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ED. H. WATSON, State Engineer

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GROUND WATER IN TOOELE VALLEY TOOELE COUNTY, UTAH

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GROUND WATER IN TOOELE VALLEY, TOOELE COUNTY, UTAH

By H. E. Thomas

ABSTRACT

Tooele Valley is a typical basin of the Basin and Range Province located about 30 miles southwest of Salt Lake City. It is roughly 15 miles long and 10 miles wide and has a population of about 7,000. Bordered on the west by the Stansbury Range, on the east by the Oquirrh Range, and on the south by South Mountain, it opens northward to Great Salt Lake. The bordering mountain ranges are formed by Paleozoic rocks ranging in age from Lower Cambrian to Pennsylvanian but with the Ordovician and Silurian periods unrepresented. There is no sedimentary record of the interval between Pennsylvanian and Tertiary times, and the Tertiary, Quaternary, and Recent sediments are of continental origin. These continental deposits play the dominant role in the ground-water hydrology of the basin, and were mapped and studied in detail. Pleistocene sediments are of major importance because they form the surface rock over most of the area, and give rise to conditions which yield water by artesian flow in the lower part of the valley.

The development of the present land forms in this area began with the folding of Paleozoic and probably Mesozoic sediments during the Laramide revolution. The cycle of highland erosion and lowland deposition thus initiated has continued through recurrent uplift along Basin-Range faults to the present day. The principal physiographic subdivisions of the valley were developed as a result of the Basin-Range faulting, which began early in the Tertiary and has continued to Recent times.

There are about 1,100 wells in Tooele Valley, about 90 per cent of which yield or have yielded water by artesian flow. Most of them are located in the lower part of the valley below an altitude of 4,400 feet. These wells and many of the springs derive their water from the unconsolidated Quaternary sediments, which include discontinuous, lenticular and commonly elongated bodies of sand, clay, gravel, and boulders of alluvial origin alternating and inter-fingered with lacustrine beds of the same materials which are more regularly stratified and better assorted. The larger springs are intimately related to the bedding planes and faults in the bedrock and alluvial formations. The

well assorted sands and gravels deposited along the shore lines of Lake Bonneville are important as recharge areas for the artesian reservoir.

A zone of coarse sediments 60 to 125 feet thick, encountered at depths of 90 to 210 feet in the western and 180 to 300 feet in the eastern parts of the Grantsville district and at depths of 170 to 230 feet in the western and 100 to 160 feet in the eastern parts of the Erda district, constitutes the principal aquifer in the valley. Several flowing wells yield water from strata above this principal aquifer and some wells reach deeper aquifers. In all cases the deeper wells have a greater head than the shallow wells and some differential head has been observed in wells reaching different parts of the principal aquifer. The several aquifers are not mutually independent and the intervening strata are not truly impervious. Thus the ground water in the valley is considered to occur in a common reservoir in which the strata that separate the aquifers are not continuous enough or impervious enough to form major separations although they undoubtedly have a pronounced local effect on the movement of the water.

The ground-water reservoir is subdivided into the following five districts bounded for the most part by faults: Lake Point, Erda, Marshall, Grantsville, and Burmester. The ground water within each of the subdivisions is derived principally from a common source, has a fairly consistent direction and rate of movement, and ranges within moderate limits in kind and concentration of chemical constituents.

In its broad general aspects the form of the piezometric surface of the principal aquifer is similar to that of the land surface but in detail it is notably different. These differences are due to variations in the permeability of the aquifer, discharge from wells, and ground-water dams produced by faulting. The seasonal changes in form of the piezometric surface are very largely due to seasonal changes in ground-water draft. In most wells the static level is highest each year just before the beginning of the irrigation season, declines during the spring and summer, and reaches a low stage for the year toward the end of the irrigation season. In an intensively developed area of about 2 square miles in Grantsville and another of about 4 square miles in Erda the seasonal fluctuation in 1941 ranged from 2 to 10 feet. On the other hand, in the relatively undeveloped Marshall and Burmester districts the changes of water levels in observation wells from season to season are commonly less than half a foot.

Net changes from year to year of water levels in selected observation wells, measured in December when artesian pressure effects are at a minimum, are the most satisfactory index to the annual changes in ground-water storage. Using this index, comparisons are made of the storage during each year of the decade from 1935 to 1945.

Additions to the ground-water body are received by seepage from streams and underflow in canyons that drain the mountains bordering the valley, direct penetration of rain and melted snow within the valley, and penetration of excess water applied for irrigation. Water rises along faults to form the largest springs in the valley. These faults generally act as conduits for water already in the ground-water basin rather than as sources of additional water. The movement of ground water in Tooele Valley follows more or less the pattern of the surface drainage down the alluvial slopes toward the central and lowest part of the valley and thence northward toward Great Salt Lake. The natural disposal of this water is by springs and by evapo-transpiration especially in the northern part of the valley. The present discharge of springs is nearly 20,000 acre-feet annually, and evapo-transpiration losses may be considerably greater than this amount. In addition to the natural losses, some 6,000 to 7,000 acre-feet are withdrawn each year from wells. Of the total discharge about 10,000 acre-feet from springs and about 5,000 acre-feet from wells is put to beneficial use.

Much of the 11,000 acre-feet now wasted from wells and springs can probably be conserved and put to beneficial use. A part of the large evapo-transpiration losses may also be prevented by sufficiently lowering the head on the artesian aquifers by pumping, but this would greatly increase the cost of the water, which is now obtained by artesian flow. Recommendations are made for the conservation of the water supplies of each district.

Chemically the well and spring waters fall into three classes: calcium-bicarbonate waters of low concentration, sodium-chloride waters of high concentration, and waters of intermediate concentration containing considerable amounts of both of the constituents dominant in the other two types. Increase in mineral load is chiefly in sodium chloride, but although the other mineral constituents do not increase in proportion, their total quantity is commonly greater in the more highly mineralized waters. The areas where there is considerable draft for irrigation, particularly the Erda and Grantsville districts, commonly yield water of better quality than the areas of lesser ground-water development. Most of the sampled wells in the Erda and Grantsville districts contain less than 700 parts per million of dissolved solids.

INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION

The investigation upon which this report is based is one of a series that are being made in cooperation between the Federal Geological Survey and the State Engineer to evaluate the ground-water resources of the State of Utah. A comprehensive study of Tooele Valley was suggested by the State Engineer because of the critical ground-water problems there 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 ground-water division of the Federal Geological Survey. This report comprises a summary of the data and conclusions resulting from the investigation. A more comprehensive analysis will be published as a water-supply paper by the Federal Geological Survey.

General data concerning water-level fluctuations in observation wells in Tooele Valley have been obtained since 1935, when the State-wide cooperative investigation was begun. The detailed investigation which forms the basis for this report was begun in October 1940 under the direction of G. H. Taylor, who had been in charge of the State-wide ground-water project since its beginning. Mr. Taylor was called to active duty with the Army in November 1940, and the investigation was continued by H. E. Thomas. F. C. Foley assisted in the geologic mapping during the spring of 1941, and G. B. Maxey aided in this work during the spring of 1942. Much of the field work involved in the study of ground-water occurrence was performed by W. K. Bach, and P. E. Dennis spent several weeks in the compilation and interpretation of data. The field work was carried on intermittently between October 1940 and June 1942.

The State Engineer of Utah has obtained a considerable amount of data concerning ground-water development throughout the State, and has made freely available all of this information, so that the present report is more detailed and conclusive than would otherwise have been possible. In particular the State Engineer provided locations and elevations of bench marks established at each well in the valley, compilations of the descriptive data concerning the wells as given to him by the well owners, computations of the quantity of water withdrawn from wells in the years 1938 to 1940 inclusive, and a large number of measurements of water level in wells. This information has been drawn upon freely in the preparation of this report, particularly in the discussion of ground-water development.

PREVIOUS WORK

The most valuable sources of geologic information concerning the region are the publications of Gilbert[1] for Pleistocene history of Tooele Valley, and Gilluly[2] for the stratigraphy and structure in an area immediately south and southeast of the valley. The principal hydrologic features of the area are described in a report by Carpenter,[3] which is based on a reconnaissance of Box Elder and Tooele Counties. These and other publications that have been of value in connection with the work in Tooele Valley are noted at appropriate places in the report.

ACKNOWLEDGMENTS

Aerial mosaics of the "Saltair 3" and "Dunstein 4" quadrangles (40°30′ to 40°45′ N. Lat.: 112°15′ to 112°37′30″ W. Long.) and aerial photographs of adjacent areas were furnished by the Soil Conservation Service of the U. S. Department of Agriculture; these form the base for the several maps that are included in this report. The Soil Conservation Service was also responsible for the drilling of the Erda experimental well, which has yielded much valuable information concerning the aquifers underlying the eastern part of Tooele Valley. The International Smelting & Refining Co. made available considerable data concerning the Elton tunnel and waters obtained therefrom, and both that company and the United States Smelting, Refining, & Mining Co. furnished data on water levels in bore holes near Great Salt Lake.

The cooperation of the residents of the area in the field investigation is appreciated. The writer is especially grateful to L. T. Liddell for records of rainfall at Erda, for information concerning the Erda district, and for other assistance; to Volney Crocheron, well driller, for information concerning various wells in the valley; to Franklin Whitehouse, who collaborated with Messrs. Liddell and Crocheron in a compilation of data concerning the history of development of ground water in Erda; to A. N. Barrus, well inspector for the State Engineer, for assistance during special tests; and to Fred Arbon, Ida L. Clegg, Rollin H. Nelson, and the State Land Board for permission to install recording gages upon wells owned by them.

[1]Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Mon. 1, 438 pp., especially pp. 90-153, 189-200, 214-230, 258-318, 340-380, 1890.

[2]Gilluly, James, Geology and ore deposits of the Stockton and Fairfield quadrangles, Utah: U. S. Geol. Survey Prof. Paper 173, 171 pages, especially pp. 1-91, 1932.

[3]Carpenter, Everett, Ground water in Box Elder and Tooele Counties, Utah: U. S. Geol. Survey Water-Supply Paper 333, 90 pp., especially pp. 75-79, 1913.

GEOGRAPHY

LOCATION AND GENERAL FEATURES

Tooele Valley is located in the eastern part of Tooele County, in north-central Utah (fig. 1). The valley is bordered on the north by Great Salt Lake, and is 20 to 40 miles southwest of Salt Lake City. About 7,000 of Tooele County's 9,130 inhabitants (1940 census) live in Tooele Valley. The largest town and county seat, Tooele, is located in the southeastern part of the valley and had a population of 5,001 in 1940, most of whom derived their livelihood from the mining and smelting industry. This population was increased considerably during the war years, due to the construction and operations of the Army's Tooele Ordnance Depot, west of the town. Several agricultural centers are located within the valley, of which the largest are Grantsville, population 1,242, in the northwest part of the valley; Erda, population 188, about 6 miles east of Grantsville; and Lake Point, population 231, in the northeast corner of the valley.

The agricultural districts of Grantsville, Erda, and Lake Point depend almost entirely upon irrigation to produce their crops, chief of which is alfalfa. In the higher southern part of the valley, where the average annual rainfall exceeds 15 inches, dry-farming is moderately successful, and a considerable amount of grain is harvested.

TOPOGRAPHY

Tooele Valley lies within the Great Basin of the Basin and Range physiographic province, which, as Fenneman[4] shows, extends from the Wasatch Range near Salt Lake City westward to include practically all of the State of Nevada and small portions of California. Typical of the valleys of the Great Basin, Tooele Valley is an aggraded desert plain bordered by rugged mountain ranges, and is exceptional chiefly in that it opens northward into Great Salt Lake. The valley is about 15 miles long, from north to south, and is about 10 miles wide at Tooele, increasing to about 17 miles toward its north end.

The Oquirrh Range forms the east border of Tooele Valley. It is less than 30 miles long, but is a link in a roughly linear uplift that is continued, with only a few interrupting lowlands, far to the south in the East Tintic and Canyon Ranges and to the north in Antelope Island, in Great Salt Lake. The Oquirrh

[4]Fenneman, N. M., and others, Physical divisions of the United States: Assoc. Am. Geog. Annals. vol. 6, pp. 19-98, map. 1917.

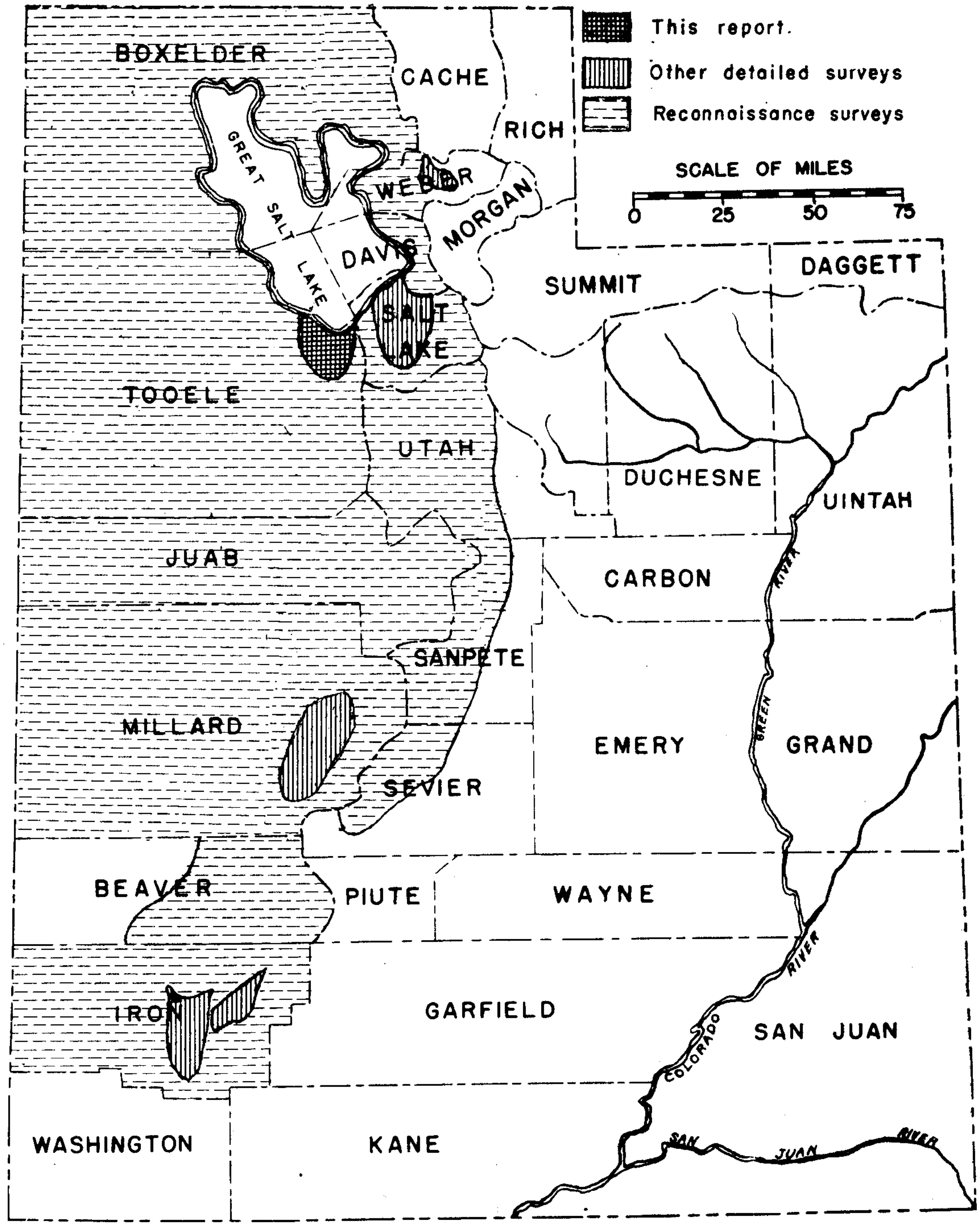

Figure 1.—*Index map of Utah, showing location of Tooele Valley and other areas covered by ground-water investigations.*

Range trends practically north-south and is from 5 to 12 miles wide. The mountains are rugged, especially near the border of Tooele Valley; the highest peak (unnamed) is 10,626 feet above sea level, and several others reach altitudes greater than 10,000 feet.

The Stansbury Range, which borders Tooele Valley on the west, is about 25 miles long and like the Oquirrh Range is only a portion of an uplift that is represented farther south by the Onaqui Range and the Sheeprock Mountains, and to the north by Stansbury "Island," which has been an island in Great Salt Lake only during the highest historic stages of the lake. The Stansbury Range is 2 to 10 miles wide, and its eastern slope toward Tooele Valley is somewhat less precipitous except in the glaciated summit areas than the west slope of either the Oquirrh or Stansbury Range.

Tooele Valley is separated from Rush Valley to the south by a comparatively low transverse divide, South Mountain. The floor of Rush Valley has a gentle northward slope but there is no surface drainage into Tooele Valley, and its lowest portion, at the extreme north end, is occupied by Rush Lake, a fresh-water body. Practically the entire area of Tooele Valley was formerly occupied by the waters of Lake Bonneville,[5] whose shores extended along the bases of South Mountain and the Stansbury and Oquirrh Ranges. The shore features of that water body are clearly recognizable throughout Tooele Valley and one of the most marked—the Stockton bar[6]—has been instrumental in closing Tooele Valley to drainage from Rush Valley (see p. 194 for a discussion of the permeability of the Stockton bar).

The drainage of the mountain masses is effected by ephemeral streams occupying many small canyons and a few perennial streams occupying large canyons. The principal streams entering Tooele Valley from the Stansbury Range are North Willow, South Willow, and Box Elder Creeks, all of which furnish water for use in Grantsville and vicinity. From the Oquirrh Range the principal drainage courses are Settlement, Middle, and Pine Canyons, of which the first two carry perennial streams appropriated for use in the town of Tooele and vicinity. All these streams are very small, though of vital importance to the people of the region. Their courses are generally toward the central and lowest part of Tooele Valley and thence northward toward Great Salt Lake. Tooele Valley is thus a part of the drainage basin tributary to Great Salt Lake.

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[5] Gilbert, G. K., op. cit.
[6] Idem. pp. 137, 143

CLIMATE

The climate of western Utah ranges from arid to semiarid. Precipitation is ordinarily least over Great Salt Lake and the adjacent Salt Lake desert, which extends westward to the Nevada state line, where the mean annual precipitation is less than 6 inches. In Tooele Valley the annual rainfall is ordinarily least at the north end along the border of Great Salt Lake, and increases toward the south, east, and west borders of the valley.

The mean annual precipitation at Tooele in the period 1897-1945 was 16.67 inches, according to records of the Weather Bureau, which are given in the following table. Records of rainfall at Grantsville (12 miles northwest of Tooele) and at Erda (6 miles north of Tooele) are available for periods of 27 and 9 years respectively. Comparison of these records with data for corresponding years at Tooele shows that the annual precipitation at Grantsville averages about 6½ inches less, and at Erda 5 inches less than at Tooele. Comparison of annual precipitation is shown graphically in figure 2.

The precipitation that falls on the Oquirrh and Stansbury Mountains to the east and west of the valley is an important factor in the recharge of the ground-water basin, and also supplies the surface water for irrigation in the valley. No precipitation stations have been established on either range, but records are available for stations at various altitudes on the Wasatch Range about 40 miles east of Tooele Valley. From these records it appears that the precipitation increases more or less proportionately with increasing altitude, and the mountains above 7,000 feet in altitude may be expected to receive more than twice as much and the crests at 10,000 feet perhaps three times the amount of precipitation that falls upon the floors of the valleys.

The graph of cumulative departure from normal precipitation at Tooele, shown in figure 2, portrays the trend of long-term deficiencies or excesses of precipitation. On the curve, abnormal periods of rainfall are indicated by a rising trend and subnormal precipitation by a declining trend. The curve drops sharply during the periods of most severe drought on record, from 1899 to 1903, and from 1931 to 1939. The rising trend from 1905 to 1922 and from 1940 to 1945 indicates periods when precipitation was generally above normal, and the horizontal trend from 1923 to 1931 indicates a series of years of approximately normal precipitation. This curve has significant relationships to the changes of storage in the ground-water reservoir, which will be developed more fully in a later chapter.

The precipitation is distributed rather irregularly throughout the year. It is greatest during the four months from February to May, when more than 40 percent of the annual total is commonly received. Ordinarily only about 20 percent of the total falls from June to September, when the farmers need it most.

Monthly and Annual Precipitation at Tooele, Utah, in Inches

(From Records of U. S. Weather Bureau)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1896			1.09			0.02	0.88	0.93	0.30	0.92	2.07	0.29	
1897	1.15	1.95	1.68	0.91	0.36	0.16	0.91	0.51	0.18	2.92	1.83	1.93	14.49
1898	0.75	0.34	2.38	1.21	6.35	1.58	0.14	0.38	0.13	2.40	1.79	0.80	18.25
1899	0.27	1.29	2.88	0.58	2.28	2.43	0.63	0.98	0.03	1.46	0.79	1.25	14.87
1900	0.80	0.78	0.29	3.95	0.36	0.12	0.32	0.36	1.92	1.53	1.87	0.01	12.31
1901	0.74	0.92	1.54	1.33	3.71	0.72	0.35	0.82	0.20	1.14	0.89	1.83	14.19
1902	0.67	0.55	1.19	2.32	1.26	0.10	0.29	0.14	0.18	0.28	2.56	0.58	10.12
1903	1.46	1.05	1.80	1.73	1.60	0.19	0.05	T	0.79	0.77	1.64	0.95	12.03
1904	2.82	2.10	4.25	2.05	3.84	0.40	0.55	0.55	0.17	0.75	0.00	0.65	18.13
1905	1.02	1.03	3.21	1.88	1.42	T	0.11	1.15	2.19	0.55	1.67	0.71	14.94
1906	0.66	1.57	3.26	3.17	2.66	1.14	0.61	2.85	1.26	0.54	1.84	0.75	20.31
1907	1.87	1.98	2.69	0.82	2.23	1.68	0.43	1.43	0.05	1.85	0.62	2.00	17.65
1908	0.97	1.34	1.39	0.65	5.48	1.29	0.65	2.05	3.85	2.48	2.34	1.01	23.50
1909	1.94	2.36	2.75	2.09	1.73	0.18	1.90	2.93	2.54	0.44	2.12	1.99	22.97
1910	2.14	1.15	0.96	0.64	0.49	0.02	1.35	0.41	0.72	1.67	0.85	0.74	11.14
1911	1.40	2.23	1.73	1.50	0.86	1.21	0.21	0.06	1.11	1.70	1.18	1.07	14.26
1912	0.48	0.79	4.12	2.27	1.87	1.16	0.46	1.17	0.82	4.43	1.68	0.43	19.68
1913	1.19	1.79	1.95	2.92	1.00	3.34	2.33	0.23	1.66	1.24	1.87	1.01	20.53
1914	2.91	1.77	1.42	2.90	1.50	2.53	1.81	0.65	0.48	2.35	0.25	0.57	18.14
1915	1.30	3.10	1.70	2.35	3.46	0.26	0.11	0.06	2.43	0.10	1.14	1.73	17.74
1916	4.74	1.02	2.88	1.11	0.81	1.03	0.25	1.21	0.80	1.91	1.47	2.55	19.78
1917	1.36	1.49	1.58	2.79	4.23	0.15	1.60	0.12	1.03	0.04	1.69	0.25	16.33
1918	3.11	2.24	1.26	1.13	1.57	0.24	0.97	T	1.18	1.70	1.37	0.41	15.18
1919	0.11	2.20	0.72	1.91	1.12	0.00	0.48	0.52	1.19	3.29	1.78	1.55	14.87
1920	1.53	1.29	4.37	4.90	1.60	0.51	1.27	0.75	0.21	4.16	1.52	2.30	24.41
1921	1.29	1.64	2.45	4.89	2.36	0.50	0.58	1.25	0.89	1.85	0.51	1.93	20.14
1922	1.83	2.00	3.08	4.36	2.71	0.51	0.31	1.56	0.03	1.21	3.60	2.22	23.42
1923	1.79	1.05	1.49	3.59	2.33	0.71	0.52	0.47	1.97	3.50	0.48	2.26	20.16

Monthly and Annual Precipitation at Tooele, Utah, in Inches (continued)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1924	0.75	*0.3	*1.5	*1.8	*1.4	0.00	0.04	0.73	0.55	1.56	1.24	2.71	*12.6
1925	0.46	1.92	1.43	2.45	1.81	1.53	1.11	1.27	0.89	1.23	2.53	0.67	17.30
1926	1.12	2.12	0.94	1.05	3.11	0.77	1.64	1.37	0.72	0.60	0.93	1.50	15.87
1927	0.92	1.76	3.15	2.35	1.47	0.84	0.33	0.91	1.93	0.95	1.76	1.42	17.79
1928	0.68	0.42	2.59	1.97	1.84	0.60	0.37	0.03	T	2.76	2.81	0.58	14.65
1929	1.28	1.24	2.59	3.80	0.10	0.54	0.66	1.05	2.28	1.78	0.47	0.52	16.31
1930	1.11	2.36	1.10	1.44	1.31	0.18	1.70	1.79	2.43	2.00	2.11	0.16	17.69
1931	0.17	1.31	1.13	2.05	0.44	0.37	1.34	0.35	0.40	0.54	2.32	1.50	11.92
1932	1.66	1.26	1.21	1.51	0.28	2.08	0.25	2.86	T	1.91	0.42	1.55	14.99
1933	1.80	1.15	1.14	2.38	3.00	0.02	0.31	0.70	0.53	0.94	1.11	0.74	13.82
1934	1.58	1.71	0.08	0.21	0.05	0.53	1.34	1.40	0.87	0.68	2.52	1.63	12.60
1935	0.12	1.76	1.20	2.39	2.36	0.14	0.28	0.41	0.46	T	0.95	1.66	11.73
1936	1.16	3.13	1.41	0.67	0.49	1.73	2.46	0.87	0.18	0.89	1.60	2.15	16.74
1937	2.44	1.89	0.84	1.58	1.31	0.43	2.79	0.97	1.20	1.11	0.64	1.29	16.49
1938	0.82	2.01	4.89	2.14	2.00	0.21	1.03	0.99	0.24	2.00	1.79	0.93	19.05
1939	1.43	2.00	0.66	0.68	0.67	1.36	0.15	0.39	0.81	1.22	T	0.56	9.93
1940	2.48	2.25	2.73	1.55	0.39	0.22	0.09	0.17	2.07	1.80	3.06	1.60	17.91
1941	0.65	2.44	1.83	2.76	1.81	1.15	1.15	1.01	0.44	3.21	1.38	3.29	21.12
1942	0.65	0.91	2.22	1.99	2.61	0.86	1.33	0.27	0.94	1.91	2.17	1.09	16.95
1943	1.04	2.15	1.46	0.60	1.10	1.19	0.67	1.16	T	1.52	0.38	0.87	12.14
1944	1.31	1.60	4.29	3.95	2.17	2.10	0.02	T	0.68	0.61	2.13	0.67	19.53
1945	0.56	1.97	2.81	2.50	1.23	3.16	0.33	2.37	0.66	0.64	2.41	1.47	20.11
49-year mean	1.32	1.59	2.03	2.08	1.84	0.86	0.78	0.89	0.94	1.56	1.52	1.26	16.67

*Estimated from surrounding stations.

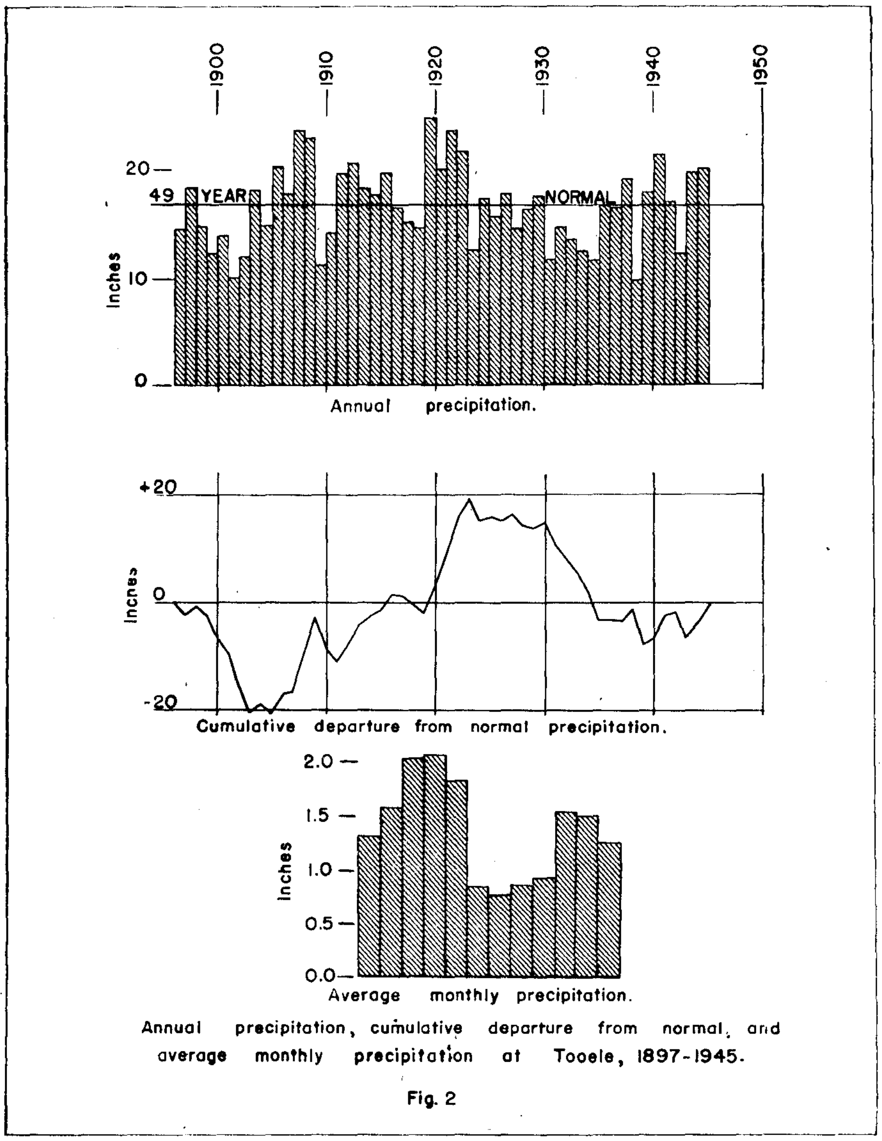

Figure 2.—*Annual precipitation, cumulative departure from normal, and average monthly precipitation at Tooele, Utah.*

GEOLOGY

STRATIGRAPHY

GENERAL RELATIONS

The rocks exposed in the drainage area tributary to Tooele Valley range from Lower Cambrian to Recent in age. The geologic map that accompanies this report covers in detail only the area of Tooele Valley and the lower slopes of the encompassing mountain ranges, where the formations are Carboniferous to Recent in age. The higher parts of the Stansbury and Oquirrh Mountains, which form the limits of the Tooele Valley watershed, were covered by rapid reconnaissance, and individual formations were not mapped. Paleozoic rocks are exposed in the southern part of the Oquirrh Range, where they have been studied by Gilluly,[7] and are also well exposed in the higher parts of the Stansbury Range. The Paleozoic history of the region, as summarized by Gilluly,[8] includes submergence and marine sedimentation during the Cambrian period, probable emergence and erosion as indicated by absence of any sediments of Ordovician and Silurian age, a short re-submergence in the middle part of the Devonian, emergence, and then re-submergence early in the Mississippian epoch of the Carboniferous period, followed by accumulation of a great thickness of marine Carboniferous sediments culminating in the Oquirrh formation, which alone comprises more than 15,000 feet of interbedded quartzite and limestone.

No sedimentary record of the interval between Pennsylvanian and Tertiary time is to be found in the Tooele Valley region. However, as Gilluly points out, "the presence of Permian, Triassic, and Jurassic rocks in considerable thickness in the Park City district,[9] about 30 miles to the east, suggests that during at least part of this time the site of the southern part of the Oquirrh Mountains was receiving deposits. It was probably emergent during most of Cretaceous time, however." Toward the end of this long interval of missing sedimentary record, the Paleozoic rocks were compressed to form large folds with a general north to northwesterly trend, probably as part of the Laramide orogeny. The development of present land forms in Tooele Valley may be said to have begun with this folding.

Following the late Mesozoic or early Tertiary orogeny, sediments of probable Eocene age, considered to be equivalent to the Wasatch formation elsewhere in Utah, were deposited along the east flank of the major anticlinal fold that now forms the Stansbury Range, and may have been distributed widely as fluviatile and perhaps lacustrine deposits in Tooele Valley. After the deposition of the Wasatch formation, volcanic eruptions on a moderate scale distributed latitic flows, breccias, and

[7]Gilluly, James, Geology and ore deposits of the Stockton and Fairfield quadrangles, Utah: U. S. Geol. Survey Prof. Paper 173, pp. 6-34. 1932.
[8]Idem. pp. 90-91.
[9]Boutwell, J. M., and Woolsey, L. H., Geology and ore deposits of the Park City district, Utah: U. S. Geol. Survey Prof. Paper 77, pp. 49-59, 1912.

tuffs over the region. Basalt was erupted locally in the Stansbury Range as the last stage of volcanic activity in the area. These volcanic rocks have been extensively eroded from the highland areas and redeposited by streams at lower elevations.

Block faulting typical of the Basin and Range province appears to have begun during the volcanic activity and has continued intermittently to the present day. This faulting has involved the rotation of huge blocks of the earth's crust, with resultant large displacements along the faults that form the east and west boundaries of the blocks. The raised western portions of these blocks now form the Oquirrh and Stansbury Ranges, and the depressed part of the Stansbury block with its alluvial cover forms Tooele Valley. Skull Valley, west of the Stansbury Range, and Jordan Valley, east of the Oquirrh Range, appear to be analogous valleys formed on the depressed portions of adjacent blocks. The entire sedimentary sequence of which these blocks are composed was tilted eastward by the rotation.

Throughout the Tertiary and probably a large part of the Quaternary period the region has had an arid climate. Tooele Valley and similar depressed areas were filled to unknown depths by torrential stream and playa deposits. The rate of sedimentation was probably increased following each displacement along the major normal faults, due to more rapid erosion of the uplifted mountain masses.

The desert-basin deposition was followed during the Pleistocene by at least one epoch, and probably several earlier epochs, when the climate of the region was humid and cold. During the last epoch, probably corresponding to the latest (Wisconsin) glacial stage farther east, waters accumulated in the interior basins that make up the Great Basin, and rose until great inland lakes were formed. The largest of these, Lake Bonneville, had a maximum areal extent of nearly 20,000 square miles and a maximum depth of about 1,000 feet. In Tooele Valley the lacustrine phenomena resulting from the incursion of this lake are remarkably distinct and constitute at the present time the dominant physiographic features throughout the area that was covered by the lake. During the Pleistocene also, probably contemporoeous with the development of Lake Bonneville, the summit areas of the Stansbury and Oquirrh Ranges were glaciated. Since the end of the Pleistocene the geologic record has been one of gradual but progressive subsidence of the ancient lake, increasing dessication of the region, and reestablishment of the desert basin cycle of highland erosion and torrential deposition in the lowlands.

The Quaternary deposits are of predominant importance so far as the water resources of Tooele Valley are concerned, and all older rocks, including the thick Paleozoic section and the Tertiary effusives and continental deposits, play a minor role.

The stratigraphy of the Tooele Valley area is summarized in the following table.

Stratigraphy of Tooele Valley and Environs, Tooele County, Utah

Generalized Section[a]

Geologic age: System	Geologic age: Series	Group or formation and symbol on plate 1	Maximum thickness (feet)	General character	Water-bearing properties
Quaternary	Recent	Dunes (Qd)	10	Aeolian deposits, dominantly silt along the borders of Great Salt Lake, coarser and more sandy on higher parts of the valley floor.	Permeable sand in deposits so shallow as to be of no economic value as a source for water.
		Lacustrine deposits (Ql)	5	Evaporites, clay, silt, and perhaps some coarser sediments, deposited on the floor of Great Salt Lake	Fine clastics impregnated by soluble salts and saturated at very shallow depths. Brines yielded by these lacustrine deposits may be of economic value.
		Alluvium (Qal)	50	Poorly assorted boulders, gravel, sand, and silt, forming torrential deposits in canyons and on alluvial fans.	Permeability has a wide range, depending upon coarseness of material and degree of sorting. Deposits on upper parts of fans are commonly highly permeable.

Stratigraphy of Tooele Valley and Environs (continued)

Geologic age		Group or formation and symbol on plate 1	Maximum thickness (feet)	General character	Water-bearing properties
System	Series				
Quaternary (continued)	Pleistocene	Lake Bonneville beds (Qb)	530	Well assorted gravel, sand, and cobbles of ancient beaches, bars, and other shore features along the edges of the valley; lacustrine sand, silt, and clay in central part of valley.	Coarser materials extremely permeable, constituting principal source of ground water in the valley. Fine materials have low permeability and form the confining layers that give rise to artesian conditions.
		Alluvium (Qt)	50	Poorly assorted boulders, gravel, sand, and silt, forming terraces along larger stream courses.	Highly permeable deposits in very narrow belts above present stream beds.
		Glacial moraines (Qm)	300	Unassorted angular to subrounded quartzite boulders, cobbles, gravel, and sand forming lateral and medial moraines near summits of ranges.	Highly permeable, but less so than the coarse alluvium which has since accumulated in the canyon bottoms.

Stratigraphy of Tooele Valley and Environs (continued)

Geologic age		Group or formation and symbol on plate 1	Maximum thickness (feet)	General character	Water-bearing properties
Series	System				
Tertiary and Quaternary (?)	Pliocene and possible Pleistocene (?)	Salt Lake formation (QTsl)	350	Gray to buff beds of water-worn boulders, gravel, and sand, commonly consolidated, forming fanglomerates along the base of the ranges. Materials derived chiefly from limestone and quartzite, but toward the base an increasing proportion of debris of volcanic origin. In the central part of the valley, buried under the Pleistocene Lake Bonneville beds, finer sediments of fluviatile and perhaps in part of lacustrine origin are probably contemporaneous.	Similar in coarseness and texture to recent alluvial deposits in comparable locations in the valley, (that is, gravel along the mountains and finer sediments in the central part of the valley), but with porosity reduced by cementation.
Tertiary	Pliocene (?)	Basalt (Tb)	200	Medium-gray dense to scoriaceous basalt, in thin flows of small extent.	Impermeable except along joints and possibly through certain vesicular zones. Outcrop area too small to have much bearing on ground-water occurrence.

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Stratigraphy of Tooele Valley and Environs (continued)

Geologic age: System	Geologic age: Series	Group or formation and symbol on plate 1	Maximum thickness (feet)	General character	Water-bearing properties
Tertiary (continued)	Miccene (?)	Tuff (Tst)	850	Fluviatile tuff whose particles range from sand grains to boulders. Very few thin and probably local latite flows.	Permeability probably about equal to that of the Salt Lake formation.
		Unconformity			
		Agglomerate (Tsa)	1,500	Latite breccias and flows, gray to brown, weathering brown or dark red, and tuffs, weathering white. Breccias form hard, resistant hogbacks, tuffs commonly easily eroded.	Relatively impermeable consolidated rocks that form barriers to ground-water movement down many canyons, and thus give rise to numerous springs.
		Unconformity			
	Eocene	Wasatch formation (Tw)	100	Coarse fanglomerate, composed chiefly of subangular to subrounded fragments of Paleozoic limestone and quartzite firmly cemented with a pink calcareous cement.	Presumably relatively pervious in comparison with other consolidated rocks, but an unimportant source of water in Tooele Valley because of limited outcrop area and deep burial elsewhere under younger formations.
		Unconformity			

Stratigraphy of Tooele Valley and Environs (continued)

Geological age		Group or formation and symbol on plate 1	Maximum thickness (feet)	General character	Water-bearing properties
System	Series				
Carboniferous	Permian (?) and Pennsylvanian	Oquirrh formation (Co)	15,000+	Interbedded quartzite and limestone, some beds fossiliferous.	Permeable zones, formed by solution of limestone, give rise to a few springs. Most of formation appears to be dense and impermeable.
Carboniferous	Pennsylvanian and Mississippian	Manning Canyon shale (Cm)	500+	Shale and shaly limestone, with two thin persistent quartzite beds in lower part.	Relatively impermeable because of high proportion of shale. Numerous springs rise in canyons at upper limit of outcrop.
Carboniferous to Cambrian	Mississippian to Cambrian	Undifferentiated Paleozoic rocks (CCu)	6,900	A thick series of marine sediments, chiefly limestone, some dolomite, quartzite, and shale, described in detail by Gilluly in the Stockton-Fairfield district, and recognized in the South Willow Canyon section.	Cavernous limestones form the chief permeable zones and give rise to numerous springs in the mountainous areas where these rocks are exposed.
Cambrian	Lower Cambrian	Tintic quartzite (Ct)	4,000+	Massive white to pink metaquartzite, weathering to buff color. Conglomeratic zones toward base.	Bedding planes and fractures form the only permeable zones.

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

UNCONSOLIDATED DEPOSITS IN TOOELE VALLEY

PLIOCENE AND PLEISTOCENE (?) SERIES

SALT LAKE FORMATION

Along the base of the Stansbury Range alluvial beds rest upon a tuff formation of Miocene (?) age and grade downward into the uppermost beds of that formation. Elsewhere along that range and along the base of South Mountain and the Oquirrh Range the beds rest with marked unconformity upon Palezoic rocks. These alluvial beds are older than the deposits of Lake Bonneville, and have been eroded and reworked by waves and shore currents of that lake, particularly during the highest (Bonneville) stage. The beds are regarded as probable Pliocene and perhaps lower Pleistocene age, and are included in the Salt Lake formation.[10]

The Salt Lake formation forms the foothill slopes above the highest shore line of Lake Bonneville in discontinuous areas along the margin of Tooele Valley. It is especially well exposed in the southwestern part of the valley where it is cut by the canyons of North Willow, South Willow, and Box Elder Creeks. In these exposures the formation is a typical fanglomerate, comprising poorly assorted subangular to subrounded boulders, gravel, and sand in irregular beds loosely to firmly cemented by a calcareous cement. The formation is especially well exposed along South Willow Canyon above the tuff formation of Miocene (?) age, and includes 470 feet of well-cemented conglomerate, consisting of poorly rounded to angular boulders and pebbles in a matrix of silt and sand. Limestone pebbles predominate, but volcanic fragments are common, particularly in the lower beds. Quartzite pebbles are rare except in the uppermost beds at the ridge top. Higher ridges farther south may expose beds as much as 100 feet higher stratigraphically than the section in South Willow Canyon. The ridge tops appear to be remnants of a somewhat dissected piedmont plain having a slope valleyward of 10 to 12°, which probably represents the upper limit of deposition of the Salt Lake formation and which was dissected during the Pleistocene, when streams had increased erosive power. If the slope of the plain represents the inclination of the uppermost beds of the formation, those beds dip more gently than the base of the formation, and further tilting is indicated analogous to that which occurred during the deposition of the Miocene (?) tuff.

The Miocene (?) tuff and Salt Lake formation together record the denudation of the Stansbury Range following the Tertiary volcanic activity. Most of these extrusive rocks were

[10]This term was suggested by Mansfield (Geography, geology, and mineral resources of southeastern Idaho: U. S. Geol. Survey Prof. Paper 152, pp. 110-112, 202-203, 1927) for beds originally described as the "Salt Lake group" by Hayden and Peale, both of whom noted that the beds were widely distributed along the margins of the mountains surrounding the valley of Great Salt Lake, as well as in other parts of northern Utah and southeastern Idaho.

removed from the range during the interval of time represented by the tuff, and the thick Paleozoic limestones and quartzites were being extensively eroded during the time represented by the Salt Lake formation. The Tintic quartzite, which now forms the crest of the range, was not exposed over any considerable area until later, as shown by the absence of fragments except in the uppermost beds of the Salt Lake formation. The erosion of the quartzite has progressed in subsequent time, and that rock constitutes a dominant proportion of Pleistocene and Recent deposits.

On the east side of Tooele Valley, along the base of the Oquirrh Range, the outcrops of the Salt Lake formation are of much smaller areal extent, and the constituent materials are prevailingly coarser, as is to be expected, for the western front of the Oquirrh Range is more precipitous than the east slope of the Stansbury Range. It is also likely that the angle of deposition of the beds along the Oquirrh Range was generally greater than that of the sediments at the foot of the Stansbury Range. However, the beds of the formation along the Oquirrh Range now dip valleyward at angles prevailingly less than the inclination of beds along the Stansbury Range, presumably because of eastward tilting of all beds by later block faulting.

The exposures of the Salt Lake formation in Tooele Valley represent only the margins of a depositional area that is doubtless continuous under the floor of the valley and northward under Great Salt Lake. The greatest thickness exposed in these outcrops (estimated less than 600 feet opposite South Willow Canyon) is considered to be less than the maximum thickness of the formation where it is buried under subsequent deposits, but no information is available as to that maximum thickness. Well (C-1-5)31dbb1,[11] drilled for oil in the north-central part of the valley to a depth of 1,265 feet (p. 140), apparently did not reach the volcanic rocks that presumably underline the Salt Lake formation. In the Jordan Valley, which lies east of the Oquirrh Range, volcanic rocks have been encountered in a well drilled 1832 feet deep, and a 2½ foot bed of tuff was reported at 1,308 feet.[12] In both wells the uppermost beds encountered are those of Lake Bonneville and probably earlier Pleistocene lakes, which extend to an unknown depth. The sediments underlying these Pleistocene lake beds and overlying the volcanic rocks presumably belong to the Salt Lake formation.

The outcrops of the Salt Lake formation in Tooele Valley are composed of coarse, poorly-assorted, loosely consolidated debris that is presumably moderately permeable. The buried equivalents of these beds under the floor of the valley are doubtless of finer texture, perhaps somewhat better assorted

[11]For explanation of well-numbering system in Utah, see Thomas, H. E., and Bach, W. K., Utah, in Water levels and artesian pressure in observation wells in the United States in 1940, pt. 5, Northwestern States: U. S. Geol. Survey Water-Supply Paper 910, p. 38, 1941.

[12]Eardley, A. J., and Haas, Merrill, Oil and gas possibilities of the Great Salt Lake basin; Utah Acad. Sci. Arts & Letters Proc. vol. 13, p. 73, 1936.

but probably less permeable, particularly beyond the north end of the valley under Great Salt Lake, where clay is doubtless an important constituent.

PLEISTOCENE SERIES

ALLUVIUM

The Pleistocene history of the ranges bordering Tooele Valley was presumably one of stream erosion in the higher areas and transportation of the debris to the lowlands, which in the latter part of the Pleistocene epoch were in large part submerged by the waters of Lake Bonneville. In the mountains, therefore, degradational processes continued which had been in operation throughout the Tertiary period, with this difference: during the humid climate that is postulated for the Pleistocene epoch the streams must have had more volume than in pre-Pleistocene times, with consequent increases of erosive power in the highlands and carrying power at lower elevations. Tertiary deposition was followed, at least in certain areas, by renewed erosion and lowering of grade of streams—perhaps because of this postulated change in climate, perhaps because of diastrophic changes discussed in a later chapter.

Alluvial features tentatively correlated with the Lake Bonneville beds are the terraces developed by streams at several levels between the present canyon beds and the piedmont plain on the Salt Lake formation. Alluvial terraces are well shown along the south side of South Willow Canyon, in secs. 32 and 33, T. 4 S., R. 6 W., where the piedmont plain formed on the top beds of the Salt Lake formation has an eastward slope ranging from 10° to about 5° at its easternmost extensions. Below this plain a terrace can be traced continuously along the side of the canyon for nearly 2 miles; this terrace has a slope of about 3° and a maximum width of about 800 feet. At its lower end it appears to merge with the plain on the Salt Lake formation. About 35 feet below this terrace and approximately parallel to it, a second terrace extends for a distance of nearly a mile, and fans out into a broad plain nearly half a mile wide. This lower terrace appears to extend to the highest shoreline of Lake Bonneville, and is evidently the remnant of the flood plain of the stream when that lake was at high stage. It is about 25 feet above the present flood plain of the creek.

Settlement Canyon appears to have had an analogous history, for there are two terraces, the higher one extending up the canyon for a distance of about 4,500 feet from its mouth, and the lower apparently correlative with the Bonneville stage of Lake Bonneville. The alluvium of both terraces is coarse, poorly assorted, with boulders nearly a foot in diameter, and roughly bedded. At the Bonneville shore line the present stream has developed a flood plain about 25 feet below the lower (Bonneville) terrace, which extends little more than half a mile upstream from the mouth of the canyon. The stream descends to this flood plain through a gorge from a higher flood plain in the upper part of the canyon, which appears to be equivalent to the Bonneville terrace at the mouth of the canyon. It appears that the stream has developed the lower flood plain during its Recent history by cutting headward in the old Pleistocene flood plain, a process which has proceeded for a distance of half a mile from the mouth of the canyon.

Two terraces are prominent also along the east side of Middle Canyon. The lower terrace is about 40 feet above the present flood plain, and appears to extend to the highest shore line, so that it is correlated with the Bonneville stage. It has a slope of about 3°. The other terrace is about 30 feet higher and parallel to it. Both are well below the piedmont plain on the Salt Lake formation.

In Box Elder Canyon one terrace is clearly evident south of the flood plain for a considerable distance above the canyon mouth. The stream has eroded hardly at all at the Bonneville shore line, and the flood plain, 300 to 700 feet wide, that extends upstream from that point is considered to be the old Pleistocene flood plain (equivalent to the Bonneville terraces in other streams described above) into which the present channel is only slightly entrenched. The terrace above this flood plain has an eastward slope of nearly 5° and is 125 feet above the flood plain at Martins Fork but only 65 feet higher 2 miles downstream. A single Pleistocene terrace was observed and mapped also along North Willow Canyon.

The material of these terraces is comparable in texture, size, sorting, and presumably in permeability to the Recent alluvium along the stream beds below the terraces. The Pleistocene terraces are of small areal extent, and are high enough above present stream beds that they probably do not influence seepage from the streams or recharge to the ground-water reservoir in the valley.

Pleistocene alluvium has not been identified in the valley floor below the highest level of Lake Bonneville, for it has been covered or reworked there by lake processes. It is believed to occur, however, beneath the surface of the valley, and is encountered in wells, where sediments of alluvial origin alternate with beds believed to be lacustrine, presumably deposited in intermontane lakes antedating Lake Bonneville. (See page 133.)

LAKE BONNEVILLE BEDS

General Statement

The Lake Bonneville beds are of major importance in Tooele Valley, from the standpoint of areal extent, physiographic expression, and general economic value. The lake at its maximum stage covered the entire floor of the valley, and washed against the bases of the mountains to the east, south, and west. The entire area below this highest shore line, approximately 1,000 feet above the present level of Great Salt Lake and 5,200 feet above sea level, has received lake sediments. The topography below that level is dominated by features of lacustrine origin which have been very little modified by subsequent activity of wind and stream; the Tertiary and older formations crop out chiefly in the marginal areas of higher land.

The history of Lake Bonneville, the shore features and their development, the deposition within the lake, and the relation of the lake to Pleistocene volcanism and diastrophism have been described in detail by Gilbert,[13] and his monograph is freely drawn upon in the present discussion. It is evident from Gilbert's descriptions that the record of Lake Bonneville in Tooele Valley is outstanding when compared with the record in other areas covered by the lake, so that the valley might be termed a type locality for the Lake Bonneville features. Many features are described and figured in greatest detail, and numerous others are referred to briefly. The Pleistocene history of the Bonneville Basin is summarized from Gilbert's work in the following paragraphs, and subsequent sections are devoted to the detailed record in Tooele Valley.

Lake Bonneville at its highest stage—the Bonneville stage —had a maximum depth of about 1,050 feet, an area of nearly 20,000 square miles, and a shore line more than 2,500 miles long. The submerged area included small portions of Idaho and Nevada, and extended in Utah from Cache County to Utah County and thence to Iron County, an area whose greatest length is nearly 350 miles. The outline of the lake at this stage was intricate, with many promontories and islands formed by the Basin Ranges, and deep bays where the lake extended over the intervening valleys. By reason of its position at the top of a series, marking the boundary between land sculpture and lake sculpture, the Bonneville shore-line is the most conspicuous of all shore lines.

The record of Lake Bonneville preceding this maximum stage is one of an oscillating water surface and is preserved in the "Intermediate" shore lines, characterized by embankments of great size but without correspondingly great sea cliffs and terraces. The term "Intermediate," a misnomer as far as age is concerned, is descriptive of the position of these shore features between the Bonneville and Provo shore-lines. Most of the "Intermediate" features were formed by the lake during the expansion that culminated in the Bonneville stage. In one area, however, Gilbert found a double series of "Intermediate" embankments, the earlier one long antedating the other, and representing an earlier high-water epoch of the lake lasting about five times the later epoch and ending with an epoch of desiccation longer than post-Bonneville time.

[13]Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Mon. 1, 1890.

The Bonneville stage of the lake was ended by outflow at the north end of Cache Valley through Red Rock Pass and thence to the Snake River. During the outflow the discharging current cut a channel that caused the lake level to drop about 375 feet. When the outlet had been cut down to the limestone bedrock, rapid erosion ceased and the lake level became stabilized for the duration of the period of outflow. During this prolonged stage, the Provo stage, the most prominent of all the Lake Bonneville features were produced, including the broadest wave-cut terraces, the most massive embankments, and the greatest deltas. The name Provo is derived from the great delta built during this stage by the Provo River, near the town of the same name. The area of the lake at the Provo stage was about 13,000 square miles.

After the outflow through Red Rock Pass had ceased, the water level fell by desiccation to its present level in Great Salt Lake. The record of this recession is one of an oscillating water surface, during which shore cliffs and embankments were produced at several horizons. At one level, about 330 feet below the Provo shore-line, shore features of especial prominence have been produced, which, however, are not sufficiently accented to be everywhere identified. This shore line has been named the Stansbury shore-line because of its development on Stansbury Island north of Tooele Valley; it represents the longest still-stand of the lake since the Provo stage. The Stansbury lake had an extent of about 7,000 square miles. The final drying of the basin divided it into a number of independent interior basins, of which several now contain lakes, and others contain playas.

The beach and littoral deposits of Lake Bonneville are extremely permeable. This is especially significant because wave and current action eliminated the pre-Bonneville channels of streams below the Bonneville shore-line. Since the recession of the lake, channels have not yet been formed by several of the smaller drains. Instead their runoff is poured out upon the Lake Bonneville beds, where it seeps rapidly into the ground. Even the larger streams lose heavily by seepage where they cross these beds. Thus the area covered by these deposits is very important for ground-water recharge.

Lake Bonneville Beds in Tooele Valley

"Intermediate" shore features.—The "Intermediate" shore features are seen at their best in Tooele Valley. They are exceptionally well developed toward the south end of the valley, where they provide some impressive examples of the magnitude of the deposits along the shores of Lake Bonneville. A group of embankments opposite Box Elder Canyon in the southwest corner of the valley is described in detail by Gilbert.[14] Briefly, these embankments, built across an angle of the valley containing a bay of Lake Bonneville, include in order of increasing

[14]Op. cit., pp. 135-136, pl. 15.

altitude: a bar carried entirely across the bay during the Provo stage; a second bar, one of the "Intermediate" embankments; three other "Intermediate" embankments whose development was arrested while they were yet spits; and highest, a spit, shortest of all, developed during the Bonneville stage. The "Intermediate" embankments appear to range in length between 2 and 3 miles; the bar has a height of 80 or 90 feet and a crest width of nearly 500 feet where it has been cut through by Box Elder Creek; the spits have crests 300 to 1,000 feet wide and heights ranging from about 80 to nearly 200 feet at their outer ends. These accumulations were made in a part of the valley where there is a considerable exposure of the Salt Lake formation above the highest lake shore line, a formation that is loosely cemented and an excellent source for the material.

An even greater thickness of material has accumulated in the pass between Rush and Tooele Valleys, including a succession of bars at "Intermediate" horizons, and culminating during the Bonneville stage in the development of the wave-built barrier known as the Stockton bar.[15] The crest of the bar is about 350 feet above the floor of the channel of the former outlet to Rush Valley. The material was derived from the slopes of the Oquirrh Range and of South Mountain, and swept southward by littoral currents. Elsewhere in Tooele Valley the "Intermediate" shore lines are characterized by wave-cut terraces, and at many places they are too faint to be readily discernible.

Bonneville shore features.—The Bonneville shore-line is conspicuous throughout every mile of its length, and everywhere the contrast between wave work below and stream work above the shore line is strong (pl. 2). This contrast is clearly evident also from above, as shown by aerial photographs (pl. 3).

For the most part the Bonneville shore extended along the steep slopes of the ranges bordering the valley, and the line is marked principally by sea cliffs and wave-cut terraces. The cliffs are commonly 20 to 50 feet high and may exceed 100 feet. The terraces, with their wave-built extensions, may be several rods wide, and are sometimes used as roadways along the mountain front. Shore drift accumulations along these steep slopes are generally small, and include chiefly small spits extending from projections of the coast.

The largest depositional features of the Bonneville shore are at the south end of the valley, at the sites where the "Intermediate" embankments are conspicuously displayed. Along Box Elder Creek the spit built during the Bonneville stage is more than a mile long, more than 200 feet high at the end, and as much as a quarter of a mile wide. Box Elder Creek has been deflected around the end of this spit and of three lower "Intermediate" spits, and has cut through an "Intermediate" bar and a bar built during the Provo stage. Farther east, the building of the Stockton bar was completed during the Bonneville stage, after

[15] Op. cit., pp. 149-151, pls. 9, 14, 20, 23.

Plate 2A. Sea cliffs and terrace along the Bonneville shore-line south of Bates Canyon along the Oquirrh Range.

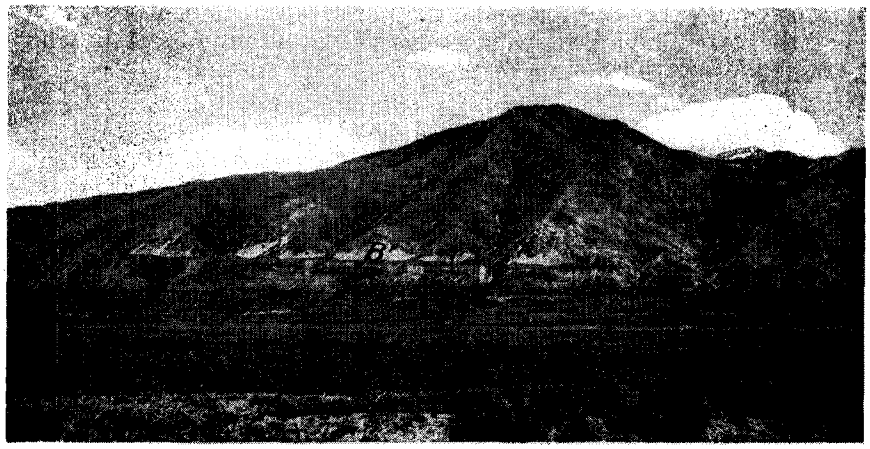

Plate 2B. West front of the Oquirrh Range showing Bonneville and Provo shore-lines and recent fault scarp.

spits had been built paralleling the fronts of the Oquirrh Range and of South Mountain. The spit along the Oquirrh Range is about 6,000 feet long, 200 to 800 feet wide at the crest, and 60 or 70 feet high; that along South Mountain is only about 700 feet long, and is hooked to the southwest.

Provo shore features.—Toward the north ends of both the Stansbury and Oquirrh Ranges the Provo shore-line extends along slopes nearly as steep as those cut by the Bonneville shore-line, and the Provo shore features are chiefly those produced by wave cutting: sea cliffs and terraces. These features dominate the shore line in Townships 1 and 2 South on both sides of Tooele Valley. Calcareous tuff, cementing the gravel deposits, is especially prevalent along the Provo shore-line; commonly these conglomerates are undermined by erosion of underlying loose gravels and slump down the slope, their bedding planes showing an appreciable tilt valleyward.

In the southern part of the valley the Provo shore-line extends along gentle slopes. There the southbound littoral currents along both sides of the valley have carried much debris, which has been built into numerous bars. The embankments north of Bauer include a series of 65 individual bars having an aggregate width of more than a mile. These bars are comprised of cobbles and gravel so clean that many exposures are devoid of any vegetative cover.

Stansbury shore features.—In Tooele Valley and on Stansbury Island farther north, the lake at the Stansbury level formed cliffs, beaches, and littoral deposits that in some places rival those of the earlier, higher shore lines. The sea cliffs and wave-cut terraces of the Stansbury shore-line are limited to the northern tips of the Stansbury and Oquirrh Ranges, where the shore extended along steep, rocky coasts. Elsewhere in the valley the Stansbury shore-line follows the gentle slopes of the valley floor, where it forms the most prominent beach ridge in the series below the Provo shore-line (pl. 4).

The Stansbury shore-line extends around the western margin of the outcrops of the Oquirrh formation in sec. 10, T. 2 S., R. 4 W., which formed a projection westward from the main front of the Oquirrh Range into the lake. A prominent spit was formed by shore currents at the south end of this projection, which is more than half a mile long and as much as 50 feet high. There and elsewhere the beach and littoral deposits of the Stansbury shore have been excavated for gravel and road metal (pl. 5).

Lake beds below the Stansbury shore.—Below the Stansbury shore-line, and indeed over a greater part of the area below the Provo shore-line, the lake sediments have given a fair degree of smoothness to the surface topography, and the lacustrine features referable to shore actions are relatively inconspicuous. These shore deposits, thin and inconspicuous though they may be, nevertheless represent the latest and uppermost deposits of the receding lake, and thus form a surficial layer on the floor of much of Tooele Valley. The deposits have been accumulated along beaches left at progressively declining levels of the lake; they may not be recognized in traveling across the valley but from the air they stand out clearly. These beaches are represented by faint ridges of coarser detritus—coarse gravel on the higher, older ridges, and fine gravel on ridges at the altitude of Erda and Grantsville—with intervening finer sediments.

The lake sediments that underlie this thin layer of littoral debris are exposed in very few places, chiefly along shallow channels that have been cut by post-Bonneville streams. About

Plate 3. Southwestern part of Tooele Valley showing **Bonneville, Provo, and minor shore-lines.**

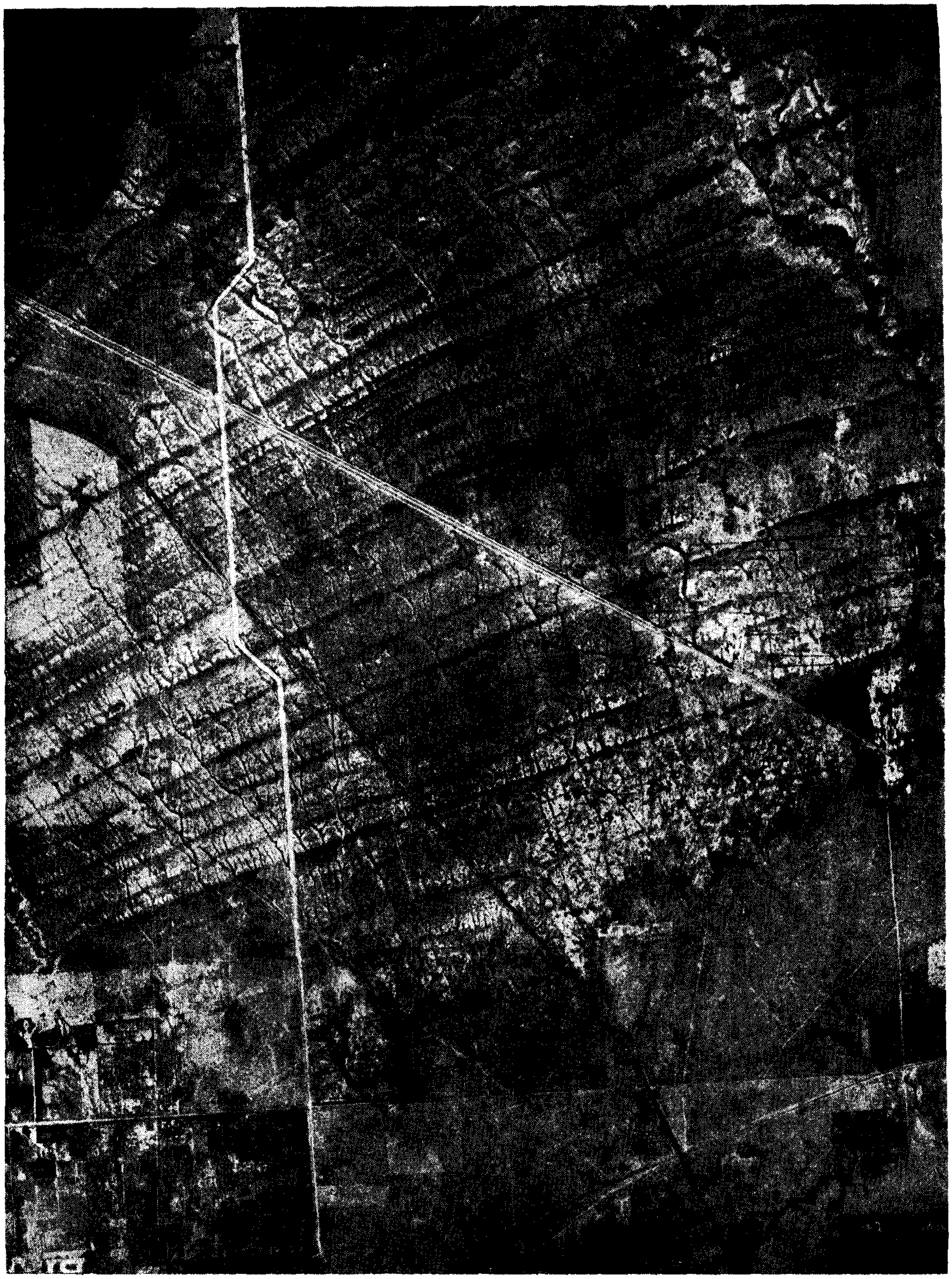

Plate 4. Tooele Valley floor east of Grantsville showing Stansbury and other shore-lines.

15 feet of these sediments is exposed along the banks of Three-mile Creek, about 3 miles east of Grantsville. These beds consist entirely of lake clay in horizontal beds that show a rude columnar jointing. The upper 6 feet of the exposure consists of greenish-gray clay, underlain by a 3-foot bed of reddish-brown clay of similar texture, and then more greenish-gray clay to the bottom of the section. Farther east, near the head of Six-mile Creek, greenish-gray clay of similar texture is exposed to a depth of about 20 feet below the land surface. No lenses of sand or gravel were observed in either of these exposures.

Farther north, close to the highest shore line of Great Salt Lake in historic times, there are considerable quantities of oolitic sand, which is nearly pure calcium carbonate, containing less than 10 percent of acid-insoluble residue and a very low proportion of sodium chloride. This sand is mined for use as flux at the Tooele (International Smelting Co.) and Midvale (United States Smelting and Refining Co.) smelters, whose 1941 rate of consumption averaged about 180 tons a day. The bed of oolites forms the surficial material over an extensive area, is commonly 2½ to 4 feet thick, and is underlain by gray clay. A rough mechanical analysis of a 600-gram sample indicates that the oolites range in size from 0.06 to more than 1 millimeter, and constitute more than 80 percent of the particles in the fine to coarse sand sizes (0.125 to 1.0 millimeter). More than 90 percent of the sample was included within these grade sizes. Particles of granule size include many blebs of calcium carbonate and some shells of small gastropods and pelecypods. The smallest particles consist mainly of clay and calcium carbonate dust.

The area developed by the smelter companies adjoins the highest historic level of the lake and extends southward for more than 200 yards. Farther south for several hundred yards the oolites form an important constituent of the soil. The present development extends along the ancient lake shore for about a quarter of a mile, but the oolitic deposit continues indefinitely both to the east and west. Similar oolitic deposits, described by Eardley, are forming along the present shores of Great Salt Lake but are generally unsatisfactory for use as flux because of excessive insoluble materials or sodium chloride.

RECENT SERIES

Recent gradational processes have modified only very slightly the physiography of Tooele Valley during the closing stages of the Lake Bonneville epoch; erosion has scratched the surface in places, and deposition has covered it locally with a thin veneer of debris. The agents active in these processes have been the streams that drain the mountains, the wind, and Great Salt Lake at the north end of the valley.

Plate 5. Cross-section of spit along Stansbury shore-line east of Erda, exposed in cut of Union Pacific Railroad.

ALLUVIUM

Alluvium is being deposited in present stream channels, and is slowly accumulating on the gentle slopes below the mouths of the canyons. The extent of this activity since the final recession of Lake Bonneville has been slight, attesting to the shortness of the period of time represented by the Recent deposits. The channels leading from the canyons to the valley floor had all been destroyed or filled in by lake action below the level of the Bonneville shore-line. Many of the smaller streams have not yet cut new channels below this line, nor have they deposited enough debris to obliterate any appreciable part of the lacustrine features. The larger streams have of course cut channels across these lake deposits, some extending to the shores of Great Salt Lake, and have distributed alluvium over the lake sediments in extensive areas. In many parts of these areas, however, the alluvial cover is so thin that the underlying shore features are distinctly shown in aerial photographs. These photographs in fact form the basis for delineation of the areas covered by Recent alluvial sediments: they are shown on the geologic map wherever they have been sufficient to obliterate the older pattern of lacustrine features.

Characteristic of the arid region that embraces Tooele Valley, the stream channels are dry or occupied by very small streams throughout the greater part of each year. Transportation of debris occurs during the spring, when there is ordinarily appreciable runoff from melting snow, and occasionally in the summer, when cloudbursts may produce floods. The deposits resulting from these floods are of torrential type, poorly sorted, filling the channels that had previously been established by the streams. The cloudburst floods that produce these deposits carry an enormous volume of water in a very short time interval, considering the small size of many of the drainage basins. The effect of one such flood, on July 26, 1941, was strikingly shown in Miners Canyon, northwest of Grantsville. The drainage basin above the mouth of the canyon covers less than 2 square miles. The Utah Bunker Hill mining properties are located near the head of this canyon, and prospectors had built an access road along the canyon floor, which toward the mouth has a slope of about 7°. During the flood of July 26 much of this mountain trail was mutilated beyond recognition: ruts were eroded 2 or 3 feet deep and in places expanded into pot-holes nearly as wide as the road; where the road had criss-crossed the stream course it was alternately covered by boulder trains as much as 3 feet high and 200 feet across, and excavated at cut-banks 3 or 4 feet deep; and where it had followed the stream its course was littered with boulders as much as 5 feet in diameter (pl. 6). The high-water mark left by the flood was clearly shown by brush and timber; it is estimated that the stream had a depth of about 10 feet, and a probable cross-sectional area of 250 square feet at the peak of the flood.

The Recent alluvium along the margins of the valleys is prevailingly coarse and highly pervious. At lower elevations the materials are finer, consisting largely of silt and clay, and permeability is presumably low.

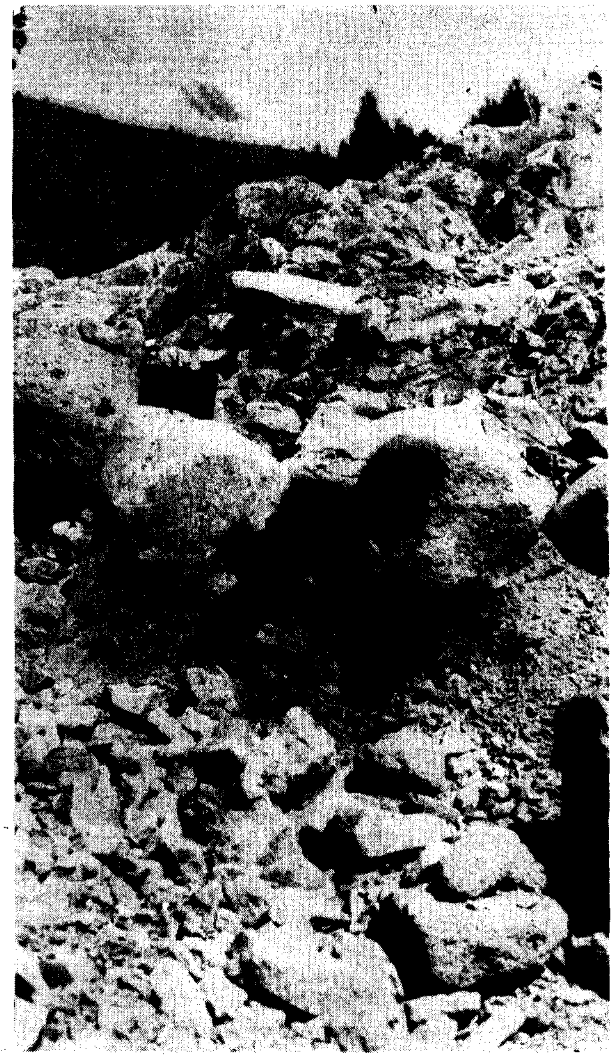

Plate 6. Debris in Miners Canyon left by flood of July 26, 1941.

LAKE BEDS

The waters ponded in the Great Salt Lake basin have undergone a noteworthy modification since the higher stages of Lake Bonneville: presumably fresh during the time when there was outflow from Lake Bonneville through Red Rock Pass, they have increased in saline content until at the present time they form a saturated brine from which crystalline salt has been precipitated on the floor of Great Salt Lake. As Clarke has pointed out,[16] these waters are similar in composition to ocean waters but are four to seven times as concentrated.

The salinity of Great Salt Lake varies inversely with the lake volume. According to analyses shown by Clarke, it has been found to range from 13.8 percent in 1877, when the lake surface was 4,210.3 feet above sea level, to 27.7 percent in 1904, when the lake was at altitude 4,196.8 feet. Throughout this range in elevation the saline content increases at the rate of about 1 percent for each foot of decline in lake level. The waters become saturated for sodium chloride and sodium sulphate when salinity reaches 27 percent, approximately at a lake level of 4,197 feet. As the lake falls below this level the salinity increases very slightly due to further concentration of magnesium and potassium chlorides, while sodium chloride and sodium sulphate are precipitated. In historic times the lake level has been low enough to cause this precipitation during two periods; 1902-07 and 1931-41. During the latter period the lake bed was covered with a layer of granular halite as much as a foot thick.

Saline deposits extend far beyond the present limits of Great Salt Lake, and are especially prominent in the Salt Lake desert, which covers a large area 40 to 100 miles west of Tooele Valley and includes the "Bonneville salt flats" of racing-car fame. The brines in this desert have economic value as a source for sodium and potassium chloride and other salts, and have been discussed by Nolan.[17]

The Recent sediments of Great Salt Lake have been described in detail by Eardley.[18]

Toward the north end of Tooele Valley and beyond the present borders of Great Salt Lake there are extensive areas that are nearly level and very few feet higher than the level of the lake. The surface is largely covered by dazzling white crystal salt and oolitic sand, and the area is thus readily discriminated on aerial photographs; its southern boundary appears to coincide with the upper limit of Great Salt Lake at its highest historic level, in 1873, as shown by Gilbert.[19] Throughout the area there is practically no vegetation except where dunes have been formed on the flat. South of the lake flat there are areas where brackish water stands at the surface or at shallow depths, and where saline incrustations are formed by evaporation, but there are no barren areas comparable to the salt-incrusted area covered by the lake at its highest historic level. It is suggested therefore that either the time when these higher areas were submerged was so remote that subsequent

[16]Clarke, F. W., Data of geochemistry: U. S. Geol. Survey Bull. 770 p. 157, 1924.
[17]Nolan, T. B., Potash brines in Great Salt Lake Desert, Utah: U. S. Geol. Survey Bull. 795, pp. 25-44, 1928.
[18]Eardley, A. J., Sediments of Great Salt Lake, Utah: Am. Assoc. Petroleum Geologists Bull. 22, No. 10 pp. 1305-1411 1938.
[19]Gilbert, Op. cit., pp. 242-244, pl. 33.

stream and wind action have buried any chemical deposits, or the concentration of salts in the lake at these higher stages was insufficient to cause precipitation in large quantities. Because of this indication of a considerable time interval between deposits above and below the highest historic level, that level is selected arbitrarily as the boundary between Pleistocene and Recent lake sediments.

Recent (post-Bonneville) lake sediments are represented by the uppermost of the saline beds below this highest historic level. These Recent deposits are very thin, judging by the conclusions of Nolan,[20] who considers brines encountered at depths of 7 to 9 feet along the margins of the desert to be equivalent to the long inter-Bonneville epoch of aridity, which preceded the high-water epoch represented by the Bonneville, Provo, and Stansbury shore-lines. In view of these considerations, it is believed the Recent lake deposits generally have a thickness considerably less than 5 feet.

DUNES

Wind action has caused some modification of the surface of the Tooele Valley floor. Wherever surface material is loose, of a convenient size, and not held down by vegetation or water, wind erosion occurs and dunes are formed. The largest areas of dunes are south and east of Grantsville, where they commonly adjoin and have threatened to encroach upon the irrigated lands near the town. These dunes are as recent as any geologic features in the valley, having been developed chiefly during the drought years of 1934 and 1935, when the vegetative cover was destroyed by desiccation over large areas; loose surface materials were left unprotected from wind action, and the territory around Grantsville became a miniature "dust-bowl" area. These wind deposits have obliterated the lake shore features over extensive areas, as shown in aerial photographs, and their mapping on plate 1 is based largely on those photographs. The dunes formed at that time are commonly less than 3 feet high. In certain areas farther south, however, extending almost to the Provo shore-line, some dunes are more than 10 feet high, and are believed to have originated long before the drought years of the past decade.

According to rough mechanical analyses of a few samples of the materials in the dunes near Grantsville, about 75 percent of the grains are medium or fine sand (size range 1/8 to 1/2 millimeter), and there are practically no grains larger than 1 millimeter. The material is dirty in comparison with typical dune sand, due to a considerable amount of silt. Most of the grains are of sub-rounded quartz, but there is much calcium carbonate in all grade sizes. The proportion of lime is particularly high in the coarse grains, many of which are oolitic.

[20]Nolan, Op. cit., pp. 40-41.

Dunes also cover extensive areas of the lake flat west of Burmester, including a large part of the bar that extends from Stansbury Island to the "mainland." Some of these dunes are barchans, whose crescent shapes indicate the prevailing southerly direction of wind in the valley. The material of these dunes is highly calcareous, and many of the grains between 1/8 millimeter and 1 millimeter in diameter are oolitic. Calcareous fragments of irregular shape are common and have evidently been formed by solution of original oolites and subsequent redeposition. The non-calcareous materials are generally finer than in most dune sands, and include a high proportion of silt and very fine sand, less than 1/8 millimeter in diameter. In general the material of these dunes is different from ordinary aeolian deposits, but is consistent with the characteristics of the sediments of the lake flat that are the source for the material.

FORMATIONS ENCOUNTERED IN WELLS

All known wells in Tooele Valley are located in the area below the Bonneville shore-line, and nearly all are below the Stansbury shore-line. Hence the formation outcropping at all well sites is the Lake Bonneville beds, except where there is a thin veneer of Recent materials. Only three of the wells in the valley are known to have penetrated to bedrock, one reaching the agglomerate of Miocene (?) age and the others the Oquirrh formation. All others bottom in the unconsolidated Pleistocene beds or in the underlying Salt Lake formation.

Log of well (C-2-4) 31dad2.—A deep experimental well, drilled as part of the water facilities program of the U. S. Department of Agriculture in 1941 to determine the quantity and economic value of water in deep aquifers, provides the best source of information concerning the sediments underlying Tooele Valley. One hundred and sixty-five samples were collected of the materials encountered in drilling to a depth of 727 feet. The log is based largely on mechanical analyses of these samples by the Soil Conservation Service, supplemented by field examination by the author at the time of drilling. The interpretation of the log follows Gilbert's terminology,[21] and the notes upon which the interpretation is based are included in the log. In all samples the fragments are angular or sub-angular unless noted otherwise; chiefly they are of quartzite and limestone, which are the dominant rocks of the mountains bordering the valley (see also p. 217).

[21]Gilbert, Op. cit., pp. 188-203, 259-262, 316.

Log of well (C-2-4)31dad2, based on driller's samples and mechanical analyses by Soil Conservation Service

State application 14298. Utah Water Storage Commission, owner. Eight-inch flowing well drilled 727 feet deep, plugged below 450 feet, and perforated 288 to 316 feet during 1941, by Soil Conservation Service. Well is in west part of Erda ground-water district (see p. 161).

	Thickness (feet)	Depth (feet)	Geologic notes
Lake Bonneville beds, "second epoch of high water":			
Soil, silt and clay, dark brown	2	2	
Silt, dark gray, some well-rounded pebbles	1	3	
Silt and clay, calcareous, light gray	25	28	"White marl" of Gilbert?
Silt and fine sand with much peat, dark brown	2	30	Indicates swamp conditions.
Fine sand and silt, gypsiferous, some pebbles	5	35	Desert basin deposition. Struck first water.
Silt and fine sand with some peat, brown	2	37	Swamp conditions.
Clay and silt, calcareous, greenish-gray	13	50	More marl.
Lake Bonneville beds, "inter-Bonneville epoch of low water":			
Silt and fine sand, some gravel, calcareous, buff	12	62	Poorly sorted, apparently alluvial.
Very fine sand and silt, buff	5	67	
Very fine sand and silt, brown, some pebbles	5	72	
Silt, sand, and gravel, buff	3	75	
Fine sand and silt, gray	2	77	
Silt and very fine sand, gravel to ½ inch	5	82	Small aquifer.
Medium and coarse sand	5	87	
Silt and very fine sand, brown	5	92	Resemble playa deposits.
Clay and silt, buff	5	97	

Log of Well (C-2-4)31dad2 (continued)

	Thickness (feet)	Depth (feet)	Geologic notes
Silt and clay, brown, some fine gravel	25	122	Probably alluvial.
Lake Bonneville beds, "first epoch of high water":			
Clay, buff, calcareous	10	132	Probably lacustrine; "Yellow clay" of Gilbert?
Fine sand, well rounded, yellow	5	137	Small aquifer.
Sand, rounded gravel to ¼ inch	1	138	
Gravel and coarse sand, dark gray	1	139	
Clay and silt, brown, some sand and gravel to 1 inch	8	147	
Coarse and medium sand, well assorted, white	2	149	
Gravel to ½ inch, coarse to fine sand, clean, buff	6	155	Channel deposit.
Sand, silt and gravel to ½ inch, buff	12	167	Probably alluvial-fan material.
Coarse to fine sand	2	169	Principal artesian aquifer in Tooele Valley is in this zone.
Gravel to ¾ inch, coarse to medium sand, clean, buff	2	171	
Gravel and coarse sand, buff	6	177	
Silt and fine sand, some gravel, buff	5	182	
Coarse to fine sand, buff, and fine gravel	25	207	
Fine gravel and coarse sand, dark gray	18	225	
Coarse gravel, rounded, black	1	226	
Coarse to fine sand, light buff	6	232	

Log of Well (C-2-4)31dad2 (continued)

	Thickness (feet)	Depth (feet)	Geologic notes
Pleistocene beds antedating "first high-water epoch":			
Silt, sand and gravel, light tan	25	257	Probably alluvial.
Gravel to ½ inch, some sand	2	259	
Coarse to fine sand, some gravel	7	266	
Silt and fine sand, light buff	6	272	
Coarse to fine sand and fine gravel, light buff	20	292	
Fine gravel and coarse sand, dark gray	8	300	Excellent artesian aquifers in this zone.
Coarse to fine sand, buff, some gravel	7	307	
Sand, some gravel to ½ inch, silt, light buff	17	324	
Gravel to ½ inch, and coarse sand, gray	3	327	
Sand, silt, and gravel	2	329	Alluvial-fan type of beds.
Gravel and coarse sand, dark gray	3	332	
Sand, silt, and gravel, buff	15	347	
Coarse to fine sand, gray, gravel to 2 inches	7	354	Small aquifer.
Coarse and medium sand, gray	8	362	
Sand, gravel, and silt, buff	14	376	Alluvial-fan deposit.
Gravel to 3 inches, some silt and sand, light brown	5	381	
Sand, some silt and gravel, buff	5	386	
Coarse to fine sand, fine gravel, dark gray	5	391	Aquifer of unknown yield.
Coarse and medium sand, some gravel	11	402	
Coarse gravel to 1 inch, sand and silt	2	404	
Silt, fine sand and clay, some gravel, buff to brown	43	447	Alluvial-fan deposit?

Log of Well (C-2-4)31dad2 (concluded)

	Thickness (feet)	Depth (feet)	Geologic notes
Fine sand and silt, yellow	5	452	
Silt, fine sand and clay, some gravel to 1 inch, light brown	25	477	
Coarse sand and fine gravel	5	482	Several artesian aquifers in this zone.
Gravel and coarse sand, yellow	15	497	
Silt and fine sand, some fine gravel, buff	25	522	
Coarse and medium sand	7	529	
Fine gravel, coarse and medium sand	8	537	
Salt Lake formation (?):			
Silt, sand, and clay, some gravel	5	542	Dominantly clay below this depth.
Clay and silt, some sand, pink	20	562	
Clay and silt, red-brown	30	592	
Clay and silt, buff	15	607	
Clay and silt, pink, some gravel	30	637	
Clay and silt, medium brown	20	657	
Clay and silt, some sand, light brown	15	672	
Silt, sand, and clay, some pebbles	5	677	Aquifer of small yield.
Coarse to fine sand, well rounded, yellow	10	687	
Fine sand, silt, and clay, medium brown	10	697	
Fine to coarse sand, silt, some pebbles	5	702	
Silt, fine sand, and clay	25	727	

The identification of the upper 50 feet of sediments as Lake Bonneville beds of the "second epoch of high water" has a sound basis, for these beds appear to be of lacustrine origin, and include evidence of swamp conditions that may well have occurred during the epoch. The section from 50 to 122 ft. includes beds that closely resemble present-day playa deposits and also beds of poorly-sorted, angular fragments similar to the torrential deposits of alluvial fans; these sediments are clearly not of lacustrine origin and are considered therefore to represent the "inter-Bonneville epoch of low water." The first "Bonneville epoch of high water" is believed to be represented by beds at depths of 122 feet to 232 feet in the well, of which the lower 65 feet are prevailing coarse and yield most of the artesian water supplies in the valley. Some of the beds in this zone are of well-assorted materials, but more are made up of fairly angular grains having a wide range in size, so that they are considered to be probably of alluvial origin. The sediments are correlated with a "high-water epoch" because they are prevailingly coarser than the beds above and below, probably a result of the greater transporting power that would obtain at that time.

The beds below 232 feet are believed not to be correlative with any of the sections of the Lake Bonneville beds described by Gilbert, and presumably represent deposits of his pre-Bonneville low-water epoch and earlier Pleistocene deposits. These beds were thus accumulated during an epoch of which no record has yet been found in outcrops in the Bonneville basin, but which has been postulated on the basis of analogy with other areas. Antevs[22] states that the chief events in the Pleistocene history of the Great Basin must certainly have been parallel with the main events in the northern part of the continent: "In the North, four or five glacial epochs, separated by warm interglacial periods, have followed each other. In the Great Basin glaciations combined with expansions of the waters have alternated with arid periods. * * * The mountain glaciations and the slightly lagging high levels of the lakes of the Southwest were contemporaneous with the climaxes of the great glaciations and the early stages of ice retreat. The arid periods corresponded to the interglacial epochs." Following this argument, the last mountain glaciation and Gilbert's "second high-water epoch" would correlate with the Mankato (Late Wisconsin) substage in the eastern part of the continent, and the "first high-water epoch" would correspond to an earlier glaciation, perhaps of early Wisconsin age.

The beds from 232 to 537 feet are believed to have been deposited during glacial and interglacial stages antedating the Wisconsin glacial stage, for they include zones of prevailingly coarse material that yields water under artesian pressure, alternating with strata of generally finer material, indicating cyclic deposition of the same sort that is shown higher in the well by the beds of the first and second high-water stages and the intervening low-water stage of Lake Bonneville. It is suggested that these alternations may represent deposition of the glacial stages and intervening interglacial stages of the Pleistocene, the coarse water-bearing materials (of which there

[22]Antevs, Ernst, On the Pleistocene history of the Great Basin: Carnegie Inst. Washington Pub. 352. pp. 53-104, esp. p. 101, 1925.

are a total of at least five) having been accumulated during humid climates perhaps contemporaneous with glaciation. The Pleistocene deposition at this well is thus believed to be represented by the upper 537 feet of section.

Below the depth of 537 feet the materials encountered in the well were predominantly pink to red-brown clay, with much less gravel and sand than was found in higher beds. The coarser beds yielded very little water although some were well sorted and presumably permeable. These beds are referred tentatively to the Salt Lake formation.

Log of well (C-3-5)36ddd1.—In 1942 a deep well was drilled by the U. S. Army to provide water for the Tooele Ordnance Depot. The well is located in the southern part of the valley, above the Provo shore-line, and penetrated unconsolidated sediments throughout its depth of 763 feet.

Driller's log of well (C-3-5)36ddd1

State application 14752. U. S. War Department, owner. Twenty-inch well, drilled 763 feet deep in 1942 by Roscoe Moss, and perforated opposite all sand and gravel strata between depths of 392 and 743 feet. Water level upon completion of drilling was reported to be 380 feet below land surface; after perforating the casing, the water level rose 8 feet. Drawdown is reported to be 12 feet while pumping 880 gallons a minute.

	Thickness (feet)	Depth (feet)
Lake Bonneville beds, "second epoch of high water":		
Sand, gravel, boulders to 6″	51	51
Clay, gray	23	74
Conglomerate, loosely cemented	11	85
Clay, yellow	35	120
Lake Bonneville beds, "inter-Bonneville epoch of low water" (?):		
Sand, gravel, and cobbles to 4″	60	180
Clay, sand, gravel, and cobbles to 4″	45	225
Lake Bonneville beds, "first epoch of high water" (?):		
Conglomerate	117	342
Clay, yellow	10	352
Conglomerate	40	392
Dominantly alluvial beds:		
Clay, fine sand, and gravel to ¾″	8	400
Clay, yellow, soft	6	406
Sand, clay, and gravel to 1″	8	414
Sand, angular, gravel, and boulders to 6″	9	423
Clay, yellow	11	434
Sand, gravel, and cobbles to 4″	36	470

	Thickness (feet)	Depth (feet)
Clay and gravel	5	475
Sand, gravel, and boulders to 6"	27	502
Clay and gravel	8	510
Sand, gravel, and boulders to 6"	10	520
Dominantly lacustrine beds:		
Clay, yellow, with calcareous shells	53	573
Sand, gravel, and cobbles to 4"	31	604
Clay, yellow	8	612
Clay, yellow, with calcareous shells	18	630
Sand, gravel, and cobbles to 4"	6	636
Sand, gravel, and boulders to 8"	9	645
Clay, yellow	28	673
Clay, yellow, with calcareous shells	27	700
Conglomerate	14	714
Dominantly alluvial beds:		
Sand, poorly assorted, gravel, and cobbles to 3"	29	743
Clay, yellow, and gravel	20	763

In this well, Gilbert's "second epoch of high-water" is considered to be represented by the upper 120 feet of material, of which the upper part comprises beach deposits accumulated during the Provo stage, and the underlying clays and conglomerate represent the Bonneville and "Intermediate" stages. The beds between depths of 120 and 225 feet are relatively poorly assorted, and are tentatively correlated with the "inter-Bonneville epoch of low water." The "first epoch of high water" is believed to be represented by the beds between depths of 225 and 392 feet.

Below 392 feet the well penetrates a succession of unconsolidated sediments considered to represent the pre-Bonneville Pleistocene, of which the beds between depths of 573 and 714 feet contain fossiliferous zones and appear to be of lacustrine origin, and the overlying beds are poorly assorted and probably fluviatile. These sediments evidently represent one or more of the alternations of glacial and interglacial epochs which characterize Pleistocene history elsewhere in North America.

Other well logs.—Very few logs are available for other wells drilled in Tooele Valley. More than 750 of these wells are covered by underground water claims filed by the owners with the Utah State Engineer. Search through these claims showed that the vast majority of owners had very little information concerning the materials penetrated by their wells, and credible logs were found for only about 25. Eight of these logs are reproduced on the following pages. Six of the wells are located below the Stansbury shore-line, and two, nos. (C-3-4)22dcd1, and (C-4-5)13bcb1, are located between the Provo and Bonneville shore-lines, one northwest of Bauer and the other east of Tooele. Both of these wells were drilled deep enough to reach the bedrock that underlies the valley fill. The logs are listed by ground-water districts described on pages 163 and 164.

According to available records, the deepest well drilled in Tooele Valley is No. (C-1-5)31dbb1,[24] a prospect for oil drilled 1,265 feet deep by the National Oil & Gas Co. near Burmester. No log is available for the well. According to Eardley,[23] "the sediments consisted of fine clay and sand layers. Petrified (?) wood was reported encountered at 1,200 feet. Bedrock was not reached. An odor of hydrogen sulphide gas comes from the hole. The information available is too meager to ascertain the existence of the Salt Lake formation."

Wells in the Lake Point District

(C-2-4)2aab2. State claim 17016. Ralph L. Griffith, owner. Three-inch flowing domestic well drilled 193 feet deep in July 1932. Well is near center of district.

	Thickness (feet)	Depth (feet)
Soil	3	3
Clay	120	123
Gravel, water-bearing	8	131
Clay	40	171
Sand, water-bearing	6	177
Gravel, water-bearing	2	179
Hardpan	1	180
Clay	10	190
Gravel, water-bearing	3	193

(C-1-4)35dcc1. State application 12193. Herbert Anderson, owner. Three-inch flowing domestic well drilled 277 feet deep in 1937. Well is in northwest part of district.

	Thickness (feet)	Depth (feet)
Soil	6	6
Clay, white	10	16
Clay, blue	67	83
Clay, white	23	106
Clay, blue	14	120
Hardpan, water-bearing	1	121
Clay, white	26	147
Clay, blue	30	177
Clay, white	20	197
Clay, blue	20	217
Clay, white	25	242
Hardpan, water-bearing	1	243
Clay, blue	20	263
Clay, white	10	273
Hardpan	½	273½
Gravel, water-bearing	3½	277

[23]Eardley, A. J., and Haas, Merrill, Oil and gas possibilities in the Great Salt Lake Basin: Utah Acad. Sci. Arts & Letters Proc. vol. 13, p. 75. 1936.

[24]For explanation of well-numbering system see U. S. Geol. Survey Water-Supply Paper 910, p. 38, 1941.

Well in the Erda District

(C-2-4)33bcd1. State claims 810 and 8284. Franklin Whitehouse, owner. Four-inch flowing irrigation well drilled 283 feet deep in September 1934 by Earl Hale. Well is in central part of district.

	Thickness (feet)	Depth (feet)
Surface soil and clay	20	20
Gravel	12	32
Clay	18	50
Sand and gravel	15	65
Clay	25	90
Gravel	13	103
Clay	12	115
Sand	20	135
Clay	15	150
Gravel, tight	12	162
Clay	4	166
Gravel, cemented	24	190
Sand, hardpan	18	208
Clay	10	218
Gravel, tight	16	234
Clay	6	240
Gravel, cemented, with loose strata about 1 inch apart, water-bearing	43	283

Wells in the Grantsville District

(C-2-5)7ddd1. State claim 1553. Albert B. Cole, owner. Three-inch flowing irrigation well jetted 400 feet deep in September 1929, cased to depth of 175 feet. Well is in northern part of district.

	Thickness (feet)	Depth (feet)
Clay	7	7
Gravel	1	8
Clay	160	168
Quicksand	10	178
Clay	10	188
Quicksand	11	199
Clay	40	239
Quicksand	2	241
Clay	30	271
Quicksand	1	272
Clay	20	292
Gravel	10	302
Clay	20	322
Quicksand	5	327
Clay	20	347
Quicksand	5	352
Clay	35	387
Quicksand	3	390
Gravel	4	394
Quicksand	3	397
Gravel	3	400

(C-3-6)1aaa1. State claim 1555. Albert B. Cole, owner. Three-inch domestic well jetted 153 feet deep in October 1918. Well is in southwestern part of district.

	Thickness (feet)	Depth (feet)
Soil	10	10
Gravel	15	25
Sand	17	42
Hardpan	2	44
Gravel	52	96
Sand	15	111
Gravel	4	115
Hardpan	3	118
Sand	19	137
Sand, coarse	16	153

Well in the Marshall District

(C-2-5)34add1. State application 13537. Ben H. Woodward, owner. Two-inch flowing domestic well jetted 440 feet deep in 1941 by owner. Well is in northern part of district.

	Thickness (feet)	Depth (feet)
Clay	5	5
Sand	5	10
Gravel	18	28
Clay	2	30
Sand	9	39
Clay	2	41
Sand	2	43
Gravel	7	50
Sand	2	52
Gravel	14	66
Sand	3	69
Gravel	13	82
Clay	4	86
Sand	4	90
Gravel	4	94
Clay	14	108
Sand	2	110
Gravel	2	112
Clay	8	120
Gravel	18	138
Sand	4	142
Hardpan	1	143
Gravel	8	151
Clay	15	166
Sand	7	173
Clay	27	200
Sand	35	235
Gravel	10	245
Clay	25	270
Sand	15	285
Gravel	20	305
Clay	19	324
Sand	6	330

	Thickness (feet)	Depth (feet)
Clay	5	335
Sand	5	340
Clay	4	344
Sand	36	380
Clay	5	385
Sand	35	420
Sand and clay	10	430
Sand	9	439
Gravel	1	440

Wells Near the South End of the Valley

(C-3-4)22dcd1. State application 12936. International Building Association, owner. Eight-inch abandoned well drilled 337 feet deep in 1936 by J. Bosone without obtaining water. Well is near the east limit of Tooele, half a mile from the Bonneville shore-line, beyond which the Salt Lake formation crops out. Nearest outcrop of bedrock, the Oquirrh formation, is more than a mile to the southwest.

	Thickness (feet)	Depth (feet)
Lake Bonneville beds:		
Soil	2	2
Sand	36	38
Lake Bonneville beds and/or Salt Lake formation:		
Boulders	54	92
Boulders, very little clay	171	263
Oquirrh formation:		
"Quartz," solid	7	270
"Porphyry," loose	16	286
"Quartz," solid (blasted at 286 and 288 ft.)	7	293
"Porphyry," loose	42	335

(C-4-5)13bcb1. Combined Metals Reduction Co., owner. Six-inch abandoned well drilled 500 feet deep in 1935 by Volney Crocheron, without obtaining water. Well is under tailings pond northwest of the Bauer smelter, 4,000 feet east of an outcrop of agglomerate of Miocene (?) age. Log is a compromise between the memories of driller and company superintendent.

	Thickness (feet)	Depth (feet)
Probable Lake Bonneville beds:		
Soil	3	3
Sand clay	37	40
Coarse sand	10	50
Sand and clay	50	100
Gravel, water-bearing	3	103
Lake Bonneville beds or Salt Lake formation:		
Sand and silt	137	240
Agglomerate of Miocene (?) age:		
Lava	60	300
Interbedded lava and ash	200	500

Depth and extent of aquifers, based on depths of wells.— Except for the few well logs listed above, the reported depths of wells constitute the only available source of information concerning water-bearing strata in Tooele Valley. These data may be utilized to a somewhat greater extent than one might at first suppose, because of the prevailing method of construction of wells in the valley. Nearly all are small-diameter jetted wells with unperforated casings that permit entry of water only at the open lower end. Thus, for most wells the depth indicates the position of the aquifer tapped by the well, and groups of adjacent wells of varying depths may give a rough approximation of the zones of water-bearing strata in a particular area. Since these aquifers are typically of coarser materials than the intervening nonproductive beds, the data give some indication of the sediments penetrated by the wells.

Following this premise, the sea-level elevation of the bottoms of more than 500 wells have been determined, based on reported depths of the wells and on ground surface elevations established by instrumental leveling. The bottom elevations of these wells are shown graphically on figure 3.

In this diagram each column represents a 160-acre tract, and the horizontal lines represent the bottoms of the wells within that tract. The tracing of aquifers based on the grouping of these lines is subject to some error in the cases of wells that have been jetted beyond the aquifers but are only partly cased, or of wells that derive their water supplies from perforated casing rather than from the bottom of the well. The chief source of error, however, is the failing memory of many well owners, resulting in considerable inaccuracies of the reported depth. Even with the large chances for error, the water-bearing zones appear to be fairly well defined by the bottom elevation, particularly where the density of wells is greatest, and correspond rather closely to the positions of the coarser sediments as shown in logs of nearby wells.

In the vicinity of Grantsville the majority of wells evidently obtain water from an aquifer that is 100 to 120 feet thick, its top being about 4,260 feet above sea level in the southwest part of the town, and declining northeastward at a rate of about 100 feet in a mile. Farther east, in the Erda area, most wells evidently reach an aquifer that is 60 to 80 feet thick, represented in well (C-2-4)31dad2 by the strata between depths of 167 and 232 feet which have been tentatively correlated with Gilbert's Lake Bonneville beds of the "first epoch of high water." This aquifer is nearly horizontal; its top is at elevation 4,260 feet above sea level in the eastern part of sec. 33, T. 2 S., R. 4 W., and declines westward to about 4,200 feet in the west part of sec. 31. About two-thirds of the wells represented on figure 3 reach these zones in the Grantsville and Erda districts, and they are obviously the principal aquifers of the groundwater reservoir. The aquifers are made up predominantly of coarse sediments—gravel and coarse sand—as shown by the logs of three wells that are included in the figure. They are evidently not continuous across the valley, for wells in the central part of the valley (in secs. 34, 35, and 36, T. 2 S., R. 5 W.,) are commonly more than 300 feet deep and yield only small quantities of water of inferior quality. Instead, the coarse sediments forming these aquifers were doubtless accumulated along the sides of the valley while finer materials were collected in the central part. The principal aquifer in the Grantsville area is believed to be approximately contemporaneous with that of the Erda district, because of its comparable thickness, water-bearing property, and position with respect to the land surface.

In both the Erda and Grantsville districts wells are shown in most sections that do not end in the principal aquifer. Some of these wells reach aquifers shallower than the principal aquifer, and others reach deeper aquifers, many of which are well defined and appear to be fairly continuous throughout the individual districts. These shallow and deep aquifers can be recognized in the log of well (C-2-4)31dad2 and in drillers' logs of other wells in the valley.

STRUCTURE

The dominant structural features of the Tooele Valley area are folds and normal faults, many of which are northward continuations of the folds and faults described by Gilluly in an adjoining area.[25] The ranges bordering Tooele Valley on three sides—the Stansbury Mountains, South Mountain, and the Oquirrh Mountains—consist for the most part of simple folds of large dimensions, except that the strata at the northern tip of the Oquirrh Range have been thrown into several small, tight folds. The few outcrops of bedrock in Tooele Valley suggest that the valley is likewise underlain by broad, open folds of Paleozoic rocks, analogous to and in part continuous with the structures exposed in the ranges.

The Oquirrh Mountains are bounded on the west by a zone of normal faults that truncate the folds sharply, displacement along which has been responsible for the present topographic expression of range and valley. No such faults mark the east margin of the Stansbury Mountains, but there have been great displacements along the west side of the range, adjoining Skull Valley. These north-south fault zones along the steep western fronts of both ranges, are parts of the Basin-Range system.

The Tooele Valley area comprises parts of two major structural units or crustal blocks—the Oquirrh Mountain fault block and the Stansbury Mountain fault block. Several smaller blocks bounded by faults are by-products of the rotation of these major blocks. The Stansbury Range, Tooele Valley, and South Mountain are considered to be surficial features of the Stansbury Mountain fault block, and the Oquirrh Range constitutes the

[25] Gilluly, James. Geology and ore deposits of the Stockton and Fairfield quandrangles, Utah: U. S. Geol. Survey Prof. Paper 173, pp. 69-90, 1932.

western part of the Oquirrh Mountain fault block, which extends eastward under the floor of Jordan Valley.

FOLDS

The main part of the Stansbury Range is formed by a single great fold having a north-south axis, with several small subsidiary folds at the north end of the range. Farther east the strata composing the Oquirrh Range and South Mountain are formed into seven large folds, four anticlines and intervening synclines, plus two or more small isoclinal folds at the north tip of the Range. From Pine Canyon southward the axes of these folds trend and pitch northwesterly. Toward the north end of the range, and also at South Mountain, the trend of the folds is westerly. Several of the large folds continue into the Stockton and Fairfield quandrangles and have been named and described by Gilluly.[26] The axes of the large anticlines are commonly zones of intense folding, where beds may be vertical or even overturned. Minor flexures occur on the flanks of the major folds.

The Paleozoic strata are all involved in the folding, and the Tertiary strata are not. Thus, from information available in the Tooele Valley region, the date of the folding can be placed as post-Pennsylvanian and pre-Wasatch. Following the conclusions of Gilluly after reviewing the evidence as to date of folding in adjacent regions, "the probabilities point to late Cretaceous or very early Eocene time for the * * * folding." Thus the folding evidently occurred during the time of the Laramide revolution, which, according to Spieker,[27] includes several deformations probably ranging in age from early Cretaceous to mid-Eocene time.

BASIN-RANGE FAULTING

West Front of the Oquirrh Mountains

Faulting along the west front of the Oquirrh Range was long ago recognized by Gilbert.[28] Along the southern part of the range opposite Rush Valley, Gilluly has described in detail the zone of Basin-Range faults that marks the boundary between mountain mass and valley[29] based on actual exposure of clearly defined fault planes, stratigraphic displacement, transection of structures, or topographic unconformity. Several significant features of these faults were pointed out by Gilluly: many of them are en echelon, some are step faults, few are continuous along the strike, and the dip of the fault planes ranges from 40° to 80°. Faults could be traced along fully half of the mountain front bordering Rush Valley. By contrast, no

[26]Op. cit., pp. 69-73.
[27]Spieker, E. M., Oral communication.
[28]Gilbert, op. cit., pp. 352, 367.
[29]Gilluly, James, Basin Range faulting along the Oquirrh Range, Utah: Geol. Soc. America Bull. 39, pp. 1103-1130, 1928.

evidence of faulting was found along the east front of the range, and Gilluly supports Gilbert's conclusion that the Oquirrh Range is an eastward-tilted fault block whose eastern margin is buried under the valley fill of Jordan Valley.

In Tooele Valley the evidence of faulting along the front of the Oquirrh Range is fully as conclusive as in Rush Valley, and locally is more striking. The Recent escarpment described by Gilbert is seen on plate 4, partly below and partly above the Bonneville shore-line. This fault can be traced northward from Flood Canyon to the north end of the range, and it forms discontinuous escarpments 10 to 50 feet high. It can also be traced southeastward from Flood Canyon for several miles to the head of Pine Canyon and thence across the summit of the range and into the western edge of the Bingham mining district, where it is known as the Occidental Fault.[30] This fault was intercepted by the Elton Tunnel in the SE¼ sec. 28, T. 3 S., R. 3 W. (see p. 158). In the SW¼ sec. 18, T. 2 S., R. 3 W., the fault plane dips 37° westward and is marked by a brecciated zone 10 or more feet wide; the Bonneville sea-cliff has been cut into the upthrown block and follows the trace of the fault for more than a mile to the south. In other exposures the dip of the fault plane was found to range from 40° to 65°.

South of the International Smelter, at the mouth of Pine Canyon, the front of the range is marked by a prominent escarpment that trends southwestward across Middle and Settlement Canyons. This fault was encountered in the Elton Tunnel about 8,500 feet from the portal, where it marks the contact between the Oquirrh formation and the valley fill. Its trace is marked by springs in both Middle and Settlement Canyons; in the latter canyon the fault scarp is more than a mile from the edge of Tooele Valley. It is not discernible beyond Settlement Canyon, and is not mapped as a continuous fault on the Stockton quadrangle, although Gilluly shows several short faults east of Stockton.

There is no evidence of faulting along the front of the Oquirrh Range between Settlement and Selkirk Canyons. According to the logs of wells (C-3-4)22dcd1 and (C-3-4)30aac1 the bedrock (Oquirrh formation) is at shallow depth below the surface of the valley along the projected crest of the Long Ridge anticline. Apparently the displacement between mountain and valley in the vicinity of Tooele has occurred chiefly along the fault described in the preceding paragraph, and the mountain front is marked by little if any displacement. Still farther south Gilluly shows a fault extending northward as far as Stockton with a trace about half a mile east of the highway along the valley's edge. This is the northernmost of the Basin-Range fault segments mapped by him; the dip of the fault plane—40° to 55° westward—is typical of the faults that occur along the southern part of the Oquirrh Range.

[30]Lyon, Tom, geologist for International Smelting & Refining Co., oral communication.

The total displacement in the fault zone along the Oquirrh Mountain front can be estimated only within wide limits; it must be greater than the present topographic break between the valley and the crest of the range, amounting to 4,000 to 5,000 feet, and it is probably less than the total thickness of the Oquirrh formation, estimated at more than 15,000 feet, because outcrops of the formation occur in both upthrown and downthrown blocks along the crests of each of the four major anticlines.

Minor Fault Blocks in Tooele Valley

Several faults striking more or less parallel to the Oquirrh Mountain front have been traced for short distances along the floor of Tooele Valley. One of these faults is well expressed in the topography; another is shown in outcrops; still others are not at all apparent on the surface, and have been identified chiefly by means of well logs and hydrologic data. These faults appear to mark the boundaries of small blocks that have been broken off from the eastern part of the great Stansbury fault block which underlies Tooele Valley, and perhaps also from the western edge of the Oquirrh block. The small fault blocks with their boundary faults are thus products of the Basin-Range faulting which caused the rotation of the larger blocks.

The easternmost fault observed in Tooele Valley is about 2 miles west of the front of the Oquirrh Range and passes with north-south strike through outcrops of the Oquirrh formation near Lake Point. At one exposure the dip of the fault plane measured 76°. Displacement along this particular plane is believed to have been small, but it is likely that the fault exposed is one of a series of step faults that may occupy a fairly wide zone.

About a quarter of a mile farther west, passing through the junction of State Highway 36 with U. S. Highway 40, the Mill Pond fault is prominently expressed in the topography for a distance of about 2 miles and is also marked by two large springs that flow into Mill Pond and Dunne's Pond, and by outcrops of the Oquirrh formation on the upthrown east side. The area that lies between this fault and the Oquirrh Mountain front is a minor fault block that includes the Lake Point ground-water district (page 161). Its southward extent is a matter of conjecture: it may be ended by displacement along a line projecting northwestward from the mountain front, perhaps in line with the fault that passes along Pine Canyon; or it may possibly continue to the mountain front south and southwest of Tooele (if the latter, its western boundary fault constitutes no barrier to ground-water movement, for hydrologic data indicate that water moves from Pine Canyon and Tooele toward Erda). To the north the Lake Point district extends as far as the high-water line of Great Salt Lake. How much farther northward the fault block continues unbroken is not known, but it is plausible that it may be intercepted by a cross fault near the north end of the Oquirrh Range, similar to and perhaps continuous with or parallel to the Box Elder Canyon fault, described below.

The Erda fault, located about 2½ miles west of and approximately parallel to the Mill Pond fault, is traced on the basis of well data (p. 179), and of the ground-water dam identified on maps of the piezometric surfaces (Fig. 10). This fault marks the west edge of a fault block that contains the Erda ground-water district (p. 161).

At the south end of Tooele Valley, South Mountain is terminated at its west end by a fault that trends somewhat west of north. This fault, mapped by Gilluly, is marked by a low escarpment. It may continue northward, buried under the Lake Bonneville beds in Tooele Valley, perhaps until it is intersected or ended by the Box Elder Canyon fault.

Box Elder Canyon Fault

The Box Elder Canyon fault has a northeasterly trend, but nevertheless appears to be one of the products of the Basin-Range tilting. It is expressed in the topography at the mouth of Box Elder Canyon, in sec. 8, T. 4 S., R. 6 W., the upthrown side to the south forming a prominent ridge composed of Paleozoic limestone and quartzite. From there the fault trends southwestward to the crest of the Stansbury Range. The fault appears to be a hinge fault, for the movement at the crest of the range has been upward on the north side, exposing older beds of the Tintic quartzite, whereas near the mouth of Box Elder Canyon the upthrown side is to the south, and Paleozoic limestones and quartzites occur along the south side of the fault opposite the outcrop of the Miocene (?) agglomerate. The fulcrum of the hinge would presumably be somewhere in the headwaters of Box Elder Canyon not far from the crest of the range.

The outcrop of Miocene (?) agglomerate near the east edge of South Mountain may well be the continuation of the outcrop in the Stansbury Range, offset along the Box Elder Canyon fault. Indeed, the difference in present inclinations of the pyroclastic beds in the two exposures, averaging about 15°, may be indicative of the difference in the amount of rotation of the two parts of the Stansbury Range fault block that are separated by the Box Elder Canyon fault. By this hypothesis the block north of the fault has been rotated several degrees more than the south block, with consequent greater height of the Stansbury Range and deeper erosion into the Tintic quartzite, and corresponding greater depth of valley fill in that portion of Tooele Valley north of the Box Elder Canyon fault. In substantiation of this hypothesis, South Mountain and several knolls along its north and west flanks, one as far north as sec. 24, T. 3 S., R. 5 W., project above the valley fill, and two of the wells drilled in the southern part of the valley have reached bedrock at comparatively shallow depths. On the other hand, in the area north of the projected line of the Box Elder Canyon fault there are no outcrops of bedrock nor has bedrock ever been encountered in any well.

The displacement of the sediments in Tooele Valley along the Box Elder Canyon fault has had an important bearing on the occurrence of ground water and particularly on the quality of the water in the central part of the valley. The area north of this fault has been relatively depressed and, with the contiguous area now occupied by Great Salt Lake, has long constituted the sink for a large area of interior drainage. Water entering this lowest part of the basin has accumulated to form lakes during humid cycles, and in arid cycles has been dispelled by evaporation to leave beds of soluble salts similar to those that are accumulating in the Great Salt Lake basin today. As a result, evaporites are presumed to be more common in the section north of the Box Elder Canyon fault than farther south, where the sediments are more largely of fluviatile origin. In confirmation, water obtained from wells north of the fault has a higher mineral content than that in wells south of the fault.

The Box Elder Canyon fault is considered to be contemporaneous with the Basin-Range faulting, probably developed to relieve the stress of differential rotation of segments of the great Stansbury fault block.

Date of Faulting

The Basin-Range faulting is clearly later than the folding in the region, for the folds are transected by the faults, and thus began subsequent to the Laramide orogeny. The Lake Bonneville beds have been displaced along the base of the Oquirrh Range near Lake Point, leaving a pronounced escarpment, and faulting has quite evidently taken place since the last recession of Lake Bonneville. It is considered that the Basin-Range faulting has occurred intermittently from early Tertiary time practically to the present day.

Some indication of the proportionate amount of displacement during the several epochs of the Tertiary and Quaternary may be derived from the present inclination of the sediments deposited along the east flank of the Stansbury Range during those epochs. The older Tertiary sediments, including the Wasatch formation and the agglomerate and tuff of Miocene (?) age, have eastward dips of more than 30°. The lower beds of the Salt Lake formation are tilted about 20°, and the upper surface of that formation has a slope of 10° to 12°. The Recent alluvial deposits are accumulating on slopes of 5° to 7°. These eastward inclinations, except for the small angle of original dip, are correlated with the rotation of the Stansbury Mountain fault block which, with similar rotation of the adjacent Oquirrh and Cedar Mountain blocks, resulted in the great displacements along the west base of the Stansbury, Oquirrh, and Wasatch Ranges. A large proportion of the displacement, representing perhaps as much as a third of the total rotation of the Stansbury block, occurred during the deposition of the tuff, before the last stages of Tertiary volcanic activity; further tilting occurred during the accumulation of the overlying Salt Lake formation, and continued during the Pleistocene, for the Bonneville and Provo shore-lines are as much as 80 feet higher along the Stansbury Range than they are along the Oquirrh Range. Recent tilting may be inferred also from the present dips of the principal aquifer that serves the Grantsville and Erda districts. The slope of this aquifer in the Grantsville district, which borders the moderate eastern slope of the Stansbury Range is more than 100 feet per mile eastward. In the Erda district, which is adjacent to the steep west slope of the Oquirrh Range where original deposition is presumed to have been on a steeper gradient, the aquifer now has a westward gradient less than 25 feet in a mile. The folded Paleozoic rocks that make up the Stansbury Range were of course involved in all the tilting: the strata on the west limb of the Stansbury anticline commonly have dips of 45° or less, while the beds on the east limb are very steeply inclined and locally overturned.

No comparable correlation of the Basin-Range faulting with the sedimentary record can be made for the Oquirrh Range block. For the southern part of the range, however, Gilluly has described an erosion surface in the stage of early maturity, which was developed prior to the Basin-Range faulting, and which he considers to be not younger than middle Pleistocene nor older than Oligocene.[31] He concludes that the Basin-Range faulting began during the Miocene and has continued until the present day.

GEOLOGY IN RELATION TO OCCURRENCE OF GROUND WATER

The occurrence of ground water in Tooele Valley and the area tributary to it is largely a function of the development of the land forms described in the preceding section. The folding of the Laramide orogeny, the Basin-Range faulting and concurrent rotation of the major fault blocks, the desert-basin deposition in Tooele Valley throughout most of the Tertiary, the modification of surficial features by Lake Bonneville, the long-continued lacustrine sedimentation in the lowest part of the Great Salt Lake basin—all have contributed some part to the present pattern of ground-water occurrence.

The folds exert some control over the movement of ground water in the rock masses bordering Tooele Valley, for this movement is largely along bedding planes and other fractures, and ground water in the porous beds moves downward along the dip of the strata. The northward plunge of the axes of the sev-

[31] Gilluly, James, Geology and ore deposits of the Stockton and Fairfield quandrangles, Utah: U. S. Geol. Survey Prof. Paper 173, pp. 40, 77, 86, 1932.

eral folds may bring some water into Tooele Valley from areas farther south, by movement down the synclinal troughs.

Several of the largest springs in Tooele Valley rise along the Basin-Range faults. The Bryan Springs are located along a fault plane that follows the west front of the Oquirrh Range and is clearly indicated by Recent escarpments. Farther west, two of the largest springs in the valley, at Dunne's Pond (Factory Creek) and Mill Pond, are located along the Mill Pond fault. These springs each have a discharge of more than 5 second-feet. Just west of the northern tip of the Stansbury Range the Timpie Big Spring rises along the fault that bounds the west front of the range. Two large springs rise along the Box Elder Canyon fault at Threemile and Sixmile Creeks, east of Grantsville.

The upland erosion and desert-basin deposition that have followed these mountain-making movements have been of great importance in the development of the ground-water reservoir. The sediments range from coarse fanglomerates along the margins of the valley to fine-grained playa and lacustrine deposits in the center, and include a considerable thickness of alternating coarse and fine clastics. The beds of coarser sand and gravel constitute the aquifers in Tooele Valley, which are discussed in detail in a subsequent chapter. The differential erosion of the rocks in the mountain ranges has left resistant ledges that create many springs in the canyons by forcing to the surface water that has been moving as underflow in the gravel of the canyon bed.

The advent of Lake Bonneville has had a marked influence upon the occurrence of ground water in Tooele Valley. The beaches, terraces, bars, and other lake shore features, consisting of extremely well-sorted gravel and coarse sand, are outstanding in their ability to transmit water. Many of the smaller canyons draining the mountains have debouched over the lake deposits below the Bonneville shore-line ever since the recession of the lake from that level without having established a channel across these deposits, and it is evident that the run-off from these canyons has been absorbed almost entirely by the coarse gravels. Thus the recharge area for the ground-water reservoir in the valley, because it includes extensive areas of these lake shore deposits, absorbs a great portion of the run-off from the surrounding mountains, and practically none of the water from the canyons continues in channels across the lower part of the valley and into Great Salt Lake.

The deposition of lacustrine sediments, throughout the Pleistocene series and probably part of the Tertiary period, has resulted in the development of a vast plain extending northward from Tooele Valley and encompassing the north ends of the Stansbury and Oquirrh Ranges. The clays underlying this plain are presumed to extend almost to the bedrock of the ranges. The bedrock and the lake sediments of today, however, are separated in many places by a narrow belt of talus, slope wash, and alluvial debris that is markedly coarser than the lake sediments and more permeable than either the bedrock or the lake beds. Presumably as the lake sediments accumulated in past epochs, they were likewise separated from the bedrock by a narrow belt of coarser detritus, which would thus be more or less continuous over the bedrock beneath the present land surface. Many springs arise in this zone along the borders of both the Stansbury and Oquirrh Ranges.

SURFACE WATER

The perennial streams of the Tooele Valley drainage basin have been mentioned in the discussion of topography (p. 106). These streams constitute the only source of water for irrigation in the vicinity of Tooele and are the principle source of water in the Grantsville area. Two of the streams furnish water for power, and for these some records of stream flow have been kept. The other streams are used for irrigation and municipal supply, and no systematic records of their yields have been kept by the officials of the small irrigation companies that distribute the water. The available information on surface water is summarized in the following paragraphs.

South Willow Creek—The discharge of South Willow Creek ranges from an estimated 20 to 40 second-feet during the spring freshets to a base flow of 5 to 2 second-feet during the months from August to February inclusive. The water is diverted through a steel pipe line 12 to 20 inches in diameter and 4½ miles long from the outcrop of the Miocene (?) agglomerate in the canyon, to a power house of the Utah Power & Light Co. in the SW¼ Sec. 27, T. 3 S., R. 6 W. This pipe line, constructed in 1912 and 1913, has a capacity of 8.45 second-feet and carries the full flow of the stream for 8 to 11 months of the year. Below the power house the water is carried through a concrete pipe line 4 miles to the south limits of Grantsville, and is then distributed by the South Willow Irrigation Co. for irrigation of about 1,100 acres of land.

North Willow Creek—The discharge of North Willow Creek is reported to be ordinarily between 2 and 4 second-feet at the mouth of the canyon except during the spring freshets, when discharge as high as 38 second-feet has been reported. The water is distributed by the North Willow Irrigation Company, which supplies water for about 600 acres, chiefly in the western part of Grantsville, although when supplies are sufficient some may be sold to the South Willow Irrigation Co. and diverted to the lower, eastern part of the Grantsville area. A concrete pipe line 24 inches in diameter was constructed by the Soil Conservation Service in 1937 from bedrock outcrops (the Miocene (?) agglomerate) in North Willow Canyon, northeastward about 7 miles to the south edge of Grantsville. By construction of this pipe line, seepage from the stream has been largely eliminated except during periods when the stream flow exceeds the capacity of the pipe line. According to E. M. Clark, president of the North Willow Irrigation Company, about 75 percent of the water was lost between the canyon mouth and the town before construction of the pipe line.

In 1939 the city of Grantsville, which owns a right to 1 second-foot of spring water in Davenport Canyon, sponsored construction by the Works Progress Administration of a pipe line 1½ miles long from that canyon to the head of the North Willow Irrigation Company's pipe line. Under reciprocal easement agreement the city mixes the municipal supply with the company's water, and then retakes it at the city limits—an agreement which is economical in pipe lines, although the city water supply may be somewhat turbid during the freshet of North Willow Creek.

Settlement Creek—According to records furnished by Amos Bevan of the Settlement Canyon Irrigation Co., the discharge of Settlement Creek has ranged from 1.3 second-feet in February 1935 to 36 second-feet in June 1921. The stream has a freshet each year during May, June, and rarely in July, when the flow may exceed 10 second-feet for several days or weeks. Throughout the rest of the year the discharge is at a fairly steady rate that decreases gradually from July until the following March, except for infrequent flash floods resulting from cloudbursts. This base flow has been less than 3 second-feet during each of the years from 1931 to 1935, in 1939, and probably during other years when there was a marked defficiency in rainfall. In normal years the base flow has ordinarily been 4 to 6 second-feet, and in years of excessive precipitation (1908-9, 1920-22, 1941) it may have been continuously above 6 second-feet. The water of Settlement Creek was used until 1927 to develop power at the Utah Power & Light Company's plant near the mouth of the canyon in the NE¼NW¼ SE¼ Sec. 33, T. 3 S., R. 4 W., for which two steel pipe lines of 14-inch and 10-inch diameters were laid for distances of 2½ and 2 miles in 1902. The water was sufficient to operate the plant at capacity 3 months of the year. After leaving the power plant the water is distributed by the Settlement Canyon Irrigation Company for irrigation of about 1,100 acres. In addition, about a quarter of Tooele's municipal supply is piped from springs located in Settlement Canyon.

Middle Creek—Middle Creek is reported to have a flow of 8 to 10 second-feet during the spring run-off, and an average flow of 1 or 2 second-feet during the rest of the year. This water is distributed by the Middle Canyon Irrigation Company for irrigating 800 acres (flood water rights), chiefly in the vicinity of Tooele but including land as far north as sec. 35, T. 2 S., R. 4 W. (the Droubay ranch), which lies east of Erda.

In addition to this surface flow, Middle Canyon has furnished about three-fourths of Tooele's municipal water supply, which is taken from springs in the NE¼ Sec. 35, T. 3 S., R. 4 W., through a steel pipe line 12 inches in diameter and 1.2 miles long, to a concrete reservoir near the mouth of the canyon. According to John Gollaher, city engineer of Tooele, the yield of these springs and tunnels in 1941 averaged about 630 gallons a minute, but the flow diminishes appreciably following dry years. Also, Lincoln community diverts water from Middle Canyon for culinary use through a pipe line 2 or 3 inches in diameter and 1.4 miles long. This diversion is reported to average about 55 gallons a minute.

GROUND WATER

GENERAL RELATIONS

The unconsolidated sediments that form the valley fill to untested depths in Tooele Valley yield by far the most important supplies of ground water. All wells now in use obtain water from these sediments, and so far as known all the springs within the valley do likewise. Accordingly, the following discussion relates almost entirely to the water in the Quaternary and, for perhaps a few of the deepest wells and some springs, the late Tertiary sediments. However, water occurs also in the rocks that underlie the unconsolidated sediments and that make up the great ranges bordering the valley, and because the principles of occurrence of water in these formations are considerably different from those of the younger sediments, the bedrock formations are considered briefly first.

WATER IN THE BEDROCK

The bedrock formations of the Tooele Valley area, which include the Paleozoic marine sedimentary rocks and the Tertiary rocks below the Salt Lake formation, are generally much less permeable than the unconsolidated or loosely cemented younger rocks. These formations are composed chiefly of quartzite and limestone, with subordinate amounts of sandstone, conglomerate, shale, and pyroclastics. Beds of limestone where solution has been active and layers of sandstone that are loosely cemented may be pervious enounugh to yield water. Otherwise ground water occurs chiefly along fractures, joints, and fissures in the limestone, quartzite, and other rocks.

The water in the bedrock is derived from downward penetration of precipitation upon the areas of outcrop. Water moves down the dip of the permeable strata and doubtless follows the northwest plunge of the several synclines. Water in fractures follows those breaks until it reaches unfractured strata, when further movement is likewise determined by the attitude of the beds. Where strata are displaced by faulting the water in them may move along the fault planes; several springs along faults mark places where this water comes to the surface. Because of the dominance of structural control the direction of movement of water in the bedrock may be quite different from that in the younger unconsolidated rocks, where ground-water circulation follows approximately the present drainage pattern of the land surface.

Many of the mines of the Bingham and Stockton mining districts of the Oquirrh Range have encountered water in the bedrock, and many workings have been discontinued because the inflow was greater than could be economically removed by pumping. Primarily for the purpose of draining some of these workings, two long tunnels have been drilled into the range from Tooele Valley, and both yield water derived from the bedrock. These tunnels and certain springs that appear to originate in the bedrock are described in following paragraphs.

ELTON TUNNEL

The Elton tunnel was driven by the National Tunnel and Mines Company, subsidiary of the International Smelting & Refining Co., to provide facilities for drainage of deep mines in the upper (western) part of the Bingham mining district and also to afford a means of rapid transportation of ore and personnel between those mining properties and the smelter at Tooele. The portal of the tunnel is in the NE¼ sec. 13, T. 3 S., R. 4 W., at an altitude of 5101 feet; the approximate location of the bore is shown on plate 1. Started in May 1937, the tunnel was completed to the Rood shaft of the Utah-Apex mine in August 1941, having a length of about 24,000 feet with a grade of 0.35 per cent.[32]

The source of the water issuing from the Elton tunnel was determined by weir measurements made by the National Tunnel and Mines Company at intervals of 1,000 feet from the portal. The following table shows the results of measurements made on April 26, 1941, when the face of the tunnel was 23,158 feet from the portal.

Proceeding from the portal of the tunnel, the first source of water was approximately under Dry Canyon, and was probably derived largely from underflow. The greatest flow of water, representing nearly half the discharge on the date of measurement, was obtained from the Oquirrh formation 9,000 to 12,000 feet from the portal, just beyond the fault contact with the unconsolidated rocks. The beds from which this water is derived are exposed on the upthrown side of the fault in sec. 30, T. 3 S., R. 3 W. A fairly large amount of water is also yielded from the Oquirrh formation under the floor of Dry Canyon 14,000 to 15,000 feet from the portal and is probably replenished from underflow in the unconsolidated materials flooring the canyon.

The rest of the water, constituting about one-third of the total discharge, was derived from porous zones, fractures and fissures 15,000 to 23,100 feet from the portal, the discharge increasing more or less regularly in this portion of the tunnel. This water is derived partly from the headwaters of Bingham

[32]Huttl, J. B., Driving the Elton tunnel: Eng. and Min. Jour., vol. 141, pp. 33-36, Mar. 1940.

Canyon east of the summit of the range. The Occidental fault, marked on the surface by a prominent scarp, yielded no water.

Water in the Elton Tunnel April 26, 1941

(Measurements by National Tunnel and Mines Company)

Distance of gaging station from portal (feet)	Discharge in gallons a minute	Increase in discharge between stations, gallons a minute	Remarks on geology
23,000	207		Oquirrh formation
		304	
22,000	511		Do.
		195	
21,000	706		Do.
		0	
20,000	706		Do.
		85	
19,000	791		Do.
		89	
18,000	880		Do. Occidental fault at 18,275 ft.
		156	
17,000	1,036		Do.
		79	
16,000	1,115		Do.
		160	
15,000	1,275		Do.
		453	
14,000	1,728		Do. Dry Canyon at approximately 14,000 feet.
		0	
12,000	1,728		Do.
		776	
11,000	2,504		Do.
		850	
10,000	3,354		Do.
		50	
9,000	3,404		Do. Basin-Range fault at 8,472 ft.
		0	
7,000	3,404		Alluvium, chiefly loose gravel.
		247	
6,000	3,651		Do. Dry Canyon at 6,500 feet.
		0	
0	3,651		Do.

The overflow from the tunnel since water was first encountered in November 1937 is shown in the following table.

Outflow from Elton Tunnel, in Acre-feet

(based on weir measurements by the National Tunnel and Mines Co.)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1937												30	30
1938	40	45	80	65	115	130	100	80	75	75	65	70	940
1939	70	55	70	65	105	120	110	165	200	460	615	705	2740
1940	705	645	680	670	655	570	580	565	515	510	480	495	7070
1941	535	540	565	505	540	685	580	540	495	530	500	450	6460
1942	400	345	385	415	470	460	470	445	405	420	405	425	5050
1943	430	385	415	385	370	330	325	305	280	285	270	290	4060
1944	275	235	255	295	370	405	420	400	360	350	325	330	4020
1945	315	270	295	330	385	365	365	345	310	315	305	315	3930
1946	315	300	345	335	345	335							

In the course of drilling the discharge fluctuated considerably as porous zones were encountered and drained, but showed a general increase each year. The maximum recorded discharge was about 13 second-feet, and occurred during the draining of the mine shaft in June 1941, just prior to completion of the tunnel. Much of the flow during 1941 was withdrawn from storage in the overlying bedrock, and resulted in a permanently lowered water level. The decrease in flow during each year since completion of the tunnel in 1941 suggests that withdrawal from storage has continued at a progressively diminishing rate through 1945.

During the years 1942, 1944, and 1945, the rate of discharge from the tunnel was greater during the spring and summer than it had been earlier, showing that the ground-water supplies were replenished by recharge from melting snow on the mountain mass. In the dry year of 1943 there was no evidence of recharge, and the outflow from the tunnel continued to decline throughout the year. The records of outflow during the past three years indicate that a continuous flow of about 5 second-feet may be expected from the tunnel, and that rainfall in normal years will be sufficient to replenish this outflow.

HONERINE TUNNEL

The Honerine tunnel, owned by the Combined Metals Reduction Company, was drilled about 1910. It drains several workings to a level 1,200 feet below the old Honerine shaft and provides a haulage level to the company's mill at Bauer. The portal is in the SW¼ sec. 13, T. 4 S., R. 5 W., and the tunnel extends in a southeasterly direction about 13,000 feet. The rocks encountered were chiefly limestone and quartzite of the Oquirrh formation, cut by numerous impervious dikes of monzonite porphyry which are reported to control the movement of ground water. According to Gilluly,[33] the tunnel yielded between 1,500 and 1,900 gallons of water a minute in 1927 (partly by pumping from the Honerine mine 400 feet below the tunnel level), which sufficed for the needs of the mill and for irrigation of 160 acres of orchard and 200 acres of alfalfa at Bauer. By 1941 the discharge from the tunnel was only 750 gallons a minute, all of which was required for milling purposes. Of this discharge 450 gallons a minute was pumped from the Honerine mine 400 feet below the level of the tunnel, and 250 gallons from the Calumet mine, 900 feet below the tunnel.

The discharge from the Honerine tunnel in the past has been partly at the expense of storage, and water levels have been lowered more than 1,000 feet in certain areas since mining operations began. The present flow, however, is obtained by pumping from approximately the same levels as in 1927. It is likely that this flow is partly replenished by precipitation upon mountain areas tributary to Rush Valley, and the tunnel serves to divert this water for use in Tooele Valley.

[33]Gilluly, Op. cit., p. 160, pl. 31.

SPRINGS

Most of the numerous springs in the Stansbury and Oquirrh Ranges are on the upstream side of resistant beds that form dams across the canyons and force to the surface water that has been moving through the gravel of the canyon floor. A few springs issue directly from bedrock. One of these, on the south wall of South Willow Canyon in sec. 11, T. 4 S., R. 7 W., rises in a limestone bed of the Ophir formation of Cambrian age. Some calcareous tufa has been deposited by the spring, which issues at a temperature of 42° F. Another spring rises along the contact between the Paleozoic rocks and the Miocene (?) agglomerate, in the SW¼ sec. 13, T. 3 S., R. 7 W. Other springs rise in Davenport and North Willow Canyons close to the base of the volcanic rocks. These springs probably originate in porous zones of the pre-Pennsylvanian sediments and are forced to the surface either along the contact with the volcanic rocks or along the contact with the Manning Canyon shale (Carboniferous), which does not appear at the surface because of the overlap of the agglomerate of Miocene (?) age.

WATER IN THE UNCONSOLIDATED SEDIMENTS

The unconsolidated sediments constitute the only source of water in wells and the principal source of spring water in Tooele Valley. These sediments, consisting chiefly of alluvium and lake beds, are far more permeable than the consolidated rocks that make up the mountain masses, and the bedrocks act as barriers to ground-water movement and thus form the boundaries along three sides of the ground-water reservoir in Tooele Valley.

The unconsolidated sediments include discontinuous, lenticular, and commonly elongated bodies of sand, clay, gravel, and boulders of alluvial origin; and lacustrine beds of the same materials, which are generally more extensive and better sorted. Considering Tooele Valley as a whole, the valley fill is a heterogeneous assortment of these unconsolidated materials, through which ground water moves freely in the permeable coarse sand and gravel, particularly in the beds that are well sorted. In the finer materials, including clay, silt, and even the finer grades of sand, the movement of ground water is slower. In general the direction of ground-water movement is from the west, south, and east margins of the valley and toward the low central part, following approximately the drainage pattern established by streams and washes on the land surface.

Practically all wells in Tooele Valley are located in the lower part of the valley, where the land surface is less than 4,400 feet above sea level, and where beds of clay, silt, and fine sand are common in the valley fill. Ground water, moving most freely in beds of coarser sand and gravel, is confined beneath strata of low permeability under artesian pressure sufficient to cause wells to flow throughout the greater part of the present area of ground-water development. Indeed, only about a hundred of the approximately 1,100 wells drilled in the valley are reported never to have flowed. Information as to the source and movement of ground water throughout this area is based largely on knowledge of the piezometric or pressure-indicating surfaces of the several artesian aquifers tapped by wells. Water not confined under artesian pressure is used from several dug wells in the Lake Point district. For the rest of the valley there is practically no information as to position of the water table, although it is inferred that ground water occurs under water-table conditions in the coarse sediments of the marginal parts of the valley and also in the shallow strata overlying the impermeable beds that create the artesian conditions.

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 Tooele Valley. Ground water enters this reservoir from a number of sources which are discussed subsequently, moves generally toward the central and lowest part of the valley, and is largely disposed of by discharge within the limits of the valley, although an unknown quantity may be discharged through aquifers that extend northward under Great Salt Lake. For the subterranean reservoir as a whole the sources of the water, the direction and rate of its movement, its chemical characteristics and other features vary within wide limits. The reservoir may conveniently be divided, however, into units which are fairly homogeneous insofar as ground-water hydrology is concerned.

The ground-water reservoir within the present area of development of Tooele Valley has been subdivided into five districts, which are shown on figure 10. The boundaries of three of these districts are located along faults that have been described in the geologic chapter. For the most part the locations of these faults across the valley floor cannot be determined closely, because the traces have been obscured by deposition subsequent to the faulting, but their positions are indicated approximately by features on the piezometric surfaces such as ground-water dams. The ground water within each of the described subdivisions is derived principally from a common source, has a fairly consistent direction and rate of movement and ranges within moderate limits in kind and concentration of chemical constituents. The individual ground-water districts are outlined briefly in following paragraphs, and the source, movement, and disposal of the water in them are described in detail subsequently.

The Lake Point ground-water district includes the part of Tooele Valley east of the Mill Pond fault, and north of a line connecting Mill Pond Spring and Bryan Springs. Practically all the wells in the district are located within three miles of the present shore of Great Salt Lake.

The Erda district lies immediately west of the Mill Pond fault. Its north boundary extends along the Victory Highway (US-40 and 50), which is believed to mark approximately the trace of the Box Elder Canyon fault. The western limit of the Erda district is set along the west boundary of Range 4 West, which lies within a few hundred yards east of the probable trace of the Erda fault.

The Marshall district borders the Erda district on the west, and is likewise bounded on the north by the Box Elder Canyon fault.

The Grantsville district embraces the town of Grantsville and its environs, and extends from the Cooley slough on the northwest to the Box Elder Canyon fault on the southeast. Its north boundary is conventionalized along section lines to include an area that extends as much as 4 miles north of the town, in which fresh water of good quality is obtained from wells. The district is thus believed to include the area in which there has been free circulation of the ground waters that have originated in South Willow and North Willow Canyons of the Stansbury Range (p. 213).

The Burmester district extends westward from the northern part of the Lake Point district, and lies north of the Erda, Marshall, and Grantsville districts. It is the largest district within the area of present ground-water development, and extends indefinitely northward toward and perhaps under Great Salt Lake. Relatively few wells have been drilled in this extensive area, and the water obtained from these wells is generally of inferior quality (p. 214).

FLUCTUATIONS OF GROUND-WATER LEVEL

Fluctuations of water level and artesian pressure are caused chiefly by variations in the rates at which water is taken into or discharged from the aquifers. These fluctuations are observed in wells, where they cause changes in the position of the water level or pressure head. Because the fluctuations in wells afford a 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. Information concerning these fluctuations is based upon data collected from observation wells. Detailed data are obtained from recording gages that provide continuous records of the fluctuations of the static level in a well, and records from other wells are based upon weekly, monthly, or less frequent measurements of the position of the water level. These records are published annually.[34]

[34]Meinzer, O. E., and Wenzel, L. K., Water levels and artesian pressure in observation wells in the United States: published in U. S. Geological Survey Water-Supply Papers as follows:

Year	Water-Supply Paper	Pages	Year	Water-Supply Paper	Pages
1936	817	396-402	1941	940	94-121
1937	840	543-547	1942	948	104-111
1938	845	647-651	1943	990	117-120
1939	886	877-881	1944	1020	
1940	910	136-140	1945		

Fluctuations of water level in wells in Tooele Valley are caused by several factors, such as pumping of wells, discharge of flowing wells, seepage of water from stream channels or irrigation ditches, evaporation and transpiration in areas where the water is at shallow depth, changes in atmospheric pressure, earth tides, and earthquakes. Of these, the last three factors cause minor fluctuations that are not related to changes in ground-water storage, and they are considered only because of the corrections that must be applied to the hydrographs of wells in which such fluctuations occur. The other fluctuations are indicative of changes in storage, for they are caused by the changing rates at which water is being added to or withdrawn from the aquifer tapped by the well.

Fluctuations Involving No Changes in Ground-Water Storage

Barometric fluctuations—Fluctuations of water level in response to changes in atmospheric pressure have been recognized in all wells that have been equipped with water-level recorders in Tooele Valley, and are noted in numerous wells elsewhere in the State. Although characteristic of artesian wells, they occur also in certain shallow wells not known to be artesian. The typical barometric fluctuations include a diurnal cycle induced by solar heating of the atmosphere, and fluctuations associated with cyclonic storms. In response to the diurnal cycle the water level commonly rises in wells during the hours of solar radiation (8:00 a.m. to 6:00 p.m. in midsummer; 10:00 a.m. to 2:00 p.m. in midwinter), and then declines. The rise in midwinter is ordinarily less than 0.03 foot; in summer it may be as much as 0.05 or 0.06 foot, and rarely exceeds 0.1 foot. The barometric fluctuation in response to cyclonic storms is ordinarily considerably less than an inch of mercury, and the corresponding fluctuations of water level in wells are ordinarily not more than one or two-tenths of a foot, although extreme ranges in atmospheric pressure may cause a change of as much as 0.5 foot in certain wells. The effect of changing atmospheric pressure is clearly shown in figure 4. The barograph at Salt Lake City (lowest line in the figure) has been converted to feet of water and is shown at one-fourth the scale of the hydrographs. The close similarity of minor fluctuations of barograph and hydrographs at these scales indicates that the wells are about 25 per cent efficient as water barometers. These barometric fluctuations are just as pronounced on August 19 and 20, when water levels are lowered by pumping from a nearby well, as on other days.

Tidal Fluctuations—Fluctuations in response to earth tides have been recognized by Robinson[35] in wells in New Mexico and Iowa. Similar fluctuations have been noted in certain wells in Tooele Valley, and have been identified in hydrographs after

[35]Robinson, T. W., Earth tides shown by fluctuations of water levels in New Mexico and Iowa: Am. Geophys. Union Trans. Twentieth Am. Meeting, pp. 656-666, 1939.

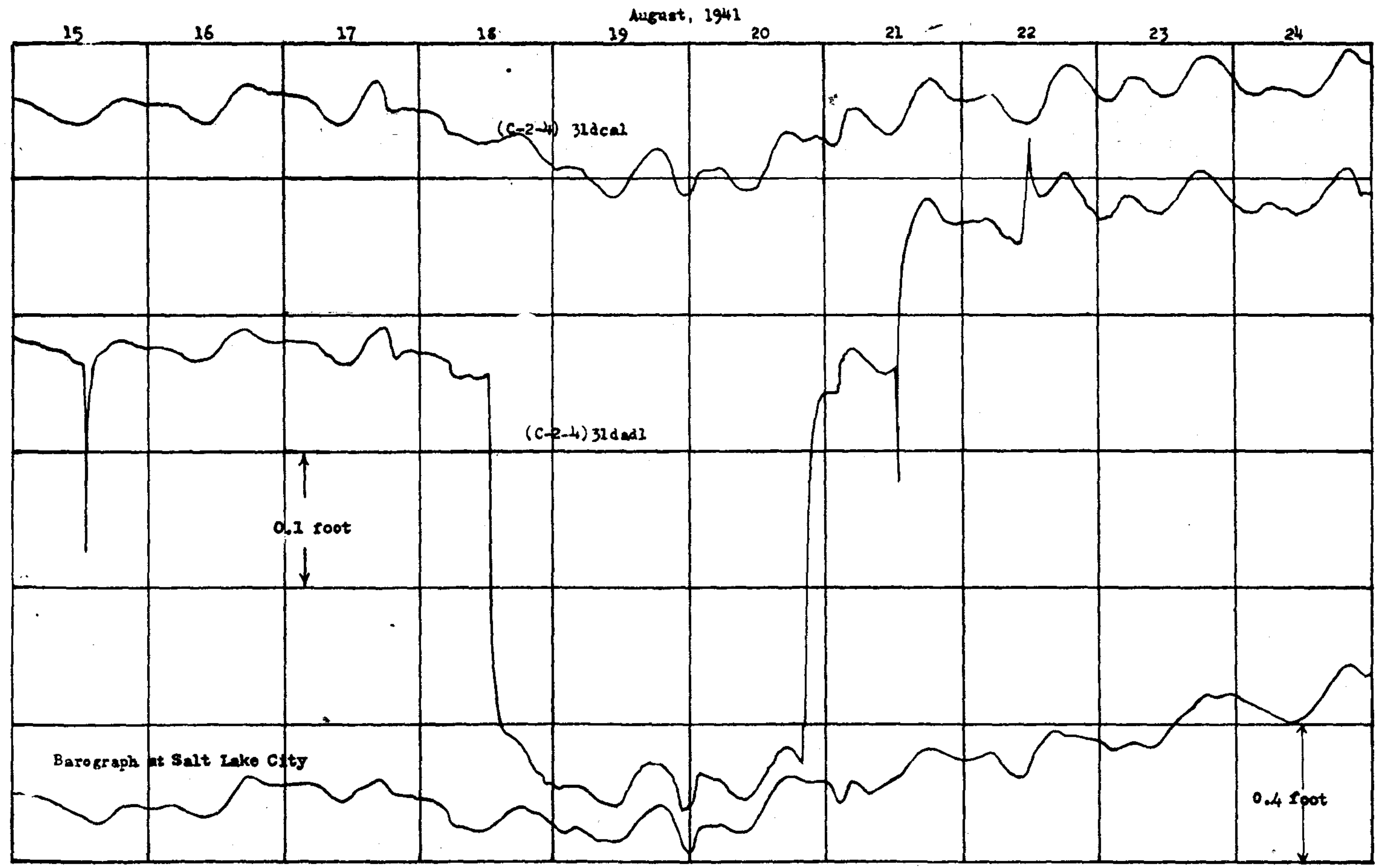

Figure 4.—*Hydrographs of two wells showing barometric fluctuationsand fluctuations due to pumping.*

corrections have been applied to eliminate barometric fluctuations. The corrected hydrographs closely resemble Robinson's residual curves and show two daily cycles of water-level fluctuations, whose troughs coincide with the transit of the moon at upper and lower culmination. During the periods of new and full moon the fluctuations are largest and have a maximum observed amplitude of 0.02 foot.

Correction of hydrographs for minor fluctuations—Changes in atmospheric pressure and earth tides result in fluctuations of water level in wells which, though small, may modify appreciably the fluctuations caused by other forces. Fluctuations caused by discharge from flowing wells are of particular concern in the tests of interference between wells described on page 216, and for these tests correction of the hydrographs was undertaken to eliminate the effects of atmospheric changes and earth tides.

The hydrograph for well (C-2-4)31dca1 during the period covered by the interference tests is shown in figure 5, together with graphs in which corrections have been applied, first for changes in atmospheric pressure and then for the effect of earth tides. The effect of atmospheric pressure was determined during periods when it appeared that the water level in the well was remaining practically stationary except for the minor fluctuations caused by extraneous forces. One such period lasted througout most of August 1941. A small semi-diurnal fluctuation during certain parts of this month indicated that earth tides might affect the water level in the well, and the effect of atmospheric pressure was therefore determined for points on the hydrograph when earth-tide effects would presumably be at a minimum and probably constant: three hours after the upper culmination of the moon each day. At these times a rise of atmospheric pressure equivalent to an inch of mercury caused a decline of water level of about 0.3 foot in the well, or, in other words, the well during this period appeared to be about 25 per cent efficient as a water barometer. Comparisons of barometric and water-level fluctuations during several other periods indicate that this is the approximate order of magnitude of the barometric efficiency of the well. According to records of wells in other areas, barometric efficiency is not necessarily constant for a well but varies in response to several factors, of which an important one is the rapidity of the barometric change.[36] In figure 5 the line above the hydrograph represents the computed position of water level at a constant barometric pressure of 26 inches, assuming an efficiency of 25 per cent in the well. In this line semi-diurnal fluctuations presumably caused by earth tides are clearly shown. The correction for these fluctuations has been made graphically in the uppermost line of the figure by connecting the mid-points between the semi-diurnal peaks and troughs.

[36]Thomas, H. E., and Taylor, G. H., Geology and ground-water resources of Cedar City and Parowan Valleys, Utah: U. S. Geol Survey Water-Supply Paper 993, 207 pp., 1946.

Fluctuations Related to Discharge from Wells

Water is used only intermittently from the great majority of wells in Tooele Valley; many of the wells yield water from day to day as needed for culinary or stock uses, and a large number are used seasonally for irrigation. The irrigation wells, including practically all the larger wells and about 60 per cent of all wells, are drawn upon heavily during the months from April to October of each year, particularly in midsummer, and remain idle during the other months. The short-term and seasonal use of wells causes fluctuations of water level in most of the wells in the area, including those that are not in use.

Only two or three wells have been pumped for irrigation in Tooele Valley. One of these, No. (C-2-4)35cbbl, is more than a mile distant and across the Mill Pond fault from the nearest observation well, and its operation causes no recognizable change of water level in the observation well. Another pumped well in the western part of the Erda district yields water by artesian flow when other wells are closed and when the pump is not operating. Fluctuations produced in two nearby wells by pumping about 120 gallons a minute from this well are shown in figure 4. These fluctuations are the result of pressure effects induced by pumping from the artesian aquifers, and are quite different from the more gradual declines noted in other areas that result from unwatering of sediments. Practically all other irrigation wells in Tooele Valley yield water by artesian flow. The discharge from them causes fluctuations in adjacent wells identical to those produced by pumping, as shown by comparison of figures 4 and 5.

Seasonal discharge of irrigation wells causes a regional drawdown that is greatest in the areas of greatest discharge, and is registered to a greater or less extent in the majority of observation wells in the valley. The seasonal fluctuations in several wells are shown in Figure 6.

Well (C-2-4)27ccb1 is at the eastern edge of the intensively developed Erda district (p. 161). Each spring its water level is lowered about 3 feet by the opening of irrigation wells, which in 1941 was authorized on May 1, and there is a corresponding rise in the autumn when those wells are closed. The rise during June 1941 was caused by closing several large wells between June 10 and 16. The hydrograph of well (C-2-4)33add1 is similar in general trend, but the amplitude of fluctuations is always smaller because of the greater distance of the well from the center of the intensively developed area.

Well (C-2-4)31dcal is in the western part of the Erda district, where operation of wells has been on a somewhat different schedule from that of the area farther east. In this area wells were opened about the first of April 1941 (as shown in detail in figure 5), and the water-level in well (C-2-4)31dcal rose gradually during November and December, apparently because of the closing of wells in the eastern part of the Erda district.

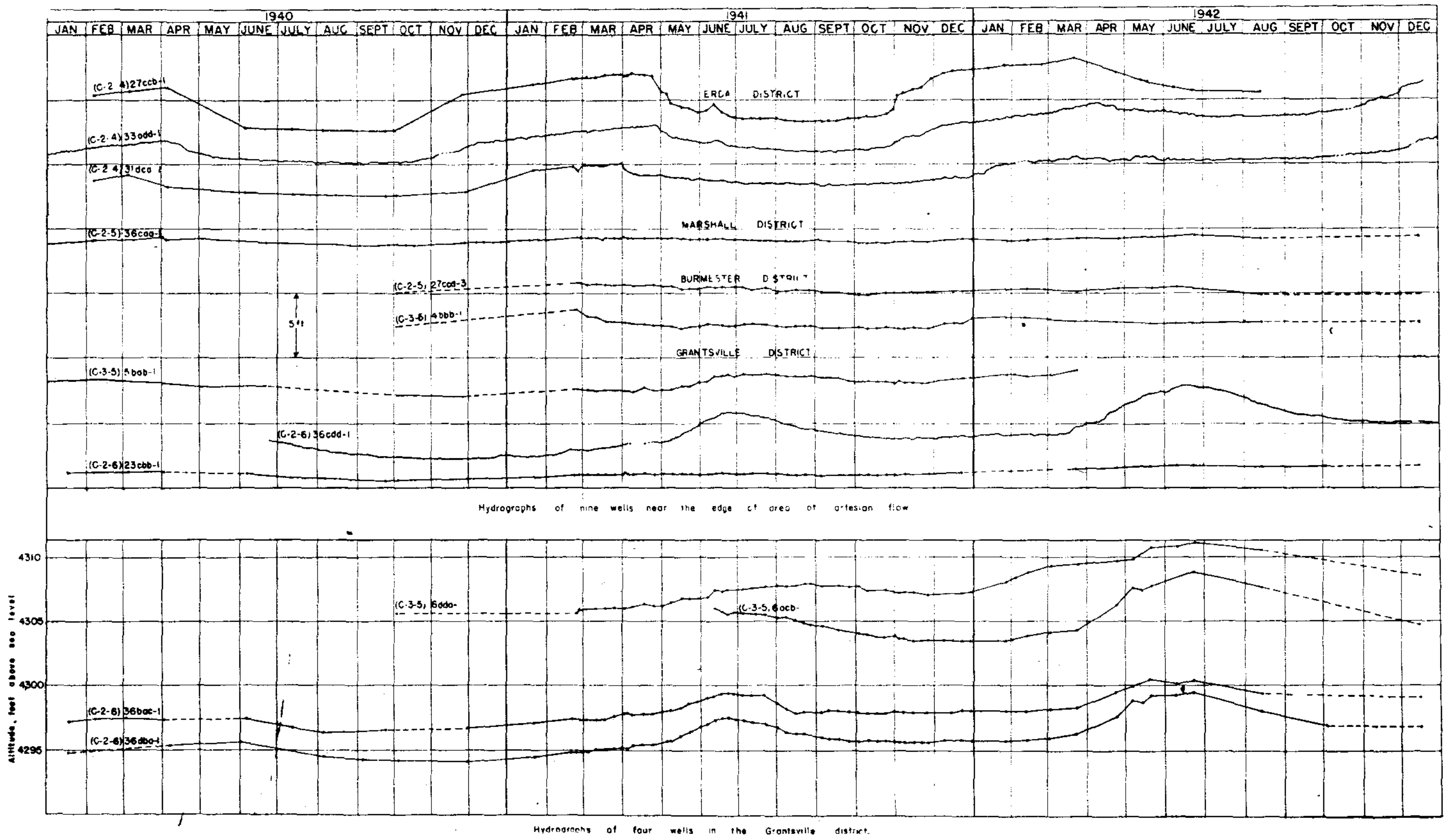

Figure 6.—*Seasonal fluctuations of water level in wells in Tooele Valley.*

Wells (C-2-5)36caa1 and 27ccd3 are in the unproductive area between the Erda and Grantsville districts, where there are very few wells. Fluctuations of water level in these wells throughout the year are of small amplitude and are evidently due to seasonal discharge from wells in adjacent areas, for they show an annual cycle that is ordinarily highest in March, before the irrigation wells are opned, and lowest in September toward the end of the irrigation season.

Well (C-3-5)4bbb1 is near the eastern edge of the Grantsville district, where many wells are used for irrigation. The annual fluctuation of water level is due largely to seasonal withdrawal of water from those wells. The remaining hydrographs shown on the figure are for wells in which the principal fluctuations of water level are caused by recharge from streams or irrigation ditches.

Fluctuations Related to Evapo-transpiration

In the northern part of Tooele Valley—including most of the area north of highway US 40 and 50—ground water occurs at such shallow depths that considerable quantities are lost by evaporation and transpiration. The wells in this area are drilled into artesian aquifers beneath this shallow zone, and the water level in them bears no relation to the shallow water. Fluctuations of the shallow-water level, however, are shown in several holes bored to shallow depths in the vicinity of the oolitic sand deposits west of Lake Point (p. 127). Hydrographs of three bore holes are included in figure 7, which shows also the fluctuation in level of Great Salt Lake, and certain climatologic data for the area.

The level of Great Salt Lake is determined by the balance between the losses by evaporation and the gains by precipitation on the lake surface, inflow from streams, and discharge from the ground-water reservoir. It is commonly at its highest stage each year during April or May, and declines between 0.5 foot and 2.6 feet during the succeeding four or five months, indicating that the amount of water evaporated during the summer exceeds the input from all sources. The influence of meteorologic conditions upon the lake level is clearly shown: During each month that the evaporation at Utah Lake (about 40 miles southeast of Tooele Valley) exceeded 7 inches, the lake level declined, and the trend was generally upward during the other months; and storms that caused precipitation of an inch or more at Tooele generally resulted in a greater rate of rise or a decreased rate of decline in the level of the lake.

The fluctuations of water level in the bore holes are similar to those of the lake level, but there are some marked differences. In all bore holes there is a downward trend of water level from May until September each year, caused by the draft on ground water by evaporation and transpiration. Thus the low levels

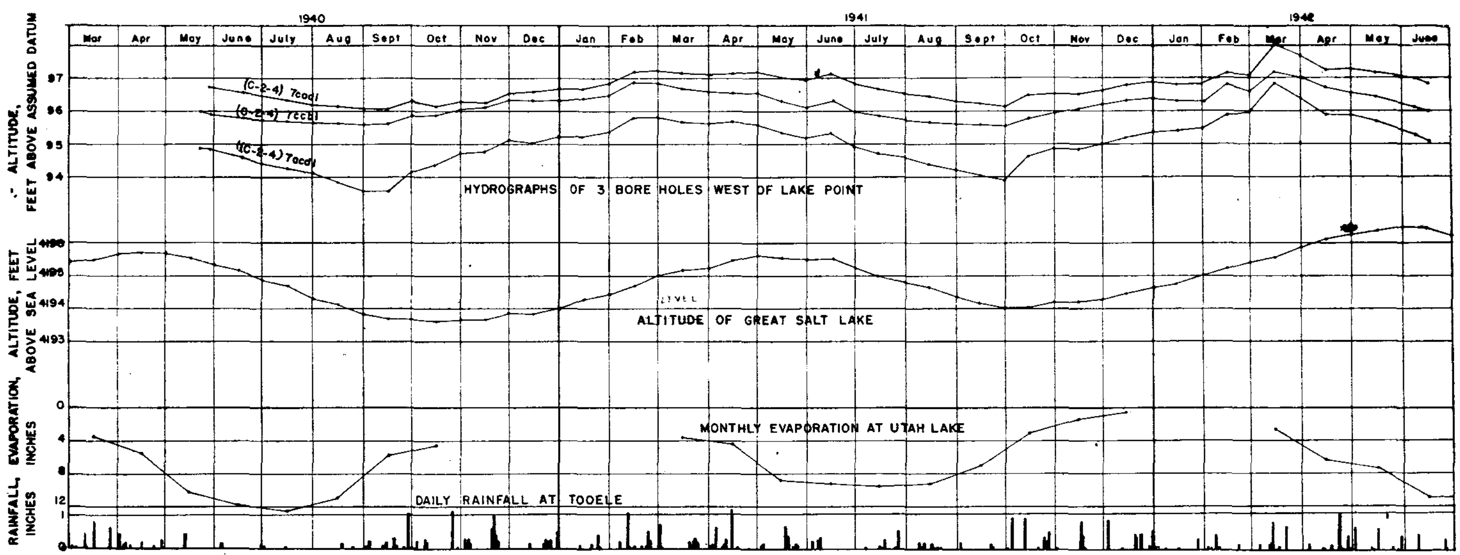

Figure 7.—*Fluctuations of water level in three bore-holes and in Great Salt Lake.*

in the bore holes coincide approximately with the lowest stage of the lake, which is to be expected since both are caused by evaporation in the heat of summer. From the low stages of September the water level in the bore holes rises to a maximum in February or March, and an important part of this rise appears to be due to deep penetration from rainfall, as shown particularly in the hydrographs for September 1940, February and October 1941, and March 1942. The highest water levels in the bore holes thus occur two or three months earlier than the high stage of the lake.

Fluctuations Related to Recharge

Fluctuations of water level attributed to recharge of the ground-water reservoir from surface water are noted especially in the highest wells in the Grantsville area, because these wells are farthest from the large flowing wells that are used for irrigation and nearest to the area where water enters the ground-water reservoir. The hydrographs of wells (C-3-5)5bab1 and especially (C-2-6)36cdd1, on figure 6, show the effect of recharge in the southern part of Grantsville; the water level in both wells rises slowly during the winter, and then with accelerated pace in May and June during the period of the annual freshet. Soon after the freshet, the water level in the wells begins to decline and continues downward until the following winter. In well (C-2-6)23cbb1, remote from the alluvial fans of the larger streams, the water level rises and falls very gradually in response to recharge by underflow from Mack Canyon and adjacent drains, and to discharge from springs and wells elsewhere in the Grantsville district.

The hydrographs of the lower part of figure 6 represent wells located along a line extending northwesterly across the town of Grantsville. Well (C-3-5)6dda1 is the highest and southernmost, and is about three-fourths of a mile northeast of the end of a pipe line that diverts water from South Willow Canyon. The water level rises during the winter and spring, and falls during the last months of the year, after the close of the irrigation season. The other three wells are down the alluvial slope to the northwest, in a line paralleling one of the principal ditches serving the Grantsville area. The water level in all three wells rises to a yearly maximum in June, contemporaneous with the peak of the spring freshet, and declines thereafter. The northernmost well—(C-2-6)36bac1—reaches a deeper aquifer and the water level is consistently higher than the well next higher on the slope.

Fluctuations of water level caused by deep penetration of precipitation have been noted only in a few shallow test holes west of Lake Point (p. 186), in the central and lowest part of the valley. The surficial materials are generally coarser and more permeable in the higher parts of the valley, and the opportunity for deep penetration would therefore be greater, but no wells reach unconfined water in those areas. Fluctuations caused by rainfall have not been discriminated in artesian wells.

Long-term Fluctuations

Measurements of the artesian pressure have been made periodically in several wells in Tooele Valley since 1935. The fluctuations shown by these measurements represent the composite effects of the several forces that influence the water level at each well, and thus show the balance between the recharge to the reservoir from streams, irrigation, precipitation, and other sources, and the discharge therefrom by wells, springs, transpiration, evaporation, and any other methods of disposal. Hydrographs of nine wells in Tooele Valley for the years 1935 to 1945 are assembled in figure 8, based on these measurements. The curve showing cumulative departure from normal precipitation at Tooele during this period affords a basis for comparison of water-level fluctuations with precipitation.

Well (C-2-4)2aba2 shows a very close correlation with the precipitation, the water level rising in wet years, declining during dry years, and remaining stationary in years of normal rainfall. The hydrographs of the four wells in the Erda district show prominent troughs during each irrigation season, caused by operation of irrigation wells in the district. They also show a general downward trend from 1936 until 1939, although the precipitation was approximately normal in 1936, 1937, and 1938. From 1940 to 1945 the trend has been upward at a rate not duplicated in other districts, and not to be expected from the rainfall, which was comparable to that in earlier years; this rise is attributable partly to the effect of discharge from the Elton tunnel (p. 192). Wells (C-2-4)33add1 and 33abb2 are about half a mile apart and end in the same aquifer; the latter well, located within the area of artesian flow, exhibits the same seasonal fluctuations but with greater amplitude.

Of the two wells in the Grantsville district, No. (C-2-6)36-baa8 is within the area of artesian flow, and its water level is affected somewhat by well discharge. No. (C-2-6)36cdd1 is about a mile to the south; its principal fluctuations are due to recharge from South Willow Creek, which was low during dry years such as 1943, and high following the heavy precipitation of 1941, 1944, and 1945. The graphs for the wells in the Burmester and Marshall districts show little seasonal fluctuation. A faint correlation with precipitation is discernible, although considerable lag is indicated.

PIEZOMETRIC SURFACES

The great majority of the wells in Tooele Valley reach water that is confined under artesian pressure. About 870 of the wells flowed during 1941, about 90 others have flowed in earlier years, and most of the remaining wells in the valley are deep enough that they undoubtedly tap artesian aquifers. As

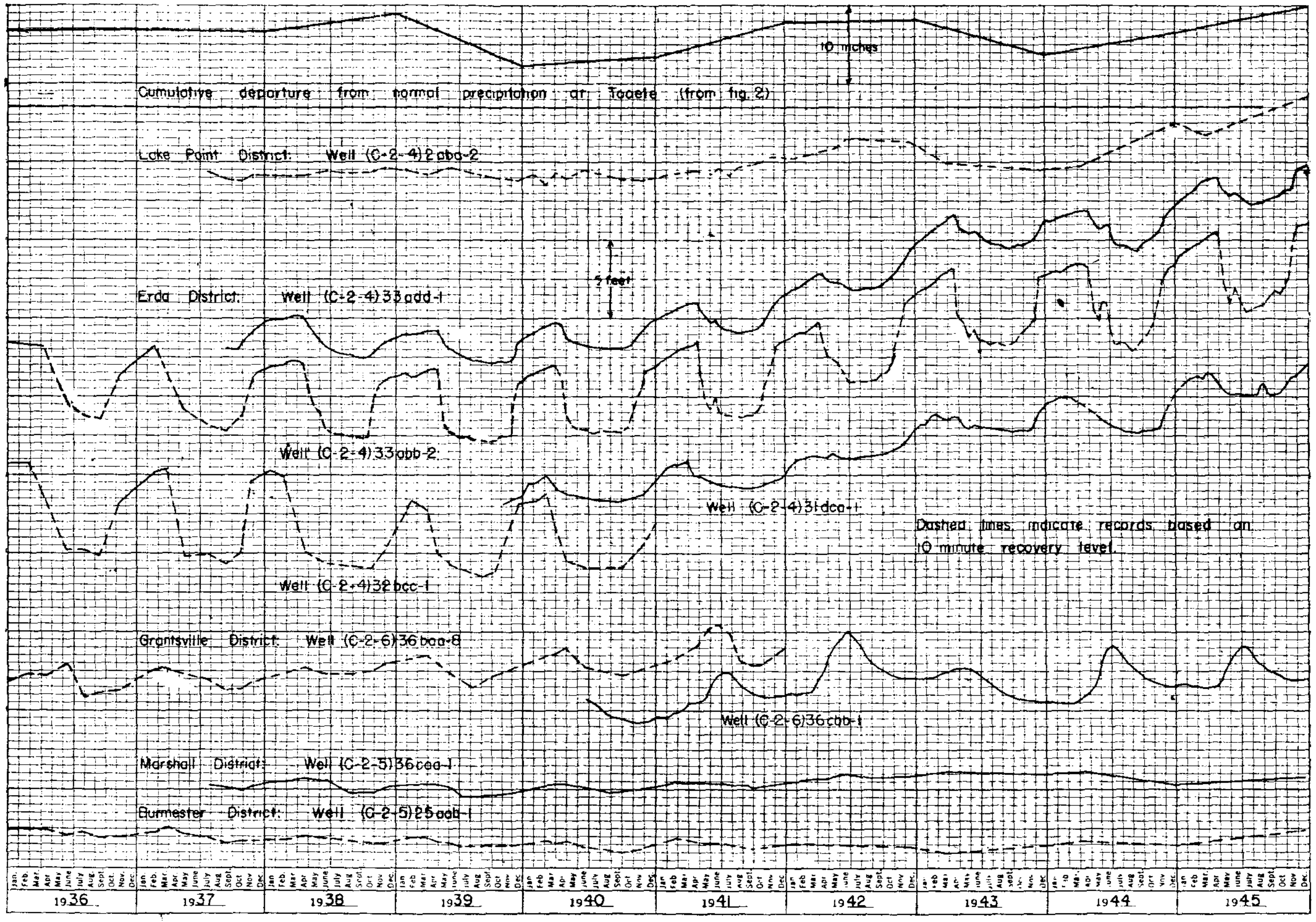

Figure 8.—*Hydrogrphs of nine wells in Tooele Valley showing long-term fluctuations of water level.*

shown by the logs of wells and by their range in depth (pp. 133-145), there are several of these artesian aquifers under Tooele Valley at varying depths below the land surface. The piezometric surfaces of the individual aquifers are separate and distinct, as shown by differential head at adjacent wells of different depths.

Information as to the unconfined water in the valley is so scant that practically nothing is known of the position or extent of the water table except in the Lake Point district. This paucity of information is readily explained by the concentration of present ground-water development in a relatively small part of Tooele Valley (see fig. 20). Bordering this small area to the west, south, and east there are much larger areas underlain by sediments predominantly coarser than those of the developed area, as described in the geologic chapter. In these areas, particularly near the margin of the valley, ground water is presumed to occur under water-table conditions, for it is believed unlikely that clay and silt would occur in quantities sufficient to form confining layers. The unconfined water in these marginal areas moves toward the central and lowest part of the valley, where beds of finer sediments introduce the artesian conditions.

Differential Head of Wells in Aquifers of Different Depths

The water level in adjacent wells of different depths indicates the comparative positions of the piezometric surfaces of the aquifers tapped by the wells. About two-thirds of the wells represented in figure 3 reach a zone of coarse sediments 60 to 125 feet thick, which is the principal aquifer in Tooele Valley. This principal aquifer is encountered at depths of 90 to 210 feet in the western part of Grantsville and 180 to 300 feet toward the east edge of town. Farther east the aquifer is 170 to 230 feet below the surface in the west part of the Erda district, and only 100 to 160 feet deep at the eastern edge of the district. Although most of the water yielded by wells is obtained from this aquifer, there are many other water-bearing zones. Several flowing wells yield water from strata above this principal aquifer, and some wells reach aquifers far deeper. In the following table the water levels in wells reaching the principal aquifer are compared with contemporaneous water levels in wells tapping deeper and shallower aquifers. The measurements that form the basis for the table were made during winter months, when most wells are closed and interference caused by discharge is at a minimum. However, several of the wells were found flowing and were shut in for a period of 10 minutes prior to measurement of water level. It is likely that this 10-minute recovery level was lower than the static level in these wells, and that the computed differential head may be in error by several feet.

Differential Head in Adjacent Wells of Different Depths

(Reported depth of well is shown below well number)

Note: In all cases the well reaching the deeper aquifer has the higher head

Wells reaching shallow aquifers	Distance between wells (feet)	Date of measurement	Differential head (feet)	Wells reaching principal aquifer	Distance between wells (feet)	Date of measurement	Differential head (feet)	Wells reaching deep aquifers
				(C-2-4) 2bdb2 155 ft.	50	Feb. 1941	5.4	(C-2-4) 2bdb1 285 ft.
				(C-2-4) 27cca1 165 ft.	600	Feb. 1941	4.4	(C-2-4) 27cbd1 400 ft.
(C-2-4) 28bdd3 100 ft.	110	Feb. 1941	1.6	. . . . .	. . .	. . .	. . .	(C-2-4) 28bdd4 295 ft.
				(C-2-4) 28daa1 205 ft.	210	Mar. 1941	8.0	(C-2-4) 28daa2 309 ft.
				(C-2-4) 28dcb3 182 ft.	260	Mar. 1941	7.0	(C-2-4) 28dcb2 313 ft.
				(C-2-4) 29bdd2 165 ft.	1,000	Feb. 1941	2.8	(C-2-4) 29bcd1 300 ft.
				(C-2-4) 31dad1 184 ft.	140	Jan. 1942	8.3	(C-2-4) 31dad2 305 ft.
(C-2-4) 31dbc6	5	Mar. 1941	7.5	(C-2-4) 31dbc7 202 ft.				
				(C-2-4) 32acc2 160 ft.	1,250	Feb. 1941	6.2	(C-2-4) 32abc1 272 ft.
				†(C-2-4) 32caa4 208 ft.	250	Mar. 1941	11.2	(C-2-4) 32cab1 258 ft.

Differential Head in Adjacent Wells of Different Depths (continued)

Wells reaching shallow aquifers	Distance between wells (feet)	Date of measurement	Differential head (feet)	Wells reaching principal aquifer	Distance between wells (feet)	Date of measurement	Differential head (feet)	Wells reaching deep aquifers
(C-2-4)33aac8 90 ft.	80	Feb. 1942	0.6	(C-2-4)33aac1 182 ft.	250	Feb. 1942	0.4	(C-2-4)33aac2 307 ft.
(C-2-4)33abb4 90 ft.	350	Feb. 1941	3.1	(C-2-4)33abb2 169 ft.				
*(C-2-4)33bba2 80 ft.	500	Mar. 1941	5.2	(C-2-4)33bba3 152 ft.	640	Oct. 1937	14.6	(C-2-4)33bbb1 277 ft.
(C-2-4)33bcb2 80 ft.	520	Feb. 1942	2.9	*(C-2-4)33bcb4 200 ft.	570	Feb. 1942	5.1	*(C-2-4)33bcb1 283 ft.
*(C-2-5)24cac2	110	Feb. 1941	7.7	. . . . .	. . .	. . .	. . .	*(C-2-5)24cac4
(C-2-5)27ccd3 100 ft.	730	Feb. 1942	1.3	*(C-2-5)27ccd7 200 ft.				
(C-2-5)29dcc5 60 ft.	120	Feb. 1941	7.7	. . . . .	. . .	. . .	. . .	(C-2-5)29dcc1 340 ft.
(C-2-5)31bdd3 100 ft.	360	Feb. 1942	7.8	. . . . .	. . .	. . .	. . .	(C-2-5)31bdd1 278 ft.
(C-2-5)32caa1 60 ft.	50	Mar. 1942	1.0	(C-2-5)32caa3 180 ft.				
				*(C-2-5)32bdb1 200 ft.	5	Feb. 1942	16.5	(C-2-5)32bdb2 400 ft.
(C-2-5)34aac1	1,900	Feb. 1941	10.4	. . . . .	. . .	. . .	. . .	(C-2-5)34abc1 320 ft.

†Adjacent well (C-2-4)32caa5 flowing 100 gallons a minute during measurement
*Well flowing prior to measurement.

In the shallowest wells listed in the table, ranging in depth between 60 and 100 feet, the static level at the time of comparison was commonly 1 to 5 feet lower than that in adjacent wells reaching the principal aquifer. In the deep wells, 260 to 400 feet deep, the static level was ordinarily 5 to 8 feet higher than that in wells tapping the principal aquifer. Comparisons also show that the differential head between wells tapping the shallow and deep aquifers ordinarily ranges between 7 and 10 feet. A remarkable feature of the measurements shown in the table is the absence of appreciable differential head between wells (C-3-4)33aac1, 33aac2, and 33aac8, reported to be respectively 182, 307, and 90 feet deep. All these wells flowed formerly, and they thus quite obviously tap artesian aquifers. The nearly uniform water level in the three wells suggests that all three wells may tap the same aquifer, and hence the reported depths of the wells are questioned. Water levels in certain other wells in the valley are not in accord with those of adjacent wells of similar reported depths, and suggest the possibility that several of the reported depths may be considerably in error.

Detailed comparison of water levels in adjacent wells indicates that even in wells reaching different parts of the principal aquifer there may be some differential head, which is attributed to the heterogeneous character of the sediments, as shown for instance by the alternating layers of gravel and silty beds at the horizon of the principal aquifer in well (C-2-4)31-dad2, the log of which is given on pages 134-137. In the course of drilling this well, the water near the bottom of the principal aquifer (depth 234 feet) was found to have a head about 4 feet higher than that at the top of the aquifer (depth 172 feet). The level of the water encountered in the several aquifers during drilling of this well is shown in the following table. After pumping and surging to remove the finer grains from the developed

Standing Level of Water Encountered During Drilling Well (C-2-4)31dad2

Date	Depth of well below land surface (feet)	Standing level in feet above sea level		Differential head (feet)
		Well (C-2-4)31dad2	[a]Well (C-2-4)31dad1	
June 12, 1941	35	[b]4,335	4,364	—29
June 21	172	4,364.0	4,363.9	+0.1
June 28	201	4,365.0	4,363.8	+1.2
June 30	204	4,365.8	4,363.8	+2.0
July 9	234	4,368.1	4,363.8	+4.3
July 21	300	4,369.1	4,363.9	+5.2
Oct. 17	477	4,371.2	4,364.1	+7.1
Dec. 17	[c]316	4,372.8	4,364.5	+8.3

[a]140 feet northwest of well (C-2-4) 31dad2. This well is 183 feet deep and reaches the upper part of the principal aquifer.
[b]Water table.
[c]After plugging bottom, perforating 288 to 316 feet, pumping and surging.

aquifer in the well (288 to 316 feet deep), the static level was raised 3.7 feet, and it is likely that in other aquifers similarly the water level observed in drilling may not represent the full pressure head of the aquifer. The table nevertheless shows a rise of static level with increasing depth of aquifer, just as in the case of pairs of adjacent wells already described.

The differential head between several pairs of wells is indicated graphically in figure 9, which is a profile showing piezometric surfaces along the Erda road. The data define the piezometric surface of the principal aquifer along the entire line of the profile. Only one well—No. (C-2-4)33bcb1—penetrates aquifers deeper than the principal aquifer, but shallow aquifers are tapped by a well in Grantsville, two in Erda, and three wells intermediate between the two towns.

In general the differential head between adjacent wells on different aquifers proves the existence of more than one piezometric surface at the location of the wells, and measures the vertical distance between the surfaces. The available data concerning the piezometric surfaces of several aquifers are presented in the following paragraphs.

Piezometric Surface of the Principal Aquifer

Form in February 1941—The form of the piezometric surface of the principal aquifer is shown in the accompanying map (fig. 10). In its broad general aspects the form is similar to that of the land surface, with a gentle northeastward slope in the area northwest of Grantsville, a northerly slope in the central part of the valley, and a northwestward slope in the vicinity of Erda. The gradient of the piezometric surface is about 6 feet to the mile in the northern part of the valley near Burmester and increases to the south.

In detail the piezometric surface of the principal aquifer is notably different from the topographic surface. The land surface has a gradually but progressively increasing gradient southward for a considerable distance beyond the area shown in figure 10. The piezometric surface, approximately parallel to the land surface near the north edge of the area in which wells have been drilled, rises at a somewhat steeper gradient in the central part of that area. Its slope exceeds 30 feet to the mile at the north edge of Grantsville and approaches 60 feet per mile in Erda. Still farther south, near the edge of the area of artesian flow, the piezometric surface appears to have a gradient of 20 feet per mile or less and is thus flatter than the land surface in that area. Beyond the upper limit of present development of wells, the piezometric surface is believed to rise toward the borders of the valley at a gradient likewise more gentle than that of the land surface. According to the profile of figure 15, the slope of the water table in the upper parts of the valley may average about 25 feet per mile.

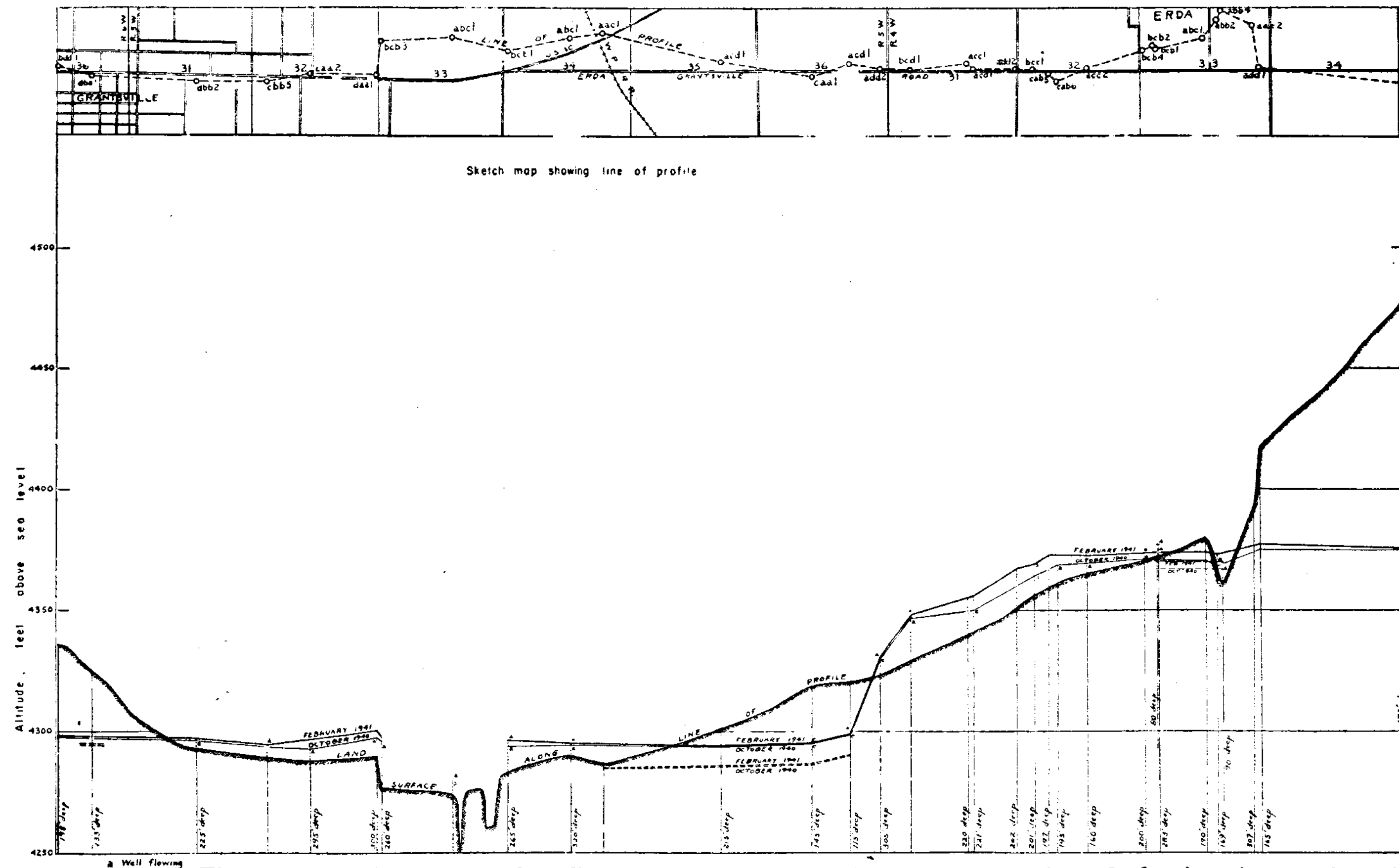

Figure 9.—*Profile across Tooele Valley approximately along the Erda-Grantsville road, showing piezometric surfaces.*

The piezometric surface as depicted in figure 10 appears to be markedly influenced by certain faults, which have been described in the geologic chapter. The Mill Pond fault, a north-south fault that lies between Erda and Lake Point, is prominently expressed in the topography, for ledges and buttes of the Oquirrh formation are exposed on the eastern, upthrown side of the fault. According to data obtained from a few wells located near the trace of this fault, the piezometric surface of the principal aquifer east of the fault appears to be higher, and a ground-water dam has evidently been formed along the fault. Water rises along this fault to form the large springs at Mill Pond and Dunne's Pond. A ground-water dam has also been formed along the Erda fault in the east half of sec. 36, T. 2 S., R. 5 W., where the piezometric surface slopes abruptly from elevations generally more than 4,350 feet above sea level in Erda to an altitude of less than 4,300 feet in the vicinity of Marshall and Grantsville.

Several features of the piezometric surface of the principal aquifer in February 1941 are shown in figures 11 and 12, which follow lines approximately at right angles to the contours shown on figure 10. They thus represent the direction of maximum slope of the piezometric surface and therefore the direction of movement of the ground water. In the lower, northern parts of both profiles the piezometric surface has a gradient about equal to that of the land surface, but it rises more steeply, with the result that wells in the central parts of the profile commonly have higher pressure head (measured above the land surface). Still farther south the gradient of the piezometric surface becomes less, and that of the land surface increases, so that water levels in the southernmost wells are below the land surface, and the wells do not flow. These are the uppermost wells in the towns of Erda and Grantsville respectively. Many of the observation wells were flowing prior to the measurements which form the basis for these profiles, as indicated on the graphs by footnote. Because of this discharge the water level in these wells is lower than the line of the profile based on measurements in wells that had not been flowing. Most of the irregularities in the profile are accounted for by this effect of discharge from certain wells prior to the measurement of water level; minor irregularities are caused by varying depths of the wells measured and by the crookedness of the lines of profile.

Neither of the profiles described above crosses the faults that are known to influence ground-water movement in Tooele Valley, and therefore neither shows the magnitude of ground-water dams caused by these faults. The profile along the Erda-Grantsville road, however, cuts across the Erda fault and shows clearly the ground-water dam created by that fault (fig.9). This profile may cut across the southward continuation of the Mill Pond fault also (p. 149) but there are too few wells to provide adequate information as to the form of the piezometric surface in that part of the valley.

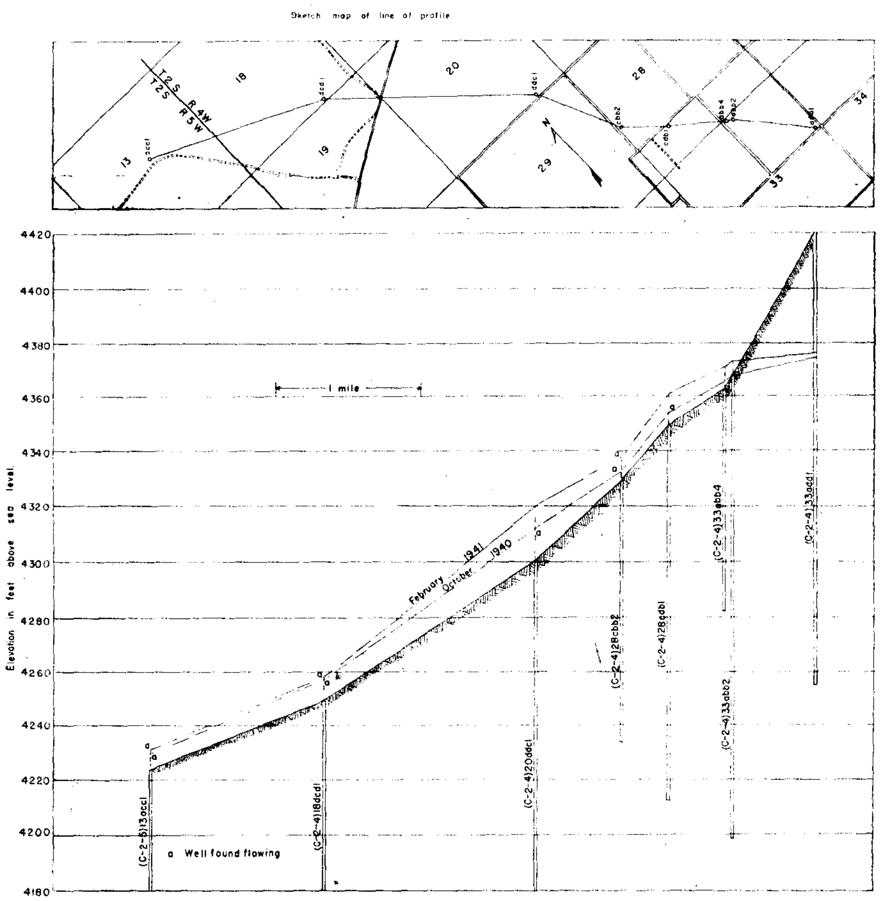

Figure 11.—*Profiles of the piezometric surface in the Erda district.*

Seasonal Changes.—Study of the seasonal fluctuations in groups of wells provides a basis for several conclusions regarding the seasonal changes in the position and form of the piezometric surface of the principal aquifer. In Tooele Valley the dominant fluctuations in most wells are caused by variations in discharge from the ground-water reservoir. In consequence, the major changes of the piezometric surface are due to seasonal changes in ground-water draft. In most wells the static level is highest each year 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. The piezometric surface of the principal aquifer in February-March 1941 (fig. 10) represents approximately the highest position attained by that surface during the year, except in the southern part of the town of Grantsville, where recharge from stream run-off causes significant fluctuations of water level in

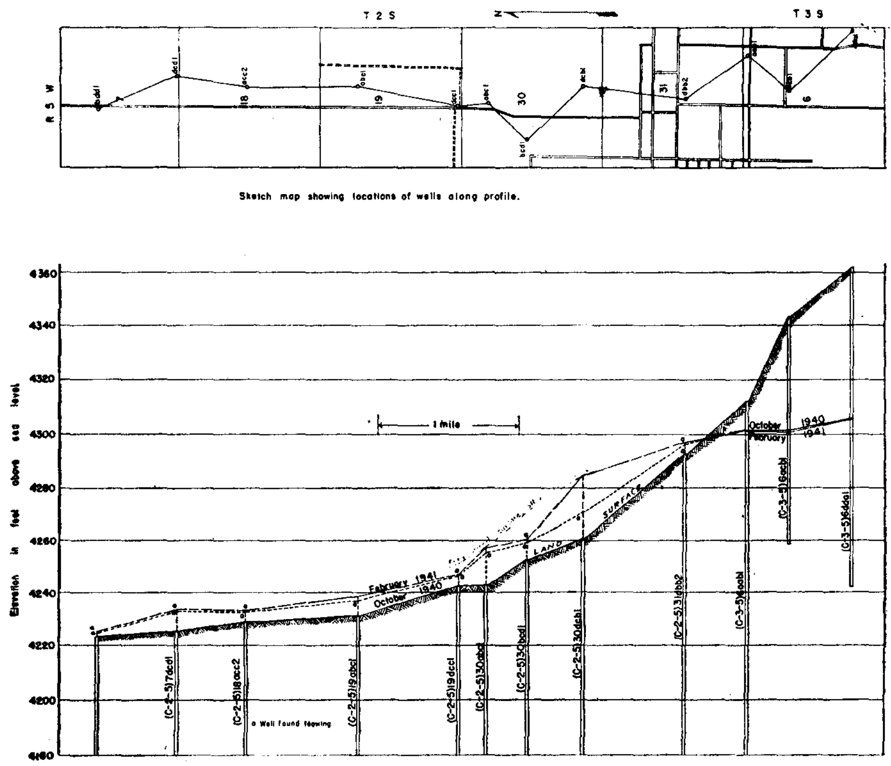

Figure 12.—*Profiles of the piezometric surface in the Grantsville district.*

wells and where consequently the piezometric surface reaches its maximum altitude during June and July.

A comparable map based on data collected at the end of the irrigation season—in September or October—would presumably depict the lowest position of this piezometric surface during the year. Data collected during October 1940, however, were found to be entirely inadequate for the completion of such a map. Most of the observation wells used in February and March were flowing during October and the static level could not be determined. Of the observation wells that were not discharging in October, many were near one or more wells that were flowing, and available data were generally not sufficient to show the extent of interference.

Judging by comparative measurements in more than 130 wells, the water levels in wells throughout the greater part of the developed area in Tooele Valley were not more than 2 feet higher in February 1941 than they had been the preceding October, except where the observation wells had been close enough to discharging wells that pronounced interference could be noted. In two rather extensive areas, however, the water levels in all observation wells were more than 2 feet higher in February than in October. The location and extent of these areas are shown on figure 13. One of the areas extends east from the northern part of Grantsville and covers about 2 square miles; the other embraces Erda and is about twice as large. In both areas there is a notable concentration of flowing wells, particularly those having diameters of 4 inches or more, and in both areas the wells are drawn upon heavily for irrigation. In fact, the use of ground water for irrigation of cultivated crops is largely confined to these two areas. Within these areas the seasonal lowering of the piezometric surface, amounting to 2 feet or more, is considered to be regional drawdown resulting from the heavy draft upon the principal aquifer for irrigation. In certain wells in these areas the water level was more than 10 feet higher in February than it had been the preceding October. These large changes reflected local conditions, in some cases resulting from interference of adjacent wells during the October measurement and in some instances indicating incomplete recovery of the observation well from discharge prior to the October measurement.

The seasonal change in the piezometric surface of the principal aquifer is well shown in the profiles forming figures 9, 11, and 12. That surface in February is generally within a foot of its position in October, except in the Grantsville and Erda districts where the wells are closely spaced. The 10-minute recovery level, indicated by footnote "a" in the profiles, is somewhat lower than the static levels in adjacent wells which had not been flowing prior to measurement.

According to available records, the seasonal changes in the piezometric surface of the principal aquifer in earlier years were of comparable magnitude to those of 1940-41, and that surface commonly reached its highest position during the months of February and March and was lowest toward the end of summer. In general the changes from season to season are not large, except in the vicinity of wells where there is considerable draft for irrigation. The seasonal fluctuations are due principally to reduction of artesian pressure when there is withdrawal from wells and a corresponding increase in pressure when the withdrawal ceases. They do not measure substantial changes of storage in the ground-water reservoir, because they are not proportional to the amount of unwatering or recharge of the aquifers.

Annual and Long-term Changes—Information concerning ground water in Tooele Valley in years other than 1941 consists primarily of periodic measurements of the static level (or of the 10-minute recovery level) in representative wells, begun by the Geological Survey in 1935. This information is inadequate for mapping of the piezometric surface of the principal aquifer but serves to indicate the changes of that surface from year to year in various parts of the valley. During 1936 measurements were made in 12 wells in Tooele Valley, and the number was increased gradually until by 1940 measurements were being made periodically in more than 20 wells, and automatic recording gages were in operation on two wells. Records of nine of these wells are discussed on page 171 and shown graphically in figure 8. The annual changes of water level in 24 selected key wells are summarized in the discussion of changes in ground-water storage in Tooele Valley. (pp. 189-192). From these and other data on water levels, the following conclusions may be drawn concerning the form of the piezometric surface of the principal aquifer during the winter months (when discharge from wells is minimum) of the years 1935 to 1945:

1. The position of the piezometric surface varies only slightly from year to year in the Burmester and Marshall districts, which occupy the central and lowest parts of the Valley. Ordinarily the change in individual wells is less than half a foot in any year, and the maximum recorded yearly change is less than a foot.

2. The piezometric surface in the Lake Point, Erda, and Grantsville districts fluctuates appreciably from year to year. At many wells the rise or decline of water level has exceeded two feet in a single year. At the end of 1945 the piezometric surface at many wells in the Grantsville and Lake Point districts was more than 3 feet higher than it had been 10 years earlier, resulting in an appreciable increase in gradient toward the Burmester district.

3. Since 1942 the water levels in wells in the Erda district have risen markedly in comparison with those of wells elsewhere in the Valley. As a result, by the end of 1945 the piezometric surface at several of these wells was more than 7 feet above its position in 1935. The slope of the piezometric surface toward the Marshall and Burmester districts was correspondingly increased.

Information concerning the position of the piezometric surface of the principal aquifer prior to 1935 is based on the statements of well owners on the "underground water claims" filed with the State Engineer and on the reports of long-time residents in the area. Most well owners have stated whether their wells flowed originally, and many former flowing wells are located beyond the limits of the present area of artesian flow. These data form the basis for the demarcation of the boundary of the "maximum area of artesian flow" on figure 20.

There are several former flowing wells in both the Erda and Grantsville districts in which the water level in 1941 was 10 or 12 feet below the surface. The maximum altitude at which artesian wells on the principal aquifer have flowed is about 4,255 feet in the Lake Point district, 4,385 feet in the Erda district and 4,305 feet in the Grantsville district. In February 1941 the upper limit of the area of artesian flow was generally within 200 or 300 yards of the boundary of the maximum area of artesian flow, and the static level in these former flowing wells had declined about 8 to 10 feet on the average. This decline represents the change in the piezometric surface from its highest reported position to its position in February 1941. It is far larger than the annual changes that have been noted in observation wells in recent years, and is greater than the total net change in the period since measurements in these wells were begun (tables, pp. 191 and 192). In fact, the amount of decline is 4 to 6 times as great as the seasonal change in the wells near the edge of the present area of artesian flow in the Erda and Grantsville districts.

Piezometric Surfaces of Minor Artesian Aquifers

Wells reaching artesian aquifers other than the principal aquifer are too few in number to define the piezometric surfaces of those aquifers. The form of these piezometric surfaces may be inferred by comparison of the water levels in wells of the principal aquifer with those wells of other aquifers. These comparisons have already been presented (p. 173) for many wells during periods when the piezometric surfaces are most stable. They show that in the areas of greatest ground-water development the most-developed shallow aquifer, which is about 80 feet above the top of the principal aquifer, has a piezometric surface about 1 to 5 feet below that of the principal aquifer. The deep aquifer reached by the greatest number of wells is about 60 feet below the bottom of the principal aquifer and has a piezometric surface about 5 to 8 feet above that of the principal aquifer at those wells.

Throughout the greater part of Tooele Valley wells are not available for determining the relative positions of the piezometric surfaces of these minor aquifers. It is probable that the piezometric surfaces for aquifers of different depths are most widely separated in the areas for which comparative data are available. In the higher marginal parts of the valley the aquifers become less differentiated because the intervening strata are of coarser and more permeable materials, and toward the apexes of the several alluvial fans these materials are so coarse that ground water is probably not confined and occurs under water-table conditions. In the other direction, on the central valley floor, the northernmost artesian wells have a pressure head only a few feet above the static level of unconfined water in the shallow zone. Thus it is considered that the piezometric surfaces of the minor aquifers, while they appear to be roughly parallel to that of the principal aquifer in the area where wells are numerous, actually converge both upvalley and downvalley beyond the area of present development toward the piezometric surface of the principal aquifer.

Seasonal and annual changes in form of the piezometric surfaces for the minor aquifers are closely parallel to those of the piezometric surface of the principal aquifer, judging by the hydrographs of adjacent deep and shallow wells (fig. 14).

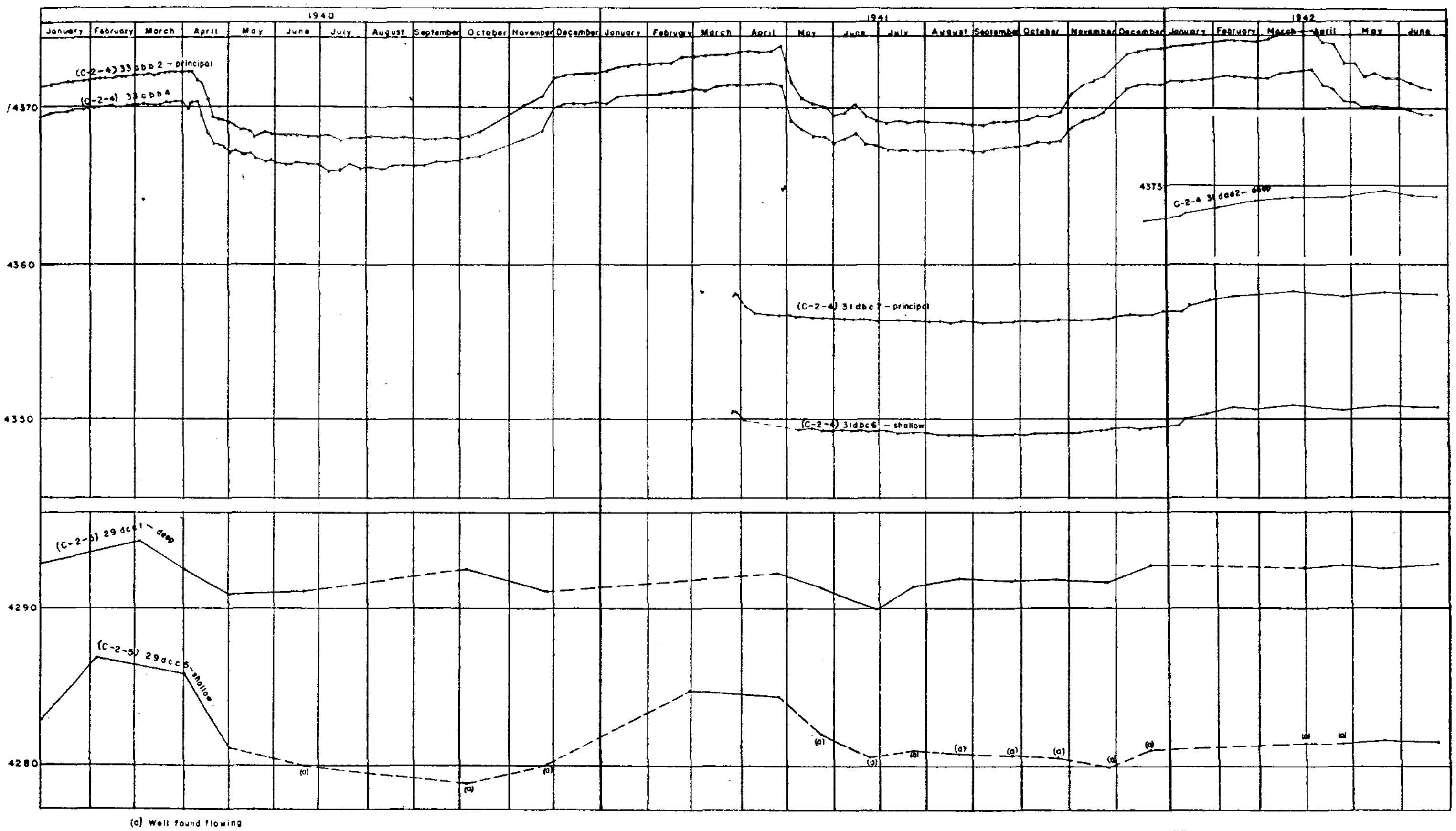

Figure 14.—*Hydrographs of three pairs of adjacent deep and shallow wells in Tooele Valley.*

The upper pair of hydrographs are nearly parallel, and all major fluctuations and many minor ones are remarkably similar. Well (C-2-4)33abb2, on the principal aquifer, has a head 2 to 2.5 feet above that of the shallow well in the winter, but the differential head may be as low as 1.5 feet in the midst of the irrigation season, because of the greater draft from the principal aquifer for irrigation. The hydrographs of the next group of wells, located in the western part of the Erda district, are likewise closely parallel. The differential head between well (C-2-4)31dbc7 (reaching the principal aquifer) and shallow well (C-2-4)31dbc6 ranges from 7.5 feet during the winter to 7 feet in the irrigation season. Fluctuations exhibited in the hydrographs of these wells appear also in the hydrograph of deep well (C-2-4)31dad2, but there is some divergence of the hydrographs beginning in April 1942 when wells on the principal aquifer were opened for irrigation. No wells were drawing water from the deep aquifer in the vicinity of this group of wells during the period represented by the hydrograph. The other pair of hydrographs is for wells in the Grantsville district, but the record is not very satisfactory because of intermittent operation of the shallow well. The shallow well was left open and the deep well remained closed throughout the period from May 1941 to June 1942, and during this period the graphs are approximately parallel.

The parallelism of hydrographs of adjacent deep and shallow wells is especially noteworthy in view of the fact that one aquifer is drawn upon much more heavily by wells than all others. From this parallelism it is concluded that the several aquifers are not mutually independent, and that therefore the intervening strata are not truly impervious although they have a lower permeability than that of the aquifers. This conclusion is confirmed by the results of interference tests described on pages 216-224. It follows that these aquifers are not mutually exclusive sources of water, one resting above another, but are rather all a part of one large reservoir which occupies Tooele Valley.

Water Table

The position of the water table can be delineated only in a very small area of Tooele Valley—in the vicinity of Lake Point, where about 20 shallow wells have been dug. In that area the water table slopes northwestward in the same general direction as the land surface, but with a more gentle gradient. Thus in the northwest part of sec. 36, T. 1 S., R. 4 W., where the slope of the land surface ranges from 150 to 400 feet per mile, the slope of the water table averages only 60 feet per mile. The gradient of the water table becomes less toward the north end of the valley. According to data collected by the United States Smelting, Refining & Mining Co. from test holes near the highest historic lake shoreline (in secs. 12 and 13, T. 2 S., R. 5 W.) the water table had a northward slope of about 12 feet per mile in May 1940, and about 18 feet per mile in August of that year. Still farther north the water table is nearly horizontal, and it underlies the lake flat at depths ranging from a few inches to two or three feet. South of the Lake Point district, under the high land east of the Mill Pond, the water table is only a few feet higher than it is under the lake flat. Hence the depth to water is considerable, and increases almost as rapidly as the elevation of the land surface.

Elsewhere in Tooele Valley fewer than a score of wells end at the water table, but its position is considered to be more or less analogous to that in the Lake Point district—within a few inches of the surface under the lake flat at the north end of the valley and rising toward the margins of the valley to east, south, and west, but with a more gentle slope than that of the land surface— except near the mountains at the alluvium-bedrock contact where the water table slope is for a short distance steeper than that of the land surface. The form of the water table in the marginal areas of the valley is largely a matter of conjecture. By analogy with other desert-basin areas in Utah[37], it is presumed to have a surface more nearly level than the land surface, which rises at moderate and progressively increasing gradients toward the bordering mountain masses. This form is suggested also by the data that form the basis for the profile of figure 15. The upper (southeastern) part of this profile extends to the area in Middle Canyon in which the city of Tooele has developed most of its water supply; the elevations of land surface and of water table in this area were furnished by John Gollaher, city engineer of Tooele. Between Middle Canyon and the southernmost wells of the Erda area, the only information concerning the water table is that obtained in drilling well (C-3-4)30aac1 at the Tooele Ordnance Depot about 2½ miles from the line of the profile, and the negative knowledge obtained in drilling well (C-3-4)22dcd1 337 feet deep, in which water was not encountered. From these records, the water table is clearly shown to have a lower gradient than the land surface between Tooele and the Erda area. Within the artesian area, which includes most of the irrigated area in Tooele Valley, the water table probably continues at this gentle slope toward the lowest parts of the valley, with minor irregularities due to differences in the rate at which water is being contributed to the saturated zone from local irrigation or from rainfall.

The seasonal changes in the position of the water table are known only from the fluctuations in test holes which are located west of Lake Point where the water table is within a few feet of the surface. There the water table reaches a high stage in February or March, which results at least in part from the deep penetration of rainfall (p. 170) and then declines until the following October because of the draft on ground water for

[37]Thomas, H. E., and Taylor, G. H., Geology and ground-water resources of Cedar City and Parowan Valleys, Iron County, Utah: U. S. Geol. Survey Water-Supply Paper 993, 207 pp, 1946.

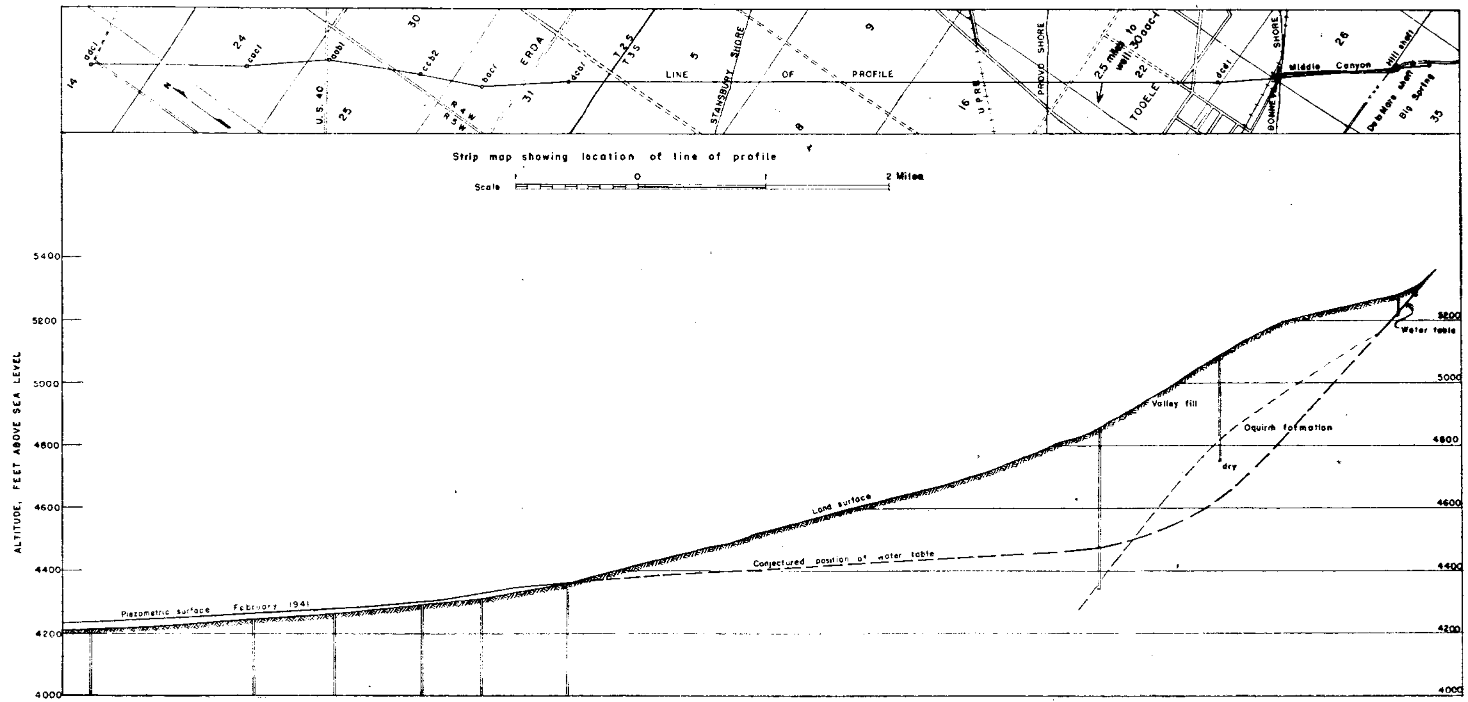

Figure 15.—*Profiles of land and water surfaces between Middle Canyon and Erda.*

evapo-transpiration (p. 168). The amount of the seasonal decline in the test holes is usually between 1 and 3 feet. Under the irrigated areas the water table probably rises during the irrigation season and declines during the winter months, as in wells in the southern part of Grantsville (fig. 6). In the marginal parts of Tooele Valley there is no information as to the changes in the water table. It is presumed that these changes are caused chiefly by the variations in seepage from the canyons, and therefore that the water table would be highest during or soon after the period of the annual freshet.

Estimates of Changes in Storage in the Ground-water Reservoir

The quantity of water stored in a subterranean reservoir can be determined only if the volume and porosity of the saturated materials are known. At present the total thickness of the saturated sediments is not known for any point in the valley, and very little is known as to porosity except that it probably is quite variable within short distances both vertically and horizontally throughout the valley fill. Although the total storage of water at any date is not determinable, some comparison of the changes in storage from year to year may be made, just as comparative storage in a surface reservoir may be based on changes in reservoir level without knowledge of the total volume of the reservoir. In Tooele Valley, the several water-bearing zones have been shown to be inter-dependent, and pronounced changes in one aquifer are reflected in deeper and shallower aquifers. Thus the ground water in the valley is considered to occur in a common reservoir, in which the strata that separate the aquifers are not continuous enough or impervious enough to form major separations although they undoubtedly have a pronounced local effect on the movement of water.

Twenty-four wells have been selected in Tooele Valley as especially suitable for indicating changes of storage in the ground-water reservoir. Most of these key wells are in the upper parts of the respective ground-water districts as close to the recharge areas as possible. Many are beyond the upper edge of the area of artesian flow (fig. 20), so that interference from the wells in that area is at a minimum. Three of these wells have been equipped with water-stage recorders for periods of four years or more. The majority tap the principal aquifer, but some reach deeper or shallow artesian aquifers, and one is a water-table well, so that all the developed water-bearing strata in the valley are represented. These key wells are listed by districts in the following table, together with available records as to annual changes of water level in them. Comparisons of water levels have been made in December, because the withdrawal from wells is least and the piezometric surfaces most nearly approach stability during the months from November to March.

Annual Changes of Water Level in Key Wells in Tooele Valley

(Based on Measurements in December)

Well Number	(feet) Depth	Water level with respect to land surface 1945	Net rise (+) or fall (—) of water level, in feet 1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1936-1945
					Lake Point District								
(C-2-4) 1bcc1	50	—34						+1.7	+3.6	—1.9	+ .6	—1.4	
2aba2	315	+11	[b]—1.6	[b]+1.4	[b]— .3	[b]— .2	0	+1.5	+1.0	—1.8	+3.0	+1.7	+4.7
3dcc1	[a]145	— 4						+ .7	+2.5	—2.2	+ .1	+ .1	
					Erda District								
(C-2-4)27ccb1	[a]165	+ 5					+ .2	+1.2	+1.9	+1.0	+ .9	+2.9	
31dca1	[a]214	+ 7	— .6	— .2	— .1	— .1	+ .1	+1.0	+2.8	+2.3	+1.2	+ .8	+7.2
33abb2	[a]169	+11	—2.2	+ .3	— .4	— .5	+1.1	+1.7	+2.7	+1.3	+ .8	+2.8	+7.6
33abb4	80	+11	— .9	+ .8	— .5	— .2	+ .9	+1.3	+2.3	+ .9	+ .7	+1.8	+7.1
33add1	[a]165	—34			— .4	— .7	+1.3	+1.6	+3.1	+1.5	+ .9	+2.9	
33bcb2	80	+ 2						+1.0	+2.0	+1.2	+ .9	+1.8	
					Marshall District								
(C-2-5)34add1	440	+10							+ .4	+ .4	— .2	+ .3	
36caa1	[a]145	—32			— .1	— .2	+ .2	+ .3	+ .4	+ .2	— .8	+ .5	
					Grantsville District								
(C-2-5)19dcc1	[a]289	+ 5			+ .2	0	— .3	+ .9	— .5	— .3	+ .3	+1.2	
31bbd3	[a]130	+18	+ .1	+ .3	+1.7	— .5	— .3	+1.3	+ .4	— .9	+ .9	+ .6	+3.6
(C-2-6)36bac1	302	—21					— .7	+1.5	+1.0	—1.2	+ .8	+ .3	
36cdd1	[a]176	—79					— .7	+1.4	+1.2	—1.6	+1.0	+ .4	
(C-3-5) 5bbb1	[a]200	0			[b]+ .5	[b]+ .1	[b]—1.0	+1.4	+ .2	—1.1	+ .7	+ .5	
6dda1	120	—54						+1.5	+1.3	—1.6	+ .7	+ .7	

Annual Changes of Water Level in Wells in Tooele Valley (continued)

Well Number	Depth (feet)	Water level with respect to land surface 1945	Net rise (+) or fall (—) of water level, in feet										
			1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1936-1945
Burmester District													
(C-2-4)16aad2	300	— 6						+ .9	+ .5	— .5	+ .5	— .4	
17dad1		+25	— .4	+ .1	— .2	— .3	0	+ .4	+ .4	— .1	+ .9	+ .9	+1.7
(C-2-5) 5acc3	153	— 1						+ .3	0	— .3	+ .2	+ .1	
25aab1		+12	— .4	— .3	— .1	— .1	— .3	+ .1	— .7	+ .7	0	+1.0	— .1
27ccd3	100	— 1						+ .1	— .2	— .3	+ .4	+ .5	
(C-2-6)23cbb1	[a]210	— 3			+ .2	+ .1	— .3	+ .4	+ .5	— .4	+ .2	+ .1	
(C-3-5) 4bbb1	360	— 9						+ .2	+ .3	+ .1	+ .5	+ .2	
Summary by Districts													
Lake Point District			—1.6	+1.4	— .3	— .2	0	+1.3	+2.4	—2.0	+1.2	+ .1	+2.3
Erda District			—1.2	+ .3	— .3	— .4	+ .7	+1.3	+2.5	+1.4	+ .9	+2.2	+7.4
Marshall District					— .1	— .2	+ .2	+ .3	+ .4	+ .3	— .5	+ .4	+ .8
Grantsville District			+ .1	+ .3	+ .8	— .1	— .6	+1.3	+ .6	—1.1	+ .7	+ .6	+2.6
Burmester District			— .4	— .1	— .1	0	— .2	+ .3	+ .1	— .1	+ .4	+ .3	+ .2
Average, Tooele Valley			— .8	+ .5	0	— .2	0	+ .9	+1.2	— .3	+ .5	+ .7	+2.5

[a]Well ends in principal aquifer.
[b]Estimated from record of adjacent well.

Records from key wells prior to 1941 are inadequate to afford close correlation with precipitation data. From 1936 to 1938, with precipitation deviating only slightly from normal, water levels in some wells rose and in others declined. In 1939, a year of marked deficiency of precipitation, ground-water storage evidently diminished, as indicated by declines of water level in most of the observed wells. In 1940, when rainfall was slightly above normal, water levels rose in most of the wells for which comparisons are available, probably due to increased recharge and concurrent decrease in natural discharge as a result of the deficiency of water in 1939. Three years, 1938 to 1940 inclusive, are of especial interest because of the data collected concerning discharge from wells (pp. 228-234). At the end of 1940 the water levels in the twelve key wells for which records are available, were practically the same as at the end of 1937, and it is probable that there was no appreciable difference in quantity of water stored in the subterranean reservoir at the beginning and end of the 3-year period. The recharge during this period must therefore have been approximately equal to the discharge of ground water by all methods (p. 197).

During 1941, the first year for which records are available for all key wells, there was a net rise of water levels in all wells, and the amount of rise is fairly consistent among the wells in each district. The rise in the key wells of the Erda district ranged from 1.0 to 1.7 feet, and in the Grantsville district from 0.9 to 1.5 feet. In the Burmester district, which is more distant from the principal recharge areas for the valley, the rise of water level was considerably less, ranging from 0.1 to 0.9 foot. The rise of water levels in all parts of the valley indicates a significant increase in storage of ground water during a year when precipitation was considerably above normal. During 1942 most of the key wells showed a net rise in water levels despite the fact that precipitation was about normal. Largest rises were recorded in the Erda and Lake Point districts, and least change occurred in the Burmester district. Thus the recharge effects of the wet year 1941 continued into 1942.

In 1943, when precipitation at Tooele was less than 75 per cent of normal, water levels declined in practically all the key wells in the Lake Point, Grantsville, and Burmester districts, and a similar decline occurred during 1944 in the Marshall district. During 1944 and 1945, when rainfall at Tooele was approximately normal, the water levels in most districts rose sufficiently to offset the decline resulting from the drought of 1943. The exceptional rise of water levels in the Erda district in each of those years as well as the large cumulative rise in that district during the decade ended in 1945 are indicative that exceptional conditions of recharge prevailed there. Since these exceptional conditions are not apparent in the records prior to 1940, when large quantities of water began to flow from the Elton tunnel, it is concluded that that outflow has contributed appreciably to recharge of the Erda district.

SOURCES OF GROUND WATER

The ultimate source of the ground water in Tooele Valley is precipitation. By far the greater part is derived from precipitation over the drainage basin, but some is obtained from tunnels that take water from the adjacent basins of Jordan Valley and Rush Valley, and a small quantity may move from Rush Valley into Tooele Valley through pervious strata under the Stockton bar. Additions to the ground-water body may be either by direct penetration of rain or snow water within the limits of the valley, by seepage from streams or underflow in rock materials flooring the canyons that drain the mountains bordering the valley, or by penetration of excess water applied for irrigation. A considerable quantity of water rises along faults to form the largest springs in the valley, but these faults generally act as conduits for water already in the ground-water basin rather than as sources for additional water. Some of the faults also have a marked influence on ground-water circulation in the valley.

Seepage From Streams

Streams tributary to Tooele Valley lose water after leaving their canyons in the mountains, chiefly by seepage into the coarse materials of the upper part of the alluvial fans. People who use surface water for irrigation have long been aware of the losses caused by seepage from streams, and pipe lines have been constructed to carry the water of North Willow, South Willow, Box Elder, and Middle Canyons across the areas where seepage is greatest. Some residents report that the discharge from the pipe lines is in some instances two or three times greater than the quantity that had previously been delivered by the natural channel. The intermittent flow of many of the smaller streams disappears into the ground in the lower part of the canyon or within a few hundred yards of the mouth of the canyon.

The water lost by seepage from stream channels clearly reaches the ground-water reservoir, as shown for instance by the fluctuations of water level in the uppermost wells on the South Willow Creek alluvial fan. The hydrograph of well (C-2-6)36cdd1 (fig. 6) follows closely that of South Willow Creek, the water level rising during the spring run-off from melting snow, and declining after the freshet has passed. The water that has been saved to stream users by the construction of pipe lines and consequent reduction of seepage has been lost to the ground-water users who have developed the artesian reservoir by means of wells.

Underflow in Beds of Canyons

Most of the mountainous area tributary to Tooele Valley is drained by small canyons from which there is discharge for only short periods each year; in some canyons there may be no run-off for several years. Such small canyons drain the north slope of South Mountain, the Stansbury Range north of Davenport Canyon, and the Oquirrh Range north of the International smelter. The intermittent flow from these canyons seeps into the ground soon after it enters the valley, generally within a few hundred feet of the Bonneville shore line, for the smaller drains have very poorly-defined channels below this prominent marker. In these minor canyons probably the greater part of the water moves as underflow through the alluvial debris in the bottom of the canyon until it reaches the upper part of the alluvial fan, and thence toward the central part of the ground-water reservoir. In the larger canyons that contain the perennial streams, also, there may be considerable underflow through the gravels in the canyon bottom, a flow which is not observable or measurable at the mouth of the canyon but which is contributed to the ground-water reservoir in the valley.

The existence of this underflow is proved by the springs that rise in "dry" canyons where resistant rock ledges crop out in the bed of the stream and force the water to the surface. Some indication of the quantity involved may be obtained from the Elton tunnel, where about half of the flow in 1941 was derived from the portion of the tunnel under Dry Canyon, presumably from underflow (see page 158).

All the developed artesian aquifers are recharged by seepage from streams and by underflow down the numerous canyons, for these aquifers are no doubt open at their upper ends toward the great masses of coarse alluvial debris that receives this water. It is possible, however, that some of the coarser sediments at greater depth in Tooele Valley—particularly the strata accumulated prior to the glacial stages of the Pleistocene—may be cut off from present seepage areas by relatively impermeable material. This condition was suggested by the low artesian pressure and discharge of the deeper aquifers encountered during drilling of the deep experimental well, (C-2-4)-31dad2. These aquifers probably form a part of the Salt Lake formation.

Underflow From Rush Valley

Prior to the rise of Lake Bonneville, Rush Valley was evidently tributary to Tooele Valley, with an outlet through the gap between South Mountain and the Oquirrh Range. During the highest stage, Rush Valley contained an embayment of Lake Bonneville that was about 25 miles long and nearly 250 feet deep near the north end of the valley. The Stockton bar was formed across the gap east of South Mountain during this stage, and separated Rush Valley from Tooele Valley. Since that time Rush Valley has been a closed basin, and there has been no surface outflow from it into Tooele Valley. The barrier that separate the two valleys at Stockton is composed of material so coarse and permeable, however, that it has raised speculation as to the quantity of water that may be moving northward from Rush Valley beneath the surface.

Surplus waters of Rush Valley accumulate in the lowest part of the basin to form Rush Lake, which lies just south of the Stockton bar. The history of this lake is typical of the sink areas of closed basins in the Great Basin, and offers no suggestion that there may be subterranean flow from the lake through the materials that form the barrier. In 1855 according to Gilbert[38] the lake had a length of about 2½ miles. By 1862 only a small pond remained, the remainder of the lake bed being occupied by meadowland. In 1865 the water began to increase, and by 1872 the lake was 4½ miles long. At this time it extended southward as far as the warm springs in sec. 9, T. 5 S., R. 5 W., had a maximum depth of 10 feet, and was fresh enough that it served for domestic use. By 1880 the lake had shrunk to half its maximum size and had a depth not over 6 feet; the water was by that time too brackish to be palatable. In 1916 the lake was about 1¼ miles long, and during the years following the drought of 1934 it dried up entirely, leaving only a small area of marshy ground. By the spring of 1942 it was still dry, although precipitation had been above normal for several months. Thus, the lake increased in size following periods of abundant rainfall and diminished in dry periods, with some lag behind the climatic cycles. The decrease in size resulted largely from evaporation, as shown by the accompanying increase in salinity of the water. The lake bed is made up chiefly of clay, and it is likely that the accumulation of similar materials in the floor of the valley has effectively prevented seepage and underflow to Tooele Valley from Rush Lake.

There remains the possibility of underflow into Tooele Valley through permeable strata underlying the floor of Rush Valley, extending under the Stockton bar and Rush Lake perhaps at considerable depth. There is no information available concerning the pre-Bonneville sediments in this area, but it is suggested on the basis of analogy with other valleys in the Great Basin that sediments under the floor of the valley generally and under this outlet area in particular are probably chiefly of fine texture, the boulders, gravel, and sand having remained in the alluvial fans near the borders of the valley. It is considered therefore that the pre-Bonneville sediments at the outlet to the valley have a low permeability and that the underflow through them into Tooele Valley is not large.

Recharge From Irrigation Water

The ground-water reservoir receives some of the water diverted from canyon streams for irrigation, by seepage from the irrigation canals and ditches analogous to that which occurs along natural channels, and by deep penetration of excess water applied over the irrigated lands. The irrigated lands supplied

[38]Op. cit., pp. 228-229.

by the several perennial streams are generally a considerable distance from the mouths of the canyons of those streams. The lands served by North and South Willow Creeks are 5 to 10 miles northeast of the canyon mouths, and the water of these canyons is carried 6 and 8 miles respectively through pipe lines. In contrast, the water of Settlement Creek is used mostly within the city limits of Toole, located practically at the mouth of the canyon. Some of the water of Middle Creek is used near the mouth of the canyon, and some is piped about 2 miles to the settlement of Lincoln.

The water which has been discharged from the Elton tunnel, of which a portion has demonstrably reached the artesian reservoir serving the Erda district, has entered that reservoir entirely by seepage from canals and irrigated lands served by those canals. One-third of this water is diverted from the portal southwesterly toward the eastern suburbs of Tooele, and two-thirds moves northwesterly along a ditch through Lincoln community. In the summer all water is used for irrigation of lands along these ditches, and in the winter it enters the ground by seepage chiefly along the north ditch, disappearing entirely before it reaches the Droubay ranch in sec. 35, T. 2 S., R. 4 W.

The position of the irrigated area on the alluvial fan may determine what portion of the water may join the ground-water body. Toward the apex of the fan the soil and underlying strata are likely to be more coarse and permeable, downward penetration of water more rapid so that more water is applied for irrigation, and thus the proportion that migrates to the zone of saturation will be greater. Water from these higher areas joins the ground-water reservoir and then moves through either the deep or shallow aquifers toward the lower, central part of the valley. The irrigated lands farther down the slopes of the fan commonly lie above artesian aquifers, and are separated from them by relatively impermeable strata. Excess water applied on these lands moves into the shallow saturated zone above the artesian aquifers. The irrigated areas north of Grantsville are of this type. In Erda, where irrigation is entirely from artesian wells, excess water applied contributes to the shallow-water bodies at the expense of the artesian reservoir.

Penetration of Precipitation

Water from precipitation may penetrate directly to the ground-water reservoir, provided the precipitation is greater than that needed to satisfy the soil-moisture deficiency. As is true of recharge from irrigation water, the opportunity for penetration of rainfall is greatest in the permeable materials of the upper parts of the alluvial fans, and recharge to the artesian aquifers occurs only in these areas. Penetration of water from rain or snow in the lower parts of the fans adds increments to the shallow water above the confining layers.

Water Rising Along Faults

Numerous springs rise along faults in Tooele Valley and in the mountainous area tributary to the valley. The largest springs in the Valley— at Mill Pond and Dunne's Pond and at Three-mile and Six-mile Creeks—originate along fault planes. The waters of these springs are similar in mineral constituents and in temperature to waters yielded by nearby wells, and it is likely that the fault serves as a conduit for water that is already a part of the ground-water reservoir and derives no water from sources beyond the limits of that reservoir.

MOVEMENT AND DISPOSAL OF GROUND WATER

General Relations

The movement of ground water follows more or less the drainage pattern of Tooele Valley and, like surface streams, is generally from the mouths of the canyons that drain the bordering mountain ranges, down the alluvial slopes toward the central and lowest part of the valley and thence northward toward Great Salt Lake. Water at shallow depths—in strata overlying the artesian aquifers—may be discharged by evapo-transpiration or it may move northward until it reaches Great Salt Lake. The water under artesian pressure may be discharged from springs, some of which are practically at the level of Salt Lake, and then evaporate or flow in shallow channels toward the lake. Over the area of ground-water development the direction of movement is indicated by the contours of the piezometric surface on the principal aquifer (fig. 10), for the water moves in the direction of maximum slope, at right angles to the direction of the contour lines. The piezometric surfaces of other aquifers have been shown to be more or less parallel to that of the principal aquifer, depicted on this figure, and movement in these aquifers is presumed to follow the same general trend.

Grantsville District

Ground water moves northeastward and northward in the alluvial fans of Box Elder, South Willow, and North Willow Creeks and half a dozen smaller streams farther north that rise in the Stansbury Range. Some of the water is discharged from springs within the district—notably those that contribute to Cooley Slough—and a considerable amount is discharged from flowing wells. The rest of the ground water moves northward into the Burmester district.

The discharge of Cooley Slough in May 1941 was 0.3 second-foot, but it was reported to have been about 3 second-feet in April 1940. The discharge of this slough diminishes during the summer, and by fall the channel is commonly dry. Other springs in the Grantsville district discharge smaller quantities of ground water, which is evaporated or transpired at the spring or along a channel draining the spring area. The loss to the ground-water reservoir through springs in the Grantsville district is estimated to average about 1,000 acre-feet a year. In addition an unestimated quantity is lost from the shallow-water zone above the artesian aquifers by evapo-transpiration, particularly in the northern part of the district.

Erda District

The movement of ground water is generally northwestward from the apexes of the alluvial fans of Settlement, Middle, and Pine Creeks and adjacent minor streams that head in the Oquirrh Range south and east of Tooele. Several springs rise within the Erda district, some of which were formerly used for irrigation. These springs evidently rise from the principal artesian aquifer and from shallower water-bearing strata, and some of the best wells in the district are situated in or near certain spring areas. Since the construction of wells for irrigation in the Erda district, some of these springs have dried up entirely, and others flow only during the winter when the irrigation wells are capped. The discharge from springs and the evapo-transpiration from the shallow-water zone in the northern part of the district constitute practically the only natural loss of ground water in the Erda district; it is believed to be small, and is probably less than the quantity wasted from wells (p. 236). Most of the water not utilized by wells continues northward into the Burmester district, and a small quantity probably moves westward into the Marshall district.

Marshall District

According to scant evidence from a very small number of wells, the direction of movement of ground water is northward, and the water is presumably derived from the south-central part of the valley, including the north slope of South Mountain and the gap farther east through which must come any underflow from Rush Valley. Some water also enters from the Erda district, adjacent to the east. There is no natural discharge within the Marshall district, but two large springs—at Three-mile and Six-mile Creeks—rise along the Box Elder Canyon fault, which forms the north boundary of the district. The measured discharge from Three-mile Creek north of the spring area was found to range from 2.7 to 4.7 second-feet in 1941, and the discharge of Six-mile Creek in May of that year was 3 second-feet. Allowing for transpiration and evaporation within the spring areas, it is estimated that the annual run-off from both spring areas probably ranges between 5,000 and 7,000 acre feet. The water of these springs is presumably derived from the south, and hence from the Marshall district. The rest of the water of this district moves northward across the Box Elder Canyon fault and into the Burmester district.

Lake Point District

Ground water moves in a general northwesterly direction from the Oquirrh Range toward the lake flat. A considerable quantity of water is discharged from large springs along the west boundary of the district at Mill Pond and Dunne's Pond, and some probably moves into the Erda district without reaching the surface. According to records which were furnished by the Garfield Water Co., the discharge of the Mill Pond spring has diminished gradually during the past two decades, from about 10 second-feet prior to 1930 to 9.2 in 1932, 8.6 in 1935, 6.9 in 1937, 6.4 in 1940, and about 6 second-feet in 1941. According to daily weir measurements in July and August of 1941, the discharge from this spring ranged from 2,400 to 2,800 gallons a minute. The discharge of Dunne's Pond (or Factory Creek) has been increasing gradually during the same period, from 6.2 to 7.8 second-feet, and it is suggested that the two spring areas probably have the same general source and that an increasing proportion of the water is discharging through the springs at Dunne's Pond because of their lower altitude.

The combined discharge from the two spring areas has decreased gradually during the period for which records are available. In recent years the springs are estimated to have yielded 9,500 to 10,000 acre-feet a year, but it is probable that in earlier years the annual flow was as great as 12,000 acre-feet. During the summer the flow from the Mill Pond spring is used for several days each week for irrigation in the Lake Point district. The rest of the water from this spring and all the water from Dunne's Pond is available for diversion by the Garfield Water Co.

The springs along the east side of the valley in the Lake Point district are small, but several others rise along the north end of the Oquirrh Range. Annual discharge from these spring areas (in Tooele County) is estimated to be about 500 acre-feet. Ground water is also discharged from the district by movement toward Great Salt Lake and by evapo-transpiration, analogous to the Burmester district.

Burmester District

This district and the northern part of the adjacent Lake Point district embrace the low northern part of Tooele Valley, which receives water that moves underground from the Grantsville, Marshall, and Erda districts. Ground water occurs at very shallow depth under this flat and is discharged from these shallow horizons by evaporation and by transpiration where vegetation has gained a foothold. Some water in this shallow zone moves northward beneath the surface down a very gentle gradient until it reaches Great Salt Lake, the evaporating pan of the drainage basin. The water in this shallow zone, derived from precipitation and excess irrigation on the valley floor above the artesian aquifers, has a moderate to high mineral content because of the soluble salts that are left in the strata by evaporation. The quantity that is discharged from Tooele Valley through the shallow zone has not been estimated but it is probably considerable.

Water in the artesian aquifers of the Burmester and Lake Point districts moves northward at least as far as wells have been drilled, and the piezometric surfaces for these aquifers have a slope of about 6 feet per mile in the northwestern part of T. 2 S., R. 5 W. Some of this water may move upward through the relatively impermeable strata above the artesian aquifers, as suggested by experiments by Israelsen and McLaughlin in Cache Valley.[30] The rate of this upward percolation might be infinitesimal and yet the total loss from artesian aquifers might be appreciable, because of the great area over which such upward movement can occur. The water lost from the artesian reservoir would be added to the overlying shallow water body or to Great Salt Lake farther north, from which it would be evaporated.

Numerous springs that rise along the edge of the lake flat where it ends abruptly against the principal mountain ranges may obtain water from the artesian aquifers underneath the lake flat. These springs rise along a narrow zone where it may be presumed that coarser debris, talus, and slope wash have accumulated between the bedrock of the ridge and the lake beds. This permeable zone of coarser detritus may intercept the edges of the artesian aquifers and provide an avenue of discharge for water under artesian pressure. The high mineralization of the waters issuing from many of the springs is indicative that the water is derived from the sediments under the valley floor rather than from the mountains. The springs are located at the level of the lake flat only a few feet higher than Great Salt Lake, and the hydrostatic head necessary to cause discharge from them is very little greater than would be necessary to lift the water to the lake level. Thus the source of these springs may quite plausibly be the artesian aquifers underlying Tooele Valley. Grantsville Warm Springs and other springs discharging water at higher than average temperatures are believed to yield water that has risen from considerable depth beneath the valley floor (see page 215).

Discharge of the springs along the base of the Stansbury Range northwest of Grantsville is estimated to have been at least 5 second-feet in May 1941, including losses by evapotranspiration, on the basis of measurements of flow from certain spring areas totalling about 2 second-feet. The discharge from these areas had diminished only slightly by November of the same year, and it is believed that the rate of discharge is fairly constant. Thus the springs along the west side of the valley in the Burmester district are estimated to yield about 3,500 acre-feet annually.

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[30]Israelsen, O. W., and McLaughlin, W. W., Drainage of land overlying an artesian ground-water reservoir: Utah Agri. Exp. Sta. Bull. 242, pp. 12-15, fig. 6, 1932.

CHEMICAL CONSTITUENTS OF THE GROUND WATER

Chemical Analyses

Chemical analyses of the waters from 13 wells, 8 springs, and one stream in Tooele Valley are reported in the following table, and the results of these analyses are shown graphically in figure 16. Samples of water were also collected from 102

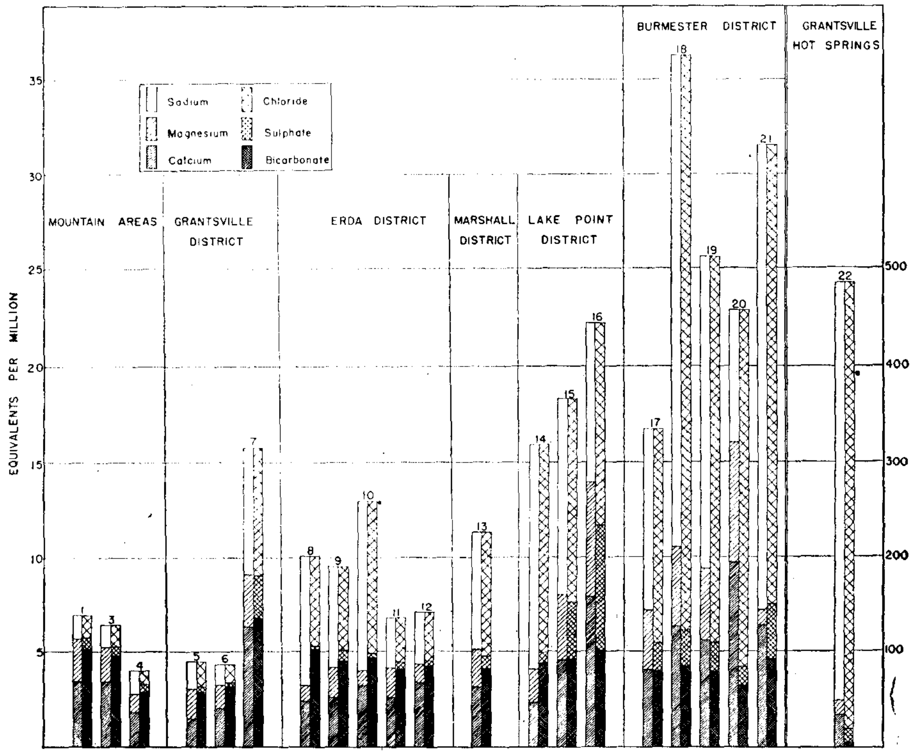


Figure 16.—*Graphic representation of chemical analyses of water in Tooele Valley.*

wells and springs and analyzed to determine hardness, alkalinity (bicarbonate), chloride, sulphate, and in certain samples nitrate and fluoride. Results of the partial analyses are presented in a subsequent table.

The waters selected for complete chemical analysis are considered to be fairly representative of the waters encountered in wells and springs in Tooele Valley. These waters fall naturally into three groups: Calcium-bicarbonate waters of low concentration represented by wells (C-2-5)7bdd1 and (C-2-5)19dcc1; sodium-chloride waters of high concentration such as that in well (C-2-5)27aad1 and especially the Grantsville Warm Springs (C-2-6)16aad; and waters of intermediate concentration con-

Analyses of Ground Water in Tooele Valley, Utah

[N. A. Talvitie, U. S. Geological Survey, analyst unless otherwise indicated. Parts per million.]

No. on figure 18	Well or spring number	Depth (feet)	Temperature (°F.)	Use[a]	Date of collection	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)
				MOUNTAIN AREAS				
1	(C-2-4)26ddd	Spring	62	R	Apr. 4, 1941	12	.04	69
2[b]	(C-3-3)20bbc	Spring		In	May 18, 1928	2	—	53
3[c]	(C-3-4)35aac	Spring		M	Feb. 26, 1941	4	.0	69
4[d]	(C-3-6)30baa	Stream		M	Dec. 18, 1940	7	.0	36
				GRANTSVILLE DISTRICT				
5	(C-2-5) 7bdd1	300	57.2	S	Aug. 28, 1941	56	.04	30
6	19dcc1	289	55	D	Apr. 4, 1941	37	.05	41
7	(C-2-6)36baa8	85	55	S	Do.	26	.03	128
				ERDA DISTRICT				
8[e]	(C-2-4)29dd	Spring				—	—	48
9	31acd1	221	61.5	I	Apr. 4, 1941	18	.06	53
10[e]	32aad1	300	57.1	I	Aug. 25, 1941	—	—	64
11	33abb2	169	55.5	S	Apr. 4, 1941	15	.03	53
12[e]	33abb4	80	55.7	D	Aug. 25, 1941	—	—	68
				MARSHALL DISTRICT				
13[e]	(C-2-5)35cca1	400	69.8	S	Aug. 26, 1941	—	—	64
				LAKE POINT DISTRICT				
14	(C-2-4) 2aba2	315	63	D	Apr. 4, 1941	16	.05	47
15	15cab	Spring	62	I	Do.	18	.03	92
16[e]	35cbb1	178	56.3	S	Aug. 26, 1941	—	—	160
				BURMESTER DISTRICT				
17	(C-2-5)17bda1	100	54.5	S	Apr. 4, 1941	30	.11	82
18[e]	26cdc	Spring	64.6	S	Sept. 5, 1941	—	—	128
19	27aad1	120	59	S	Apr. 4, 1941	27	.04	112
20	32daa1	300	56	I	Do.	24	.04	195
21[e]	33add	Spring	62.4	I	Sept. 5, 1941	—	—	128
22	(C-2-6)16aad	Spring	85	N	Apr. 4, 1941	28	.04	677

[a]D, domestic; In, industrial; I, irrigation; M, municipal; N, none; R, railroad; S, stock.
[b]Analysis by International Smelting & Refining Co.
[c]Big Spring and tunnels, chief source of Tooele municipal supply. Analysis by M. E. Christensen, Utah State Board of Health.

Analyses of Ground Water in Tooele Valley, Utah

[N. A. Talvitie, U. S. Geological Survel, analyst unless otherwise indicated. Parts per million.]

Magnesium (Mg)	Sodium (Na)		Potassium (K)	Bicarbonate (HCO_3)	Sulphate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Total dissolved solids	Total hardness as $CaCO_3$ (calculated)
				MOUNTAIN AREAS						
27	29		2.1	314	28	43	.0	.5	366	283
29	—		—	—	50	—	—	—	336	252
22		26		58	20	40	.0	T	334	263
12		27		76	18	25	.0	T	198	140
				GRANTSVILLE DISTRICT						
19	34		3.8	175	13	47	.1	1.0	278	153
15	26		2.8	189	12	33	.1	.8	251	164
34	157		3.6	402	109	239	.0	16	925	459
				ERDA DISTRICT						
10		157		307	12	168	—	—	546	161
19	125		3.2	278	28	158	.1	7.5	541	210
10		205		283	12	285	—	—	715	201
19	61		1.7	246	18	84	.0	5.7	373	210
12		62		259	14	90	—	—	374	219
				MARSHALL DISTRICT						
24		141		254	31	230	—	—	615	258
				LAKE POINT DISTRICT						
21	272		8.8	272	27	292	.2	1.5	916	204
42	238		6.8	283	145	382	.1	3.6	1096	402
73		192		307	315	380	—	—	1271	699
				BURMESTER DISTRICT						
38	221		6.8	244	73	405	.3	1.6	1009	361
51		595		261	90	1073	—	—	2066	529
47	375		8.5	245	74	718	.3	1.7	1614	473
78	160		4.2	198	45	665	.0	1.8	1372	807
10		564		283	138	858	—	—	1837	361
185	9980		256	247	694	16700	—	—	29500	2451

[d]Derived from North Willow and Davenport Creeks. Analysis by M. E. Christensen, Utah State Board of Health.

[e]Analysis by Soil Conservation Service, soils laboratory at Albuquerque, New Mexico.

taining considerable amounts of both of the constituents dominant in the other two types. Increase in mineral load is chiefly in sodium chloride, but although the other mineral constituents do not increase in proportion their total quantity is commonly greater in the more highly mineralized waters. The areas where there is considerable draft for irrigation, particularly the Erda and Grantsville districts, commonly yield water of better quality than the areas of less ground-water development.

The total amount of inorganic constituents dissolved in the ground waters of Tooele Valley ranges from about 200 parts per million in the springs that furnish the municipal supply for the city of Grantsville to about 29,500 parts in the Grantsville Warm Springs.[40] Most of the sampled wells in the Erda and Grantsville districts yield water containing less than 700 parts of dissolved materials, but in certain wells used for domestic supply in other parts of the valley (particularly in the Lake Point district) the dissolved materials may be as great as 1,500 parts per million, according to estimates based on the partial analyses. The mineral content of waters used for the larger public supplies in the United States is generally less than 500 parts per million.

Quality of Water for Domestic, Stock and Irrigation Use

The analyses give some indication of the fitness of the sampled waters for the common uses to which ground water is put in Tooele Valley, insofar as that fitness is determined by mineral constituents. Hardness of a water is caused chiefly by the bicarbonates and sulphates of calcium and magnesium, and is undesirable because insoluble compounds of these elements are produced when the water is used for ordinary domestic or industrial purposes. Thus in washing, calcium and magnesium ions combine with soap to form a curd and must be entirely removed before the soap can form a lather, so that larger quantities of soap are required in a hard water. Heating hard water forms an insoluble residue or "scale", which consists of precipitated carbonates and sulphates of calcium and magnesium and perhaps other salts. In the complete analyses the hardness is computed from the quantities of calcium and magnesium present. In the partial analyses the hardness is measured by the quantity of a standard soap solution that is required before a lather is formed, and it thus serves as an approximate indication of the amount of calcium and magnesium in the water. A hardness of less than 150 parts per million does not seriously interfere with the use of water for most purposes, but if the hardness is greater than 200 parts it is generally economical to soften the water for household or industrial uses. Waters with a hardness greater than 500 parts per million may have a saline taste. The hardness of water in Tooele Valley is caused chiefly

[40]Inasmuch as the waters from the Grantsville Warm Springs and other saline springs farther northwest can be used only for bathing or wading, they are neglected in the following discusion of quality of water.

Partial Analyses of Ground Water in Tooele Valley, Utah

C. G. Seegmiller and E. W. Lohr, U. S. Geological Survey, analysts. Parts per million

Well or spring number	Depth (feet)	Temperature (°F.)	Use[a]	Date of collection	Bicarbonate (HCO_3)	Sulphate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Total hardness
				Grantsville District						
(C-2-5) 7abd[b]	335-368		D	Sept. 2, 1941	170	13	220		1.0	290
7dcc1	490	65.2	D	Aug. 28, 1941	180	20	95	.3	.8	160
7dcc2	606	62.7	D	Do	150	24	75	.3	.4	130
18acc1	350	60.2	D	Sept. 2, 1941	200	30	55		.4	120
18dcc1	300	57.8	S	Do	180	20	35		.4	100
19cad1		56		Sept. 2, 1941	200	12	35		.3	150
30bbc1		53.9	S	Do	210	8	35		.5	190
30daa1		57.3	S	Aug. 28, 1941	190	14	35		.9	160
31aaa3		55.6	S	Do	170	12	40		.6	160
32abc1		56.2		Aug. 27, 1941	180	14	60		.9	190
32bdb1	200	59.6	S	Aug. 27, 1941	180	12	35	.0	.9	150
32bdb2	400	57.3	S	Do	200	12	35		.9	135
32dab2	320	55.8	D	Do	150	25	180		1.5	270
32dac1	275	55.6	S	Do	230	25	195		1.5	320
32dad1	510	58.7	D	Do	190	20	435	.0	2.0	620
32dad3		55.8		Aug. 27, 1941	190	25	185		1.2	310
(C-2-6) 24cbb2		54	S	Sept. 4, 1941	200	14	45		.7	180
24cbc2		54.3	D	Do	210	11	50		.5	190
24ccb4		54		Do	190	6	45		.5	150
24ccc6		53.2	D	Do	160	11	55		.8	190

Partial Analyses of Ground Water in Tooele Valley (continued)

Well or spring number	Depth (feet)	Temperature (°F.)	Use[a]	Date of collection	Bicarbonate (HCO_3)	Sulphate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Total hardness
				Grantsville District (continued)						
(C-2-6)24dba1	125	53	S	Sept. 4. 1941	190	12	35		.6	170
25abc1	100	52.3	S	Sept. 2, 1941	170	14	60	.0	.9	200
25bcb2	150	54.7	D	Do	170	16	65		.8	200
25cbc1	200	54.1	I	Sept. 4, 1941	200	25	50	.1	1.1	200
26adb1	160	54.5	S	Do	180	12	50		1.4	160
(C-3-5) 6aaa3	400		D	Aug. 27, 1941	200	8	45	.0	1.1	150
6bba1	120		D	Do	90	20	285		.5	470
6caa1	90		D	Do	360	25	80	.0	14	400
(C-3-6) 1aaa1	153		N	Do	100	20	170	.0	.2	280
				Erda District						
(C-2-4)22ccb1	43		D	Aug. 25, 1941	280	300	310	.2	4.3	590
27cbd1	400	60.2	S	Do	260	35	95		7.1	280
27ccb1	165	54.5	D	Do	210	35	110	.2	3.5	240
28cca1	264	57.5	I	Aug. 26, 1941	270	13	150		1.5	170
28cca2	120	55.9	D	Do	280	20	150	.2	2.9	200
28dcb2	313	57.5	I	Aug. 25, 1941	260	16	95		2.2	190
28dcb3	192	56.2	I	Do	240	14	110		3.2	180
28dcc3	76	52	I	Do	200	16	70	.1	3.9	170
29bcd1	300	55.2	S	Aug. 26, 1941	270	20	215		1.5	200
29ddd1	200	55.2	D	Do	280	25	170	.1	2.2	150
31bdc1		62.1	D	Do	270	25	185		4.3	220
32aad5	125	56.8	D	Aug. 25, 1941	290	25	215		1.8	170
32ada2	233	56.4	D	Aug. 26, 1941	290	25	250		2.5	180
32bcc1	201	59.7	I	Do	280	25	110		7.9	220
33bba1	222	55.7	I	Aug. 25, 1941	270	20	150		1.5	160

Partial Analyses of Ground Water in Tooele Valley (continued)

Well or spring number	Depth (feet)	Tem-pera-ture (°F.)	Use[a]	Date of collection	Bicar-bonate (HCO_3)	Sul-phate (SO_4)	Chlo-ride (Cl)	Fluo-ride (F)	Ni-trate (NO_3)	Total hard-ness
				Erda District (continued)						
(C-2-4)33bba2	80	55.4	D	Aug. 25, 1941	290	20	130		3.1	140
33bbb1	296	57.3	I	Do	220	20	190		1.9	140
33bcb1	283	57.5	I	Do	280	25	215	.2	2.0	160
				Marshall District						
(C-2-5)25dcd1		57.4	S	Sept. 2, 1941	230	30	155		.0	140
34add1	200	68.9	I	Aug. 26, 1941	210	30	330		1.0	250
36acd1	115		N	Feb. 20, 1942	50	3	290		1.0	100
36add2	305	60.5	D	Sept. 2, 1941	270	30	180		3.3	250
36dad1	259	59.5	S	Do	200	25	245		3.0	230
				Lake Point District						
(C-1-4)35cda1	400		D	Aug. 25, 1941	370	30	345	.8	.5	70
35cdd1	80	61.4	D	Do	290	40	670	.3		230
(C-2-4) 2bdb1	275	62.5	I	Do	280	25	475	.2	1.0	260
2bdb2	155	57	N	Do	400	50	375		.5	80
2cccl	90		D	Do	260	240	590		17	340
				Burmester District						
(C-2-4)10cdb1	140		D	Aug. 25, 1941	300	110	680			380
18dcd1	250	57.7	S	Aug. 27, 1941	170	15	320		.0	310
19bdd1		55.2	S	Do	220	15	170			210
(C-2-5) 5acc1		62.6	N	Sept. 2, 1941	70	50	5250			5200
6dcd1	250	62.6	I	Do	90	8	1750			2200

Partial Analyses of Ground Water in Tooele Valley (continued)

Well or spring number	Depth (feet)	Temperature (°F.)	Use[a]	Date of collection	Bicarbonate (HCO_3)	Sulphate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Total hardness
				Burmester District (Con'td)						
(C-2-5) 6ddc1	360	62.3	N	Sept. 2, 1941	70	7	3220	.0		4000
8ccc2	260	59.4	I	Aug. 28, 1941	190	15	165		1.0	240
13acc1	280	57.2	S	Aug. 27, 1941	270	5	160		1.2	140
14adc1	80	56.3	S	Do	270	30	260		1.0	200
14dbb1	300	56.1	S	Do	270	50	410		1.0	260
17aac2		54.3	S	Aug. 28, 1941	240	50	420		.5	330
23caa1	80	53.9	S	Aug. 27, 1941	270	80	610			340
23cad1	80	55.8	S	Do	260	60	625			360
23cdc1	65	57.0	S	Do	220	60	695			370
24cac2		55.4	N	Do	220	100	785			790
25aab1		55.9	N	Oct. 2, 1940	280	30	130		1.5	200
28dcc3	100	61.4	S	Aug. 27, 1941	240	110	400		2.5	330
29cba1		55.7	S	Aug. 28, 1941	220	270	410		2.0	550
29dcc1	340	57.4	I	Aug. 27, 1941	150	25	470		2.3	690
29dcc5	60	56.4	S	Do	125	30	240		1.5	330
33abb1		59.6		Aug. 26, 1941	250	80	460		2.5	350
33adc1	265	62.8	S	Do	240	60	410		1.5	400
33cbb1	244	56.4	S	Aug. 27, 1941	200	45	215	.0	2.0	310
33ccb1		56.1		Do	200	25	190		1.2	290
34abc1	320	68.7	S	Aug. 26, 1941	200	50	1040			720
34bca1	300	72.0	I	Do	190	110	1720			700
34bcd1	310	72.8	I	Do	180	80	1190			670

Partial Analyses of Ground Water in Tooele Valley (continued)

Well or spring number	Depth (feet)	Temperature (°F.)	Use[a]	Date of collection	Bicarbonate (HCO_3)	Sulphate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Total hardness
				Burmester District (continued)						
(C-2-6)15dcb1		68.1	N	Sept. 5, 1941	170	70	1370			910
15dcb2	84	67.4	N	Do	180	40	990			670
15ddc1		64.2	N	Do	155	50	825			520
23bad1	70	59	S	Sept. 4, 1941	160	25	500		.5	300
23bbc1		69.0	S	Sept. 5, 1941	170	55	1160			640
23bcd1	128	66.3	I	Sept. 4, 1941	180	50	750	.1		390
23bdd1	150	59.6	S	Do	160	20	350	.0	.5	320
23bdd3	110	60.1	I	Do	160	12	175		.4	180
23cba2	128	66.5	S	Sept. 5, 1941	150	25	510		.8	290
(C-3-5) 4bbb1	360		S	Aug. 27, 1941	210	25	475		2.0	650
				Springs Along Boundary Between Lake Flat and Mountain Ranges						
(C-1-4)26d	Spring	60.1	N	Sept. 5, 1941	250	60	1250			520
(C-1-6)30dd	Spring	63.9	N	Do	220	240	3600			580
(C-1-7)15b	Spring	74.4	N	Do	230	440	6700			1020
25ac	Spring	68.1	N	Do	210	540	9600			1280
25ad	Spring	65.8	N	Do	180	340	6800			500
25a	Spring	59.2	N	Do	200	170	3600			620
(C-2-6)15dcc	Spring	65.5	S	Do	220	25	200		.2	150
16da	Spring	72.6	N	Do	250	280	6100			1020

[a]D, domestic; I, irrigation; N, none; S, stock.
[b]Composite from wells (C-2-5) 7abdl, 7, and 8.

by calcium bicarbonate, which is a major constituent in most waters used for domestic purposes. In most of the waters for which complete analyses are available practically all the hardness is "carbonate hardness." The sulphates of calcium and magnesium contribute to the hardness of the water in certain wells and would increase the cost of softening.

The water used for municipal supply in Grantsville has a hardness of 10 parts per million. Most of the wells sampled in the Grantsville and Erda districts yield water with hardness ranging between 150 and 200 parts, but in certain outlying domestic wells the hardness may be as great as 600 parts. The Middle Canyon supply for Tooele has a hardness of about 260 parts, and it is likely that the springs in Settlement Canyon, which also rise within the area of outcrop of the Oquirrh formation, yield water of about the same hardness. In the Lake Point, Burmester, and Marshall districts the sampled waters generally have a hardness greater than 200 parts per million, and in certain wells and springs the hardness exceeds 1,000 parts. So far as is known, the waters used for domestic purposes have hardness of less than 600 parts per million.

A major constituent in many well waters in Tooele Valley is sodium chloride, or common salt. As shown by the complete analyses, waters having a high chloride content commonly have a correspondingly high proportion of sodium, and the total mineral content is also great. In the partial analyses and field tests, likewise, the chloride content is believed to offer some indication as to the concentration of the mineral matter dissolved in the sampled waters. In practically all wells used for culinary purposes the chloride content is less than 700 parts per million, but some waters used by stock may have as much as 1,200 parts, and in certain irrigation wells the chloride content is as great as 1,750 parts. In waters from three wells and six springs the chlorides range from 3,200 to 16,700 parts per million; the waters from these sources are not used.

The minor constituents shown in the chemical analyses are generally present in such small quantities that they are not objectionable for the present uses of water in Tooele Valley. The greatest amount of iron found, for instance, was 0.11 part per million, which is below the tolerance generally set for acceptable water supplies. In 3 of 35 waters tested the fluoride content was 0.3 part per million or less, and in well (C-1-4)35cda1 it reached 0.8 part per million. These small quantities are reported to be beneficial in reducing the incidence of dental caries.[41] Silica is present in normal amounts and is of no significance except that it contributes to the formation of scale. The sulphate content is generally too low to impart a bitter taste to the waters, but several waters having a moderate sulphate content are impotable because of the high concentration of other dissolved

[41]Dean, H. T., Arnold, F. A., and Elvove, Elias, Domestic water and dental caries: Public Health Reports, Vol. 57, pp. 1155-1179, 1942.

materials. The nitrate content of the waters is likewise of no significance: of 91 waters analyzed none contained more than 17 parts per million of nitrate, and only 5 contained more than 5 parts per million.

These analyses of mineral constituents give little indication of the sanitary condition of the waters. Chlorides occur in animal wastes and nitrates are sometimes formed by decomposition of organic materials, so that these ions may be indicative of pollution. Most of the waters represented by the above analyses, however, are from artesian wells where likelihood of pollution is slight and where the presence of these ions is ascribed therefore to natural conditions.

The great majority of the inhabitants of Tooele Valley live in the cities of Tooele and Grantsville and are thus dependent upon the municipal systems of those cities for their domestic supply. As shown by analyses nos. 3 and 4 on page 202 these waters have little dissolved mineral matter other than calcium bicarbonate, and except for their moderate hardness are excellent waters for domestic purposes.

Chemical Constituents in Relation to Geology

The mineral constituents in natural waters reflect the composition and solubility of the rock materials with which the waters have been in contact. The ultimate source of the ground water in Tooele Valley (with the possible exception of the Grantsville Warm Springs) is precipitation over the drainage basin. This rain or snow water contains only an infinitesimal quantity of mineral constituents, dissolved from dust particles and gases in the atmosphere. By the time this water enters the Tooele Valley ground-water reservoir it may have a greater mineral content, dissolved from the rock materials in the stream channels, soil, debris, etc, through which the water passes before it enters the reservoir.

Most of the water from the bordering mountain ranges appears to be fairly low in mineral content as it enters Tooele Valley, for water in streams is generally of good quality, and springs near the margins of the valley that are derived from underflow in the canyons yield excellent water (analyses 1 to 4 on page 202). The springs that constitute the sources of the municipal waters for the principal towns are believed to be typical of the waters that enter Tooele Valley. The Grantsville supply is derived from canyons that drain a large area of Tintic quartzite and that contain in their beds a predominance of quartzite pebbles, although limestone is also widespread over the drainage basin; the water has a low mineral content, with calcium bicarbonate predominating. The Tooele supply comes from canyons that drain areas underlain by the Oquirrh formation, and includes a larger proportion of calcium bicarbonate than does the water used by Grantsville.

The ground water in Tooele Valley includes the mineral constituents that were in solution as the water entered the reservoir plus any that are dissolved by the water during its movement through the aquifers of the reservoir. The degree of increase is dependent upon the solubility of the materials through which the water passes and the distance through which the water moves. The importance of the solubility of the strata through which the water passes is evident in the variations noted in the amount of chemical constituents contained in waters yielded by aquifers of different depths. The several aquifers, lying one over another, receive water from a common source, and the variation in amount of dissolved material in the waters is attributed to differences in the character of the material in the several beds; these differences in turn result from the varying degrees of aridity under which the sediments were accumulated.

The quantity of soluble mineral constituents in the alluvial and lacustrine strata—the amount available for solution by ground water—is dependent in large part on climatic conditions that prevailed at the time of deposition of those strata. As pointed out in the geologic chapter (pp. 119, 138), the climate during the Pleistocene epoch was represented by several arid periods similar to the present, alternating with cold humid periods that were probably contemporaneous with the continental glacial advances farther east. The climate during the deposition of the Salt Lake formation is presumed to have been more or less arid, comparable with the climate of recent times.

Practically all the coarse sediments that now constitute the artesian aquifers in Tooele Valley are inferred to have been deposited during the humid periods of the Pleistocene, when the transporting power of streams was greater than in the intervening arid (interglacial) times (pp. 133-145). These water-bearing sediments no doubt contain a smaller proportion of soluble mineral matter than the beds accumulated during the arid periods. Partial analyses of waters obtained from several aquifers encountered in well (C-2-4)31dad2, tabulated below, show that there is some variation in chemical constituents between aquifers but that the several aquifers contain water of comparable quality.

The similarity in chemical composition of waters from different aquifers in the Erda district is also shown by comparison of waters from adjacent wells of different depths (See complete analyses for wells (C-2-4)33abb2 and 4; partial analyses for wells (C-2-4)28cca1 and 2, (C-2-4)28dcb2 and 3, (C-2-4)33bba1 and 2 and 33bbb1). In the Grantsville district, likewise, the waters from different aquifers are generally similar in quality.

On the other hand, striking differences are shown in the analyses from adjacent wells in other parts of Tooele Valley. These differences are not consistent with respect to the several aquifers, and the water of better quality is sometimes encountered in the shallow aquifers, sometimes in the deeper zone.

Partial Analyses of Samples of Water Collected During Drilling of Well (C-2-4)31dad2

E. W. Lohr and C. G. Seegmiller, analysts

Depth (feet)	Chemical Constituents in parts per million					
	Bicarbonate (HCO_3)	Sulphate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Total hardness as $CaCO_3$
85	160	40	133	.4	2.2	150
145	260	30	101	.3	4.8	180
175	265	20	102	.3	7.7	185
207	200	25	106	.2	8.5	145
237	170	30	94	.2	10.0	110
305	190	25	92	.1	9.6	115
480	180	30	405	-	—	190
675	80	15	162	-	.0	85

Thus in the Lake Point district the water in deep well (C-2-4)-35cra1 has a lower mineral content than that of well (C-1-4)-35cdd1, but water of better quality is obtained in shallow well (C-2-4)2bdb2 than in well (C-2-4)2bdb1. In the Burmester district there is even greater range in mineral content between adjacent wells of different depths. And according to reports of residents, water from adjacent wells of approximately the same depth may vary greatly in purity.

There is a close relationship between the mineral constituents of the ground water and geologic formations that crop out over the drainage basin from which this ground water is derived, for these rocks have been the source not only of the mineral content of the stream waters, but also of the great debris cones through which the water moves and from which it is obtained in wells. Details of the relationship between these chemical constituents and areal geology in the several ground-water districts are brought out in following paragraphs.

Grantsville district.—The ground water in the Grantsville district is derived chiefly from the drainage basins of North Willow, South Willow, and Box Elder Creeks, all of which include large outcrop areas of the Tintic quartzite, which also constitutes the predominant material of the gravels and boulders of the canyon beds. Waters from most wells have a low mineral content, chiefly of calcium bicarbonate derived from the limestone of the drainage basin. Generally the total hardness is less than 200 parts per million, the chloride less than 100, and the dissolved solids between 200 and 500 parts per million. The area in which these good waters are obtained extends northward nearly to Burmester, and is bounded on three sides by the Burmester district in which well waters are markedly inferior. The Grantsville district thus covers an area where alluvial materials were probably deposited under fresh-water conditions and where ground-water recharge has been largely of pure water from mountain streams.

Erda district.—Ground water in the Erda district is derived from the south, especially from Settlement, Middle, and Pine Canyons near the town of Tooele. The Oquirrh formation, consisting mainly of limestone and quartzite, crops out over the drainage basins of these streams. Most of the waters of the Erda district have a hardness of 150 to 250 parts per million, a chloride content between 100 and 250 parts, and an estimated total mineral content of 400 to 700 parts per million. Thus the waters generally are somewhat more highly mineralized than those of the Grantsville district. The greater hardness is attributed to the higher proportion of limestone in the drainage basin, and the greater concentration of other constituents to the longer distance traveled by the water through alluvial sediments.

Marshall district.—The ground water in the Marshall district is similar in chemical composition to that of the adjacent Erda district and doubtless is derived largely from the same sources. The waters of the Marshall district are obtained from somewhat greater depth, and have temperatures 5 to 10° higher than those prevailing in the Erda district.

Lake Point district.—Here the ground waters are sodium-chloride waters of low to moderate concentration, the dissolved solids ranging from an estimated 900 to 1,500 parts per million, and the chloride from about 300 to 700 parts. The water is derived chiefly from the west slope of the adjacent Oquirrh Range, and moves through strata which evidently contain soluble salts in widely varying proportions. Some waters in the Lake Point district have a hardness of less than 100 parts per million and are thus softer than any others in the valley. In these waters the original calcium and magnesium ions derived from the Oquirrh formation have evidently been replaced by base exchange as the water moved through the alluvial beds, which presumably contain a moderate amount of sodium chloride available for solution. The large springs rising along the fault that forms the west edge of the Lake Point district discharge sodium chloride waters similar to those encountered in wells within the district.

Burmester district.—Most of the ground water of inferior quality in Tooele Valley is obtained in the Burmester district, which includes chiefly the saline flats that extend northward from the Grantsville, Marshall, and Erda districts toward Great Salt Lake. The district lies north of the trace of the Box Elder Canyon fault, and the artesian aquifers are evidently impregnated with salts which are being dissolved by the waters. The Grantsville district also lies on the north side of the fault, and the boundary between it and the Burmester district is taken arbitrarily along section lines, although there appears to be a marked interfingering of aquifers containing waters of poor and good quality. In sec. 32, T. 2 S., R. 5 W., the chloride content of well waters ranges from 110 to 665 parts per million, and the dissolved solids range from about 200 to 1,400 parts per million.

The most highly mineralized waters in this part of the Burmester district, and those having the highest temperature, rise at the head of Three-mile and Six-mile Creeks.

Lake flat along the borders of the ranges.—The Grantsville Warm Springs, in the Burmester district about 4 miles northwest of Grantsville, yield water that is considerably more mineralized than any other well or spring water in the area. The recorded temperature of 85° is more than 10° higher than that of any other water in Tooele Valley, and is more than 25° warmer than most well waters. The water from these springs is similar in composition to the water of Great Salt Lake but considerably less concentrated as shown in the following table:

Analyses of Water in Great Salt Lake and in Grantsville Warm Springs

Quantities are percentages of dissolved solids.

	Great Salt Lake		Grantsville Warm Springs
	1.	2.	3.
Cl	56.21	55.25	58.1
Br	—	T	—
SO_4	6.89	6.73	2.5
CO_3	.07	—	.4
Li	—	T	—
Na	33.45	34.65	34.8
K	?	2.64	1.0
Ca	.20	.16	2.4
Mg	3.18	.57	.6
	100.00	100.00	99.8
Salinity, percent	13.79	27.72	2.95

1. Analysis in 1877. From Clarke, F. W., Data of Geochemistry: U. S. Geol. Survey Bull. 770, p. 157, analysis B, 1924.
2. Analysis in 1904. From Clarke, F. W., Data of Geochemistry: U. S. Geol. Survey Bull. 770, p. 157, analysis F, 1924.
3. Analysis in 1941. See table, p. 204.

Waters from flowing wells and springs within 2 miles of the Warm Springs are warmer and more mineralized than those in the Grantsville district but cooler and fresher than that of the Warm Springs. The concentration and temperature increase more or less proportionately, particularly for waters having a temperature greater than 65°, suggesting that some of the waters having the same source as the warm springs have moved into artesian aquifers and have been diluted by waters from other sources in those aquifers, and that the temperature declines more or less in proportion to the amount of dilution.

Between the Grantsville Warm Springs and the northern tip of the Stansbury Range several springs yield waters that are too highly mineralized for any ordinary use. Just west of the north end of the range the Timpie Spring discharges water that is also highly mineralized. Along the east edge of Tooele Valley also, near the north end of the Oquirrh Range, water issuing from springs has a high mineral content, and several springs around the north end of that range are similar. All these springs issue along the edge of the lake flat where it borders the bedrock ridges of the mountain ranges. They emerge practically at the level of the lake flat and empty into shallow drains that trend northward toward the lake. On page 199 it has been suggested that the source of these springs may be the artesian aquifers under the lake flat and that the opportunities for discharge from those aquifers are probably greater through talus and debris along the rock ridges that jut into the flat than by upward movement through the clay and thence into Great Salt Lake. This explanation is supported by the chemical analyses of water from these springs, for it is unlikely that water of such great mineral content would originate in the mountain areas, since those areas are comprised of the same rocks that crop out farther south where the water is of excellent quality. On the other hand, the aquifers under the lake flat are known to contain highly mineralized waters, encountered in wells (C-2-5)-5aac1 and (C-2-6)11ddd1 and many others in the Burmester district. The waters in these aquifers are under artesian pressure and will come to the surface wherever there is a permeable zone. Permeable zones are evidently formed in the talus which has accumulated at the bases of both mountain ranges as the basin was filled, and now extend downward more or less continuously between the bedrock and the lake beds. The Grantsville Warm Springs may be fed by water rising along such a zone, probably from greater depth than water in other springs.

Water also rises from the artesian aquifers along fault planes. The Timpie Spring is clearly formed thus, and the springs at Six-mile Creek, (C-2-5)26cdc, and Three-mile Creek, (C-2-5)33add, evidently rise along the Box Elder Canyon fault. The waters of these springs are probably derived from aquifers at varying depths, some perhaps considerably more than a thousand feet below the surface, for temperatures range from 59° to 74° F. The springs exhibit a wide range in mineral concentration also, and some springs, such as No. (C-2-6)15dcc, yield relatively pure water. Such variation is to be expected of water derived from sediments accumulated under the variable climatic conditions postulated for the sediments of the valley floor.

INTERFERENCE TESTS OF WELLS IN THE ERDA DISTRICT

Tests to determine interference between wells were made at four wells in the Erda district during 1942. In the Grantsville district the materials of the aquifers are of comparable coarseness and degree of sorting, and it is probable that the extent of interference is comparable to that in the Erda district. In the Marshall district and particularly in the lowest parts of the valley comprising the Burmester and Lake Point districts, it is believed that the sediments are prevailingly finer and the average permeability therefore lower. Wells in these areas generally yield smaller quantities of water than wells having similar diameter and artesian pressure in higher areas. Most of the tests were made on wells reaching the principal aquifer, but some tests were also made to determine the amount of interference caused in wells by discharge from wells tapping a different aquifer. Data collected during these tests are summarized below. Three of the tested wells and most of the observation wells that were used during the tests are located within half a mile of deep well (C-2-4)31dad2, whose log appears on pages 134-137. The following mechanical analyses of driller's samples from that well were made in the laboratory of the Soil Conservation Service in Albuquerque; they show the character of the material of the principal aquifer, and indicate the general texture and heterogeneity of the principal aquifer in the area. In most samples gravel and coarse sand are dominant but several samples are comprised largely of very fine sand.

Mechanical Analyses of Driller's Samples From Principal Aquifer at Well (C-2-4)31dad2

(Analyses by Soil Conservation Service in laboratory at Albuquerque, New Mexico.)

Quantities are in percent by weight.

Laboratory No.	Depth below land surface (feet)	Gravel greater than 2.38mm.	Fine gravel, 2.38—1.19 mm.	Coarse and medium sand, 1.19—.250 mm.	Fine sand, .250—.149 mm.	Very fine sand, .149—.05 mm.	Silt, .05—.005 mm.	Clay, less than .005 mm.
21153	171		2.5	41.8	23.8	30.1	0.7	1.6
21154	175	60.4	2.5	11.2	5.6	12.6	5.9	1.8
21155	177	46.7	3.3	12.6	6.4	15.8	9.4	5.8
21156	182	9.8	0.7	2.6	4.1	36.9	29.8	16.1
21157	184	.0	2.5	16.4	12.5	49.9	13.7	5.0
21158	187	38.5	19.3	19.9	3.1	11.3	4.6	3.3
21159	192	38.0	4.5	15.4	5.0	20.5	13.5	3.1
21160	197	9.3	11.3	39.4	10.4	20.9	6.3	2.4
21161	202	19.4	8.0	45.1	10.3	12.7	2.3	2.2
21162	207	10.6	7.1	16.7	13.9	38.5	9.2	4.0
21163	212	22.6	26.3	44.6	1.7	3.4	0.2	1.2
21164	220	27.9	29.1	29.8	3.0	7.8	1.1	1.3
21165	225	20.1	14.6	23.7	7.2	20.2	10.1	4.1
21166	226	66.1	6.0	11.5	2.4	9.3	3.9	0.8
21167	232	.0	1.8	41.0	22.1	30.1	3.4	1.6

A recording gage was operated on well (C-2-4)31dca1 throughout the period of the tests (March 17 to April 1, 1942). The hydrograph for this period (fig. 5) shows the fluctuations created by the operation of three of the tested wells. In response to each well opening, there is a decline of the water level in the recorder well which begins within 5 to 60 minutes of the opening, a time lag which depends chiefly on the distance to the discharging well. This decline is rapid at first, when the line of the hydrograph may be nearly vertical, then more and more gradual until eventually the trend of the hydrograph approaches parallelism with that established before the well was opened. The recovery curve that results from closing the well is approximately the inverse of this drawdown curve. The rising trend of water level from March 23 to 27 was caused chiefly by the progressive closing of wells rather distant from the recorder, in preparation for the test of well (C-2-4)31add2 on March 27-28. The sharp decline from March 29 to April 1 resulted from opening wells for the 1941 irrigation season. The authorized date for opening was April 1, but five wells in the vicinity of the recorder were opened earlier in order to determine the effect of each individual well. Most of the decline at the recorder occurred as these five wells were opened. When the other wells were opened on April 1 there was a slight additional decline at the recorder, and a reduction of discharge from each of the five wells previously opened.

In these tests the piezometric surface at the recorder well was considered to have reached approximate equilibrium in response to a change in discharge when the hydrograph resumed the trend established before the change. Such an equilibrium was established on March 20 within four hours after well (C-2-4)31dac3 was opened, 200 feet away. Approximate equilibrium appears to have been established also during the test of well (C-2-4)31add2 on March 27-28. On the other hand, the water level was still declining upon cessation of discharge from wells (C-2-4)31acd4 (Mar. 17-18) and (C-2-4)31acd1 (Mar. 22-23). These wells are more distant from the recorder than well (C-2-4)31dac3, and discharged at a greater rate than well (C-2-4)31add2. That the 24-hour period of these two tests was nearly long enough for establishment of approximate equilibrium at the recorder well is suggested by the hydrograph for March 12-14. During this period one of these wells was opened by the owner for about 42 hours, but approximate equilibrium was established during the first 24 hours and the hydrograph thereafter resumed the trend established before the well was opened.

Test of the Vorwaller Well (C-2-4)31add2

The Vorwaller well is 6 inches in diameter and is reported to be 202 feet deep, with casing extending the entire depth and not perforated. Water enters the well from a zone about 30 feet above the base of the principal aquifer, which is about 60 feet thick, according to the log of well (C-2-4)31dad2 one quarter of a mile to the south. The well is used for irrigation, and ordinarily discharges 60 to 120 gallons per minute during the irrigation season.

Prior to the test the static level was measured in 36 wells located within half a mile of the Vorwaller well, and all wells that were flowing within that area were noted. Figure 17 shows smooth contours of the piezometric surface of the principal aquifer based on these measurements, and also the locations of all wells in the vicinity that reach the principal aquifer, including those that were used for observation and those that were observed to be flowing during the test of the Vorwaller well. The piezometric surface slopes northward in the vicinity of the Vorwaller well, with a gradient about 40 feet per mile.

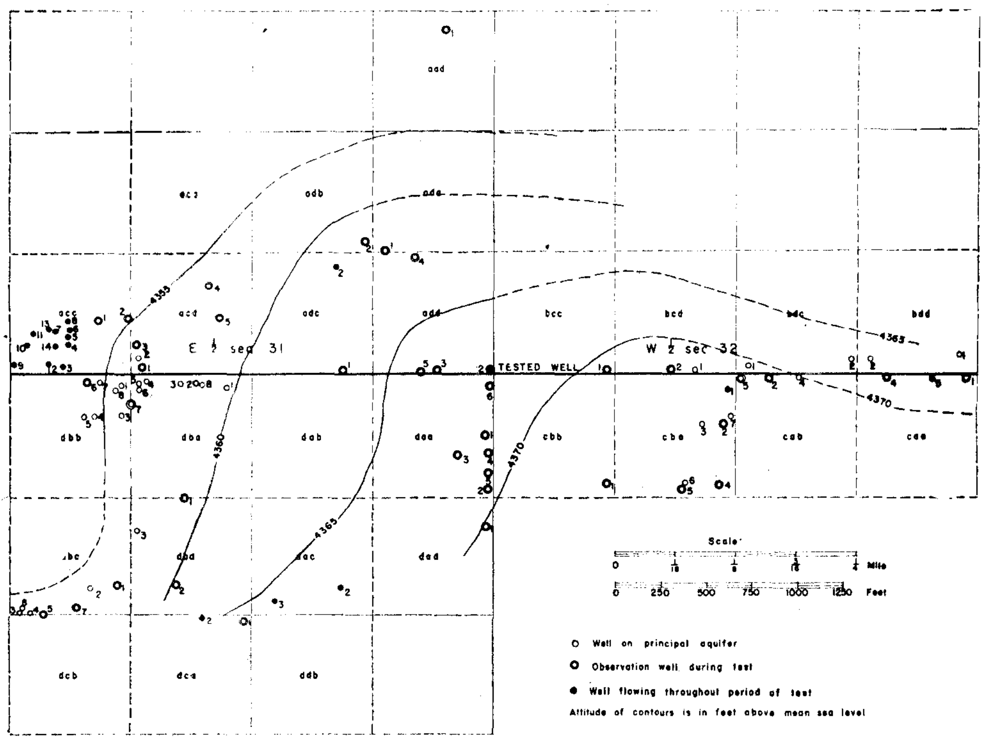


Figure 17.—*Map showing locations of wells on the principal aquifer in the vicinity of the Vorwaller well (C-2-4)31add2, and contours of the piezometric surface on March 27, 1941, prior to test.*

Farther east the gradient appears to be somewhat steeper. Toward the western edge of the mapped area the direction of movement is more westerly because of the discharge of numerous wells. Minor irregularities in the surface may be caused by discharge of other wells (such as Nos. (C-2-4)31dac3, 31dca2, and 32caa5), or by the slight differential head between wells reaching different parts of the principal aquifer. (See p. 176.)

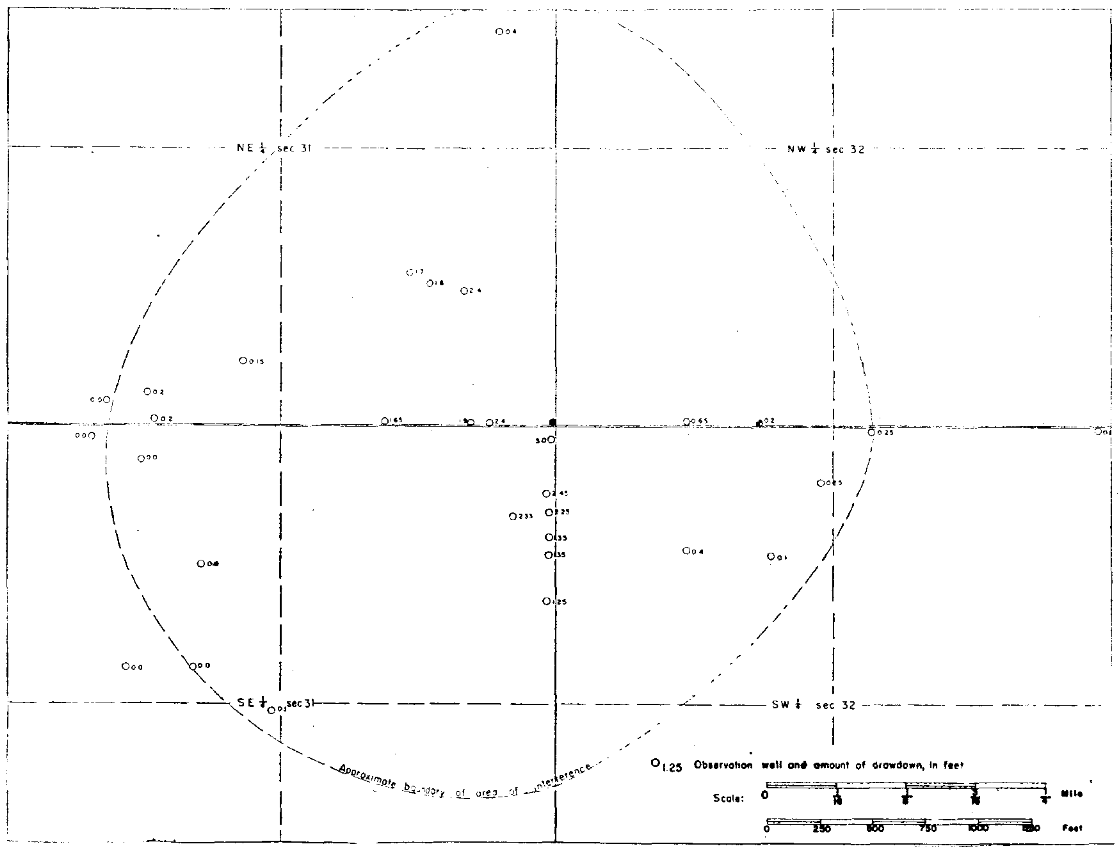


Figure 18.—*Map showing drawdown in observation wells at end of test of well* (C-2-4) 31*add*2.

The Vorwaller well was opened at 5:30 p.m. on March 27 and flowed continuously until 4:15 p.m. on March 28. At the beginning of this 22¾-hour period the well yielded 130 gallons per minute, but the discharge diminished gradually and amounted to only 115 gallons per minute at the end of the test. As shown in figure 5 the water level at well (C-2-4)31dca1 (1900 feet southwest of the tested well) started to decline one hour after the well was opened; dropped 0.07 foot in the next 5 hours, and after 12 hours resumed the trend that had been established prior to opening of the Vorwaller well.

The area of measurable interference is outlined in figure 18. It is rudely elliptical in shape, its long axis having a north-south direction which probably reflects the general elongation of the lenticular alluvial beds deposited by northward-draining streams. The area is asymmetric with respect to the tested well; its southern and eastern boundaries are about a quarter of a mile from the well, but it extends northward and westward more than three-eighths of a mile. Some wells in the eastern part of the area were influenced by discharge of adjacent domestic wells during the test, and the measured drawdown cannot be attributed to the Vorwaller well.

The amount of interference is also illustrated by figure 18. The discharge from the Vorwaller well caused the pressure head to decline more than a foot over an area of about 80 acres, whose boundary was about 500 feet east and about 1,500 feet north of the well. In well (C-2-4)31daa6, which is about 110 feet south of the tested well, the pressure was reduced 5 feet, which is more than a third of the initial pressure head. Had this well been flowing also, the two wells would have interfered mutually with each other, the discharge from the Vorwaller well would have been less, and well (C-2-4)31daa6 would probably have yielded a larger quantity than might be expected from the reduced head.

Test of the Walters Well (C-2-4)31acd1

Well (C-2-4)31acd1 is a 6-inch well reported to be 221 feet deep and cased the entire depth. Water enters the well about 10 feet above the base of the principal aquifer. The well ordinarily yields about 60 to 90 gallons per minute during the summer months when it is used for irrigation.

The well was opened at 10:20 a.m. March 22 and closed at 10:45 a.m. March 23. During this period of 24 hours and 35 minutes the well discharged at an average rate of 195 gallons per minute. The water level in recorder well (C-2-4)31dca1, 1,450 feet to the south, began to drop after 30 minutes, and declined about 0.22 foot during the test (corrected for a barometric fluctuation of +.03 foot). The pressure head of well (C-2-4)31acd3, 320 feet northwest of the discharging well, was reduced from 18 feet to 9.3 feet above land surface by the discharge of the tested well; two-thirds of this decline occurred during the first 30 minutes of the test.

Test of the Walters Well (C-2-4)31acd4

Well (C-2-4)31acd4 is a 6-inch well reported to be 228 feet deep, and water enters the well near the base of the principal aquifer. The well is used for irrigation and flows about 95 gallons a minute during the summer. It was opened at 2:15 p.m. March 17 and closed at 2:50 p.m. the next day. During this period of 24 hours and 35 minutes the average discharge is estimated to have been 130 gallons a minute. During the test and for several hours thereafter periodic measurements were made of the static level in well (C-2-4)31acd5, located 190 feet to the southeast. The pressure head declined from 18.8 feet to 6.15 feet above land surface during the first 20 hours (or less) of the test and thereafter did not change. The decline in this well during the first 10 minutes after the tested well was opened amounted to 10.4 feet. The drawdown curve during the first 30 minutes is appreciably steeper than the corresponding part of the recovery curve, because the initial rate of discharge was greater than the discharge just before the well was closed. In well (C-2-4)31dca1, 2100 feet south of the discharging well, the water level declined 0.19 foot during the 24-hour test.

Tests of Wells on Different Aquifers

Discharge of wells from one aquifer in the Erda district may cause interference in adjacent wells that reach a different aquifer. The amount of interference is small compared to that observed in wells of comparable distance that tap the same aquifer, and is ordinarily not great enough to cause appreciable reduction in flow of the well interfered with, so that well owners are generally unaware of the interference. Nevertheless, such interference between wells of different depths is clearly shown by fluctuations of artesian pressure, particularly in wells equipped with recording gages, and indicates that the sediments that separate the aquifers are somewhat permeable, and that there is movement of water between aquifers as well as along the plane of the individual aquifers.

Wells (C-2-4)28dcb2 and 28dcb3.—Well (C-2-4)28dcb3 is a 4-inch well, 192 feet deep, that reaches the principal aquifer. Well (C-2-4)28dcb2, 110 feet to the north, is 313 feet deep and thus reaches the aquifer that lies about 60 feet below the base of the principal aquifer. The well casing is not perforated, and water enters the well only from the deep aquifer.

Well (C-2-4)28dcb3 was opened at 1:30 p.m. March 25, and allowed to flow for 24 hours and 20 minutes. The discharge was 220 gpm 30 minutes after opening, 170 gpm after 60 minutes, and 150 gpm just prior to closing. Average discharge during the test is estimated to have been 160 gpm. Before the well was opened, the pressure head in the deep well was 30.4 feet above the land surface, and about 7 feet higher than that in the tested well. The water level in the deep well started to decline within 10 minutes after the shallow well was opened, and dropped 0.2 foot during the first 3 hours of the test and 0.4 foot by the end of the 24⅓-hour period of discharge. When well 28dcb3 was closed the static level in the deep well rose for 3 hours, by which time it had almost reached the level observed before the test began.

Wells (C-2-4)31dad2, 31dad1, and 31dca1.—Well (C-2-4) 31dad2 is the deep test well drilled by the Soil Conservation Service between June and December 1941. The drilling was carried to a depth of 730 feet, but no satisfactory water supplies were found in the lower 300 feet; the casing was therefore plugged with cement at 450 feet and perforated 288 to 316 feet below the surface. Thus the well yields water from a stratum whose top is about 60 feet below the base of the principal aquifer. This deep aquifer is reached by less than a dozen wells in the Erda district, one of which is well (C-2-4)28dcb2, discussed above.

The other two wells reach the principal aquifer. No. (C-2-4)31dad1 is 140 feet north-northwest of the test well and has a measured depth of 183 feet. During the drilling of the test well it was equipped with a water-stage recorder. Well (C-2-4)31dca1 is the recorder well that was used in several of the tests of wells on the principal aquifer. Its depth was measured as 214 feet and it is located 1,440 feet southwest of deep well (C-2-4)31dad2. Well (C-2-4)31dad1 evidently reaches a zone about 45 feet above and (C-2-4)31dca1 15 feet above the base of the principal aquifer.

The casing of well (C-2-4)31dad2 was perforated at the horizon of the deep aquifer about noon of December 10, and the well thereafter discharged from that aquifer, the rate of discharge increasing gradually during the afternoon because of surging when the driller used his bailer. The well remained open until December 16, and then was yielding 160 gallons a minute. The well was closed at 3:00 p.m. on that date and remained closed until 3:00 p.m. December 17, when it was reopened. Fluctuations of water level in the two wells on the principal aquifer in response to these changes at well (C-2-4) 31dad2 are shown in figure 19.

The water level in both wells tapping the principal aquifer started to decline when the deep well was perforated, but that in well (C-2-4)31dad1 rose and then fluctuated during the afternoon, doubtless because of surging of the deep well. After 5:00 p.m., when the drillers stopped working and the deep well began to flow steadily, the water level declined rapidly. After the deep well was closed on December 16 the water level in well (C-2-4)31dad1 rose 0.2 foot, and in well 31dca1 0.18 foot. In well 31dad1, which is closest to the deep well, the water level began to rise within 5 minutes of the well closing, then rose about 0.05 foot during the next 10 minutes, and completed the 0.2 foot rise within 2½ hours after the well was opened. Opening of the deep well on December 17 produced a comparable drawdown in both observation wells.

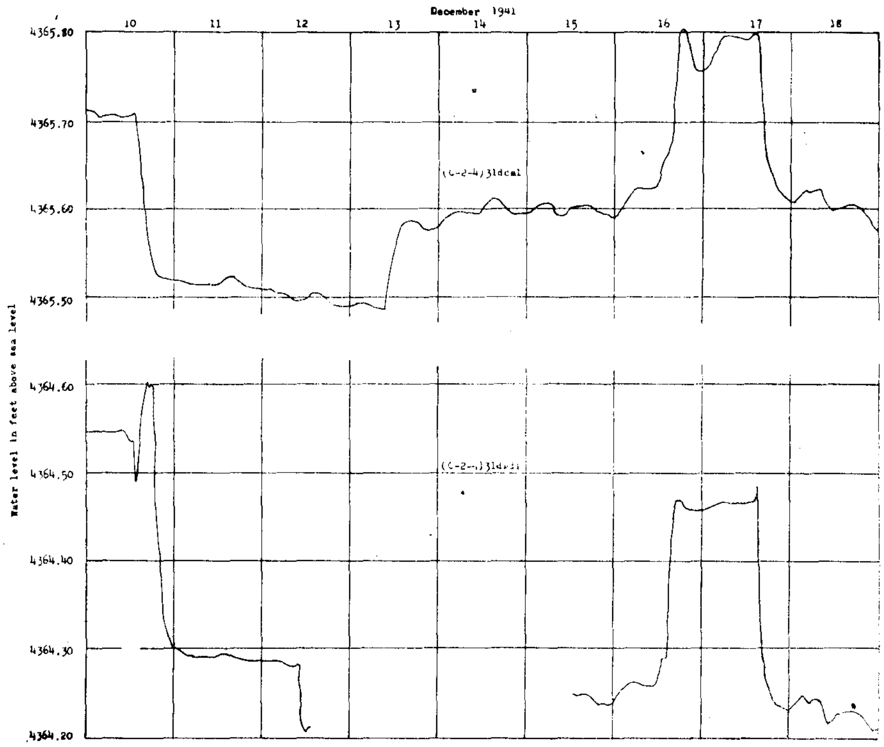


Figure 19.—*Hydrographs of two wells reaching the principal aquifer in the Erda district showing fluctuations caused by discharge from a deeper aquifer.*

The interference caused in wells tapping the principal aquifer by operation of deep well (C-2-4)31dad2 may be compared with that caused by operation of the Walters well (C-2-4)31acd1, which ends in the principal aquifer. The wells used to observe the interference in the two tests are about the same distance from the respective discharging wells. Well (C-2-4)31dad1 is 140 feet from well 31dad2, and well (C-2-4)31acd3 is 320 feet from well 31acd1; the recorder well (C-2-4)31dca1 is about equidistant from both tested wells. There is a striking contrast in the amount of interference measured in the near observation wells, for the head in well 31acd3 was reduced 8.7 feet by discharge of 195 gallons per minute from well 31acd1 which reaches the same aquifer, whereas the head in well 31dad1 declined only 0.2 foot as a result of discharge of 160 gallons per minute from well 31dad2, reaching a deeper aquifer. On the other hand, the water level in the recorder well 31dca1 declined almost as much when deep well 31dad2 was operated as when well 31acd1 was discharging from the principal aquifer.

GROUND-WATER DEVELOPMENT

STATUS OF DEVELOPMENT, 1941

There were about 1,050 wells in Tooele Valley in 1941, nearly all of which are included in the area represented by figure 20. Records for the great majority of these wells, containing information as to ownership, date of completion, size and depth, discharge, use, and equipment, have been submitted by owners and are on file in the office of the State Engineer in Salt Lake City. According to these records, about 630 wells yield water by artesian flow, 160 others have small hand, electric, or gasoline pumps, and 250 are unused or abandoned. The great majority of wells are jetted; most of them have diameters of 2 or 3 inches and fewer than 50 are 6 inches or more in diameter. There are fewer than 30 shallow dug wells in the valley, practically all in the Lake Point district, where several are equipped with windmills.

About 310 wells, including practically all the wells of larger diameters, are used entirely or partly for irrigation. Turbine pumps were used on two wells for this purpose in 1941. A common practice is to collect the flow from one or more wells in a small rectangular reservoir, generally not over 4 feet deep, and then to release this water rapidly in an "irrigating stream" of one or two second-feet.

Most of the wells are within the area of artesian flow, and they are irregularly distributed over this area, as is clearly shown in figure 20. The greatest concentration is in the vicinity of Grantsville, and the grouping around Erda is almost as dense. There are smaller groups of wells in Lake Point and south of Burmester, and a few wells are scattered elsewhere over the valley floor. The number of wells within the several ground-water districts in 1941 was as follows: Grantsville, 477; Erda, 306; Burmester, 198; Lake Point, 45; and Marshall, 16. Most of the wells in the Grantsville district have been used for domestic purposes and for stock, and many of these were not used after the completion of the pipe line from Davenport Canyon and the installation of a municipal distribution system. In the Erda district wells are used primarily for irrigation of cultivated crops. The wells in the Burmester district are of value chiefly for stock-watering and for irrigating small tracts of pasture land around the wells. Most of the wells in the Lake Point district are used for domestic purposes, and hardly any are used for irrigation.

HISTORY OF DEVELOPMENT

In Tooele Valley the first artesian wells were obtained by driving pipes 1¼ or 1½ inches in diameter to the shallowest artesian aquifers, 60 to 100 feet in depth. In the Erda district the oldest wells are reported to be No. (C-2-4)33bba2, driven 70 feet deep about 1885, and (C-2-4)33abb4, driven 90 feet deep in 1887. In the Grantsville area, well (C-2-6)25dbb2 is reported to have been completed to a depth of 210 feet in 1867, but it is more likely that the oldest artesian wells were 1-inch to 1½-inch pipes driven to the shallowest aquifer, similar to those in Erda. Half a dozen such wells, 80 to 110 feet deep, are reported to have been completed by 1885 in the town of Grantsville. As development continued, more and more wells tapped the aquifer that now is the principal producer of water, and the development of this aquifer has continued until quite recently. Occasionally throughout the period of development wells have been drilled to aquifers deeper than the principal aquifer, and the owners of several of these wells have been rewarded by higher artesian pressures and less reduction in discharge during the summer when draft on the principal aquifer is greatest.

The present pattern of ground-water development was well defined at the time of Carpenter's visit in 1911.[42] He noted that there were then two distinct areas of flowing wells, one near Erda and the other at Grantsville, and that the artesian flows were obtained from 2- to 4-inch wells drilled 80 to 300 feet deep at Erda and 90 to 434 feet deep in the Grantsville area. Carpenter also reported that "the wells in both areas have been allowed to flow continuously since their completion, with the result that their yield has greatly diminished." The only successful non-flowing wells reported by Carpenter in Tooele Valley were the dug wells of the Lake Point area.

Although only two wells are currently pumped for irrigation in the valley the practice is by no means a recent innovation. According to available information, well (C-3-5)5aba3 (not used in recent years) was pumped for irrigation as early as 1927, and of the two wells now in use well (C-2-4)35cbb1 was pumped as early as 1928 and well (C-2-4)32cbb1 began pumping in 1933. In recent years there has been little indication of a desire to increase the amount of pumpage for irrigation, perhaps because the water from these pumped wells is considerably more expensive than that from flowing wells or surface streams, which is available in the vicinity.

The dates of construction of about 775 of the known wells in Tooele valley are reported on the underground-water claims made by the owners to the State Engineer. These claims were not made until 1935, and for many wells, particularly the older ones, the reported dates are based on memory and are no doubt considerably in error. A majority of wells whose dates of construction are not reported are old wells, and many of them were probably completed before 1900. On the other hand, where the dates of drilling were known from well drillers' records or other data it was found that the reports based on memory were frequently erroneous in advancing the date of construction several years. Because of these inaccuracies the following summary may be in error as to details

[42]Carpenter, Everett, Ground water in Box Elder and Tooele Counties, Utah: U. S. Geol. Survey Water-Supply Paper 333, pp. 78-79, 1913.

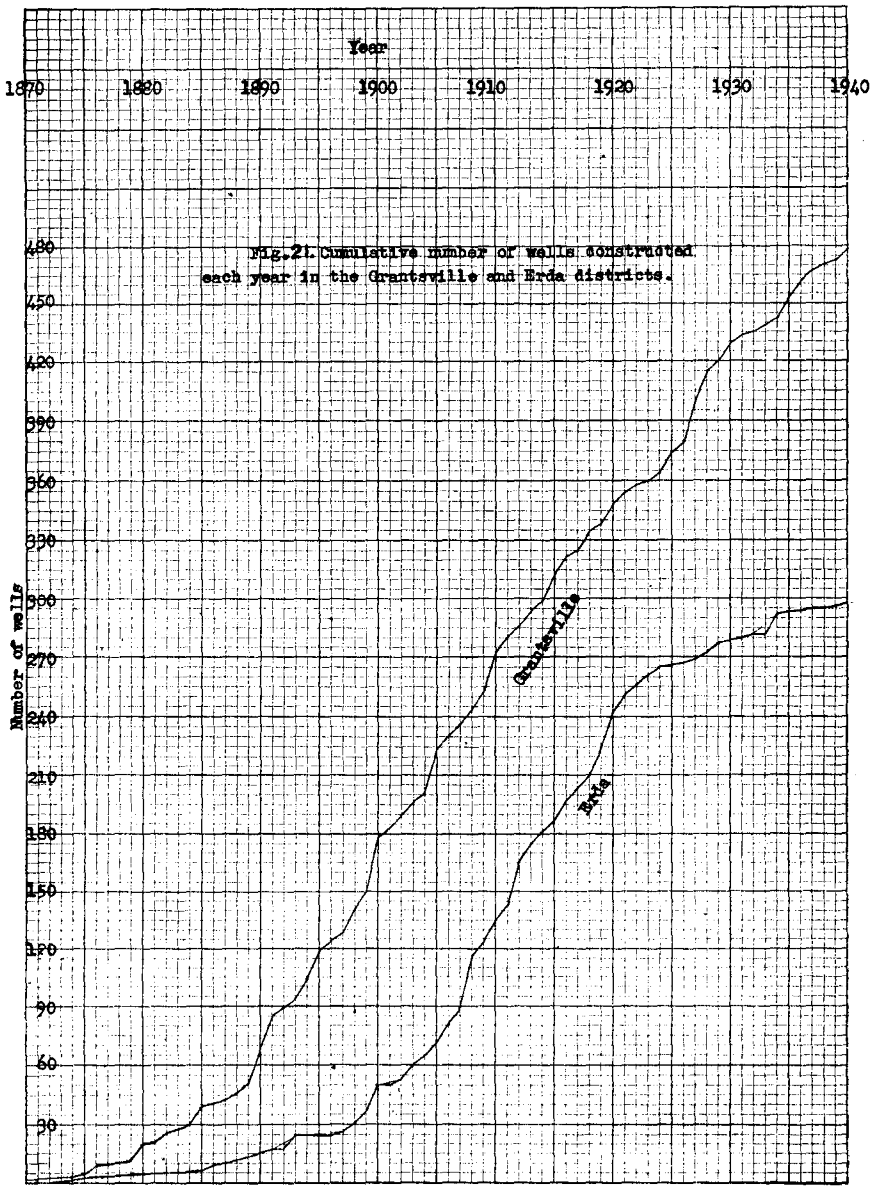


Figure 21.—*Cumulative number of wells constructed each year in the Grantsville and Erda districts.*

although it probably gives a true picture of the general trend of development.

The increase in the number of wells for all purposes between 1870 and 1940 is shown graphically in figure 21 for the two principal ground-water areas. In the Erda district early development was slow, only about 30 wells having been drilled prior to 1898. From 1898 to 1920 the development was fairly steady at the rate of about ten wells per year except for a period of inactivity from 1900 to 1902 and increased development in 1908. Since 1920 only about 60 wells have been drilled in that district. In the Grantsville district development began somewhat earlier, and from 1890 to 1940 the rate of drilling has averaged about eight wells per year. The influence of unusually wet and dry seasons on the number of wells drilled can be noted on the graph since 1920, that is, during the period when it may be presumed that recorded dates of drilling are more nearly accurate. The years 1920 to 1923, inclusive, were wet years in Tooele Valley and there was a marked decrease in the number of wells drilled during these years in both the Erda and Grantsville areas. The increase in number of wells drilled following the dry years of 1924 and 1931 to 1935 is best shown in the graph for the Grantsville area. The apparent increase of construction at the end of each five years prior to 1915 doubtless reflects the rough estimates that have been made concerning the age of the older wells.

CONSUMPTIVE USE FROM WELLS

The best information as to the yield of wells in Tooele Valley and the uses to which this water has been put is obtained from the comprehensive "diversion and use" surveys made by the Utah State Engineer in cooperation with the Federal Works Projects Administration in 1938, 1939, and 1940. During each of these years nearly every well in the valley was visited at least once, the discharge was measured and the beneficial use noted. The results of the surveys have been summarized by the State Engineer as follows:[43]

> "These two surveys (1938 and 1939) have determined the quantities of water used for each of the various purposes, provided a means for evaluating the worth of existing underground-water developments, and furnished sufficient data for the tentative division of many of the State's underground-water areas into basins. The two surveys gave almost identical results regarding both the quantities used for domestic, municipal, miscellaneous, and stock purposes, and the total rate of discharge of all flowing wells; in fact, the maximum difference in these items was only 2.5 per cent. The quantity used for irrigation, however, was 11.5 per cent (about 15,000 acre-feet) higher, and the total rate of discharge of all pump wells was 12 per

[43]Humpherys, T. H., Underground water; in 22d Biennial Report of State Engineer, p. 33, 1940.

Consumptive Use of Water From Wells in Tooele Valley, 1938 to 1940
(Data chiefly from "diversion and use" surveys by Utah State Engineer)

Location			Number of Wells				Yearly Discharge in Acre-feet					
							1938		1939		1940	
T	R	Sec.	Total	Irr.	Dom.	Stock	Irr.	Waste	Irr.	Waste	Irr.	Waste
						Lake Point District						
1S.	4W.	26	1		1		—	—	—	—	—	—
		35	6		2	2	—	—	—	—	—	—
		36	9		6	5	—	—	—	—	—	—
2S.	4W.	1	1		1		—	—	—	—	—	—
		2	25	4	16	12	56	8	57	8	64	8
		3	1		1		—	—	—	—	—	—
		10	1		1		—	—	—	—	—	—
		11	1				—	—	—	—	—	—
Total			45	4	27	19	56	8	57	8	64	8
						Erda District						
2S.	4W.	17	4			2	—	20	—	13	—	14
		20	6	1		1	5	10	5	7	7	7
		21	6	1	2	2	3	—	2	—	2	—
		22	3		1	1	—	—	—	—	—	—
		27	12	1	2	3	6	—	5	—	5	—
		28	72	37	10	14	1423	200	1677	100	1861	75
		29	31	10	5	12	71	15	37	17	58	5
		30	8	1		4	2	10	2	12	3	10
		31	87	48	4	7	814	150	821	130	712	130
		32	40	28	6	6	441	100	460	80	546	75
		33	35	7	3	5	205	—	343	—	190	—
		35	2	1		1	—	—	203	—	85	—
Total			306	135	33	58	2970	505	3555	359	3469	316

Consumptive Use of Water from Wells in Tooele Valley (continued)

Location			Number of Wells				Yearly Discharge in Acre-feet					
							1938		1939		1940	
T	R	Sec.	Total	Irr.	Dom.	Stock	Irr.	Waste	Irr.	Waste	Irr.	Waste
						Marshall District						
2S.	5W.	25	9	1		1	—	4	—	4	—	4
		35	2				—	12	—	10	—	10
		36	5		2	3	—	—	—	—	—	—
Total			16	1	2	4	—	16	—	14	—	14
						Grantsville District						
2S.	5W.	7	31	8	10	9	88	44	110	36	77	15
		18	4	1	1	2	—	5	—	1	—	—
		19	9	2	2	3	10	7	12	2	10	—
		30	22	8	3	11	45	19	32	15	14	10
		31	163	12	101	77	67	34	68	41	102	4
		32	70	28	17	29	370	288	364	37	388	—
2S.	6W.	24	20	1	6	5	3	13	—	23	7	—
		25	43	12	9	24	123	55	143	85	234	25
		26	3	2		3	4	6	2	4	—	—
		36	83	9	35	30	163	—	177	1	103	—
3S.	5W.	5	10	1	2	7	—	—	27	—	38	—
		6	16		4	2	—	—	—	—	—	—
3S.	6W.	1	3		2	1	—	—	—	—	—	—
Total			477	84	192	203	873	471	935	245	973	54

Consumptive Use of Water from Wells in Tooele Valley (continued)

Location			Number of Wells				Yearly Discharge in Acre-feet					
							1938		1939		1940	
T	R	Sec.	Total	Irr.	Dom.	Stock	Irr.	Waste	Irr.	Waste	Irr.	Waste
						Burmester District						
2S.	4W.	16	3			1	—	2	—	2	—	2
		18	2				—	4	—	4	—	4
		19	2			1	—	25	—	25	—	22
2S.	5W.	5	24	15	3	5	54	49	56	50	43	50
		6	10	7			28	20	18	20	7	15
		8	14	8	3	2	56	34	22	17	18	7
		13	1	1		1	2	24	1	—	—	—
		14	3	1	1	2	3	14	8	—	6	—
		17	4	2	1	2	27	18	2	26	—	28
		22	1	1		1	4	12	6	13	4	14
		23	5	5			49	—	54	—	63	—
		24	4	1	2		—	15	1	19	—	15
		27	19	2	1	2	70	15	78	19	71	—
		28	18	14	2	5	197	10	129	65	222	—
		29	21	3	1	2	7	11	1	10	1	10
		33	39	17	5	15	269	35	200	100	253	25
		34	7	4	1	2	27	9	43	12	38	10
3S.	5W.	4	1			1						
2S.	6W.	11	1				—	2	—	2	—	2
		15	4			4	—	50	—	50	—	50
		23	15	7	2	4	43	25	33	19	26	10
Total			198	88	22	50	836	374	652	453	752	259

Consumptive Use of Water from Wells in Tooele Valley (concluded)

Location	Number of Wells				Yearly Discharge in Acre-feet					
					1938		1939		1940	
	Total	Irr.	Dom.	Stock	Irr.	Waste	Irr.	Waste	Irr.	Waste
					Summary					
Lake Point District	45	4	27	19	56	8	57	8	64	8
Erda District	306	135	33	58	2970	505	3555	359	3469	316
Marshall District	16		2	4	—	16	—	14	—	14
Grantsville District	477	84	192	203	873	471	935	245	973	54
Burmester District	198	88	22	50	836	374	652	453	752	259
Total	1042	313	276	334	4735	1374	5199	1079	5258	651
Total yield of wells, estimated					6700		7000		6400	

of 1938 to 1940, and because several wells for which comparative measurements are available had a lower rate of discharge in 1935 or 1936 than in 1938, it is inferred that the total yield of wells in the valley in the later years of the drought was probably less than from 1938 to 1940.

Prior to 1931 the number of wells in the valley was less than during the past decade, but there was nevertheless a general decline in artesian pressures. During some of these years precipitation was excessive and it is probable that runoff of the canyon streams as well as recharge to the subterranean reservoir was greater than normal. Since it is considered that the discharge of 6,500 to 7,000 acre-feet from wells in 1938 to 1940 (when precipitation was slightly less than normal) was approximately equivalent to the recharge, it is likely that the total discharge from wells may have been considerably greater than 7,000 acre-feet during many of the earlier years, even though the number of wells was smaller. The same conclusion is suggested by the records that have been assembled by Messrs. Volney Crocheron, L. T. Liddell, and Franklin Whitehouse in the Erda district, where practically all irrigation is from wells. According to these records the maximum area irrigated in the Erda district in the past has been of the order of 1,300 acres. In recent years, the irrigated area in that district has been only about 1,000 acres. In part a larger annual discharge in earlier years may have been accomplished by allowing wells to flow continuously whether used or not, a practice which was rather general prior to the passage of the 1935 ground-water law.

POSSIBILITY OF FUTURE DEVELOPMENT OF THE GROUND-WATER RESERVOIR

During the years 1938 to 1940 the annual yield of wells and springs in Tooele Valley is estimated to have been at least 26,000 acre-feet, of which about 6,500 acre-feet was from wells and 19,500 acre-feet from springs. The total discharge from the reservoir was considerably greater than this, because of the losses by evapo-transpiration from the valley. Adequate data have not been collected as to the evapo-transpiration losses, but it is suggested that these losses may be of the order of magnitude of the aggregate flow from wells and springs, or about 25,000 acre-feet annually.

The total recharge to the ground-water reservoir in Tooele Valley in these three years must have been approximately equivalent to the total discharge, for the quantity stored at the end of the period was practically the same as at the beginning (p. 194). During the three years the precipitation over the State as a whole was about 14 per cent above normal, but at Tooele it was 24 per cent less than normal. On the basis of the record of this single station within the drainage basin it is considered that the long-term average recharge to the valley may be somewhat greater than the recharge from 1938 to 1940.

artesian flow is unprofitable for farming, and if water now lost by springs and by movement toward Great Salt Lake is to be recovered, it will probably be by pumping on lands above the area of artesian flow.

Burmester district.—This is the chief area of natural disposal of ground water in the valley, and large quantities are lost by transpiration, evaporation, and discharge from springs along the edge of the valley. The water in the artesian reservoir in this district is believed to be discharged at least in part by the springs near the edge of the district. The few farmers who are utilizing artesian water from wells in certain parts of the district are to be commended in their successful use of the water. The land is generally too poor for cultivation, however, and no great increase in ground-water development is foreseen.

Erda District.—In the Erda district the water used from wells prior to 1941 was ordinarily 3,000 to 4,000 acre-feet a year. No surveys have been made to determine the total discharge from wells in the district since that year, but an exceptional rise of artesian pressures has been noted (p. 192), and it is likely that the quantity yielded in 1945 was appreciably greater than in 1940. This rise in artesian pressure is ascribed partly to recharge by water from the Elton tunnel, which is used for irrigation of lands two to five miles south and southeast of Erda. From 1940 to 1942 the flow from this tunnel was greater than the total discharge of wells in the Erda district, and a considerable proportion has obviously penetrated to the ground-water reservoir in that district. Since 1943 the annual flow from the tunnel has been fairly constant, although appreciably less than in earlier years, and the recharge from this source to the Erda district is assumed also to have reached a fairly uniform rate. It is considered that this additional source has gone a long way toward offsetting any overdevelopment of the district, and may even be sufficient to supply a few additional wells.

The amount of water wasted in the district is comparatively small, perhaps 300 to 500 acre-feet from wells and a negligible quantity from springs. By thorough conservation much of this waste could be eliminated, for many wells are permitted to waste water because owners are negligent or are unwilling to take the initiative in closing their wells while the wells of their neighbors continue to flow. Some wells waste large quantities of water by leakage outside the casing, and this waste cannot be eliminated until the well is plugged and sealed or otherwise brought under control.

Water in the Erda district not discharged by wells or springs moves northward into the Burmester district, where significant natural losses occur by evapo-transpiration. Recovery of this water within the Erda district could be accomplished by increasing the draft upon wells so that the slope of the piezometric surfaces and therefore the rate of northward movement would be reduced. This greater withdrawal could be accomplished by pumping, but because of interference that would be caused, adjacent wells would cease flowing and the entire Erda community would eventually be forced to install pumps. Thus, a greater quantity of water could be developed by resorting to pumps, but the cost of water would be far greater than the supply now obtained from flowing wells. Whether the value of the additional water obtained would justify the cost of pumping all the water used in the district is a problem of vital concern to all the land owners and water users in the district. Unless the members of the community are willing to bear this cost, the district is near the limit of economic development, and the quantity of water available for beneficial use can be increased only by the elimination of waste from wells. The need for thorough conservation in this district is thus apparent.

Deep aquifers yield water by artesian flow which can serve land in the Erda district too high to be irrigated from wells drawing on the principal aquifer, from which most of the present water supplies are obtained. Insofar as the higher land is more suitable for agriculture, greater benefits might be obtained if wells on the principal aquifer near the edge of the area of artesian flow were replaced by wells on deeper aquifers. However, such deep wells would not develop a new and independent water supply, for the deep aquifers are not completely separated from the principal aquifer. Therefore, it is to be expected that production from the principal aquifer will decline as that from deeper aquifers increases.

Marshall district.—There are no natural losses of ground water in the Marshall district except by discharge from spring areas along Three-mile and Six-mile Creeks at the north edge of the district. Except for a very small quantity discharged by wells, the rest of the ground water in the district crosses the Box Elder Canyon fault and enters the Burmester district. Several wells have been drilled within the area of artesian flow to depths greater than 300 feet and their yield is very small, so that that area offers dubious prospects for obtaining satisfactory irrigation wells. Wells drilled by the Army for the Tooele Ordnance Depot, in the southern part of the district, have yielded ample water from excellent aquifers, but the water table in that area is so far below the land surface that the pumping lift is nearly 400 feet, which is excessive for irrigation under present economic conditions. North of the ordnance depot, the piezometric surface is at progressively decreasing depths below the ground, but aquifers can be expected to have increasing amounts of fine material and hence poorer yield. Prospects for satisfactory pumped wells in this district are best in the northern part of T. 3 S., R. 5 W., but these prospects are still only fair.

Grantsville district.—In the Grantsville district about 1,000 to 1,400 acre-feet of water is discharged annually from wells, and approximately the same amount is discharged from springs. Commonly 100 to 500 acre-feet of the flow from wells is estimated to be wasted each year, and most of the discharge from springs is also wasted. As in the Erda and Marshall districts, water not discharged from wells or springs within the Grantsville district moves northward into the Burmester district.

The natural losses from the Grantsville district are believed to occur chiefly from artesian aquifers, and can best be eliminated by lowering the pressure head of those aquifers, which may be accomplished by pumping. Pumping for irrigation is essential if the maximum economic development is to be reached, because it will make available some of the water that will otherwise be wasted from springs within the Grantsville district, and will also result in decreased rate of movement northward to the Burmester district.

The water supplies available to the Grantsville district could be used more efficiently if there were some trading or other redistribution of existing rights to surface and ground waters. The South and North Willow Irrigation Companies currently furnish water to numerous tracts of land that are within the area of artesian flow. Excess irrigation of these tracts, as well as seepage losses from the ditches serving the tracts, contribute to the shallow water above the artesian aquifers which moves northward toward Great Salt Lake and is eventually discharged by evapo-transpiration. This shallow water is commonly mineralized somewhat and in any event is available only in areas where the land is generally unsuitable for cultivation. A more effective use of the available water supplies would result if lands within the area of artesian flow (or perhaps the slightly larger area of economic pumping lift) were irrigated entirely from wells, and water from streams were used only on higher areas. Seepage from excess irrigation or from ditches would then be available in large part for recharge to the artesian reservoir from which the wells at lower elevations obtain their water.

EXPLANATION

Sedimentary and igneous rocks

QUATERNARY

RECENT

- **Qd** — Dunes (*Silt and sand, highly permeable.*)
- **Ql** — Lacustrine deposits (*Evaporites, clay, and silt, impregnated byzsoluble salts and saturated at shallow depths.*)
- **Qal** — Alluvium (*Boulders, gravel, sand, and silt moderately to highly permeable.*)

PLEISTOCENE

- **Qb** — Lake Bonneville beds (*Gravel, sand, and cobbles of ancient shore features along edges of valley; sand, silt, and clay in central part of valley; coarser materials extremely permeable.*)
- **Qt** — Alluvial terraces (*Boulders, gravel, sand, and silt, highly permeable.*)
- **Qm** — Glacial moraines (*Angular to sub-rounded boulders, cobbles, gravel, and finer materials, relatively permeable.*)

PLEISTOCENE (?) AND PLIOCENE

- **QTsl** — Salt Lake formation (*Water-worn boulders, gravel, and sand, commonly consolidated, somewhat permeable.*)

TERTIARY

PLIOCENE

- **Tb** — Basalt (*Medium-gray, dense to scoriaceous basalt, impermeable except along joints and certain vesicular zones.*)

MIOCENE

- **Tst** — Tuff (*Fluviatile tuff, sand grains to boulders, moderately permeable.*)
- **Tsa** — Agglomerate (*Latite breccias and flows, and tuffs, relatively impermeable.*)

EOCENE

- **Tw** — Wasatch formation (*Firmly cemented fanglomerate relatively pervious.*)

CARBONIFEROUS

PERMIAN AND PENNSYLVANIAN

- **Co** — Oquirrh formation (*Quartzite and limestone, impermeable except for a few zones.*)

PENNSYLVANIAN AND MISSISSIPPIAN

- **Cm** — Manning Canyon shale (*Shale, shaly limestone, and quartzite, impermeable.*)

- **CCu** — Undifferentiated Paleozoic rocks (*Chiefly limestone, some dolomite, shale, and quartzite; cavernous limestones are chief permeable zones.*)

CAMBIAN

LOWER CAMBRIAN

- **Ct** — Tintic quartzite (*Metaquartzite with conglomeratic zones toward base, permeable only along bedding planes and fractures.*)

Principal shore-lines of Lake Bonneville: B, Bonneville; P, Provo; S, Stansbury (dotted where covered, destroyed, or indeterminable.)

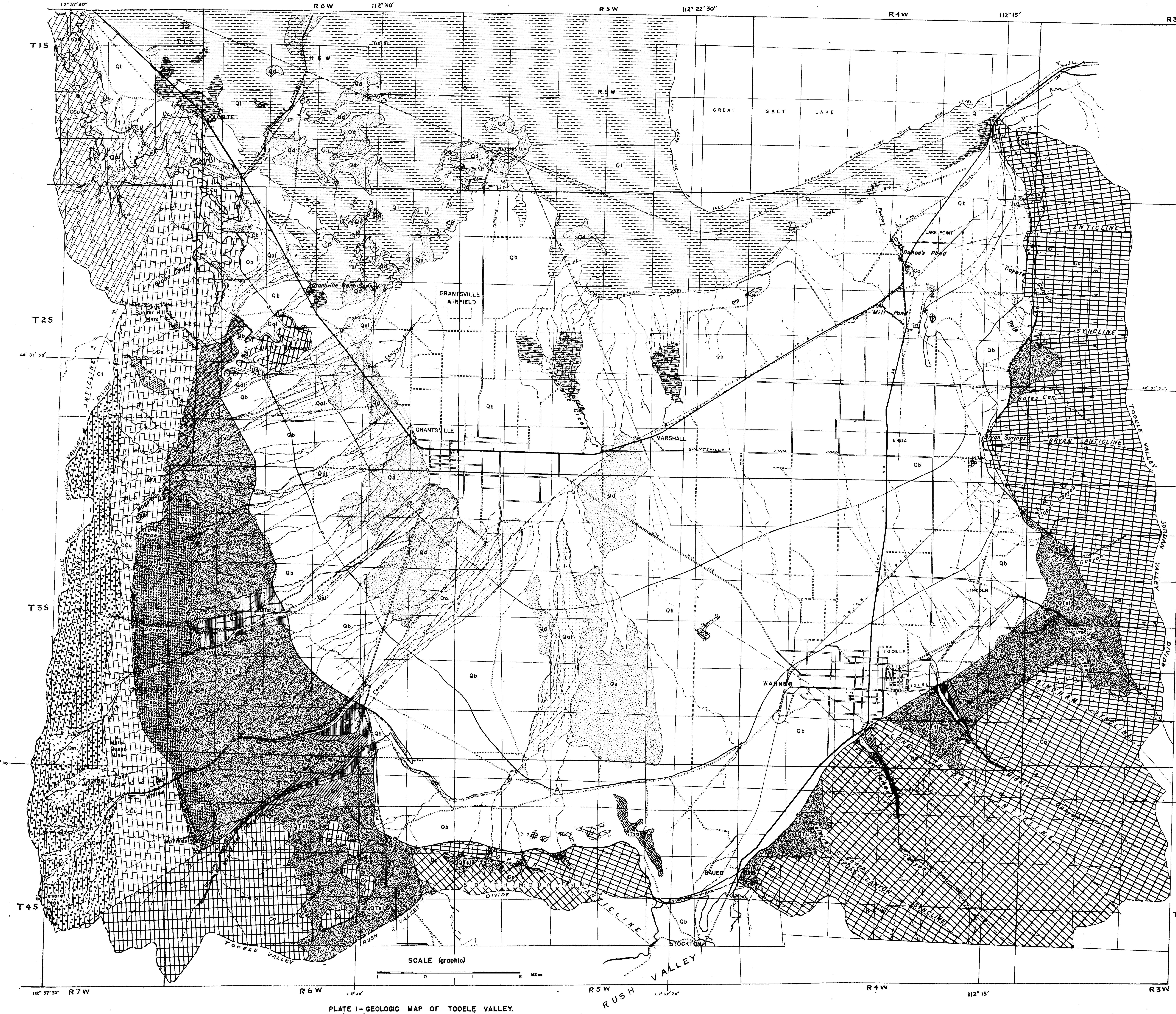
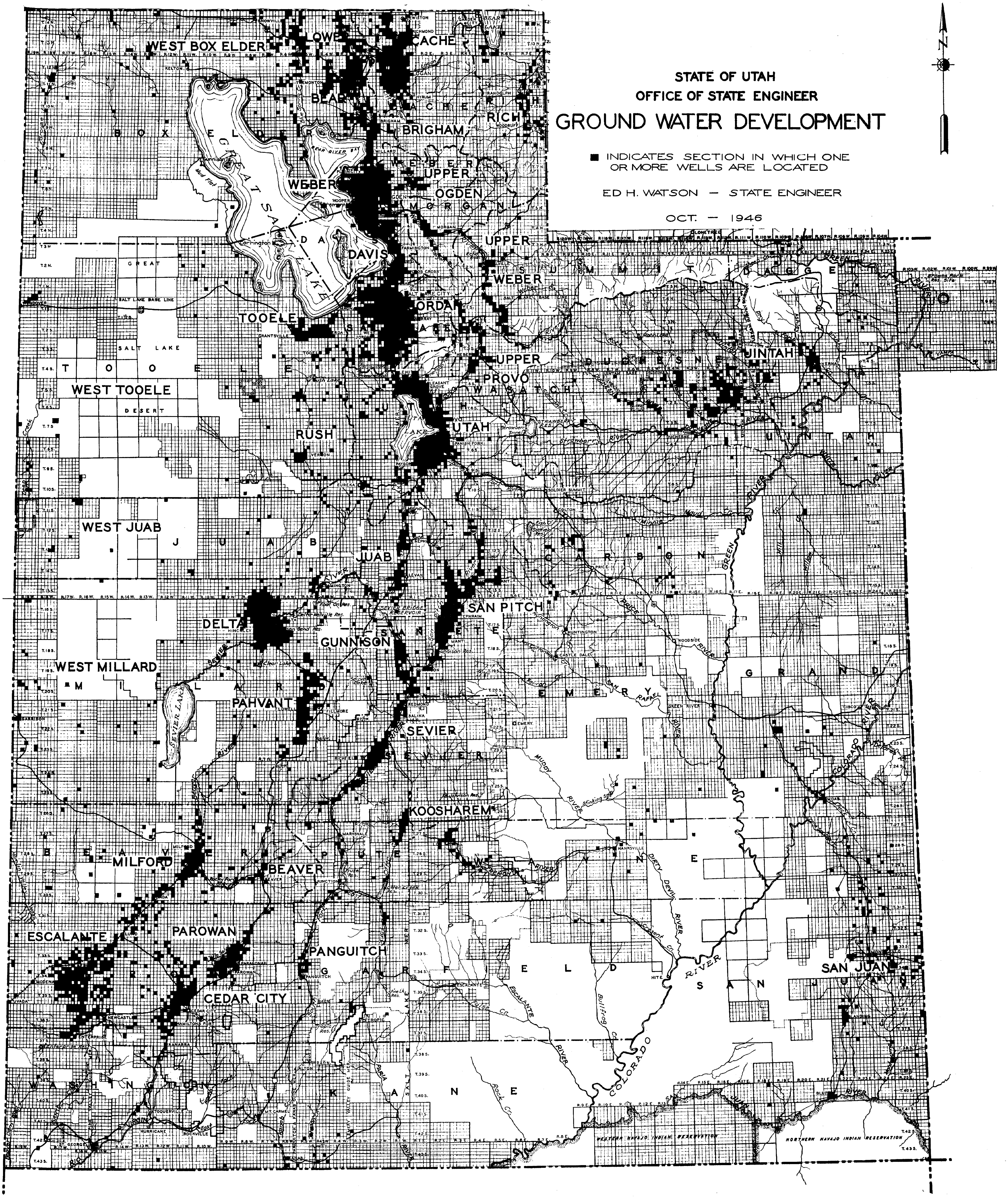


PLATE 1 – GEOLOGIC MAP OF TOOELE VALLEY.


STATE OF UTAH
OFFICE OF STATE ENGINEER
GROUND WATER DEVELOPMENT
■ INDICATES SECTION IN WHICH ONE OR MORE WELLS ARE LOCATED
ED H. WATSON — STATE ENGINEER
OCT. — 1946
N
WEST BOX ELDER
LOWER
CACHE
BEAR
BRIGHAM
RICH
WEBER
UPPER
OGDEN
DAVIS
UPPER
WEBER
JORDAN
TOOELE
UPPER
PROVO
UINTAH
WEST TOOELE
RUSH
UTAH
WEST JUAB
JUAB
DELTA
SAN PITCH
GUNNISON
WEST MILLARD
PAHVANT
SEVIER
KOOSHAREM
MILFORD
BEAVER
ESCALANTE
PAROWAN
PANGUITCH
CEDAR CITY
SAN JUAN
GREAT SALT LAKE
BOX ELDER
TOOELE
JUAB
CARBON
DUCHESNE
SUMMIT
DAGGETT
WASATCH
MORGAN
MILLARD
SANPETE
EMERY
GRAND
BEAVER
PIUTE
WAYNE
IRON
GARFIELD
WASHINGTON
KANE
SAN JUAN
COLORADO RIVER
GREEN RIVER
SEVIER LAKE
UTAH LAKE
SALT LAKE BASE LINE
WESTERN NAVAJO INDIAN RESERVATION
NORTHERN NAVAJO INDIAN RESERVATION