtz Creek water, like that of other streams, doubtless varies from day to day and from season to season, and consequently single analyses can give little information as to mineral content of the waters contributed by these streams to the valley sediments over a period of a year. The single sample whose analysis is shown above, however, shows how highly mineralized the stream water may be before it seeps into the ground-water reservoir. Most samples from wells in the Hamiltons Fort district were much lower in sulfate and in hardness than the single sample from Shurtz Creek but were comparable in bicarbonate and chloride. They are similar to well waters from the fans of Coal and Fidlers Creeks farther north, but are not, as a rule, as highly mineralized. Inasmuch as the drainage basins of all four streams include outcrops of the gypsiferous San Rafael group and of other formations that contain soluble rock materials, the similarity of the mineral constituents in well waters is to be expected.

Queatchupah Creek drainage basin.—The Queatchupah Creek drainage basin is formed almost exclusively within the outcrop area of the Tertiary volcanic rocks. According to a single analysis, the water of Queatchupah Creek, at least during certain seasons, is rather soft and relatively pure—exceptionally so for Cedar City Valley. Waters from sampled wells are of quite similar composition; they are calcium bicarbonate waters, with a mineral content so low, however, that the waters are the softest obtainable in the valley.

Chemical constituents in wells near major faults.—The difference in sulfate content in wells on opposite sides of the West Enoch fault—that is, in the Enoch and Midvalley districts—has been pointed out. These differences evidently are due to the fact that the source of water in the Enoch district is distinct from that in the Coal Creek fan farther west. However, the wells immediately adjacent to the fault show no appreciable difference in chemical constituents from more remote wells on the same side of the fault. Neither is there any distinction in the chemical quality of water from wells along the Stockyards fault and from wells remote from this fault. Thus, to the question whether water moves upward along these faults and enters the aquifers tapped by wells, the evidence from chemical analyses is negative. Comparison of temperatures of water in wells near these faults likewise shows no abnormalities and thus gives no evidence that any water is contributed to the reservoir by upward movement from deep sources along these faults.

GROUND-WATER DEVELOPMENT

STATUS OF GROUND-WATER DEVELOPMENT, 1940

The locations of all known wells in Cedar City Valley are shown on plate 18, and the records of those wells, obtained chiefly from records filed in the office of the Utah State Engineer, are summarized in the table on pages 116-124. Three hundred and fifty wells are listed of which about half are in T. 35 S., R. 11 W. Grouped by ground-water districts, the number of wells is as follows: Coal Creek, 92; Iron Springs, 83; Midvalley, 79; Enoch, 26; Queatchupah, 26; Rush Lake, 21; Hamiltons Fort, 13; and Kanarraville, 10.

The table lists 68 wells that were being used chiefly for irrigation in 1939-40 (see p. 129), of which 57 were pumped by electrically driven turbines. The list also includes 93 stock wells and 63 domestic wells, of which 85 were pumped by windmills and 20 by automatic pressure systems comprising a plunger or centrifugal pump driven by a small electric motor. About 125 wells were not in use during 1939-40.

Record of wells in Cedar City Valley

[Chiefly from underground water claims filed by well owners with the Utah State Engineer]

Well No.	Owner	Claim No.	Date completed	Diameter (inches)	Depth (feet) [1]	Pumping equipment [2]	Horsepower of motor [3]	Principal use [4]
(C-33-10)16dac1	J. B. Dalton	13497	1929	6	118	W		S
31adb1	A. C. Hatch	17645	1900	7	65	L		
31adb2	A. C. Hatch	[5] Ap 12819	1939	12	100	T	G	I
(C-33-11)29ccb1	J. S. Green	13996	1927	6	72	W		S
30abd1	G. P. Stapley			6	18d			
30bca1	H. C. Perry	13985	1918	3	60	W		S
30ddd1	G. P. Stapley	6005	1930	12	250			
31aad1	G. W. Perry			6		W		S
33dbb1	T. R. Adams, et al	5137	1890	60	25	C	G 1½	S
(C-33-12)11aaa1	S. C. Mortensen, et al	2239	1923	4	60	W		S
14dca1	S. C. Mortensen, et al	2240	1900	48	65	W		
(C-34-10) 6ccc1	Clark Orten, et al	11213	1924	84	14	L		S
30ddd1	Public domain			60	70d			
31cbc1	M. S. Jones			3	109m	L		S
(C-34-11) 3ccb1	H. L. Adams	11587	1916	3	519	F		S
5cda1	Public domain			3	31m			
9ccd1	J. W. Melling, et al	5226	1913	4	194	W		S
9cdc1	George Eyre			4	61m			
10cdd1	Public domain			2	51m			
12dbd1	J. W. Bergstrom	10294	1896	2	250	F		D
13bab1	J. W. Bergstrom	10293	1896	2		F		S
15bab1	E. L. Childs			4	55m			
16bcc1	T. J. Webster, et al.	13699	1914	3	85	W		S
20dba1	E. E. Williams	2825	1912	3	260	W		S
20ddd1	E. E. Williams	2824	1916	3	960	C	G 6	
21dcd1	George Perry	17928	1915	144	18d			
22bda1	Iron County			3	52m			
22ccc1	E. L. Crooks	4876	1932	6	300			
29bad1	E. E. Williams			3	56m			
29ddd1	George Perry			3		W		S
32cba1	David Murie	17514	1912	72	26			
32ccd1	Joseph Placek			36				
33acc1	D. & P. Mackelprong	17688	1925	3	212	W		
33cad1	Federal Land Bank	6807	1912	2	197			
33dac1	Carlos Stevens	5120	1916	3½	167			
33dac2	Carlos Stevens	5122	1912	3	312	W		S

See footnotes at end of table.

Record of wells in Cedar City Valley—Continued

[Chiefly from underground water claims filed by well owners with the Utah State Engineer]

Well No.	Owner	Claim No.	Date completed	Diameter (inches)	Depth (feet)[1]	Pumping equipment[2]	Horsepower of motor[3]	Principal use[4]
(C-34-11)33dac3	G. & R. Grimshaw	14014	1916	2	267			
33dad1	G. & R. Grimshaw	14017	1911	2	255			
36adc1	S. M. Clark	13704	1928	3	200	F		S
36cbc1	G. D. Grimshaw	10818	1928	4	60	A		D
36cbc2	G. D. Grimshaw	10820	1934	8	195			
36ccc1	G. D. Grimshaw	10819	1928	2	60			
(C-35-10) 7bbc1	W. F. Armstrong	16812	1870	60	20			
7cad1	F. W. Matheson	17814	1934	8	101	T	7½	ID
7cdd1	Claude Crosby	15342	1931	8	70	C	5	ID
7dbb1	S. A. Smith	10522	1933	48	33			
18cba1	Richard Williams					W		D
18cbb1	Richard Williams			10	112m	L		S
(C-35-11) 1acc1	J. N. Smith, et al	8964	1928	3	179m	F		S
1ccd1	G. & R. Grimshaw	14015	1911	2	214			
1ccd2	R. & R. Grimshaw	14016	1911	2	156	W		D
(C-35-11) 1cdc1	Ray Grimshaw	17278	1929	3	217			
2ddd1	F. H. Grimshaw	13751	1934	4	40	L		D
4bbc1	W. H. Wood	14011	1912	2	127			
4bbd1	W. H. Wood	14009	1926	2	210			
4bbd2	W. H. Wood			3	21^{+}m			
4cad1	H. W. Webster	10359	1927	3½	100			S
4dda1	Carlos Stevens	5121	1916	3	267			
4dda2	Carlos Stevens			2	144m			
5aab1	H. W. Webster	10358	1920	2	110	W		S
5bbc1	J. T. Leigh	2817	1903	4	260	W		
5bcd1	J. T. Leigh	17336	1924	6	140			
7acc1	Vera Alleman			48	34d	W		
7dcc1				72	15d			
8cdd1	C. L. Corry	13703	1919	6	130			
8ddd1	Ira Heaton	11597	1928	5	178	T	5	ID
8ddd2	J. C. Heaton	13491	1927	4	200	L		D
9abc1	Fred Biederman					W		S
9abd1	T. J. Webster, et al	13700	1925	2	203			

(C-35-11) 9add1	Federal Land Bank			2	151m	F		S
9bcd1	J. C. Heaton, et al	13475	1912	2	130			
9ccc2	J. C. Heaton	13490	1912	2	124	W		S
9ccc3	J. C. Heaton		1899	2	90			
9dbd1	LeRoy Bauer			2				
10bbd1	Federal Land Bank	6738	1915	2	215	W		S
10ccc1	Federal Land Bank	6739	1923	8	459	T	10	ISD
10ccd1	Federal Land Bank	6741	1914	2	145			
10cdd1	Federal Land Bank	6740	1923	8	499	FTA	10	DS
10dbd1	Owen Matheson	5127	1929	3	90	W		D
10dbd2	Owen Matheson	5128	1914	2	248			
10dbd3	Owen Matheson	13701	1910	2	197	F		S
10ddc1	D. L. Matheson	13710	1922	2	305	L		D
10ddd1	Olive Maxwell	17218	1929	4	166	L		D
11acc1	Walker Davis	Ap 12450	1937	10	156			
11dcc1	C. P. Halterman	5093	1923	2	292	A	⅓	D
12adc1	W. F. Armstrong	16811	1915	144	25			
12cbc1	W. H. Grimshaw	13711	1909	2	204			
12ccc1	W. H. Grimshaw	13712	1910	2	228	FL		DS
12ddd1	West Enoch Irr. Assn	32	1935	12½	250	T	15	I
12ddd3	L. S. Armstrong	5130	1933	2	100	W		D
3cac1	A. Bullock, et al			3	65m			
13cac2	A. Bullock, et al			2	121m	FL		S
13dca1	J. U. Williams	9379	1916	3	60	W		D
13ddb2	Union Field Irr. Co	8178	1934	12½	166	T	15	I
13ddb3	Union Field Irr. Co	491	1934	12	166	T	15	I
14aac1	W. H. Grimshaw, et al	13713	1930	16	334	FT	15	IS
14bac1	Millard Halterman	14005	1923	4½	339			
14bac2	Millard Halterman	14006	1913	3	230	A		D
14bdb1	R. B. Nelson	5054	1926	2	230	W		S
14dab1	David Murie	14000	1900	2	153	L		D
14ddd1	David Murie	14001	1918	3	25	A	½	D
14ddd2	David Murie, et al	17513	1931	4	23			
14ddd3	David Murie, et al	14002	1932	8	158	T	5	I
15aab1	Leonard Haight	13500	1925	2	266	A	½	D
15aac1	H. D. Haight	1220	1910	7	300			
15aba1	Sherman Haight	Ap 12547	1937	6	267	A	½	D
15adc1	H. D. Haight	1219	1930	12	300	W		DS
15bbb1	J. S. Woodbury	10525	1915	2	160			
15cca1	Federal Land Bank	6361	1927	3	125	W		S
15dba1	C. J. Haight	1214	1928	3	84	W		D
15dba2	C. J. Haight	1213	1912	2	227	W		D

See footnotes at end of table.

Record of wells in Cedar City Valley—Continued

[Chiefly from underground water claims filed by well owners with the Utah State Engineer]

Well No.	Owner	Claim No.	Date completed	Diameter (inches)	Depth (feet) [1]	Pumping equipment [2]	Horsepower of motor [3]	Principal use [4]
(C-35-11)15dcb1	R. H. Haight							
16aab1	G. W. Perry	10524	1927	2	115	W		D
16aab2	G. W. Perry							
16aba1	LeRoy Bauer	3391	1918	6	270	A	½	D
16aba2	LeRoy Bauer			12	168			
16acb1	LeRoy Bauer			12	500			
16acd1	LeRoy Bauer	3390	1934	12	268	T	10	I
16cdd1	L. B. Corry	17242	1926	2	167			
16dba1	Mellin Bros			4	104m	L		S
17acd1	L. B. Corry	17243	1911	2	114			
17dad1	E. M. Corry	11594	1924	3	270	W		S
17dbc1	L. B. Corry	17244	1912	2	114			
17dbd1	L. B. Corry	17241	1912	2	124			
17dcb1	L. B. Corry	17240	1924	2½	154	A	¼	D
17dcd1	H. B. Liston	Ap 12341	1936	12	200			
19bad1	C. T. Wooster			8	d			
19bad2	C. T. Wooster			8	d			
19bda1	John Sherratt	4882	1923	3	175	W		D
19cdd1	LeRoy Davis		1940	4	145	W		S
20abd1	K. L. Jones	17333	1912	2	150			
20cda1	K. L. Jones	17332	1916	2	160			
20cda2	K. L. Jones	17334	1916	2	150			
21abb1	D. C. Urie	1223	1924	2	131	W		S
21bac1	B. McConnell, et al		1907	2	138m			
21bda1	B. McConnell, et al			3				
21bda2	B. McConnell, et al			3				
21ccd1	A. F. Walker	4880	1929	12	172	T	10	I
21ccd2	A. F. Walker			8	75m	L		D
21cdb1	A. R. Fife	9926	1934	12	176	T	10	I
21dab1	G. M. Hunter, et al	17217	1927	2½	160	L		
21dbd1	D. C. Urie	1222	1933	12	228			
21dbd2	D. C. Urie	ap 1505	1940	12		T	10	I
21dcc1	W. R. Fife	11599	1931	12	180	T	10	I
22aab1	Grant Hunter		1919	2	115			
22acb1	Federal Land Bank	6801	1913	2	227	A	⅛	D
22acd1	Federal Land Bank	6802	1930	16	350			
22cac1	T. W. Munford	5243	1913	4	25			
22dab1	M. F. Higbee			3	68			

(C-35-11)22dac1	M. F. Higbee	15884	1912	4	82	W	...	S
22dcc1	Fernleigh Gardner	1221	1917	3	61	W	...	SD
23abb1	Mrs. B. Nelson	5052	1914	2	96	A	1	D
23bdc1	A. J. Bryant	13746	1912	3	100	A	½	D
23cba1	R. B. Nelson	5053	1926	6	125	L	...	S
26bbb1	S. B. Jones	11593	1926	4	140	W	...	D
27aba1	L. W. Jones	13707	1900	4	75	L	...	S
27aca1	Walker & Halterman	5222	1934	12	108	T	15	I
27aca2	Rube Walker	13709	1919	3	67	W	...	D
27acc1	Fernleigh Gardner	382	1930	12	113	T	10	I
27acc2	Samuel Bauer	13714	1912	4	61	A	¾	D
27acd1	M. Halterman, et al	5224	1934	12	114	T	15	I
27adc1	Drought Relief Adm.	8177	1933	12½	148	T	10	I
27bab1	G. W. Hunter	13717	1917	3	54	L	...	...
27bab2	C. A. Esplin	1216	1934	12	150	T	10	I
27bba1	Robt. Munford	496	1912	4	185	W	...	D
27bbc1	Drought Relief Adm	8175	1934	12½	117	T	15	I
27bcc1	C. N. Corry	1217	1910	3	50	W	...	S
27bdb1	C. A. Esplin	1215	1934	12	156	T	15	I
27ccb1	William Corry	...	...	...	...	W	...	S
27cdd1	Grant Hunter, et al	8182	1934	12	147	T	20	I
27dbb1	L. F. Luke, et al	5223	1931	12	99	T	15	I
27dbd1	L. F. Luke	...	...	4	85	W	...	S
27dcd1	L. F. Luke	...	1931	12	150	T	20	I
28aab1	Ether Perry, et al	...	1931	3	80	W	...	S
28aac1	Ether Perry, et al	14222	1931	12	93	T	10	I
28adc1	G. K. Urie	...	...	3	...	W	...	S
28bad1	A. J. Gardner, et al	13708	1925	4	100	W	...	D
28bcc1	J. S. Woodbury	10526	1925	3	85	W	...	S
28bdd1	J. W. Melling, et al	5225	1924	3½	80	W	...	D
28ccc1	R. F. Winterrose	10521	1923	2	30	...	...	...
28cda1	W. K. Granger	13697	1920	6	100	A	1	S
28dab1	C. J. Bryant	6491	1933	12	162	T	10	I
28dbc1	L. Bracken	17601	1923	3	100	W	...	S
28dda1	—— Tucker	...	...	3	...	W	...	S
29abd1	H. L. Jones	13513	1912	6	100	W	...	D
29abd2	K. L. Jones	11603	1911	6	120	W	...	D
29abd3	K. L. Jones	17331	1910	4	150	L	...	...
29acd1	H. L. Jones	13512	1934	12	300	T	15	I
29add1	K. L. Jones	11606	1930	12	110	T	10	I
29dbd1	Wm. Whitney	1230	1929	12	91	T	10	I
29dbd2	A. B. Williams	17216	1918	3	100	...	...	...

See footnotes at end of table.

Record of wells in Cedar City Valley—Continued

[Chiefly from underground water claims filed by well owners with the Utah State Engineer]

Well No.	Owner	Claim No.	Date completed	Diameter (inches)	Depth (feet) [1]	Pumping equipment [2]	Horsepower of motor [3]	Principal use [4]
(C-35-11)29dbd3	A. B. Williams	17794	1928	2½	90	W		D
29dcb1	E. T. Higbee, et al	15782	1920	4	95	W		D
29dcd1 [6]	E. T. Higbee, et al	490	1930	12	207	T	7½	I
29dcd2	E. T. Higbee, et al	ap 1365a	1939	12	204	T	7½	I
29ddd1	F. L. Biederman	5153	1925	3	90			
30acd1	K. L. Jones	11604	1923	4	150			
30bbd1	K. L. Jones	11607	1922	6	200			
30bbd2	K. L. Jones	17330	1918	3	150			
30caa1	John Sherratt	17823	1921	16	180			
30caa2	John Sherratt	34	1935	12	200			
30cad1	John Sherratt	4883	1912	3	150	W		S
30dcc1	O. J. Bryant	14004	1917	3½	164	L	G 1½	D
31acd1	H. C. Jensen	13498	1919	12	248	T	15	I
31add1	Federal Land Bank	17519	1918	16	200	W		D
31add2	Federal Land Bank	12518	1918	3½	140			
31baa1	H. C. Jensen	10152	1920	14	174			
31bac1	J. C. Jensen	13499	1913	2	157			
31cab1	J. M. Palmer	5097	1920	2	147	A	¼	S
31ccd1	T. J. Higbee	11596	1914	3½	160			
31cdc1	Sidney Ashdown	13505	1924	4½	185			S
31dab1	E. M. Corry	11593	1918	3	180	W		S
32aad1	D. C. Urie	13311	1924	3	87	W		D
32aba1	Donald Whitney	Ap 12304	1936	6	100	W		S
32abd1	O. J. Bryant, et al	14003	1934	12	220	T	15	I
32aca1	Donald Whitney	Ap 12242	1936	16	223	T	15	I
32acc1	R. G. Dalley	Ap 11872	1935	16	200			
32acd1	Drought Relief Adm	8176	1934	12½	168	T	15	I
32add1 [7]	E. M. Corry	6935	1928	12	89	T	10	I
32add2	E. M. Corry		1940	12	200	T	15	I
32bdd1								
32ccd1	E. M. Corry, et al	5098	1930	12	287	T	10	I
32cdd1	C. R. Matheson	11595	1928	4	75	W		D
33aac1	Cottonwood P. & I. Co	5126	1930	16	138	T	25	I
33aba1	G. R. Parry	11591	1934	6	110	A	1	D
33abd1	G. R. Parry	11590	1931	12	187	T	15	I
33bac1	F. L. Biederman	5131	1929	12	239	T	15	I
33bbb1	F. L. Biederman	5132	1928	4	90	A	½	D
33cdd1	A. H. Rolls, et al	411	1933	10	116	T	10	I

(C-35-11)33dbb1	W. H. Wood	14010	1912	6	73	A	1	D
33dbc1	W. H. Wood	14012	1930	12	140	T	20	I
34bbb1	Rafael Ortega	13476	1916	2		L		S
(C-35-12)13dad1	C. T. Wooster			4	78m	W		S
18ddd1	L. A. & S. L. R. R.	4258	1924	9½	282	L		Ind
18ddd2	Columbia Steel Co		1923	10	44			
25ddd1	D. C. Bullock			3		W		S
34aac1	Federal Land Bank			3				
34dcd1	R. J. Shay, et al	4873	1925	12	120	T	G 20	ID
34dcd2	R. J. Shay, et al	17190	1928	8	70	L		D
36aad1	D. C. Bullock	10671	1924	3½	80			
36aad2	G. W. Foster	13992	1919	3	305	W		S
36add1	G. W. Foster	13990	1919	4	143	W		D
36cad1	J. M. Foster	4783	1923	2	198			
36daa1	J. D. Foster, et al	Ap 11745	1937	12	400	T [8]		I
36dad1	J. D. Foster	11586	1929	4	269	W		D
(C-36-10)21caa1 [9]	Drought Relief Adm	8183	1934	16	213			
(C-36-11) 5abb1	Federal Land Bank	7884	1914	3	260	W		S
5abd1	F. J. Perry	Ap 12255	1936	16	166	T	G 20	I
5baa1	F. J. Perry	Ap 12636	1938	12	132	T	15	I
5bdd1	Sidney Ashdown	13503	1935	12	144	T	15	I
5cab1	James Smith	13509	1934	12	230	T	15	I
5cac1	James Smith	13510	1934	13	220	T	15	I
5cdc1	R. W. Bullock	13487	1924	12	84	W		S
5dca1	W. H. Bullock	5092	1924	8	100	T	5	DI
5dcb1	W. H. Bullock	5091	1925	12	144	T	15	I
5dcc1	R. W. Bullock	13488	1935	12	150	T	15	I
6aaa1	Leonard Hargrave	13493	1934	12	255	T	15	
6aad1	Leonard Hargrave	17943	1928	12	260	W		S
6bda1	Sidney Ashdown	13504	1914	2	156	W		S
6ccc1	James Smith	15881	1912	4½	190	W		S
6ccd1	James Smith		1916	4	190	L	G 2	D
7aaa1	J. L. Bess	13984	1935	6	147	T	2	SD
(C-36-11) 7baa1	Alfred Stuki	4180	1917	3	167	W		D
7dbc1	Hugo Hunt	17267	1923	6	147	W		D
8aab1	Leonard Hargrave	13494	1935	10	103	T	3	D
8bba1	Alfred Stuki	Ap 11977	1936	12	158	T	15	I
8bbd1	J. L. Bess	13983	1928	12	100	T	15	I
8bda1	A. T. Jones	6560	1930	12	150	T	10	I
8bda2	A. T. Jones	6561	1934	12	80	T	10	I
8cab1	Drought Relief Adm	8180	1934	12½	200	T	15	I
8cab2	Higbee & Seegmiller	17273	1927	4½	68	W		D

See footnotes at end of table.

Record of wells in Cedar City Valley—Continued

[Chiefly from underground water claims filed by well owners with the Utah State Engineer]

Well No.	Owner	Claim No.	Date completed	Diameter (inches)	Depth (feet) [1]	Pumping equipment [2]	Horsepower of motor [3]	Principal use [4]
(C-36-11) 8cbb1	L. M. Jones	317	1927	12	60	T	7½	IS
8dab1	L. A. & S. L. R. R.	4259	1924	10	192	L	G 5	S
10bcc1	Southern Utah Power Co.	12680	1928	8	195	T	20	Ind
17baa1	E. L. Jones	13514	1920	6	85	A	1½	D
18aba1	J. N. Smith	8963	1923	4½	200	W		S
18aba2	J. N. Smith	17383	1926	8	200			
18ada1	H. C. Esplin	4881	1910	12	230	T	15	I
18ada2	H. C. Esplin			8	230	A	¾	D
18bcc1	H. C. Esplin	Ap 12070	1936	12	300			
18cdc1	W. W. Montgomery	15422	1931	12	110	T	10	
18cdd1	David Thorley			6	d			
18daa1	David Thorley	17277	1917	4½	90	W		S
31ada1	Drought Relief Adm.	8179	1934	6	210	A		DS
(C-36-12) 1aaa1	M. J. MacFarlane	13994	1922	3	158			
1aaa2	M. J. MacFarlane	13995	1929	12	366	T	7½	IS
1ada1	Fred Barnson			5		L		
1bbb1	Federal Land Bank	9772	1921	6	190	W		S
1bbb2	Federal Land Bank	9773	1921	4	190			
1dcc1	Isaac Parry		1918	2				
2adb1	Lawrence Hanchett		1920	12	408	T	15	
3bba1	W. R. Palmer	13663	1900	48	18	F		
3cba1	W. R. Palmer	13662	1891	2	78			
9aaa1	E. L. Jones	Ap 12955	1939	6	257	F		S
9dcb1	H. B. Robinson	5234	1918	2		F		S
10ada1	D. G. Wolfskill	1218	1927	12	389	FT		I
10dda1	D. G. Wolfskill	15946	1927	12	397	FW		D
12aaa1	R. H. Lunt	13154	1915	4	90			
12dac1	H. W. Leigh	13716	1910	2	200	W		S
12dba1	Branch Agr. College	15411	1925	10	600	T	10	I
13ada1	Harmel Bauer	13978	1928	4½	14	L		S
13bda1	Federal Land Bank	9774	1916	54	20			
14bbd1	Geo. H. Pratt			12	200+			
14cbc1	Trehorne Jones			3		F		
16bba1	H. L. Jones, et al	13515	1900	1½	90	F		S
16bcc1	H. L. Jones, et al	13518	1908	2	125	F		S
20ddc1	H. L. Jones, et al	13516	1916	2				S
21ccb1	D. C. Bullock, et al	10673	1912	3	180	F		IS
21ccb2	D. C. Bullock, et al	10674	1912	2	50	F		S

(C-36-12)23ddd1	David Thorley	17279	1898	6	70	W	.....	S
26bcb1	Frank Thorley	13748	1915	2	110	F	.....	S
26cbb1	E. A. Cox, et al	13747	1915	3	113	F	.....	S
27dac1	E. V. Hardy	6857	1926	2	.....	F	.....	S
28ccc1	A. P. Spilsbury	.....	.....	2	140	F	.....	S
29aaa1	H. H. Lunt	6011	1913	2	145	F	.....	S
29dab1	H. H. Lunt	6010	1914	3	168	F	.....	S
29dab2	H. H. Lunt	.....	.....	4	230	C	.....	.....
29dbb1	H. H. Lunt	6009	1928	12	280	T	15	.....
33ccb1	A. P. Spilsbury	.....	.....	2	.....	F	.....	S
33ccb2	A. P. Spilsbury	.....	.....	2	.....	F	.....	S
33ccb3	A. P. Spilsbury	.....	.....	2	.....	F	.....	S
33dbc1	A. P. Spilsbury	.....	.....	2	.....	F	.....	S
35add1	—— Middleton	.....	1905	6	24d	.....	.....	.....
36daa1	Drought Relief Adm.	.....	1934	12½	90d	.....	.....	.....
(C-37-12) 3ccc1	F. W. Middleton	16359	1890	1¼	150	F	.....	S
3ddd1	M. Vandenberghe	5129	1929	4	230	FC	2½	DI
4bac1	A. P. Spilsbury	.....	.....	2	.....	F	.....	S
4bbc1	A. P. Spilsbury	.....	.....	2	.....	F	.....	S
4bbc2	A. P. Spilsbury	.....	.....	2	.....	F	.....	S
4bca1	F. A. Palmer	13750	1913	3	90	F	.....	.....
4bca2	F. A. Palmer	.....	.....	3	.....	F	.....	.....
4bcb1	F. A. Palmer	13749	1929	12	208	FT	.....	.....
4cbc1	Federal Land Bank	12827	1918	6	250	FC	.....	.....
5aad1	Federal Land Bank	7853	1917	3	140	F	.....	I
5aad2	Federal Land Bank	7854	1917	3	100	F	.....	I
5aad3	Federal Land Bank	7855	1917	3	185	F	.....	I
5ada1	Federal Land Bank	.....	.....	3	.....	F	.....	S
9aad1	G. W. Foster	13989	1888	1½	.....	F	.....	S
9add1	G. W. Foster	13991	1931	9	135	C	.....	.....
9baa1	P. E. Watson	16350	1907	2	90	F	.....	S
10aca1	R. S. Tiernan	16629	.....	1½	63m	F	.....	S
10bbc1	R. Middleton	16630	.....	1½	75m	F	.....	S
11cbb1	J. G. Pace	15847	1890	6	90	F	.....	S
11dbc1	P. L. Geeslin	.....	.....	12	24m	W	.....	.....
13ccc1	J. C. Platt	13752	1934	6	122	W	.....	D
14abd1	J. G. Pace	.....	.....	2	.....	W	.....	.....
14baa1	J. G. Pace	5235	1918	4½	88	W	.....	D
14dcc1	J. W. Platt	13753	1931	12	285	T	10	.....
14ddd1	Federal Land Bank	.....	.....	8	161m	.....	.....	.....

See footnotes at end of table.

Record of wells in Cedar City Valley—Continued

[Chiefly from underground water claims filed by well owners with the Utah State Engineer]

Well No.	Owner	Claim No.	Date completed	Diameter (inches)	Depth (feet) [1]	Pumping equipment [2]	Horsepower of motor [3]	Principal use [4]
(C-37-12)22cbc1	W. J. Williams	Ap 12071	1936	16	340	...	...	...
23acb1	N. O. Pengilly	13010	1915	16	250	[10] T	...	I
23bca1	C. N. Quinn	*11212*	1935	6	*150*	L	...	...
34abb1	Kanarra Field & Reservoir Co.	1646	1934	12	190	T	20	I
(C-38-12) 3bcb1	Alton Ford	Ap 12845	1939	12	152	T	G	...

[1] d, Dry hole; m, measured depth; all others reported.

[2] A, Automatic pressure system; C, centrifugal pump; F, flowing well; L, lift pump; T, turbine; W, windmill.

[3] G, Gasoline-or diesel-powered; all others electric.

[4] D, Domestic; I, irrigation; Ind, industrial; S, stock.

[5] Ap, Application to appropriate water; ap, application for transfer of point of diversion.

[6] Replaced in 1939 by well 29dcd2.

[7] Replaced in 1940 by well 32add2.

[8] Removed in 1940.

[9] In Coal Creek Canyon.

[10] Submersible turbine in 1940.

HISTORY OF DEVELOPMENT

The dates of construction of 288 of the 350 known wells in Cedar City Valley are reported on the underground-water claims made by the owners. These claims were not made until 1935 and for many wells, particularly the older ones, the reported dates are based on memory and may be somewhat in error. The 62 wells whose date of construction is not reported are probably older wells for the most part; many are wells of small diameter that have been jetted, presumably for artesian flow, and were probably completed more than 15 years ago, when the area of artesian flow in the valley was more extensive than in recent years.

The increase in number of wells for all purposes between 1880 and 1939 is shown graphically on figure 15. The development was fairly uniform—at a rate of about 10 wells a year—from 1910 until the State ground-water law became operative in 1935. Prior to 1910 there was very little ground-water development, and only 25 of the existing wells were reported to have been completed by that year. The apparent increase of construction at the end of each decade prior to 1910 doubtless reflects the rough estimates that have been made concerning these early wells. Meinzer [76] mentions somewhat less than 25 wells in his description of ground-water conditions in Cedar City Valley during 1908. Some of the wells he describes are still in existence but many have been destroyed.

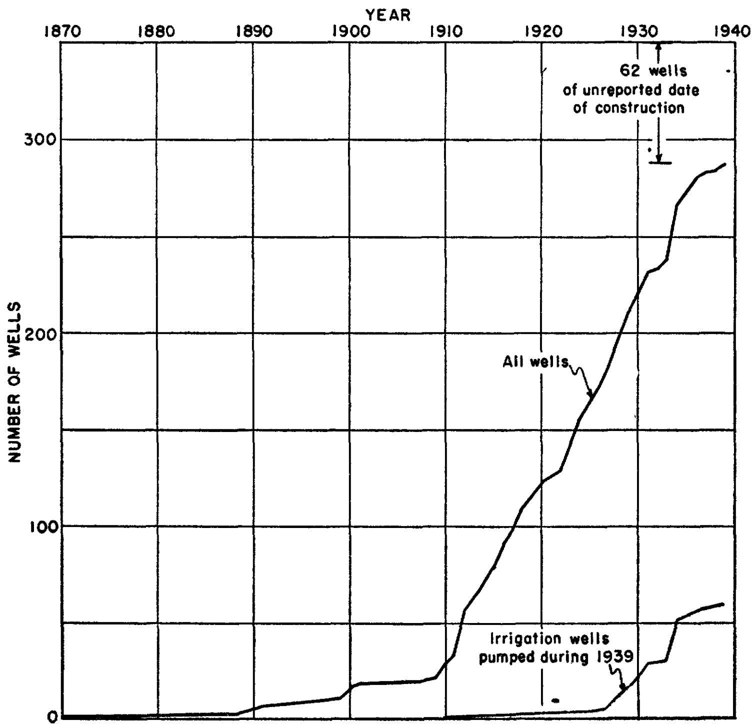

FIGURE 15.—Graph showing cumulative number of wells constructed in Cedar City Valley, 1870–1939.

Although in general the development between 1910 and 1935 has been fairly uniform, the number of wells drilled each year reflects rather closely the amount of precipitation for that year. As shown by figures 1 and 15,

[76] Meinzer, O. E., Ground water in Juab, Millard, and Iron Counties, Utah: Geol. Survey Water-Supply Paper 277, pp. 145–148, 1911.

the construction has increased during each period of subnormal rainfall, and tapered off during years of more than normal precipitation. During 1934, the year of greatest deficiency in rainfall, 27 wells were constructed in the valley. Between 1910 and 1935, 183 wells were completed during 16 years of subnormal precipitation, and only one-third as many were drilled during 9 years of more than normal precipitation.

Wells constructed prior to 1910 are distributed rather widely over Cedar City Valley, particularly where ground water is at shallow depths. A few of these early wells are in each ground-water district, except that practically no wells were completed prior to 1910 in the Coal Creek district, which has since become the area of greatest ground-water development. Many of the earliest wells were dug for domestic supplies, and some doubtless were constructed soon after the first settlers arrived in the valley in 1851. The oldest existing well is reported to have been dug in 1870. Flowing wells were obtained as early as 1888, and a large proportion of wells completed after that date obtained artesian flows.

The intensive ground-water development that began in 1910 was largely in areas of artesian flow, and during the following two decades a large number of flowing wells were obtained. Of 94 wells reported to have been completed between 1911 and 1920, 55 are reported to have flowed originally, and of 97 wells completed during the following decade, 31 were flowing wells. Since 1930 only one flowing well has been obtained.

Ground water is reported to have been used for irrigation as early as 1910, when Henry Esplin's well (C-36-11)18ada1 was drilled. Two groups of flowing wells in the Queatchupah district were drilled before 1920 and are reported to have been used for irrigation ever since. Several of the existing irrigation pump wells also were drilled prior to 1925 but for the most part were very little used for irrigation prior to that date, although Meinzer suggested this means of further development at the time of his visit in 1908. Generally abundant surface-water supplies prior to that year probably made unnecessary any great increase in utilization of ground water.

The development and use of irrigation wells were greatly accentuated during the 7 years 1928 to 1934, a period when precipitation and stream runoff were generally subnormal. During the first 4 of these years, irrigation wells were completed at a rate of about five a year. This pace slackened in 1932 and 1933 perhaps partly because of the considerable precipitation and runoff in 1932, and no doubt partly because of more stringent economic conditions. The drought of 1934 caused an intensified ground-water development which was assisted by Federal funds for drought relief, and 20 new irrigation wells were completed during the year.

Since March 1935 the development of ground water in Utah has been controlled by the State Engineer, according to provisions of the State ground-water law. The irrigation wells drilled since this date number less than a dozen and include some that were begun before the law became operative, some that replace deteriorated wells, some that have been drilled without the approval of the State Engineer, and some in outlying districts where the new developments could not conceivably affect prior rights to any extent. During these years the demand for new irrigation wells has been as great as ever, as is shown by the considerable number of applications on file with the State Engineer.

FLOWING WELLS

The development of flowing wells occurred almost entirely during the years prior to 1930. Data concerning these wells prior to the present investigation, which was begun in 1935, are limited to the statements of owners as to static level and flow of the wells upon completion of drilling. These data form the basis for the outline of the "maximum area of artesian flow", shown on plate 18, which marks the approximate boundary of the the area in which flowing wells have been obtained.

The time when this maximum area of artesian flow was achieved can best be estimated from the dates of completion of wells near the edge of the area. Evidently many were drilled prior to 1920, but a large number also were completed between 1922 and 1925, and it seems evident that ground-water storage was at least as great during those years as at any time since development began. It has already been shown that there was a great accumulated excess of precipitation and resultant high runoff from Coal Creek during the years 1919–25, and a correspondingly high storage in the ground-water reservoir during those years might be expected. Within this maximum area of artesian flow some artesian wells, completed prior to 1920, did not flow when drilled but began to flow some years later, presumably as the storage in the ground-water reservoir increased. One of these, the Webster well, described by Meinzer, already has been referred to. (See p. 94.)

During the past several years the area of artesian flow has been at a minimum during September as a result of the withdrawals from the reservoir by pumping for irrigation. Presumably the minimum area of artesian flow, since the beginning of ground-water development, was reached during September 1936, for the ground-water storage at that time was exceptionally low. The area of artesian flow in September 1939 is approximately of the same extent, for most of the flowing wells that define the area also were flowing in 1936. The area of artesian flow by that time had shrunk to less than half the maximum area that existed at some time prior to 1925. As a result of this shrinkage there are three separate areas of artesian flow in Cedar City Valley—one in the vicinity of Shurtz Lake, embracing parts of the Queatchupah, Hamiltons Fort, and Iron Springs ground-water districts; one northwest of Enoch, including the northwest part of Enoch district; and an area in the vicinity of Rush Lake, poorly defined by two wells 3 miles apart, between which the area of artesian flow may be continuous, analogous with the area around Shurtz Lake.

In winter and spring those areas of artesian flow are ordinarily somewhat greater than in September, because of the gradual recovery from the effects of pumping. The areas near Enoch and Shurtz Lake both become more extensive during the nonpumping season, and certain wells near the border begin to flow. During this season also there is commonly an area of artesian flow in the Midvalley district, east of the Stockyards fault, in secs. 9 and 10, T. 35 S., R. 11 W. During the past few years, at least, this area has not extended farther east than the Bulldog fault, and so has not become continuous with the area of artesian flow in the Enoch district.

During 1939 there were about 50 wells in Cedar City Valley with sufficient artesian pressure to overflow at the surface during part or all of the year. Five of those wells are used for irrigation; they have an aggregate discharge of 100 to 125 gallons a minute, or about 200 acre-feet a year. In the remaining 45 wells the discharge ranges from a dribble to 15 gallons a minute. The total discharge during 1939 from the 45 wells used for purposes other than irrigation in Cedar City Valley is believed not to have exceeded 200 acre-feet. From casual observations, the discharge from flowing wells during 1939 was more or less comparable to that during the other years since 1935, and 400 acre-feet may be taken as the average annual discharge by artesian flow in the valley during recent years. Of this amount considerably more than half is discharged within the Queatchupah district alone, and a large proportion of the remainder is discharged in the Enoch district.

When the area of artesian flow was of maximum extent, presumably about 1925, there were at least 110 flowing wells in Cedar City Valley, some 60 of which have since entirely ceased to flow. Some of the wells that have ceased to flow are reported to have discharged as much as 75 gallons a minute, and many of the wells that now flow have in the past yielded greater quantities of water. The total quantity of water discharged from flowing wells prior to 1925 was undoubtedly far greater than during recent years, and the maximum yearly discharge by artesian flow was perhaps of the order of 1,500 to 2,000 acre-feet.

The area in which the former flowing wells are located is easily distinguished on plate 18 within the maximum area of artesian flow, but beyond the limit of the area of artesian flow in 1939. Two of these nonflowing wells are in the Queatchupah district, and some others are in the Enoch district; they show clearly that there have been appreciable declines in head of artesian wells in both districts during recent years. The great majority of these former flowing wells, however, are located on the lower parts of the Coal Creek alluvial fan, particularly in the Midvalley and Iron Springs ground-water districts. Both districts have become areas of moderate pumping for irrigation since 1925, and furthermore, both are dependent for most of their recharge upon water that moves through the Coal Creek district, an area in which intensive ground-water development likewise has occurred almost entirely since 1925. A moderate decline in pressure head of artesian wells in all parts of Cedar City Valley has no doubt resulted from a natural decrease in storage during a climatic cycle when precipitation and runoff have ordinarily been below normal.The great decline of flowing wells in the Midvalley and Iron Springs district in comparison with other districts is believed to be a result of the increasing use of ground water for irrigation on the Coal Creek fan.

A large proportion of the present discharge of flowing wells in Cedar City Valley goes to waste, partly because many of the wells are allowed to flow continuously whether the water is being put to beneficial use or not and partly because the water is not used economically. Watering of livestock is by the mud-puddle method, and probably half the water intended for irrigation is lost by evaporation before it gets to the furrow. The wastage, however, is almost entirely in areas where there are large losses from the ground-water reservoir by transpiration and evaporation. The possibility of salvaging and putting to economic use water now wasted from wells and water now lost by evaporation and transpiration is discussed on p. 136.

Some water may be lost from artesian strata by underground leakage from wells in Cedar City Valley, but the quantities lost or the number of wells involved were not determined during this investigation. These losses would be most likely to occur in wells that are only partly cased and in wells where casings are perforated excessively; they are preventable by proper well construction. The harmful effects of these losses would be largely limited to the leaky well; in flowing wells the flow would be diminished by the amount of leakage; in pumped wells, losses might be into less permeable strata, and the recovery of the water rendered somewhat more difficult. Losses from these wells do not represent losses from the ground-water reservoir, and a large proportion of the developed ground water is yielded by the shallower strata, which may receive the leakage from wells.

IRRIGATION WELLS

The annual discharge of irrigation wells in Cedar City Valley has been computed by the Utah State Engineer for 1938, 1939, and 1940, based on one or two measurements each year of the rate of discharge of each well together with records of kilowatt-hour consumption by the electrically-operated pumps and estimates of the periods of operation of the other pumping plants. Computations for the year 1930 by Arthur Fife, former Iron County agricultural agent, are based on estimates of the average rate of discharge and on records of the number of days of operation of each well.

The measurements of rate of discharge and pumping lift, and the computed annual discharge from irrigation wells during 1930, 1938, 1939, and 1940 are tabulated below. The table does not include flowing wells that are used principally for irrigation. (See p. 127.) As shown in this table, the rate of discharge in midpumping season (July or August) is ordinarily lower than that measured near the beginning or end of the season, but generally within 10 percent of the higher figure, although exceptionally (as in wells (C–35–11)27acd1 and 27adc1) the spread may be as great as 40 percent. The computed annual discharge of irrigation wells in Cedar City Valley is considered to be accurate within perhaps 15 percent. This degree of accuracy is greater than can be expected in computations of the discharge from most ground-water areas in Utah, because the rate of discharge fluctuates through a comparatively small range, and because the preponderance, probably more than 90 percent, of the water is pumped by electric power, which is metered, so that the total pumpage may be determined closely by the power consumption.

Discharge of irrigation wells in Cedar City Valley

[For 1930, by Arthur Fife; for 1938 to 1940, by the Utah State Engineer]

Well No.	1930		1938				1939				1940				Specific capacity (estimated) (gal. per min. per foot of draw-down)
	Rate of discharge (gal. per min.)	Annual discharge (acre-feet)	Date of measurement	Rate of discharge (gal. per min.)	Pumping lift (feet)	Annual discharge (acre-feet)	Date of measurement	Rate of discharge (gal. per min.)	Pumping lift (feet)	Annual discharge (acre-feet)	Date of measurement	Rate of discharge (gal. per min.)	Pumping lift (feet)	Annual discharge (acre-feet)	
(C-33-10)31adb2							June 22	618		16				6	
(C-35-10) 7cad1			May 9	262	44	156	June 6	251	51	126	May 20	250	49	199	22
			July 23	262	49		Aug. 31	246	51		Sept. 18	230			
7cdd1			Aug. 30	140		45	June 6	146		27	May 20	94		39	8
							Aug. 31	110							
(C-35-11) 8ddd1	120	70	July 21	118		45	June 8	103		54	May 20	86		61	
							Sept. 1	101			Sept. 18	79			
9ccc2	60	19													
10ccc1	250	194	July 21	178		58	June 8	185		125	May 20	184	27+	28	12–
			Aug. 24	213			Sept. 1	212							
10cdd1	400	231									June 14	255		84	
12ddd1			May 7	467	56	383	June 6	473		390	May 20	500		443	12
			July 23	477	65		Aug. 31	466	61		Sept. 9	411			
13ddb2			July 23	368	57	251	June 6	360		217	May 27	393	57	256	23
							Aug. 31	351	59		Sept. 23	296	63		
13ddb3			July 23	366		223	June 6	372		219	May 27	329	62	293	
							Aug. 31	343			Sept. 28	404			
14aac1	400	139					July 7	260		129	May 27	300	83	225	4
							Aug. 31	332	88		Sept. 18	281			
14bac1	60	33													
14ddd3			July 23	197		74	June 6	175		85	May 27	185	41	109	10
							Aug. 31	163	39						
15adc1	200	75													
16aba2	240	133													
16acd1			July 21	460		227	June 8	458		246	May 27	420		291	
							Sept. 1	445							
21ccd1	540	130	May 6	275	51	143	June 8	276		97	May 27	273	56	135	
			Aug. 1	288			Aug. 29	271							
21cdb1			July 15	355	44	197	June 8	356		224	May 28	326	49	209	23
			Aug. 29	345			Aug. 29	347	49						

(C-35-11)21dbd2			Aug. 29	345							May 27	346	61	161	
21dcc1			Aug. 1	382	46	154	June 8	385		182	May 27	275	54	166	24
							Aug. 29	394	49						
27aca1			July 22	380		194	June 6	411		193	May 28	335	47	238	45
			Aug. 1	361	39		Aug. 31	358	50						
27acc1			July 22	468	48	95	June 7	469		219	May 28	352	55	186	52
							Aug. 30	417	57		Sept. 9	354	60		
27acd1			July 22	540	49	234	June 6	530		230	May 28	376	52	173	45
27acd1							Aug. 31	336	55		Sept. 9	169			
27adc1							June 6	520		151	May 28	307	57	175	
							Aug. 30	325	65						
27bab2							June 7	469		176	May 29	392		332	45
							Aug. 30	411	47						
27bbc1							June 7	598		292	May 29	614	50	313	54
							Aug. 30	589	52		Sept. 26	508	53		
27bdb1			July 22	585		262	June 7	557		314	May 29	465		224	
							Aug. 30	520							
27cdd1			July 22	697		249	June 7	718		336	May 28	585		282	
							Aug. 30	610			Sept. 9	479			
27dbb1			July 22	697	51	376	June 14	667		349	May 28	643	60	430	48
							Aug. 30	619	62						
27dcd1			July 22	783		255	June 7	732		382	May 28	662		442	
							Aug. 30	669	81						40
28aac1			May 6	330		153	June 20	347		200	May 29	283		189	
			July 12	342			Aug. 29	292			Sept. 26	226			
28dab1			July 15	374		180	June 20	372		240	May 29	329	55	193	
							Aug. 29	339							
29acd1			May 16	307		119	June 12	338		190	May 29	329	76	227	9
			July 20	248			Aug. 28	329	75		Oct. 22	329			
29add1			Aug. 1	171	51	22	June 16	284		112	May 29	218	62	145	12
							Aug. 25	242	60						
29dbd1	500	233	May 9	224		118	June 13	347		162	May 29	202	60	116	
			Aug. 1	194			Aug. 25	262			Sept. 18	129	62		
29dcd1 [1]	600	31	May 9	189	59	59	June 13	176	58	69					13
	200		Aug. 1	173	58		Aug. 25	109	80						
31acd1	530	276	July 19	284	63	105	June 15	258	62	139	May 31	250	61	125	8
							Aug. 23	260	63						
32abd1			July 20	702	53	306	June 14	624	51	352	May 31	551	54	350	
							Aug. 25	528	56		Sept. 18	519	59		
32aca1			May 17	468	51	321	June 13	460	53	284	June 14	410	57	263	50
							Aug. 28	429	56						
32acd1			July 18	486	54	176	June 14	512	53	296	May 31	482	55	286	50
							Aug. 23	488	58						
32add1 [2]	550	410	July 18	328	46	146	June 12	306		150	June 14	614	63	430	46
							Aug. 25	274	63						
32ccd1			July 19	627	53	384	June 9	637	52	437	May 31	614	54	433	45

See footnotes at end of table.

Discharge of irrigation wells in Cedar City Valley—Continued

[For 1930, by Arthur Fife; for 1938 to 1940, by the Utah State Engineer]

Well No.	1930		1938				1939				1940				
	Rate of discharge (gal. per min.)	Annual discharge (acre-feet)	Date of measurement	Rate of discharge (gal. per min.)	Pumping lift (feet)	Annual discharge (acre-feet)	Date of measurement	Rate of discharge (gal. per min.)	Pumping lift (feet)	Annual discharge (acre-feet)	Date of measurement	Rate of discharge (gal. per min.)	Pumping lift (feet)	Annual discharge (acre-feet)	Specific capacity (estimated) (gal. per min. per foot of draw-down)
(C-35-11)32ccd1			Aug. 30	630			Aug. 23	637	55		July 29	597	57		
33aac1	850	605	July 18	576	77	251	June 7	601		314	May 31	520	85	338	35
							Aug. 29	521	85		Sept. 23	440	86		
33abd1			Aug. 29	432	71	172	June 8	383		164	June 3	399		169	
							Aug. 28	302			July 31	335			
33bac1	660	440	July 18	583		194	June 8	588		332	May 31	587		398	
							Aug. 25	558							
33cdd1			May 9	135		42	June 20	269		127	May 3	211		100	15
			July 21	140	81		Aug. 29	211							
33dbc1	650	405	July 21	383		83	June 16	428	85	143	May 31	450		170	23
							Aug. 29	342	90						
(C-35-12)34dcd1	515	230	Aug. 4	340	336	6				3				3	18
36daa1			July 19	152	59	67	June 15	128		17					3
			Aug. 30	149											
(C-36-11) 5abd1							June	1100	66	147					
5baa1			July 28	900	66	236	June 15	720	60	233					50
							Sept. 1	690	65						
5bdd1			July 20	572	58	204	June 10	504	57	262	June 3	540		290	54
							Aug. 25	488	61		July 29	410	62		
5cab1			July 20	606	58	198	June 14	553	57	330	June 1	540	60	334	30
							Aug. 25	512	62		July 29	459	63		
5cac1			July 20	478	51	199	June 14	459	50	260	June 1	422	52	264	36
			Aug. 30	464	55		Aug. 25	386							
5cc [3]	520	346													
5dcb1			July 20	553	58	256	June 14	482		261	June 1	465		288	49
			Aug. 30	517			Sept. 1	450	63						
5dcc1			July 20	576		160	June 15	530		258	June 1	509		310	
							Aug. 25	512			July 29	429			
6aaa1											July 29	216		91	
6aad1		[4] 300													

(C-36-11) 8bba1			Aug. 2	541	53	216	June 13	510	53	302					35
							Aug. 28	465	56						
8bbd1	690	411	July 19	573		245	June 15	567	52	303	May 31	563		413	43
			Aug. 2	541	57		Aug. 28	532	52		July 30	519			
8bda1											June 1	178		114	
											July 30	140	59		
8bda2			May 16	522		249	June 14	395		240	June 1	329		223	
			July 22	409			Aug. 23	381			July 30	281	65		
8cab1			July 19	392		199	June 14	374		252	June 1	326		224	
							Aug. 28	355			July 30	275	53		
8cbb1	300	267	May 9	175		71	June 14	139		98	June 1	96	36	49	22
			July 19	143	34		Aug. 23	118	38		July 30	77	37		
			Aug. 30	149											
18ada1	275	153	May 9	193		92	June 16	178		72	June 3	160		98	
			July 20	171			Aug. 23	164			July 29	152			
(C-36-12) 1aaa2	358	207	July 19	150	53	60	June 15	146		76	May 31	140		102	5
							Aug. 29	159	51		July 29	147			
12dba1	400	259	July 19	341	48	112	June 15	358	48	182	June 3	338		168	15
							Sept. 22	386			July 29	314			
(C-37-12)23acb1	1350	900	Aug. 11	500		11	June 21	720		168	June 3	519		256	18
							Sept. 22	630							
34abb1				[4] 750		296	June 16	640	62	390	June 3	617	65	402	40
							Sept. 22	617	63						

[1] 29dcd2 in 1939.
[2] 32add2 in 1940.
[3] Replaced by well 5dcb1 in 1934.
[4] Estimated.

The number of irrigation wells operated in the several ground-water districts and the annual discharge from those districts are summarized for the years of available record in the table below. From this table it is evident that most of the increase in the use of ground water for irrigation in Cedar City Valley between 1930 and 1940 may be accounted for by developments in the Coal Creek district. There has likewise been a considerable increase in pumping in the Enoch district, but this is partly offset by a decline in the amount of water pumped in the Midvalley and Kanarraville districts. The quantity of water pumped in the Iron Springs district remains about the same, but the number of pumped wells has been increased.

Annual discharge, in acre-feet, for irrigation in ground-water districts of Cedar City Valley

[Summary from table above]

Ground-water district	1930		1938		1939		1940	
	No. of wells	Discharge	No. of wells	Discharge	No. of wells	Discharge	No. of wells	Discharge
Coal Creek	9	3,200	33	6,500	37	8,800	36	9,000
Iron Springs	7	1,500	10	1,100	10	1,500	9	1,400
Midvalley	7	750	3	350	3	430	4	450
Enoch	1	150	6	1,150	7	1,200	7	1,600
Rush Lake	0	0	0	0	1	20	1	10
Kanarraville	1	900	2	300	2	550	2	650
Total	25	6,500	54	9,400	60	12,500	59	13,100

The number of irrigation wells pumped each year is shown in the table below, and the increased use of wells for irrigation during the dry years 1931, 1934, and 1939 is clearly indicated. Data as to the total discharge of irrigation wells are not available for the years 1931 to 1937, nor for the years prior to 1930. It may be deduced from the estimated number of irrigation wells in operation each year, however, that the total discharge in 1939, amounting to more than 12,000 acre-feet, was probably greater than in any previous year. In 1940 the owners of several wells whose contruction had not been authorized by the State Engineer were restrained from pumping, and hence fewer wells were operated than in 1939. The pumping lifts were quite generally greater in 1940 than in 1939, and the rate of discharge of most wells was therefore diminished. Nevertheless, the total discharge for irrigation was slightly greater in 1940, due presumably to a marked increase in the length of the irrigation season.

Number of pumped irrigation wells

Year	Number of irrigation wells pumped			Year	Number of irrigation wells pumped		
	By electricity [1]	By other power [2]	Total		By electricity [1]	By other power [2]	Total
1925	....	5	5	1933	29	1	30
1926	....	5	5	1934	49	1	50
1927	....	6	6	1935	42	1	43
1928	....	12	12	1936	53	1	54
1929	....	18	18	1937	53	1	54
1930	18	7	25	1938	52	2	54
1931	39	1	40	1939	56	4	60
1932	32	1	33	1940	57	2	59

[1] From records of Southern Utah Power Co., compiled for Utah State Engineer.
[2] Estimated.

SPECIFIC CAPACITY OF WELLS

The specific capacity, or rate of discharge per foot of draw-down, provides a convenient basis for comparison of the water-yielding capacity of wells. In Cedar City Valley the measurements of the discharge of the wells are believed to be reasonably accurate, but the draw-down is not accurately known for most wells, and the computed specific capacities are based on incomplete data on draw-down. Generally, the total pumping lift was known but the original water level before pumping was interpolated from ground-water contour maps or hydrographs of the well. It has been assumed that the specific capacity of a particular well is more or less constant throughout the range of discharges normally encountered in the irrigation wells in Cedar City Valley.

Specific capacities have been estimated for more than half the irrigation wells in Cedar City Valley and are shown in the table on page 130 in gallons per minute per foot of draw-down. There is a wide range in the specific capacity, from 3 or 4 in some of the poorest wells to more than 50 in several of the best wells. Some wells are so closely spaced that they undoubtedly cause mutual interference; the draw-down measured while both wells are pumping includes this undetermined amount of interference, and the computed specific capacity for those wells is therefore lower than the true specific capacity. For some wells, particularly wells (C–35–11)13ddb2, (C–36–11)5cab1 and (C–36–11)8bba1, adjacent wells are so close that the computed specific capacity is obviously low. For many other wells in the intensively pumped areas the specific capacity would likely be higher also but for the undetermined amount of interference by adjacent wells.

Some of the differences in specific capacity reflect differences in the construction and development of the wells. Thus the specific capacity of a well of large diameter would be greater than for one of smaller diameter at the same location; in Cedar City Valley more than 80 percent of the irrigation wells have a diameter of 12 inches, and comparatively few of the differences in specific capacity can be attributed in any degree to the size of the well. The method of development also may affect the specific capacity, as illustrated by well (C–35–12)34dcd1, a gravel-packed well, specific capacity of which is higher than that of most other wells in the Iron Springs district. Ineptly perforated wells, of course, will have a lower specific capacity than those that are properly finished. In Cedar City Valley wells have been constructed almost exclusively by farmers with drilling machines, and scientific development of wells practically does not exist. Consequently, in areas where the strata are highly permeable and yield water readily, good wells are obtained; in areas where scientific development of wells is necessary, the existing wells must be classed either as very poor or as complete failures.

Differences in specific capacity of wells in Cedar City Valley appear generally to reflect differences in the porosity and permeability of the sediments encountered by wells in various parts of the valley. These differences are best shown on the Coal Creek alluvial fan. Commonly the wells in the Coal Creek district, on the upper part of the fan, yield more than 40 gallons per minute per foot of draw-down, and all the best wells in the valley, having a specific capacity of 50 or better, are in that district. Toward the lower or outer margin of the Coal Creek district, where well logs show a greater proportion of fine sediments, the specific capacity is lower, as in wells (C–35–11)21cdb1, (C–35–11)21dcc1, and (C–36–11) 18ada1. Still lower on the Coal Creek fan, in the Midvalley district, the specific capacity is commonly less than 20. The decrease in specific capacity in wells lower on the fan is also implied by the increasing proportion of unsuccessful irrigation wells (pl. 18), for these wells were generally abandoned after tests showed that they would yield supplies insufficient for irrigation. On some of the alluvial fans of the minor streams entering Cedar City Valley, wells of fairly large specific capacity also have been obtained.

Westward on the Coal Creek alluvial fan there is a distinct change in specific capacities of wells along the line of the Stockyards fault, which separates the Coal Creek and Iron Springs districts. This sharp distinction is in contrast to the gradual lowering of specific capacities northward through the Midvalley district. The wells in the Iron Springs district commonly yield less than 15 gallons per minute per foot of draw-down, while those just east of the fault in the Coal Creek district include some of the best wells in the valley. [77] The number of unsuccessful irrigation wells, shown on plate 18, which are so listed either because of statements of owners, or because of the circumstantial evidence of a casing of large diameter, also indicates that ground-water supplies are poor and not easily obtained. On the Coal Creek fan, three unsuccessful wells are shown in the Coal Creek district, eight in the Midvalley district, and 14 in the Iron Springs district. Some wells in the Iron Springs district do not yield enough water to justify use of a windmill.

The sharp distinction in specific capacities of wells on opposite sides of the Stockyards fault, representing no doubt a corresponding distinction in the sediments, is apparently due to the faulting of the coarse sediments that are believed to have accumulated during the Pleistocene period (p. 45), and the subsequent burial of these sediments in the Iron Springs district under a layer of finer materials hundreds of feet in thickness.

POSSIBILITIES OF FUTURE DEVELOPMENT OF THE GROUND-WATER RESERVOIR

Maximum development of a ground-water reservoir involves the fullest possible economic use of the inflow to that reservoir, which in turn involves, among other factors, the elimination so far as possible of the natural losses from the reservoir. The amount of recharge to the Cedar City Valley reservoir could not be measured or even estimated directly, because of the many and varied sources of this recharge. So long as the storage in the reservoir remains constant, the recharge balances the amount of water discharged by all processes, and estimates have already been made of many of the components of this total discharge. The discharge by pumping from irrigation wells has been shown to have increased from about 6,500 acre-feet in 1930 to 9,400 acre-feet in 1938 and 12,500 acre-feet in 1939. (See p. 134.) The discharge from flowing wells has remained more nearly constant, and has been estimated to be about 400 acre-feet annually between 1936 and 1940. (See p. 128.) In addition there are somewhat more than 100 wells used principally for stock and domestic purposes and pumped by hand, windmill, or small motor, the aggregate discharge from which is probably less than 100 acre-feet per year and well within the limit of error of the determinations of discharge for irrigation or from natural causes. The discharge by natural processes has been estimated to have been about 4,700 acre-feet

[77] Well (C-35-11)32ccd1, shown west of the fault, has a specific capacity comparable to those farther east, indicative that the trace of the Stockyards fault perhaps is not as straight as shown on maps accompanying this report and should be located west of this well. However, information is insufficient to derive the exact location of the fault, and the location shown is regarded as only approximate. Also, it is entirely possible that a well of high specific capacity might be located west of the fault, along a channel of Coal Creek that may have been developed toward Iron Springs Gap subsequent to the faulting.

during 1939. (See p. 106.) In 1939 the total discharge from the valley by all processes was thus computed to be of the order of 18,000 acre-feet. During that year, however, the ground-water storage diminished somewhat, as was shown by a general decline of water levels in wells. (See p. 93.) The recharge to the basin must therefore have been somewhat less than 18,000 acre-feet.

In 1938 the total discharge from the reservoir was probably less than that in 1939, for the withdrawals by irrigation pumps were smaller by about 3,000 acre-feet. The recharge in 1938 exceeded the discharge, and there was a general rise in the water levels in wells. In 1940 the quantity of water pumped from wells exceeded that in 1939, while the natural discharge from the valley probably diminished somewhat, because water levels were generally lower following the decline in 1939. Thus the total discharge from the valley during 1940 may have been about as great as in 1939, that is, about 18,000 acre-feet. In 1940, however, there was a further and more pronounced decline in water levels throughout the valley. It is evident that the recharge was markedly less than the discharge and that a considerable portion of the water withdrawn was removed from storage. The recharge in 1940 was presumably far below normal, for both precipitation and runoff during the 1940 hydrographic year were less than 65 percent of normal.

The recharge to the ground-water reservoir is dependent upon precipitation over the drainage area tributary to Cedar City Valley, and hence fluctuates in response to climatic conditions. It is relatively high in years of plentiful precipitation and relatively low in dry years. The discharge under natural conditions would probably show the same general trend, with a certain amount of lag representing the time required for movement through the reservoir.

The discharge from wells, however, is ordinarily not correlative with precipitation or runoff. Judging from the number of irrigation wells in operation each year, and from the total discharge during the past few years, it is the practice of many well owners to leave their wells idle for all or part of seasons when precipitation and runoff are high and to draw heavily on the ground-water reservoir when precipitation and runoff are inadequate. As a consequence, there is likely to be a greater amount of storage during wet years, as indicated by rising water levels, and a correspondingly greater draft on storage during dry years, in areas of intensive pumping for irrigation than in the other parts of the valley. (See table, p. 93.) Under this practice, the acreage irrigated in the valley from year to year (by both surface and ground water) can be held more or less constant—a condition which would not be obtained if the users of ground water tried instead to maintain a constant amount of ground water in storage, that is, to stabilize the water levels at some predetermined levels.

The investigation has shown that Cedar City Valley is approaching the maximum practicable development of ground water. The following discussion of the several ground-water districts is primarily for the purpose of pointing out the possibilities of additional developments for eliminating losses of ground water by natural processes and thus making the greatest possible use of the available supply. Such developments should be made gradually, with continual observation of their effects on the ground-water reservoir, in order to minimize reduction of yield from existing wells.

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Coal Creek district.—The Coal Creek district is by far the most important ground-water district in Cedar City Valley. The amount of water pumped for irrigation in that district during 1939 amounted to about 8,800 acre-feet, which was more than twice the amount utilized in all other districts combined. The discharge in 1939 from 37 wells was nearly three times the amount discharged in 1930 from nine wells, showing clearly the great increase in development during the past decade. Because of the general high quality of wells in the Coal Creek district, it is one of the most economical producers of ground water so long as the pumping lifts are kept within reasonable limits.

During the past decade there has been a considerable lowering of the water levels in wells in the Coal Creek district and a corresponding increase in pumping lift. The effect of this increased lift is shown in the decreasing yield of the wells in the district. Thus, in 1930 the nine wells operating had an average discharge of 500 gallons a minute, but in 1939 the average discharge of the same wells was only 325 gallons a minute. In 1930 the yield per well averaged about 350 acre-feet, while by 1939 the yield per well was less than 240 acre-feet. There can be no doubt that further lowering of the water table will result in further decreases in the yield of each well and hence in increased cost of water for irrigation.

There are no losses of ground water directly from the Coal Creek district by natural discharge. However, some of the water that is lost from Rush and Shurtz Lakes by evaporation and from the surrounding lowlands by transpiration, and most of the water that moves through Iron Springs Gap by underflow, enters the upper part of the Coal Creek alluvial fan and moves through the Coal Creek district. Conceivably this water could be salvaged and used in the Coal Creek district if the water table were lowered sufficiently to prevent movement to the localities where loss occurs. However, such a project would not be feasible, for the pumping lifts and hence the cost of water throughout the district would be increased entirely out of proportion to the value of the water. Present pumping lifts in the Coal Creek district range from about 35 to 90 feet. The water table would need to be lowered at least 50 feet below the levels that existed during September 1939 to prevent movement of water toward Iron Springs Gap or Shurtz Lake basin, and more than 100 feet below those levels to stop the movement toward Rush Lake, which lowering would call for a corresponding increase of pumping lift throughout the Coal Creek district. These increases in pumping lift would not be limited to this district but would necessarily extend over the Iron Springs and Midvalley districts, which are intermediate between the Coal Creek district and the localities where the losses by natural discharge occur.

The ground-water level established in the Coal Creek district of necessity determines the highest levels that can be reached in the adjacent Iron Springs and Midvalley districts. Withdrawals in these latter districts can lower the level below that of the Coal Creek district, but cessation of these withdrawals will not increase storage beyond levels corresponding to those in the Coal Creek district. The great decline of water levels in both the Iron Springs and Midvalley districts since 1925, while withdrawals from the Coal Creek district were increasing, has already been pointed out. (See p. 128.) In recent years the changes in the outlying districts have corresponded with those in the Coal Creek district, although withdrawals have been only a minor fraction of those in the Coal Creek district.

The Coal Creek district does not, however, appear to be seriously overdeveloped. It is true that during the 15 years of development for irrigation the water levels have declined at a rate alarming to the owners of pumps, and that the withdrawals during 1939 have far exceeded the average during the 15 years. But it also is true that the recharge to the ground-water reservoir during those years must have been below normal, for precipitation and surface-water runoff, upon which recharge is dependent, were below normal during 9 of the years since 1925, and the accumulated deficiency in precipitation since that year has amounted to 14.34 inches. The deficiency has been especially marked since 1930, and rainfall has been subnormal in 6 of the succeeding 9 years. In 1932 and 1938 precipitation and runoff were considerably above normal, the recharge to the Coal Creek district was more than enough to balance the discharge, and water levels rose somewhat. Precipitation also was slightly above normal in 1936, but after an extended period of drought there evidently was a large soil-moisture deficiency throughout the drainage basin of Coal Creek at the beginning of that year, resulting in a runoff in that year that was only about 75 per cent of normal and a decline in ground-water levels in the Coal Creek district.

Contemporaneous records of changes in water levels and of discharge from irrigation wells are available only since 1938. Fortunately these records cover one year (1938) when precipitation and runoff were above normal and one year (1939) when both were below the normal established over a long term of years. During the two years the precipitation at Cedar City averaged 12.34 inches a year, which is about 0.8 inch below the normal established in 34 years, and the runoff of Coal Creek averaged nearly 28,000 acre-feet a year, which is also somewhat below normal. (See p. 66.) During 1938 the discharge from irrigation wells in the Coal Creek district amounted to about 6,500 acre-feet; the recharge during this year was sufficient to offset this discharge and to cause a rise in water levels that averaged about 3.1 feet over the district. In 1939 the irrigation withdrawals within the district amounted to about 8,800 acre-feet; the recharge this year was insufficient to replace the discharge, some water was drawn from storage, and water levels declined about 2.7 feet over the district. Drawing a balance sheet for the 2 years, the recharge from slightly less than normal precipitation and runoff was sufficient to balance an average annual withdrawal for irrigation of 7,500 acre-feet and to increase storage slightly. Tentatively, then, on the basis of a very short period of record, it is suggested that 7,500 acre-feet represents approximately the average annual yield from the Coal Creek district with the water levels at about their present position. If the climate should become increasingly arid, as would be indicated by a gradual lowering of the figure for normal precipitation, the figure for ground-water yield would need to be lowered.

If the annual discharge is restricted to some quantity less than the average net recharge to the district under present water-level conditions, storage in the reservoir will increase over a term of years, and the water levels will rise in this district and in the Midvalley and Iron Springs districts. However, these increases in storage will be accompanied by an increase in natural losses in the lower parts of the Coal Creek fan.

If further developments are made in the Coal Creek district the increased withdrawals will be at the expense of storage, water levels will be lowered, and pumping lifts will be increased. As partial compensation, there will doubtless be some decrease in movement from the Coal Creek district toward the localities where natural discharge occurs, corresponding to the decreased hydraulic gradient as the water levels in the district are lowered. Whether this additional quantity will be worth the additional cost of pumping within the district is problematical.

There is some opportunity for waste of water pumped from irrigation wells, a rather curious result of the rate structure of the company that furnishes electric power. Prior to 1938 electricity was furnished at a flat rate per horsepower of connected load, on a contract of 4, 5, or 6 months duration. During summers when rainfall sufficed for crops for several days or weeks at a time—a condition that should have worked to the advantage of ground-water supplies—there was instead a tendency for many irrigators to "get what was paid for" and to operate their pumps for the full term of the contract regardless of need. Since 1938 the electricity has been metered, but the new rates still do not work for conservation of ground water; the charge is 2 cents per kilowatt-hour for the first 500 kilowatt-hours per horsepower of demand, which is roughly the power consumed during the first month of pumping; the rate is lowered to 1.5 cents for the next 500 kilowatt-hours per horsepower. Above 1,000 kilowatt-hours per horsepower, the cost of power is lowered to 0.7 cents per kilowatt-hour, and many irrigators continue pumping for a long season, because they get water for one-third the cost of that during the first month of operation. It would seem that for thorough conservation of ground water the present rate structure should be replaced by a uniform rate per kilowatt-hour, with a suitable service charge or minimum charge to cover the cost of maintenance to wells operated only for short periods. Such a rate would eliminate the incentive to waste "cheap" water.

Midvalley district.—The Midvalley district is a minor user of ground water in Cedar City Valley and has become less important during recent years. Wells in the district ordinarily have low specific capacities, and, although the water levels are closer to the land surface, the pumping lifts are about as great as those in wells of the Coal Creek district, and the discharge is commonly less. In parts of the district water is close enough to the surface that there may be some loss by transpiration, but such loss is probably small. Water levels are reported to have been considerably higher during years prior to the present investigation, and no doubt there was then considerably more loss by transpiration and probably by evaporation.

The Midvalley district is dependent in large part upon water that moves northward from the Coal Creek district. Quite clearly the increased use of ground water there has had some effect upon the Midvalley district. As has been pointed out, in that district, once an area of artesian flow, there are no longer any wells that flow during the pumping season, and only two or three that flow during the rest of the year. The loss in artesian pressures has coincided with the development of the Coal Creek district and, incidentally, with the elimination of losses by natural discharge within the Midvalley district.

Some of the water in the Midvalley is believed to be derived from the Enoch district to the east. As shown on plate 13, any water thus derived apparently moves northward in the zone between the Bulldog and West Enoch faults, a zone where there have been very few ground-water developments. Thus the water that comes from the Enoch district appears not to be utilized.

As in the Coal Creek district, there is a possibility of using in the Midvalley district some water that now passes through that district and is discharged naturally from the Rush Lake district. Existing irrigation wells in the Midvalley, however, cause interference over a wide area when pumped, in some cases as much as 2 or 3 square miles, and new wells would need to be established in the practically undeveloped northern part of the district to minimize interference with existing wells, which are more or less concentrated in the southern part. New wells in the northern part of the district would probably encounter the same problems of low-grade land and aquifers of low yield as are predicted in the Rush Lake district farther north. Furthermore, such wells would certainly perform inefficiently the function of eliminating natural losses from the vicinity of Rush Lake.

Rush Lake district.—The Rush Lake district receives water from the Midvalley district and probably also from the Spanish Treasure Wash, which enters the valley northeast of Rush Lake, and from the slopes that form the north and northwest borders of the valley. Until 1939 the district was not utilized for irrigation, and ground water was disposed of by transpiration and evaporation around Rush Lake and to an unimportant degree by underflow through Twentymile Gap. This natural loss has been estimated at about 1,200 acre-feet annually in recent years.

An excellent irrigation well, (C–33–10)31adb2, has been obtained recently by Mr. A. C. Hatch in the Spanish Treasure Wash. In 1939 the discharge from the well measured more than 600 gallons a minute. The ground-water reservoir extends, with very little slope of the water table, from Rush Lake up the Spanish Treasure Wash, and water pumped by Mr. Hatch is likely derived from this reservoir rather than from underflow in the wash alone. Thus, pumping from this well probably will eventually diminish the natural losses from the Rush Lake area. Other wells in the district, so spaced as to keep mutual interference at a minimum, might lower the ground water until natural losses are to a large extent eliminated. At first this developed water would be derived primarily from storage, but as the water levels are lowered the discharge by pumping would replace natural losses to a progressively greater degree.

Obstacles to such development are, of course, the possible difficulties of obtaining good wells and the relatively low quality of the soil over much of the Rush Lake district. Water-bearing strata have been encountered in wells in the district, however, as indicated by the log of well (C–34–11)3ccb1. Mr. H. L. Adams, the owner, reports strata of gravel having an aggregate thickness of more than 80 feet in the upper 330 feet penetrated by the well, and three strata totalling 35 feet within 80 feet of the surface. Certainly there is a possibility that a well properly constructed in this vicinity might yield water in quantities sufficient for irrigation. It is believed that elsewhere in the vicinity of Rush Lake, good wells may also be obtained, although it is likely that some sites will prove unsatisfactory for irrigation developments.

The loss from Cedar City Valley through Twentymile Gap is estimated to be too small to supply even a single irrigation well. Two attempts have been made to develop the water that is lost through the Gap, but neither was successful. Well (C–33–11)30ddd1 (see log, p. 41), was reported to yield nearly 700 gallons a minute with a draw-down of 35 feet. It was abandoned, according to the owner, because of excessive cost of operation. The other, a trench across the narrowest part of the Gap, presumably intended to reach bedrock, is still in existence, partly caved in now, but the project was evidently abandoned before any water was developed.

Enoch district.—The Enoch district, practically undeveloped in 1930, has become an important district for irrigation by ground water. During 1939, about 1,200 acre-feet were pumped by seven wells concentrated in the southern half of the district. At that time considerable losses by natural discharge occurred, chiefly in the northern half of the district, where several artesian wells and springs continue to flow throughout the year. It is estimated that the natural losses from the district during 1939 were only slightly less than the amount pumped from wells.

The present natural losses could perhaps be eliminated by additional pumping of water for irrigation, provided the new wells were properly distributed. During the past few years it has appeared that the development of the southern half of the district has been at least partly at the expense of storage, for certain springs in Enoch have stopped flowing, and the static levels in certain wells, as in well (C-35-10)7cad1, have declined somewhat over a period of years. However, the pumping has had no great effect on water levels in wells in the northern part of the district and certainly has not eliminated the natural discharge there. It is thus evident that if these losses are to be stopped and if interference with wells in the southern part of the district is to be kept at a minimum, further development should be made in the northern half of the district, in T. 34 S. This development in the Enoch district would probably reduce the amount of water that moves into the Midvalley district, especially in T. 34 S., which is in turn contributory to the Rush Lake district.

Iron Springs district.—The Iron springs district has had about the same amount of ground-water development as the Enoch district, but it began much earlier. Many of the oldest irrigation wells are in this district. In addition to the discharge from wells, some water is lost from the district by spring discharge and underflow through Iron Springs Gap, by evaporation from Shurtz Lake, and by transpiration from the adjacent lowlands.

Loss of water through Iron Springs Gap, estimated to be about 500 acre-feet a year, may possibly be eliminated by construction of wells just above the gap, which would be far enough from most other irrigation wells that no great amount of interference would be expected. Wells here, as in most of the Iron Springs district, would likely penetrate sediments consisting chiefly of sand, silt, and clay. A satisfactory well has been obtained within 1½ miles of the upper end of the gap by gravel-packing, and no doubt other wells could be developed by similar methods.

In the low southwest portion of the Iron Springs district, north of Shurtz Lake, there is probably some loss of ground water by natural discharge. This area receives its water supply chiefly by westward movement through the Coal Creek alluvial fan, and the static levels in wells near the west border of the valley fluctuate in response to pumping farther east. It is reasonable to suppose, therefore, that any considerable amount of pumping in this lower western portion of the Iron Springs district would affect somewhat the existing wells farther east. Probably the development of new wells will cause the loss of artesian flow of wells in the western part of the district.

Additional pumping from the upper or eastern part of the Iron Springs district would, of course, raise the same problems as in the adjacent Coal Creek district, already discussed. (See p. 138.) The wells probably would be less productive than those in the Coal Creek district.

Hamiltons Fort district.—The Hamiltons Fort district has no irrigation wells and very few wells of any kind, and the water in the district is evidently disposed of almost entirely by natural discharge in the western part of the district, around Shurtz Lake. Thus any future developments in this district would not interfere seriously with existing wells. Inasmuch as Shurtz Creek is about the same size as Kanarra Creek, at least as much development for irrigation might be expected as there is in the vicinity of Kanarraville.

As to the possibilities of obtaining satisfactory wells in this district, available data give a dubious answer. Only one well is known to have been drilled for irrigation, well (C-36-12)36daa1, which is reported to have been rejected as of no value. However, the log (p. 42) indicates that approximately one-third of the sediments are coarse enough to include gravel. Whether the well was rejected because the depth to water (107 feet) was too great for economical pumping or whether the well was not developed sufficiently to produce the amount available in the aquifers is not known. For prospective developments it would appear that the best locations would be perhaps a mile west or northwest of this well, where the depth to water probably would be less than 50 feet. In order to eliminate the present natural discharge from the vicinity of Shurtz Lake, it might be necessary to obtain wells farther west, within the present area of artesian flow, where, however, the prospects of obtaining productive wells are rather poor.

Queatchupah district.—The Queatchupah district is recharged from the New Harmony and Iron Mountains that border Cedar City Valley on the west. Except for a few hundred acre-feet discharged from flowing wells, the ground water is discharged by evaporation and transpiration in the Shurtz Lake basin. It is believed that these natural losses could be eliminated by pumping for irrigation from several wells, but this pumping would probably mean the sacrifice of the present flowing wells in the area.

Five wells have been constructed for irrigation in the Queatchupah district; none of these is now in use, and all of them are therefore marked "unsuccessful" on plate 18. Two of these, wells (C-36-12)29dab2 and (C-36-12)29dbb1, are reported to have been satisfactory for irrigation, having yielded, respectively, 325 and 525 gallons a minute with a specific capacity of about 20. They fell into disuse, according to the owner, because of the prohibitive cost of pumping by motor fuel in a region remote from electric power. Well (C-37-12)4bcb1, about 2 miles farther south, apparently caved soon after it was completed, and thereafter it yielded less than 100 gallons a minute with a draw-down of 50 feet. Other wells, still farther south, evidently were likewise unsatisfactory for irrigation.

Four of these unsuccessful irrigation wells are within the area of artesian flow, and the fifth is close to it; the wells are thus in a position comparable to those in the Midvalley district on the Coal Creek fan, where wells are generally of poorer quality than those higher on the fan in the Coal Creek district. By analogy, wells located somewhat higher on the Queatchupah Creek fan might be expected to have a higher specific capacity, the depth to water, however, increasing rapidly westward.

It has been roughly estimated that the natural losses from the ground-water reservoir in the vicinity of Shurtz Lake, which includes the area of natural discharge from the Queatchupah and Hamiltons Fort districts as well as that from the southwest part of the Iron Springs district, has been of the order of 2,000 acre-feet during the years of the present investigation. How much of the water that otherwise will be lost can be recovered and put to use can best be determined by close observation during a gradual and orderly development.

Kanarraville district.—The Kanarraville district is an area of limited development of ground water for irrigation. During 1939 the withdrawals amounted to less than 600 acre-feet. Ground water also is discharged naturally from the district by underflow and by effluent seepage into tributaries of Ash Creek, where some may be lost by evaporation. No figures are available as to the amount of this discharge.

Of the five wells drilled for irrigation in this district, only two were in use during 1939. One of these, well (C–37–12)34abb1, centrally located on the Kanarra Creek fan, is an excellent well comparable to many of those in the Coal Creek district, and the other, on the Muries Creek fan, is a fairly good well. Two of the unsuccessful irrigation wells were drilled in locations where the depth to water is apparently too great for economical pumping. The fifth well was operated for several seasons, the reason for discontinuance being unknown.

The fluctuations of water levels in wells in the Kanarraville district indicate that the two irrigation wells now being operated are not taxing the resources of the respective fans upon which they are located. In the absence of estimates of water lost by natural discharge, however, any future development should be made slowly and under close observation, for the drainage area tributary to the district is known to be small, and the recharge in consequence is limited.

GROUND WATER IN PAROWAN VALLEY

GENERAL FEATURES

Ground water in Parowan Valley is derived largely from the unconsolidated sediments that constitute the valley fill. All wells in the valley obtain water from these sediments, and numerous springs, notably the group north of Paragonah in T. 33 S., R. 8 W. and those along the west margin of Little Salt Lake, likewise originate within these unconsolidated deposits.

The consolidated rocks that border Parowan Valley, ranging in age from Cretaceous to Pleistocene, yield small quantities of ground water for use within the valley. Several springs along the south border of the valley between the towns of Parowan and Summit furnish water for culinary purposes, for some irrigation at several ranches, and for the municipal supply of Summit; these springs evidently arise along a fault that has displaced the Tertiary volcanic rocks. No other springs are known along the borders of the valley, but there are many in the mountainous areas tributary to the valley, particularly in the dissected Markagunt Plateau to the east. Some of these springs furnish the municipal water supply for the towns of Parowan and Paragonah, but most of them discharge into the canyons of the principal streams. Because a large proportion of the flow of these streams, particularly of Parowan, Red, and Little Creeks, is contributed by springs, the discharge is distributed more evenly throughout the year than is the case in the major streams in Cedar City Valley. (See pp. 64 to 68.) Water from these springs in the mountainous areas is of course not a component of the ground-water body in the valley, although it may contribute to that body by stream seepage or underflow when it is discharged from the stream canyons.

The conditions of occurrence of ground water in the alluvium of Parowan Valley are similar to those of Cedar City Valley, and the general discussion of its occurrence there (pp. 69 to 72) applies almost equally well to Parowan Valley, where, however, most of the ground-water development has occurred within the area of artesian flow. Hence the water in the great majority of wells appears to be under some artesian pressure, which eliminates the possibility of determining the position of the water table. Therefore, the discussion of piezometric surfaces begins with those surfaces concerning which the fullest information is available—the artesian-pressure surfaces—and then proceeds to show the probable position of the water table or normal-pressure surface with respect to those surfaces.

FLUCTUATIONS OF GROUND-WATER LEVEL

Fluctuations of water level in wells in Parowan Valley result from forces similar to those which act upon the ground-water reservoir in Cedar City Valley. (See pp. 72 to 86.) However, artesian conditions are more prevalent and more pronounced than in Cedar City Valley, and it is perhaps due to this fact that fluctuations of water level in Parowan Valley are somewhat different in character from most of those observed in Cedar City Valley. These differences are most marked in areas of heavy withdrawal from wells, and for purposes of discussion the fluctuations observed in Parowan Valley are grouped as those related to discharge from flowing wells, those related to pumping from irrigation wells, and other fluctuations.

FLUCTUATIONS RELATED TO DISCHARGE FROM FLOWING WELLS

About three-fourths of the wells in Parowan Valley flow by artesian pressure during part or all of each year. State law requires that these wells be closed when not in use; as a result many wells are allowed to flow only intermittently, and the great majority are closed during the winter months. These changes in the rate of withdrawal from season to season cause fluctuations in the water level that exceed 10 feet a year in some wells. The fluctuations are caused in part by discharge from the observed well and in part by flow from other wells in the vicinity. The hydrographs shown in plate 19 are representative of the records that have been obtained from flowing wells; from them may be pointed out some of the weaknesses and some of the interpretations of such records. The hydrograph for well (C–33–9)24aba1 has been obtained since September 1939 from an 8-day continuous pressure-recording gage. The other hydrographs are based upon periodic measurements of pressure head, using an adapted mercury manometer tube.[78]

Commonly, particularly during the summer months, the observation wells are found to be flowing when visited. The measurements taken during these visits are indicated by a footnote on plate 19. When a well is closed following a period of discharge the pressure will rise rapidly for a short time and then more gradually, following a recovery curve more or less comparable to that of a pumped well upon cessation of pumping. Tests made in a few wells indicate that essentially the same recovery curve is followed each time a well is closed; therefore, if a constant period of time be allowed between the closing of the well and the measurement of the pressure head, the measurements represent a more or less comparable degree of recovery. Accordingly, the practice of the Geological Survey in Utah has been to close a well 10 minutes before the measurement of pressure head, which interval is ordinarily long enough to include the period of most rapid recovery from discharge.

How long a period is required before the pressure head will approxi-

[78] Taylor, G. H., Mercury manometer pressure gage: Geol. Survey Water Resources Bull., Dec. 11, 1933, p. 45; also Apr. 10, 1936, pp. 43–47. (Processed.)

mate the nonpumping level had the well not been flowing is a problem that must be solved for each individual well, because rates of recovery have been observed to range widely even in wells of close proximity. The interval required for complete recovery of the water level in well (C–33–9)24aba1 is indicated on plate 19. About noon of September 20, 1939, this well was found flowing, and the pressure head, after the usual 10-minute interval, was measured as 5.6 feet above the measuring point. A pressure-recording gage was then installed and the well kept closed. By noon of the following day the head had increased to 9.95 feet, and during the succeeding 24 hours it rose 0.85 foot more. Thus in 48 hours after closing the well, the head rose 5.2 feet, and it appears that this rise was caused principally by the closing of the well. The continued increase in head after the 48-hour interval may likewise have been caused partly by closing the well, but the parallelism of this graph with that of well (C–33–9) 24cdd1 during this period suggests that the rise is largely due to regional recovery from summer withdrawals.

The earlier record of this well affords an interesting comparison of measurements of the water level, made following a long period when the well was closed, with measurements after a 10-minute recovery from flowing. The measurements of nonflowing level form the basis for the hydrograph (solid line). Below this line, and tied to it by vertical dashed lines, are the measurements taken when the well was found flowing. These measurements are always lower than the true nonflowing level, and they are farther from that level at certain times than at others, as indicated by the length of the dashed lines. The recovery of the water level during a 48-hour period immediately following the initial 10-minute closing interval on September 20, 1939, amounted to 5.2 feet, whereas the hydrograph indicates the recovery to have been nearly 10 feet in March 1939. Such a difference might well be expected, because the increased pressure head in March 1939 was being dissipated in part by increased flow from the well. Thus the relationship between the nonflowing level and the 10-minute recovery level seems to be that as the pressure head and rate of flow diminish, the 10-minute recovery level will more nearly approach the true water level until finally the two coincide upon cessation of flow. A hydrograph based upon the 10-minute recovery levels will therefore be lower than the true hydrograph but will not be parallel to it, for the seasonal fluctuations will have less amplitude.

The hydrographs in plate 19 are shown as solid lines only where they are based on measurements of the nonflowing level; the dashed lines mark those portions of the hydrograph based on measurements of the 10-minute recovery level and are therefore below the level that might have obtained had the well not been flowing. The hydrograph for well (C–32–8)35bcb1 is based almost entirely upon measurements of the 10-minute recovery level. Judged from the measurements of March 1939 and February 1940, when the well was found closed, the 10-minute recovery level is approximately a foot lower than the true water level. The portion of the hydrograph of this well that is based on 10-minute recovery levels probably offers a closer approximation of the changes in the regional piezometric surface than do the hydrographs of wells (C–33–8)4cdd3 or (C–33–9) 24cdd1, for instance, which are based partly on the true water levels and partly on 10-minute recovery levels.

The fluctuations of the water level shown by the hydrographs in plate 19 are due only in part to variations in discharge at the observation wells. A considerable amount of fluctuation may be ascribed to interference of adjacent wells or to regional draw-down resulting from operation of wells other than the observation wells. The fluctuations of the 10-minute recovery level in well (C-32-8)35bcb1, and of the nonflowing level in well (C-33-9)24aba1 are not caused by changes in discharge at these wells but rather by seasonal withdrawal of water from other wells. The fluctuations of water level in well (C-33-8)20aad1 may likewise be caused principally by regional draw-down rather than by discharge from the observation well, for the free flow from this well is ordinarily less than 2 gallons a minute. The effect of regional draw-down upon the water level in this well is indicated between April 6 and May 8, 1939, when the nonflowing level declined 3.6 feet, although the well remained closed the entire period, and between October 5 and November 20, 1939, when the 10-minute recovery level rose 4.1 feet, although the well was flowing. Eleven flowing wells, some discharging as much as 25 gallons a minute, are within half a mile of well (C-33-8)20aad1. Their operation during the spring and summer of 1939 is probably the chief cause of the reduction of head in the observation well.

Well (C-33-8)4cdd3 is one of six wells surrounding a small reservoir, which have a combined discharge ranging from 15 to 35 gallons a minute. Although the considerable differences between the nonflowing levels in winter and the 10-minute recovery levels in summer may be due chiefly to draw-down in the observation well, it is more likely that some of the difference is due to interference created by discharge from the other wells

Well (C-33-9)24cdd1 is controlled by a gate valve. During the summer and fall of 1938 it was allowed to flow freely, and its discharge ranged from 50 gallons a minute in August to 70 gallons a minute in November. Prior to the December 1938 measurement the well was flowing about 3 gallons a minute. From January to April 1939, inclusive, the well was closed, and during May, June, and July it was left half open so that the well discharged about 20 gallons a minute. Since July 1939 the well has been closed. This historical record aids in interpreting the hydrograph. The rather uniform rise in nonflowing level from August 1939 to April 1940 reflects the regional recovery from the heavy withdrawals of the summer of 1939. Since this well is within a mile of the edge of the irrigation-pumping district, it is likely that the low levels of 1939 were due partly to pumping. During the spring of 1939 the 10-minute recovery levels were undoubtedly somewhat lower than the nonflowing level would have been had the well been closed, but they were substantially above those of the corresponding period in 1938, when the well was discharging its full flow. The hydrograph thus offers a rough comparison between the fluctuations due to regional draw-down, in 1939 and 1940, and those due to regional draw-down plus draw-down in the observation well, in 1938. From the hydrograph it also is evident that the 10-minute recovery levels do not afford even an approximation of the changes in nonflowing level unless the rate of discharge is held constant, or unless the well is permitted to flow freely at all times.

FLUCTUATIONS RELATED TO PUMPING FROM IRRIGATION WELLS

In recent years 25 to 30 wells in Parowan Valley have been pumped for irrigation, practically all of which are on the lower part of the alluvial fan of Parowan Creek, in an area about 5 miles long and 2 miles wide, north and northwest of Parowan. This area is lower on the fan than the land irrigated by surface water, and hence the wells in Parowan Valley, unlike those in Cedar City Valley, do not ordinarily serve to supplement surface supplies. Since the well owners are almost entirely dependent upon ground water for irrigation, the length of the pumping season and the quantity of water pumped do not vary from year to year to such an extent as in Cedar City Valley, where the quantity of available runoff is an important factor in determining how much ground water shall be withdrawn.

The hydrographs of four wells located along a north-south line through the pumping district are assembled in plate 20. Well (C–34–9)3cba2 is just beyond the area of artesian flow and is in the district of most intensive pumping for irrigation. The fluctuations of the water level in this well are strikingly similar to those in well (C–35–11)8cdd1 (compare pl. 12 and fig. 6), and are ascribed to the same conditions: The pressure effects of pumping from artesian aquifers encountered in nearby wells. The smaller fluctuations in well (C–34–9)3cba2 probably are caused chiefly by pumping from irrigation well (C–34–9)3bcd1, 900 feet to the northeast, whereas the major seasonal draw-down and recovery are regional. Similar pressure effects are to be anticipated in most of the wells located in and near the pumping district in Parowan Valley, for of the 28 wells pumped for irrigation in 1939, 17 flowed during the following spring, and it is obvious that the ground water throughout most of the district is confined under artesian pressure. Pumping from these aquifers causes changes similar to those already described in artesian wells in Cedar City Valley. (See pp. 72–76.)

Well (C–34–9)10bdd1, the southernmost of the four, is one of the highest on the Parowan Creek alluvial fan and is situated half a mile south of the highest irrigation well. The water level in this well is ordinarily highest in April, just before the beginning of the pumping season, and lowest in July or August. The annual range of fluctuation may be as much as 8 feet. During the nonpumping season, October to April, the hydrograph of this well parallels that of well (C–34–9)3cba2. During the pumping season, also, the fluctuations in the two wells are of the same type, as shown best by comparison of the hydrograph of well (C–34–9) 10bdd1 in April and May 1940, when a recording gage was operated, with that of well (C–34–9)3cba2 in previous years. These fluctuations, attributed to changes in pressure head occasioned by pumping, have considerably less magnitude in well (C–34–9)10bdd1, no doubt because the well is more remote from any pumped irrigation well. Well (C–34–9)10bdd1 is considered to be an excellent well for the recording of changes of storage in the Parowan Creek alluvial fan, for the fluctuations occasioned by these changes are accompanied by a minimum amount of the pressure effects of the pumping farther down the slopes of the fan.

The hydrograph of well (C–33–9)34cbd2 shows considerably larger seasonal fluctuations than in the other three wells, primarily because of the pumping in irrigation well (C–33–9)34cbd1, only 3 feet away. The cone of depression formed by this irrigation well commonly does not disappear until 4 or 5 months after pumping ceases. This slow recovery is in striking contrast to the usual recovery shown in artesian wells when pumping ceases, as typified by well (C–34–9)3cba2.

Well (C–33–9)28abd1 is more than three-quarters of a mile north of the nearest irrigation well, and considerably farther than that from the area most heavily pumped for irrigation. This well has sufficient artesian pressure to flow throughout the greater part of the year, and the only wells within a half a mile are four flowing wells similar to it. The hydrograph of the well is quite similar to those shown in plate 19, illustrating the fluctuations due to artesian flow. The 10-minute recovery levels, marked by footnote, are clearly below the hydrograph as defined by the measurements of the nonflowing level. Indeed, the fluctuations in this well might be attributed entirely to the discharge from this and nearby artesian wells, were it not for one distinctive feature.

Each summer, at least for the past 3 years, well (C-33-9)28abd1 has ceased to flow, and so have all the other artesian wells lying between it and the pumping district, including the four that are situated within half a mile of the observation well. The lowering of pressure head in this area, although of course hastened by flow from the wells themselves, is inferred to be due primarily to pumping in the area farther south. Thus these wells, although they are beyond the limit of the pumping district, are still within the area of influence of that district. The hydrographs in plate 20 are plotted with respect to sea-level elevation, and the nonflowing level in well (C-33-9)28abd1 is shown to be persistently above that in well (C-33-9)34cbd2 farther south. The southward gradient is much accentuated during the summer by the pumping from well (C-33-9)34cbd1 and adjacent wells, but even during the nonpumping season the gradient counter to the general slope of the land surface—that is, the alluvial fan of Parowan Creek—is maintained.

OTHER FLUCTUATIONS

The fluctuations so far considered have all been the result of the ground-water developments that have been made in Parowan Valley. Throughout a large part of the valley these fluctuations overshadow all other types of fluctuations. Within the area of artesian flow, as delimited on plate 25, the pressure effects of changing discharge from flowing wells are so prominent that fluctuations due to other causes may not be distinguishable. And throughout the irrigation pumping district and a rather broad contiguous area the pressure effects of pumping are so great as to mask the fluctuations due to other causes during the pumping season.

Minor changes—changes in water level in response to barometric fluctuations or to seismic disturbances—are distinguishable in those wells upon which recording gages have been maintained, particularly during the winter and early in spring, when pressure effects of well discharge are at a minimum. Barometric fluctuations are evident in plate 19 (well (C-33-9)24aba1) and in plate 20 (well (C-34-9)3cba2). They are comparable to those observed in wells in Cedar City Valley (pp. 82 to 84), and a detailed discussion is not warranted here.

As in wells in Cedar City Valley, fluctuations of water level due to recharge from surface water and those caused by transpiration and evaporation might be expected in wells in Parowan Valley. Such fluctuations, however, especially those caused by evaporation and transpiration, would probably not be discerned in wells where pressure effects of withdrawal of water are prominent, and hence the wells remote from these withdrawals are most likely to show such fluctuations. The hydrographs of six wells that are remote from areas of intensive ground-water development are assembled in plate 21.

Well (C-32-8)1ada1 is on the alluvial fan of Fremont Wash, the ephemeral stream that enters Parowan Valley from its northeast end and whose course is followed by United States Highway 91 as it enters the valley from the north. During the period of record the water level in this well has remained almost constant, and the hydrograph suggests that there was no recharge wave of any significance down this wash during 1940.

Well (C-34-8)5bca1, near Paragonah, on the alluvial fan of Red Creek, is more than a mile distant from any other well and is about 1½ miles east of the nearest irrigation well. The annual fluctuation of water level in this well seems to record the wave of recharge from Red Creek, with a moderate rise in water level during the early spring months, a high point in April, May, or June when stream runoff is greatest, and a more gradual descent during the ensuing months.

The next hydrograph in plate 21 represents a well on the alluvial fan of Parowan Creek, but nearly 2½ miles distant from the nearest irrigation well. Well (C–34–9)22acd1 is on the southwest slope of the fan, so near to the edge of the valley that the well log indicates black rock, gravel, and boulders below a depth of 6 feet, which are probably derived from the volcanic materials that crop out about 300 feet to the south. In this well the gradual rise of water level from January to April or May is probably attributable in part to recharge from Parowan Creek and in part to a regional recovery of the ground-water surface after summer withdrawals cease from wells lower on the fan. The rather pronounced decline during the summer, and particularly the troughlike indentation (shaded) in the otherwise smooth graph outlined by the measurements of May 23 to October 25, 1939, appear to be very much like the pressure effects of pumping, even though the pumping district is more than 2½ miles to the north.

Well (C–34–9)16cdd1 is 1½ miles from the nearest irrigation wells, and thus is considerably closer to the pumping district than is well (C–34–9)22acd1. The water level in this well, however, fluctuates through a range of only 1 to 3 feet in a year, whereas in well (C–34–9)22acd1 the range may exceed 5 feet. The possible pressure effects of pumping upon the water level in this well in 1939 (shaded) are clearly much smaller than in well (C–34–9)22acd1, although they operate through slightly more than half the distance. The dominant feature shown by the hydrograph of well (C–34–9)16cdd1 is the sharp rise in water level during the winter and early in spring culminating in a peak in April or May. This rise was clearly much greater in 1939 than in 1940, and probably reflects the greater runoff in that year. The source of this recharge to the vicinity of well (C–34–9)16cdd1 is not known. One of the principal ditches leading from Parowan Creek diverts water through the south edge of the town of Parowan and thence westward to the vicinity of this well. Recharge may be principally from this ditch, or it may be directly from the south edge of the valley, along which a line of springs may be indicative of a surplus of water available to the ground-water reservoir. (See p. 144.)

Well (C–34–9)6bcd1 is within a quarter of a mile of the bed of Little Salt Lake. During 1938 there were no withdrawals from the well, and the principal fluctuations of water level that year appear to reflect the regional changes in head that were created by seasonal withdrawals from the artesian basin. During 1939 the well flowed for several months, and the lowering of head during the summer of that year is no doubt due in part to discharge from the well.

Well (C–34–10)24abd1 is in the southwest part of Parowan Valley about 2 miles north of the town of Summit. The very slight changes of water level in this well, from season to season and from year to year, are typical of wells in this end of the valley. The hydrograph of this well shows an annual fluctuation through a range of a foot or less, usually highest in April or May and lowest in the fall.

Ground-water draft by evaporation and transpiration may cause some fluctuation of static levels in shallow wells, particularly in the vicinity of

Little Salt Lake, where ground water is at shallow depth. Information concerning these types of fluctuations was not obtained, primarily because no shallow wells exist in this area and their importance to this report did not justify special test wells.

LONG-TERM FLUCTUATIONS

Records of water-level fluctuations have been obtained from several wells in Parowan Valley since 1935. The annual high-water levels in five of these wells are shown in figure 16. Also reproduced on this diagram is a portion of the curve showing cumulative departure from normal precipitation at Parowan (from fig. 1) so that the figure presents information analogous to that shown for Cedar City Valley in figure 14. The general upward trend of water levels during the past 5 years is remarkable because it has occurred during a period when the precipitation was consistently somewhat less than normal. At first glance this relationship appears to be in contrast with the correlation that has been shown to

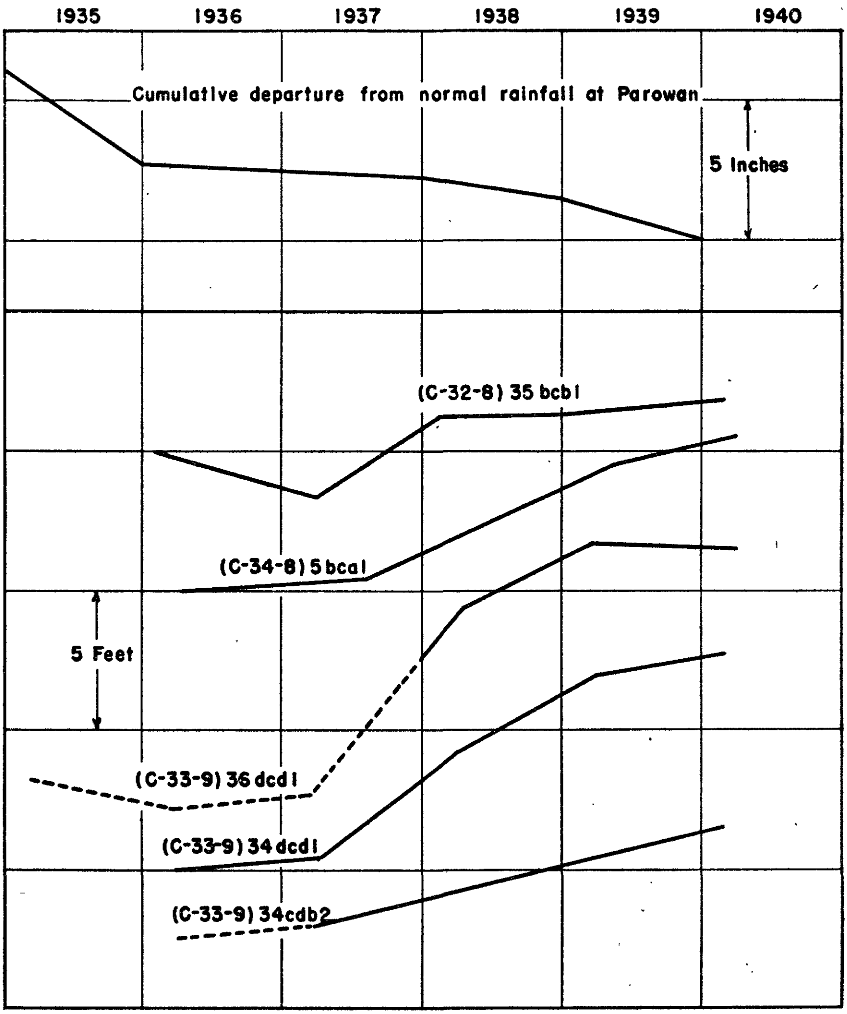

FIGURE 16.—Hydrographs showing annual high-water levels in five wells in Parowan Valley, 1935–40.

exist in Cedar City Valley between ground-water levels and the cumulative departure from normal precipitation.

The years covered by figure 16, however, follow a series of years when the precipitation at Parowan was far below normal, so that between 1927 and 1935 the accumulated deficiency amounted to more than 26 inches. Records of ground-water levels during those years are not available but, according to residents of the valley, there was a material decline in water level in wells in the pumping district and a decreased yield (suggesting a lower pressure head) from flowing wells. During the years 1936–39 the average annual precipitation, although slightly below the 34-year normal, was considerably greater than that during the preceding years. In detail, the diagram shows 2 years (1936 and 1937) when the rainfall was practically normal, following an extended period of drought. At the end of these 2 years the water level in all five wells was substantially higher than it had been at the end of 1935. During 1938 and 1939 the precipitation became progressively less, and the rate of rise of the ground-water level also diminished. The net rise of the high-water level from 1936 to 1940 ranged from 1.8 feet in well (C–32–8)35bcb1 to about 9 feet in well (C–33–9)36dcd1. This general rise of water level during years when precipitation was slightly less than normal is suggestive that the present ground-water withdrawals are somewhat less than the normal recharge to the ground-water reservoir. (See p. 164.)

The upward trend of water levels in many wells during years of subnormal precipitation is probably due in large part to increasing control of the flowing wells in the valley since the passage of the Utah State ground-water law in 1935. A large number of wells flowed continuously prior to that year. Under the able administration of the State Engineer, the number of uncontrolled wells has decreased each year. In March 1940, 230 of the artesian wells were closed by cap, plug, or valve, and only 23 of the wells capable of control were found flowing, of which several had been closed earlier in the winter. (See p. 176.) The rise of water levels within the area of artesian flow is not entirely due to an increase in storage, because many of the observation wells are within the area of influence of flowing wells that have been brought under control since 1935. The higher level in the observation wells would thus be due in part to pressure-recovery effects occasioned by closing the well. For example, the water level in well (C–32–8)35bcb1 was considerably lower in 1937 than in 1936 or 1938 (fig. 16), and this lower level is evidently due to loss in head caused by discharge from a well in 1937 that was closed in 1936 and 1938. Nevertheless, so widespread have been the rises of ground-water level in Parowan Valley, as shown by observations in wells distributed throughout the valley, it is certain that a considerable increase in ground-water storage has occurred during the past 4 years.

The annual high-water level in well (C–33–9)34cdb2 rose at a fairly uniform rate of about 1 foot a year between 1936 and 1940, and its hydrograph is therefore rather distinct from the others shown on figure 16. As is described in more detail on page 155, the ground water in the vicinity of this well has evidently moved across the Culver fault, which forms a formidable barrier to the free circulation of water. This barrier is evidently capable of damping the effects of changes in storage east of the fault to such an extent that these changes are hardly noticeable west of the fault.

PIEZOMETRIC SURFACES

The great majority of wells in Parowan Valley reach water that is confined under artesian pressure. About three-fourths of the wells in the valley overflowed during at least a part of 1940, several others are reported to have flowed in earlier years, and a large proportion of the remainder are deep enough that they undoubtedly tap artesian aquifers. On the other hand, only five wells in the valley are shallow dug wells which would unquestionably define the water table. The great preponderance of information obtainable from wells therefore applies to the artesian-pressure surfaces in the valley, and information as to shallow water is so scant that practically nothing is known as to the position or extent of the water table.

The artesian-pressure surfaces that are described in the following pages do not conform to the accepted definition of piezometric surfaces, and these surfaces are therefore introduced here with a short explanation of the methods used in deriving them. For any piezometric surface usually described as such, an aquifer is postulated which shall give rise to that surface. In Parowan Valley, however, one is confronted by an almost complete absence of information concerning the aquifers within the valley fill. It seems evident that there are many; they are probably discontinuous, generally lenticular and elongated, and may range widely in thickness and permeability, as is common in alluvial materials. But the few available well logs have been shown (p. 47) to furnish no basis for correlation of the water-bearing strata. Practically no records were kept of the construction of wells in the valley, and it is doubtful whether the reported depths (see table, p. 177) are even approximately correct for more than 10 percent of the wells. For about half the wells information as to depth is entirely lacking.[79] Clearly there are no data from which one might outline the individual aquifers and then derive the piezometric surfaces of these aquifers.

Accordingly, the piezometric surfaces discussed in the following pages have been derived without the benefit of knowledge of the aquifer or aquifers to which they pertain. During March and April 1940 measurements of water level were made by the State Engineer and the Geological Survey in 215 of the 392 listed wells in Parowan Valley. These measurements appear in the table of well records (p. 177), and the highest and lowest artesian-pressure surfaces, shown in Plate 22, are based on them. Although these surfaces do not pertain to any particular aquifer in the valley, it can be stated with reasonable assurance that the piezometric surface of any developed aquifer in the valley probably lies somewhere within the limits set by these two surfaces.

In several parts of Parowan Valley the high and low artesian-pressure surfaces are shown as merging. In some areas this apparent merging may result merely from insufficient data to define two separate surfaces; elsewhere the merging may be indicative that there is practically no differential head between wells that tap different aquifers. The measurements in 76 wells were used to derive the highest artesian-pressure surface, and the lowest surface was indicated by the levels in 86 wells, of which 26 de-

[79] Because of the paucity of information concerning the aquifers in Parowan Valley, measurement of depth of all wells there was considered for a time. It is likely, however, that many of those measurements would have indicated less than the true depth, for the following reasons: (1) Many wells are probably not cased throughout and so have caved somewhat; (2) the partial filling or sanding even of completely cased wells is not uncommon in this and other areas; (3) many wells are reduced in casing diameter at some depth, and the measurement obtained might show only the depth of the larger casing; (4) the casings of some wells may have deteriorated to such an extent that plumbing lines would not be able to pass constricted zones; and (5) many wells are in the bottoms of pump pits and would be practically inaccessible for plumbing. At the time of writing only a very few wells had been subjected to measurement of depth.

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fine the common surface where the two merge. These 136 wells are indicated in the table of well records. Measurements of head in wells found flowing were ordinarily not used, because, as shown on page 146, the 10-minute recovery level is commonly considerably lower than the water level would have been had there been no flow. The same 136 wells were used to derive analogous artesian-pressure surfaces in September 1940. (See pl. 23.)

It might be presumed that deep aquifers would define the highest artesian-pressure surface, and shallow aquifers the lowest surface. In substantiation of this many of the reportedly deep wells mark the highest surface, and many of the wells forming the lowest surface are shallow. If the true depths of these wells can eventually be measured, the correlation between depth of well and position of nonpumping or nonflowing level may be better shown. It is almost certain that the highest piezometric surface throughout the valley as a whole is not based on data from wells of equivalent or even comparable depths, because the surface of necessity must be defined by the developed aquifers, and present developments reach considerably greater depths in certain parts of the valley, notably in the pumping district. The chief objection to the scientific use of a composite surface of this type is considered to be this unavoidable tie to the present stage of development.

The lowest artesian-pressure surface is of course admitted to have the same handicap in being linked with the present ground-water development, so that the surface as shown may be of doubtful value. In a body of sediments as heterogeneous as the Parowan Valley fill it would seem that there should be piezometric surfaces at levels ranging all the way from the highest artesian-pressure surface down to the normal-pressure surface or water table. The surface depicted on plate 22 is therefore by no means the lowest artesian-pressure surface, but is more likely the lowest artesian surface that would produce flowing wells satisfactory to the land owners.

The lowest pressure surface, as shown on plate 22, has other objectionable features which render it of less scientific value than the highest pressure surface. The water levels in certain wells that were used in deriving this surface may not represent the true nonpumping level, because the well has partially caved or been plugged so that some of the head is lost. Or certain wells may be within the area of influence of some flowing wells, so that the water level is low because of the interference of these adjacent wells. For many wells, particularly those with casings that discharge into dug pits, part of the artesian head of deeper aquifers is probably dissipated by seepage into the shallow strata that form the walls of the pit. Because of the many uncertainties in the interpretation of the data as to lowest artesian-pressure surface, the highest artesian-pressure surface forms the principal basis for the conclusions of this report, and the lowest surface is used only for comparative purposes.

HIGHEST ARTESIAN-PRESSURE SURFACE IN 1940

FORM IN MARCH

Every effort was made to obtain the position of the water level in wells in Parowan Valley when ground-water discharge was lowest, so that losses in head due to discharge would be at a minimum. Accordingly, the time chosen for these measurements was late in March, after several months of recovery from the 1939 irrigation season and just prior to the date, April 1, set by the State Engineer as the beginning of the 1940 season. Even so, a considerable number of wells were found flowing, including some that had been open intermittently throughout the winter, evidently for stock watering; some that had been opened a few days before the authorized date; and 46 wells which could not be shut in. Some of the minor irregularities shown by certain contours, as the 5,750-foot contour in sec. 35, T. 33 S., R. 9 W., are likely due to discharge from flowing wells during the period when observations were made.

In general the slope of the highest piezometric surface is downward toward the lowest part of the valley, occupied by Little Salt Lake. To some extent the form of this surface follows the pattern of the land surface, particularly under the alluvial fans that form the east border of the valley northward from Paragonah. Here the piezometric surface rises toward the apex of each fan, with probably a lesser gradient than that of the land surface.

On the Parowan Creek alluvial fan, however, the form of the highest piezometric surface does not even approximate that of the land surface. So far as can be learned from existing wells, the gradient of the water surface southeast from the Culver fault is extraordinarily flat. There are no wells near the apex of the fan, and this gradient is of necessity established on the basis of nonpumping levels observed in four or five wells, particularly wells (C-34-9)2ccc1, (C-34-9)9dbc1, (C-34-9)10bdd1, and (C-34-9)22acd1. The flat gradient of the water surface under the Parowan Creek alluvial fan may well be analogous to that of Coal Creek in Cedar City Valley and to others in desert areas already mentioned. (See p. 95.) The surface indicated on plate 22, however, is exceptionally flat and the number of observation wells is so small that the accuracy of the map for the upper part of the Parowan Creek fan is subject to question.

Ground-water dams form a conspicuous feature of the highest piezometric surface as shown in plate 22. Most prominent is the one along the Culver fault from its junction with the Summit Creek fault northeast for about 3 miles. For a considerable part of this distance the piezometric surface in March 1940 was more than 40 feet lower on the west side of the fault than on the east side. The ground-water dam is not clearly shown northeast of sec. 26, T. 33 S., R. 9 W., perhaps because there are no wells within half a mile west of the fault. Another ground-water dam is formed by the Parowan fault, and is shown best by wells about 2 miles west of the town of Paragonah, where the dam is more than 10 feet high.

West of the Culver fault the form of the highest piezometric surface is complex, evidently governed by a variety of factors. Northeast of Little Salt Lake the 5,730- and 5,740-foot ground-water contours turn westward, and it is inferred that the piezometric surface slopes toward Little Salt Lake from the mountains that lie west of it, and that therefore the piezometric surface has a basinlike form with the lowest point near Parowan Gap, more or less similar to the topographic surface.

In the SE¼ of T. 33 S., R. 9 W., the 5,730- and 5,740-foot contours are broadly arcuate, and in the NW¼ of T. 34 S., R. 9 W., the 5,710- and 5,720-foot contours appear to outline a similar form. Between these two areas the piezometric surface is relatively depressed, and this depressed area is bounded by the ground-water dam along the Culver fault and perhaps by a similar dam along the Summit Creek fault, although hydrologic data are insufficient to prove the existence of a dam along this fault. It is the extraordinarily steep slope of the piezometric surface west of the Culver fault and the depressed area beyond that serve to distinguish the ground-water contours on the Parowan Creek fan from those on the other fans in Parowan Valley. These irregularities are believed to have been caused by pumping in an area where the recharge is limited because of the barriers that have been developed by faulting. The piezometric surface on the Parowan Creek fan may be imagined as it might have been if not modified by pumping—a broadly convex surface of which the contours mentioned above would be remnants along the outer edges of the fan. Pumping from wells in the wedge between the Culver and Summit Creek faults has lowered ground-water levels, and recharge to this area during the 6 or 7 months since the cessation of pumping in 1939 has been restricted to such an extent that it is inadequate to conceal or counteract the effects of this pumping.

Only four wells have been constructed in the southern two-thirds of T. 34 S., R. 9 W., which includes the southwest part of the Parowan Creek fan, west of Parowan. The data from these wells are entirely inadequate to show the ground-water conditions over this extensive area, although the water levels suggest that the water surface may have irregularities, perhaps due to faulting. Thus, on March 30, 1940, the water level in well (C-34-9)16cdd1 was 8.3 feet lower than that in well (C-34-9)21bad1, a quarter of a mile to the south. The two wells are reported to be of the same depth and to penetrate 70 feet or more below water level, so that it is unlikely that either well taps a perched zone.

SEASONAL CHANGES

The position and form of the piezometric surfaces for artesian aquifers in Parowan Valley change constantly in response to the forces that induce fluctuations of water level in wells. It has been shown that the fluctuations caused by variations in discharge from wells, whether by pumping or by natural flow, are especially prominent in the great majority of wells in the valley. In consequence the seasonal changes of the piezometric surfaces are very largely resultant from the seasonal changes in ground-water draft, and in practically all wells the water level reaches its annual high stage just before the beginning of the irrigation season, declines during the spring and summer, and reaches a low point for the year toward the end of the irrigation season. Thus the highest artesian-pressure surface in March, shown on plate 22, represents approximately the highest water level reached during 1940. For comparison, plate 33 shows an artesian-pressure surface in September based upon observations in the same wells that were used to define the highest artesian-pressure surface in March. These two figures thus represent approximately the high and low positions of the highest piezometric surface during 1940.

Information concerning artesian pressures in September is less abundant and less substantial than that collected in March. A large number of the observation wells used in March were found flowing or pumping during September, and of course could not be used because the nonpumping or nonflowing level could not be determined. Of the observation wells that were not discharging in September, many were undoubtedly within the area of influence of one or more wells that were flowing or were being pumped, and available data were generally not sufficient to show to what extent the position of the water level was determined by local conditions. Accordingly the diagram is of necessity an interpretative sketch of the probable position of the highest piezometric surface, rather than a portrayal based upon complete and conclusive data.

In the outlying districts of Parowan Valley the water levels in wells were not much lower in September than in March, except where the observation wells were close enough to discharging wells that pronounced pressure effects could be noted. East of the Parowan fault, from Paragonah to the north end of the valley, the water levels in the supposedly deep wells that define the highest pressure surface in March were ordinarily not more than 3 feet lower in September than in March. In the few wells on the west side of Parowan Valley north of Little Salt Lake there was a comparable decline of water levels, and toward the south end of the valley there was a similar moderate decline. In wells in the vicinity of Summit and of Parowan Gap the water level dropped not more than 2½ feet between March and September.

The principal changes in position of the ground-water contours between March and September were of course in and adjacent to the irrigation-pumping district. Pumping caused a general lowering of water levels throughout the Parowan Creek alluvial fan, upon which practically all the irrigation pumps are located. On this fan, even in the wells most remote from the pumping district the water levels were lowered 4 feet or more. Pumping in the southeast corner of T. 33 S., R. 9 W., served to accentuate a valley on the piezometric surface that was vaguely suggested by the 5,760-foot contour in March. Pumping in this area also increased the height of the ground-water dam along the Parowan fault, which lies entirely east of the pumping district. Water levels in wells west of the fault were lowered 8 feet or more, whereas the capped artesian wells east of the fault had a head ordinarily only 1 or 2 feet lower in September than in March.

The change of position of the highest piezometric surface in the vicinity of the Culver fault is especially remarkable, because the ground-water dam along that fault was even higher in September than in March, although the major ground-water development for irrigation is east of the fault. Of 29 irrigation wells located on the Parowan Creek fan and pumped during 1940, 24 are east of the Culver fault, and 14 of these are within half a mile east of the fault. The rate of discharge of the 14 wells alone is estimated to have been about 1½ times the rate of discharge of the five wells west of the fault. Yet the piezometric surface was lowered considerably more by pumping west than east of the fault. Thus, in September even more than in March, the Culver fault stands out as one of the major structural features controlling ground-water circulation in Parowan Valley.

The decline of ground-water levels in and adjacent to the pumping district of Parowan Valley during the irrigation season of 1940 is shown on plate 24. The lines of equal decline of water level are necessarily quite generalized, and they depict a surface considerably smoother and more regular than the actual piezometric surface during the pumping season, for no attempt has been made to show the cones of depression of the individual pumped wells. Data were insufficient to permit bounding the area in which the water levels declined 5 feet or more; it is presumed that the line of 5-foot decline would be more or less parallel to the 10-foot contour, probably within a quarter of a mile to the west, and perhaps a mile or more distant on the south and east. There is no evidence that the seasonal decline of water levels has exceeded 5 feet in any other part of Parowan Valley, except locally as the result of interference by adjacent wells.

Water levels have declined 10 feet or more over an area of about 15 square miles, which includes practically the entire district on the Parowan Creek fan in which wells are pumped for irrigation, plus a marginal area that ranges in width from half a mile to 2 miles. The portion of this area in which the water levels have declined most lies west of the Culver fault, and this greater decline is of course responsible for the increased height of the ground-water dam along the fault during the irrigation season. In the part of the pumping district east of the Culver fault the water levels have ordinarily been lowered less than 15 feet, except in the most intensively pumped area in secs. 34 and 35, T. 33 S., R. 9 W., where the decline locally may exceed 20 feet.

Comparison of plate 24 with a corresponding diagram for Cedar City Valley (pl. 15) brings out some rather distinctive features concerning the ground water in the two valleys. The maximum decline in Parowan Valley is of course considerably greater than that in Cedar City Valley, and the area in which the decline exceeded 10 feet is considerably larger. But the decline of water levels on opposite sides of the Stockyards fault (p. 90) is more or less analogous to the condition in Parowan Valley on opposite sides of the Culver fault; in both areas the lowering of the water levels on opposite sides of the fault is out of proportion to the quantities of water withdrawn. In both valleys the faulting has quite evidently interposed a barrier to the free circulation of ground water, and hence water is replenished more readily on one side of the fault than on the other. This restriction of recharge is primarily responsible for the limited development on one side of the fault.

POSITION WITH RESPECT TO LAND SURFACE

The area in which ground water has been developed in Parowan Valley includes a large central area in which wells obtain water that flows under artesian pressure. This area varies considerably in size in the course of a single year, being ordinarily largest early in the spring and smallest in late summer, near the end of the irrigation season. Surrounding this area of artesian flow are the steeply sloping fans of the several streams that enter the valley, in which ground water occurs at some depth below the surface. Only on the alluvial fan of Parowan Creek has there been any considerable development of ground water outside the area of artesian flow, and it must be assumed that the relationships of the piezometric surface to the topographic surface of the other fans are more or less analogous to those that are seen to exist on that fan. The position of the highest piezometric surface with respect to the land surface is shown on plate 25.

The area of artesian flow during March 1940 was a rudely triangular area about 15 miles long and nearly 5 miles wide near Paragonah. The northwest boundary and the east boundary are shown as fairly straight regular lines, but this regularity may be due chiefly to insufficiency of data, for very few wells are in the vicinity of those boundaries. The south boundary, extending from Parowan Gap eastward toward Paragonah, is a very irregular line, whose position is determined within rather narrow limits by a large number of wells.

The principal irregularities of the south boundary are evidently caused by faulting. The ground-water dam along the Culver fault is indicated on this map by the long narrow prong of the area of artesian flow that projects southwestward for about 3 miles along the east side of the fault and by the area west of the fault in which the piezometric surface may be as much as 20 feet below the land surface. The effect of the Parowan fault, though less marked, is also suggested. The embayment just west of Paragonah does not conform to any physiographic feature, but is due to the higher position of the piezometric surface east of the ground-water dam along the Parowan fault than west of that fault. The irregularities in the boundary of the area of artesian flow near the Little Salt Lake fault reflect principally the irregularity of land surface, which here shows the effect of recent displacement along the fault. (See p. 54.) The data upon which this map is based do not indicate whether or not there is also some irregularity of the piezometric surface along the trace of the fault.

The gradient of the Parowan Creek alluvial fan is about 50 feet in a mile throughout the irrigation pumping district, which is about 3 miles north and northwest of the town of Parowan; toward the apex of the fan, of course, the gradient increases, so that in Parowan the slope is more nearly 100 feet per mile. The water levels in wells on the upper part of this fan, above the area of artesian flow, appear to define a piezometric surface which, as suggested by plate 22, has a gradient far less than that of the land surface, so that in March 1940 at a distance of a mile from the edge of the area of artesian flow the ground-water surface was 40 to 60 feet beneath the land surface.

The area of artesian flow diminished considerably during the spring and summer of 1940. The north and east boundaries of the area were very little changed, but the south boundary by September had been shifted as much as 3 miles north from its position in March. East of the Culver fault the boundary had been shifted less than a mile northward, but the prong that extended into sec. 8, T. 34 S., R. 9 W., had disappeared. The area in which wells stopped flowing between March and September includes the irrigation-pumping district and an additional marginal area about half a mile wide, and this cessation of flow was undoubtedly the result of loss in head due to the pumping.

On the west side of the Culver fault the area of artesian flow had shrunk markedly, and by September no wells west of the center of R. 9 W. were flowing. The loss in pressure head in this area was evidently caused also by pumping. Since only five irrigation wells are operated west of the Culver fault, it appears that the pumping from these few wells affects a relatively much greater area than an equivalent amount of pumping east of the fault. This indicates aquifers with a considerably lower coefficient of transmissibility on the west side of the Culver fault and less opportunity for recharge to reach this area.

The relation of the highest piezometric surface to the land surface is also shown by the profiles of plate 26. The line of this profile is east-west across the northern part of the alluvial fan of Parowan Creek. Each of the principal faults that have displaced the alluvium in the valley cuts across the line of this profile. As shown in plate 26, the piezometric surface is fairly smooth and regular in the intervals between these faults, but has an abrupt change of slope especially in the vicinity of the Culver and Parowan faults and perhaps also along the Little Salt Lake fault. No appreciable change of slope is indicated along the Summit Creek fault, because the position of the piezometric surface within a mile east of the fault is unknown. These steep gradients in the vicinities of the principal faults represent in cross section the ground-water dams described above.

The wells east of the Parowan fault are not along the line of the profile. It is evident from the contour map (plate 22) that the slope of the piezometric surface westward, along the line of the profile, would be somewhat less than that shown between wells. Thus the actual height of the ground-water dam caused by the Parowan fault is probably greater than the 9 feet indicated in the profile.

LOWEST ARTESIAN-PRESSURE SURFACE IN 1940

FORM IN MARCH

The lowest artesian-pressure surface is mapped only where the available hydrologic data show an appreciable differential head between wells of varying depths. In certain parts of Parowan Valley the highest and lowest artesian-pressure surfaces cannot be discriminated because the wells are too few to indicate the amount of differential head, if any, between aquifers at varying depths beneath the surface. This is particularly true of that part of the valley west of the Culver fault, and of the north end of the valley in the vicinity of Buckhorn. A single piezometric surface is shown in those areas, but it should not be inferred that there is no differential head between aquifers, for those areas include some of the lowest parts of the valley, where artesian pressures and flowing wells are the rule.

In its major features the lowest artesian-pressure surface is similar to the highest surface (pl. 22). The general slope is toward the lowest part of Parowan Valley, and therefore northwesterly from the east edge and southeasterly from the west border of the valley. The Culver fault, certainly, and the Parowan fault, probably, create ground-water dams along this lowest piezometric surface analogous to those shown on the highest surface.

The closed 5,720-foot contour near the northeast end of Little Salt Lake is a feature of the lowest artesian-pressure surface whose existence is not very well supported by evidence. In only two wells in this area are the water levels below 5,720 feet, and these levels may be lower than the true nonflowing level, for one of the reasons listed on page 154. However, in several wells in the vicinity the observed water levels were very little above 5,720 feet, and the generally higher levels farther southwest offer at least a suggestion that there is a closed depression there on the lowest pressure surface. A depression there is plausible, for the shallow aquifers farther southwest are closer to the apex of the fan of Parowan Creek and may receive recharge earlier and to a greater extent from that direction than do the beds within the area of the depression contour. The depression on the piezometric surface created by this recharge farther southwest would disappear if time were allowed for equilibrium to be established by reason of movement of ground water from the north and east as well as from the southwest.

The separation of the highest and lowest artesian-pressure surfaces is most marked—in other words, the differential head between adjacent wells is greatest—in the area north and west of Paragonah, which includes the alluvial fans of Red and Little Creeks. In that area the differential head between wells of different depths may exceed 20 feet, and is commonly more than 10 feet. [80] Also, it should be noted that the contours on the lowest surface do not conform to the pattern of the highest surface, which has a slight bulge over the fans of Red Creek and Little Creek. The absence of a comparable bulge on the lowest surface is attributed to loss in head through discharge from the shallower aquifers via the numerous springs that rise along the line of the Parowan fault and farther west, particularly in secs. 8 and 17, T. 33 S., R. 8 W. Those springs were flowing during March, when the measurements of water level in wells were made. In summer, when most of the artesian wells are open, the major-

[80] These differential heads are shown by comparisons of nonflowing levels in wells used to define the highest surface and the lowest surface, footnoted respectively [7] and [8] in the table on pp. 177–187. Thus the differential head between wells (C-33-8)18abc2 and 18acb1 is 20.3 feet, and that between wells (C-33-8)19ddd 2 and 19ddd3 is 12.1 feet.

ity of the springs cease flowing, and thus the artesian aquifers are indicated to be the source of the spring water.

SEASONAL CHANGES

Seasonal changes in the position of the lowest surface are more or less comparable to those of the highest pressure surface (p. 156) with, however, some pronounced local differences that are ascribed to differences in amount of withdrawal from the deep and shallow aquifers. In the irrigation pumping district the decline of water levels in shallow wells is generally of the same order of magnitude as that measured in adjacent deeper wells, probably as a result of the common practice in Parowan Valley of perforating the casings of irrigation wells opposite all permeable strata, so that aquifers of all depths may contribute to the quantity pumped. The amount contributed by individual aquifers tapped by those wells is indeterminable, but the relative draft may be surmised roughly by comparison of the decline of water levels in adjacent deep and shallow wells.

Throughout most of the pumping district the seasonal decline of water level in deep wells is somewhat greater than that in adjacent shallow wells, as is suggested in the table below. Greater draft upon the deeper aquifers might well be expected, for the 28 irrigation wells pumped in 1940 on the Parowan Creek fan have an average depth of about 480 feet, and only two are less than 350 feet deep. On the other hand, near the south end of the pumping district the decline of head in the presumed shallow strata is greater than in the deeper strata, as shown by the last two pairs of wells listed. The only irrigation wells having a reported depth of less than 350 feet are in this southern part of the pumping district. The other irrigation wells in sec. 9, T. 34 S., R. 9 W., may also draw water from shallow aquifers, for the owners concede that there are no records as to the actual depths of the wells and that the reported depths are mere guesses.

Decline of nonpumping level in pairs of presumed deep and shallow wells in the Parowan Valley pumping district from March to September 1940

Deep (?) wells			Shallow (?) wells		
Well number	Reported depth (feet)	Decline of water level (feet)	Well number	Reported depth (feet)	Decline of water level (feet)
(C-33-9)24ccc1		19.3	(C-33-9)23ddd1		17.1
(C-33-9)26aad2	270	18.3	(C-33-9)26cac1	133	11.5
(C-33-9)32ddd1		27.4	(C-33-9)32dcd3		13.5
(C-33-9)34aad3	300	19.6	(C-33-9)34aad5		17.3
(C-33-9)35bbc3	300	23.2	(C-33-9)35bbd1		13
(C-34-9)3cbc2		12.1	(C-34-9)3cbc1		8.5
(C-34-9)4dcd2		13.9	(C-34-9)4dcd1	144	6.8
(C-34-9)6dbd1	356	6	(C-34-9)6bcd1	81	1.7
(C-34-9)8add1		11.7	(C-34-9)8add2		22.1
(C-34-9)9bcc4		11	(C-34-9)9bcc3		26.8

WATER TABLE IN 1940

The artesian conditions which have given rise to the large number of flowing wells in Parowan Valley are inferred to exist over only a part, although a large part, of the valley. In the direction of the apexes of the principal fans the alluvial sediments become coarser, and quite likely there is progressively increasing permeability of those strata which lower on the fans form the confining layers and thus are primarily responsible for the artesian conditions. Near the apex of each fan there is probably free circulation of ground water, and therefore essentially water-table conditions. Where the ground water is unconfined there should be no differential head between wells of different depths, a condition which obtains over the upper part of the Coal Creek alluvial fan in Cedar City Valley. (See p. 97.)

In Parowan Valley the differential head between deep and shallow wells becomes less in the direction of the apex of the Parowan Creek fan. (See table, pp. 177 to 187.) The wells on the upper part of the fan, however, are too few to show whether the water there is unconfined. On the other hand, the pressure effects observed in some of the highest wells, and inferred to be due to pumping (p. 148) are suggestive that artesian conditions may exist very near the apex of the fan. Certainly it appears from available data that a very large proportion of the water in the Parowan Valley ground-water reservoir is confined under artesian pressure.

Even in those areas where water occurs under artesian pressure there probably is ground water above the confining beds that overlie the artesian aquifers. This water is encountered in the few shallow wells that have been dug within the area of artesian flow in Parowan Valley. Comparison of the nonpumping level of water in those wells with that in nearby artesian wells shows the relationship of the artesian and normal-pressure surfaces in the vicinity of the wells.

Well (C-33-8)29bdd1 is a dug well, reported to be 35 feet deep. The water level in the well fluctuates annually through a range of about 3 feet, highest in July and lowest in winter, presumably in response to the downward penetration of excess irrigation water applied on the Red Creek alluvial fan. Well (C-33-8)29bdd2, 475 feet to the east, is a flowing well. In common with other artesian wells in the valley, the nonflowing level in this well is ordinarily highest during the winter, when ground-water withdrawal from wells is least, and lowest during the summer. The water level in this well in March 1940 was about 3 feet below the highest artesian-pressure surface. Observations during 1938 and 1939 indicate that the differential head between wells (C-33-8)29bdd1 and 29bdd2 ranged from about 18 feet in July to about 22 feet in January. In other words, the shallow-water level has been as much as 25 feet below the highest piezometric surface, and probably more than 15 feet below the lowest artesian-pressure surface.

Well (C-32-8)26bda2 is 200 feet deep and is one of the flowing wells used to define the highest artesian-pressure surface. Well (C-32-8)26bda1, dug about 400 feet farther east, is about 18 feet deep, and therefore no doubt shows the level of the shallow, unconfined water. The water level in the shallow well is highest during the summer, indicating that the effect of recharge probably reaches the well about that time, and declines slowly thereafter to a low level early in spring. During the spring the head of the adjacent artesian well is ordinarily greatest, and may be more than 12 feet above the water table.

Well (C-33-9)32ccd1 has a measured depth of 24 feet, and the water level fluctuates so little that it may be questioned whether the well is not insulated from the zone of saturation. Well (C-33-9)32ccd2 is reported to be 400 feet deep; it flows during the winter months, and during the past 2 years its nonpumping level has fluctuated through a range of 22 to 28 feet. The water level in this well is believed to represent the highest piezometric surface; in March 1940 it was 14 feet above that in well 32ccd1; in August 1939, however, the water level in the flowing well was about 9 feet below that in the shallow well, apparently because of pressure effects of pumping farther east. This lowering of piezometric surfaces to a level beneath that of the water table, by pumping, is believed to be a common midsummer phenomenon under the southwest part of Little Salt Lake.

The shallow water that overlies the artesian confining layers in the lower parts of Parowan Valley is presumed to be continuous with the water surface of Little Salt Lake or with the water that is encountered at depths of a few inches when the lake bed is dry. The occurrence of the shallow water is thus believed to be analogous with that in the vicinity of Rush Lake and Shurtz Lake in Cedar City Valley. (See p. 94.) Shallow bore holes on the lake bed and within a quarter of a mile east of the lake support this presumption, although levels were not run, and the shallow-water surface was not determined except by casual observation.

ANNUAL CHANGES OF PIEZOMETRIC SURFACES, 1936-39

Periodic measurements of the nonpumping or nonflowing level, or of the 10-minute recovery level, in wells in Parowan Valley were begun by the Geological Survey in 1935. During 1936 these measurements were made in six wells; the number of observation wells was increased to 12 in 1937 and to more than 30 in 1938 and 1939. A continuous water-stage recorder was maintained on well (C–34–9)3cba2 between October 1937 and March 1940 and on well (C–34–9)10bdd1 after that date. Also a pressure-recording gage has been operated on well (C–33–9)24aba1 since September 1939. In addition, hundreds of miscellaneous measurements of the water level in wells have been made by the State Engineer, chiefly during the summer of 1938. Most of them are not published but are on file in the State Engineer's office. These constitute the available records concerning ground water in Parowan Valley prior to 1940, and it is realized that they are meager, especially prior to 1938. This insufficiency must be considered in the discussion of annual changes.

These records show that there are pronounced seasonal fluctuations in practically all wells within the area of ground-water development, and that these fluctuations are principally due to reduction of artesian pressure when there is withdrawal from wells and a corresponding increase in pressure when withdrawal ceases. Because these seasonal fluctuations are caused chiefly by pressure effects rather than by saturating and unwatering of strata, they do not measure changes of ground-water storage within the reservoir.

In an artesian reservoir changes in storage occur primarily in the recharge area and are best indicated by the change in the level of the water table in that area. However, in Parowan Valley, as in many other artesian areas, the lack of wells in the recharge areas precludes obtaining adequate records of the fluctuations of the water table. Changes of storage would best be measured when artesian-pressure effects are at a minimum, namely, during the latter part of the winter, when the withdrawal from wells is least, and when the piezometric surfaces most nearly approach stability. Thus the month of March is recommended as the time of year most satisfactory for estimating ground-water supplies, and the following summary of annual changes in water levels is based on observations made in March of each year. The discussion under the section "Long-term fluctuations" (p. 151) is also pertinent to the present section.

Between March 1936 and March 1937 the general trend of water levels in Parowan Valley was downward, as is indicated by observations in four wells. Since 1937 a fairly consistent rise of water levels throughout the valley has been observed in an increasing number of wells. Thus, from 1937 to 1938 the high-water level rose in each of five observation wells, and the average rise was about 3½ feet. Records for the following year show a higher water level in each of 13 observation wells, with an average rise of about 2 feet. During 1939-40 water levels again rose, on the average about 1 foot, in 26 of 32 observation wells. The majority of observation wells used each year were among those used in 1940 to represent the highest piezometric surface, and the discussion that follows is therefore especially applicable to that surface. Some of the observation wells used each year were among those representing the lowest artesian-pressure surface. The available data are insufficient to permit comparisons of the changes in the individual piezometric surfaces from year to year, but the changes in adjacent deep and shallow wells are generally in the same direction, and there is no evidence to indicate any striking differences in the changes of the several piezometric surfaces.

In part, the rising water levels during these 3 years may be attributed to natural conditions, for the rate of precipitation since 1936 has been greater than during the 8 or 9 preceding years, and it is presumed that recharge to the valley likewise would be somewhat greater. A large amount of this rise, however, is believed to have resulted from the State Engineer's efforts to eliminate waste of ground water by closing flowing wells when not in use. (See p. 152.) The program of well control started in 1935 has achieved a greater measure of success during each succeeding year.

Only a part of the general rise in water levels since 1937 is considered to represent increases in ground-water storage. An unknown and undeterminable proportion of this rise undoubtedly has been caused by changing conditions of artesian pressure as a result of changing conditions of discharge from one year to the next. Thus, several of the observation wells are located within the area of influence of wells that were permitted to flow throughout the winters of the earlier years of the investigation and that have been controlled in later years. Water levels in these observation wells have risen primarily because of the cessation of flow in the adjacent wells, much as they rise each fall when pumping for irrigation and discharge from flowing wells cease.

Changes in ground-water storage in Parowan Valley cannot be estimated on the basis of the data cited above, because the discharge from wells, even during the season most favorable for making such estimates, has varied from year to year, and because this variation causes changes of artesian pressure in the observation wells that cannot be discriminated from changes caused by increases or decreases in storage. Furthermore, no group of key wells can be used as a basis for estimating storage in the future unless conditions of discharge during the period of observation of these wells can be duplicated in each subsequent year. As an instance, records in 1941 might be comparable with those obtained in 1940, provided the same 230 wells were capped, the same 23 wells were open and flowing, and the same 46 wells still "uncontrolled." (See p. 176.) Then the changes in water level in properly selected wells would give a reasonable approximation of the change in storage in the ground-water reservoir, or, better, if the cooperation of well owners could be obtained to the extent of eliminating all flowing-well discharge during the month of March, the observed changes in water level from year to year would indicate the changes in storage in the reservoir. It would, however, be necessary to know also the extent of the recharge area and the permeability of the zone unwatered or saturated to approximate the quantity of water involved in the change in storage.

In five of the highest observation wells on the alluvial fan of Parowan

Creek the trend of water level between March 1939 and 1940 was downward and counter to the trend in wells throughout the rest of the valley. The greatest amount of decline, about 1¼ feet, was measured in the three wells highest on the fan and therefore farthest removed from the area of artesian flow. In the other two wells, within the area of artesian flow in March, the water level declined, respectively, 0.9 and 0.5 foot. The declining trend in these wells is in accord with the trend in precipitation at Parowan—less in 1939 than in 1938. Significantly, these five wells are located on that part of the fan which might be expected to show the effects of recharge earliest, and the downward trend from 1938 to 1939, in accord with the trend of precipitation, is suggestive that these wells above the area of artesian flow may be satisfactory indicators of ground-water supply in the Parowan Creek fan.

Well (C–34–9)10bdd1, upon which an automatic water-stage recorder was maintained until March 1942, has been cited as an excellent well to show conditions in the pumping district on the Parowan Creek fan, distorted by a minimum amount of pressure effects due to variations in discharge in that district. (See p. 148.) Records from this well, supplemented by periodic measurements in several other wells above the area of artesian flow and used in conjunction with accurate records of annual discharge from wells, may provide a basis for estimating a comparative annual recharge to the pumping district and thus for predicting roughly the quantity of water that will be available during each irrigation season. (See p. 198.)

CHANGES OF PIEZOMETRIC SURFACES PRIOR TO 1936

Information concerning the position of piezometric surfaces prior to 1936 is limited primarily to that which can be gleaned from the "underground water claims" filed by well owners with the State Engineer. (See p. 176.) The information on these claims is believed to be much less accurate than similar data for wells in Cedar City Valley, partly because of the generally earlier ground-water development and partly because of the higher proportion of jetted wells, whose drillers have done a vast amount of unrecorded work. Reports of the position of the water levels in wells at the time of construction have been submitted for comparatively few wells, and these are probably quite inaccurate as a whole, but statements as to whether or not a well flowed when drilled are believed to be generally reliable. According to these statements, there are several wells in the valley which flowed when drilled but which were outside the area of artesian flow in March 1940. (See pl. 25.) Most of these wells were drilled during the years 1912 to 1916, and it is inferred that during at least a part of that period the area of artesian flow exceeded that shown in March 1940. An enlargement of the area of artesian flow may well have occurred during those years as a result of abnormal recharge, for the precipitation at Parowan from 1912 to 1916 was greater than normal each year except 1915, and during 1914 and 1916 it was more than 25 percent above normal.

The north and east boundaries of the maximum area of reported artesian flow coincided approximately with the March 1940 area, according to available data. Practically the only changes in the area of artesian flow between about 1914 and 1940 have been along the south boundary. East of the Culver fault, throughout the length of the pumping district (from sec. 8, T. 34 S., R. 9 W., to sec. 36, T. 33 S., R. 9 W.) the area of artesian flow during the earlier period extended not more than a quarter of a mile farther south than during 1940. Because the only appreciable changes in area of artesian flow have occurred in the vicinity of the irrigation-pumping district, it is inferred that the decline of water levels and resulting decrease in area of artesian flow have been caused chiefly by pumping for irrigation.

In the majority of the wells that have formerly flowed, the nonpumping level was within 5 feet of the land surface in March 1940. The distribution of wells in the vicinity of the edge of the maximum area of artesian flow is of some significance; scores of wells are immediately to the north of the line, within the area of artesian flow (pl. 25), and only a dozen wells are within a mile south of the line. This distribution is strongly suggestive that development has progressed right up to the limit at which flowing wells could be obtained, and inferentially the wells along this line had only a small head when the area of artesian flow was greatest. Hence it is considered that the change in area of artesian flow from its maximum to its position in March 1940 resulted from a decline of the piezometric surface of probably not more than 10 feet. Some confirmation of this estimate may be obtained from the underground-water claims filed by owners of wells south of the maximum area of artesian flow. In only one of these wells was the water level in March 1940 more than 12 feet lower than the reported level upon completion of drilling. This lowering of the piezometric surface is of approximately the magnitude caused by pumping between March and September 1940 east of the Culver fault. (See pl. 24.) The quantity of water removed from storage in order to cause this lowering of the piezometric surface is small, for the total pumpage east of the Culver fault (see p. 194) during 1940 amounted to 4,550 acre-feet.

West of the Culver fault the change from the maximum area of artesian flow has been much more marked. According to the records of wells, the area of artesian flow prior to 1920 extended just as far south on the west side of the Culver fault as it did (and still does) east of that fault Thus it is implied that the ground-water dam along the Culver fault, which was so prominent in March 1940 (p. 155), did not exist during the earlier period. Here again the change is inferred to be due to the pumping developments of the past few years, but this change is the more remarkable because it has resulted from pumping in only five wells in recent years, at no time in more than eight wells, whereas the smaller change east of the fault resulted from the pumping of some 20 or more wells. The decrease in area of artesian flow since these early years has resulted from a pronounced lowering of the piezometric surface in the region west of the fault, shown by water levels as much as 20 feet below the surface in some wells that formerly flowed. Here again the decline in water levels does not imply a very large decrease in storage, for the pumping in the course of a single season commonly causes a lowering of water levels of as much as 30 feet. The pumping from irrigation wells west of the Culver fault (p. 194) amounted to 1,800 acre-feet, and it is believed that this is about the magnitude of the difference in storage in this district between the period of maximum storage and March 1940.

Except for the scant evidence of somewhat higher artesian-pressure surfaces during the decade prior to 1920, there is practically no recorded information concerning the position of piezometric surfaces prior to 1936. By report of residents, there was a considerable decline in water level and a corresponding diminution of flow from artesian wells during the several years of subnormal rainfall between 1927 and 1935, but is likely that the fullest effect of this subnormal precipitation, and recharge, was not felt until some time subsequent to 1935, and therefore is included in the period for which records of water-level fluctuations are available.

Judging from Meinzer's description of ground-water conditions in Parowan Valley in 1908, [81] the area of artesian flow was then about as extensive as it has been in recent years, although ground-water developments at that time were insufficient to define the entire area. All the flowing wells mentioned by Meinzer would be within the area of artesian flow as of March 1940.

In summation, the most marked changes in the area of artesian flow since the early years of development have occurred in the vicinity of the area where ground water is now pumped for irrigation, and this pumping is inferred to be chiefly responsible for these changes, even as it has been shown to be responsible for marked changes from season to season in recent years. The scant evidence available indicates that before pumping for irrigation was begun, the area of artesian flow was fairly constant from year to year, and if comparisons are made between those earlier seasons and the nonpumping season early in 1940 the boundaries of the area of artesian flow have undergone only minor changes for the most part, although greater changes have evidently occurred in that part of the pumping district west of the Culver fault. These changes in area of artesian flow, of course, presuppose changes in the position of the piezometric surface that determines the area of artesian flow.

SOURCES OF GROUND WATER

The sources from which the ground-water reservoir of Parowan Valley receives replenishment are analogous to the sources of ground water in Cedar City Valley, which have already been described in some detail. (See pp. 98 to 102.) In both valleys the ultimate source of ground water is precipitation over the drainage basin, and recharge may be either by direct penetration of precipitation within the limits of the valley or by seepage from the streams that drain the bordering mountainous areas.

Water that enters the valley from the surrounding mountains may enter the ground-water reservoir by underflow through the alluvium that floors the canyons or by seepage from the streams that empty into the valley. As in Cedar City Valley, the rate of seepage from these streams is probably greatest as the stream crosses the upper part of its fan, where the alluvium is ordinarily coarsest and most permeable. In all probability the confining layers that separate the artesian aquifers and the unconfined water in the central parts of the valley do not continue into these steepest parts of the fan, where recharge is presumably greatest. Thus the aquifers of all depths are believed to receive replenishment from the streams in these areas.

Most of the irrigation ditches that divert water from the principal streams in Parowan Valley are on the upper parts of the alluvial fans, and very few extend more than 2 miles from the mouth of the stream canyon, at the apex of the fan. Seepage from some of these ditches may be comparable to that from the natural channels in the vicinity. Other ditches, because of low gradient and regulated flow, may be partly filled with silt so that seepage losses are likely to be low.

Excess water, diverted from these streams and applied for irrigation, may penetrate below the root zone and continue downward to the zone of saturation. On the highest parts of each fan the soil is likely to be more porous, downward percolation of water more rapid, and the pro-

[81] Meinzer, O. E., Ground water in Juab, Millard, and Iron Counties, Utah: Geol. Survey Water-Supply Paper 277, pp. 140–142, pl. 2, 1911.

portion that migrates to the zone of saturation greater. Water from these higher areas, after joining the ground-water body, may move through either deep or shallow aquifers. Irrigated lands farther down the fans are probably separated from artesian aquifers by layers of impermeable materials, and excess irrigation water would be able to penetrate only to the zone of shallow, unconfined water. Most of the lands irrigated by surface water in Parowan Valley are on the higher parts of the respective alluvial fans. On the fans of Parowan Creek and Red Creek, however, areas as much as 3 miles from the apex of the fans are irrigated from those streams.

Seepage from streams and diverting canals is presumably greatest when the stream flow is greatest—during the spring when melting snows contribute heavily to runoff—and the recharge to the ground-water reservoir might likewise be expected to be greatest at that time. In the great majority of wells the changes in artesian pressure caused by changes in ground-water withdrawals from wells are so great that they mask all other seasonal fluctuations. (See p. 149.) Effects of recharge are recognized in some of the wells most remote from areas of ground-water development (pl. 21) and show that in those areas the recharge is ordinarily greatest during April or May.

Each of the streams and dry canyons that enter Parowan Valley may contribute to the ground-water reservoir by underflow or direct seepage, and the larger streams may contribute indirectly by seepage of irrigating water that is derived from them. The relative importance of these streams is suggested on the maps showing the piezometric surfaces (pls. 22 and 23). Clearly the most important sources are the streams that enter the valley from the east, although there is some indication that water also moves into the valley from the north, that is, from the general direction of the Black Mountains.

Penetration to the ground-water reservoir of precipitation that falls directly on the valley floor may occur under favorable conditions. The opportunity for such penetration would be greatest in the coarse, porous materials of the upper parts of the alluvial fans. Recharge from precipitation would be most likely to result from the melting of snow that commonly accumulates over the valley during the winter, but storms during other seasons also may be able to supply any soil-moisture deficiency and contribute to the ground-water body.

There are numerous springs along the trace of the Parowan fault in T. 33 S., R. 8 W., and others along the faults that have displaced the alluvium on the west side of Little Salt Lake. Like the springs in Cedar City Valley (p. 101), these springs are attributed to displacement along the faults, which has created barriers to the free circulation of ground water. It already has been suggested (p. 160) that the springs along the Parowan fault appear to be derived from shallow artesian aquifers. The springs along the west margin of Little Salt Lake have generally more volume during the winter than during the summer—fluctuations that correspond with those of the artesian-pressure surfaces of the ground-water reservoir. It is inferred that the source of these springs also may be water in artesian aquifers that have been broken by faulting.

MOVEMENT AND NATURAL DISPOSAL

GENERAL RELATIONS IN PAROWAN VALLEY

The direction of movement of ground water in the areas of ground-water development is indicated on the maps showing contours on the piezometric surfaces, for movement is in the direction of maximum slope of the piezometric surface. Regional movements are best shown in March (pl. 22) when pressure effects due to discharge from wells are at a minimum. Movement of ground water follows approximately the surface drainage pattern in the areas covered by these maps. Information is scant as to the position of piezometric surfaces along the west edge of Parowan Valley, and there are no data whatsoever for the south end of the valley, west and southwest of the village of Summit. In those areas, by analogy with the developed areas in Parowan Valley and also with Cedar City Valley, it is inferred that ground-water movement likewise follows more or less the surface drainage pattern. Thus the two independent drainage basins within the valley are presumably occupied by independent ground-water basins that are separated by a ground-water divide in the undeveloped part of Parowan Valley west of Summit. Movement of ground water is generally from the mouths of the canyons that empty into these respective basins toward the lowest part of each basin. Disposal of ground water may be by spring discharge, by evaporation or transpiration, or by underflow beneath the channels that form the outlets to Parowan Valley at Parowan and Winn Gaps.

MOVEMENT AND DISPOSAL IN SUBDIVISIONS OF THE GROUND-WATER RESERVOIR

WINN BASIN

Winn Basin is the southern and smaller of the two topographic basins that comprise Parowan Valley. It is so named here after the chief tributary, Winn Creek, and the principal agricultural development, Winn's ranch. The north boundary of the basin is arbitrarily set along a line trending northwest from the village of Summit to the west edge of the valley. There are no wells in this basin, and data are lacking as to the occurrence and movement of ground water. It is inferred that water enters the basin from the canyons of Winn Creek and other tributaries that rise on the Markagunt Plateau to the east. The alluvial fan of Summit Creek forms the divide between Winn Basin and the Little Salt Lake Basin farther north, much as the Coal Creek alluvial fan divides Cedar City Valley into separate basins, and therefore ground water moving down the southwest slope of the Summit Creek fan also enters Winn Basin. Ground water is inferred to move westward from these canyons toward Winn Gap and southwestward toward the village of Enoch.

Surface water flows through Winn Gap only during very short periods, ordinarily as a result of cloudbursts. There is a small amount of underflow down the gap, however, as shown by springs in sec. 33, T. 34 S., R. 10 W., where some of the underflow, about 30 gallons a minute in December 1940, is forced to the surface by bedrock. Ground water moving through this gap, estimated to amount to about 200 acre-feet a year, discharges into the Enoch district of Cedar City Valley.

Ground water in Winn Basin also moves southwestward through the unconsolidated materials that form the south end of Parowan Valley and eventually enters Cedar City Valley farther west. Springs in the vicinity of Enoch represent the part of this ground water that is brought to the surface along the Enoch fault (p. 103); their discharge is estimated to be 4 or 5 second-feet, or perhaps about 3,000 acre-feet a year. In addition, some water undoubtedly moves westward from the south end of Parowan Valley into the Enoch district without ever appearing at the surface, for the greater part of ground-water withdrawal in that district is from the area south of Enoch, whereas the springs occur in

Enoch and farther north. It is believed that 5,000 acre-feet is a conservative estimate of the total amount of ground water that moves annually from the Winn Basin into Cedar City Valley, including both underflow and spring discharge.

LITTLE SALT LAKE BASIN

The ground-water reservoir in the Little Salt Lake Basin may logically be subdivided according to the principal topographic features that make up the basin—the alluvial fans of the principal tributaries and the lake bed that occupies the lowest part of the basin. Ground-water subdivisions so outlined would be distinguished largely according to source, for the streams that formed these fans also have been the principal source of the ground water within the fans. These subdivisions happen also to be along lines of economic development, for the agricultural developments have tended to radiate outward from the several communities in the valley, which in turn are near the apexes of the alluvial fans of the principal streams. For the purposes of this report the Little Salt Lake Basin is divided into five districts, which are defined and discussed below. These districts are outlined on the sketch map comprising plate 27.

Summit district.—The Summit district embraces principally the northern slope of the Summit Creek alluvial fan; it lies north of the Winn Basin and is separated from the Parowan district to the east by the Summit Creek fault. The district comprises approximately the southern two-thirds of T. 34 S., and thus includes the ground-water developments in T. 34 S., R. 10 W. Ground water in the Summit district moves northward from the head of the Summit Creek alluvial fan and probably also to some extent from across the Summit Creek fault. It leaves the district by movement into the adjacent Little Salt Lake district.

Parowan district.—The Parowan district, adjacent to and east of the Summit district, is outlined almost entirely by faults that have a pronounced effect on ground-water circulation in Parowan Valley. The west border of the district is formed by the Summit Creek and Culver faults, and the east border follows the Parowan fault. The upper part of the Parowan Creek alluvial fan occupies approximately the southern half of the Parowan district. Ground water moves northward and northwestward from the apex of this fan, and probably also from springs along the south edge of the valley. Farther north, in T. 33 S., R. 8 W., some ground water enters the Parowan district from the adjacent Paragonah district by crossing the Parowan fault, and moves northwestward. Ground water leaves the district by moving across the Culver fault into the Little Salt Lake district, or perhaps across the Summit Creek fault into the Summit district.

There are several spring openings along the north edge of the Parowan district, in the vicinity of the Culver fault, and some ground water was formerly discharged from the district through these springs. During recent years, however, many of the springs have ceased to flow, and others have flowed only during the winter, forming small pools. The annual discharge from these springs during recent years is believed to be negligible.

Paragonah district.—The Paragonah district lies east of the Parowan district in Ts. 33 and 34 S. Thus the district includes principally the alluvial fans of Red and Little Creeks, which enter the valley near the town of Paragonah. Ground water enters the district from the apexes of these fans and those of smaller streams and moves westward toward the Parowan fault. It leaves the district either by moving across the barrier created by that fault or by discharge from numerous springs alined along the fault. These springs consist of small pools, most of which do not overflow during the irrigation season, April to October, so that their discharge then is limited to the quantity evaporated from the pool plus that transpired by plants in the vicinity. During the winter many of these pools overflow and flood the adjacent land, and the total discharge from the group of springs may be as much as 6 or 8 second-feet. The annual discharge from these springs is estimated to be about 2,000 acre-feet. Several of the springs are west of the fault trace as shown on plate 3. They are included within the group presumed to have been formed by faulting, and they suggest that displacement along the Parowan fault has occurred through a zone perhaps half a mile wide rather than along a single break.

Buckhorn district.—The Buckhorn district covers the north end of Parowan Valley, and its south boundary is arbitrarily set along the south edge of T. 32 S. Ground water enters this district from canyons that enter the valley, particularly from the east but also from the north and west. Movement is generally toward the central part of the valley and then southward toward the Parowan or Little Salt Lake districts. Ground water is within a few feet of the surface in the lower part of the Buckhorn district, and saltgrass flourishes over an area estimated to be about 1,200 acres. (See pl. 27.) Throughout this meadowland there is discharge of ground water by transpiration, estimated about 1,200 acre-feet annually on the basis of White's estimate that about 1 acre-foot per acre is discharged by transpiration and evaporation from land of this sort. (See p. 104.)

Little Salt Lake district.—The Little Salt Lake district comprises that part of Parowan Valley west of the Culver fault in T. 33 S. and the northern third of T. 34 S. Ground water enters this district, especially from the Parowan district farther east, by crossing the Culver fault; there probably is also come contribution from the north, Buckhorn district, and from the south, Summit district. The Little Salt Lake district is the principal area of natural discharge in Parowan Valley, and ground water may be discharged by evaporation from the lake or from the lake bed, by transpiration from a narrow belt surrounding the lake bed, by spring discharge along the west margin of the lake, and perhaps by underflow through Parowan Gap.

The greatest amount of ground-water discharge from the Little Salt Lake district is by evaporation from the lake bed. The area of the lake bed is approximately 3,850 acres, or about 6 square miles. The lake bed is ordinarily not covered with water except for short periods, and the water is largely derived from flood runoff rather than ground-water discharge. During most of the year water is at the surface only in small pools, generally in the vicinity of the springs along the west border of the lake and doubtless maintained by them. On the other hand, ground water is commonly within a few inches of the surface of a large part of the lake bed, and it may be treacherous to the person who is misled by the apparent dryness of the white salt flat. It is estimated that throughout the months of greatest evaporation the zone of saturation is within a foot of the surface of the entire lake bed, and that at certain times or at certain places the depth to water may be only 1 or 2 inches. Accordingly, using White's experimental data as a basis (pp. 105), it is estimated that the ground-water discharge by evaporation from the bed of Little Salt Lake is about 1½ acre-feet per acre, or 5,800 acre-feet annually.

Beyond the edge of the lake bed there is a belt, ranging in width from perhaps a hundred feet to more than a quarter of a mile, which is covered by ground-water plants of which saltgrass is most abundant. Using White's estimate that transpiration from such areas will probably amount to 1 acre-foot per acre, it is estimated that ground-water discharge from this belt amounts to about 1,000 acre-feet annually.

There are several springs within the Little Salt Lake district, all of them along the west side of Little Salt Lake. The discharge from these springs is evidently greatest in winter, and it practically ceases during summer. Most of these springs are located along lines of faulting, but the temperatures of the springs, the field tests for chloride, and especially the fluctuation in discharge corresponding to fluctuation in draft upon the ground-water reservoir all suggest that these springs represent discharge from the ground-water body that occupies the Parowan Valley fill. Discharge from most of the springs is over a rather wide seepage area, where loss by evaporation and transpiration may be so great that the yield cannot be measured. Certainly the discharge is small, and it is likely that the total discharge from the 10 mapped spring areas does not average more than 1 second-foot. Thus the annual discharge from these springs would be of the order of 700 acre-feet.

The discharge by underflow through Parowan Gap is believed to be negligible. The gap throughout most of its length is 300 to 800 feet wide and is bordered by steep rock walls. Water has been encountered in the alluvium in the gap at a depth of about 15 feet, and it is probable that there is no loss there by transpiration or evaporation. The lower end of the gap is formed by the very narrow Hieroglyph Canyon, whose floor is barely wide enough for a roadway, and it is very doubtful that there is any appreciable discharge of ground water through this canyon and into Cedar City Valley beyond.

Summary.—The ground-water districts in which there probably is natural discharge of ground water from Parowan Valley and the estimated annual amount of this discharge are listed below.

Estimated annual natural discharge, in acre-feet, from ground-water districts in Parowan Valley during recent years

District	Estimated natural discharge
Winn basin	5,000
Little Salt Lake basin:	
Paragonah district	2,000
Buckhorn district	1,200
Little Salt Lake district	7,500
Total	15,700

CHEMICAL CONSTITUENTS OF THE GROUND WATER

Samples of water from 43 wells, 1 spring, and 4 streams in Parowan Valley were collected and were analyzed in the laboratory of the Geological Survey at Washington, D. C., for total hardness, bicarbonate, sulfate, chloride, and nitrate. The results are given in the table below. In addition to these laboratory analyses, field tests were made to determine the chloride content in water from 65 other wells and from 3 springs. Results of these tests appear in a supplementary table.

Most of the waters sampled in Parowan Valley are calcium bicarbonate waters, but about one-fifth of them contain more sodium bicarbonate than calcium bicarbonate. In general, the waters having the lowest mineral content are in the northern part of the valley, and waters from wells farther south are somewhat more highly mineralized. The most highly mineralized water sampled—that from well (C–34–9)7bdd1—has probably about 1,000 parts per million of dissolved solids, which is a lower mineral content than that of much of the water in the heavily-developed Coal Creek fan in Cedar City Valley. The waters of Parowan Valley are generally quite similar in chemical character to those of the Enoch district of Cedar City Valley, whose drainage basin forms the south end of Parowan Valley.

Chemical constituents in parts per million of ground water in Parowan Valley

[M. D. Foster and G. J. Petretic, analysts]

Well number	Reported depth of well (feet)	Total hardness as $CaCO_3$	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)
(C-32-8) 14dad1	156	100	136	8	14	1.2
32ccc1		87	130	6	18	1.1
35bcb1	250	93	186	6	16	
(C-33-8) 4cdd3		48	110	14	22	
8dcd3	200	38	185	18	27	
17cad1		66	160	10	16	
17cad	(Spring)	138	218	12	11	1.6
17ccd1	40	174	232	12	17	2.9
18abc1		34	129	15	52	
20aad1		38	139	13	38	
29caa1		159	189	15	5	.6
31acb1		210	224	14	14	3.0
(C-33-9) 1dad1	200+	74	120	10	18	
1dad2	200+	50	119	8	12	
1dda1	179	81	129	11	20	
11acb1	350	28	115	10	28	
13ddd1		46	141	19	60	
14adc1	550	117	145	20	36	
14ccc1	342	135	154	25	31	
24cdd1		99	149	17	58	
25cdd4	120	172	192	20	32	
26bbb1	500	198	188	25	22	
26cbc2		186	175	16	9	4.8
28abd1		100	147	18	18	1.5
33aad1	740	180	200	13	6	
34daa1	530	204	229	17	6	
34dcd1	550	210	224	15	8	
35aad1	400	196	176	30	25	
35bad1	608	177	196	10	4	
35ddd1	500	276	281	25	11	
36dcd1	499	195	196	32	34	
(C-33-10) 25cdd1	15	152	206	26	22	
(C-34-9) 2bdd1	350	276	301	16	6	
3bcd1	560	225	252	15	6	
5bda1	567	180	190	14	4	
6bcd1	81	120	164	14	5	1.9
6dbd1	356	138	157	18	4	.0
7bba1	110	156	178	18	4	1.8
7bdd1	100	668	414	360	101	6.4
9bca2	500	279	287	16	7	
16abd1	73	345	414	22	4	5.3
22acd1	125	234	358	23	14	55
(C-34-10) 11dcd1	82	432	241	20	191	4.2
24abd1	90	171	217	22	8	1.9

Chemical constituents of stream water in Parowan Valley

Stream	Date	Total hardness as $CaCO_3$	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)
Willow Creek	Mar. 15, 1940	168	244	10	9	0.0
Red Creek	Sept. 29, 1939	158	187	8	2	....
Parowan Creek	...do	182	208	10	2	....
Summit Creek	Mar. 7, 1940	225	228	24	7	.2

Supplementary analyses, in parts per million, of chlorides in well water in Parowan Valley

Well number	Reported depth (feet)	Chlorides	Well number	Reported depth (feet)	Chlorides
(C-32-8)12cdd1		10	(C-33-9)25bdd1	[1] Shallow	35
26bda2	200	55	25bdd2	[1] Deep	15
27cdd2		10	26add2	[1] Shallow	35
32acb1		10	26add6	[1] Deep	30
(C-33-8) 5ddd1		20	26add7		55
7cca1	100	255	26cac5	500	15
8dcd1		20	26cbc2		10
8dcd2		50	27aac1		10
9bcb1		230	27dbc2		5
9ccd2	[1] Shallow	140	28dcd1	716	5
9dab1		10	32ccd2	400	5
17ccd2		10	33bbd1	400	5
17ddd1		10	34aad1	350	10
18abc2	[1] Shallow	25	34cbd1	489	5
18acb1	[1] Deep	70	34dbd1		5
18dad1		25	34dbd2		5
19ddd1	250	10	34ddd1	515	5
20acd2	[1] Shallow	20	35acd1	500	10
20acd3	226	30	35bac2		5
20acd4	[1] Deep	35	36aaa1	120	25
20cdd10		10	(C-33-10)25cdb1	85	10
28bbb1	350	25	(C-34-9) 2ccc1	84	5
29bdd1	35	15	3cdd1	355	5
30dad1	80	5	5dad1	665	5
(C-33-9)11aaa1	[1] Deep	40	8bdd1	100	25
11aaa2	[1] Shallow	20	8dca1	330	5
13ddd2		10	9aad1	126	5
14adc2		40	9baa1	300	5
14cca1		20	9bbd1	600	5
14ddc1		40	9bca1	500	5
23ddd1		30	9bcc1	540	5
24ab1		40	(C-34-10)23ddb1		20
24bdd1		20			

[1] Presumed from artesian head measured in March 1940. (See table on pages —.)

Supplementary analyses, in parts per million, of chlorides in spring water

Spring number	Date	Chlorides	Spring number	Date	Chlorides
(C-33-9)20ddc	Apr. 11, 1940	40	(C-33-9)21cbc	Apr. 11, 1940	30
21aad	do	40			

The five southernmost wells sampled yielded water that contains appreciably more dissolved mineral matter than waters from wells farther north in the valley. The water from three of these wells has a hardness greater than 300 parts per million, the highest being 668 parts. Water from one or another of these five wells also contains the greatest amounts of bicarbonate (414 parts), of sulfate (360 parts), and of nitrate (55 parts) that were found in Parowan Valley. Two of the wells yielded water with more than 100 parts per million of chloride, which is considerably above the average for wells in Parowan Valley.

Except for the water in these most southerly wells, the ground water in Parowan Valley has a moderate mineral content. Water from 38 sampled wells north of the Parowan-Lund highway ranges in total hardness from 28 to 279 parts per million; that from 20 of these wells has a hardness of less than 150 parts per million; and water from 6 wells near the north end of the valley has a hardness of less than 50 parts and may be classed as soft. In water from these 38 wells the bicarbonate ranges from 110 to 301 parts per million and in general is lowest in water from wells toward the north end of the valley. The sulfate and nitrate content is also very low in waters in the part of Parowan Valley north of the Parowan-Lund highway. The sulfate ranges between 6 and 32 parts, and the nitrate content is not more than 5 parts per million.

Chloride in the water from the 38 sampled wells north of the Parowan-Lund highway ranges from 5 to 60 parts per million. In 60 other wells, which were sampled for field tests, four waters contained chloride in excess of 60 parts, and one contained 255 parts per million. Practically all the sampled water was from artesian strata. The shallow ground water in the vicinity of the Little Salt Lake playa contains chloride in considerably greater amounts than was found in water from the wells sampled and the playa is covered with salts that have been left by evaporation.

Samples of water from four streams that enter Parowan Valley predominate in calcium bicarbonate and are very similar to several of the waters encountered in wells. Single samples of stream water are of course entirely inadequate for any estimation of the quantity of dissolved matter that is contributed over a period of time to Parowan Valley. They do show, however, that the water obtained from wells is similar in type as well as in amount of mineralization to that entering the ground-water reservoir from streams, at least during certain seasons of the year.

The ground water in Parowan Valley is quite generally superior to that of Cedar City Valley for domestic use, but fewer than a score of families use it for this purpose. The water from wells is also suitable for stock or for irrigation, the two principal uses of ground water in the valley, except for some of the soft waters in the northern part of the valley, which contain too large a proportion of sodium to be suitable for irrigation.

SOURCE AND SIGNIFICANCE OF THE CHEMICAL CONSTITUENTS

The calcium bicarbonate that is the dominant mineral constituent in most of the sampled well waters of Parowan Valley has evidently been derived from the lime-bearing rocks that crop out in the region. As shown on the geologic map (pl. 1, A), Cretaceous and Eocene strata crop out over much of the area tributary to the southern part of Parowan Valley. These formations include much limestone and calcareous sandstone and shale. Farther north, the valley is bordered by an increasing proportion of volcanic rocks, and the lime-bearing rocks do not appear north of T. 33 S. This distribution of calcareous rocks is reflected in the analyses of ground water in the valley, for the total hardness is generally less than 100 parts per million in wells in the northern part of the valley and increases to more than 250 parts in several wells near the south limit of the developed area. The bicarbonate content also increases correspondingly from north to south.

Neither the sulfates nor the nitrate content of the well waters of Parowan Valley is recognized as having any significance in relation to ground-water movements. Within the drainage basin tributary to Parowan Valley there are no known outcrops of the Jurassic and Triassic continental deposits, which in the vicinity of Cedar City Valley contains considerable quantities of evaporites, particularly gypsum. The principal streams entering the valley appear to contain amounts of sulfate and nitrate that are very low in comparison with the quantities found in many streams entering Cedar City Valley. The ground water likewise is low in these constituents, which are rather evenly distributed throughout the waters of the valley.

GROUND-WATER DEVELOPMENT

STATUS OF DEVELOPMENT, 1940

The locations of all known wells in Parowan Valley are shown on plate 25, and the records of these wells, obtained chiefly from information collected by the State Engineer of Utah and filed in his office, are summarized in the table below. Three hundred and ninety-five wells are listed,[82] of which 392 are in the Little Salt Lake Basin, and distributed as follows among the several districts within that basin: Parowan 185; Little Salt Lake, 79; Paragonah, 77; Buckhorn, 43; Summit, 8. The table lists 29 wells that are currently (1940) being pumped for irrigation, all but one by electric motors. Only 15 wells are shown to be used chiefly for domestic purposes. Seventeen were found to have been buried or filled with debris, so that they were unavailable for use. About 300 wells had sufficient artesian head to flow at the surface during a part or all of 1940.

Some qualification is necessary for the large number of wells listed as used principally for stock. These wells might better be classified as "available for use by stock," with no implication as to the proportion of the well discharge that was actually used by stock. In fact, the classification was used as a catch-all to include wells that probably have yielded water in recent years and that were not known to be used for irrigation of cultivated crops or for domestic purposes. Most of the wells listed as stock wells have been claimed for that purpose by their owners, and a large number are so used during all or part of each year. Many of the flowing wells are used for "pasture irrigation," an effortless agricultural pursuit that yields abundant watercress near the well, a water-logged area of several square yards, and a rather narrow belt of green pasture. All the flow from certain wells and some of the discharge from the majority of these "stock" wells is wasted, for some well owners neglect to close their wells when not in use, and very few make any attempt to obtain the greatest possible value from them.

The table shows the positions of the nonpumping or nonflowing level in about 250 of the wells in Parowan Valley, based on measurements in 215 wells by the Utah State Engineer during March and April 1940 and on estimates for the other wells based on earlier records. In addition, the 10-minute recovery levels are shown for 23 wells that were found flowing. Forty-six other wells that were found flowing during those months could not be shut in for measurement of the artesian pressure. The measurements that form the basis for the discussion of the high and low artesian-pressure surfaces (pp. 154, 160) are indicated by footnotes.

[82]See discussion of this list of wells on pages 153 and 195.

Records of wells in Parowan Valley

Well No.	Owner	Claim No. [1]	Date completed	Diameter (inches)	Depth (feet) [2]	Pumping equipment [3]	Horsepower of motor [4]	Principal use [5]	Water level in 1940: Date	Water level in 1940: Above (+) or below (-) land surface (feet)	Water level in 1940: Elevation (feet above sea level) [6]
(C-32-8) 1adal [7, 8]	O. C. Snow			6		L			Mar. 4	-49.0	5798.6
12cdd1 [7, 8]	Tolton Inv. Co.			2		F		S	Mar. 6	+ 1.8	5794.0
13bdal	U. V. Limb			2		F		S			
13bda2	do			2		F		S			
13dbcl [9]	Iron County			48	18 d						
14aad1 [7, 8]	F. E. Dodge		1910	3	156	F		S	Mar. 6	+ 2.0	F 5786.0
14adal [10]	O. C. Snow	12761	1928	4½		F		S	Mar. 6	+	U
14ada2	do	7819	1890	6	93	FC	G 6	SI	Mar. 6	+	U
14ada3 [10]	do		1908	3		F		S	Mar. 6	+	U
14dad1 [7, 8]	do	12762	1928	2	156	F		S	Apr. 2	+11.8	5787.7
14dad2	do	7817	1890	2	118	F		S	Apr. 21	+11.5	5787.4
15dad1 [7, 8]	do	17850	1916	2	190	F		S	Apr. 21	+ 3.5	5764.5
23dbal	U. V. Limb			72	23	W					
23dbc1 [7, 8]	do		1913	3	47	L		D	Mar. 6	-15.4	5778.3
23dcal [9]	J. W. Jones	12925	1930	72	20 d	L					
26baal [9]	do	12924	1909	72	10 d						
26bdal	M. L. Dailey	Ap 12159	1936	60	18m	C			Mar. 6	-	E 5781.0
26bda2 [7]	do	13478	1921	2	200	F		S	Mar. 6	+ 4.3	5792.7
27cdd1	J. C. Robinson	18349	1900	2		F		S	Mar. 7	+19.3	5759.1
27cdd2	do			2		F		S	Mar. 7	+19.7	5758.2
27dbcl	N. B. Nielson et al.	17851	1914	2	190	F		S	Mar. 7	+29.2	5775.4
27dcal [7]	A. F. Robinson			2		F		S	Mar. 7	+29.8	5781.9
32acal	W. H. McGinty			2		F		S			
32acb1 [7]	do			3		F		S	Mar. 15	+20.4	5750.0
32acb2	do	18517	1920	2		F		S	Mar. 15	+18.7	5749.1
32abc3	W. H. McGinty			2		F		S	Mar. 15	+12.9	5743.7
32bdd1	do	18519	1920	4½		F		S	Mar. 15	+ 5.6	5736.8
32bdd2	do			4½		F		S	Mar. 15	+ 3.3	5734.4
32bdd3 [8]	do			3		F		S	Mar. 15	+ 3.5	5733.3
32ccal	do	18518	1920	2		F		S	Apr. 23	+ 9.3	F 5724.0
32cccl [8]	do			2		F		S	Mar. 15	+10.1	5731.3
32ccc2	do	18520	1920	3		F		S	Mar. 15	+11.9	5732.9
34aad1	J. C. Robinson			2		F		S	Apr. 21	+20.0	F 5781.8
34aad2 [8]	do	18167		2		F		S	Apr. 24	+12.6	5775.2
34aad3	do	18168	1910	2		F		S	Apr. 24	+	E 5778.0

Records of wells in Parowan Valley—Continued

Well No.	Owner	Claim No.[1]	Date completed	Diameter (inches)	Depth (feet)[2]	Pumping equipment[3]	Horsepower of motor[4]	Principal use[5]	Water level in 1940: Date	Water level in 1940: Above (+) or below (-) land surface (feet)	Water level in 1940: Elevation (feet above sea level)[6]
(C-32-8)34aba1	J. E. Lister			2		F		S	Mar. 7	+16.7	5765.7
34aba2	...do			2		F		S	Mar. 7	+	E 5762.0
34abd1	...do	13486	1911	2		F		S	Mar. 6	+33.1	5783.9
34abd2[7]	...do	13484	1911	2		F		S	Mar. 6	+33.5	5784.5
34abd3	...do	13485	1911	2		F		S	Mar. 6	+30.8	5783.0
34abd4	...do			2		F		S	Mar. 6	+32.5	5784.0
34baa1[8]	A. F. Robinson			2		F		S	Mar. 7	+20.1	5759.6
35bcb1	H. N. Edwards	5683	1921	3	250	F		S	Feb. 1	+10.8	5778.4
(C-33-8) 4acc1	J. H. Mitchell	15960	1917	4		F		S	Mar. 7	+18.9	5755.4
4ccc1	...do	15966	1917	4		F		S	Mar. 7	+22.2	5746.8
4cdd1	...do	15967	1917	1		F		IS	Mar. 7	+19.5	5757.0
4cdd2[8]	...do			2		F		IS	Mar. 7	+14.9	5752.9
4cdd3[7]	...do	15969	1917	2		F		IS	Mar. 4	+26.9	5765.0
4cdd4	...do	15968	1908	4		F		IS	Mar. 7	+24.7	5763.0
4cdd5	...do	17444	1915	3		F		IS	Mar. 7	+	
4cdd6	J. H. Mitchell	17445	1915	2		F		IS	Mar. 7	+23.7	5761.1
5ddd1[8]	W. C. Mitchell	10048	1915	3		F		S	Mar. 7	+22.6	5742.3
7cca1[8]	Philip Benson	6930	1904	3	100	F		S	Mar. 15	+19.7	5710.1
8dcd1	W. T. Talbot	4738	1917	4	200	F		S	Mar. 12	+29.3	U 5749+
8dcd2	...do	15766	1917	2	200	F		S	Mar. 12	+	U
8dcd3	...do	15767	1917	2	200	F		S	Mar. 12	+	UE 5757
9aaa1[7]	J. H. Mitchell	15961	1912	3		F		S	Mar. 12	+15.7	5777.8
9bad1	...do	15965	1917	3		F		S	Mar 12	+25.8	5764.8
9bad2	...do	15963	1917	2		F		S	Mar. 12	+28.5	5766.3
9bad3[7]	...do	15964	1917	3		F		S	Mar. 12	+28.8	5766.8
9bbd1	W. C. Mitchell	10047	1915	4		F		S	Apr. 8	+26.5	5756.9
9bca1	...do	10049	1915	4		F		S	Mar. 7	+	E 5763
9bcb1	J. H. Mitchell			2		F		S	Mar. 7	+ 6.6	F 5737.0
9bcb2	...do			2		F		S	Mar. 7	+ 7.8	5737.5
9ccd1[8]	R. N. Lund estate	19399	1915	2		F		S	Mar. 12	+15.0	F 5745.0
9ccd2	...do	19398	1915	2		F		S	Apr. 25	+13.3	F 5745.6
9cdc1	...do	11751	1897	2		F		S	Mar. 12	+	U
9dab1	J. H. Mitchell	15962	1915	3		F		S			
15bba1	R. W. Talbot	18229	1904	2	200	F		S	Mar. 12	+ 1.7	F 5765.1
15bbd1[8]	...do	18610	1904	2	200	F		S	Mar. 12	+ 6.6	5770.1

(C-33-8)15cbd1	Iron County		1934	60±	47				Apr. 2	-17.4	5740.7
17cad1	W. W. Bettridge	1225	1916	4		F		S	Mar. 12	+27.7	5754.0
17ccd1 [8]	T. W. Jones	13702	1901	2	40	F		S	Mar. 12	+12.0	5736.1
17ccd2	...do			2		F		S	Mar. 12	+18.2	5742.5
17ccd3	...do			2		F		S	Mar. 12	+14.6	5738.5
17ccd4	T. W. Jones			2		F		S	Mar. 12	+15.3	5738.9
17cdd1 [8]	...do			2		F		S	Mar. 12	+ 8.3	5741.6
17ddd1 [7]	T. R. Robinson	10325	1910	2		F		S	Mar. 12	+19.6	5774.0
17ddd2	...do	10326	1910	2		F		S	Mar. 12	+12.6	5767.4
17ddd3	...do	17964	1910	3	150	F		S	Mar. 13	+	U
17ddd4	...do	17963	1903	3	150	F		S	Mar. 13	+	U
18abc1	Eva Talbot et al.	11722	1897	2		F		S	Mar. 13	+25.2	5739.8
18abc2 [8]	...do	11723	1897	2		F		S	Mar. 13	+13.1	5727.3
18acb1 [7]	...do	11724	1897	2	140	F		S	Mar. 13	+32.9	5747.6
18dad1	T. R. Robinson	4781	1900	2		F		S	Mar. 13	+	U
18dad2 [9]	...do	4782	1900	2							
19ddd1	State of Utah	15143	1915	2	250 q	F		S	Mar. 13	+21.0	5755.6
19ddd2 [8]	...do	15144	1915	2	250 q	F		S	Mar. 16	+20.4	5754.9
19ddd3 [7]	...do	15145	1915	2	250 q	F		S	Mar. 13	+32.5	5767.0
19ddd4	...do	15146	1915	2	250 q	F		S	Mar. 13	+20.9	5755.1
19ddd5	...do	15147	1915	2	250 q	F		S	May 6	+28.9	F 5763.6
20aad1 [7]	T. R. Robinson			3		F		S	Mar. 14	+15.7	5779.2
20acc1	J. R. Topham	4297	1901	2	150	F		S	Mar. 13	+	U
20acd1	...do	4293	1901	2	295 q	F		S	Mar. 13	+17.9	5771.0
20acd2 [8]	...do	4294	1901	2	228	F		S	Mar. 13	+	E 5766
20acd3	...do	4295	1897	2	226	F		S	Mar. 13	+26.2	5779.0
20acd4 [7]	...do	4296	1901	2	228	F		S	Mar. 13	+26.3	5779.1
20acd5	...do	18480	1910	2	125	F		S	Mar. 13	+17.6	F 5772.4
20acd6	...do	18479	1910	2	125	F		S	Mar. 13	+19.8	5772.6
20acd7	...do			2		F		S	Mar. 13	+	U
20cdd1	Federal Land Bank (Marion Dalley)	7871	1926	8	200	F		IS	Mar. 13	+	U
20cdd2	...do	7872	1917	3	150 q	F		I	Mar. 13	+15.5	5768.7
20cdd3	...do	7873	1907	2	125 q	F		I	Mar. 13	+11.8	5768.9
20cdd4 [8]	...do	7874	1907	2	125 q	F		I	Mar. 13	+13.8	5767.6
20cdd5	...do	7875	1907	2	125 q	F		I	Mar. 13	+13.0	5769.3
20cdd6	...do	7876	1905	2	125 q	F		I	Mar. 13	+22.5	5775.8
20cdd7	...do	7877	1907	2	125 q	F		I	Mar. 13	+16.4	5769.6
20cdd8 [7]	...do	7878	1905	2	125 q	F		I	Mar. 13	+23.2	5776.2
20cdd9	...do	7879	1907	2	125 q	F		I	Mar. 13	+14.6	F 5767.5
20cdd10	...do	7880	1905	2	125 q	F		I	Mar. 13	+15.0	5769.3
28bbb1 [8]	State of Utah	15133	1918	4	250	L		S	July 17	-11.0	5771.1

See footnotes at end of table.

Records of wells in Parowan Valley—Continued

Well No.	Owner	Claim No. [1]	Date completed	Diameter (inches)	Depth (feet) [2]	Pumping equipment [3]	Horsepower of motor [4]	Principal use [5]	Water level in 1940: Date	Water level in 1940: Above (+) or below (-) land surface (feet)	Elevation (feet above sea level) [6]
(C-33-8)29abd1 [7, 8]	L. E. Bastian	13705	1912	3	125	F		S	Mar. 14	+ 8.4	5776.3
29bac1	A. E. Topham					F		S			U
29bac2	...do					F		S			U
29bbd1 [8]	S. T. Topham	13981	1890	2	160	F		S	Mar. 14	+13.4	5758.1
29bbd2	...do	13980	1890	2	186	F		S	Mar. 14	+14.4	5760.2
29bdd1	A. E. Topham		1935	60	35				Mar. 14	−	
29bdd2	...do			2		F		S	Mar. 14	+ 7.3	5778.0
29bdd3	...do			60					Mar. 14	−	
29caa1	S. T. Topham			2		F		S	Mar. 14	+13.9	5779.0
29caa2	...do			2		F		S	Mar. 14	+11.4	5777.3
29caa3 [8]	...do	11803	1901	2	275	F		S	Mar. 14	+12.3	5776.1
29caa4 [7]	...do	13982	1898	2		F		S	Mar. 14	+ 8.4	F 5780.9
29ccd1 [8]	H. E. Owens	17351	1908	2		F		S	Mar. 14	+ 8.8	5774.3
29ccd2 [7]	...do	17350	1908	2		F		S	Mar. 14	+12.3	5779.4
29cdd1 [9]	T. R. Robinson, Jr.										
30aad1	E. R. Robinson	13706	1895	2	90	F		S	Mar. 14	+20.3	5758.8
30ada1	...do			2		F		S	Mar. 14	+21.8	5761.9
30dad1 [8]	M. E. Prothero	1265	1900	2	80 q	F		S	Mar. 14	+19.4	5766.0
30dad2 [7]	...do	15892	1897	2	80 q	F		S	Mar. 14	+28.7	5775.2
30ddd1	W. T. Davenport			2					Mar. 5	− .5	5755.8
31acb1 [7, 8]	T. A. Topham	4780	1890	2		F		S	Mar. 14	+12.9	5774.3
31bdb1 [7, 8]	W. H. Boardman	13979	1914	4½	325	F		S	Mar. 14	+ 8.1	5772.9
(C-33-9) 1daa1 [7]	H. A. Mitchell estate	4740	1910	3		F		S	Mar. 15	+ 6.0	5740.2
1dad1	...do	4744	1910	3		F		S	Mar. 1	+11.2	5731.3
1dad2 [7]	...do	4743	1910	3		F		S	Mar. 1	+17.2	5737.3
1dad3 [8]	...do	4742	1910	2		F		S	May 14	+ 5.8	5723.1
1dda1	...do	4741	1910	2	179m	F		S	Mar. 1	+ 9.4	5729.6
11aaa1 [7]	Lenora Stubbs	5123	1912	3	342	F		S	Mar. 15	+14.2	5735.5
11aaa2 [8]	...do	5124	1915	3	200	F		S	Mar. 15	+ 9.6	5730.9
11acb1 [7]	Emil Witte et al.	5134	1921	3	350	F		S	Mar. 15	+14.4	5732.7
11acb2 [8]	...do	5135	1921	3	250	F		S	Mar. 15	+11.0	5729.5
13ddd1	Iron County			3		F		S	Mar. 15	+21.4	5729.8
13ddd2 [8]	...do			2		F		S	Mar. 15	+ 6.2	5714.6
14adc1 [8]	E. W. Jensen	6929	1920	3	550 q	F		SI	Mar. 18	+11.9	5722.8
14adc2 [7]	...do	6928	1916	3	377 q	F		SI	Mar. 18	+13.4	5724.3

(C-33-9)14cca1 [7]	Nannie Eyre et al.	6488	1914	4½	550	F		ID	Mar. 18	+15.3	5732.8
14ccc1	...do	6489	1920	4	342	F		I	Mar. 18	+22.7	5731.4
14dcd1 [7]	Iron County	18768	1912	3		F		S	Mar. 18	+10.1	5732.4
23aab1 [9]	Samuel Bradshaw			2							
23aba1 [9]	Samuel Bradshaw			2							
23ddc1	T. E. Fowler	1226	1901	2	68	F		S	Mar. 18	+21.1	5726.7
23ddd1 [8]	...do			2		F		S	Mar. 18	+20.0	5726.5
23ddd2	...do			2		F		S	Mar. 18	+ 5.1	5711.3
24aba1 [7]	D. B. Decker			3		F		S	Mar. 18	+21.5	5741.7
24baa1	Iron County			4½		F		S	Mar. 18	+	U
24bdd1 [8]	...do	17657	1918	4		F		S	Mar. 18	+15.4	5721.4
24ccc1 [7]	D. H. Waid			2		F		S	Mar. 18	+32.3	5741.8
24cdd1 [7]	W. L. Adams et al	17353	1917	4		F		IS	Mar. 18	+33.9	5750.0
24dac1 [8]	Iron County	18230	1920	2	100	F		S	Mar. 18	+13.9	5728.0
25bdc1 [8]	J. W. Taylor			2		F		S	Mar. 18	+10.0	5738.9
25bdd1	...do	11592	1895	2	190	F		S	Mar. 18	+12.0	5740.6
25bdd2	...do	17833	1905	2		F		S	Mar. 18	+11.4	5739.6
25ccc1	Federal Land Bank (R. W. Hulet)	18705	1918	2	260 q	F		SI	Mar. 19	+13.1	5755.9
25ccc2 [7]	...do	18704	1918	2	260 q	F		SI	Mar. 19	+14.5	5756.7
25ccc3	...do	18702	1918	2	260 q	F		SI	Mar. 19	+ 8.4	5751.5
25ccc4	...do	18703	1918	2	260 q	F		SI	Mar. 19	+12.4	5755.4
25ccc5	...do	18701	1918	2	260 q	F		SI	Mar. 19	+13.0	5756.5
25ccc6	...do			2		F		SI	Mar. 19	+ 3.9	5746.1
25ccc7	...do	18700	1918	3	360	F		SI	Mar. 19	+	U
25cdd1 [10]	State of Utah	13811	1916	6	400	F			Mar. 19	+	E 5750
25cdd2 [10]	...do	17709	1915	6		F			Mar. 19	+	E 5750
25cdd3	...do	17710	1910	3		F		S	Mar. 19	+	5753.0
25cdd4	...do	ap 1444	1939	12	120	FT	15	I	Mar. 19	+	U
25cdd5	...do			2		F		S			
25cdd6	State of Utah			3		F		S	Mar. 19	+ 2.6	5749.0
25cdd7	...do			2		F		S	Mar. 19	+ 2.9	5750.0
25cdd8	...do			3		F		S	Mar. 19	+ 2.7	5749.7
25dbc1 [9]	S. R. Pritchard	7897	1905	2							
25dbc2	...do	7899	1905	2		FL		D	Mar. 18	+ .2	5735.3
25dcb1	...do			2		F		S	Mar. 18	+ 4.9	F 5745.0
25dcc1 [10]	...do	7898	1920	5	360	F			Mar. 18	+	5746+
25dcc2 [10]	...do			2		F			Mar. 18	+	5746+
25dcc3	...do		1939	8	120	FT	10	I	Mar. 18	+	U
25dcd1	...do	15932	1917	2		F		S	Mar. 18	+ 7.7	5752.6
25dcd2	...do			2		F		S	Mar. 18	+ 2.0	5746.9
25dcd3	...do			2		F		S	Mar. 18	+ 2.9	5748.5

See footnotes at end of table.

Records of wells in Parowan Valley—Continued

Well No.	Owner	Claim No. [1]	Date completed	Diameter (inches)	Depth (feet) [2]	Pumping equipment [3]	Horsepower of motor [4]	Principal use [5]	Water level in 1940: Date	Water level in 1940: Above (+) or below (-) land surface (feet)	Elevation (feet above sea level) [6]
(C-33-9)26add1	M. E. Trimmer			2		F		SI	Mar. 18	+	U
26add2 [8]	...do	19597	1900	2		F		SI	Mar. 19	+ 5.0	5728.4
26add3	...do			12		F		SI	Mar. 19	+	U
26add4 [7]	...do			2		F		SI	Mar. 19	+24.8	5748.7
26add5	...do	19599	1900	2		F		SI	Mar. 19	+	U
26add6	...do	19598	1900	2		F		SI	Mar. 19	+14.5	5739.2
26add7	...do	6490	1906	4½	550	F		I	Mar. 19	+	U
26bbb1 [7]	Federal Land Bank (John Miller)	12820	1912	4½	500	F		SI	Feb. 28	+23.8	5740.8
26bbb2	...do	12821	1914	4	400	F		SI	Mar. 29	+18.2	5733.6
26bbb3	...do			2		F		S	Mar. 29	+12.2	F 5727.6
26bdc1 [8]	Federal Land Bank	6758	1912	2	60	F		S	Mar. 29	+	E 5724
26bdc2 [9]	...do	6754	1912	2	200						
26cac1 [8]	...do	6751	1901	2	133	F		S	Mar. 29	+ 7.0	F 5732.0
26cac2	Federal Land Bank	6752	1918	4½	600	F		SI	Mar. 29	+15.6	F 5740.8
26cac3	...do	6756	1912	2	270	F		SI	Mar. 29	+	U
26cac4	...do	6757	1901	2	133	F		SI	Mar. 29	+ 8.6	F 5733.0
26cac5	...do	6759	1918	4½	600	F		SI	Mar. 29	+17.3	F 5742.5
26cac6	...do	6760	1918	3		F		SI	Mar. 29	+	
26cac7	...do			2		F		SI	Mar. 29	+	U
26cad1	...do	6753	1918	4½	600	F		SI	Mar. 29	+	U 5738+
26cad2 [7]	...do	6755	1912	2	270	F		S	Mar. 29	+19.2	F 5744.1
26cbc1	F. F. Morris	4874	1895	3		F		S	Mar. 29	+20.0	5742.3
26cbc2	...do			2		F		S	Mar. 29	+13.3	5734.8
26cbd1	...do			2		F		S	Mar. 29	+14.8	5738.8
26cbd2	...do			2		F		S	Mar. 29	+14.9	5737.7
26cbd3	...do			2		F		S	Mar. 29	+10.7	5735.0
26dda1	State of Utah			2		F		S	Mar. 29	+	U
26dda2	...do					F		S	Mar. 29	+	U
26ddd1	...do	13807	1918	6	400	FT	10	I	Mar. 29	+	U
26ddd2 [9]	...do	13808	1910	2	150						
26ddd3 [10]	...do			6		F			Mar. 29	+	5743+
26ddd4	...do			2		F		S	Mar. 29	+ 4.5	5747.6
27aac1	W. W. Bettridge	18091	1902	2	100	F		S	Mar. 29	+32.1	5737.9
27aac2	...do	18090	1902	2	100	F		S	Mar. 29	+30.9	5737.3

(C-33-9)27aac3 [7]	W. W. Bettridge	18092	1902	2	100	F		S	Mar. 29	+31.8	5738.1
27abd1	Thomas Taylor, Jr	13501	1910	3	315	F		S	Mar. 29	+29.5	5735.8
27bbc1 [7]	H. C. Parcells et al	492	1913	4	300	F		S	Mar. 30	+21.4	5729.0
27cad1 [7]	J. P. Bayles			2		F		S	Mar. 30	+ 9.2	5729.6
27cad2 [8]	J. P. Bayles			2		F		S	Mar. 30	+ 6.9	5727.3
27dbc1 [8]	Thomas Taylor, Jr	13502	1906	2	226	F		S	Mar. 30	+ 6.6	5728.6
27dbc2	do	18623	1910	3	336 q	F		S	Mar. 30	+ 7.8	5729.3
27dbc3	do	18622	1906	2	226	F		S	Mar. 30	+ 7.8	5729.0
27dbc4	do	18624	1906	2	226	F		S	Mar. 30	+ 5.7	5728.5
28abd1 [7, 8]	Iron County	17259	1917	4½		F		S	Mar. 30	+15.1	5728.5
28aca1	do	17260	1917	4		F		S	Mar. 30	+10.9	5725.5
28ada1	L. P. Morris			3		F		S	Mar. 30	+18.8	5728.0
28add1 [8]	C. G. Paramore			3		F		S	Mar. 30	+10.3	5727.8
28dcd1 [7, 8]	Arthur Joseph	1231	1925	6	716	FT	15	ID	Mar. 30	+	U 5710+
31dda1	Iron County			3		F		S	Mar. 31	+	U
31ddd1	do	18613	1905	2		FL		S	Mar. 30	+	U 5695+
32ccd1	A. S. Wilcock	11601		10	24m				Mar. 30	– 3.0	5694.4
32ccd2 [7]	do	17335	1915	4½	400	F		S	Mar. 30	+11.3	5708.7
32cdd1 [7]	E. E. Meyers estate	19510	1915	3		F		S	Mar. 30	+ 6.8	5709.7
32cdd2	do	19511	1915	2		F		S	Mar. 30	+ 1.5	5704.4
32cdd3	do	19513	1915	2		F		S	Mar. 30	+ 2.1	5705.0
32cdd4	do	19512	1915	12		FT			Mar. 30	+	U 5704+
32dad1 [8]	State of Utah	10621	1915	2		F		S	Mar. 31	+ 3.0	5706.0
32dad2	do	17338	1912	4		F		S			
32dcc1 [9]	Taylor Miller			3							
32dcd1	State of Utah	10619	1915	3	280	F		S	Mar. 31	+ 6.9	F 5710.2
32dcd2	do	10622	1925	3		F		S	Mar. 31	+ 5.5	5709.2
32dcd3 [8]	do	16543	1925	2		F		S	Mar. 31	– .5	5702.6
32ddd1 [7]	do	10620	1925	8		F		S	Mar. 2	+ 3.0	5710.8
33aad1 [7, 8]	J. P. Bayles	1233	1918	15½	740	FT	20	IS	Mar. 31	+	U 5713+
33bbd1 [7, 8]	Arthur Joseph	1232	1925	4½	400	F		S	Mar. 31	+	5707+
34aad1	Eugene Warren	1227	1928	12	350	FT	5	IS	Mar. 31	+	U 5736+
34aad2 [9]	do			2							
34aad3 [7]	do		1885	3	300	F		S	Mar. 31	+ 4.1	5739.6
34aad4	do	16819	1887	3	350	FL		D			
34aad5 [8]	do			2		F		S	Mar. 31	+ 3.5	5738.9
34bad1 [8]	H. E. Bayles	3717	1908	12	472	T	10	S	Mar. 31	–	5726–
34bcc1	Mary Marsden	17483	1915	2½	475						
34bcd1	do	17482	1915	4½	375	W					
34cbd1	do	5694	1925	12	489	T	20	I			
34cbd2 [7, 8, 10]	do			4½	500				Mar. 4	–18.4	5718.3
34daa1 [10]	J. B. Dalton	13495	1911	4½	530	F					

See footnotes at end of table.

Records of wells in Parowan Valley—Continued

Well No.	Owner	Claim No. [1]	Date completed	Diameter (inches)	Depth (feet) [2]	Pumping equipment [3]	Horsepower of motor [4]	Principal use [5]	Water level in 1940: Date	Water level in 1940: Above (+) or below (-) land surface (feet)	Elevation (feet above sea level) [6]
(C-33-9)34daa2 [10]	J. B. Dalton			2		F					
34daa3	...do		1939	10	127	FT	10	I	Mar. 4	+	UE 5753
34dbd1	O. M. Lyman	493	1913	4½	425	FT	5	I	Mar. 4	+	U 5753+
34dbd2 [7, 10]	...do	16046	1911	4½	443	F		S	Mar. 4	+	U 5755+
34dbd3 [8, 10]	...do			2	40	F		S	Mar. 4	+	E 5754
34dbd4	...do	ap 1400	1938	12		FS	5	I	Mar. 4	+	U 5755+
34dbd5 [9]	...do	16493	1911	2	80						
34dbd6	...do			4½	120	FL		D			
34dcd1 [7, 8]	Federal Land Bank	6750	1923	6	550						
	...do	ap 1426	1938	12	130	T	15	I	Mar. 31	− 2.5	5760.0
34ddd1 [7, 8]	J. B. Dalton	13496	1912	12	515	T	15	I			
35aad1 [8, 10]	Federal Lank Bank (Harrell Dalton)	13933	1912	4½	400				Apr. 2	−	E 5746
35aad2	Federal Land Bank (Harrell Dalton)	16413	1912	3	300	L					
35aad3 [10]	...do	16414	1929	8	150				Apr. 2	−	E 5747
35aad4	...do	ap 1468	1939	12	400	S	10	I			
35abd1 [9]	Federal Land Bank	17559	1913	3	375						
35acd1	State of Utah	13810	1909	12	500	T	15	I	Apr. 1	−17.9	5747.8
35adc1	...do	13809	1924	3	80	A	1½	D			
35baa1	Federal Land Bank (J. M. Ward)	7849	1900	2½	150	F		S	Apr. 1		E 5743
35baa2 [8]	...do	7852	1900	2	150	F		S	Apr. 1		E 5743
35baa3	...do	7850	1900	2	150	F		S	Apr. 1		E 5743
35bac1	Clark Orton	11216	1913	4½	387	FC	10	I	Apr. 1	+	U 5746+
35bad1	Federal Land Bank	7848	1920	8	608	FT	10	I	Apr. 1	+	U 5745+
35bba1	Clark Orton	11215	1910	2		F		S	Apr. 1	+	E 5747
35bbc1	...do	19589	1905	2	150	F		S	Apr. 1	+ 3.0	F 5740.5
35bbc2	...do	19591	1905	2	150	F		S	Apr. 1	+ 4.3	F 5741.3
35bbc3 [7]	...do	13508	1900	2	300	F		S	Mar. 4	+ 9.4	5747.2
35bbd1 [8]	...do	11214	1900	2		FL		S	Apr. 1	+	E 5745
35bbd2	...do	19590	1905	2	200	F		S			
35caa1	State of Utah	13806	1911	3	300	L	1	S			
35caa2 [9]	...do	18387	1911	3	300						
35caa3 [9]	...do	18388	1911	3	312						

(C-33-9) 35cbb1 [8]	Emil Witte	4554	1916	4	300	T	2	SI	Apr. 1	- 7.5	5747.6
35ddd1 [7, 8]	State of Utah	13812	1912	12	500	S	20	I	Apr. 1	-33.1	5759.1
36aaa1 [7, 8]	Emerson Adams	5136	1916	2	120	F		S	Apr. 2	- 9.9	5754.5
36bbc1	R. W. Hulet	1264	1926	4½	560	T	10	I	Apr. 2	- 4.0	5750.5
36dcd1 [7, 8]	H. L. Adams	494	1925	4½	499	T	10	IS	Apr. 2	-36.0	5760.7
(C-33-10) 25cdb1 [7]	Edgar Benson	19517	1928	2	85	F		S	Apr. 1	+ .4	5685.4
25cdd1 [8]	...do	10612	1910	144	15	L		S	July 19	- 1.0	5683.5
27dbd1 [9, 11]	...do	10611	1930	72	13 d						
(C-34-8) 5bca1 [7, 8]	Drought Relief Adm		1934	12	420				Apr. 2	-20.9	5781.1
7bdd1	R. D. Garner et al										
30bcb1 [12]	Parowan City et al	15669	1933	12	60	FT	10	M			
30bcb2 [12]	...do	15669	1933	8	195	F					
(C-34-9) 1daa1 [7, 8]	S. A. Halterman	18525	1926	6	70	L			Mar. 30	-59.7	5784.9
2bdd1	Jasper Stubbs	17526	1912	3	350	L		S			
2ccc1 [7, 8]	J. R. Lister estate	13659	1920	4½	84	W		D	Mar. 30	-54.6	5766.1
3bcd1	S. A. Halterman	920	1927	12	560	FT	15	I	Mar. 30	+	U 5761+
3bcd2	...do				120						
3bda1	C. C. Connell			2					Mar. 30	+ .6	5762.8
3bda2	...do	4292	1914	4½	310				Mar. 30	-	
3bda3 [7]	...do			2					Mar. 30	+ .1	5762.9
3bdc1	S. A. Halterman	Ap 12026	1936	2	90	L	½	S			
3cba1	Federal Land Bank	7883	1919	2							
3cba2 [7]	...do	7882	1914	10	340				Mar. 30	- 4.9	5762.6
3cbc1 [8]	F. W. Pendleton	14187	1914	4½	238				Mar. 30	- 4.7	5759.7
3cbc2 [7]	...do	17419	1900	2					Mar. 30	- 1.0	5764.1
3cbc3	...do	17418	1900	2					Mar. 30	- 4.8	5761.6
3cbc4	...do	17420	1915	4½	240+				Mar. 30	- 2.6	5762.9
3cbc5	...do			2					Mar. 30	- 1.4	5762.7
3cbc6	...do								Mar. 30	- 4.4	5761.6
3cbc7	...do			2					Mar. 30	- .7	5763.7
3cdd1	W. C. Rowley	1170	1927	8	355	T	10	I			
4dca1	F. W. Pendleton			2					Mar. 30	- .7	
4dcd1 [8]	...do	13988	1926	4½	144	L		D	Mar. 30	- 2.6	5763.2
4dcd2 [7]	...do	17417	1900	2	120				Mar. 30	- .7	5765.2
5add1	J. C. Robinson	5090	1918	6	665?	A	1½	D			
5bad1 [9]	H. E. Bayles	17352	1916	3							
5bca1 [7, 8]	...do	3718	1916	3		FL		S	Mar. 30	+	U 5706+
5bca2 [8, 9]	...do	3719	1916	2		F					
5bda1 [8]	...do	3716	1916	10	567	FT	10	I	Mar. 30	+	U 5708+
5dab1 [8]	J. C. Robinson	5088	1918	4½	300	A	1½	S			
5dad1 [7, 8]	...do	5089	1918	12	665	T	20	I	Mar. 30	-	E 5710
6bcd1 [8]	G. D. Hyatt	13506	1905	3	81	F		S	Mar. 30	- 4.8	5695.3

See footnotes at end of table.

Records of wells in Parowan Valley—Continued

Well No.	Owner	Claim No. [1]	Date completed	Diameter (inches)	Depth (feet) [2]	Pumping equipment [3]	Horsepower of motor [4]	Principal use [5]	Water level in 1940: Date	Water level in 1940: Above (+) or below (-) land surface (feet)	Elevation (feet above sea level) [6]
(C-34-9)6dbd1 [7]	G. E. Bentley	11562	1911	3	356	F		S	Mar. 30	+	E 5714
7bba1 [8]	G. A. Lowe, Jr	5125	1910	2	110	F		S	Mar. 30	+	E 5699
7bdd1 [8]	P. H. Gurr	4869	1920	6	100	W		S	Mar. 30	-15.7	5696.9
8add1 [7]	P. H. Gurr et al	4872	1910	3	500	F		S	Apr. 1	+10.2	5759.4
8add2 [8]	do	17494	1914	2		F		S	Apr. 1	+ 4.6	5755.8
8add3	do	17503	1933	2		F		S	Apr. 1	+	E 5756
8add4	do	17501	1914	3		F		S	Apr. 1	+	E 5756
8bdd1 [8]	do	4868	1920	6	100	L			Apr. 1	-26.1	5708.7
8dbd1 [8]	do	4866	1910						Apr. 1	-	E 5746
8dbd2 [7]	do	17493	1933	2		F		S	Apr. 1	+	E 5754
8dca1	C. J. Stubbs	495	1927	8	330	T	10				
9aad1 [8]	F. W. Pendleton	13987	1921	16	126	T	15	I	Mar. 30	-28.4	5762.8
9abb1	Daniel Crawford	17800	1914	3	300	F		S	Mar. 30		
9abb2	Daniel Crawford	17799	1914	2	350	F		S	Mar. 30	- .7	5757.8
9baa1	do	1266	1931	12	300	FT	10	I	Mar. 30	+	U 5758+
9baa2 [8]	do	17798	1915	4½	275	F		S	Mar. 30	- 1.0	5757.5
9baa3	do	17797	1914	5	300	F		S	Mar. 30	+	5760+
9bac1	Federal Land Bank (Horace Evans)	11600	1905	4	550	FL		S	Mar. 30	+	E 5757
9bac2	do	5796	1916	3	460	F					
9bac3	do	5800	1908	3		F					
9bac4	do	5799	1916	2		F					
9bac5	do	5797	1916	2		F					
9bac6	Federal Land Bank	19593	1908	2	150	F					
9bad1	Daniel Crawford	1267	1931	3	500	A	¾	D	Apr. 1	-	5758-
9bbd1	Federal Land Bank	5786	1921	6	600	FT	15	ID	Apr. 1	+	U 5753+
9bbd2	do	5787	1908	3	324	F		S	Apr. 1	+ 2.0	F 5755.0
9bbd3 [7]	do	5788	1908	3	286	F		S	Mar. 4	+ 5.9	5758.1
9bbd4	do	5789	1908	3	318	F		S	Apr. 1	+ 1.0	F 5753.4
9bbd5 [8]	do	5790	1916	2		F		S	Apr. 1	+ 2.2	F 5753.7
9bbd6	do	5793	1916	3	362	F		S			
9bbd7	do	5794	1916	4½		F		S	Mar. 4	+	E 5758
9bbd8	do	5791	1908	2	40	F			Mar. 4	+	E 5757
9bbd9	do	5792	1908	2	52	F					
9bbd10	do	5798	1916	2		F					

(C-34-9) 9bca1	P. H. Gurr et al.	4867	1910	3		F			Mar. 4	-	E 5759
9bca2	...do	4871	1910	12	500	FT	15	ID	Apr. 1	- 1.3	5759.4
9bcc1	...do	4870	1910	12	540	FT	15	I			
9bbc2	...do	17500	1914	2		F					
9bcc3 [8]	...do	17496	1914	2		F			Apr. 1	+ 1.5	5754.7
9bcc4 [7]	...do	17495	1933	3		F		S	Apr. 1	+	5757+
9bcc6	...do	17497	1933	2		F		S	Apr. 1	+	5756+
9bcc7	P. H. Gurr et al.	17498	1933	3		F		S	Apr. 1	+	5756+
9bcc8	...do	17499	1933	2		F		S	Apr. 1	+	5756+
9cdd1	J. B. Adams	17788	1933	2½	70	L		S	Mar. 30	- 1.1	5786.1
9dbc1 [7, 8]	H. M. Adams	1224	1924	6	450				Mar. 30	-24.6	5762.0
10bdd1 [7, 8]	A. R. Barnes	8801	1913	8	500				Apr. 1	-52.2	5766.6
16abd1	J. B. Adams	13997	1930	4	73	L		S		-	
16cdd1	Federal Land Bank	5818	1923	8	100				Mar. 30	-28.5	5778.5
21bad1	G. A. Lowe, Jr	18420	1932	6	100				Mar. 30	-22.2	5786.8
22acd1 [7, 8]	Federal Farm Mortgage Corp.	6434	1923	5	125	L		D	Mar. 30	-118.5	5765.9
(C-34-10) 11dcd1 [7, 8]	Rulon Lyman	18010	1933	5	82	W		S	Mar. 30	-67.3	5703.0
13cba1 [7, 8]	Iron County		1936?	3		W		S	Apr. 2	-31.0	5715.5
13cca1 [9]	...do	17658	1920	12	107					-	
23ddb1	Federal Land Bank	6749	1910	3	100	L		S		-	
24abc1 [7, 8]	R. J. Green	Ap 12115	1936	8	104				Mar. 30	-55.0	5717.0
24abd1 [7, 8]	...do	10523	1926	5	90	LW		D	Mar. 30	-49.5	5717.5
24cda1	Lyle Farrow	Ap 12241	1938	10	247	T	G 30	I	Mar. 30	-91	E 5717
24ddc1 [7, 8]	Public domain			6	139m				Mar. 30	-132.0	5719.9

[1] Ap, Application to appropriate water; ap, application for transfer of point of diversion.
[2] d, Dry hole; m, measured depth; all others reported. q, Reported depth questioned on basis of available hydrologic data.
[3] A, Automatic pressure system; C, centrifugal pump; F, flowing well; L, lift pump; S, submersible turbine; T. turbine; W, windmill.
[4] G, Gasoline or diesel powered; all others electric.
[5] D, Domestic; I, irrigation; M, municipal; S, stock.
[6] Leveling by Utah State Engineer. E, Estimated from records for other years and by comparison with adjacent wells; F, well flowing prior to measurement; U, flowing well, uncontrollable for measurement of nonflowing level.
[7] Water levels in this well used to define highest piezometric surface in 1940.
[8] Water levels in this well used to define lowest piezometric surface in 1940.
[9] Well is buried or filled with debris.
[10] Well is in common pit or pump house with pumped irrigation well.
[11] In Parowan Gap.
[12] In Parowan Creek Canyon.

HISTORY OF DEVELOPMENT

The construction of wells in Parowan Valley is shown graphically on figure 17, which is based on information obtained from well owners' claims to ground water, analogous to the records for Cedar City Valley that have already been described. The reported dates of construction of wells in Parowan Valley are based largely on memory and may be somewhat in error. The 93 wells whose dates of construction were not reported are presumed to be older wells for the most part, because the old-timers would probably remember anything that had happened in the valley during the past 20 years.

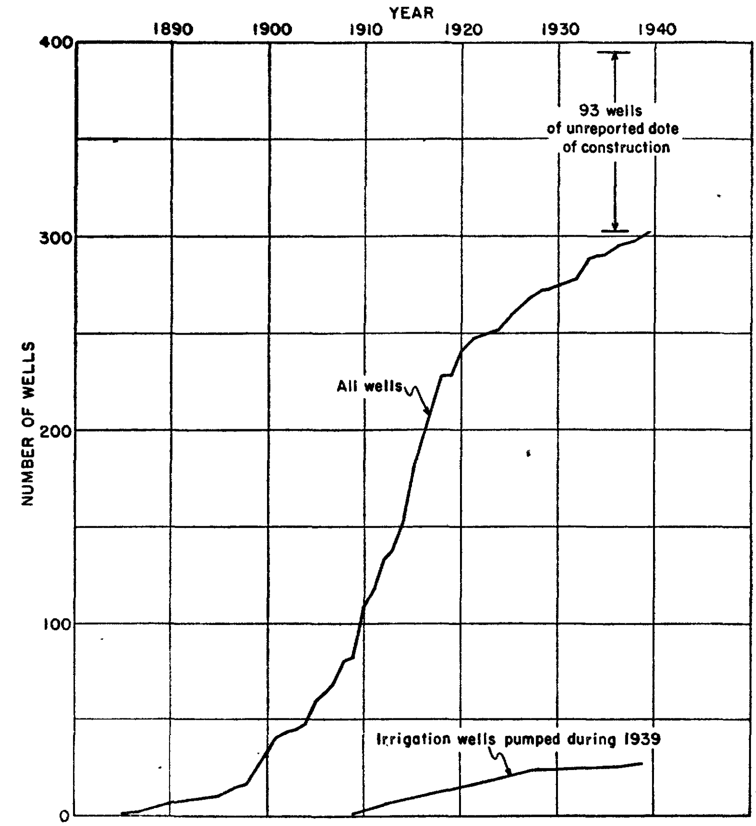

FIGURE 17.—Graph showing cumulative number of wells constructed in Parowan Valley, 1885–1939.

Intensive ground-water development in Parowan Valley, insofar as it is manifested by well-drilling activity, began a decade earlier than in Cedar City Valley, as is shown by comparison of figures 15 and 17. According to report, the oldest well in the valley was completed in 1885, and 17 of the existing wells were constructed prior to 1900. All these are artesian wells that flowed during March 1940. The increase in ground-water development about the turn of the century may be attributed largely to the drought of 1899-1904 (p. 94), especially since there was a slackening of well-drilling activity as the drought cycle ended. This slackening, however, was only temporary—the existence of artesian conditions had been well established, well construction continued, and, as Meinzer noted in 1908, further ground-water development was being prosecuted with enthusiasm.

The golden age for well drilling in Parowan Valley was between 1909 and 1918, when 145 of the existing wells are reported to have been drilled. This rapid development was during a period when rainfall and runoff were greater than normal and suggests an increase in the agricultural development of the valley rather than a need of additional water for established areas. A very large proportion of the wells drilled during those 9 years were flowing wells. Most of these were drilled for irrigation, and reservoirs were constructed to pond the water discharged from groups of adjacent wells. The close spacing of several wells about reservoirs is indicated by the grouping of wells as shown on plate 25.

The rapid development of ground water came to an abrupt halt in 1919, the year following the first World War, and then proceeded at a much slower but fairly uniform rate during the following two decades. During these years there has been a notable increase in well construction outside the area of artesian flow, so that the number of nonflowing wells completed since 1920 has approximately equalled the number of flowing wells. Of 30 wells located above the maximum area of artesian flow in the Summit, Parowan, and Paragonah districts (pl. 25), only 7 are reported to have been completed prior to 1920. Practically all the ground-water development in the Summit district has taken place since 1920, and most of the higher irrigation wells in the Parowan district, including some that have since been abandoned, were completed after that date. [83]

The beginning of irrigation from flowing wells is not clearly indicated by the records. The practice was well established by 1908, for Meinzer [84] cites three ranches on which some three dozen flowing wells were used for irrigation during that year. On the underground-water claims covering these wells, however, the present owners rather generally underestimate the age of the wells, for only one or two are claimed to have been drilled prior to 1908. So far as shown by underground-water claims, the oldest wells that are grouped around a reservoir, and therefore presumably drilled for irrigation, are those in the NE¼ sec. 18, T. 33 S., R. 8 W., reportedly constructed in 1897.

The history of the development of pumping for irrigation is likewise obscure. Irrigation was entirely from flowing wells in 1908, and Meinzer at that time recommended the installation of pumping plants to increase the yield of the basin. [85] The graph showing the year of construction of the existing pump wells does not record the actual development of pumping, because the majority of these wells were originally drilled for artesian flows, and installation of a pump followed years later as the need for water increased or the supply decreased. According to this graph, the drilling of the wells began as early as 1909 and continued at a uniform pace until about 1927. Doubtless the installation of pumps took place during the last few years of this period, either on new wells or on older wells because of failing artesian supply. Since 1927 development of pumped irrigation wells has been practically at a standstill; nearly all the recent construction has been to replace wells already in use. Only one new pump

[83] Meinzer (Ground water in Juab, Millard, and Iron Counties, Utah: U. S. Geological Survey Water-Supply Paper 277, p. 142) reports that in 1908 there were several nonflowing wells directly west of Parowan, evidently at ranches that receive water for irrigation from Parowan Canyon. The wells are no longer in existence, having been destroyed soon after the installation of a pipe line, which now furnishes to the ranches water for culinary needs from the Parowan city water supply, piped from springs in Parowan Canyon.

[84] Meinzer, O. E., op. cit. p. 141.

[85] Meinzer, O. E., op. cit., Water-Supply Paper 277, p. 142.

well, Lyle Farrow's well (C-34-10)24cda1 in the Summit district, has been completed during the 5 years since the State ground-water law became operative. Furthermore, judging by the very few applications filed with the State Engineer, there is little demand for further ground-water development in the valley.

IRRIGATION WELLS

Data concerning the discharge of pumped irrigation wells in Parowan Valley have been furnished for 1930 by Arthur Fife, former Iron County agricultural agent, and for recent years by the Utah State Engineer. This information is assembled in the following table, which is analogous to the table showing discharge of irrigation wells in Cedar City Valley. (See pp. 130-133.) In wells whose discharge has been measured twice in a single season, the decrease in rate of discharge from early season (May) to mid-season (July and August) is commonly greater than 10 percent and may be as high as 40 percent, and there is a corresponding increase in discharge late in the season (September). Because of this wide range in discharge of the individual wells, the limit of error of the computed annual discharge is necessarily greater than in Cedar City Valley, where the rate of discharge is more nearly constant. On the other hand, all except one of the irrigation pumps in Parowan Valley are operated by electricity, and the total pumpage may thus be computed from power consumption, with a fair degree of accuracy.

Discharge of irrigation wells in Parowan Valley

Well No.	1930		1938				1939				1940				Specific capacity
	Rate of discharge (gal. per min.)	Annual discharge (acre-feet)	Date of measurement	Rate of discharge (gal. per min.)	Pumping lift (feet)	Annual discharge (acre-feet)	Date of measurement	Rate of discharge (gal. per min.)	Pumping lift (feet)	Annual discharge (acre-feet)	Date of measurement	Rate of discharge (gal. per min.)	Pumping lift (feet)	Annual discharge (acre-feet)	
(C-33-9)25cdd1,4	500	298					June 22	400	33+	214	June 13	347	33+	165	
25dcc3							Sept. 7	188	25+	42	May 23	129	34+	61	
26ddd1	200	124	Aug. 5	284		100	July 8	279		83	May 23	275	38+	190	
							Sept. 7	336	27+		Sept. 12	265	39+		
28dcd1	480	290	May 16	440		201	June 20	405		221	May 23	422	45	205	
			Aug. 17	363			Sept. 8	459	42		Sept. 11	365			
32cdd4	500	300													
32ddd1	260	156													
33aad1	200	124	May 16	755		343	June 20	473		270	May 23	563	45+	286	
			Aug. 17	517			Sept. 15	650	46+		Sept. 12	563			
34aad1	200	116									May 22	90		32	
34cbd1	580	364	May 16	740		344	June 20	590	45+	314	May 22	652	47+	348	
			Aug. 17	583			Sept. 8	664							
34daa1, 3							June 21	222		81	May 23	220		108	
							Sept. 8	245	32		Sept. 12	203			
34dbd1	300	180	May 17	257		149	June 21	255		197	May 22	258	45+	169	
			Aug. 18	217			Sept. 8	259			Sept. 12	287			
34dbd2, 4			Aug. 6	225		78	June 21	202		134	May 22	224	45	137	
							Sept 8	240	32						
34dcd1	350	218	May 17	422		192	June 20	372		252	May 21	428	54	271	
			Aug. 18	375			Sept. 8	400			Sept. 16	399	54		
34ddd1	530	320	Aug. 6	390		235	June 20	372		240	May 22	357	39	225	
							Sept. 11	411	38		Sept. 12	422	38		
35aad1, 4	320	43	Aug. 5	543		256	June 22	538		251	May 22	625		266	
							Sept. 9	624			Sept. 11	540			
35acd1	350	221	Aug. 5	336		264	June 22	400	47	224	May 22	395	49	270	
											Sept. 11	329	50		
35bac1	200	111	May 17	260		140	June 21	220		131	May 22	214		165	
			Aug. 5	201			Sept. 11	222			Sept. 11	181			
35bad1	290	168	Aug. 5	200		100	June 22	219		95	May 22	220		125	
							Sept. 10	230	33		Sept. 12	198			

Discharge of irrigation wells in Parowan Valley—Continued

Well No.	1930		1938				1939				1940				Specific capacity
	Rate of discharge (gal. per min.)	Annual discharge (acre-feet)	Date of measurement	Rate of discharge (gal. per min.)	Pumping lift (feet)	Annual discharge (acre-feet)	Date of measurement	Rate of discharge (gal. per min.)	Pumping lift (feet)	Annual discharge (acre-feet)	Date of measurement	Rate of discharge (gal. per min.)	Pumping lift (feet)	Annual discharge (acre-feet)	
(C-33-9)35cbb1	100	53									May 21	81	24	53	
											Sept. 12	82	24		
35ddd1	450	260	Aug. 6	504		388	July 8	694		387	May 22	625		408	
							Sept. 9	694	81		Sept. 11	465			
36bbc1	330	198	Aug. 5	328		122	June 22	351		70	Sept. 11	229	34+	73	
							Sept. 14	116							
36dcd1	200	124	Aug. 18	194		135	July 8	206		130	Sept. 12	180	72+	145	
							Sept. 11	217	71+						
(C-34-9) 3bcd1	590	362	May 11	508		360	June 20	581		443	May 21	639		397	
			Aug. 6	555			Sept. 8	581							
3cdd1	300	180	May 13	333		182	June 20	319		203	May 21	300		193	
			Aug. 6	306			Sept. 8	319			Sept. 16	291			
5bda1	600	360	May 13	544		426	June 19	459		412	May 23	443		416	
			Aug. 17	463			Sept. 8	433			Sept. 11	436			
5dad1	570	355	Aug. 17	477		331	June 19	520		399	May 21	576	55+	536	
							Sept. 12	503	56+		Oct. 18	628	54+		
9aad1	300	173	Aug. 6	287		167	June 19	284		148	May 21	300	57+	199	
							Sept. 13	336	54+		Sept. 11	255	59+		
9baa1			May 13	292		139	June 19	286		176	May 21	207	32+	144	
			Aug. 6	272			Sept. 8	260	40+		Sept. 11	204	36+		
9bbd1	500	367	May 12	315		181	June 19	329		211	May 22	273		206	
			Aug. 6	292			Sept. 8	297	45		Sept. 12	465			
9bca2	450	378	May 12	477		308	June 19	390		266	May 21	469		300	
			Aug. 17	421			Sept 8	411			Sept. 14	399			
9bcc1	500	120	May 12	376		252	June 19	367		243	May 21	366		265	
			Aug. 17	375			Sept. 8	381			Sept. 11	385			
10bdd1	300	173													
(C-34-10)24cda1			Aug. 18	265		52					July 12	275	101	49	

The number of irrigation wells pumped in the several ground-water districts and the annual discharge from those districts are summarized in the table on page 194. Electric power was first supplied to the valley in 1930, and pumping prior to that time was by internal-combustion engine. Information as to the number of irrigation wells pumped prior to 1930 is not available, but it is presumed that there were several, for irrigation by pumping was well established by 1930, and more pumps were in operation during that year than during the 8 succeeding years.

The total discharge by irrigation pumps in 1930 amounted to more than 6,100 acre-feet, which was nearly equal to the quantity pumped for irrigation in Cedar City Valley during that year. More than two-thirds of this quantity was derived from the Parowan district, and all the rest was pumped from the Little Salt Lake district. In 1938 the discharge from 25 irrigation wells in the valley was less than 5,500 acre-feet, and it is presumed that between 1931 and 1937 the discharge was of about the same magnitude, for approximately the same number of pumps were operating in those years. During 1939 the discharge from the Parowan district was about equivalent to that in 1930, but the quantity pumped in the Little Salt Lake district was appreciably less than in 1930. The discharge by pumps in 1940 was slightly greater than that computed for the valley in 1930 by Fife.

Number of pumped irrigation wells and annual discharge in acre-feet in ground-water districts of Parowan Valley

Ground-water district	Number of irrigation wells pumped during the years —											Discharge [2]			
	1930	[1] 1931	[1] 1932	[1] 1933	[1] 1934	[1] 1935	[1] 1936	1937	1938	1939	1940	1930	1938	1939	1940
Parowan	21	20	19	19	17	16	16	18	19	22	24	4,200	3,750	4,200	4,550
Little Salt Lake	7	4	6	6	8	7	7	5	5	5	5	1,950	1,650	1,600	1,800
Summit	....	....	....	....	....	....	....	....	1	0	1	0	50	0	50
Total	28	24	25	25	25	23	23	23	25	27	30	6,150	5,450	5,800	6,400

[1] Based on records compiled for Utah State Engineer by Southern Utah Power Co.
[2] Summary from table above.

The total discharge of flowing wells used for irrigation in Parowan Valley may be derived from information given by the Utah State Engineer, who from 1936 to 1940 conducted a well-control program that included measurements of rates of discharge of wells throughout the State, estimation of the annual amount diverted, and determination of the purposes for which the water is used. [86] Computations by the State Engineer indicate [87] that the total annual discharge of wells in Parowan Valley for irrigation was 5,800 acre-feet in 1938, and 6,500 acre-feet in 1939. Subtracting from these totals the amount that was discharged by pumps, the quantity of water diverted from flowing wells is obtained—about 350 acre-feet in 1938, and 700 acre-feet in 1939. These figures are of course subject to a rather large probability of error, for they involve not only estimates of the average rate of discharge of each well and the length of time during which discharge occurred, but also determination that this water was actually used for irrigation. Even though these totals are very rough approximations, they show clearly that the yield of flowing wells for irrigation is very minor in comparison with the discharge by pumped wells.

Many of the irrigation wells in Parowan Valley have unusual features of construction which are the result of the change-over to pumping, following an original development in which irrigation was from artesian flows. In this original development the common practice throughout the valley has been to drill several closely-spaced wells and to construct a reservoir wherein the artesian discharge from these wells is ponded until a quantity sufficient for irrigation has accumulated. These wells are commonly 2 or 3 inches in diameter, rarely as large as 4 inches, and may be drilled to different depths so that the reservoir receives water from several aquifers. This is the present stage of development of the Paragonah and Buckhorn districts, as well as of the less-developed areas in the Parowan and Little Salt Lake districts.

Over a rather extensive area on the lower part of the Parowan Creek alluvial fan the demand for ground water has exceeded the supply available by artesian flow, and here the pumping district has been developed. Most common adaptation for pumping has been to dig a sump perhaps as much as 60 feet deep around a group of the small-diameter artesian wells, and to cut off the casings so that these wells discharge into the bottom of the sump. Centrifugal pumps have been operated in several of these sumps, but the annual fluctuation of water level is so great throughout most of the area that the centrifugal pumps are not satisfactory. Only one well in the valley is currently pumped by a centrifugal pump; all other wells are pumped by turbines, of which three are submersible.

Quite generally the sumps have proved to be not deep enough to furnish an adequate supply for irrigation, and further modifications have been undertaken. One common procedure has been to drill a 12-inch well in the bottom of the sump to a depth which may be considerably less than the depths of the original flowing wells that are also located in the sump. The 12-inch casing is then perforated opposite all aquifers encountered in the drilling, and the smaller casings are perforated at the same depths, insofar as possible. After this procedure the well owners believe that they are pumping from all of the wells in the sump, which of course is true insofar as the smaller-diameter wells are within the cone of depression of the pumped well. If these older wells penetrate considerably deep-

[86] Humpherys, T. H., Underground water: 21st biennial report of the State engineer to the governor of Utah, for the biennium July 1, 1936, to June 30, 1938, pp. 48-51, 1938.

[87] Utah State Engineer, unpublished data.

er than the pumped well, it is indeed likely that they may increase the yield of the well, for water in the deeper strata commonly has a greater head than that in shallow aquifers. It is believed, however, that these auxiliary wells form a rather inefficient substitute for a casing of larger diameter drilled to the deeper aquifers. Where the pumped well does penetrate to these deeper aquifers, the auxiliary casings are considered to be functionless.

Several of the later irrigation wells have been drilled adjacent to older flowing wells where no sump has been constructed. The drillers commonly have perforated the casing of these wells opposite each of the coarser strata encountered, and then have perforated the older, smaller casings at the same depths with the purpose of making the water in all the wells available to the pump. Here again the chief value of the smaller casings is that they may make available to the pump water that originates from strata below the bottom of the pumped well.

The pumped irrigation wells are deep, at least by Utah standards. Two are more than 700 feet deep, two others are deeper than 600 feet, and more than 75 percent reach depths of 400 feet or more. Wells large enough to admit the equipment are likely perforated opposite all water-bearing strata, for the individual artesian aquifers in Parowan Valley generally fall short of yielding enough for irrigation.

Because of these features of construction, Parowan Valley offers many problems to the well-control program. Many of the irrigation wells are within the area of artesian flow during the winter and waste water by discharge from the casing around the pump or from a sump. Much of this waste is preventable only if reconstruction is undertaken. Measurements of positions of the water levels in sump or well casings are of doubtful value, because they give no clue concerning the head of individual aquifers. Even the listing of wells is a problem, because a "well" must first be defined. In the table that appears on page 177, the listing generally is in accord with that of the State Engineer, which in turn is determined largely by information from well owners. That the listing is inconsistent may be demonstrated by two examples. Well (C–33–9)34dcd1 consists of a concrete-lined sump 5 feet in diameter and 50 feet deep, filled with gravel to a depth of about 25 feet. Within this sump are four casings, as follows: One 12-inch casing 130 feet deep, perforated, in which a turbine pump is operated; one 4½-inch casing 140 feet deep, now filled with gravel; two 6-inch casings, perforated in upper 130 feet, one of which connects with a perforated 3-inch casing 160 to 340 feet deep, the other extending to a perforated 3-inch casing, 400 to 550 feet deep. The owner describes everything within the sump as one well. A very similar set-up in an adjacent section involves three casings within a sump 17 feet deep, but the owner here makes claim to three wells, as follows: Well (C–33–9)35aad1, 4½-inch casing 400 feet deep; well (C–33–9)35aad3, 8-inch casing 150 feet deep; and well (C–33–9)35aad4, 12-inch casing 400 feet deep, equipped with submersible turbine. Obviously, the number of wells listed in the table is subject to modification depending upon what is considered to be a well.

The specific capacities have been determined for only a very few pumped wells in Parowan Valley. No well was found to yield more than 25 gallons a minute per foot of draw-down, and the specific capacities of wells in the valley, on the basis of the few tests made, appear to range from about 5 to 20. Most of the pumped wells are located in or adjacent to the area of artesian flow in Parowan Valley. Their positions are thus analogous to those of the irrigation wells drilled in the Midvalley district and in the Queatchupah district in Cedar City Valley. The specific capacities of wells in Parowan Valley appear likewise to be comparable to those of wells in those districts of Cedar City Valley. (See pp. 135, 143.)

WELLS USED FOR PURPOSES OTHER THAN IRRIGATION

Wells currently used for purposes other than irrigation include the great majority of wells in Parowan Valley. Practically all are flowing wells. Fewer than 20 are located outside the area of artesian flow (pl. 25); these are generally equipped with windmills, hand pumps, or automatic-pressure systems and are used for domestic or stock-watering purposes. The annual discharge from these wells is very small, and, for the purposes of this report, negligible.

The flowing nonirrigation wells in Parowan Valley include a very few that are used for domestic purposes, and a large number that are classed as stock wells in the table on page 177. The State Engineer has made measurements of the rate of discharge of these wells, and on the basis of well inspectors' reports as to the period of discharge has computed the total yield of the wells. From this total yield the State Engineer has deducted an amount ample for the watering of stock in the valley and has classified the remainder as waste. The computed wastage from wells was about 1,300 acre-feet in 1938, and 1,400 acre-feet in 1939.

The quantity of water permitted to waste from wells in Parowan Valley has probably decreased since 1936, because of continually increasing effectiveness of the State Engineer's well-control program. This conservation has resulted in increased ground-water storage even during times of less than normal precipitation. (See p. 152.) In the winter of 1939–40 few controllable wells were permitted to flow when not in use, and a large proportion of the observed wastage was from wells which by reason of leaky or corroded casings or defects in construction could not be controlled. Even greater reduction of waste from wells used for stock watering can of course be had by constructing troughs to replace the puddles now in use, and then restricting the flow of wells to the quantity actually used by the stock.

In Parowan Valley many wells that no longer flow are reported to have flowed in the past (pl. 25), and it is evident from the locations of these wells that the area of artesian flow has been more extensive during past years than during March 1940. The area of artesian flow is believed to have been of maximum extent at some time during the period 1912–16 (p. 165), at which time irrigation from flowing wells was a common practice, although pumping for irrigation had not yet begun. The larger area of artesian flow would require higher artesian pressures, and hence it is likely that the rate of discharge of the individual wells was greater than the rate measured in recent years, except of course for those in which pumps have since been installed. During that early period, therefore, it is certain that the discharge from the group of wells considered here—those currently used for purposes other than irrigation—was greater than in recent years, and may have been two or three times as great as the computed wastage from the same wells in 1938 and 1939. During the years 1912–16 these wells were used principally for irrigation, a function which during the past decade has been taken over almost entirely by the pumped wells. The quantity of water discharged for purposes other than irrigation during those early years has not been estimated; presumably it was greater than the amount that has been wasted during recent years since well owners have been making serious efforts at conservation.

POSSIBILITIES OF FUTURE DEVELOPMENT

A reconnaissance survey is enough to indicate that there are prospects for further ground-water development in Parowan Valley. At present it is estimated that less than half of the water that enters the ground-water reservoir is used beneficially. There are considerable losses, both by natural discharge—evaporation from the playa of Little Salt Lake, transpiration from extensive saltgrass meadows, and discharge from numerous small springs—and by discharge from flowing wells, of which the proportion put to a beneficial use is low. The quantities of ground-water discharge in the valley have been shown in the preceding discussion. To summarize here, the discharge from all wells in the valley is estimated by the State Engineer to have ranged between 7,000 and 8,000 acre-feet annually in 1938 and 1939, of which some 1,500 acre-feet was wasted each year. Natural discharge during those years by evaporation, transpiration, and from springs has been about 10,700 acre-feet a year. Transfer of ground water by underflow into Cedar City Valley (Enoch district) is estimated to have been 5,000 acre-feet. Thus, in 1938 and 1939 the total annual ground-water discharge from the valley has been of the order of 23,000 acre-feet.

The amount of inflow, or recharge, to the ground-water reservoir could not be determined directly, because of the many and varied sources of this recharge. Changes in quantity of water stored in the ground-water reservoir, however, afford a basis for estimating the amount of recharge in relation to the discharge from the valley. Thus, if the storage increases, as shown by rising water levels in wells, it is because the recharge exceeds the discharge; declining water levels indicate a decrease in storage and, therefore, discharge at a greater rate than recharge. Measurements of water level in observation wells closest to the recharge area during March of each year—the time of year when storage is greatest—have indicated a slight decline in storage between 1936 and 1937, an increase from 1937 to 1938 and a further increase by 1939, and then a decrease by 1940. (See pp. 151, 164.) Quantitative estimates of the yearly changes in storage are not possible.

The recharge to the ground-water reservoir is dependent upon precipitation and might be expected to fluctuate in response to climatic conditions, thus being greater during wet than dry years. The precipitation at Parowan was considerably below normal during the 3 years prior to 1936, was approximately normal during 1936, 1937, and 1938, and below normal again in 1939 and 1940. It is noteworthy that each year of deficient rainfall was followed by a decline in ground-water levels, and each year of normal precipitation was followed by a year of rising water levels in these wells near the recharge area. Thus, the annual changes in storage indicated above are confirmed by evidence from climatic data.

Changes in high-water levels in wells from year to year since March 1936 have been shown to be small in comparison with the seasonal changes occasioned by discharge from wells. (See pp. 156, 163.) These small changes might be ascribed to fairly constant climatic conditions, for the rainfall during each year from 1936 to 1939 has been within 10 percent of normal. On the other hand, it has been pointed out that the storage during March of each recent year has been not far below the estimated maximum storage in the reservoir, achieved probably some time between 1912 and 1916 (p. 165); and the maximum annual storage, as indicated by high-water levels in wells during March of each year, has probably varied less than 10,000 acre-feet since the beginning of ground-water development. That ground-water storage should reach a fairly constant peak each year is not in accord with the range in rainfall and runoff; especially it does not show cumulative effect on storage of excess recharge during series of wet years, or of deficient recharge during extended drought periods. This constant peak in yearly storage is indicative that greater-than-normal recharge is quickly dissipated by increased natural discharge through springs, evaporation, and transpiration, and that deficient recharge soon results in a correspondingly decreased natural loss.

The discharge from pumped wells is likely to be greater during dry years, when the need for water is acute, than in other years. Thus the total annual pumpage from these wells was 5,450 acre-feet during 1938, when the precipitation was 0.66 inch below normal; 5,800 acre-feet during 1939, when the precipitation was 1.48 inches below normal; and 6,400 acre-feet in 1940, when the precipitation was 1.38 inches below normal.

A striking feature of the ground-water reservoir in Parowan Valley is the small effective storage capacity indicated in the developed area in the Parowan and Little Salt Lake districts. In this respect it may be likened to a surface reservoir in a canyon, which can be emptied by comparatively small withdrawals and is refilled rapidly when runoff occurs. Similarly, the Parowan Valley ground-water reservoir is filled to overflowing practically every year, and then is depleted throughout the developed area by a small amount of withdrawal, so that by midseason many pumps have a lift that approaches the economic limit. The upper limit of this storage is determined by the recharge-discharge relationship that has been described. From this filled reservoir water may be withdrawn down to the limit of economic pumping lift, perhaps 75 feet, a limit which is approached about midsummer in several wells. The quantity of water available between these two limits has been referred to above as the effective storage capacity. Locally the ground-water development has approached this capacity, as will appear in the detailed discussion below.

The problem of future development in Parowan Valley—except in the local areas just mentioned—is quite different from that of Cedar City Valley. The amount of ground water withdrawn for irrigation in Cedar City Valley—commonly about 13,000 acre-feet—may be half to two-thirds of the total recharge in a normal year, and may exceed the recharge in a dry year; hence it has been recommended that further development in that valley be restricted to certain outlying areas. (See pp. 138-144.) In contrast, the quantity of ground water put to beneficial use in Parowan Valley—about 6,000 acre-feet in a normal year—is less than half the amount that is lost from the reservoir annually by wastage and natural discharge. Thus the present development does not approach the maximum development possible in the valley as a whole. The possibilities of future development are considerable although limited by the advisability of so spacing the wells that mutual interference will be minimized. In the past the effect of such interference—an increased pumping lift—has not been foreseen, and some of the irrigation wells have been so closely spaced that they have caused local overdevelopment.

Parowan district.—The Parowan district is the most important ground-water district in Parowan Valley. The amount of water pumped for irrigation in this district was about 4,000 acre-feet annually during

1938 and 1939, and, according to available records for earlier years, the annual discharge since 1930 has been of about this magnitude. The annual discharge ordinarily amounts to about two-thirds of the total quantity of water pumped in the valley; hence, in respect to proportion of ground-water development, the Parowan district is comparable to the Coal Creek district in Cedar City Valley. In most other respects, however, the Parowan district is more nearly comparable to the Midvalley district in Cedar City Valley. Each is located on the lower portion of the largest alluvial fan in its valley, within or adjacent to an area of artesian flow, and each has wells in which nonpumping levels are close to the surface but in which specific capacities are low and areas of influence during pumping extraordinarily large. Thus neither district is a very economical producer of ground water.

All the pumped irrigation wells, and the great majority of all wells, in the Parowan district are on the lower part of the Parowan Creek fan, within a mile of the Culver fault. Evidently Parowan Creek is the chief source of water obtained from these wells. It may be inquired, after study of the distribution of the irrigation wells in this district (pl. 25), whether there is not a possibility of considerable development on the upper part of the Parowan Creek fan, analogous to the Coal Creek district on the Coal Creek fan. From all available evidence the answer is negative. First, the slope of the land surface is greater than 50 feet per mile, whereas the piezometric surface is evidently very nearly flat, so that pumping lifts are likely to be excessive where the land surface is more than 5,800 feet above sea level. In substantiation, well (C-34-9)10bdd1 was abandoned for years, probably because of excessive pumping lift. Secondly, pumping from the area adjacent to the Culver fault appears to cause a pronounced lowering of water level throughout a large portion of the alluvial fan, so that inferentially water is already being obtained from the higher areas by pumps, without the necessity of an excessive amount of lift.

There are no losses of ground water directly from the Parowan district by natural discharge, except perhaps for small quantities dicharging from springs along the Culver fault during the winter. Water moves from the Parowan district across the Culver fault into the Little Salt Lake district, and perhaps also across the Summit Creek fault into the Summit district. Although the Culver fault, particularly, is known to constitute a formidable barrier to ground-water circulation, the quantity of water that crosses it is believed to be considerable, and the Parowan district is thus regarded as an important source of water for the Little Salt Lake district. Although the piezometric surfaces are generally higher on the east than on the west side of the fault, any attempt to obtain further supplies from the east side, that is, in the Parowan district, seems unwarranted because such development would tend to diminish the supplies available to the owners of wells in the Little Salt Lake district, whose legal right to ground water would of course have priority over any contemplated further development, and because irrigation wells on the east side of the fault are already so heavily concentrated that they might be said to get in each other's way, and further development would serve to increase this mutual interference.

Practically no ground water has been developed in the north end of the Parowan district, particularly in T. 33 S., R. 8 W. Ground water is presumed to have entered this part of the Parowan district principally from the Paragonah district across the Parowan fault, and also probably from the adjacent Buckhorn district. Further development of this area could proceed with considerable assurance that there would be little interference with existing rights. The comparative lack of development, however, may be an indication that the Parowan fault, along which dozens of springs have developed, is so effective as a barrier to ground-water circulation that very little water crosses into the Parowan district, and most of the water leaving the Paragonah district is discharged through the springs. If this be true, the northern part of the Parowan district may offer only slight possibilities for obtaining satisfactory irrigation wells. Nevertheless, it is recommended that drilling of new irrigation wells in the Parowan district be limited to the northern part of the district, preferably a mile or more beyond existing pumped wells.

Changes in ground-water storage in the Parowan district can best be estimated from the water levels in wells remote from the area of artesian flow and therefore relatively high on the fan. Well (C–34–9)10bdd1 has been selected as a key well for this purpose, and detailed records of water-level fluctuations are obtained from a continuous water-stage recording gage. The fluctuations observed in this well are checked by periodic measurements in several observation wells outside of the area of artesian flow, particularly wells (C–33–9)34ddd1, (C–33–9)36dcd1, and (C–34–9)16cdd1. If further development is contemplated in the northern part of the district, periodic measurements of pressure should also be made in several of the flowing wells in that vicinity, in order to determine the effect of the new wells.

Little Salt Lake district.—The Little Salt Lake district is the only area, outside of the Parowan district, where any considerable amount of ground water is pumped for irrigation. In 1930 the district yielded nearly 2,000 acre-feet, or about one-third of the total pumped in the valley; since then the annual discharge has declined slightly and in recent years has totalled 1,600 to 1,800 acre-feet. The pumped irrigation wells in the Little Salt Lake district are in the only area in Parowan Valley where there has been a marked decline in water levels since the beginning of ground-water development. They also occupy the portion of the valley where the deline of nonpumping levels is greatest during the pumping season. The conclusion has already been advanced that these declines are caused by the pumping, and that the slight recovery after pumping, as compared with other parts of the valley, is due to the ground-water dam along the Culver fault.

Only five irrigation wells are currently being pumped west of the Culver fault, but they appear to recover practically all the water that can be economically reached in an area of several square miles. Certainly, no further development of ground water is recommended in the vicinity of these wells, or, for that matter, within the area of influence created by pumping from the group, which would cover at least the area in which the seasonal decline during 1940 exceeded 20 feet. (See pl. 24.)

The natural discharge of ground water from the Little Salt Lake district is estimated to be greater than that from all other ground-water districts combined. It occurs primarily by evaporation from the lake bed and by transpiration from vegetation bordering this lake flat. Some of this discharge undoubtedly originated as storm water that flowed down the streams and out over the lake flat and thence entered unsaturated strata above the artesian reservoir. Some water may also have entered this shallow zone as surplus irrigation water, derived from wells or irrigation ditches. The water that is discharged by springs along

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the west border of the lake is probably derived from artesian aquifers, which are thus presumed to be continuous under the lake bed. From these artesian aquifers there also may be some upward migration of water through the so-called confining layers of clay, silt, and sand that give rise to the artesian conditions.

Of the water that enters the area of natural discharge either as stream runoff or irrigation water and then seeps downward into shallow strata, only small quantities are likely to be recovered and put to economic use. Shallow water under the lake flat is so highly mineralized as to be classed as a brine, and would be of no economic value, even if the accumulation of salts on the lake flat did not preclude the use of the water for irrigation. It is obvious, therefore, that any attempt to utilize ground water from this shallow zone would be restricted to the belt of the small saltgrass meadow bordering the lake bed.

Prospects appear to be more favorable for obtaining additional water from the artesian aquifers that underlie the bed of Little Salt Lake, thus reducing the natural losses from the district. The method of making this development is suggested by the effects of pumping from existing wells; the conspicuous decrease in area of artesian flow between March and September 1940 (pl. 25) and the coincident cessation of flows from several springs along the west edge of the lake near Parowan Gap show that artesian pressures have been lowered even in areas more than 2 miles distant from the pumped wells. Farther north, within the area of artesian flow as of September 1940, irrigation wells could be drilled at some distance from the lake bed, and yet pumping from them would doubtless reduce artesian pressures until wells and springs ceased to flow. This development probably would be largely at the expense of natural discharge. However, some 20 wells in this part of the Little Salt Lake district probably would lose their artesian flow during the summer as a result of such development.

The west side of Little Salt Lake does not appear to be very favorable for further development of ground water. Near Parowan Gap steep alluvial slopes border the lake bed and there is little tillable land. One of the few attempts to develop water here is evidenced by a ditch constructed many years ago in the floor of Parowan Gap. Some of the residents declare that the purpose of the ditch was to divert the water of Little Salt Lake through the gap and into Cedar City Valley, but more likely it was an attempt to divert the flow of the several springs that rise along the edge of the lake just north of the gap. Much of the ditch is now filled with debris, but spring water still enters the upper end during the winter and is used by stock in the gap. Farther northeast, near the northeast corner of the Little Salt Lake district, several flowing wells are used for stock watering. Here some additional water could probably be developed by pumping, but the quantity likely would be small, because the water is evidently derived from the canyons that enter Parowan Valley from the northwest, and little recharge is to be expected.

There are very few wells near the south end of the Little Salt Lake district adjacent to the Summit district. The water levels in these wells are appreciably lower than when the wells were drilled, indicating a gradual depletion of storage that is evidently the result of pumping farther north. The seasonal changes of water level in these wells have been small, and it is evident that the pumping does not cause pronounced changes in pressure in the south end of the district. If new wells were drilled here they would encounter water at shallow depth, but the alluvial material would probably be so fine-grained that the yield of the wells would be low per foot of draw-down. Chances of obtaining good wells are believed to be better somewhat farther south in the Summit district, where aquifers might be expected to be coarser and more permeable.

The ground-water storage in the Little Salt Lake district is dependent upon inflow from several sources, of which the Parowan Creek fan is perhaps most important. Changes in storage in the district, however, are not necessarily equivalent or even proportional to those that might be recorded in the Parowan district, because the water that crosses the Culver fault has moved through the Parowan pumping district, and its quantity is therefore determined not only by the recharge but also by the pumpage.

During recent years measurements of water level in wells (C-33-9)-28abd1, (C-33-9)32ccd1, and (C-33-9)34cbd2 have been used to indicate changes in storage in the Little Salt Lake district. All are within the area where seasonal fluctuations due to pumping exceed 20 feet, and thus are considered to be satisfactory indicators of the balance between inflow to the district and pumping therefrom. If additional wells are contemplated outside this area, the new development should of course be accompanied by a program of observation of water levels that would show the effects of the new development on existing conditions.

Paragonah district.—In proportion to the quantity of ground water available in the Paragonah district, the amount used is exceptionally low. No water is pumped for irrigation, and the 70-odd flowing wells in the district are used for stock watering and for a very minor amount of irrigation. Probably a very large percentage of the available ground water in the district is lost, either by discharge from springs near the west edge of the district or by wastage from flowing wells.

The discharge from springs is put to very little use, and elimination of this discharge probably would cause very little harm to anyone. In recent years the flow from these springs has fluctuated in response to varying draft on the artesian reservoir—it has been considerably less during the summer, when most of the wells are flowing, than during the winter, when the wells generally are closed. Presumably the annual discharge from these springs has been less than before the drilling of the wells, when the springs constituted the only surface outlets for ground water in the district. Presumably also if the yearly withdrawal from wells were large enough, the loss from the district by spring discharge would be eliminated.

Probably as a result of the State Engineer's well-control program considerable progress has been made during the past few years on conservation of well water, so that recently the great majority of wells have been closed from November to April, when utilization of water is least. Further conservation will involve some expense, which may be rather small at certain wells requiring only stock-watering facilities or faucets and fittings for regulation, but which may be considerable where uncontrolled wells must be modified. At the present stage of development any considerable expense is probably not justified, for it is likely that the elimination of waste from wells would be accompanied by an increase in spring discharge, and the loss from the ground-water reservoir would continue practically undiminished. Furthermore, several of the wells in this district have been drilled in original spring areas. In any program of reconstructing uncontrolled wells, these should be avoided, for attempts at controlling the well would be equivalent to trying to plug the spring orifice.

The present losses of ground water by spring discharge and by waste from flowing wells could be substantially decreased by the development of several pumped irrigation wells in the district. Following such development, conditions in the Paragonah district would probably be similar to present conditions in the Parowan district. Pumping each year would lower the piezometric surfaces below the land surface, and this would eliminate artesian flow and spring discharge in the district. The water removed from the artesian reservoir would be replaced by recharge from Red and Little Creeks and smaller streams. The maximum utilization would be achieved if withdrawals were sufficient to allow storage space for the entire amount of annual recharge without overflow by springs or wells. The Paragonah district, however, may be analogous to the Parowan district, where draft of an amount equivalent to the recharge would require an excessive pumping lift, and where therefore there is some loss from wells and springs prior to each pumping season.

Little information is available to show what measure of success might be expected in drilling wells for irrigation. Only well (C-34-8)5bca1 was drilled for this purpose, and it was never used. According to the log of this well (p. 47), the gravel strata penetrated by the well have an aggregate thickness of 30 feet, and gravel was found to be at least a minor constituent throughout nearly half the thickness penetrated by the well. Judging by the reported coarseness of much of the material, successful wells might be obtained in this locality, although prospects are believed to be more favorable farther north, toward the axis of the Red Creek fan.

The fans of Red and Little Creeks are smaller but similar to that of Parowan Creek in form and steepness of slope. The gradient of the Red Creek fan northwest of Paragonah is about 50 feet in a mile, and it is likely that the depth to water in the area east of the Paragonah fault will be too great for economical pumping. According to experience in the Parowan district, satisfactory irrigation wells should be obtained in the area just east of the Parowan fault, where springs and flowing wells are now to be found in abundance. Alluvial materials are likely to be coarser, and hence the yield of wells greater, somewhat higher on the fans, perhaps in the vicinity of United States Highway 91.

Changes in ground-water storage under present conditions may be satisfactorily indicated by fluctuations of water levels in two wells located above the area of artesian flow—wells (C-33-8)28bbb1 and (C-34-8)-5bca1. It is believed that further development of ground water can not be made without decreasing and perhaps stopping the flow of existing wells. If construction of pumped irrigation wells is permitted, however, it is certain that the value of the increased supply will far exceed that of the water now used from these wells. Any new development should be accompanied by close observation of water-level fluctuations throughout the district not only to ascertain the effect of the development on existing rights to ground water but also so that further development can be planned and wells spaced to give the greatest yield with the minimum amount of interference.

Buckhorn district.—The Buckhorn district receives ground-water recharge from several small streams that enter the north end of Parowan Valley from the east, north, and west. The inflow to the district probably is small in comparison with the ground-water districts already discribed, but it is sufficient so that there is some natural loss by transpiration in the lowest part of the district and also some discharge from 35 flowing wells. Further development of the ground water in the district by pumped irrigation wells would no doubt eliminate at least a part of the natural losses; in all probability it also would cause several of the existing wells to cease flowing, at least in the vicinity of the new developments.

Two wells have been pumped for irrigation in the Buckhorn district, each used for a short term only, and neither in use at the present time. Well (C-32-8)14ada2 is reported to have been pumped for irrigation as early as 1902. The well at present flows into a pond, which also receives the discharge from wells (C-32-8)14ada1 and (C-32-8)14ada3. Well (C-32-8)26bda1 was dug in 1936 and was tested with a centrifugal pump. Evidently the shallow strata did not yield enough water, and pumping was discontinued. Neither of these wells offers much indication as to the likelihood of obtaining satisfactory pumped wells or the locations where these should be attempted. In general it might be inferred that the most satisfactory locations for wells would be about on the axis of one of the larger fans in the district, just within or slightly above the area of artesian flow. The available supply is not considered to be large, and hence the amount of further development will probably be limited.

Summit district.—Very little ground water is used within the Summit district, and none is lost by natural discharge. Some of the water that is discharged within the adjacent Little Salt Lake district, however, particularly from the little-developed southwestern part, is derived from the Summit district, and might therefore be reclaimed within that district.

Three irrigation wells have been drilled in the Summit district, but only one is now in use. Well (C-34-10)24cda1, 247 feet deep, is reported to have encountered water-bearing gravel between depths of 92 and 240 feet. According to the owner, this well yields 275 gallons a minute with a draw-down of only 9 feet, giving a specific capacity of about 30, which is somewhat higher than that measured in the few irrigation wells tested in the Parowan district. The water level is more than 90 feet below the surface, however, and irrigation water is probably rather expensive, because of the high pumping lift.

Well (C-34-10)24abc1 was drilled 104 feet in 1936, but has not yet been used. The depth to water in this well is about 55 feet, and the pumping lift may be great enough to make the cost of pumping rather high. The other well drilled for irrigation, well (C-34-10)13cca1, is still farther north, and the depth to water is less than 40 feet. The well is reported to have penetrated 56 feet of water-bearing gravel in a total depth of 107 feet, and it would seem that conditions were right for obtaining a productive irrigation well. The ranch has been abandoned for several years, but the reason for abandonment is unknown.

The most likely opportunities for additional development of ground water for irrigation are in the north end of the district, preferably north of the center of T. 34 S., for the water table there is likely to be less than 50 feet below the surface, and pumping lifts would thus be only moderate. It is anticipated that only a small quantity of water is available for further development, because Summit Creek, which furnishes most of the recharge to the area, is only a minor stream. Changes in storage within the district are believed to be well indicated by fluctuations in water level observed in well (C-34-10)24abc1. The effect of new developments should be watched closely in this and perhaps in other observation wells in the district.

Winn basin.—The Winn basin receives inflow principally from the minor streams and canyons that drain the edge of the plateau southwest of the Summit Creek basin. No ground water is utilized within the basin and none is lost by natural discharge. Thus, so far as known, the entire discharge from the basin is by underflow to the Enoch district of Cedar City Valley, where considerable water is withdrawn from wells for irrigation, and where also there is considerable discharge from springs. Any attempts to obtain large quantities of ground water in the Winn basin are believed to have small chance of success, primarily because of the probability that the water table is generally rather far beneath the land surface, and pumping lifts would therefore be excessive in comparison with the Enoch district, where water is commonly obtained within a few feet of the surface. Furthermore, any attempts at development in the Winn basin might be involved in dispute with residents of the Enoch district regarding rights to ground water.

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