STATE OF UTAH

E. H. WATSON, State Engineer

TECHNICAL PUBLICATION NO. 5

GROUND WATER IN THE EAST SHORE AREA, UTAH

PART I: Bountiful district, Davis county

By H. E. Thomas and W. B. Nelson

Prepared in cooperation with the
UNITED STATES DEPARTMENT OF THE INTERIOR
Geological Survey

W. E. WRATHER, Director

GROUND WATER IN THE EAST SHORE AREA, UTAH
PART I. BOUNTIFUL DISTRICT, DAVIS COUNTY

Contents

Page

Abstract 59

Introduction 63
  Geography 63
  Purpose and scope of investigation 64
  Acknowledgments 65

Climate 67

Physiography 73

Geology 75
  Previous work 75
  General relations 76
  Geology of the tributary watershed area 83
  Stratigraphy of the Bountiful district 84
    Pre-Cambrian rocks 84
    Tertiary system 84
      Eocene (?) series 84
        Wasatch (?) formation 84
      Pliocene (?) series 85
        Salt Lake formation 85
    Tertiary (?) and Quaternary systems 87
      Pliocene (?) and Pleistocene series 87
        Pre-Lake Bonneville alluvium 87
    Quaternary system 97
      Pleistocene series 97
        Lake Bonneville beds 97
          Shore deposits of "Intermediate" stage 99
          Shore deposits of Bonneville stage 101
          Shore deposits of Provo stage 102
          Recessional shore deposits 105
          Lake-bottom deposits 105
      Pleistocene and Recent series 109
        Post-Lake Bonneville torrential deposits 109

Contents

Page

Geology—continued
- Recent series 111
  - Deposits of Great Salt Lake 111
  - Delta deposits and alluvium of Jordan River 112
  - Historic torrential deposits 112
- Structure 114
  - Basin and Range faulting 115
    - Warm Springs fault 115
    - Limekiln fault 117
    - Frontal fault 118

Hydrography 119
- Records of stream discharge 119
- Total surface inflow to the Bountiful district 123
- Usable surface outflow from the Bountiful district 126
- Precipitation runoff relationships 127

Geochemistry 131
- Chemical character of ground water east and north of the upper Bonneville canal 133
- Chemical character of ground water west of the upper Bonneville canal 133
- Significance of chemical constituents in utilization of water 140

Ground water hydrology 143
- General relations 143
- Water in the bedrock 144
- Water in the valley fill 145
  - Ground water east of the upper Bonneville canal 146
    - Fluctuations of water level in wells 146
    - Water table 152
    - Source, movement, and disposal of ground water 154
  - Ground water west of the upper Bonneville canal 155
    - Fluctuations of water level and artesian pressure 155
      - Seasonal fluctuations 156
      - Long-term fluctuations 160

Page

Ground water hydrology—Continued
    Piezometric surfaces 163
        Differential head of wells in aquifers of different depths 163
        Piezometric surfaces of Lake Bonneville beds 166
        Piezometric surfaces of pre-Lake Bonneville alluvium 167
            Shallow artesian aquifer 167
            Intermediate artesian aquifer 171
            Deep artesian aquifer 172
    Average annual changes of water level as indicative of changes in storage 172
    Interference among wells 175
        Test of the Security Investment Company well 177
        Test of the Smith well 178
        Test of the Burnham wells 178
        Miscellaneous tests 179
    Sources of ground water 181
    Movement and natural discharge of ground water 183
Ground-water development 186
    History 186
        Well construction 186
        Annual discharge from wells 188
            Well-discharge measurements 188
            Relation of well discharge to changes in storage and to total inflow 191
            Relation of well discharge to natural discharge 195
    Status in 1946 196
    Water supplies for future requirements 198
        Reduction of waste and natural losses 199
        Artificial recharge 200
        Importation of water 205

Illustrations

Plate Page

1. Geologic map of the Bountiful district........................In pocket
2. Piezometric surface of the shallow artesian aquifer in April 1946, and water table east of the upper Bonneville canal 153

Figure Page

1. Areas covered by ground-water investigations in Uath...... 62
2. Precipitation at Farmington, Utah, 1900-46 72
3. Generalized geologic map and profiles of the watershed area tributary to the Bountiful district 74
4. Geologic section west from Centerville (A-A′ on pl. 1).... 93
5. Geologic section west from Bountiful (B-B′ on pl. 1)...... 94
6. Geologic section through South Bountiful (C-C′ on pl. 1) 95
7. Geologic section along base of the Wasatch Range (D-D′ on pl. 1) 96
8. Geologic section north from North Salt Lake (E-E′ on pl. 1) 97
9. Data pertaining to water samples collected for chemical analysis 141
10. Hydrographs of nine wells east of the upper Bonneville canal 147
11. Hydrograph of the Lemon well (B-2-1)36bbd-1 for May 1936 155
12. Seasonal fluctuations of water level or artesian pressure in 12 wells during 1946 and 1947..................................157
13. Fluctuations of water level or artesian pressure in six wells from 1931 to 1947 161
14. Differential head in three groups of artesian wells.............165
15. Profiles of piezometric surfaces west from Bountiful in 1946 169
16. Profiles of piezometric surfaces along Woods Cross road in 1946 170
17. Piezometric surface of the intermediate artesian aquifer in April 1946 171
18. Relation of recharge opportunity and well discharge to storage in the artesian reservoir 192
19. Irrigated areas in the Bountiful district 197
20. Areas of recharge and discharge of ground water.................204

GROUND WATER IN THE EAST SHORE AREA, UTAH

By H. E. Thomas and W. B. Nelson

ABSTRACT

The Bountiful district in Davis County, Utah, less than 10 miles from the heart of Salt Lake City, is rapidly becoming an integral part of the metropolitan area of Salt Lake City. It cannot achieve the development that its location merits unless the present water supplies are increased. The district is a fertile agricultural area favorably situated between the largest cities in the intermountain area and athwart the major routes of transportation and communication, but development of its residential, industrial, and agricultural potentialities will be restricted until existing water resources are supplemented by importation from other drainage basins that now have surplus water supplies. This conclusion is reached in the accompanying report by the Geological Survey, prepared in cooperation with the Utah State Engineer and the Davis County Water Users Association, and based on a 2-year investigation of the existing water supplies.

All the streams entering the Bountiful district from the adjacent Wasatch Range are small, the largest being less than 7 miles long. The total discharge of these streams is estimated to average about 24 second-feet, or 18,000 acre-feet a year. This water, which constitutes the major source of ground water and surface water for irrigation in the Bountiful district, has long been insufficient to meet requirements. For the past 26 years water of poor quality has been pumped from the Jordan River for irrigation of lands near the city of Bountiful, and in recent years about 4,000 acre-feet has been pumped annually. From 11,000 to 15,000 acre-feet of water has been obtained annually from the 1,440 wells and water tunnels in the district, mostly by artesian flow, although there are about a dozen pumped municipal, industrial, and irrigation wells and scores of smaller wells that are pumped for domestic supply. This ground water

comes from a reservoir that is recharged chiefly by seepage from stream channels and irrigated lands, supplemented by precipitation upon the eastern part of the district.

Although it is evident that a large proportion of the water that flows into the Bountiful district is being used, there are several opportunities to conserve water and thus increase the beneficial use of existing supplies. Measurements of surface water flowing through the district show that 2,000 to 6,000 acre-feet has been lost in recent years to Great Salt Lake, chiefly during the spring runoff from melting snow. None of the tributary streams has suitable reservoir sites, and if this water is to be utilized it must be stored in the underground reservoir, which would require diversion into the recharge areas for the artesian aquifers. Also, many flowing wells waste considerable quantities of water, some by failure of their owners to cap them when not being used beneficially and some because of faulty well construction which permits water to leak around the well casing. The quantity wasted from flowing wells amounted to about 2,000 acre-feet in 1946. Much of this water could be saved for beneficial use at comparatively small expense. Finally, a considerable amount of water is lost from the artesian reservoir each year through springs and by upward movement in the western part of the district, where it evaporates or is transpired by salt grass and associated plants. In order to reduce this loss it would be necessary to lower the artesian head in aquifers by pumping. Thoroughgoing measures of conservation might increase the water available for beneficial use by as much as 5,000 acre-feet in an average year.

Study of the geology of the area shows the effect of a most spectacular geologic process upon the ground-water reservoir. This process, the destructive mud-rock flows that result from cloudburst bloods, has been witnessed by present inhabitants. In 1930 debris as much as 12 feet thick was deposited over the fertile lands near the mouths of several canyons as the result of intense summer rainstorms upon steep mountain slopes, where deep soils have developed in past geologic ages. Similar deposits have accumulated in a belt along the base of the range for a long time, and are more than 750 feet thick at one well site. These torrential deposits are characteristically unsorted and relatively impermeable, and wells drilled in this belt commonly yield little water. Thus conditions in the Bountiful district contrast with those found near Salt Lake City, Ogden, and elsewhere along the base of the Wasatch Range, where wells have produced abundant water supplies from sites in similar topographic positions. Because of the relative impermeability of the torrential deposits, little water is added to the ground-water reservoir where they occur at the surface; the bulk of recharge to artesian aquifers occurs farther west and at greater distance from the mountains.

The Bountiful district was inundated by ancient Lake Bonneville, and the shore lines of that lake are prominent along the eastern margin of the district. Permeable beds of gravel and sand deposited along these shores yield water to water tunnels, drains, and wells in the bench lands east of Bountiful. The artesian wells farther west, however, obtain water from gravel and sand beds deposited by streams prior to the existence of Lake Bonneville. Clay and silt were deposited on the bottom of the lake upon these alluvial beds, and confine the water under sufficient pressure to flow from wells.

The western base of the Wasatch Range is marked by a fault zone 2 to 3 miles wide, in which displacement with upward movement on the east side has been chiefly responsible for the present height and steep west slope of the range. There has been movement along at least three individual faults within this zone since the recession of Lake Bonneville. This movement has left escarpments as much as 75 feet high, has increased the gradients of tributary streams, and no doubt has contributed to the volume and extent of mud-rock flows below the escarpments. Warm springs rise along the westernmost escarpment, and farther north small quantities of warm saline water are contributed to the artesian reservoir along the fault.

The water pumped from the Jordan River has a high mineral content, and is notably different from other waters in the Bountiful district. Wells west of the upper canal yield waters similar to that of the canal and indicate that the canal water has moved as much as 2½ miles westward through aquifers as much as 200 feet deep. It is concluded that the lands irrigated by the upper Bonneville canal are within the recharge area for those aquifers, and that not only the canal water but the precipitation, water applied from streams for irrigation, and the seepage from cesspools and septic tanks in the residential areas of Bountiful and Val Verda serve to recharge the artesian reservoir.

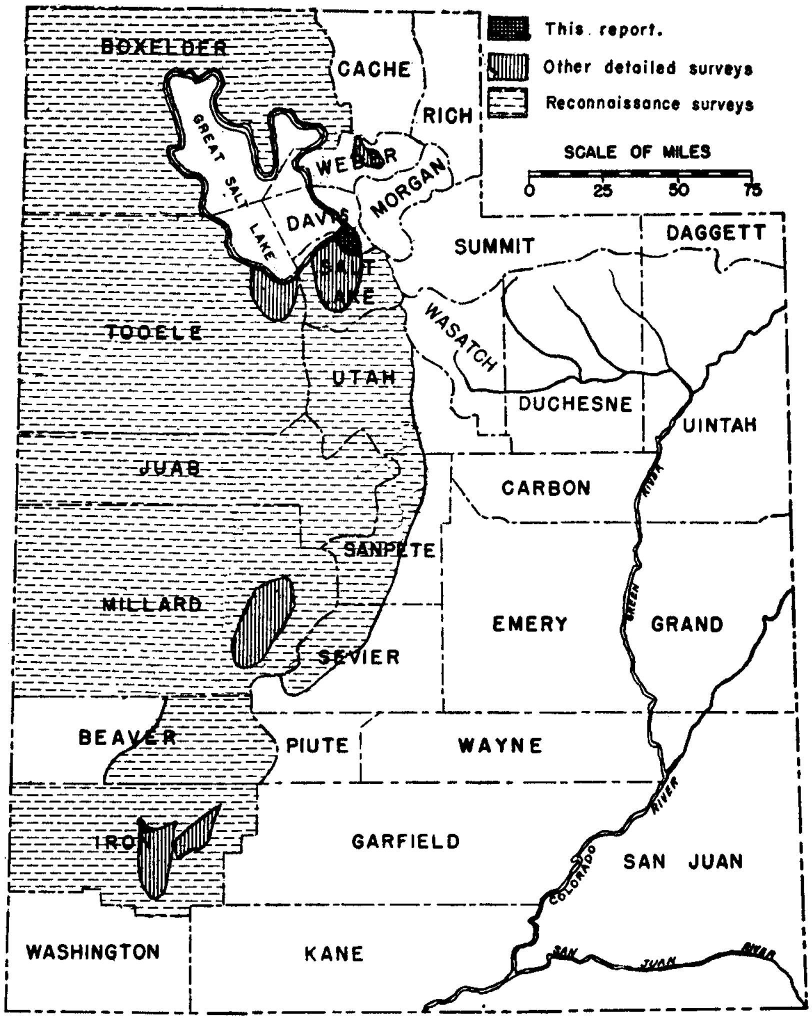


Figure 1.—*Area covered by ground-water investigations in Utah.*

GROUND WATER IN THE EAST SHORE AREA, UTAH

Part I. Bountiful District, Davis County

INTRODUCTION

One of the most populated and productive areas in the State of Utah lies along the east shore of Great Salt Lake in the north-central part of the State, between the mouths of the Jordan River and the Bear River. The economy of this area is heavily dependent upon the water supplies, which are derived principally from streams draining the Wasatch Range which borders the area on the east. Throughout the area ground water also yields a considerable proportion of the supplies for irrigation and domestic use, and constitutes the chief source of water for several municipalities, industries, and military installations.

The East Shore ground-water area is bordered on the north by the Lower Bear River Valley and on the south by the City Creek spur of the Wasatch Range, beyond which lies the Jordan Valley, in which Salt Lake City is situated. The East Shore area is a well-defined ground-water unit, in which the principal sources are the streams that head in the Wasatch Range or farther east, and movement is generally westward toward Great Salt Lake. Wells obtain water from the unconsolidated gravel and sand beds of the valley fill, and in the lower western part of the East Shore area this water is under sufficient artesian pressure to flow at the land surface.

For the purpose of describing the ground-water conditions, the East Shore area may conveniently be divided into three districts: The Bountiful district in Davis County, including that part of the East Shore area lying south of Farmington Bay; the Weber delta in Davis, Weber, and Box Elder Counties, extending from Farmington Bay to Bear River Bay of Great Salt Lake; and the Brigham district of Box Elder County, extending north from Bear River Bay to the lower Bear River Valley. The occurrence of ground water in the Bountiful district is the subject of the present report.

Geography

The Bountiful district of the East Shore area (fig. 1) lies immediately north of the north limit of Salt Lake City. Its south boundary coincides with the Davis and Salt Lake County line, which follows the crest of the City Creek spur of the Wasatch Range westward to the Jordan River, and then extends northward along that river to its mouth in Great Salt Lake. The district is bordered by the Wasatch Range to the east, and extends north to Farmington Bay of Great Salt Lake, the north boundary being set at the north edge of Township 2 North, Salt Lake Base and Meridian. As defined in this report, the Bountiful district has an area of 40 square miles, a length from north to south of 8½ miles, and a width ranging from 2 miles at its north and south ends to about 7 miles in its central part.

The population of the district in 1940 was about 6,500, of which 3,357 lived in Bountiful, the largest town, and 691 in Centerville, the only other incorporated place. Since 1940 the population of the district has increased considerably, owing to its favorable location as a suburban residential area close to Salt Lake City, and the population of Bountiful alone was estimated by city officials to be about 5,300 in 1947. The district is traversed by all the main lines of communication between Salt Lake City and Ogden, including the Union Pacific and the Denver & Rio Grande Western Railroads, the Bamberger Electric Railway, U. S. highways 89 and 91, and several power-transmission lines.

Purpose and Scope of Investigation

The rapid increase of population in the Bountiful district has caused much concern over the availability of water to satisfy the increased needs, on the part of the established agricultural users of water as well as the newcomers and the officials of the city of Bountiful, where much of the increased population has settled. The short canyons that drain this portion of the Wasatch Range yield only small surface supplies, which, except for peak flows from the spring freshets, have long since been entirely appropriated for beneficial use. Ground water has thus been recognized as the only possible source of additional water, and applications for 55 new wells to serve more than 300 new homes have been filed with the State Engineer in the past three years.

The investigation of the ground-water resources of the Bountiful district constitutes one of a series that are being made in the important ground-water areas of Utah by the United States Geological Survey in cooperation with the State Engineer. Available cooperative funds during and immediately after the war were insufficient to undertake this research, and its accomplishment is due largely to the Davis County Water Users Association, at whose suggestion the City of Bountiful and the Davis County Commissioners contributed supplemental funds amounting to

$1,000 each, which, when matched with an equal amount of Federal funds, financed much of the detailed work. Messrs. Delore Nichols and Joseph W. Johnson, respectively president and secretary of the Davis County Water Users Association, deserve special credit for the consummation of the present investigation.

Records of water levels and artesian pressures in the Bountiful district have been obtained since 1935,[1] and a detailed investigation of the occurrence of ground water in a small area around Woods Cross was made in 1936 by G. H. Taylor and H. E. Thomas, as a part of the State-wide cooperative program. Intensive field work for the current investigation was begun in April 1945 by P. E. Dennis, and was continued from January 1946 to June 1947 by W. B. Nelson and R. G. Butler, under the general direction of H. E. Thomas. Max Erickson assisted in the preparation of the geologic map during the summer of 1947. The field work included one or more measurements of water level in each of about 420 wells, and measurements of the discharge from 583 of the 1,310 wells in the district; maintenance of 14 water-level recorders on wells for periods of a year or more; location and measurement of discharge of wells, drains, springs, and other features of importance to hydrologic study; and several tests to determine the extent of interference among discharging wells in the district. The field program and preparation of this report were under the general supervision of O. E. Meinzer, geologist in charge of the Ground Water Division of the Geological Survey, and since Dr. Meinzer's retirement in December of 1946, A. N. Sayre, the present geologist in charge. Colleagues of the Geological Survey have reviewed parts of the report and offered many helpful suggestions.

Acknowledgments

Published and unpublished data from several previous investigations have been studied by the writers, and have permitted a more comprehensive analysis than would otherwise have been possible. The State Engineer, since the passage of the ground-water law in 1935, has obtained detailed information concerning the wells in the area, including descriptive data provided by the owners, well-drillers' reports on wells drilled since 1935, locations and elevations of bench marks established at most wells, and measurements of artesian pressures and flow of many wells

---

[1] Meinzer, O. E., Wenzel, L. K., and others, Water levels and artesian pressures in observation wells in the United States: U. S. Geol. Survey Water Supply Papers 817, pp. 351, 362-380; 840, pp. 527-530; 845, pp. 575-579; 886, pp. 790-795; 910, pp. 59-62; 940, pp. 54-56; 948, pp. 57-59; 990, pp. 57-59; 1020, pp. 74-76; 1027, in preparation.

during the years 1937 to 1941. William Peterson, formerly director of the Extension Service in Utah for the U. S. Department of Agriculture, provided a tabulation showing discharges of flowing wells throughout the district during the summer of 1932. Detailed information concerning the soils and water supply on the D. M. Hunter farm in Sec. 34, T. 2N., R. 1 W., was provided by the Soil Conservation Service of the Department of Agriculture.

The Davis addition of the Wasatch National Forest has been the scene of intensive research by the Intermountain Forest and Range Experiment Station of the Forest Service. Studies have been made of the precipitation, slope, and runoff relationships; terracing, reseeding, and replanting of the watershed area tributary to the Bountiful district and to Farmington Creek, which drains an area somewhat farther north; and artificial recharge of ground water in the vicinity of Centerville. Topographic maps of this portion of the Wasatch Forest, streamflow records of certain streams, and climatologic data collected in connection with these studies have been of especial value in the current investigation, and the cooperation of Reed Bailey, Director of the Experiment Station, and of G. W. Craddock and A. R. Croft is sincerely appreciated.

The writers appreciate the interest and cooperation of the residents of the district in the investigation and wish to thank all who provided information or assistance during the field work and special tests. Thanks are due especially to the Kirkland Nursery, Wasatch Oil Refining Co., and Messrs. T. A. Briggs, W. E. Cheney, John Coombs, J. W. Foster, C. R. Gull, Herbert Haacke, Will Holbrook, Ray Knighton, W. S. Lemon, George Mann, Frederick Riley, and T. Q. Williams for permission to operate recording gages for extended periods on wells owned by them; to Dean Toone, City Engineer, Wilfred Williams, City Recorder, and Blaine Mills, Water Superintendent of Bountiful, for data on water spreading and other information; to Perry Burnham, Albert Thalmann, and others of the South Davis Water Users Ass'n., for well logs and information; to Joseph Lee & Sons for logs and other data on wells drilled by them. The writers also appreciate the splendid cooperation and valuable suggestions of Ray E. Marsell, professor of geology at the University of Utah, who accompanied them in the field on many occasions and otherwise aided in the studies.

CLIMATE

The climate of the Bountiful district is temperate and semiarid, typical of the area bordering the west front of the Wasatch Range. At Salt Lake City the average annual temperature is about 52° F., with recorded extremes of -20° and 105° since the beginning of record in 1874.[2]. During the frost-free growing season, which ordinarily includes the 5 months from May through September, the wind velocity averages 7 to 10 miles per hour, the percentage of sunshine ranges from 65 to 80, and the relative humidity is low, commonly dropping below 30 per cent during most days of midsummer; the rate of evaporation from water and moist land surfaces, plants, and animals is accordingly high.

Precipitation is probably least in the western part of the district, where it may average about 15 inches a year, comparable to that at the nearby Salt Lake airport. Eastward and northward the precipitation increases, and the average annual precipitation at Farmington, beyond the north limit of the district, has been 20.28 inches between 1900 and 1946. In the Wasatch Range east of and tributary to the Bountiful district, the precipitation increases generally with increasing altitude. At the Rice Canyon station maintained by the Forest Service at an altitude of 7,000 feet, the precipitation is generally more than twice that at Farmington.

Comparison of precipitation records of 14 stations in Davis and Salt Lake Counties shows that precipitation increases more or less in proportion to increasing altitude, orographic differences probably accounting for most of the small variations at stations of similar altitude. The precipitation for 5 years is tabulated below for these stations, in order of increasing altitude, and it appears that the annual precipitation increases about 6½ to 8 inches for every 1,000-foot increase in elevation. It is noteworthy that the precipitation at the two stations in Davis County is consistently higher—commonly 20 to 40 percent higher—than at stations at comparable altitudes in Salt Lake County; also, the northernmost station in Salt Lake County, Highline City Creek, consistently records more precipitation than do others at comparable altitudes. The lesser precipitation in Salt Lake County suggests that the Oquirrh Range may cast a rain shadow over the area southward from the City Creek spur of the Wasatch Range. Because of the likelihood that the precipitation at Salt Lake City is generally less than that farther north, the record at

---

[2] Greening, G. K., Meteorological summary, Salt Lake City, 1874-1946; U. S. Dept. Commerce, Weather Bur., 8 pp., 1947.

Annual precipitation at stations in vicinity of Bountiful district

(Records from U. S. Weather Bureau)

Station	Altitude (feet above sea level)	Distance from Bountiful (miles)	Annual rainfall (inches)					5-year average 1942-46	47-year average 1900-46
			1942	1943	1944	1945	1946		
			Davis County						
Farmington	4,270	6 N	21.33	15.83	20.92	23.72	20.01	20.36	20.28
Rice Canyon	7,000	7 NE	45.55	34.59	35.96	51.95	43.32	42.27	
			Salt Lake County						
Salt Lake Airport	4,220	9 SW	13.28	10.90	18.49	17.71	15.51	15.18	
Salt Lake City	4,350	9 S	16.12	12.81	18.87	18.82	16.51	16.62	15.99
Red Butte No. 1	4,950	10 SE	24.50	20.62	24.28	21.32	19.66	22.07	
Lower Mill Creek	4,960	15 SE	21.95	17.21	25.85	25.65	22.43	22.61	
High Line City Creek	5,300	6 S	26.22	22.23	26.27	28.35	26.60	25.94	
Red Butte No. 2	5,400	9 SE	22.86	19.46	22.90	24.32	22.36	22.38	
Mountain Dell	5,500	13 SE	21.73	20.74	20.34	27.20	22.95	22.60	
Red Butte No. 5	5,750	8 SE	28.20	26.19	29.60	32.24	28.70	28.99	
Red Butte No. 3	5,800	9 SE	29.96	26.87	29.01	35.03	28.68	29.91	
Red Butte No. 4	6,200	9 SE	32.22	28.06	30.13	35.77	29.93	31.22	
Red Butte No. 6	7,200	9 SE	30.49	28.87	31.57	37.70	31.34	32.00	
Silver Lake	8,700	26 SE	39.89	47.16	44.55	51.05	40.08	44.54	

Farmington is considered to be more representative of conditions in the Bountiful district.

The distribution of precipitation throughout the year at Farmington is irregular, as shown in the accompanying table. Since 1900 there have been totals exceeding 4 inches in each month except June, July, and September, and there have also been totals of less than 0.5 inch in every month of the year. The average monthly rainfall has been about 2 inches during the months from December to May (fig. 2) when precipitation generally occurs in storms of low to moderate intensity. During the summer months, from June to September, the precipitation is an inch or less per month on the average. In this season convectional storms, with high-intensity rainfall for short periods (the so-called cloudburst type), are common, though not so frequent as in southern Utah, Arizona, and New Mexico, where a large proportion of the annual rainfall occurs in summer cloudbursts.

The annual precipitation at Farmington since 1900 has ranged from 13.52 inches in 1933 to 27.17 inches in 1916, with an average of 20.28 for the 47 years. The wettest period was from 1906 to 1909, when an excess of 19.5 inches was accumulated. The driest period of record was from 1928 to 1935, when the accumulated deficiency was 28.7 inches. Although this later drought period is by far the most vivid in the recollection of the present population, precipitation records from other localities in northern Utah indicate that a longer and probably more intense drought cycle occurred from 1879 to 1904, when the accumulated deficiency amounted to 11.2 inches at Salt Lake City and 76.5 inches at Ogden. It is likely that the wettest period in the 100 years since the first Mormon pioneers entered Utah occurred prior to the period of available climatic records, probably during the 1860's, for Great Salt Lake in 1873 reached its highest recorded level—a level presumably higher than it had reached in several decades and possibly in several centuries prior to that date (see p. 111). Other evidence concerning the climate during the centuries before the beginning of historic records has been obtained from tree-ring analysis throughout the Colorado Basin.[3] Schulman concludes from these studies that: "Since A. D. 1300, the interval of most severely dry conditions and low runoff seems to have occurred in 1573-1593, when the average deficiency was well below that of the recent, generally dry intervals 1879-1904 and 1931-1940."

---

[3] Schulman, Edward, Tree-ring hydrology of the Colorado River Basin: Arizona Univ. Bull., vol. 16, no. 4, p. 48, Oct. 1, 1945.

Monthly Precipitation at Farmington, Utah—1900-1946

(Records from U. S. Weather Bureau)

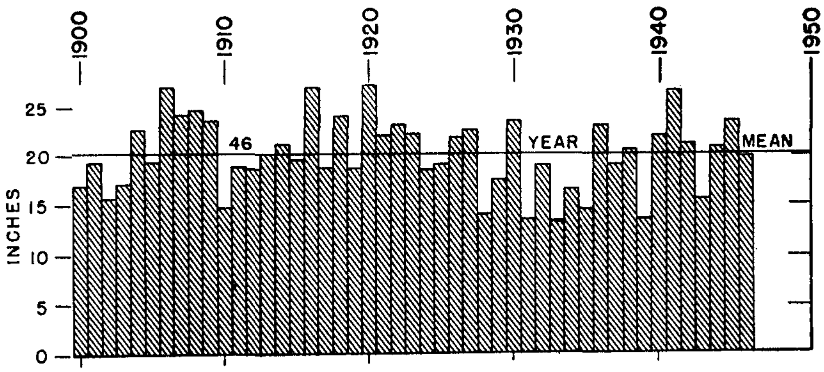
Date	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1900	*1.25	2.45	.44	4.56	.78	.25	T	.22	1.90	*2.05	*2.80	.33	17.03
1901	1.19	3.31	1.63	.65	4.77	.41	T	.91	.99	2.20	1.20	2.19	19.45
1902	1.65	1.89	1.73	2.91	2.11	.17	.95	.34	T	.32	1.73	1.92	15.72
1903	3.76	.86	1.59	1.81	3.45	.10	T	.20	.88	1.44	1.86	1.37	17.32
1904	2.51	3.59	5.26	2.82	3.05	.50	.86	.58	.03	2.02	.00	1.57	22.79
1905	1.47	2.02	4.18	2.08	2.80	.33	1.05	.52	1.91	.06	1.34	1.67	19.43
1906	2.38	2.56	3.72	*2.05	4.47	2.18	T	3.20	1.49	.30	2.35	2.39	27.09
1907	3.43	5.26	3.25	.28	3.02	2.00	.34	1.53	.10	1.07	.58	3.48	24.34
1908	1.51	1.75	1.91	.69	5.18	3.47	.09	1.14	2.62	3.31	1.86	1.15	24.68
1909	3.25	2.86	1.74	1.53	3.11	T	.57	.94	1.39	1.18	3.07	4.05	23.69
1910	2.70	1.85	.83	1.34	.17	T	1.66	.02	.91	1.97	1.16	2.24	14.85
1911	4.82	2.42	1.45	2.03	.74	.56	.11	.00	.86	2.30	1.63	2.03	18.95
1912	.32	.62	4.04	3.00	*3.00	.80	1.52	1.52	.41	1.60	1.30	.65	18.78
1913	2.18	2.16	3.67	1.99	.78	2.30	T	.31	1.40	1.00	.68	3.70	20.17
1914	3.12	1.75	1.06	4.80	.23	3.51	2.33	.03	.27	2.57	.40	1.28	21.35
1915	1.31	2.71	1.26	2.44	2.98	1.25	.00	.00	*2.50	.00	3.87	1.39	19.71
1916	3.37	1.57	3.00	1.89	.31	.95	.95	2.70	1.83	5.59	.41	4.60	27.17
1917	2.41	3.39	3.29	1.62	2.39	T	1.67	T	1.55	.10	1.71	.73	18.86
1918	5.90	1.77	2.04	1.41	2.55	.37	1.11	.08	3.26	2.01	2.85	.69	24.04
1919	.16	3.33	.86	1.91	*1.75	*.15	*.75	*.20	2.01	3.44	*1.90	2.48	*18.94
1920	*.46	*1.50	*4.75	*3.40	*2.00	*.20	.81	1.23	2.46	4.64	2.86	1.95	*27.30
1921	2.03	2.06	1.63	4.96	2.41	.53	.60	.78	.70	1.85	.97	3.57	22.09
1922	1.18	2.70	2.10	2.51	1.62	1.20	2.16	3.37	T	.52	3.17	2.69	23.22
1923	2.96	.32	1.29	4.59	1.88	1.62	.14	1.67	1.94	2.55	2.27	1.22	22.45
1924	.76	.75	2.68	.72	2.01	.65	.54	.53	.81	1.76	1.66	5.72	18.59
1925	1.08	1.72	1.97	2.25	1.74	2.28	1.78	.88	1.76	.53	1.75	1.49	19.23

Monthly Precipitation at Farmington, Utah—1900-1946

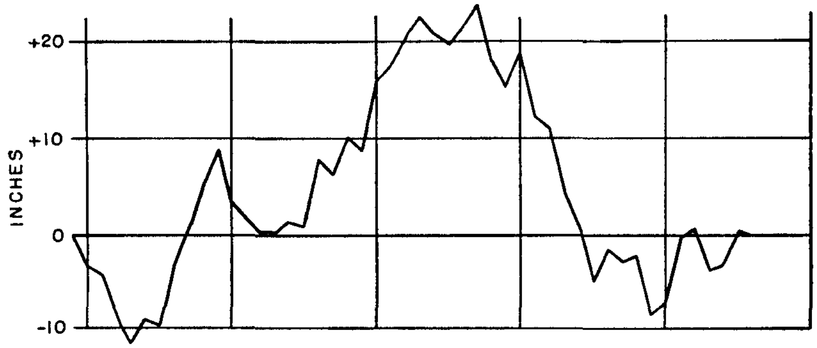
(Records from U. S. Weather Bureau)

Date	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1926	1.65	4.32	.88	1.95	2.79	.15	2.03	1.53	2.67	.77	2.10	1.10	21.94
1927	1.22	2.37	2.39	2.24	3.83	.75	.00	.53	2.31	1.23	4.30	1.47	22.64
1928	1.09	.35	2.87	1.78	1.96	.52	.75	.26	.10	1.23	2.23	1.19	14.33
1929	2.36	2.05	3.25	4.06	.17	.75	.50	.10	2.86	.88	.05	.63	17.66
1930	2.45	2.54	1.51	*2.10	2.71	.87	1.42	3.34	2.31	2.33	1.40	.74	23.72
1931	.86	.96	1.73	1.57	1.89	.04	.50	1.07	.47	.82	1.76	2.01	13.68
1932	2.08	2.19	2.02	3.65	1.28	1.53	.30	2.44	T	.25	1.05	2.37	19.16
1933	2.59	1.45	1.54	1.88	3.06	T	.08	.99	.29	.59	.30	.75	13.52
1934	2.33	2.73	.81	.65	.02	1.00	1.07	.21	.76	1.28	3.25	2.63	16.74
1935	.66	1.28	1.87	2.45	4.03	.14	T	.50	.33	.36	1.51	1.58	14.71
1936	4.27	4.66	1.26	1.04	.85	2.00	1.16	.95	.15	2.68	1.50	2.87	23.39
1937	2.96	2.64	1.41	2.23	1.23	.06	.68	.60	1.10	2.95	1.26	2.10	19.22
1938	.79	1.31	5.24	2.05	1.80	.86	.57	.13	.32	3.04	2.07	2.65	20.83
1939	2.15	1.14	1.18	1.67	1.30	1.94	.17	.19	1.24	1.74	T	.98	13.70
1940	4.57	3.59	2.09	2.11	.05	.59	1.04	T	1.61	1.70	2.12	2.60	22.07
1941	2.46	2.07	2.69	4.34	1.74	2.43	1.74	1.02	.67	2.59	2.17	2.84	26.76
1942	2.82	2.21	2.09	2.28	3.50	.19	.19	.76	1.43	.56	2.42	2.88	21.33
1943	.97	1.93	1.15	1.45	.58	3.42	.13	.63	.05	4.12	.18	1.22	15.83
1944	1.92	*1.30	3.10	5.02	1.77	3.41	.14	.03	.67	.13	2.19	1.34	21.00
1945	.58	2.88	2.60	1.26	1.17	3.51	.01	4.76	.82	.76	3.32	2.05	23.72
1946	1.45	.17	1.65	1.99	3.97	.09	.24	.46	.45	5.36	2.50	1.68	20.01
Average 1900-1946	2.11	2.16	2.23	2.30	2.10	1.06	.70	.92	1.16	1.74	1.77	2.00	20.28

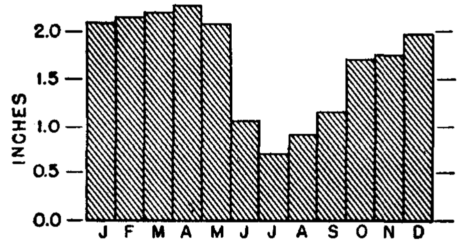
*Estimated



Annual precipitation



Cumulative departure from average precipitation



Average monthly precipitation

Figure 2.—*Precipitation at Farmington, Utah,* 1900-46

PHYSIOGRAPHY

The East Shore area lies along the eastern edge of the Great Basin section of the Basin and Range physiographic province, and the Wasatch Range to the east is a portion of the Middle Rocky Mountain province.[4] The Bountiful district is bordered on the east and south by the Wasatch Range, and on the north and west by Great Salt Lake and the Jordan River, the principal tributary to the lake that enters from the south. The lowest part of the district is along this western edge, where the lake level has ranged between 4,194 and 4,212 feet above sea level since 1850. From this western edge the land surface rises eastward, the gradient increasing from less than 5 feet per mile near the lake shore to 150 feet per mile at Bountiful, and to more than 400 feet per mile along the base of the Wasatch Range. For the most part this increase in gradient is fairly uniform, although greater at the narrow north and south ends of the district than in the central area. However, several terraces, especially at elevations about 4,260, 4,800, and 5,150 feet above sea level, interrupt the regular profile that extends from lake to mountain range. The eastern edge of the Bountiful district is set arbitrarily at the line of the highest of these terraces, about 5,150 feet above sea level, which is the highest level reached by the ancient Lake Bonneville (p. 97).

East of the Bountiful district the Wasatch Range rises abruptly to a crest line generally more than 8,500 feet above sea level (see fig. 3). Bountiful Peak, the highest in this part of the range, is 4½ miles northeast of Centerville and has an altitude of 9,264 feet. The crest line is about 3 miles east of the 5,150-foot contour at the north end of the district, and about twice as far from that line in the southern part of the district. According to a topographic map prepared by Croft and Peterson[5] of the area north and east of Centerville, the main interstream ridges have concordant slopes westward from the crest down to an altitude of about 6,000 feet, ranging from about 8° near Stone Creek to 15° along Ricks Creek. Below 6,000 feet the gradient increases to as much as 35°. Gilbert[6] has described the "evenly dressed rib crests with similar westward slopes" which run from points near the summits of the range to the tops of the frontal facets produced by faulting. Subsequently

---

[4] Fenneman, N. M., Physical divisions of the United States, U. S. Geol. Survey map, 1930.

[5] Croft, A. R., and Peterson, H. E., Topographic map of part of the Davis Addition, Wasatch National Forest. Scale 1:15,830, contour interval 50 feet; U. S. Forest Service, 1936 (unpublished).

[6] Gilbert, G. K., Studies of Basin Range structure: U. S. Geol. Survey Prof. Paper 153, pp. 47-50, 1928.

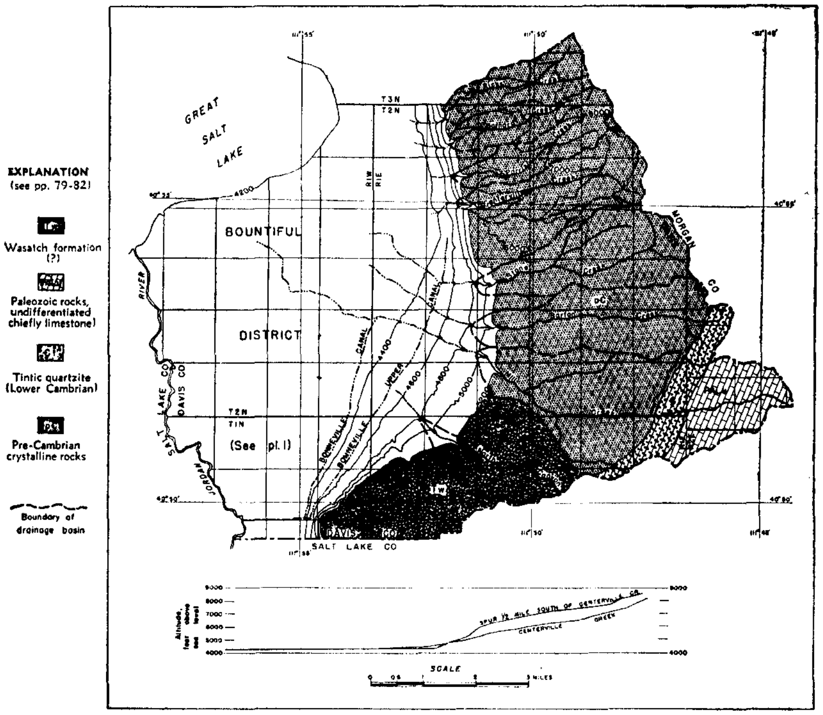


Figure 3.—*The watershed area tributary to the Bountiful district.*

Eardley[7] has concluded that these regularly sloping crests are remnants of an ancient extensive pediment which he terms the "Weber Valley surface."

All the streams entering the Bountiful district head west of the crest of the Wasatch Range, the east slope being drained by Hardscrabble Creek, which flows northeastward into Morgan Valley to join East Canyon Creek, a tributary of the Weber River. The principal canyons on the western slope have steep headwater gradients, slopes of 400 to 900 feet per mile in their middle courses (from altitudes of 7,000 to 6,000 feet), increasing to as much as 1,500 feet per mile in their lower courses. Except in the headwaters, the bottoms of these larger canyons are 500 to 1,000 feet below the spurs that border their drainage basins. Some characteristics of the basins of the streams entering the Bountiful district are summarized in the following table. The discharge of these streams is discussed on pages 119-131.

Characteristics of drainage basins tributary to the Bountiful district

Stream[8]	Length of longest channel (mi.)	Drainage area (square miles)		
		Below altitude of 7,000 feet	Above altitude of 7,000 feet	Total
Ricks (Ford)	3.0	0.8	1.4	2.2
Barnard	2.7	0.8	0.6	1.4
Parrish	3.4	1.0	1.1	2.1
Centerville (Deuel)	3.9	1.5	1.6	3.1
Stone (Ward)	4.3			5.0
Barton (Holbrook)	5.0			5.5
Mill	6.9			10.5
North Canyon	3.3			2.3
Frontal streams	2.5			5.9
Total				38.0

GEOLOGY

Previous work

Various aspects of the geology of the Wasatch Range have been studied by numerous workers, beginning with the survey of the 40th parallel from 1867 to 1873, under the leadership of Clarence King. The most recent published report on the part

---

[7] Eardley, A. J., Geology of the north-central Wasatch Mountains: Geol. Soc. America Bull., vol. 55, pp. 874-877, 1944.

[8] Two titles are in common usage for each of several streams in the Bountiful district. The northernmost stream is designated "Ricks Creek" on the U. S. Geological Survey topographic map and in the State Engineer's file of stream-gaging records, but it has been called "Ford Creek" in geological reports by Eardley and the special flood commission. Both terms are in common use locally. Centerville was originally called "Deuel Creek Settlement," and the stream has retained that name in local usage to some extent; published reports and maps, however, have designated the stream "Centerville." The officials of the city of Bountiful have adopted for streams entering that city the titles "Stone Creek" in "Ward Canyon" and "Barton Creek" in "Holbrook Canyon."

of the range contiguous to the Bountiful district is that of Eardley,[9] which includes a geologic map of an area of more than 1,000 square miles, together with a general discussion of the stratigraphy, structure, geomorphology, and geologic history of the north-central part of the Wasatch Range. Detailed mapping of the areal geology of the Bountiful quadrangle has been in progress since July 1946, by A. E. Granger of the Federal Geological Survey. The discussion in the present report of the watershed area tributary to the Bountiful district is based largely upon data from these two sources.

The Bountiful district lies entirely within the area once covered by Lake Bonneville, which has been described by Gilbert.[10] His comprehensive monograph discusses the shore features and sediments of the lake, its rise, overflow, and recession, and the faulting and volcanic activity that occurred during the history of the lake. He describes in considerable detail many features throughout the Lake Bonneville basin, although there is very little pertaining specifically to the Bountiful district.

A special flood commission appointed by Governor Dern in 1930 included in its report a short summary of the geology of the Davis County stream deposits, especially as it pertained to the disastrous floods of 1923 and 1930.[11] An unpublished map showing the area covered by debris during the 1930 floods was made available by Reed W. Bailey, Director of the Intermountain Forest and Range Experiment Station of the U. S. Forest Service. These are the only known data available concerning the geology within the Bountiful district.

General relations

The rocks exposed in the Bountiful district and its tributary watershed area range in age from pre-Cambrian to Recent. The detailed geologic map that accompanies this report (pl. 1) covers only the Bountiful district, and the geology of the tributary watershed is indicated on the sketch map that constitutes figure 3. Within the area covered by these maps, only a very little of the regional geologic history can be deciphered, because the thick Paleozoic and Mesozoic sediments that appear farther south in the Wasatch Range are absent in the mountains east of Bountiful, and in the Great Salt Lake basin to the west only the

---

[9] Eardley, A. J., Geology of the north-central Wasatch Mountains, Utah: Bulletin Geol. Soc. America vol. 55, pp. 819-894, 1944.

[10] Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Mon. 1, 438 pp., 1890.

[11] McFarlane, J. M., Bailey, R. W., Becraft, R. J., and Allen, R. E., Torrential floods in northern Utah: Utah Agr. Exper. Sta. Circ. 92, pp. 43-51, 1930.

uppermost of the great accumulations of Cenozoic sediments are exposed. From studies elsewhere, however, it is known that throughout the Paleozoic and much of the Mesozoic era a broad geosynclical trough in northern Utah was the site of sedimentation to a maximum thickness of nearly 50,000 feet,[12] but that in the vicinity of Bountiful there was a small area of pre-Cambrian crystalline rocks that stood as a highland through parts of pre-Cambrian, Paleozoic, and Mesozoic time.[13] During the interval between late Jurassic and early Tertiary time there were at least three major orogenic movements in central Utah, producing folded and thrust structures.[14] In the central Wasatch Range the Paleozoic and Mesozoic sediments were thrown into folds with a general east-west trend, as seen east of Salt Lake City, and thrust faults have been mapped east of American Fork and east of Ogden.[15] Beginning probably early in the Tertiary period and continuing to relatively recent times, the Wasatch Range and other parallel ranges to the west have been uplifted by movement along the north-south trending Basin and Range faults. This faulting has cut across the trends of the folds in the sedimentary rocks, and in the vicinity of Bountiful has raised some of the oldest rocks in the State to high altitudes on the crest of the range. The Wasatch range owes its present grandeur and its steep westward slope to this faulting.

The development of the present land forms of the Bountiful district, as well as of the ground-water reservoir which serves that district, was initiated with the beginning of Basin and Range faulting near the beginning of the Cenozoic era, estimated to be some 50,000,000 years ago. During most of the period from that time to the present the region has had an arid climate, and the low area which constitutes the Great Salt Lake basin was filled with an unplumbed thickness of torrential stream, playa, and lake deposits derived from the bordering mountain ranges. The rate of deposition was probably increased following each displacement along the major faults, owing to more rapid erosion of the uplifted mountain masses. Volcanic activity occurred over a large portion of the State, and some volcanic debris is probably included among the deeper sediments underlying the Bountiful district.

---

[12] Baker, A. A., Stratigraphy of the Wasatch Mountains in the vicinity of Provo, Utah: U. S. Geol. Survey Oil and Gas Investigations, Prelim. Chart 30, 1947.

[13] Eardley, A. J., Structure of the Wasatch-Great Basin region: Geol. Soc. America Bull., vol. 50, pp. 1285-1289, 1939.

[14] Spieker, E. M., Late Mesozoic and early Cenozoic history of central Utah: U. S. Geol. Survey Prof. Paper 205, pp. 149-156, 1946.

[15] Eardley, A. J., Geology of the north-central Wasatch Mountains, Utah: Geol. Soc. America Bull., vol. 55, pp. 847-754, 1944.

The desert-basin deposition was interrupted at least once during the Pleistocene epoch and possibly at several different earlier times, when the climate of the region was humid and cold. During the last interruption to deposition, probably corresponding to the last (Wisconsin) glacial stage in the central United States, water 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 the Bountiful district the shore lines of this ancient lake are prominent physiographic features along the base of the Wasatch Range. Also during the Pleistocene, the summit areas of the Wasatch Range were glaciated.

Since the end of the Pleistocene epoch the geologic record has been one of generally increasing desiccation of the region, with gradual recession of the ancient lake to its present remnant (Great Salt Lake) and reestablishment of the desert-basin cycle of highland erosion and torrential deposition in the lowlands. A striking feature of the present topography has been the comparative rapidity of this process. In perhaps 25,000 years since the recession of the lake from its overflow level, the shore deposits along the mountain front have been gullied in many places and buried in others by stream action; and in the lower parts of the district, over an area extending from 1 to more than 2 miles from the mountain front alluvial debris has been widely distributed over the lake sediments to a maximum depth of more than 40 feet. The extent of this post-Lake Bonneville gradation contrasts strikingly with conditions in many other parts of the Lake Bonneville basin, where the lake sediments have been practically untouched since their deposition.

The stratigraphy of the Bountiful district is summarized in the following table:

Stratigraphy of the Bountiful district

Generalized section

Geologic age		Formation and symbol on plate 1	Maximum recorded thickness (feet)	General character	Water-bearing properties
System	Series				
Quaternary	Recent	Historic torrential deposits (Qht)	12	Unsorted debris, generally coarser near canyon mouths and finer to the west, consisting of angular rock fragments of wide range in size.	Deposits derived chiefly from well-sorted materials may be highly permeable; others relatively impermeable.
		Alluvium and delta deposits of Jordan River (Qd)	5	Clay, silt, and fine sand, with some evaporites, deposited on flood plain and delta of Jordan River.	Fine clastics of low permeability, yielding water of poor quality.
		Deposits of Great Salt Lake (Qg)	5	Evaporites, clay, silt and perhaps some coarser sediments, deposited on bed of Great Salt Lake.	Fine clastics impregnated with soluble salts and saturated at very shallow depths. Brines may be of economic value.
	Recent and Pleistocene	Post-Lake Bonneville torrential deposits (Qt)	40	Unsorted debris, similar to Qht.	Similar to Qht.

Stratigraphy of the Bountiful district—Continued

Generalized section

Geologic age		Formation and symbol on plate 1			Maximum recorded thickness (feet)	General character	Water-bearing properties
System	Series						
Quaternary (Continued)	Pleistocene	Lake Bonneville beds	Recessional shore deposits (Qlr)	Lake-bottom deposits	5	Gravel and sand forming narrow terraces, recognizable in very few places.	Relatively permeable. Crops out in recharge area for shallow artesian aquifers.
			Shore deposits of Provo stage (Qlp)		80	Cobbles, gravel, and sand, forming a broad terrace south of Stone Creek, narrower and discontinuous to the north.	Highly permeable and yields water to drains and tunnels east of Bountiful. Crops out in recharge area for deep artesian aquifers.
			Shore deposits of Bonneville stage (Qlb)		55	Cobbles, gravel, and sand forming broad terrace south of Stone Creek; discontinuous thin deposits in north part of area.	Permeable, but generally above the zone of saturation in its outcrop area.
			Shore deposits of "Intermediate" stage (Qla)		120	Predominantly well-bedded silt and fine sand.	Moderately permeable.
			Lake-bottom deposits (Qlc)		120	Clay, silt, and some coarser material producing poorly drained heavy soil (contemporaneous with the shore deposits listed above.)	Relatively impermeable except for thin sand or gravel lenses; forms confining beds overlying shallow artesian aquifers.

Stratigraphy of the Bountiful district—Continued

Generalized section

Geologic age		Formation and symbol on plate 1	Maximum recorded thickness (feet)	General character	Water-bearing properties
System	Series				
Tertiary (?) and Quaternary	Pleistocene and possibly Pliocene(?)	Pre-Lake Bonneville alluvium (Qpb)	700+	Poorly sorted boulders, gravel, and sand, forming fan gravels along the base of the Wasatch Range; to the west these coarse materials become progressively finer, and are inter-bedded with clay and silt. Under Great Salt Lake, equivalent beds are composed of fine-textured sediments. In Bountiful district the sediments are encountered in most wells, and consist of discontinuous and lenticular beds of poorly sorted gravel, sand, and clay, chiefly of alluvial origin.	Gravel beds are highly permeable, and form the shallow and deep aquifers which yield the principal ground-water supplies. Sand beds are moderately permeable, and also yield water under artesian pressure. Clay beds are impermeable and constitute the confining layers between artesian aquifers. Torrential deposits along the base of the Wasatch Range, composed of unsorted materials, have a moderate to low permeability.
Tertiary	Pliocene(?)	Salt Lake formation (Tsl)	1,000(?)	Not exposed in Bountiful district. As described in well logs and exposed in other areas, this formation includes fanglomerates similar to overlying pre-Lake Bonneville alluvium but more indurated, plus volcanic ash and tuff and oolitic limestone.	Generally relatively impermeable, but may include some loose materials of coarse texture that are good aquifers.

Stratigraphy of the Bountiful district—Continued

Generalized section

Geologic Age		Formation and symbol on plate 1	Maximum recorded thickness (feet)	General character	Water-bearing properties
System	Series				
Tertiary (con.)	Eocene (?)	Wasatch formation(?) (Tw)	-	Well-cemented conglomerate, and some beds of red shaly sandstone and limestone.	Relatively impermeable.
Pre-Cambrian		(Farmington canyon complex of Eardley) (pE)	-	Crystalline rocks, including chiefly gneiss, schist, and pegmatite, projecting through the valley fill in several small outcrops along the base of the Wasatch Range.	Impermeable except along fractures.

Geology of the tributary watershed area

Most of the Wasatch Range tributary to the Bountiful district is underlain by pre-Cambrian crystalline rocks described by Eardley as the Farmington Canyon complex.[16] These rocks underlie more than half the drainage basin of Mill Creek and the entire drainage basins of the streams farther north, including Barton, Stone, Centerville, Parrish, Barnard, and Ricks Creeks.

Four classes of rocks in this complex have been recognized by Eardley and Hatch, including, in descending order of abundance: (1) Metamorphosed sedimentary rocks, such as schist and arkosite, in which quartz is the dominant mineral with chlorite, sericite, and feldspar commonly comprising 20 to 25 percent of the mass; (2) metamorphosed silicic igneous rocks, including pegmatite and gneissic granite, in which feldspars are dominant and quartz comprises 20 to 50 percent of the rock; (3) metamorphosed injection gneisses, closely related to the silicic igneous rocks; and (4) metamorphosed mafic rocks, such as hornblende-gneiss and epidote-chlorite schist, in which quartz constitutes a very small proportion. Weathering of these rocks produces angular fragments which are characteristic of the residual soils, talus, and slope wash throughout the area of outcrop.

Although there are numerous exposures of hard-rock ledges, the greater part of the mountain mass—particularly the valleys and slopes—is blanketed with a cover of broken rock fragments (the regolith) which has been observed in some places to be more than 50 feet thick. Deep soils with a high proportion of clay minerals have been found by Granger[17] in the range in Davis County, and by Baker and Hunt in other parts of the Wasatch Range. These soils, the product of long weathering of the crystalline rocks, appear to antedate the present erosional cycle and evidently have been the source of much of the clay that occurs in the valley fill west of the range, both in well-sorted beds and in unsorted deposits of torrential origin. In the beds of the short canyons that drain the area, the sand grains and larger fragments are typically angular, and the alluvial debris accumulated in the valley west of the range is likewise predominantly angular, with a very small proportion of rounded grains or pebbles. Quartz, which probably constitutes about half of the mountain mass, forms most of the sand grains and pebbles

---

[16] Eardley, A. J., and Hatch, R. A., Pre-Cambrian crystalline rocks of north-central Utah: Jour. Geology, vol. 48, pp. 58-72, 1940.

[17] Granger, A. E., Baker, A. A., and Hunt, C. B., oral communications.

in these valley sediments, although unweathered fragments of gneiss and schist are also common, and grains of biotite occur in most of the sandy sediments of the valley.

An area of about a square mile in the headwaters of Mill Creek is underlain by Paleozoic quartzite and limestone. The small contribution made to valley sediments from this area probably consists chiefly of quartzite pebbles and clay. The southern part of the Mill Creek drainage basin and the basins of North Canyon and frontal streams farther south are underlain by the Wasatch formation of Eocene(?) age, which consists of red conglomerate, sandstone, and shale. Unlike the debris from streams farther north, the materials eroded from this area and deposited in the Bountiful district consist chiefly of rounded grains and pebbles, such as occur in the source rock.

Stratigraphy of the Bountiful district

Pre-Cambrian rocks

The pre-Cambrian rocks, named the Farmington Canyon complex by Eardley, which crop out over most of the tributary watershed area, are exposed also at various places along the Wasatch front at altitudes below 5,150 feet. All these outcrops are east of the Wasatch frontal fault (p. 118), some as ledges protruding above the Lake Bonneville beds or Quaternary alluvial debris, others as rock floors in the beds of canyons. The rocks are generally impermeable and of no value as sources of ground water. The chief significance of the outcrops is that they may indicate a rather shallow depth to bedrock generally east of the frontal fault.

Tertiary system

Eocene (?) series

Wasatch (?) formation

Thick beds of conglomerate, with some red sandstone and limestone, crop out at the end of the City Creek spur of the Wasatch Range, near the south end of the Bountiful district, above an altitude of 4,500 feet. These consolidated rocks, mapped by Eardley as the Knight formation of the Wasatch group, crop out east of the Limekiln fault (p. 117). They are not exposed below the Bonneville shore line farther north, but it is probable that they occur at shallow depth beneath the Lake Bonneville sediments near that shore line. Bedrock is reported in the bottom of well (A-1-1)6aaa-1,[18] drilled for the Val Verda Irrigation Co. by J. S. Lee and Sons, in 1947. The well is at a land-surface elevation of about 4,845 feet, and is drilled to a depth of 447 feet. According to the driller's log, the well penetrates 443 feet of alluvial beds, including chiefly unsorted alluvial debris probably of torrential origin, several thin gravelly strata yielding little water, and two beds of clay 15 and 25 feet thick. Beneath these alluvial deposits, probably Pleistocene and Recent in age, 4 feet of "bedrock" is reported, which may be a part of the Wasatch (?) formation. This well is just west of the Wasatch frontal fault.

To the west the beds of the Wasatch (?) formation are probably covered by a progressively greater thickness of younger sediments. The deepest well in this part of the Great Salt Lake basin is the Guffey and Galey well, drilled unsuccessfully for oil a mile southwest of Farmington.[19] Pinkish clay, sand, and "boulders" penetrated at depths between 1,865 and 2,000 feet in that well may possibly be beds of the Wasatch (?) formation.

Pliocene (?) Series

Salt Lake formation

The term Salt Lake was originally applied by Hayden to beds chiefly of volcanic derivation in Morgan Valley, Utah, which lies east across the Wasatch Range from the Bountiful district. These beds have subsequently been renamed the Norwood tuff by Eardley, and described on the basis of paleontologic evidence as of Oligocene age.[20] Mansfield[21] has applied the term "Salt Lake formation" to alluvial and lacustrine sediments of probable Pliocene age in southeastern Idaho which overlie the Wasatch formation and antedate the Lake Bonneville beds. In Cache Valley, Utah and Idaho, beds believed to be equivalent to the Salt Lake formation are exceptionally well exposed, and

---

[18] The well number indicates the location of the well with reference to land subdivision according to a system adopted by the Utah State Engineer and described in his Twentieth Biennial Report, p. 87, 1936. Briefly, the State is divided into four quadrants by the Salt Lake base and meridian, and these quadrants are designated by capital letters; A for the northeast quadrant, representing townships north and ranges east; B for the northwest quadrant; C, the southwest; and D, the southeast. In the well number the designation of the township is enclosed in parentheses and includes one of these letters, a figure showing township, and a figure showing range. In the number of the well here cited the portion within parentheses indicates that the well is in T. 1 N., R. 1 E. The number following the parentheses designates the section, and the lower-case letters following the section number give the location within the section, quarter-section, and sixteenth section (the letters a, b, c, and d representing the northeast, northwest, southwest, and southeast quarters of each subdivision). The final number designates the particular well within the 10-acre tract. Thus, number (A-1-1)6aaa-1 represents well 1 in the NE¼NE¼NE¼ Sec. 6, T. 1 N., R. 1 E.

[19] Boutwell, J. M., Oil and gas prospects in Great Salt Lake basin, Utah: U. S. Geol. Survey Bull. 260 pp. 470-273, 1905.

[20] Eardley, A. J., Geology of the north-central Wasatch Mountains: Geol. Soc. America Bull., vol. 55, pp. 845-846, 1944.

[21] Mansfield, G. R., Wasatch and Salt Lake formations of southeastern Idaho: Am. Jour. Sci., vol. 49, pp. 402-406, 1920.

Williams[22] in his geologic mapping is tentatively including in the Salt Lake unit fanglomerates, oolitic limestone, and volcanic ash and tuff to an aggregate thickness probably exceeding 2,000 feet. These beds are generally more indurated than the younger pre-Lake Bonneville alluvium of Pliocene and Pleistocene age, and are commonly deformed or tilted by faulting. In Tooele Valley, Utah,[23] tilted fanglomerates of approximately equivalent age were mapped as the Salt Lake formation, but underlying volcanic tuffs and breccias were not included. It is expected that the studies in Cache Valley will yield much additional information on the regional stratigraphic sequence during the interval from Eocene to Pleistocene time.

The Salt Lake formation is not exposed in the Bountiful district, but is believed to be represented at considerable depth in the valley fill. In the Bountiful district the Bountiful City well (A-2-1)29cab-1 is bottomed in greenish-gray alluvial debris which has a weak calcareous cement. This material is similar to the Pliocene and Pleistocene pre-Lake Bonneville alluvium encountered at shallower depth in the well, but is slightly more indurated and may possibly be part of the Salt Lake formation (see log, p. 89).

A well 2 miles south of the district (Western Petroleum Drilling Co. well No. 1, in NE¼SE¼ Sec. 21, T. 1 N., R. 1 W.) was drilled to a depth of 1,985 feet in July 1931, and was reported to have penetrated to a 2½-foot bed of volcanic tuff at 1,308 feet.[24] The Guffey and Galey well at Farmington is not stated to have penetrated volcanic materials, but the cemented gravel and green sand encountered below the depth of 810 feet may possibly indicate beds of the Salt Lake formation. It is likely that no other well in or near the Bountiful district has gone deep enough to reach the Salt Lake formation.

The water-bearing properties of the beds of the Salt Lake formation are unknown. In the western part of the area the beds are probably saturated, for water and methane gas were obtained in both the Western Petroleum and the Guffey-Galey wells. The water below 725 feet in the former well was of poor quality, a sodium-chloride water with total mineral content exceeding 900 ppm. The meager history of the wells drilled in the Salt Lake formation would not encourage attempts to obtain water supplies from those deep sediments.

---

[22] Williams, J. S., oral communication.

[23] Thomas, H. E., Ground water in Tooele Valley, Tooele County, Utah: Utah State Engineer Technical Pub. No. 4, pp. 116-118, 1946.

[24] Berry, E. G., and Crawford, A. L., Preliminary notes on the mollusca of Lake Bonneville: Proc. Utah Acad. Sci., vol. 9, pp. 53-54, 1932.

Tertiary (?) and Quaternary systems

Pliocene (?) and Pleistocene series

Pre-Lake Bonneville alluvium

Beneath the Lake Bonneville beds, and underlying the surface of the desert basin upon which those beds were deposited, is a series of gravel, sand, and clay beds. The beds are similar in origin to the fanglomerates and finer midbasin materials of the underlying Salt Lake formation, but are not indurated and probably are not tilted appreciably. Samples collected during drilling of several wells indicate that within the Bountiful district these beds are chiefly of alluvial origin, but it is likely that beds of lacustrine origin may predominate farther west. In most of the Bountiful district the pre-Lake Bonneville beds are covered by Lake Bonneville beds or post-Lake Bonneville alluvial deposits. The pre-Lake Bonneville alluvium crops out, however, over an area of about 100 acres near Cleverly siding, in sec. 1, T. 1 N., R. 1 W., and sec. 36, T. 2 N., R. 1 W., and farther north it is within a few feet of the surface along the east margin of the clay deposited in the bottom of Lake Bonneville. Pre-Lake Bonneville alluvium is reached by nearly all the artesian wells in the district, and by the majority of the deep wells farther east.

In the vicinity of Cleverly a maximum thickness of 6 feet of the pre-Lake Bonneville alluvium has been exposed in trenches and house excavations. The material is generally coarse and poorly sorted, consisting of rounded to angular fragments as much as 12 inches in diameter. There is a rough bedding with a gentle westward dip. The exposed material is probably derived chiefly from the Wasatch (?) formation, which crops out in the drainage basins of the small streams that cross the area. More than half the pebbles are quartzite, about 40 percent are limestone, and about 5 percent are of gneiss and schist.

The deepest wells in the Bountiful district for which logs are available are the Wasatch Oil Co. well (B-2-1)24cdd-10, and the Bountiful City well (A-2-1)29cab-1. Both wells are on the alluvial fan of Mill Creek, the Wasatch Oil Co. well being in the area where the Lake Bonneville beds are composed of the lake-bottom clay facies, and the Bountiful City well 2 miles eastward in the zone of the shore deposits of the Provo stage. The logs of both wells are tabulated below.

Log of Wasatch Oil Co. well (B-2-1) 24cdd-10

State application a-2016. Drilled in August 1947 by J. S. Lee & Sons. Flowing industrial well 570 feet deep, with 10-inch casing to 110 feet, 8-inch casing 110 to 280 feet, and 6-inch casing 280 to 534 feet. Altitude of land surface at well about 4,280 feet above sea level. Log is based on driller's record and on samples collected during cable-tool operations.

		Thickness (feet)	Depth (feet)
Post-Lake Bonneville torrential deposits:			
Gravel, sand, silt, unsorted, angular grains		6	6
Lake Bonneville beds			
Lake-bottom deposits:			
Clay, black, some gravel		16	22
Coarse and medium sand, rounded grains		12	34
Sand and gravel to maximum 1 inch diameter		10	44
Clay, blue		5	49
Clay, gray to yellow, some sand and gravel to ½ inch		18	67
Clay, yellow, gastropod fossils		17	84
Pre-Lake Bonneville alluvium:			
Clay, sand, and fine gravel, unsorted, angular		31	115
Gravel and sand, artesian flow	Shallow artesian aquifers in this zone.	5	120
Clay, blue		12	132
Gravel to 2 inches, sand, some clay, unsorted, angular		8	140
Clay, sand, and fine gravel, unsorted, angular		10	150
Sand and fine gravel, angular, in brown clay		25	175
Sand and gravel ot ½ inch, some clay		7	182
Silt and sand, some gravel to ½ inch, unsorted		18	200
Gravel to ½ inch, subangular, sand and silt		5	205
Clay, sand, and fine gravel, unsorted		15	220
Gravel to ¼ inch, some clay, unsorted		4	224
Silt, some fine gravel, angular, unsorted		10	234
Gravel to ¼ inch, sand, angular	Intermediate artesian aquifers in this zone.	15	249
Silt, sand, and fine gravel, unsorted		12	361
Gravel to ⅛ inch, coarse sand, well-sorted		14	275
Gravel to ½ inch, angular, artesian flow		6	281
Silt, sand, and clay		24	305
Fine gravel and coarse sand, angular		14	319
Silt and sand, unsorted		4	323
Sand and gravel to ½ inch, angular		17	340
Silt and sand		5	345
Gravel to ½ inch, coarse to fine sand		11	356
Silt and sand, fine to coarse		9	365
Fine gravel, angular, and sand		30	395
Silt and sand, some clay		60	455
Silt, clay, sand, fine gravel, unsorted		15	470
Gravel to ¼ inch, angular, coarse to fine sand	Deep artesian aquifers in this zone.	36	506
Clay, silt, some gravel to ⅛ inch		7	513
Silt and fine sand		10	523
Gravel to 1 inch, angular to rounded, and coarse sand, artesian flow		5	528
Clay		2	530
Silt and sand, some gravel to ¼ inch		10	540
Silt and fine sand, some clay		30	570

The pre-Lake Bonneville beds encountered in the Wasatch Oil Co. well below a depth of 84 feet are characteristically of angular materials, poorly sorted, and of alluvial origin. The sediments are notably different from the beds of well-sorted clay, sand, and rounded gravel in the overlying Lake Bonneville deposits, and some appear to have accumulated as torrential stream deposits. Samples of the coarser materials bear a close resemblance to debris that has been deposited as mud-rock flows in recent years by several of the small streams draining the west slope of the Wasatch Range, and the finer silt and sand beds are lithologically similar to the sediments that have been carried down channels or spread over areas beyond the limits of the coarses mud-rock accumulations of those streams. No fragments of volcanic origin were found in megascopic examination of the samples, and none of the beds is indurated, so it is concluded that the well has not reached beds of the Salt Lake formations. In all gravel beds the pebbles were derived predominantly from pre-Cambrian crystalline rocks including pegmatite, gneissic granite, schist, and hornblende gneiss. Quartzite fragments, probably derived from pre-Cambrian and Cambrian formations, constituted 20 to 40 percent of the total. Black limestone and shale, probably from the Cambrian formations that crop out in the headwaters of Mill Creek, were identified in the gravel bed 132 to 140 feet below the surface, and were in progressively greater proportion in deeper gravels. In the bed 523 to 528 feet deep, nearly 20 percent of the pebbles were limestone and were subrounded, in contrast to the angular fragments of the crystalline rocks and quartzite.

Log of Bountiful City well (A-2-1) 29cab-1

State application 16152. Drilled May 1946 to December 1947 by Larry Dalton, but abandoned because no water-bearing strata were found. Altitude of land surface at well about 4,610 feet above sea level. Log is based on driller's record and on samples collected during cable-tool operations.

	Thickness (feet)	Depth (feet)
Post-Lake Bonneville torrential deposits:		
Gravel and sand, poorly sorted	4	4
Lake Bonneville beds, shore deposits of Provo stage:		
Fine sand	6	10
Pre-Lake Bonneville alluvium:		
Clay, gravel, and larger fragments, unsorted	48	58
Clay	18	76
Gravel and large fragments	5	81
Clay	4	85
Rock fragments, gravel, fine sand, unsorted	40	125
Sandy clay, rock fragments, water seepage	33	158

	Thickness (feet)	Depth (feet)
Gravel, sand, and clay, unsorted	65	223
Boulders, rock fragments, clay, unsorted	29	252
Gravel and clay, unsorted	3	255
Boulders, rock fragments, "sticky" clay	70	325
Gravel, dry	6	331
Rock fragments, "sticky" clay, unsorted	73	404
Sandy clay, some rock fragments	21	425
Clay and rock fragments, unsorted	35	460
Gravel, sand, silt and clay, unsorted	110	570
Silt, clay, sand, fragments to ⅛ inch, unsorted	30	600
Gravel, fragments to 3 inch, silt and clay, unsorted	20	620
Silt and clay, sand, gravel, unsorted	20	640
Gravel to ½ inch, sand, clay, unsorted	10	650
Silt and clay, sand, gravel to ½ inch, unsorted	60	710
Pre-Lake Bonneville alluvium or Salt Lake formation:		
Rock fragments to 1 inch, sand, in greenish calcareous clay	20	730
Greenish calcareous clay, silt, rock fragments	45	775

The pre-Lake Bonneville alluvium is encountered between depths of 10 and 710 feet in the Bountiful City well and may extend to the bottom. Unsorted mudrock debris of torrential origin, consisting of angular fragments of all sizes in a clay matrix, constitutes almost the entire thickness penetrated in this well, and the driller's record shows only 33 feet of moderately well-sorted clay, sand, or gravel in the pre-Lake Bonneville beds. This well is located in the belt near the base of the range which, since the recession of Lake Bonneville, has received the greatest accumulations of mud-rock debris, and the well record indicates that the belt has been topographically favorable for the depositing of similar material for a comparatively long time, probably through most of the Pleistocene epoch and possibly a part of the Tertiary period. By contrast, the Wasatch Oil Co. well is near the western limit of the area that has been covered by torrential deposits; a larger proportion of the materials there are moderately well sorted by stream action and are better aquifers because of greater permeability.

The record of Daniel Lives' well (A-1-1)6acb-1 is noteworthy in that, although the origin of the pre-Lake Bonneville alluvium is similar to that in the Bountiful City well, the hydrologic characteristics are distinctly different because the sediments were derived from a different source rock. Conglomerates of the Wasatch (?) formation cover the City Creek spur east and south of this well, and streams have deposited cobbles and gravel derived from that conglomerate. Even in the beds of torrential debris there is better sorting and hence greater permeability than in similar deposits farther north which consist of the clay and angular fragments derived from the pre-Cambrian crystalline rocks. Well-sorted beds of gravel, sand, and clay make up a greater proportion of the section recorded in this well than in the Bountiful City well.

Driller's log of Daniel Lives well (A-1-1)6acb-1

State application 18807. Drilled in July 1947 by J. S. Lee & Sons. Pumped domestic well 405 feet deep. Altitude of land surface at well about 4,820 feet above sea level.

	Thickness (feet)	Depth (feet)
Lake Bonneville beds:		
Shore deposits of the "Intermediate" stage:		
Fine sand	50	50
Pea gravel	65	115
Clay, blue	3	118
Pre-Lake Bonneville alluvium:		
Gravel, sand, and clay, unsorted	37	155
Clay, brown	17	172
Gravel, sand, and clay, unsorted	23	195
Fine sand	17	212
Gravel, sand, and clay, unsorted	37	249
Gravel	16	265
Clay, brown	5	270
Gravel, water-bearing	10	280
Clay, sandy	25	305
Gravel, sand, and clay, unsorted	37	342
Clay, brown	17	359
Gravel, water-bearing, with beds of clay	11	370
Gravel, water-bearing	25	395
Gravel, sand, and clay, unsorted	10	405

The thickness of the Pliocene (?) and Pleistocene pre-Lake Bonneville alluvium in the Bountiful district is at least 700 feet in the Bountiful City well and may be of the order of 1,200 feet at the Western Petroleum Drilling Co. well (p. 86). The maximum thickness may well occur just west of the Warm Springs fault, where present evidence suggests that the bedrock floor of the Salt Lake basin may have been dropped to its lowest altitude by faulting (p. 116). The alluvium probably becomes thinner westward with increasing distance from the principal source of material in the Wasatch Range. The eastern limit of the deposits is probably along the Wasatch frontal fault or slightly farther east, where they consist essentially of coarse and very poorly sorted alluvial debris, and the deposits extend westward across the Great Salt Lake basin beneath the Lake Bonneville beds. Characteristically the deposits consist of irregular, lenticular, and discontinuous beds of gravel, sand, silt, and clay, the coarsest materials predominant along the Wasatch front, and the clay and silt beds becoming progressively thicker westward. Samples from the Bountiful City and Wasatch Oil Co. wells consist almost entirely of poorly sorted alluvial material, but some beds of fairly well sorted alluvial, lacustrine, or playa deposits also are found in the western part of the Bountiful district. Farther from the mountains clay, silt, and chemical deposits are doubtless the essential constituents of the pre-Lake Bonneville beds.

The characteristics of the materials of the upper part of the pre-Lake Bonneville alluvium in the Bountiful district are indicated graphically in three east-west sections and two north-south sections based on drillers' logs. Logs of adjacent wells commonly show very poor correlation, owing in some cases probably to inadequacies or inaccuracies in logging, but in many instances demonstrating the lenticular and discontinuous character of individual beds. In all sections the contact between the Lake Bonneville beds and the underlying pre-Lake Bonneville alluvium is indicated with a fair degree of certainty, for the Lake Bonneville beds are predominantly clay in the area covered by the profiles, and they cover the aquifers tapped by practically all the flowing wells. The thin alluvium that overlies much of the lake-bottom deposits has not been shown in the sections. Four of the five sections cross the Warm Springs fault (p. 115), and a displacement of about 20 feet is indicated in beds near the surface on opposite sides of the fault, the displacement commonly increasing slightly in the deeper and older sediments.

Figure 4 is a section of the sediments that have been deposited west of the canyon of Centerville Creek. The pre-Lake Bonneville alluvium is encountered within 15 feet of the surface in the easternmost well, and is probably about 120 feet below the land surface at the west end of the section. It includes several gravel beds which constitute the artesian aquifers and which can be grouped into a shallow zone 80 to 120 feet thick and a deeper zone of similar thickness, separated by a zone of predominantly finer materials 100 to 150 feet thick, in which, however, there are also a few thin gravel beds. All these sediments have a westward dip of 75 to 125 feet per mile. Unsorted alluvial materials are predominant in the easternmost well, but were not indicated in the drillers' descriptions of sediments farther west.

Figure 5 for the area extending westward across the piedmont alluvial plain formed by the coalescing fans of Stone, Barton, and Mill Creeks, shows conditions similar to those described on the Centerville Creek fan. Unsorted materials of probable alluvial origin are reported in all the wells of this section. The deepest well reaches aquifers deeper than those tapped by the wells of figure 4.

Figure 6, based on wells along an east-west line still farther south, includes wells farther east and higher than any shown on the sections described above. Like the Bountiful City well, these eastern wells shows a predominance of alluvial deposits of torrential origin, which appear to have a westward dip of 125 to 200 feet per mile, slightly less than the present land surface.

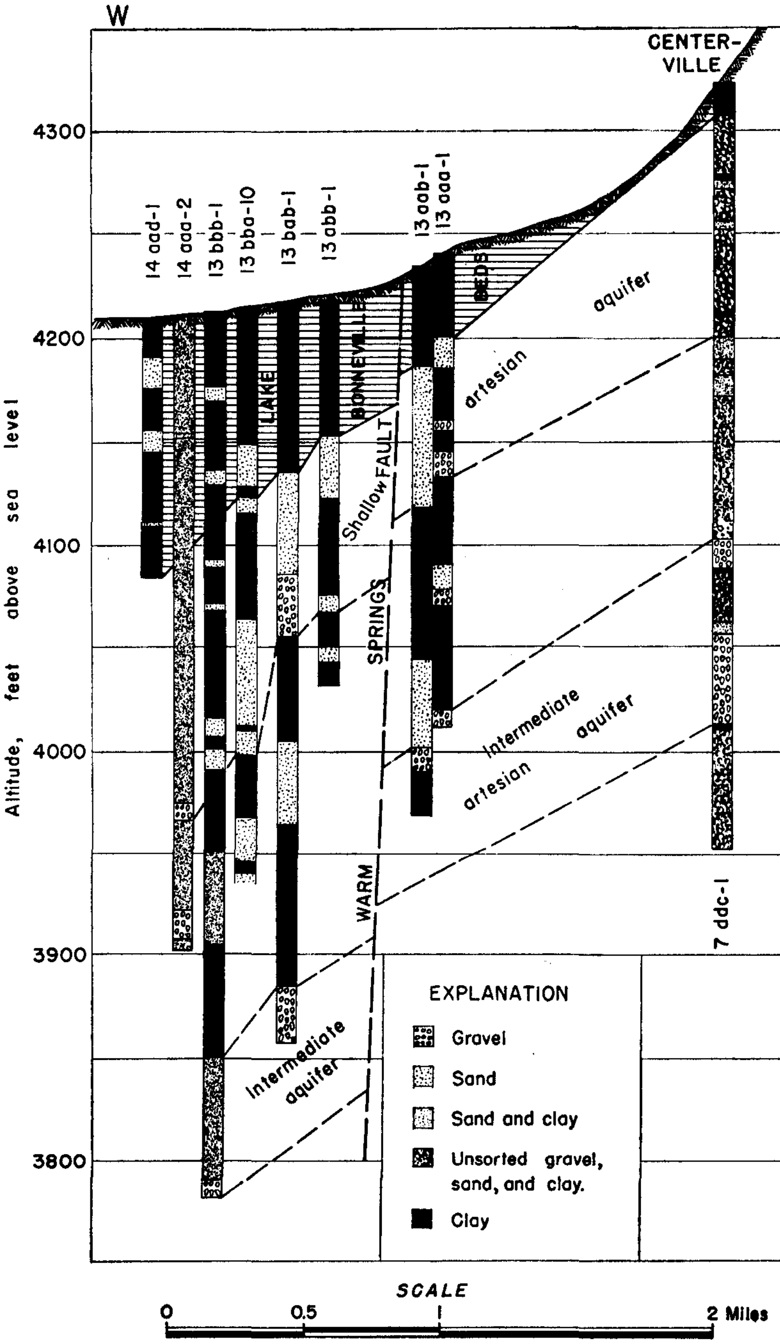


Figure 4.—*Geologic section west from Centerville (Profile A-A′ on plate* 1).

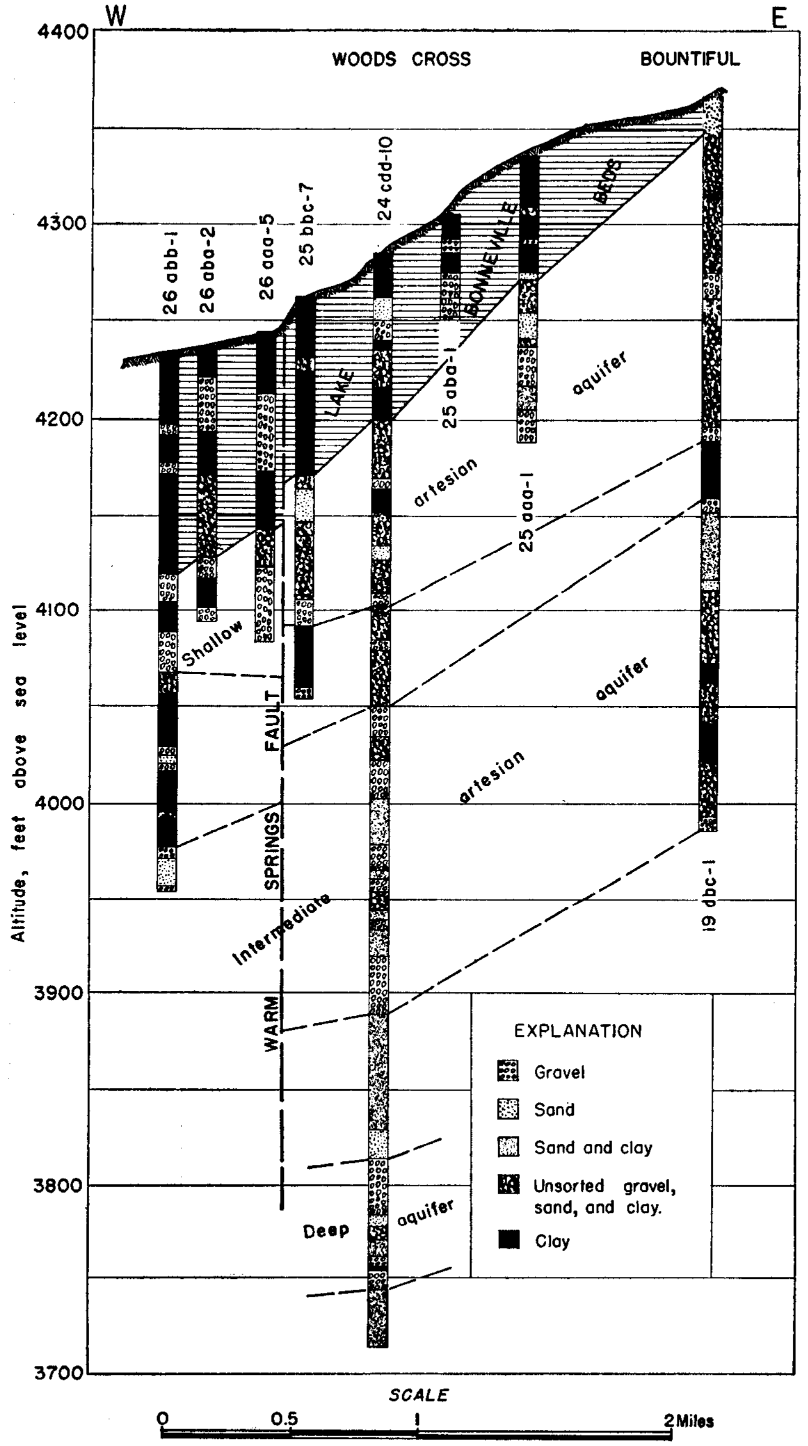


Figure 5.—*Geologic section west from Bounitful* (*Profile B-B′ on plate* 1).

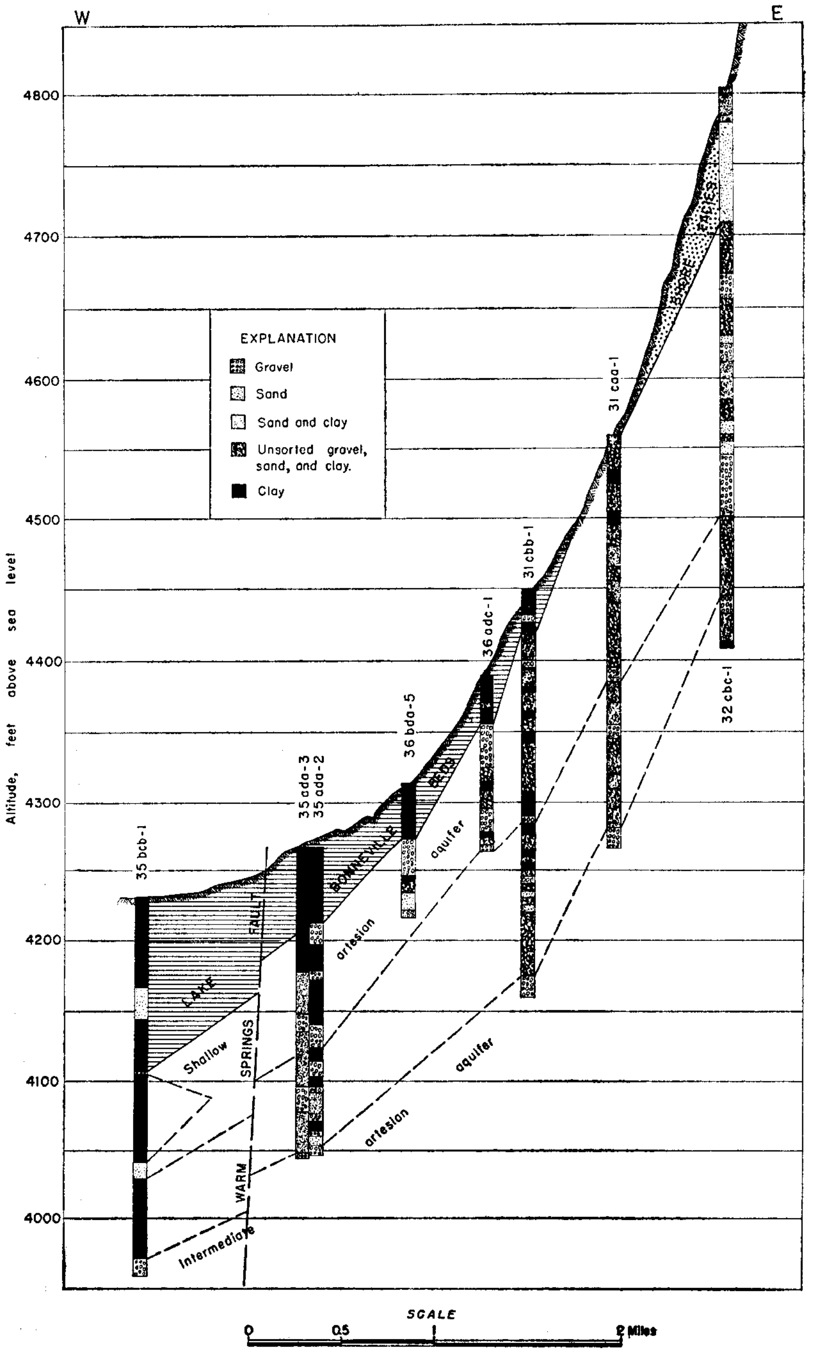


Figure 6.—*Geologic section through South Bountiful*

Figure 7 is a north-south section based on the logs of several wells near the eastern limit of the lake-bottom facies of Lake Bonneville beds. In these wells this clay is only 15 to 40 feet thick, and the uppermost pre-Lake Bonneville alluvium is close to the surface immediately to the east, being covered only by discontinuous lake-shore deposits and a thin mantle of post-Lake Bonneville alluvial debris. This area to the east constitutes the recharge area for the artesian aquifers of the Bountiful district. As shown by the section, the pre-Lake Bonneville alluvium in this area consists predominantly of unsorted debris, similar to the thin post-Lake Bonneville mantle at the surface. Along this section the alluvial material includes chiefly gravel and sand, and more than 70 percent of the beds penetrated by the wells are gravelly or sandy. "Clay" or "sand" is encountered chiefly in wells located midway between alluvial fans built by the several streams, but in the fans themselves these finer-textured materials form only a few very thin beds. The several zones of artesian aquifers that are differentiated in the sections farther west are not distinct here, and water may penetrate downward from the land surface through prevailingly coarse sediments to deep as well as shallow aquifers.

The north-south section which constitutes figure 8 shows exceptionally well the lenticular nature of the coarser pre-Lake Bonneville alluvial beds. It is a cross-section of the lower part of the Stone-Barton-Mill Creek fan and shows a general thinning northward of the tongue-like shallow artesian zone. It also shows the deeper artesian group of aquifers to be at least 200 feet thick at well (B-2-1)26ddd-1, and to be separated from the shallow aquifers by clay beds only 45 feet thick. There are many excellent artesian wells yielding water from the numerous gravel horizons in this portion of the alluvial fan, and their hydrologic characteristics are different from those of wells in other parts of the district where intervening clay beds are thicker and form more impermeable membranes (p. 171.)

In all these geologic sections the delineation of shallow, intermediate, and deep zones of artesian aquifers is a simple generalization of conditions based upon hydrologic characteristics described subsequently (pp. 143-181), as well as upon correlation of well logs. Actually, the individual gravel or sand beds reported within each of these zones may be separate and distinct, and in exceptional instances gravel beds encountered in adjacent wells, and reported to be separated by only 15 to 20 feet vertically, yield water under markedly different artesian pressures, suggesting that the two aquifers are separated by an impermeable membrane. In general, however, the gravel beds that have been grouped respectively in the shallow, intermediate, and deep aquifers define common piezometric surfaces and have other common hydrologic characteristics.

Near the western edge of the Bountiful district, and west of the Jordan River in the northern part of the Jordan Valley, the pre-Lake Bonneville beds are composed of clay and silt beds with numerous thin layers of peat, indicating periods of accumulation under marshy conditions. Several wells drilled in that belt close to the present shore of Great Salt Lake yield methane in sufficient quantities for domestic cooking or heating, and others have yielded gas for a short period. Generally water is discharged with the gas. The few logs that are available for these wells and for others farther north along the lake shore indicate that inland lakes and marshes occupied the Great Salt Lake basin during parts of the time that the pre-Lake Bonnville beds of alluvium were being deposited.[25] As no shore lines are found above those developed by Lake Bonneville, it is certain that those earlier lakes were smaller, but their extent cannot be stated from present information.

Quaternary system

Pleistocene series

Lake Bonneville beds

Lake Bonneville at its maximum stage covered the entire Bountiful district, and practically the entire area has received lake sediments. 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 by Gilbert,[26] and his monograph is freely drawn upon in the following summary.

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

---

[25] Eardley, A. J.. and Haas, Merrill, Oil and gas possibilities in the Great Salt Lake basin: Utah Acad. Sci. Proc., vol. 13, p. 67-75, 1936.

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

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 the 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 a period of time about five times as long. The period of desiccation between these high stages of the lake was considerably longer than post-Bonneville time.

The Bonneville stage of the lake was ended by outflow from the northern part 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 as a result of desiccation. 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 were produced, which, however, are not sufficiently accented to be identified everywhere. 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.

In the Bountiful district north of Stone Creek, the Bonneville, "Intermediate," Provo, and Stansbury shore lines of Lake Bonneville were fairly straight and parallel, carved into the steep west front of the Wasatch Range. South of that stream, particularly at the higher stages of the lake, there was a rather pronounced embayment. Still farther south the shore lines trended southwestward along the flank of the City Creek spur of the range to the south edge of the district.

Throughout the greater part of the history of Lake Bonneville as outlined above, the lowest parts of the Great Salt Lake basin were sites of lacustrine sedimentation, and that deposition is continuing today within the present Great Salt Lake. According to Gilbert, however, a long period of desiccation occurred prior to the Bonneville stage and the lake may have dried up completely, during which time the basin floor would have been subject to erosion and to alluvial deposition. Recently Marsell[27] has found in Jordan Valley, near Salt Lake City, evidence of channeling of Provo shore features and subsequent filling, all within the Provo stage, indicating another period when lacustrine deposition was interrupted in the lower parts of the Great Salt Lake basin.

Shore deposits of "Intermediate" stage

The deposits of the "Intermediate" stage include the oldest deposits of Lake Bonneville, the deposits of Gilbert's "Intermediate" shore lines and embankments. As found in Utah Valley by Hunt[28] these deposits are as much as 300 feet thick, and are dominantly of well-sorted, fine-textured materials, mostly silt, in thin, distinct, nearly horizontal beds. They include gravel of small areal extent deposited chiefly at the mouths of tributary canyons, sand and silt which grade laterally into the gravel and extend farther from the mouths of the canyons, and clay which is exposed along the base of the range between the canyons and underlies much of the interior of the valley, grading laterally into the coarser materials toward the canyon mouths.

In the Bountiful district the equivalent deposits of the "Intermediate" stage were not distinguished, partly because of very few and poor exposures and partly because geologic mapping was not undertaken in sufficient detail. Instead, the gravel, sand, and silt are grouped as the shore deposits of the "Intermediate" stage, and the clay deposited contemporaneously on the floor of the lake is

---

[27] Marsell, R. E., oral communication.

[28] Hunt, C. B., Geology of the Bonneville basin, Utah: U. S. Geol. Survey Bull., in preparation.

included with fine-textured materials deposited during subsequent stages as the "lake-bottom sediments" of the Lake Bonneville beds.

At the highest of the "Intermediate" shore lines, about 30 feet below the Bonneville shore line, the deposits consist chiefly of fine gravel and sand. The shore deposits of the "Intermediate" stage are also exposed in several road cuts and canyon walls between the Bonneville and Provo shore lines. Commonly in these exposures the materials are silt and fine sand in thin, nearly horizontal beds. Along the Mueller Park road between secs. 29 and 32, T. 2 N., R. 1 E., beds of these materials are exposed at altitudes of 4,850 to 5,050 feet, although the maximum thickness exposed at any single road cut is less than 15 feet. About half a mile south of this road, in Calder's well (A-2-1)32ccb-1, beds probably referable to the "Intermediate" stage have a thickness of about 90 feet, as shown in the following log. (See also p. 91.)

Driller's log of Harold Calder well (A-2-1)32ccb-1

State application 18804. Pumped domestic well drilled in May 1947, by J. S. Lee and Sons. Altitude of land surface at well about 4,805 feet.

	Thickness (feet)	Depth (feet)
Post-Lake Bonneville torrential deposits:		
Soil, gravelly loam, unsorted	6	6
Lake Bonneville beds		
Shore deposits of "Intermediate" stage:		
Clay and sand	19	25
Sand	70	95
Pre-Lake Bonneville alluvium:		
Boulders, sand, clay, unsorted	36	131
Gravel	18	149
Hardpan	2	151
Boulders, gravel, sand, and clay, unsorted	23	174
Sand	6	180
Gravel	13	193
Sandy clay	27	220
Boulders, gravel, sand, and clay, unsorted	15	235
Sand	10	245
Hardpan	5	250
Sand, water-bearing	10	260
Gravel, water-bearing	44	304
Clay, sand, gravel, unsorted	31	335
Hardpan	10	345
Clay, boulders, unsorted, with lenses of gravel	15	360
Gravel, water-bearing	12	372
Hardpan	6	378
Gravel, with clay beds	13	391
Clay	5	396

The shore deposits of the "Intermediate" stage are thickest and most extensive in the embayment of the ancient lake east and south of Bountiful, where the Calder and Lives wells are located, and they crop out in a belt more than half a mile wide. North of Stone Creek the front of the Wasatch Range is steeper, and the bedrock is covered by only a thin mantle of debris consisting of lake sediments, talus, and torrential deposits. There are several outcrops of bedrock below the Bonneville shore line where "Intermediate" shore features might be expected, and it is concluded that during those early stages of the lake wave erosion of the steep bedrock surfaces was the predominant activity.

Shore deposits of Bonneville stage

The shore line formed at the highest stage of Lake Bonneville is conspicuous because it marks the boundary between stream sculpture and the horizontal sculpture of lake action. Above this shore line the typical erosional pattern of steep-sided canyons and narrow ridges is predominant, and below it the land forms are dominantly wave-cut or wave-built terraces, bars, and deltas. The impressiveness of the Bonneville shore line as viewed from a distance is mainly the result of this contrast. In the northern part of the Bountiful district, where the mountains rise abruptly from the valley, the principal action of the lake at this high stage was erosive, and the embankments are miniscule and discontinuous. South of Centerville Creek these embankments of the Bonneville stage become larger and reach their maximum extent and thickness in the embayment east and south of Bountiful. Stream action has made many changes since the lake receded from its highest stage, for the shore embankments have been partly destroyed by the erosion of each of the larger streams, and they have been covered in other places by small alluvial cones.

The most prominent embankments occur along the flank of City Creek spur from Mill Creek southwest to the end of the spur. Only two streams in this reach have cut entirely through the shore deposits of the Bonneville stage, but several small streams have formed alluvial cones upon these deposits. Just south of Mill Creek the embankment is some distance out from the front of the range and evidently is a remnant of a bar that once extended across the mouth of Mill Creek Canyon and has since been cut by the stream. The bar has a flat crest 100 to 150 feet wide, with slopes of about 7° on the upstream and downstream faces. The material consists chiefly of gravel one-fourth to one-half inch in diameter, with some cobbles up to 3 inches and some sand and finer-grained material, derived from the pre-Cambrian crystalline rocks. At the road cut into the north end of this embankment, the shore deposits of the Bonneville stage are 55 feet thick and rest upon pre-Lake Bonneville alluvial materials. Here these shore deposits consist of coarse sand near the base, overlain by gravel with a general westward dip of about 15°, containing a zone of cobbles near the top. At the point of the City Creek spur, the lake at the Bonneville stage constructed a spit that extends southwestward about 1,500 feet from the shore line.

Between Stone Creek and Mill Creek the embankments representing the shore deposits of the Bonneville stage have a maximum width of 800 feet, nearly as wide as those south of Mill Creek. Erosion by Mill, Barton, and Stone Creeks and several of their tributaries, however, has cut this embankment into several remnants.

The shore deposits of the Bonneville stage consist mainly of fine gravel and sand, the largest fragments commonly less than 3 inches in diameter, and with many rounded pebbles as well as subangular to angular fragments. In contrast, the pre-Lake Bonneville and post-Lake Bonneville alluvial deposits are made up almost entirely of angular fragments. The embankments of the Bonneville stage commonly have a lakeward slope of 4° to 5°.

Shore deposits of Provo stage

The shore deposits of the Provo stage are generally thicker and of greater areal extent than those of the Bonneville stage in the same locality. They were accumulated when Lake Bonneville was maintained at a constant level by the rock gorge at Red Rock Pass, and represent a period considerably longer than that represented by the shore deposits of the Bonneville stage. In the Bountiful district shore deposits of the Provo stage reach their maximum thickness and areal extent in the embayment east and south of Bountiful, and along the flank of the City Creek spur. North of Centerville Creek the bedrock of the Wasatch Range is close to the surface, and shore deposits, alluvial debris, and talus form a thin cover on the steep slopes along the Provo shore line, similar to the materials along the higher Bonneville shore line.

In the southern part of the Bountiful district the shore deposits of the Provo stage have formed a terrace with a maximum width of 1,000 feet near the tributary canyons, and a minimum width of 300 feet at some distance from the tributaries. The terrace has a westward slope of 3° to 4°, which is somewhat more gradual than the slope of the Bonneville terraces, and probably reflects the gentler slope of the pre-Lake Bonneville topography. At the surface the materials of the Provo terrace are composed of rounded gravel and sand that is prevailingly coarser than that at the surface of the Bonneville terrace, some cobbles being as large as 6 inches in diameter. South of North Canyon the terrace material is probably derived in large part from conglomerate of the Wasatch (?) formation, and is better sorted than that farther north, where the streams evidently have contributed angular fragments and finer-textured materials from the pre-Cambrian bedrock and residual soils in their drainage basins. West of the terrace the shore deposits of the Provo stage form a steeper slope, ranging from about 5° east of Bountiful to 12° near the end of the City Creek spur.

The shore deposits of the Provo stage are well exposed in the Foss Lewis gravel pit in the SW¼SW¼ sec. 32, T. 2 N., R. 1 E., just north of North Canyon. The east wall of this pit is about 100 feet west of the Provo shore line. The basal beds exposed in the center of the pit are very coarse sand dipping 12° northwestward and resting conformably upon yellow to red-buff well-bedded silt and fine micaceous sand of the "Intermediate" shore deposits. Well-bedded gravel and sand above these basal beds have dips ranging from 10° in the eastern part of the pit to 15° in the center, and 22° along the west wall. These foreset beds on both sides of the pit are overlain by a 3-foot bed of boulders and gravel dipping about 2° northwestward. The vertical thickness of the Provo shore deposits is computed to be about 80 feet at the west wall, about 500 feet from the Provo shore line.

Several wells penetrate the shore deposits of the Provo stage. In the Nels Peterson well (A-2-1)31adc-1, about 1,500 feet north of the Foss Lewis gravel pit, the following section was recorded. The beds of "yellow clay" reported below the sand and gravel of the Provo stage in this and several other wells are interpreted to be part of the "Intermediate" shore deposits, which contain a high proportion of silt in their outcrop area farther east.

Driller's log of Nels Peterson well (A-2-1) 31adc-1

State application 13768. Domestic well drilled 217 feet deep by J. H. Peterson in December 1940. Altitude of land surface at well estimated to be about 4,640 feet above sea level.

	Thickness (feet)	Depth (feet)
Lake Bonneville beds		
Shore deposits of the Provo stage:		
Fine gravel	12	12
Fine sand	12	24
Shore deposits of "Intermediate" stage:		
Clay, yellow	14	38
Fine sand, yellow	4	42
Pre-Lake Bonneville alluvium:		
Boulders, gravel, and clay, unsorted	23	65
Clay, yellow	2	67
Boulders, gravel, and clay, unsorted	21	88
Clay	5	93
Boulders, gravel, and clay, unsorted	35	128
Sandy clay	19	147
Boulders, gravel, and clay, unsorted	29	176
Sandy clay, brown	4	180
Boulders, gravel, and clay, unsorted	15	195
Coarse sand and clay	22	217

The thickness of the shore deposits of the Provo stage at the terrace between Mill and Barton Creeks is indicated in the log of the Goodfellow well (A-2-1)29aaa-1, which is about 500 feet west of the Provo shore line. This well is typical of some 30 wells in sections 20 and 29, T. 2 N., R. 1 E., which obtain water from beds of the Provo shore deposits. In the same area are about 50 drains and tunnels which have been dug or bored horizontally into gravel or sand beds in the hillside for water supply.

Owner's log of Jesse Goodfellow well (A-2-1)29aaa-1

State claim 7172. Domestic well dug 50 feet deep in 1921. Altitude of land surface at well about 4,800 feet above sea level.

	Thickness (feet)	Depth (feet)
Post-Lake Bonneville torrential deposits:		
Soil, sandy, with some gravel	3	3
Lake Bonneville beds		
Shore deposits of Provo stage:		
Gravel	6	9
Sand, water-bearing	17	26
Shore deposits of "Intermediate" stage:		
Clay	22	48
Gravel	2	50

In general, the gravel and sand beds of the Provo stage are far more permeable than the underlying silt and sand beds of the "Intermediate" stage or the pre-Lake Bonneville torrential deposits encountered at greater depth. In the embayment south and east of Bountiful the Provo deposits constitute aquifers that yield water supplies for irrigation and domestic use. Along the steep mountain slopes to the north and southwest, however, the Provo shore deposits are generally above the saturated zone; water from precipitation or surface flow enters these gravels and moves downward to permeable zones of the pre-Lake Bonneville alluvium.

Recessional shore deposits

Since the end of the Provo stage the history of Lake Bonneville has been one of gradual recession, during which minor but locally conspicuous shore lines were developed at various elevations. The most prominent of these shore lines, the Stansbury shore line at an elevation about 4,500 feet above sea level, is conspicuous at several places within 50 miles of the Bountiful district, but could not be traced with any assurance within that district. It is likely that this shore line has been covered in many places by post-Lake Bonneville alluvium, and its features may have been destroyed by recent movement along the Wasatch frontal fault north of Bountiful or along the Warm Springs fault at the end of the City Creek spur.

In the Bountiful district recessional phases of Lake Bonneville are recorded by small, discontinuous gravel bars and beach ridges, and have been noted especially at elevations 4,530, 4,560, and 4,590 feet above sea level. Commonly these shore features are developed most prominently adjacent to the stream canyons, and become less discernible as they are traced from those probable sources of material. The gravel deposits have a maximum width of less than 200 feet and a thickness of only a few feet. They are believed to be of very minor importance in the occurrence of ground water in the district.

Lake-bottom deposits

The sediments deposited in the bottom of Lake Bonneville appear at the surface in the Bountiful district over an area of about 10 square miles. These sediments were deposited throughout the period represented by the four facies described above, and are doubtless contemporaneous with sediments at very shallow depth below the present floor of Great Salt Lake. The boundary between outcrops of the lake-bottom deposits and the Recent lake sediments is set arbitrarily at the highest historic shore line of Great Salt Lake, 4,212 feet above sea level. From this shore line the area of outcrop extends eastward to the areas that have been covered by post-Lake Bonneville alluvial deposits of the several tributary streams. The lake-bottom sediments extend eastward under thin alluvial cover to the Bamberger

Electric Railway in Bountiful, and still farther east in the vicinity of South Bountiful and Centerville. The approximate eastern edge of the lake-bottom clay as determined by well logs and excavations is shown on the geologic map (pl. 1).

The fine-textured lake-bottom sediments, identified as "clay" in the logs of well drillers, include not only clay but also beds in which silt or fine sand is the dominant constituent. The clay beds are light gray and plastic, with probably an increasing proportion of silt toward the mountains, forming soils of clay loam. Formerly the clay was extensively used for adobe and later for brick in construction of the early residences in the area. Abandoned clay pits are located in the W½ sec. 30, T. 2 N., R. 1 E., and in the SE¼ sec. 35 and the SW¼ sec. 36, T. 2 N., R. 1 W. The following section is exposed in the south wall of the pit in sec. 35, about 200 feet east of the trace of the Warm Springs fault.

Section in SW¼SE¼ sec. 35, T. 2 N., R. 1 W.

	Thickness (feet)
Post-Lake Bonneville torrential deposits:	
Silt-loam soil, black, angular pebbles to 1-inch diameter	1
Lake Bonneville beds:	
Lake-bottom deposits:	
Clayey silt, light tan, blocky	4½
Silty clay, greenish-gray, streaked with yellow-brown stain roughly along bedding planes	2
Medium and fine sand, yellow, micaceous, with thin lenses of clayey silt, especially in lower part	2
Silty clay, blue-gray, plastic, with numerous beds stained yellow-brown. Exposed to level of pond	8
Total section exposed	17½

West of the Warm Springs fault a "hardpan" of lime-cemented clay is found at many places within 1 to 4 feet of the land surface. The following section was measured in a drain ditch about a quarter of a mile west of the fault in section 26:

Section in NW¼NW¼SE¼ sec. 26, T. 2 N., R. 1 W.

	Thickness (feet)
Lake Bonneville beds:	
Lake-bottom deposits:	
Clay loam soil, black, containing fossils	2
Hardpan, gray, well-cemented at top, poorly cemented to irregular contact with underlying material	1
Silty clay	1
Clay, green, mottled with black	4
Total section exposed	8

The shallow streams draining the spring area to the east have cut thin channels to the level of the top of the hardpan layer. The general level of the plain between these channels is about a foot higher than the surface at the edges of the channels, and is formed on the clayey beds overlying the hardpan. A similar hardpan layer was encountered in 9 of 27 holes bored into the lake-bottom beds west of the Warm Springs fault during the present study. The hardpan ranged in thickness from 0.2 to 0.8 foot, and its top was 0.5 to 2.0 feet below the top of the Lake Bonneville beds. The hardpan was found in boreholes as far as 2 miles from the trace of the fault. This hardpan layer is considered to have been formed by deposition of calcium carbonate from waters discharged from springs that rise at or near the base of the fault scarp. It has been found only in the part of the district south of Mill Creek, where ground waters carry a considerable amount of calcium bicarbonate in solution (p. 132).

The materials of the upper beds of the lake-bottom sediments, as shown in these 27 boreholes, are principally clay and silt and sandy clay with thin beds of sand. Four of the sections are summarized below:

Log of borehole in NE¼NE¼SE¼ sec. 14, T. 2 N., R. 1 W.

	Thickness (feet)	Depth (feet)
Silt and clay	1.5	1.5
Sandy clay	1.2	2.7
Clay and silt, red	.3	3.0
Sandy clay	.5	3.5
Fine sand, micaceous	.3	3.8
Sandy clay	.4	4.2

Log of borehole in NW¼SE¼SE¼ sec. 21, T. 2 N., R. 1 W.

Clay, gray	3.0	3.0

Log of borehole in NW¼NW¼NW¼ sec. 26, T. 2 N., R. 1 W.

Silty soil, black	1.4	1.4
Clay and silt, gray	.9	2.3
Sandy clay, gray	.4	2.7
Sandy clay, blue	.5	3.2
Clay and silt, gray to brown	1.8	5.0

Log of borehole in NW¼NW¼SW¼ sec. 2, T. 1 N., R. 1 W.

Silty soil, black	1.0	1.0
Clay and silt. gray	.5	1.5
Hardpan	.3	1.8
Clay and silt, gray	.8	2.6
Sandy clay, brown	5.1	7.7
Clay and silt, blue	.5	8.2

Fossils found in a plowed field in the NW¼SW¼ sec. 25, T. 2 N., R. 1 W., were identified by Ernest Roscoe, curator of the invertebrate museum of the University of Utah, as fresh water molluscs that inhabit stagnant lakes at the present time. They are listed below. The Fossaria obrussa suggests muddy near-shore conditions in late stages of the recession of Lake Bonneville.

Fossaria obrussa Say
Gyraulis vermicularis Gould
Physa vergata Gould
Stagnicola caperata Say
Stagnicola palustris nuttalliana Lea
Pisidium variabile Prime
Pisidium abditum Haldeman

Although clay and silt predominate in the lake-bottom sediments of the Lake Bonneville beds, there are also some beds of sand and gravel, as shown by drillers' logs. On the Mill Creek alluvial fan beds of gravel up to 40 feet thick have been encountered in wells (figs. 5 and 8), and farther north beds of sand as much as 15 feet thick are interbedded with the clay (fig. 4). All these gravel and sand beds are covered by clay to a depth of 15 feet or more, and thus are considered not to be recessional shore deposits. In some wells gravel or sand occurs in the upper part of the lake-bottom beds, and in others toward the base. It is possible that these coarse-textured materials are alluvial deposits accumulated during periods of desiccation which have been inferred during the "Intermediate" and Provo stages (p. 99).

The lake-bottom beds rest upon pre-Lake Bonneville alluvial deposits, which throughout most of the Bountiful district are of coarser texture and are readily differentiated in well logs. In the geologic sections based on well logs (figs. 4 to 8) the lake-bottom sediments are about 120 feet thick in the western part of the district and are thinner to the east, grading into the coarser shore facies approximately along the boundary indicated on plate 1. Thin clay strata recorded in some wells east of this boundary may be lake-bottom deposits of the "Intermediate" or Bonneville stages of Lake Bonneville.

The lake-bottom clay and silt beds, because of their general low impermeability, act as a confining layer above the aquifers of the pre-Lake Bonneville beds, permitting the transmission of artesian pressure from the recharge areas that causes most wells in the Bountiful district to flow at the surface. The sand and gravel beds within the lake-bottom sediments are of little value as aquifers, although some wells obtain water under slight artesian pressure from them. The presence of these permeable strata, however, indicates that there may be leaks in the roof of the artesian reservoir, through which water may escape.

Pleistocene and Recent series

Subaerial processes of erosion and deposition were resumed in the progressively greater areas left uncovered by the recession of Lake Bonneville. Although Lake Bonneville is universally conceded to be of Pleistocene age, and Great Salt Lake its remnant of Recent age, there is no clear demarcation of the end of the Pleistocene epoch. Further study may show that the retreat of the last continental glaciers in other parts of the northern hemisphere coincided with the drier climate in Utah that resulted in the cessation of outflow through Red Rock Pass; in this case the Provo stage would be the last of the Pleistocene epoch, and all the recessional shore lines, including the Stansbury, would be classified as Recent in age. In this report, however, the recessional record is included with Lake Bonneville history as part of the Pleistocene epoch.

Erosion of the Lake Bonneville sediments, or deposition of alluvium upon them, began as soon as the lake receded from its highest stage. Thus in the area above the Provo shore line there doubtless are post-Lake Bonneville alluvial deposits that are contemporaneous with the shore deposits of the Provo stage; and similarly some alluvium below the Provo shore line that lies upon the lake deposits of the Provo shore deposits may be of Pleistocene age. Thus post-Lake Bonneville alluvial deposition began in late stages of the Pleistocene and has continued to the present.

Post-Lake Bonneville torrential deposits

Opposite the mouths of all the larger canyons and of many smaller canyons and gullies the well-stratified Lake Bonneville beds have been covered by torrential deposits. Several streams in the Bountiful district have produced mud-rock flows during the past 25 years; these are described subsequently. The alluvial fans of other streams are covered with torrential deposits that are characteristically unsorted and include angular fragments as large as 3 to 5 feet in maximum dimension. Some of these streams may have deposited torrential debris during the past century, but specific records of such activity have not been found. The canyon bottoms of other streams are so thoroughly grown over with vegetation that there is no indication of historic mud-rock flows, although the torrential deposits on their alluvial fans are clear evidence of cloudburst floods since the recession of Lake Bonneville.

The post-Lake Bonneville deposits of the larger streams from Mill Creek north apex at the mouths of the canyons, near the escarpment of the Wasatch frontal fault. From these apexes, debris extends westward 1 or 2 miles, fanning out to coalesce with the debris of adjacent streams. Although the material is characteristically unsorted, the large blocks are most numerous near the apexes, and the material farthest west commonly has fragments no larger than half an inch in diameter. The westward extent of the alluvium is irregular but reflects roughly the relative size and probable carrying capacities of the several streams. The debris derived from the Wasatch Range consists of angular fragments of the pre-Cambrian crystalline rocks. Few rounded pebbles are found, and it is likely that very little debris comes from the Lake Bonneville shore deposits.

The post-Lake Bonneville alluvium deposited by the small streams south of Mill Creek is similarly unsorted but contains a larger proportion of rounded cobbles and pebbles. Some of this material may be derived from conglomerate of the Wasatch (?) formation, but most of it probably comes from the Lake Bonneville shore deposits, into which these streams have cut deep gullies.

Mill Creek, North Canyon, and some other streams have cut canyons deeply into the Lake Bonneville shore deposits above an altitude of about 4,600 feet. The canyons are bordered on both sides by levee-like ridges of alluvium which project above the general sloping plain that marks the surface of the Lake Bonneville shore deposits. These alluvial deposits are inferred to have been accumulated soon after the lake began to recede, and thus they antedate the canyon and much of the alluvial debris now found at lower elevations.

The post-Lake Bonneville torrential deposits, although widespread in the Bountiful district, are not thick. The maximum thickness recorded in well logs is 20 feet, in Valeria Pack's well (A-2-1)7abd-5, and in most wells the Lake Bonneville beds are less than 10 feet beneath the surface. In Centerville the torrential debris is generally not more than 8 feet thick, as shown in excavations for buildings and cesspools. In Bountiful and Val Verda, also, the well-stratified lacustrine beds are commonly overlain by less than 10 feet of torrential debris. The maximum observed thickness of debris is at Ricks Creek, where material 40 feet thick has been deposited upon Lake Bonneville beds south of the stream. The torrential material is generally less permeable than the Lake Bonneville shore deposits, but it is sufficiently permeable to afford drainage. It is more permeable than the lake-bottom sediments below, with the result that water moves along the contact and appears at the surface at the margin of clay outcrops, particularly in the area south of Centerville.

Recent series

The time since the end of the Pleistocene epoch is a miniscule part of the millions of years represented in the geologic history of the Bountiful district, and the Recent sediments of lakes and streams are a correspondingly insignificant portion of the valley fill. Some of these sediments are accumulating at a very slow rate, measured in fractions of a foot per century. In contrast, certain streams have deposited torrential debris amounting to scores of thousands of cubic yards within a few hours. The rapidity of this action and the damage caused by mud-rock flows have been spectacular, and the recorded flows of the past 25 years are therefore discussed in a separate section, although similar deposition has occurred for a much longer time.

Deposits of Great Salt Lake

The sediments which are accumulating in Great Salt Lake have been described in detail by Eardley.[29] In the Bountiful district the eastern margin of these Recent lake sediments is set arbitrarily at the highest historic shore line of Great Salt Lake, which, according to Gilbert,[30] is probably above the limit of fluctuations for many years, perhaps even centuries, prior to 1873. Characteristically these sediments are saturated with brine to within a few inches of the surface, and have no value as a potential water supply. They consist of clays, oolites, calcareous algal deposits, the faecal pellets of the brine shrimp, and chemical precipitates. Clays and coarser detritus from streams predominate in that portion of the lake which borders the Bountiful district.

---

[29] Eardley, A. J., Sediments of Great Salt Lake, Utah: Am. Assoc. Petroleum Geologists Bull., vol. 22, pp. 1305-1411, 1938.

[30] Gilbert, G. K., op. cit., pp. 242-243.

Delta deposits and alluvium of Jordan River

The sediments being deposited by the Jordan River near its mouth are chiefly of fine texture, including silt and clay and some of the finer grades of sand. The thickness, as indicated in one hole bored near the south quarter corner of sec. 33, T. 2 N., R. 1 W., is about 4 feet. In this hole 4 feet of gray silt was underlain by a thin hardpan and then gray clay. The delta sediments are saturated with water of poor quality to within a few feet of the surface, but the texture is so fine that the sediments do not yield this water readily to wells.

Historic torrential deposits

The torrential debris deposited by streams during the past century has been a subject of much discussion by the public and some research by scientists. Cloudburst floods and resulting mud-rock flows have been reported in numerous streams throughout the State, beginning as early as 1854 in Salt Lake City. The streams draining the central Wasatch Range have produced their share of these mud-rock flows, and floods in Davis County are reported to have occurred as early as the 1860's. Cloudburst floods throughout the State have been described by Woolley[31] and the floods in Davis County have received particular attention in two reports.[32]

Within the Bountiful district the cloudburst floods of 1923 and 1930 are stated to have been of far greater magnitude and destructive effect than those reported earlier. Ricks Creek and several streams beyond the north limit of the district produced mud-rock flows in 1923 as a result of a cloudburst on August 13. In 1930 there were heavy rains on July 10, August 2, 11, and 13, and September 4, which created mud-rock flows in Ricks, Barnard, and Parrish Creeks, and in small frontal streams that drain the end of the City Creek spur. The area covered by the torrential debris of these storms is shown on plate 1, based on field observation and confirmed by maps and reports prepared soon after the deposition of the debris.[33] Since 1930 the land owners have rehabilitated most of the debris-covered area and much of the evidence of devastation has disappeared.

---

[31] Woolley, R. R., Cloudburst floods in Utah, 1850-1938: U. S. Geol. Survey Water-Supply Paper 994, 128 pp., 1946.

[32] Paul, J. H., and Baker, F. S., The floods of 1923 in northern Utah: Univ. Utah Bull., vol. 15, no. 3, 1925.

Report of Special Flood Commission, Torrential floods of northern Utah, 1930: Utah Agr. Exper. Sta. Circ. 92, 51 pp., 1931.

[33] Croft, A. R., and Peterson, H. E., unpublished topographic map of part of the Davis addition to Wasatch National Forest; Woolley, R. R., op. cit., pp. 63-66; and report of special flood commission, op. cit., pp. 43-51.

The debris left by Parrish Creek in 1930 is reported to have been 12 feet thick at the State highway in Centerville, and was deposited upon Lake Bonneville beds. The other streams, as well as Parrish Creek, produced in that year a mantle of debris comparable in thickness with the torrential deposits accumulated in the thousands of years since the recession of Lake Bonneville. It must be concluded that torrential deposition of the magnitude of that in 1930 has been very infrequent, and that there may have been periods amounting to hundreds or even thousands of years when no mud-rock flows occurred.

On the other hand, a mud-rock flow in a certain stream does not by any means insure that the canyon has been "cleaned out" and that there will be a long period of inactivity. Recent observations in Bair's Creek canyon in the Wasatch Range north of the Bountiful district have shown that, after a mud-rock flow has occurred, much debris remains in the canyon bottom and is available for further movement, and therefore the canyons most susceptible to mud-rock flows are those in which such flows have occurred in recent years. The same canyons in Davis County produced mud-rock flows after each of the four severe storms of 1930. Commonly the later mud-rock flows avoid earlier torrential deposits and drop debris upon new low ground.

Investigators have come to general agreement as to the causal factors of mud-rock flows, although they are at wide variance as to the relative importance of the individual factors. The Special Flood Commission[34] concluded that the causes of the 1930 floods were:

1. Uncommonly heavy rainfall,
2. Steep topography and geologic conditions conducive to sudden runoff and to a large quantity of flood debris, and
3. Scant vegetation on portions of the watersheds of the canyons which were flooded, owing in some cases, as in Davis County, to the depletion of natural plant growth by overgrazing, by fire, and to a small extent, by overcutting of timber.

No additional data have been collected during the current study that would aid in the evaluation of the factors of meteorology or vegetation in inducing mud-rock flows. With respect to topographic and geologic conditions, however, the Wasatch Range in the Bountiful district is an area especially conducive to the propagation of mud-rock flows and deposition upon inhabited lands of high value. On the other side of the Wasatch Range mud-rock flows originate on similar steep slopes and obtain

---

[34] Op. cit., p. 16.

material from similar source rocks, but so far they have come to rest on slopes of lesser gradient and at sites where no damage has resulted.

On the part of the Wasatch Range tributary to the Bountiful district the deep mantle of residual soil and material derived from crystalline rocks contains much clay and angular fragments which readily develop mud-rock flow characteristics when attacked by water on the prevailingly steep slopes of the range. The canyons and gullies are steepest near their headwaters, where most mud-rock flows originate, and have a decreasing gradient downstream. Near the mouth of each canyon in the Bountiful district, however, there is an increase in gradient due to displacement along the frontal fault. The mud-rock flows continue down this slope and generally come to rest upon the valley lands west of the frontal fault.

The post-Lake Bonneville movement along the frontal fault may be an important factor in the development of mud-rock flows in recent years. Fresh escarpments indicate that this displacement was about 75 feet at Ricks Creek and progressively less farther south (p. 118). Since that displacement, Ricks Creek has cut a gorge more than 100 feet deep in Lake Bonneville beds, has left the thickest observed torrential deposits, and produced mud-rock flows in both 1923 and 1930. Barnard and Parrish Creeks produced mud-rock flows in 1930, but there were no such flows in streams farther south, where post-Lake Bonneville displacement along the frontal fault was 40 feet or less. The increased gradient resulting from post-Lake Bonneville faulting undoubtedly has accelerated erosion in the lower parts of the canyons, and may thus have contributed to the volume of the torrential debris as well as to the distance traveled by that debris from the canyon mouths. The steep gradients at the headwaters of the streams, where the mud-rock flows commonly originate, are probably due to earlier uplift. This uplift evidently followed the same pattern as the post-Lake Bonneville faulting, because Ricks Creek has the steepest gradient of the larger streams and the gradients are progressively less in streams to the south.

Structure

The geologic history of north-central Utah includes much orogenic activity, as outlined on page 77. The structure of the Wasatch Range shows the composite effects of the major uplifts, folding, warping, and thrust faulting that occurred prior to Basin and Range faulting. The development of the ground-water reservoir of the Bountiful district, however, has been subsequent to those earlier structural movements. The changes of significance as far as water supply is concerned are those caused by Basin and Range faulting.

Basin and Range faulting

The great fault along the west base of the Wasatch Range—the Wasatch fault—has been described by several writers. Davis[35] visualized a peneplane before faulting, a vertical displacement of approximately 10,000 feet, and almost all the drainage pattern as a development subsequent to faulting. More recently Eardley[36] has concluded that prior to the faulting the Wasatch Range was a maturely dissected mountainous area with extensive pediments extending into the valley areas (his Weber Valley surface), and that the maximum displacement of the Wasatch fault is of the order of 3,000 feet near Ogden, and decreases southward. The bold escarpment along the west front of the range has been described by both Gilbert and Eardley; its slope is 30° to 40°, and it rises to a height as much as 6,000 feet above sea level. The Bonneville and Provo shore lines have been etched in this escarpment at many places, and it is clear that by far the greater part of the displacement occurred prior to the advent of Lake Bonneville. Thus the faulting represented by this scarp, which rises as much as 1,800 feet above the present valley floor, occurred during the period when most of the valley fill was accumulating.

A minor amount of faulting has occurred along the Wasatch front since the recession of Lake Bonneville, and the Lake Bonneville beds are offset along several faults in a zone having a maximum width of more than 3 miles. Post-Lake Bonneville faulting has formed escarpments so recent that they are preserved even in unconsolidated materials; those which have been recognized in the geologic mapping are described in following paragraphs.

Warm Springs fault

The Warm Springs fault is the westernmost displacement that has been recognized in the Wasatch fault zone. Pack[37] has described this fault in the vicinity of Becks Hot Springs, where he found the fault plane to have a westward dip of 70°. The western-

---

[35] Davis, W. M., The mountain ranges of the Great Basin: Harvard Coll., Mus. Comp. Zoology Bull., vol. 42, pp. 127-175, 1903.

[36] Eardley, A. J., Geology of the north-central Wasatch Mountains: Geol. Soc. America Bull., vol. 55, pp. 880-881, 1944.

[37] Pack, F. J., New discoveries relating to the Wasatch fault: Am. Jour. Sci., 5th ser., vol. 11, pp. 399-410, 1926.

most fault in the Bountiful district is considered to be the northward continuation of this fault, and it is so named on plate 1. It is marked by an escarpment about 15 feet high, which can be traced continuously from North Salt Lake to the north edge of the district, except where it has been covered by the post-Lake Bonneville torrential deposits of Mill, Stone, and Ricks Creeks. Alluvium also covers the escarpment between North Salt Lake and Becks Hot Springs, but the present topography strongly suggests the presence of a break in slope underneath the Recent alluvium.

The latest movement along the Warm Springs fault has occurred since the recession of Lake Bonneville but prior to the deposition of post-Lake Bonneville alluvium along the fault line, and the scarp has been covered by debris from Stone and Mill Creeks. Well logs (figs. 5 and 6) suggest that there is a somewhat greater displacement of the pre-Lake Bonneville beds along this fault. Bedrock is not exposed at any point west of the Warm Springs fault, and it is buried under more than 2,000 feet of valley fill at the Guffey-Galey well, about a mile west of the fault near Farmington. It thus appears that bedrock may be at its greatest depth, and the valley fill therefore at its maximum thickness, on the west side of this fault, which is the westernmost displacement in the Wasatch fault zone.

Several springs and seeps rise along the Warm Springs fault in the Bountiful district. The temperature of the water rising in several springs in secs. 26 and 35, T. 2 N., R. 1 W., is 52° to 53° F., which is comparable to the temperature of water issuing from wells 100 to 140 feet deep, and it is concluded that these springs have risen along the fault from the shallow artesian aquifer of the pre-Lake Bonneville beds. The discharge of these springs is reported to be less than in the early days of settlement, and they now cease to flow during the summer when artesian irrigation wells are flowing. Well-developed channels from the springs, and the hardpan ascribed to precipitation from spring waters (p. 107), constitute other evidence that the discharge of these springs was formerly greater than it is now.

A thermal spring along this fault, Becks Hot Spring, has a temperature reported to range from 126° in the summer to 134° in the winter. In the Bountiful district the waters from several wells west of the Warm Springs fault yield sodium-chloride waters of higher concentration than is found in other wells in the district (p. 139). West of the Warm Springs fault the average temperature gradient of ground water is higher than east of the fault, as shown in the following tabulation. At each depth range the waters having the highest proportion of sodium chloride have also the highest temperature, and the temperatures thus provide an indication of the proportion of the water that is derived from deep sources along the fault.

Average temperature gradient of ground water in the Bountiful district

Depth below land surface (feet)	Range in temperature (°F.)	
	East of Warm Springs fault	West of Warm Springs fault
100	50-55	56-61
200	54-58	56-63
300	57-61	59-65
400	60-64	63-67
500	63-67	66-70
600	66-70	69-73
700	69-73	72-75
800	72-76	75-78

Limekiln fault

The Limekiln fault, so named here for the abandoned lime kilns described by Gilbert, which are still in existence along the escarpment, can be traced with reasonable assurance southward from the White Hill Sand and Gravel Co. pit, in sec. 12, T. 1 N., R. 1 W. Gilbert[37] found the fault plane to have a westward dip of 70° and measured the post-Lake Bonneville displacement as 30 to 40 feet in the vicinity of Becks Hot Springs. In a stretch about 2 miles long at the end of the City Creek spur three large gravel pits and several smaller ones have been developed, utilizing the shore gravels which occur along the downthrown side of this fault. In the Utah Sand and Gravel Co. pit, in the NW¼NE¼ sec. 23, T. 1 N., R. 1 W., a curving fault surface has been exposed, the fault plane dipping 62° westward. In this pit and for nearly a mile to the north the Wasatch (?) formation or older rocks crop out on the upthrown side. Lake Bonneville shore gravels on the downthrown side dip 45° to 60° westward at the fault plane, the dip decreasing to about 25° within a hundred feet of the fault. Close to the fault the gravel is coated with calcium carbonate.

At the Wasatch Sand and Gravel Co. pit, in the NE¼NE¼ sec. 14, T. 1 N., R. 1 W., the fault plane has not been exposed but lies between the east edge of the pit and projecting outcrops of the Wasatch (?) formation. North of this pit the fault veers northeastward, with the Wasatch (?) formation on the upthrown

---

[37] Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Mon. 1, pp. 348-349, 1890; Studies of Basin Range structure: U. S. Geol. Survey Prof. Paper 153, p. 16, 1928.

side. North from the Odell reservoir, in sec. 1, T. 1 N., R. 1 W., there is a rather steep rise, 15 to 25 feet high, in the valley fill which may be an escarpment marking the northward continuance of the Limekiln fault. This physiographic feature can be traced through Bountiful to a junction with the frontal fault southeast of Centerville.

Throughout most of its length the Limekiln fault has no known effect upon the movement of water in the ground-water reservoir. Water moves westward across the fault and its probable extension and into the artesian aquifers beyond. There are not enough wells in the vicinity of the fault to show whether any barrier is created to this movement, but there are no seeps or springs along the fault and it is evident that water is not forced to the surface.

Frontal fault

The frontal fault which follows the base of the range from Centerville north has been described by Gilbert[38] and by Eardley[39]. On the geologic map the low escarpment caused by post-Lake Bonneville movement along this fault has been traced from the north edge of the Bountiful district to where it crosses the Bonneville shore line south of Mill Creek. The scarp is 75 feet high near Ricks Creek, 60 feet near Parrish Creek, 40 feet near Centerville Creek, and about 25 feet near Barton Creek. Its base ranges in altitude from 4,460 feet near Ricks Creek to 4,650 feet near Stone Creek, 4,900 feet near Barton Creek, and 5,150 feet at the Bonneville shore line. No movement is reported along this fault in historic time, but the scarp is so fresh, in an area where rapid destruction of steep slopes is inevitable, that its age is probably to be measured in hundreds rather than thousands of years. The escarpment becomes indistinct south of the Bonneville shore line on the City Creek spur.

The fault plane is exposed on both banks of the gorge cut by Ricks Creek in 1930. On the south bank sand beds of the Provo stage with a westward depositional dip of 8° are exposed east of the fault, and are dragged down adjacent to the fault plane. They are in fault contact with at least 40 feet of the post-Lake Bonneville torrential deposits, and the fault plane has a dip 62° westward. On the north bank gravel and sand are in fault contact with beds of fine sand of the Provo stage.

Southeast of Centerville, beds of the Lake Bonneville shore deposits are beveled by the fault at an angle of about 50°, and it is

---

[38] Gilbert, G. K., op. cit., pp. 349, 354, 356.

[39] Eardley, A. J., op. cit. pp. 880-881.

concluded that the fault plane generally is steeper than the frontal escarpment and is comparable with the observed planes of the Warm Springs and Limekiln faults.

In the embayment east of Bountiful the shore deposits of the Provo stage are cut by a fairly continuous escarpment, which may be a branch of the Frontal fault and is mapped as a probable fault on plate 1.

East of the Frontal fault, in the NW1/4SW1/4 sec. 32, T. 2 N., R. 1 E., a fault plane dipping to the southeast is exposed in a small canyon. Along this fault there has been a small amount of displacement, with upthrow to the west, and the trace of the fault is marked by knolls on otherwise regular alluvial slopes, and by undrained depressions east of the fault. Still farther east there may be other faults of minor displacement, extending northward from the City Creek spur where they have been mapped by Granger, and perhaps converging upon the Frontal fault in the vicinity of Mill Creek near the eastern edge of the Bountiful district. None of these faults is mapped on plate 1.

A few springs rise along the Frontal fault at the topographically low points along the escarpment, notably southeast of Centerville. Elsewhere also the fault may constitute a barrier to westward movement of ground water. In most of the larger canyons, however, bedrock is close to the surface east of the fault, and appreciable quantities of water are lost from the streams at the fault and in the unconsolidated materials farther west.

HYDROGRAPHY

Records of stream discharge

The perennial streams that enter the Bountiful district have been listed, with data as to size and area of drainage basin, in the table on page 75. These streams, together with the Jordan River, constitute the principal sources of water used for irrigation in the Bountiful district and, as will be developed in a succeeding chapter, are also the main sources of water that enters the ground-water reservoir.

The Intermountain Forest and Range Experiment Station of the Forest Service, U. S. Department of Agriculture, has established gaging stations at the mouths of the canyons of Parrish and Centerville Creeks, and has determined the daily discharge of those streams since 1937. These records, derived from a rated weir without periodic measurements of discharge, permit computation of annual runoff which may be within 10 percent of true runoff. The records are summarized in the following tables. There is also a short record of daily discharge of Mill Creek, on which a gaging station was maintained by the Geological Survey from December 1913 to September 1914.

The Utah State Engineer made miscellaneous measurements of the discharge of Ricks, Stone, Barton, and Mill Creeks near the mouths of the respective canyons above points of diversion for irrigation during the years 1937 to 1941. Beginning in 1945, he has collected data on the spring runoff of Ricks, Barnard, Parrish, Centerville, Stone, Barton, and Mill Creeks below points of diversion for irrigation, based on staff-gage readings and periodic measurements of discharge. These data are summarized in subsequent tables.

Centerville Creek at Centerville

(Record by Intermountain Forest and Range Experiment Station, Ogden)

Location. Water-stage recorder, lat. 40°55', long. 111°52', in SE¼SW¼ sec. 8, T. 2 N., R. 1 E., ¼ mile east of Centerville, 1,000 feet downstream from point of diversion to spreading basin, which is measured separately and included in totals below (see p. 201). Stream flowing over bedrock (pre-Cambrian gneiss) at altitude of 4,600 feet.

Drainage Area. 3.16 square miles.

Records Available. October 1940 to June 1947.

Extremes. Maximum daily discharge, 28.0 second-feet May 24, 1942; minimum daily, 0.3 second-foot December 6-11, 1940.

Remarks. Records based on rated broad-crested weir with specially designed flume for low discharge. Rating table used prior to December 1941 is based on current-meter measurements in 1937, with small stilling pond maintained above weir. Rating table since December 1941 is based on current-meter measurements under "natural" conditions in which stilling pond fills with gravel and slope is steep enough that excess gravel passes through the weir.

Rating Tables

Gage height (feet)	Discharge (second-feet)		Gage height (feet)	Discharge (second-feet)	
	Prior to Dec. 1941	Since Dec. 1941		Prior to Dec. 1941	Since Dec. 1941
0.2	0.8	1.1	1.2	9.2	9.9
.4	1.9	2.3	1.4	11.5	12.3
.6	3.4	4.0	1.6	13.9	14.9
.8	5.2	5.8	1.8	16.5	17.8
1.0	7.1	7.8	2.0	19.2	20.7

Monthly discharge of Centerville Creek, in acre-feet

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1940										69	70	29	
1941	53	66	129	311	782	303	126	86	77	85	82	88	2,190
1942	87	[1]101	[1]92	714	924	688	205	115	98	99	95	81	3,300
1943	79	70	99	265	243	168	110	77	56	76	71	83	1,400
1944	88	83	95	202	702	536	162	94	82	85	83	83	2,300
1945	81	68	83	141	422	349	127	79	70	77	78	84	1,660
1946	84	69	120	417	439	247	90	64	63	90	89	99	1,870
1947	92	79	157	298	589	255							

[1] Flow in spreading canal estimated.

Parrish Creek at Centerville

(Record by Intermountain Forest and Range Experiment Station, Ogden)

Location. Water-stage recorder, lat. 40°55′, long. 111°52′, in SE¼NW¼ sec. 8, T. 2 N., R. 1 E., ½ mile northeast of Centerville, above all diversions.

Drainage Area. 2.15 square miles.

Records Available. October 1937 to June 1947.

Extremes. Maximum daily discharge, 26.7 second-feet May 26, 1942; minimum daily, 0.3 second-foot, August 26-30, 1943.

Remarks. Records based on rated broad-crested weir with specially designed flume for low discharge. Rating tables used for this stream are the same as for Centerville Creek which has a structure identical in design.

Monthly discharge of Parrish Creek, in acre-feet

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1937										45	40	44	
1938	36	33	77	356	608	153	60	37	41	38	32	35	1,500
1939	36	32	76	314	286	70	48	45	35	38	35	32	1,050
1940	33	35	86	267	395	65	35	26	26	29	30	32	1,060
1941	33	45	81	210	779	185	66	33	27	29	33	32	1,550
1942	32	31	67	504	752	461	100	57	41	40	41	42	2,170
1943	41	48	64	277	205	150	56	26	22	37	35	33	990
1944	44	33	37	139	586	353	82	39	29	28	31	25	1,430
1945	26	33	46	96	432	240	60	33	22	30	32	31	1,080
1946	30	30	67	398	262	164	54	26	22	34	34	33	1,150
1947	34	37	96	241	542	130							

Discharge of streams entering the Bountiful District, in second-feet

(Measurements by Utah State Engineer)

Date	Ricks Creek near Centerville[1]	Stone Creek near Bountiful[2]	Barton Creek near Bountiful[3]	Mill Creek near Bountiful[4]
Dec. 30, 1937	1.01	1.27	1.18	1.27
Mar. 22, 1938	1.11	3.83	2.43	-
Apr. 13	.75	6.39	5.53	10.44
Apr. 23	-	-	28.8	-
Apr. 25	-	21.7	-	45.6
May 7	-	7.5	13.2	22.1
May 12	3.64	10.5	15.7	32.7
May 17	18.4	24.9	31.0	39.9
June 7	[5].75	-	10.0	29.2
Feb. 4, 1939	1.03	-	-	-
Mar. 20	-	-	2.33	-
Mar. 28	1.89	6.09	5.80	15.2
Apr. 12	.30	4.65	5.81	14.4
Apr. 19	.49	3.69	5.25	13.9
Apr. 24	-	10.6	12.1	21.2
Apr. 26	.62	-	-	-
May 4	5.09	12.4	17.7	25.2
May 16	6.23	7.16	7.67	15.2
June 3	[5].5	3.71	3.26	8.88
June 22	[5].5	-	.00	4.29
June 27	-	2.27	-	-
Aug. 24	[5].25	-	.50	.68
Mar. 30, 1940	-	4.36	4.86	9.08
Apr. 22	-	9.48	10.5	26.2
May 13	9.74	10.1	17.6	27.1

Date	Ricks Creek near Centerville	Stone Creek near Bountiful	Barton Creek near Bountiful	Mill Creek near Bountiful
Mar. 18, 1941	-	3.52	1.00	7.20
Apr. 23	[5]1.5	-	-	-
Apr. 25	-	-	11.4	-
May 8	-	17.9	-	-
May 10	-	-	-	53.1
June 4	-	7.31	5.39	17.0
July 11	-	1.22	.00	7.93

[1] Gaging station in NW¼ sec. 5, T. 2 N., R. 1 E., ¼ mile east of highway, above upper diversion and below siphon at mouth of canyon.

[2] Gaging station in NW¼ sec. 21, T. 2 N., R. 1 E., at mouth of canyon.

[3] Gaging station in NW¼ sec. 29, T. 2 N., R. 1 E., at bridge at mouth of canyon.

[4] Gaging station in SW¼ sec. 34, T. 2 N., R. 1 E., in Mueller Park, at footbridge near center lawn.

[5] Estimated.

Discharge of streams crossing the Bountiful District, in acre-feet

(Measurements made by Utah State Engineer below points of stream diversions)

Month	Ricks Creek[1]	Barnard Creek[2]	Parrish Creek[3]	Centerville Creek[4]	Stone Creek[5]	Barton Creek[6]	Mill Creek[7]
March 1945	4			18		5	
April	17			36	77	105	122
May	115			39	306	578	159
June							73
July							19
Period 1945	136			93	383	688	373
February 1946				19			2
March	17			57	15	1	146
April	223	[8]25	345	144	413	516	808
May	12	3	96	94	209	111	61
June			20	3	11		30
Period 1946	252	[8]28	461	317	647	628	1046
March 1947				90	106	116	164
April	29	[8]40	144	103	308	196	474
May	[8]41	[8]50	319	234	465	686	439
June	159		71	93	83	194	75
Period 1947	729	[8]90	534	519	962	1192	1151

---

[1] Staff gage lat. 40°57′, long. 111°53′, in NE¼NW¼ sec. 6, T. 2 N., R. 1 E., 75′ west from Bamberger Railroad and 2 miles north of Centerville.

[2] Staff gage lat. 40°56′, long. 111°53′, in SW¼SE¼ sec. 6, T. 2 N., R. 1 E., about 300 feet east of alternate highway 89 and one mile north of Centerville.

[3] Staff gage lat. 40°55′, long. 111°53′, in SW¼NE¼ sec. 7, T. 2 N., R. 1 E., 100′ east of alternate highway 89 and 0.2 mile north of Centerville city limit.

[4] Staff gage lat. 40°55′, long. 111°53′, in NW¼NE¼ sec. 18, T. 2 N., R. 1 E., 200′ east of Bamberger railroad along south side of 3600 South Street in Centerville.

[5] Staff gage lat. 40°54′, long. 111°53′, in NE¼SE¼ sec. 18, T. 2 N., R. 1 E., about 50′ upstream from culvert on Second West Street near 4000 South Street, Centerville.

[6] Staff gage lat. 40°54′, long. 111°53′, in NW¼SE¼ sec. 19, T. 2 N., R. 1 E., about 30′ south of Third North Street and one-half block west of Main Street, near Union Mortuary in Bountiful.

[7] Staff gage, lat. 40°53′, long. 111°53′, in NE¼ sec. 30, T. 2 N., R. 1 E., about 150′ west of Main Street and 650 block South, in Bountiful.

[8] Estimated on basis of incomplete monthly record.

Total surface inflow to the Bountiful District

Estimates have been made of the total surface inflow to the Bountiful district, based on the meager data summarized above. These estimates were derived by determining for Parrish Creek the annual runoff in acre-feet per square mile of drainage basin, and applying the same rate to adjacent drainage basins of streams where runoff has not been measured. Although this method of determining unmeasured inflow is not entirely satisfactory, the errors in these yearly estimates are probably less than 25 percent, judging by similar computations for City Creek in Jordan Valley, where records are available for checking; from 1938 to 1946 the annual runoff of City Creek, computed from the record for Parrish Creek, ranged from 80 to 124 percent of the actual measured runoff, and for the 9 years the computed runoff was 105 percent of the actual.

The runoff of all streams except Mill Creek has been estimated from the records for Parrish Creek, as their drainage basins are similar in altitude and exposure. As a check on the validity of estimates based on areas of drainage basins, the miscellaneous discharge measurements made by the State Engineer at the mouths of the canyons were compared with the discharge of Parrish Creek on the same days; during the spring freshets these discharges were found to be generally proportional to the drainage area, but wide variations were apparent at other times of the year.

The runoff of Mill Creek is estimated from the record of City Creek, which has headwaters adjacent to Mill Creek and a similar proportion of high mountainous area in its drainage basin. During a 10-month period in 1914 when discharge records were obtained for both streams, the runoff was closely proportional to the areas of the two drainage basins. Compared by months, these records show less uniform relationships, and it is evident that City Creek has proportionately more base flow, and less flow in the spring, than does Mill Creek. Here, as in the other streams, individual runoff characteristics may differ considerably in short periods, but these differences evidently balance out over longer periods, so that runoff relationships from year to year are more nearly uniform.

The seven streams included in the tabulation drain nearly 80 percent of the drainage basin area tributary to the Bountiful district. Not included is North Canyon, with a drainage basin of 2.3 square miles, or small frontal streams which drain a total of 5.9 square miles. The drainage basins of these streams are almost entirely below 7,000 feet in altitude. According to Croft[40], who has studied runoff characteristics of similar areas in northern Davis County, most of the precipitation at altitudes below 7,000 feet is required to offset the soil-moisture deficiency, and practically no water is available for runoff. Accordingly it is presumed that the total runoff of these frontal streams is less than that of the smallest stream tabulated, and thus well within the limit of error of the estimation. These small streams have not established channels beyond their canyon mouths. The water discharged during the spring seeps into the ground and thus contributes a small amount to storage in the ground-water reservoir.

In addition to the inflow of the several tributary streams, considerable surface water enters the Bountiful district from the Jordan River. This water is pumped by the Bonneville Irrigation Company into two main canals at elevations approximately 4,350 and 4,500 feet above sea level, and is then distributed for irrigation. The pumping plant is located near the south limit of Davis County, and water is distributed over lands as far north as Stone Creek. The pumping plant has four pumps, two of which are equipped with 750 hp. electric motors, and two with 1,500 hp. motors. The bulk of the pumping is done by the two smaller pumps, one serving the upper canal and the other the lower canal, and in some years the larger pumps have not been operated at all. The quantity of water pumped has never been measured but is estimated by company officials to average 11 second-feet, or 22 acre-feet per day of operation, from each of the smaller pumps. The larger pumps are operated when the demand exceeds the capacity of the small pumps, or when the small pumps are shut down for repairs during the irrigation season; these larger pumps are estimated by the company to discharge about 22 second-feet each. A 90-day irrigation season is covered by power contract. In some years of great demand this period has been exceeded, but since 1935 the pumping season has commonly been slightly less than the contract 90 days.

The estimated annual pumpage from 1943 to 1946, as shown in the following table, is based upon company records showing hours of operation of each pump and the rates of discharge estimated by the company. In those years the estimated discharge was at an average rate of approximately 2,200 acre-feet per million kilowatt-hours of electricity consumed. The estimates prior to 1943 are based upon records of electric-power consumption furnished by the Utah Power & Light Co., assuming a similar

---

[40] Croft, A. R., Some factors that influence the accuracy of water-supply forecasting: Am. Geophys. Union, Trans. vol. 27, p. 383, 1946.

Estimated surface inflow to the Bountiful district, in acre-feet

Year	Ricks Creek	Barnard Creek	Parrish Creek	Centerville Creek	Stone Creek	Barton Creek	Mill Creek	Tributary Streams · total	Bonneville Canals	Total
1937	1,690	1,080	1,660	2,440	3,830	4,250	6,820	21,800	3,500	25,300
1938	1,530	980	1,500	2,070	3,460	3,840	6,780	20,200	3,600	23,800
1939	1,070	680	1,050	1,370	2,420	2,690	4,810	14,100	3,900	18,000
1940	1,080	690	1,060	1,440	2,450	2,720	5,310	14,800	4,100	18,900
1941	1,580	1,010	1,550	2,190	3,580	3,970	6,680	20,600	3,500	24,100
1942	2,210	1,410	2,170	3,300	5,010	5,560	8,520	28,200	3,000	31,200
1943	1,010	640	990	1,400	2,290	2,540	6,050	14,900	3,900	18,800
1944	1,460	930	1,430	2,300	3,300	3,670	6,460	19,600	4,400	24,000
1945	1,100	700	1,080	1,660	2,490	2,770	5,350	15,200	4,600	19,800
1946	1,170	750	1,150	1,870	2,660	2,950	5,400	16,000	4,800	20,800
10-year mean	1,390	890	1,360	1,940	3,150	3,500	6,220	18,500	3,900	22,400

yield per unit of energy. As shown by the table, the estimated pumpage of the Bonneville Irrigation District has constituted 9 to 23 percent of the total surface inflow to the Bountiful district in the years 1937 to 1946. Since 1937 that pumping has contributed more to the surface-water supplies of the Bountiful district than any tributary stream except Mill Creek.

Usable surface outflow from the Bountiful district

The measurements by the State Engineer of the stream flow below points of diversion for irrigation serve to show the amount of unappropriated water which moves toward Great Salt Lake during the periods of greatest discharge of the streams. No measurements have been made farther downstream than the State Engineer's gaging stations, which are 1 to 5 miles from the lake, at elevations 50 to 200 feet above the 1947 lake surface. It is possible that some of this flow is lost by seepage into the Lake Bonneville beds, or, on the other hand, that the surficial deposits in the western part of the district may contribute return flow from irrigation during the summer and fall. Because this shallow ground water is of very little economic use, its relation to the surface water is unimportant, and it may be stated that the water which passes the State Engineer's lower gaging stations has gone beyond possible economic recovery in the ground-water reservoir, for it is separated by clay of the Lake Bonneville beds from the usable water-bearing strata. Thus the quantities measured by the State Engineer, and estimated for the remainder of each year on the basis of occasional staff-gage readings, represent water that is not now used but could be made available for irrigation of additional land in the spring, or for artificial recharge of the ground-water reservoir.

Estimated surface outflow from Bountiful district, in acre-feet

Year	Ricks Creek	Barnard Creek	Parrish Creek	Centerville Creek	Stone Creek	Barton Creek	Mill Creek	Total
1945	180	20	150	150	400	700	400	2,000
1946	400	30	570	550	700	650	1,100	4,000
1947	900	100	600	900	1,100	1,300	1,300	6,200

According to these estimates about 13 percent of the estimated flow of these streams into the district in 1945 was neither used for irrigation nor absorbed by the ground-water reservoir, In 1946 the proportion of stream flow that continued across the district rose to nearly 25 percent. In each of these two years the quantity diverted for irrigation or added to the ground-water reservoir from these streams was of the order of 13,000 acre-feet, which is approximately equal to the inflow from all streams during the dry year 1939. As total inflow increases there is appreciable increase in recharge to the ground-water reservoir (see p. 193), but a larger proportion of the inflow is wasted to Great Salt Lake.

Precipitation-runoff relationships

The long-term records of precipitation at several of the Weather Bureau stations listed on page 68, and the records of runoff of Parrish Creek in the past 10 years, afford a basis for determining the relation between precipitation and runoff in the Bountiful district. No reliable estimate of the total precipitation upon the district and the tributary basin can be made until there are enough representative stations at selected locations to determine the effect of topography and orographic influences, and until adequate topographic maps are available for the drainage area. Even without these data, however, it is possible to show whether there is a constant relation between annual precipitation at existing stations and stream runoff during the same years, or whether appreciable quantities of water appear to be held over as storage in the watershed area until succeeding years.

The precipitation from 1937 to 1946 at several stations is compared with the runoff of Parrish Creek in the following table, which shows the percentage of the 10-year precipitation that has fallen in each year, and also the percentage each year of the 10-year runoff at the gaging station. The average annual precipitation at Farmington in this period was 20.43 inches as compared with an average of 20.28 inches in the 47-year period 1900-46. The records of the four precipitation stations have been analyzed by the Hydrometeorological Section of the Weather Bureau and have been found to be representative of the region with no adjustment for the period. They are used by that section with records from other selected stations, in forecasting the flow of streams in the Jordan and Weber drainage basins, which lie south, east, and north of the Bountiful district. The weighted average shown in the sixth column is derived by weighting the precipitation records as follows: Farmington 0.4, Highline City Creek 0.4, Mountain Dell 0.1, and Silver Lake 0.1.

Comparison of annual precipitation and runoff

(Quantities are percentages of the total precipitation and runoff in the 10-year period 1937-46, inclusive)

Year Ending Sept. 30	Precipitation at					Runoff in Parrish Creek
	Farm-ington	Highline City Creek	Mountain Dell	Silver Lake	Weighted average	
1937	9.0	11.0	11.5	9.5	10.6	*12.0
1938	9.7	11.0	10.7	11.0	10.5	11.3
1939	9.4	6.4	8.9	8.3	7.9	7.8
1940	9.2	9.1	8.3	7.2	8.7	7.9
1941	12.8	12.2	12.6	10.9	12.2	11.5
1942	11.5	11.7	10.2	9.9	11.1	15.3
1943	8.1	9.0	9.7	12.6	9.3	7.5
1944	11.4	11.4	9.4	10.4	11.0	10.7
1945	10.6	9.8	9.8	11.0	10.2	7.9
1946	8.3	8.4	8.9	9.2	8.5	8.1
Total	100.0	100.0	100.0	100.0	100.0	100.0

*Estimated from Centerville Creek runoff.

The variation in the proportion of precipitation that has fallen each year at the several precipitation stations is perhaps indicative of the irregularity of the distribution of the precipitation from place to place. In some years, notably 1938, 1945, and 1946, this distribution has evidently been more regular than in other years, such as, particularly, 1943.

In most years the proportionate runoff correlates reasonably well with the proportionate precipitation, the differences being no greater than the variations among precipitation at the four stations (see records for 1938, 1939, 1940, 1941, 1944, and 1946). In the other years, however, there was considerably more or considerably less runoff than might have been expected from the proportionate precipitation reported at the four precipitation stations. Runoff was less than might be expected in 1941, when precipitation was greater than in any other year of the 10-year period. This condition was reversed in 1942, when runoff was the highest in the 10-year period, although precipitation was considerably less than in 1941. Although no supporting evidence has been obtained as to ground-water storage in the watershed area, it is considered likely that some of the precipitation in 1941 went into ground-water storage and, when released in 1942, contributed much to the high runoff of that year. The proportionate runoff in 1937 likewise may have been high because of ground-water contribution held over from 1936, when precipitation was above normal. On the other hand, the low runoff in 1945 may have been due to the fact that 35 per cent of the precipitation that year occurred in June and August and may have contributed very little to stream flow.

The amount of water stored in the ground and released for runoff in subsequent years does not appear to be proportional to the annual precipitation. Close correlation has already been noted between precipitation and runoff in most years. Computations show that no better correlation is obtained for the 10 years by weighing the precipitation to include various proportions of the precipitation which fell during the preceding years. Although correlation in individual years is shown to be slightly better, for the most part these computations show that the water stored or released from underground sources is not directly proportional to the total precipitation.

Forecasting of the annual runoff of streams draining the Wasatch Range has been undertaken in recent years by the Weather Bureau on the basis of precipitation, and by other agencies on the basis of snow surveys. These forecasts have in their favor the facts that most of the annual precipitation commonly occurs in the period from October to March, and that the runoff in most years is proportional to the total precipitation upon the drainage basin. In some years, however, forecasts made as of April 1 may be considerably in error, owing in part to exceptional rates of precipitation after April 1, and in part to the changes in storage of ground water in the drainage area from one year to another, which result in much greater or less runoff than has been forecast. The total runoff of Parrish Creek is compared below with precipitation and snow-survey records used in forecasting during the past 10 years. Parrish Creek has not been included in forecasts in the past, and the following discussion is therefore based on forecasts that could have been made for those streams from available data.

Annual runoff of Parrish Creek, compared with precipitation and snow-course records used in forecasting, 1937-46

(Quantities are percentages of 10-year total)

Year Ending Sept. 30	Measured runoff	October to March precipitation		April water content
	Parrish Creek	Farmington	Weighted average of four stations[1]	Barnard Creek snow course
1937	[2]12.	11.6	10.9	13.0
1938	11.3	11.1	11.9	9.6
1939	7.8	10.0	9.0	8.2
1940	7.9	10.6	9.6	10.2
1941	11.5	11.1	10.9	10.9
1942	15.3	12.0	12.0	12.0
1943	7.5	8.1	9.6	10.2
1944	10.7	9.7	9.7	7.7
1945	7.9	8.0	8.0	9.5
1946	8.1	7.8	8.4	8.7
Total	100.0	100.0	100.0	100.0

[1] Farmington 0.4, Highline City Creek 0.4, Mountain Dell reservoir 0.1, Silver Lake 0.1.

[2] Estimated from runoff of Centerville Creek

The Barnard Creek snow course (No. 13A), in sec. 34, T. 3 N., R. 1 E. at an altitude of 8,000 feet, appears to be well located to give reliable data for forecasting stream flow in the region. In 4 years of the 10, a forecast based upon these snow measurements without adjustment would have been within 10 percent of the actual stream runoff of Parrish Creek. In 1939 the snow measurement would have forecast the runoff more accurately than the precipitation data, and in 1941 the forecast would have been as close as forecasts based upon precipitation. In 1938, 1943, 1944, and 1945, however, forecasts for the stream based on snow surveys would have been less accurate.

In the preceding table the October-to-March precipitation is shown in percentage of the 10-year total for the Farmington station, and also for the group of four stations used previously. The annual runoff of the stream could have been forecast within 10 percent in 6 of the 10 years on the basis of the Farmington record, and also on the basis of the weighted average for the four stations. In most years the proportionate precipitation computed by the two methods is in close agreement, and not greatly different from the record obtained by snow surveys. However, precipitation records appear to correlate more closely in most years with actual runoff than do existing snow surveys.

The actual runoff in 1941 was somewhat less and in 1942 somewhat greater than the quantity that might have been expected from precipitation or snow-course records. These are years in which it has been suggested that there were marked changes in the ground-water storage throughout the watershed area, and it is apparent that forecasts for such years are subject to considerable error until some storage factor can be evaluated and included in computations for forecasting.

Comparison of the preceding table with that on page 128 shows that the precipation from October to March correlated more closely with stream runoff in 1941 and 1945 than did the precipitation for the entire year. In both those years the precipitation during the summer (June to September) was exceptionally heavy, but it occurred when opportunity for evapo-transpiration was greatest and appears to have contributed very little to runoff. Thus the runoff could have been forecast closely on the basis of data available April 1.

On the other hand, precipitation during April and May appears to make an important contribution to runoff. Precipitation at Farmington during those months was less than 50 percent of the average in 1940 and 1943, and more than 50 percent above average in 1944. In all three years a forecast based on October-to-March precipitation would have approached more closely the actual runoff if adjustment could have been made for the exceptional spring precipitation.

Croft[41] has discussed several factors that influence the accuracy of water-supply forecasting, on the basis of his studies in northern Davis County, Utah. He lists the following factors which may cause errors in forecasts that are based on water content of snow on April 1: Fluctuations in water content of the soil mantle on that date from one year to another; precipitation during the spring; and rate of melting of snow. The brief study of the precipitation-runoff relationships in the Bountiful district confirms the importance of many factors discussed by him.

In order to increase the reliability of forecasts, the moisture in the ground may be determined by soil sampling above the zone of saturation, or may be indicated with sufficient accuracy by water levels in suitably located observation wells, which would evaluate the free water available for stream flow. The spring precipitation cannot be determined until seasonal activities dependent on use of the water are well advanced, and thus it can serve only to modify earlier forecasts. The rainfall in October, which Croft suggests may be a factor contributing to soil moisture that is not measured by snow surveys, is included in the basis for forecasting from precipitation records. It is possible that forecasts based on precipitation are more accurate than snow-survey forecasts in some years because of this factor.

GEOCHEMISTRY

Although the minerals that form most of the rocky crust of the earth are relatively insoluble, they are not absolutely so; it has long been known that practically all minerals are attacked to some extent by water. The amount and kind of dissolved mineral matter in a natural water depend upon the chemical composition and physical structure of the rocks with which the water has been in contact, the temperature, the pressure, the duration of the contact, and the materials already in solution. Thus the mineral content of waters may throw considerable light on the source of those waters and the types of rock materials with which they have been in contact. An accompanying table presents analyses of waters from 9 streams, 8 springs and drains, and 80 wells within the Bountiful district.

---

[41] Croft, A. R., Some factors that influence the accuracy of water-supply forecasting in the Intermountain Region: Am. Geophys. Union Trans., vol. 27, pp. 375-388, 1946.

The rocks that form the northern part of the watershed area tributary to the Bountiful district are composed chiefly of relatively insoluble quartz and silicate minerals, including feldspars, hornblende, biotite, chlorite, and sericite. Analyses of water from streams draining this area (Nos. 1 to 6 in the table) show the mineral content to be less than 150 ppm. during the late summer when the stream flow is derived almost entirely from springs and seeps in the mountains. The constituents are primarily silica and soluble calcium, sodium, and potassium salts that result from decomposition of the parent rock.

The rocks that crop out in the southern part of the watershed area include lime-cemented conglomerates and sandstones, limestones, and shales. The streams flowing from this area have a higher mineral content than those farther north, as shown by analyses of waters from Mill Creek and North Canyon (Nos. 7 and 8), largely owing to an increase in calcium bicarbonate dissolved from the parent rocks.

Waters issuing from bedrock in springs and from tunnels and drains constructed for water supply generally carry a somewhat greater quantity of mineral constituents than waters in streams that cross the same sort of bedrock, with each constituent increasing, as shown by comparison of analyses 4 and 10 and of 8 and 15. A notable exception is the water that issues from limestone at Becks Hot Springs in Salt Lake County, about half a mile south of the edge of the Bountiful district (analyses 17a and b). This water, issuing at a temperature of 128° F. along the Warm Springs fault, carries about 13,000 ppm. of mineral solids, of which nearly 80 percent is sodium chloride.

The water pumped from the Jordan River for irrigation in the southern part of the Bountiful district is notably different in chemical character from the waters derived from the watershed area on the Wasatch Range. The total salinity is several times as great, owing mainly to larger quantities of the sulfates and chlorides of sodium and potassium. Samples collected in March, July, and August 1947 (analyses 9a, b, and c) indicate that the dissolved mineral matter ranges from about 800 ppm. during periods of high flow to more than 1,200 ppm. at low stages. Since 1921 the Jordan River water has been applied for irrigation over extensive areas (see p. 124). The chemical character of waters in wells above the upper Bonneville canal, which carries Jordan River water, is generally different from that yielded by wells below the canal.

Chemical character of ground water east and north of the upper Bonneville canal

The easternmost wells and drains in the alluvial fans of Ricks, Barnard, Parrish, Centerville, Stone, and Barton Creeks yield calcium-bicarbonate waters of slightly greater concentration than the waters carried by the several streams, the mineral content commonly ranging from 125 to 280 ppm. (see analyses 11-14 and 18-26). Waters from wells on these fans west of the Warm Springs fault commonly contain a larger amount of sodium and potassium, as well as chloride and sulfate, than do the waters from the easternmost wells. The total mineral content is also greater, generally ranging between 210 and 310 ppm. (see analyses 38-40, 42, 43, 45). Well (B-2-1)13bbb-3 (analysis 42), reported to be 800 feet deep and therefore the deepest well in the district, yields a sodium-bicarbonate and chloride water having a total mineral content of 550 ppm., considerably higher than other wells in the vicinity.

Wells and drains on the alluvial fans of Mill and North Canyon Creeks above the upper Bonneville canal yield calcium-bicarbonate waters of a composition similar to the waters of those streams, but more concentrated. The mineral content of waters collected from six of these sources ranges from 348 to 390 ppm. (analyses 15, 31, 33, 35, and 37).

Chemical character of ground water west of the upper Bonneville canal

Waters from wells west of the upper Bonneville canal are generally more highly mineralized than ground water elsewhere in the Bountiful district, the mineral content of the sampled waters ranging from 186 to 3,550 ppm. Analyses for these wells are marked with an asterisk. Wells within a mile west of the upper canal yield calcium-bicarbonate waters which differ from the well waters east of that canal in that they have a higher mineral content and a higher concentration of chloride and sulfate. It is inferred that this increased mineral content is due primarily to percolation of canal water from irrigated lands into the ground-water reservoir, because shallow wells within a quarter of a mile of the canal yield water of high mineral content, but many wells more than 200 feet deep produce water similar in mineral content to that from wells east of the canal. Furthermore, the chloride and sulfate content of the shallow waters is intermediate between those of the canal and of wells farther east.

Chemical analyses of waters in the Bountiful district, in parts per million

(Analysts, R. T. Kiser, E. L. Singleton, and W. M. Webster, U. S. Geological Survey, except as indicated)

Analysis number	Stream	Date sampled 1947	Length (feet)	Temperature (°F.)	SiO_2	[a]Ca	[a]Mg	[a]Na & K	HCO_3	[a]SO_4	Cl	NO_3	Total hardness as $CaCO_3$	Total solids (calc.)
					Streams									
1	Ricks Creek	8-28			14	12	4	9	58	10	6	1.7	48	86
2	Barnard Creek	8-28			15	22	7	19	106	19	14	.1	86	149
3	Parrish Creek	8- 8			17	15	5	13	74	13	9	.2	59	109
4	Centerville Creek	8- 8			18	16	5	12	76	11	9	.4	62	109
5	Stone Creek	8- 8			18	14	5	14	78	10	10	.2	56	110
6	Barton Creek	8- 8			13	20	6	13	94	11	9	.2	73	118
7	Mill Creek	8- 8			10	40	12	8	180	9	8	.2	150	176
8	North Canyon	8- 8			15	69	20	14	308	11	15	.4	254	296
9a	Bonneville Canal	[b]3-26				109	44	101	282	237	159			789
9b	Do	[b]7-17			14	108	61	172	230	325	227	T	520	1,020
9c	Do	8- 8			24	123	66	205	288	378	278	3.2	578	1,220
	[f]Location				**Springs, tunnels, and drains**									
10	(A-2-1)17abd-T	8-28	735		15	30	11	20	106	45	20	2.5	120	196
11	17bdc-T	8-28	85	56.1	12	39	15	15	160	31	18	3.5	159	212
12	17cad-S	8-28		54.6	17	47	17	27	192	53	24	.1	188	280
13	20caa-T	6-27	1,034	48.5	17	22	7	15	97	22	7	3.3	82	141
14	20ccd-D	9- 8	250	51.5	25	62	13	10	200	31	14	16	208	269
15	32bdc-D	8-28			22	73	23	25	320	21	30	4.2	276	356
16	(B-2-1)35ddb-S	8-18		52.8	27	106	177	407	586	670	490	0	992	2,180
17a	(B-1-1)14dcb-S				32	694	110	3,950		840	6,740			12,600
17b	Do	8-28		128	35	688	136	4,100	235	800	7,210		2,280	13,100

Chemical analyses of waters in the Bountiful district, in parts per million

Wells

Analysis number		Well number	Date sampled 1947	Depth (feet)	Temperature (°F.)	SiO_2	Ca	Mg	Na & K	HCO_3	SO_4	Cl	NO_3	Total hardness as $CaCO_3$	Total solids (calc.)
18		(A-2-1) 7aba-4	9- 8	450	62.3	23	30	8	23	140	16	18	2.1	108	189
19		7aba-7	9- 8	80	53.7	19	36	9	14	132	27	16	1.8	129	188
20		7aca-4	6-27	61	53.2	16	25	10	15	108	28	13	.3	104	160
21		7bdc-1	6-27	400	60.0	4	2	2	50	[d]94	2	30	.2	14	138
22		7dba-2	6-27	138	56.8	20	16	12	21	118	13	16	2.5	90	159
23		18aab-2	5- 9	60	49.5	17	20	7	10	78	20	11	1.4	80	125
24		18abd-7	5- 9	280	52.2	20	32	14	17	134	26	21	10.	138	206
25		18cba-1	6-27	100	54.5	19	40	15	20	160	23	32	5.4	162	233
26		18cba-14	6-27	294		22	14	4	68	175	16	27	.3	50	237
27	*	18dcd-1	9-16	140		19	81	31	34	176	119	84	22.	330	477
28	*	19aad-1	8- 8	85		19				228	149	114	4.		
29	*	Do	9- 8	255		21	71	23	43	197	94	66	16.	272	431
30	*	19dbc-1	8- 8	380	55.6	22	69	19	30	232	42	45	22.	250	363
31		31ada-1	8- 8	195		14	75	22	22	296	37	30	1.9	278	348
32	*	31bbc-1	8- 8	139		13	113	40	119	380	169	133	38.	446	812
33		31caa-1	6-27	294		13	78	26	31	336	27	41	8.1	302	390
34	*	31cbb-1	8- 8	290		18	59	17	54	274	22	58	6.4	217	369
35		31cdd-2	8- 8	284		18	78	24	27	326	24	37	8.7	293	377
36		(A-1-1) 6aaa-1	8- 8	447		13	65	39	23	354	19	44	0.2	322	378
37		6acb-1	12-31	405		12	70	20	36	292	25	44	9.2	256	360
38		(B-2-1) 12cda-1	6-26	75	54.1	45	25	10	69	256	3	28	.2	104	307
39		12dad-1	8- 8		56.8	59	18	7	75	254	3	18	.2	74	306
40		13aab-1	5- 9	264	59.4	23	12	4	80	179	15	30	1.7	44	260
41	*	13acc-2	5- 9	180	54.1	21	72	25	26	194	78	62	15.	282	395
42		13bbb-3	6-26	800	77.5	29	70	10	121	240	9	193	0	215	550

Chemical analyses of waters in the Bountiful district, in parts per million

Wells—Continued

Analysis number	Well number	Date sampled 1947	Depth (feet)	Temperature (°F.)	SiO2	Ca	Mg	Na & K	HCO3	SO4	Cl	NO3	Total hardness as CaCO3	Total solids (calc.)
43	*(B-2-1)13caa-2	5- 9	227	57.6	20	20	5	51	163	12	24	.0	70	212
44	* 13ddd-1	5- 9	162	52.9	10	82	33	25	202	102	74	22.	340	447
45	14aaa-2	6-26	308	61.8	21	24	6	60	214	5	23	.1	82	244
46	* 21dcb-1	6-26	454	69.2	29	29	16	148	441	3	68	.8	138	510
47	* 22dcc-1	12-31		64.9	24	35	11	74	224	11	70	.1	132	335
48	* 23bdd-1	6-26	600	67.6	25	53	13	111	212	14	170	.0	186	490
49	* 23daa-1	5- 9	300	61.3	10	18	4	70	201	13	24	1.8	61	239
50	* 23daa-2	5- 9	167	56.0	9	44	9	54	213	31	36	6.1	146	294
51	* 24aaa-7	5- 9	268	56.7	11	26	12	26	149	10	24	4.2	114	186
52	* 24add-5	10-15	148	51.8	17	74	26	35	230	77	58	22	292	422
53	* 24bad-2	5- 9	383	61.7	10	16	4	66	181	11	26	1.3	54	223
54	* 24bad-13	5- 9	100	54.0	9	94	29	39	265	97	68	30	354	496
55	* 24cdd-10	8-21	115	51.8	16	84	26	24	260	72	50	13	316	413
56	* Do	9- 9	280		18	63	30	30	144	97	82	15	280	406
57	* Do	9-27	535	56.0	17	54	9	12	184	10	24	3.1	173	220
58	* 24ddd-1	8- 8	84		16	125	32	51	285	136	115	21	444	636
59	* 25bab-1	6-27	262	51	16	78	26	26	231	67	64	11	302	402
60	* 25bbc-7	8- 8	208	54.9	19	86	29	44	262	89	77	16	334	489
61	* 25bbd-1	6-27	140	51	16	82	30	46	261	86	80	15	328	484
62	* 25cac-1	8- 8	110	53.8	19	160	51	89	410	208	160	29	608	918
63	* 25cbc-2	6-27	108	52.3	16	137	49	80	391	181	139	15	544	810
64	* 26aaa-3	5- 9	163	54.2	8	87	30	40	275	80	75	15	340	471
65	* 26aad-1	8- 8	250	57.5	19	47	15	37	191	33	44	9.6	179	299
66	* 26adc-2	8- 8	189	56	17	85	28	77	278	104	104	15	327	567
67	* 26bab-5	6-26	272	62.2	18	22	6	95	224	26	52	4.3	81	334

Chemical analyses of waters in the Bountiful district, in parts per million

Wells—Continued

Analysis number	Well number	Date sampled 1947	Depth (feet)	Temperature (°F.)	SiO_2	Ca	Mg	Na & K	HCO_3	SO_4	Cl	NO_3	Total hardness as $CaCO_3$	Total solids (calc.)
68	*(B-2-1)26bab-7	6-26	422	67.1	17	52	15	174	198	24	271	.0	191	650
69	* 26bba-1	6-26		60.0	18	38	9	84	180	15	107	1.4	132	361
70	* 26bdd-5	6-26	400	66.9	16	20	7	140	240	20	135	2.3	77	440
71	* 26cac-1	6-26	202	61.6	17	40	12	230	174	9	354	.2	150	748
72	* 26dad-4	6-27	160	54.7	16	94	35	56	310	96	96	14	378	560
73	* 26dca-3	8- 8	270	64.3	16	15	3	103	224	12	56	1.5	52	317
74	* 26dcd-1	8- 8	200	60.3	16	45	15	83	272	35	62	10	174	400
75	* 26dda-2	5- 9	300	57	8	60	23	31	296	16	32	8.6	244	324
76	* 27ada-1	6-25	100	57	18	14	5	80	229	10	22	.0	54	262
77	* 27ddd-4	5- 9	500	67.3	8	66	20	331	125	3	610	.0	246	1,100
78	* 28aca-1	9- 9	412	69.7	27	21	9	127	232	3	102	1.5	88	420
79	* 34ada-3	5- 9		60.0	9	36	10	161	264	55	141	10	131	552
80	* 34add-1	(e)	285	64.5		155	49	416	75	26	988		588	1,670
81	* 34add-2	(e)	410	66.3		36	19	379	194	63	304		168	897
82	* 34add-3	(e)	217	60		39	17	132	213	19	156		167	468
83	* 34daa-2	(e)	530	66		70	25	426	234	40	683		277	1,360
84	* 35ada-6	5- 9	225	53.5	8	130	43	77	362	147	140	28	502	751
85	* 35caa-1	6-26	248	59.0	19	74	24	90	270	84	115	9.0	283	548
86	* 35ddb-2	9-18	180	61.0	18	79	24	122	204	149	162	13	296	668
87	* 36dba-1	9- 8			23	482	236	325	216	1,720	635	19	2,170	3,550
88	* 36cad-5	10-15	63		19	124	38	89	306	177	148	18	466	764
89	* 36dab-1	9-16	126		19	139	46	166	284	389	164	34	536	1,100
90	*(B-1-1)1aaa-1	8- 8	258		24	83	27	48	275	50	93	16	318	476
91	* 1abb-1	9- 8	52		23	202	41	43	356	214	168	19	672	885
92	* 1cbc-1	5- 9	185		18	57	20	96	294	25	114	6.1	224	481

Chemical analyses of waters in the Bountiful district, in parts per million

Wells—Continued

Analysis number	Well number	Date sampled 1947	Depth (feet)	Temperature (°F.)	SiO_2	Ca	Mg	Na & K	HCO_3	SO_4	Cl	NO_3	Total hardness as $CaCO_3$	Total solids (calc.)
93	*(B-1-1)2abd-1	9-19		56.1	42	46	15	108	354	1	86	0.2	176	472
94	* 2aca-1	6-26	327	65.3	22	64	21	226	224	45	355	8.6	246	852
95	* 2aca-2	6-26	447	65.6	25	96	31	321	183	38	618	4.7	367	1,220
96	* 2ada-1	6-26	645	67.7	19	181	57	501	114	15	1,180	1.9	686	2,010
97	* 11caa-1	8-11	75	55.6	49	73	25	68	360	4	94	2.0	285	493

a Nearest whole part per million.

b Analysis by U. S. Bureau of Reclamation.

c Analysis reported by R. B. Riggs in U. S. Geol. Survey Bull. 42, p. 148, 1887.

d Includes 22 ppm. CO_3.

e Analysis by U. S. Soil Conservation Service in 1947.

f For description of numbering system see p. 85.

*Located west of the Upper Bonneville canal.

Although the upper Bonneville canal can thus be identified as a source of the mineralized waters in many wells to the west, it cannot be held solely responsible for the high mineral content of certain well waters. Four wells and one spring in the southern part of the district yield water more concentrated than that of the Jordan River; the easternmost of the four wells yields a calcium-sulfate water (analysis 87) and the others yield sodium-chloride waters. The wells yielding sodium-chloride waters are close to or west of the Warm Springs fault, and it is evident that sodium-chloride waters get into the ground-water reservoir from deep sources, for the temperature of ground water in this area is prevailingly higher than in the area east of the fault (p. 117).

It has already been suggested that the waters from the upper Bonneville canal are introduced into the shallow aquifer of the ground-water reservoir to a greater extent than into the deep aquifers. The analyses show that, in areas north and east of the canal, waters from all but one of the wells sampled, whether shallow or deep, have less than 400 ppm. of dissolved solids. West of the upper canal, however, all but two of the 22 wells less than 200 feet deep yield water with a concentration greater than 400 ppm. Of the 31 wells 200 to 400 feet deep west of the canal, eleven yield water with less than 400 ppm. of dissolved solids comparable to water from wells of similar depth north and east of the canal. These wells evidently tap aquifers that have not been recharged by water from the upper Bonneville canal. Conclusive statements cannot be made, on the basis of total dissolved solids, concerning the effect of the canal upon the numerous deep wells that yield water with more than 400 ppm. of dissolved solids, because of the possibility that part of that mineral content has been derived from deep sources or from moderately saline aquifers of pre-Lake Bonneville age in the valley fill.

The sulfate radical (SO^4) appears to be the best of the individual components of the chemical analyses for tracing the movement of the Bonneville canal waters into the aquifers. A sample of the canal water collected in August 1947 carried 378 ppm. of that radical. Only two sampled wells and one spring (analyses 16, 87, and 89) in the Bountiful district have higher concentrations of sulfate. The streams, as well as all sampled springs, drains, and wells east and north of the upper canal, have concentrations of less than 55 ppm. of sulfate. Of the wells located west of the canal, only 5 of the 31 sampled wells that are more than 200 feet deep had sulfate in excess of 55 ppm. But 18 of the 22 sampled wells less than 200 feet deep yielded water with sulfate greater than 70 ppm., of which 11 carried sulfate in excess of 100 ppm. It is concluded, therefore, that the upper Bonneville canal and the lands irrigated therefrom lie upon the recharge areas of aquifers furnishing water to wells less than 200 feet deep in the Bountiful district; that the water moves generally westward and is mixed in varying degrees with waters from other sources; and that it is being discharged from artesian wells west of the canal. The lower Bonneville canal traverses areas underlain by the lake-bottom sediments of Lake Bonneville, and water taken from it for irrigation would reach the artesian aquifers only under exceptional circumstances, by way of sandy lenses in the clay and silt.

The water of the upper Bonneville canal, although it can be traced to aquifers as deep as 200 feet, does not appear in all the shallower wells west of the canal. Four wells less than 200 feet deep (analyses 50, 76, 92, and 97) yield waters of low sulfate content. Two of these wells are south of the area where canal water is applied for irrigation, and the other two are in the western part of the developed area. Thus, analytical results indicate that the canal water has not yet moved that far westward in the shallow artesian aquifer.

Sulfate content greater than 55 ppm. has been found in well waters as far west as the center of sec. 13, the eastern part of sec. 23, and the east half of secs. 26 and 35, in T. 2 N., R. 1 W., and in sec. 1, T. 1 N., R. 1 W. (see fig. 9). Thus, high-sulfate waters now occur as much as 2½ miles west of the upper Bonneville canal, or about 2 miles west of the eastern limit of the lake-bottom sediments of Lake Bonneville, which form the confining layer for the shallow artesian aquifer. Inasmuch as the use of the Jordan River water for irrigation in the Bountiful district began in 1921, the rate of movement of this water in artesian aquifers under this confining bed is computed to have been 400 feet a year on the average, or slightly more than 1 foot per day. It is inferred that movement in the eastern part of the area is several times this average rate, and that farther west, where aquifers are predominantly of finer texture and hydraulic gradients are less, the rate of movement is far less than the average rate.

Significance of chemical constituents in utilization of waters

The chemical analyses give some indication of the suitability of the waters of the Bountiful district for various uses. Water having a mineral content less than 500 ppm. is generally quite satisfactory for domestic use, unless it is hard, and water con-

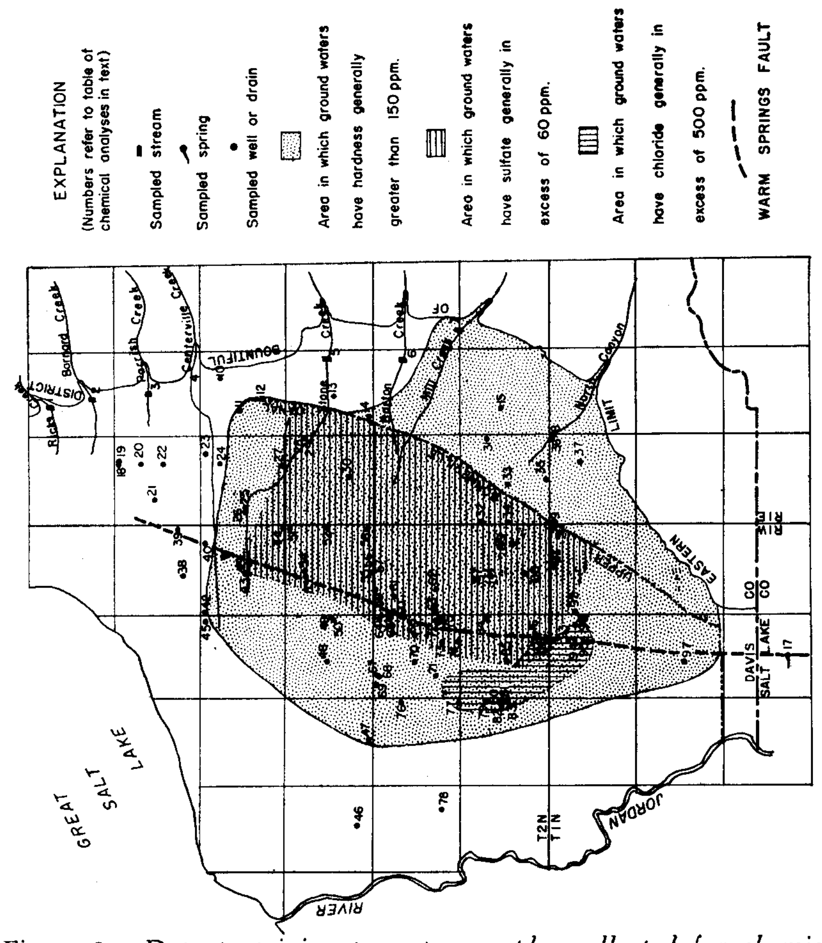


Figure 9.—*Data pertaining to water samples collected for chemical analysis.*

taining less than 1,000 ppm. is usable. When the mineral content exceeds 1,000 ppm., water is likely to be unsuitable because of objectionable taste, purgative action, corrosiveness, or other factors. In the Bountiful district the tributary streams and the majority of sampled wells and springs yield waters with less than 500 ppm. of dissolved matter, and only seven sampled wells, all in the southwestern part of the area, yield water with more than 1,000 ppm. All seven of these waters have chloride in excess of 500 ppm., which is enough to give an appreciably salty taste.

The hardness, computed from the quantities of calcium and magnesium present, is an indication of the soap-consuming and scale-forming potentialities of the water. A few wells in the northern part of the district yield soft water with total hardness less than 50 ppm. and many other wells in the vicinity have a hardness of less than 150 ppm. Laundries might find it profitable to soften these waters, but the hardness is not sufficient to interfere with the use of water for most purposes. The majority of wells, particularly in the southern two-thirds of the area, yield waters having a hardness greater than 150 ppm., sufficient to justify removal by softening processes prior to use in boilers or for washing. The sulfate content in many of these waters is sufficiently high that a part of the hardness is of the non-carbonate or "permanent" type, which produces scale difficult to remove from boilers and also increases the cost of softening. Silica, present in normal amounts in most of the Bountiful district, also contributes to scale in boilers. The areas where hardness or chloride content is excessive for normal uses, as well as where significant concentrations of sulfate result from application of Bonneville Irrigation Company waters, are shown in figure 9.

The chemical analyses of the waters of the Bountiful district give little indication of the sanitary quality of the waters. Some degree of pollution might be expected in each of the streams draining the Wasatch Range, but much of the drainage area is closed to stock and not well developed for recreational use, so that pollution is presumed to be slight. The water pumped by the Bonneville Irrigation Company from the Jordan River, however, is highly polluted, for it carries sewage and other wastes from Utah Valley as well as from Jordan Valley. In addition, the city of Bountiful and many unincorporated settlements are situated upon the recharge area for artesian aquifers, and sewage and wastes discharged into cesspools and septic tanks may enter the ground-water reservoir.

The nitrate and chloride ions in ground water are sometimes indicative of pollution, for both may be derived from organic wastes, although both may also be derived from inorganic sources. In the Bountiful district the sampled streams, water tunnels, and deep wells have a nitrate content less than 10 ppm., but the water from 25 wells that tap the shallow artesian aquifer has a nitrate content greater than 10 ppm. Commonly, in these 25 wells the chloride content, also, is greater than that in nearby wells which carry only small amounts of the nitrate ion. Inasmuch as this aquifer is recharged in an area where sewage and wastes are placed in the ground, the nitrate and chloride ions may well have been derived, at least in part, from organic wastes.

No comprehensive study has been made to determine the distance that harmful bacteria may be carried from a source of contamination, under varying conditions of permeability and rate of movement of ground water. A high rate of destruction of bacteria is presumed because of the low temperature of the water, the general absence of food supply below the root zone, and the effect of drying because of changes in the level of ground water. The rate of movement of ground water in much of the area is believed to be only a few feet a year, and bacteria therefore may travel only a short distance from contaminating sources before they die. Thus the danger of harmful pollution is believed to be greatest within the area irrigated by the Bonneville canal and occupied by numerous residences, and progressively less toward the lower, western part of the district. In the critical areas near Bountiful deeper wells are less likely to yield contaminated water than are wells that reach only the water table. The present status of information concerning bacterial contamination of ground-water supplies has been summarized in greater detail in a recent article[42].

GROUND-WATER HYDROLOGY

General relations

The unconsolidated sediments that compose the valley fill in the Bountiful district yield by far the most important supplies of ground water. All wells and most of the springs and the tunnels and drains constructed for water supply within the district obtain water from these sediments. The following discussion therefore relates almost entirely to the water in the unconsolidated materials. However, water occurs also in the bedrocks that under-

---

[42] Thomas, H. E., Sanitary quality of ground-water supplies: The Sanitarian (in press).

lie these unconsolidated sediments and that form the Wasatch Range to the east. Because the occurrence of water in these formations is different in many ways from that in the valley fill, the bedrock is considered briefly first.

Water in the bedrock

The bedrock formations that crop out in the Wasatch Range east and south of the Bountiful district are generally much less permeable than the valley fill within the district. These rocks include chiefly gneiss and schist, with subordinate amounts of conglomerate, sandstone, shale, limestone, and quartzite in the southern part of the area. Ground water occurs in fractures and joints in these rocks, derived from downward penetration of precipitation upon the area of outcrop, or from percolation through the residual soil mantle or other debris which covers a large proportion of the bedrock in the mountains. In his studies of the Farmington Creek drainage basin, Croft[43] has observed practically no surface runoff from melting snow banks except in beds of stream channels, and has concluded that "(1) practically all water from melted snow or rains of moderate intensity passes through the soil mantle [regolith] before it becomes available for stream flow; and (2) the mantle has a high capacity to retain water that otherwise would be available for stream flow." He also suggests that observed differences in annual runoff from small basins of similar characteristics may be due, at least in part, to differences in infiltration from the regolith to the underlying bedrock. The water that enters the bedrock may reappear as springs or seeps, especially in the beds of the main streams, and thus become the principal source of the base flow of those streams. Marked changes in the ratio of runoff to precipitation from year to year are attributed to changes in ground-water storage, either in the bedrock or in the overlying mantle (p. 128). Some of the water that enters the bedrock, and a large proportion of that retained temporarily in the regolith, is dissipated in transpiration and evaporation within the mountain area.

Within the Bountiful district there are several small outcrops of pre-Cambrian rocks along the mountain front at elevations as low as 4,600 feet. Some of these outcrops are in stream channels, others along the steep scarp that forms the west front of the Wasatch Range. In all respects these rocks are similar to those cropping out above the highest Bonneville shore line and

---

[43] Croft, A. R., Some factors that influence the accuracy of water-suppdy forecasting in the intermountain region: Am. Geophys. Union Trans., vol. 27, pp. 375-388, 1946.

east of the district. Very few attempts have been made to develop water from these rocks, and those attempts have met with mediocre success. As an example, a tunnel was bored 735 feet into pre-Cambrian schist at the level of the Provo shore line. The average yield of this tunnel, together with that of two shorter tunnels farther south, is only about 4 gallons a minute in late summer.

No wells obtain water from the bedrock underneath the valley fill. Well drillers have reported "hard rock" or "rock ledges" in the bottoms of the Val Verda well (A-1-1)6aaa-1, (p. 85) and the Schluter well, (A-2-1)31ada1,[44] but the water in those wells is derived from unconsolidated materials above the "rock."

Water in the valley fill

The unconsolidated sediments of the valley fill are far more permeable than the consolidated rocks of the mountain masses. They include discontinuous, lenticular, and commonly elongated bodies of clay, sand, gravel, and boulders deposited by streams; bodies of unsorted clay, sand, and larger fragments formed near the mountains by torrential streams—the mud-rock flow type of deposit; and lacustrine beds of gravel, sand, silt, and clay, generally more extensive and well-sorted. Ground water moves freely in the well-sorted beds of permeable gravel and coarse sand, but in the finer materials, including clay, silt, the finer grades of sand, and the unsorted products of mud-rock flows, the movement of ground water is restricted. In general the movement of ground water is from the mountains westward toward Great Salt Lake, following approximately the drainage pattern established by streams on the land surface.

The ground-water reservoir in the valley fill, as discussed in this report, includes the entire body of ground water that lies within the Bountiful district. For convenience in description, however, this reservoir may be divided into an upper portion, in which ground water is obtained largely from drains, tunnels, and pumped wells; and a lower portion in which most water is obtained from wells by artesian flow. The surface boundary between these two portions is placed at the upper Bonneville canal, 4,500 feet above sea level, which, as pointed out in the section on geochemistry, introduces water of different and distinctive chemical character into the ground-water reservoir. East of this canal the Lake Bonneville beds consist essentially of

---

[44] For explanation of well-numbering system, see p. 85.

permeable sand and gravel representing the shore deposits of the "Intermediate", Bonneville, and Provo stages; and the underlying pre-Lake Bonneville beds are predominantly unsorted and relatively impermeable alluvial deposits of torrential type. West from the canal, by contrast, the Lake Bonneville beds are represented chiefly by the relatively impermeable lake-bottom sediments, and the underlying pre-Lake Bonneville beds are increasingly well sorted and more permeable, with a progressively smaller portion of the mud-rock flow type of deposit.

Ground water east of the upper Bonneville canal

The unconsolidated sediments east of the upper Bonneville canal include a large proportion of the unsorted products of torrential stream deposition, commonly identified in well logs as "clay and gravel," which comprise more than half the materials penetrated in wells. (see figs. 4 to 8). Unsorted materials are encountered also in wells west of the canal, but those are thinner and interbedded with well-sorted clays, sands, and gravels, the proportion of well-sorted materials increasing progressively westward. The water derived from the wells and drains in the eastern portion of the ground-water reservoir has been shown to be similar in chemical constituents to that which flows in nearby streams from the watershed area farther east.

Fluctuations of water level in wells

Fluctuations of water levels in wells are caused chiefly by variation in the rates at which water is taken into or discharged from the aquifers. These fluctuations therefore afford a basis for determining and analyzing the factors that affect the occurrence and movement of the ground water. Information concerning fluctuations is based upon data collected from observation wells; detailed data are obtained from recording gages which provide continuous records of the non-pumping ("static") level in wells, and records from other wells are based upon periodic measurements of water level with a steel tape or of pressure head with a mercury manometer gage. These records are published annually in the series of water-supply papers of the Geological Survey[45].

The graphs assembled in figure 10 show the types of fluctuations observed in wells east of the upper Bonneville canal, and also certain factors which appear to cause some of those fluctuations. Hydrographs of nine wells are presented, of which the Knighton

---

[45] Sayre, A. N. and others, Water levels and artesian pressure in observation wells in the United States in 1945; same in 1946. (In preparation.)

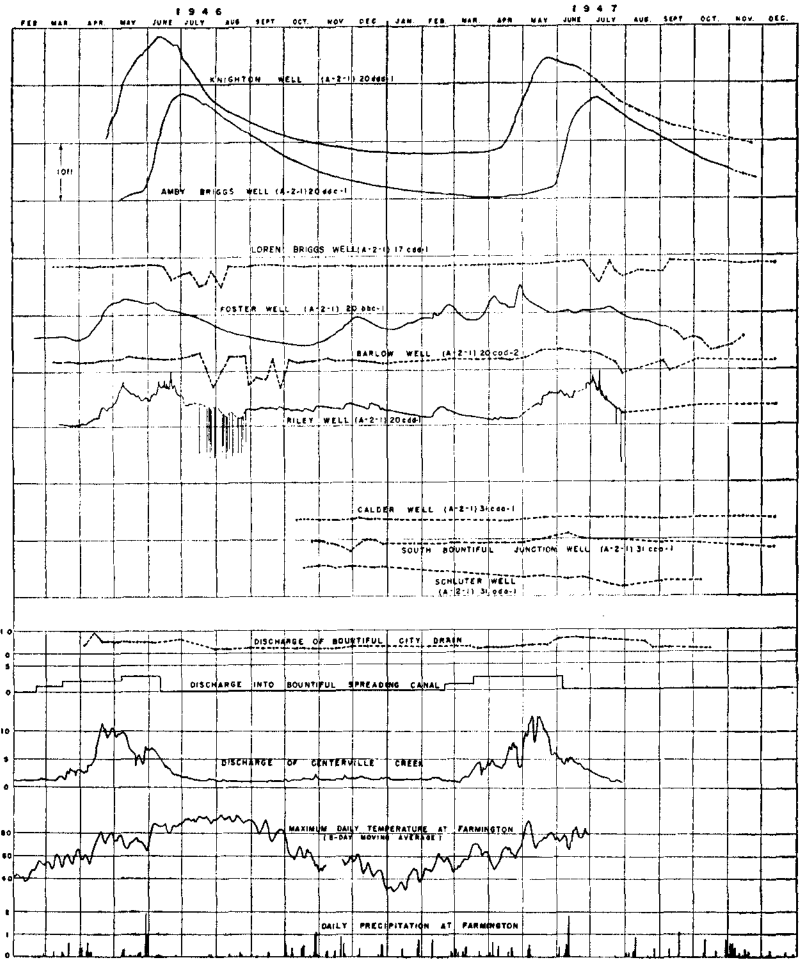


Figure 10.—*Hydrographs of nine wells east of the upper Bonneville canal, and data related to ground-water fluctuations.*

and Amby Briggs wells are located on the Provo terrace east of Bountiful, above most of the irrigated lands; the Foster, Barlow, and Riley wells are in irrigated areas lower on that bench, where numerous drains and tunnels have been dug into the hillside for water supply; the Loren Briggs well is just east of irrigated land and north of the area of drains and tunnels; and the Calder, South Bountiful, and Schluter wells are deep wells in the Val Verda area about 2 miles south of Bountiful. The hydrograph of Centerville Creek, based on records of the Intermountain Forest and Range Experiment Station, is offered as a substitute for Stone, Barton, and Mill Creeks, which traverse the area where the above wells are situated but for which no data are available as to daily discharge. These streams, like Centerville Creek, head at the crest of the Wasatch Range and drain large areas of mountainous land above a 7,000-foot altitude, so that the daily discharges are likely to be roughly proportional to that of Centerville Creek. The discharge into the Bountiful spreading canal and the outflow from the Bountiful City drains are based on weir measurements. The precipitation and maximum temperature at Farmington are obtained from records of the U. S. Weather Bureau, 5-day moving averages being used for the temperature graph.

The interrelation of the several factors that affect groundwater levels is clearly shown by comparison of the graphs in the lower part of the figure. Rainstorms of 0.5 inch or more at Farmington cause an appreciable increase in the flow of Centerville Creek, ranging from 0.2 to 1.0 second-foot during the period from July to February. During the spring freshet, rainstorms cause a more pronounced increase in stream flow, as typified by the storms of May 29-30, 1946, and May 4-9, 1947, presumably because the rain falls upon melting snow and saturated regolith in the mountainous areas. Close correlation is also apparent between stream flow and maximum temperatures during the spring. The peak discharges of the stream, obviously caused by melting snow, occur when the maximum temperatures in the valley exceed 70° for a sustained period. This condition occurred by mid-April in 1946, but not until May 1 in 1947.

In the wells fluctuations of water level result from additions to the ground-water reservoir from rainfall, melting snow, irrigation of adjacent land, water spreading for artificial recharge, and seepage from streams. The effects of pumping from wells and discharge from drains can also be discriminated.

Rainfall may cause the water levels in certain wells to rise under favorable conditions. Rains of an inch or more in 24 hours, particularly if they follow shortly after other storms that have brought soil moisture close to field capacity, have affected the water levels in the Foster and Riley wells within a few days. The storms of May 29-30, October 27-30, and November 20-24, in 1946, and June 7-12, 1947, furnish the best examples. An extended rainy period may cause a protracted rise of water levels in wells. In October 1946, the month of heaviest precipitation in the period covered by the graph, 5.36 inches of rain fell at Farmington, and this was followed by 2.50 inches during November. The rise of water level in the Foster well from October 28 to December 5, amounting to nearly 5 feet, is attributed chiefly to that rainfall. In the Riley well the storms of that period caused several individual rises of water level, each amounting to half a foot or more, but the cumulative effect was much less, presumably because of the discharging of nearby drains.

Melting snow and resultant runoff in adjacent short gullies have caused marked fluctuations of water level in both the Foster and Riley wells. Beginning about April 8, 1946, the water levels in both wells rose rapidly, correlating closely with the increase in maximum temperature, and this rise was accelerated about April 18, when daily maximum temperatures exceeded 80°. That these rises are due to local melting of snow rather than to increased flow of streams fed by snow melt at high elevations is more clearly indicated in 1947. Rises of water level beginning February 10 in both the Foster and Riley wells are correlated with a period of unseasonably warm weather, which, however, caused no increase in flow of Centerville Creek and thus evidently melted no snow at high elevations. High temperatures about March 20 also appear to have caused local melting of snow, for the water level in the Foster well rose about 4 feet in the two weeks following that date, at a time when the flow of Centerville Creek was only slightly increased above the winter minimum. On the other hand, the high temperatures of the first week in May, which brought the peak of the spring freshet in Centerville Creek, caused no sharp rise of water level in either well, presumably because the snow in the vicinity of the wells had already melted.

Irrigation of adjacent land has caused marked fluctuations in the Riley well, shown especially well in June 1946 and July 1947. The water level in the well rises 1 to 4 feet within a few hours of the irrigation and declines almost as rapidly, so that within a day or two it has resumed the trend shown by the hydrograph before the irrigation.

Water spreading for artificial recharge of the ground-water reservoir is inferred to have been chiefly responsible for the major rises of water level in the Knighton and Amby Briggs wells during 1946 and 1947. These wells are located respectively 1,740 and 2,660 feet west of a canal which has been used by the City of Bountiful since 1941 for experiments in artificial recharge. Quantities of water diverted into this canal and thence into oak-brush-covered areas below the canal during 1946 and 1947 are shown in the lower part of figure 10. In 1947 the water level in the Knighton well began to rise 40 days after water was first diverted into the spreading canal, indicating that the rate of movement from canal to well was about 45 feet per day. In the Ephraim Thalmann well (A-2-1)21cbc-1 (not represented in fig. 10), 1,140 feet north of the Knighton well, the water level began to rise about 15 days later than in the Knighton well, and the rate of movement from the canal was computed to be approximately the same. West of the Knighton and Thalmann wells the rate of movement was somewhat less. In the Amby Briggs well, 1,000 feet west of the Knighton well, the water level began to rise 45 days later than in the Knighton well, and the rate of movement was computed to be about 20 feet per day. In the Bountiful City drain, there was an appreciable increase in discharge about 40 days after the rise of water level in the Thallmann well, 1,560 feet east of the outlet to the drain. If the water from the canal continued westward at this same rate, it should have reached the Riley well by the end of September. No appreciable rise of water level in that well is shown by the hydrograph, but Mr. Riley and his neighbors reported a slight increase in flow from their drains during the latter part of September.

Seepage from streams is not an obvious factor in ground-water fluctuations except in wells that are close to the stream channels. The Eunice Orden well (A-2-1)20bdd-1 is a good example of a well clearly affected by stream seepage. The water level in this well, which is 100 feet north of the channel of Stone Creek, rises to within a foot or two of the water surface in the adjacent channel when the stream is flowing. After the stream discharge ceases, the water level in the well declines gradually to as much as 13 feet below the bed of the channel. The fluctuations in the Foster well attributed to local melting of snow are more pronounced than similar fluctuations in other wells, probably because the well is within 145 feet of a small gully that flows in early spring, owing to melting of snow at slightly higher elevations. In general, however, the effects of streams are either lacking or are masked by the larger fluctuations attributed to other causes. The hydrograph of the Riley well, 870 feet north of the Barton Creek channel, shows a rough correlation with the stream-flow hydrograph as represented by Centerville Creek, but the effects of pumping and of recharge from irrigation, rainfall, and snow melt are much more pronounced. The Loren Briggs well, half a mile north of Stone Creek, obviously is not affected by seepage from that stream. Indeed, the very slight rise of water level each spring, amounting usually to less than half a foot, indicates that recharge from all sources is very slight. This well is remote from the area affected by water spreading, and from gullies that flow during the period of local snow melting.

Pumping from the Riley well has caused sharp fluctuations in water level in July and August of both years. Ordinarily this well is pumped for only an hour or two at a time to irrigate a small garden. During a test on September 30, 1947, the well was pumped for 79 minutes, discharging at a constant rate of 27 gpm. At the end of that period the drawdown was 7.0 feet, and the specific capacity was computed to be 3.9 gpm. per foot of drawdown. This pumping had no observable effect upon a dug well 135 feet to the south. The small discharge of this well is characteristic of the wells used in this area. The hydrograph of the Riley well is believed also to typify the effect of pumping upon the water table. The water level in the well drops rapidly while the pump is operating, but rises almost as rapidly when pumping ceases. At the end of the pumping season the non-pumping water level is 1 or 2 feet lower than it would be if there had been no pumping. In general, the effects of pumping are of the same order, but opposite in direction, as the effects of irrigation of land adjacent to the well. Pumping of the Loren Briggs and Barlow wells causes fluctuations similar to those in the Riley well, as shown by periodic measurements.

Discharge from a nearby drain is inferred to be chiefly responsible for the fairly constant position of the water level in the Barlow well, which is 1,500 feet west of the Briggs well and directly down the slope from the spreading canal. Except when the pump is operating, the water level in this well is generally 23 to 25 feet below the land surface, a constancy from season to season that contrasts with the marked fluctuations of other wells in the vicinity. A drain 1,200 feet long, with its outlet 25 feet north of the Barlow well, is doubtless responsible for this condition, the drain discharging water in greater quantities as the regional water table rises. It is noteworthy that the water level in the Barlow well is highest in May, June, and July of each year, when the discharge from the Bountiful City drain is greatest. This is also the time of heaviest irrigation.

The hydrographs of the three deep wells in the Val Verda area show no marked effects of any of the individual factors that have been described above. The water levels in the Calder and South Bountiful wells rise during May and June, probably owing to a combination of the factors that were found to contribute to contemporaneous rises of water level in the shallow wells farther north. The water level in the Schluter well declined appreciably during 1947, perhaps because the aquifer tapped by that well is so thoroughly insulated by impermeable material that even the small quantity of water pumped by the well is not replaced.

Water table

About 55 wells are located east of the upper Bonneville canal. The majority of them are east of Bountiful between the canal and the Provo shore line, and are wells dug into the shore facies of the Lake Bonneville beds, ranging in depth from 15 to 75 feet. They penetrate only a few feet into the zone of saturated materials and obtain water from gravel or coarse sand under water-table conditions.

Farther south about a dozen wells have recently been drilled to depths of 195 to 775 feet. These wells are in pre-Lake Bonneville alluvium and have generally penetrated a considerable thickness of unsorted and relatively impermeable materials to obtain water from underlying thin gravel beds. The water from these deep gravels was reported by the drillers to rise several feet in most wells when the gravels were encountered, and it is inferred, therefore, that the water is under some artesian pressure, although the overlying unsorted materials may be saturated to some unknown level above the water-bearing strata. The record of drilling of the Bountiful City well (A-2-1)29cab-1 indicates that in the unsorted materials of the pre-Lake Bonneville beds the upper limit of the zone of saturation sometimes cannot be determined, even within wide limits. On October 15, 1946, after drilling had been halted for several weeks at 280 feet, the depth to water was 116 feet; on October 1, 1947, when the well was 504 feet deep and drilling had ceased for another 5 months, the water level was 172 feet below the surface; and on January 28, 1948, when the well was 775 feet deep, the depth to water was 218 feet. The relation of the water levels in these deeper wells to the water table determined in the wells farther north thus is not clear. These water levels have been used to extend southward the contours of the water table defined in dug wells east of Bountiful, although it is realized that several piezometric surfaces may be involved.

The contours east of the upper Bonneville canal on plate 2 are intended only to present average conditions of ground-water occurrence in an area where the average permeability of saturated sediments is low, as attested by drilling records, yield of wells, and the steep slope of the water table. The number of wells in the area is entirely inadequate to define the detailed form of the water table, and it is likely that if adequate data could be obtained the area would be seen to have perched water horizons, artesian conditions, and water-table discontinuities that are not apparent in the simple picture presented here.

As defined by water-level measurements in 30 wells, the water table in the area east of the upper Bonneville canal has a steep westward slope. Contours on this surface in plate 2 show the gradient to be fairly uniform from east to west, increasing from about 250 feet per mile in the vicinity of Val Verda to 450 feet per mile east of Bountiful. Wells are so spaced as to indicate slight bulges in this generally smooth surface along Stone and Barton Creeks, but there are no wells to indicate details of form adjacent to Mill Creek. The slope of the water table approximates the general configuration of the land surface along the Wasatch mountain front and the City Creek spur farther south, as shown by the broad southwestward swing of the contours in the vicinity of North Canyon. East of Bountiful the water table has a gradient equivalent to that of the general land surface, and it is approximately as far below the surface at 8th East Street as at the Provo shore line. To the south, however, the gradient is less steep than the land surface; near North Canyon the projected water table is about 125 feet below the upper Bonneville canal and twice as far below the Provo shore line.

The better-sorted and more permeable shore gravels of the Lake Bonneville beds in this area obtain water from adjacent unsorted and less permeable material, and where these permeable beds have a slope less than that of the land surface, springs, seeps, or perched water tables result. The most important of these permeable zones is the gravel in the shore deposits of the Provo stage. The water originally appearing at the surface near the base of these gravels has been developed for water supply by about 50 drains and tunnels, which are claimed to have a maximum discharge of nearly 6 second-feet. In this area, particularly, the form of the water table may be inferred to be complex because of the continuous discharge from the drains and tunnels; also, its position doubtless changes markedly from season to season in response to the fluctuations observed in wells, being generally closer to the surface during the late spring and summer than at other times of the year.

Source, movement, and disposal of ground water

The principal source of ground water in the area east of the upper Bonneville canal is precipitation upon the area and the adjacent flanks of the Wasatch Range. The streams carrying water from higher elevations of the Wasatch Range make a small contribution to this ground water, as shown by the contours in the vicinity of Stone and Barton Creeks on plate 2, but the fluctuations of water level in wells indicate that appreciable effects of stream seepage are limited to wells within a few hundred feet of the stream channels. The streams also are a source of water for irrigation in the area, some of which percolates downward to the ground-water reservoir. Recharge is greatest during the spring, from melting snow and precipitation at a time when soil moisture is close to field capacity. Rainfall later in the year may also add to the ground-water reservoir, provided that the soil-moisture deficiency is first satisfied.

Water that has entered this portion of the ground-water reservoir moves westward down a steep gradient through materials that are for the most part relatively impermeable. Where it encounters permeable zones, such as the Lake Bonneville shore deposits, the water may move through them at a lesser gradient and may appear at the surface as springs or seeps. Drains and tunnels have been developed at the base of several of these permeable strata to provide water for irrigation. In part, this water is transpired or evaporated in the soil zone, but in part, also, it may percolate downward and rejoin the ground-water reservoir. Locally, particularly along the courses of the stream channels, the water table may be near enough to the surface that it can be reached by plants, so that some water is lost from the reservoir by transpiration.

Except for the quantities used for irrigation and transpired east of the upper Bonneville canal, the water in this upper part of the ground-water reservoir moves underground into the part of the Bountiful district that lies west of the canal.

Ground water west of the upper Bonneville canal

The valley fill west of the upper Bonneville canal comprises chiefly the lake-bottom sediments of the Lake Bonneville beds, underlain by pre-Lake Bonneville beds and older sediments. The sandy shore facies of the Lake Bonneville beds crop out along the canal and somewhat farther west, especially within the city limits of Bountiful, but most of the area is blanketed by lake-bottom clay or other fine-textured material 10 to 120 feet thick. Beds of gravel and sand beneath this clay bed commonly are good aquifers and yield water under artesian pressure. Many of these beds are comprised of well-sorted materials, but near the canal there is an increasing proportion of unsorted mud-rock flow materials such as are predominant in the area east of the canal, as shown in figures 4 to 6.

Fluctuations of water level and artesian pressure

The quantity of water stored in an artesian reservoir will vary from day to day, from season to season, and from year to year in response to changes in the rates at which water is taken into or discharged from the reservoir. The water level or pressure head of a well fluctuates in response to these changing canditions. The determination of the causes of these fluctuations is therefore essential to an understanding of the ground-water conditions in the reservoir. The pressure head of wells is also of prime concern to the well owner, for, other factors being equal, the amount of water discharged by a well depends upon the pressure head at the point of discharge.

Recording gages installed on 14 wells provide a detailed record of water-level fluctuations, as illustrated in figure 11. Some of the fluctuations recorded on this graph were caused by passing trains, others by changes in barometric pressure, and still others by the opening or closing of flowing wells in the vicinity. The short vertical lines that project above the general trend of the hydrograph represent the momentary change in water level caused by trains passing about 75 feet east of the well; as the train passes, its weight causes some additional pressure on the aquifer, with a consequent rise of water in the well. Changes in barometric pressure cause fluctuations in the nondischarging or static head of artesian wells; an increase in barometric pressure lowers the water level in the well, and a decrease in pressure causes it to rise. In figure 11 a combination of forces is acting upon the water level, so that the influence of barometric pressure is partly obscured. Likewise, changes in barometric pressure partly obscure the effects caused by the opening and closing of other flowing wells. However, a comparison of the hydrograph of the well with the barograph from Salt Lake City (converted to feet of water and inverted for ease of comparison), especially in the period May 6 to 10, indicates that certain fluctuations are due primarily to atmospheric changes. Prominent among the fluctuations on figure 11 are those caused by the operation of adjacent wells. It is noteworthy that fluctuations occurred in the observation well, 167 feet deep, when other wells ranging in depth from 112 to 343 feet were opened or closed. The records from this well for other periods, as well as from other wells upon which gages have been maintained, show in similar detail the effects of operation of wells in the vicinity. They show, for instance, that in certain areas, notably around Centerville, many wells are opened daily for irrigation and closed at night; that Sunday is commonly but not universally a day of rest for the wells and their owners; that in certain localities wells remain closed for several days in the midst of the irrigation season while specific crops are harvested; and that many wells are closed during midsummer rainstorms, even though the actual rainfall is light.

Seasonal fluctuations

The hydrographs assembled in figure 12 show the fluctuations of water level in selected wells over a 2-year period. Five of these hydrographs are based on gage records similar to that presented in figure 11, and three others are derived from pressure recorders. Four hydrographs are based on periodic measurements of depth to water with a steel tape, or of pressure head with a mercury gage. The hydrographs are presented in three groups, one including wells near Centerville, another comprising wells west of Bountiful, and the third, wells about 2 miles farther south. Each group includes one or two wells east of the area of artesian flow and one or more wells within that area.

The Coombs well (A-2-1)8cbc-1 is a dug well 52 feet deep, located 1,000 feet east of the area of artesian flow as it was in early 1947, and about midway between the channels of Parrish and Centerville Creeks. The water occurs under water-table conditions. The water level in this well is ordinarily lowest during the months from October to April, begins to rise within a week of the peak discharge of the two streams, rises sharply for 6 or 8 weeks to a maximum in late June or early July, and then declines gradually and regularly until October or November. The

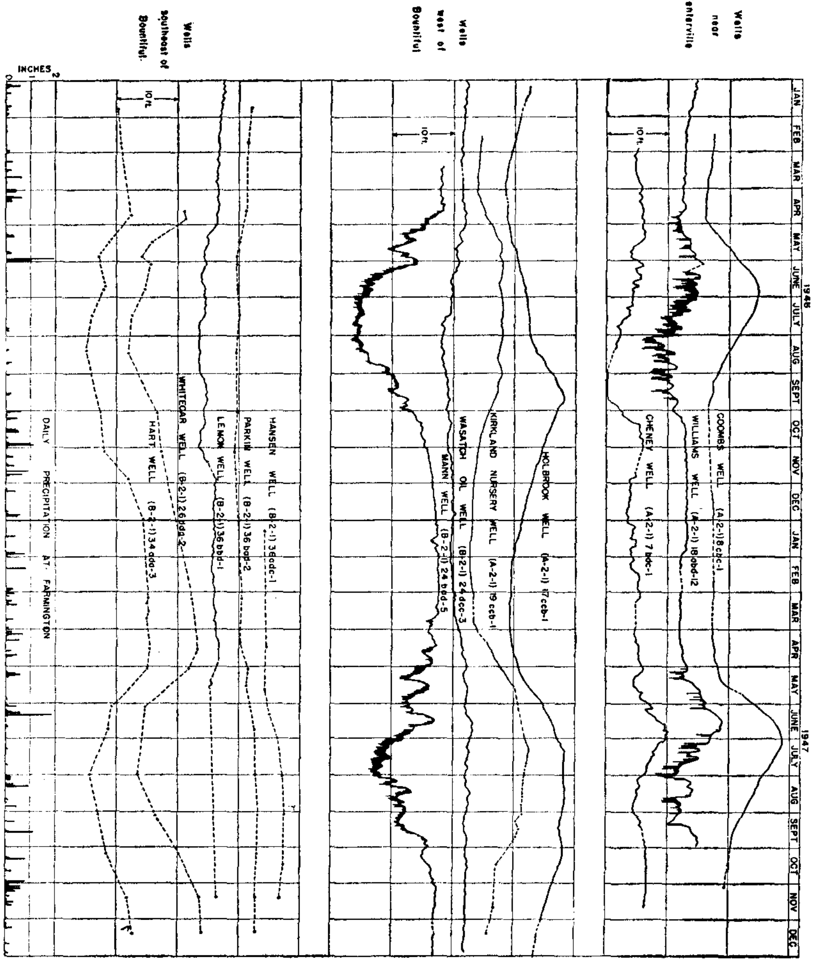


Figure 12.—*Seasonal fluctuations of water level or artesian pressure in* 12 *wells.*

annual rise of water level in this well is due primarily to recharge of the ground-water reservoir each spring by seepage from streams.

The Williams well (A-2-1)18abd-12 is an artesian well 90 feet deep and about 100 feet south of the present channel of Centerville Creek. The pressure head of this well remains fairly constant from October to April, similar to the water level in the Coombs well, and there is a coincident increase during May and part of June. In the Williams well, however, there are pronounced fluctuations of pressure head throughout the irrigation season, due to the opening and closing of flowing wells in the vicinity. In 1946 some wells were opened as early as April 20, several days before the beginning of the rise due to recharge, but in 1947 the effect of recharge is noted prior to the opening of wells. The effect of discharging wells is opposite to and tends to mask the effect of recharge. In the hydrograph the daily range of fluctuations of pressure head is indicated by a vertical line, and it is apparent that this daily operation of nearby wells caused marked fluctuations especially from June 5 to August 20, 1946, and from July 4 to August 3, 1947. The declines of April 18-25, 1946, and May 2-9, 1947, in opposition to the general rise due to seasonal recharge, are attributed to the opening of wells which thereafter flowed continuously throughout most of the irrigation season.

The Cheney well (A-2-1)7bdc-1 is an artesian well 400 feet deep. Three wells of comparable depth are located within a quarter of a mile, and there are numerous wells of higher yield and shallower depth about half a mile to the east. The hydrograph of the Cheney well is roughly parallel with that of the Williams well, but the fluctuations due to discharging wells are more pronounced, so that there is a distinct decline in May and rise in September or October, marking the beginning and end of each irrigation season. The effect of recharge in June is much more pronounced in 1947 tman in 1946.

Of the central group of wells, the Holbrook well (A-2-1) 17ccb-1 is a dug well 41 feet deep, located about 2,000 feet west of the upper Bonneville canal and 1,800 feet north of the channel of Stone Creek. As in the Coombs well farther north, the water level here is commonly lowest in March, begins to rise at the time of peak discharge of the streams, and continues to rise throughout June. In the Holbrook well, however, the effect of seepage of irrigation water from the upper Bonneville canal is clearly apparent from the hydrograph. In 1946 there was a further rise of water level during August and September from the high point reached in late June, and in 1947 the high water level reached in July was maintained throughout August and September. After September of each year the water level declines regularly until the following February or March. The Kirkland Nursery well (A-2-1)19ccb-1, a dug well 45 feet deep and less than 1,000 feet from the Barton Creek channel, exhibits characteristics similar to those shown by the hydrograph of the Holbrook well, except that the effect of seepage from the upper Bonneville canal is less pronounced.

The Wasatch Oil Company well (B-2-1)24dcc-3 is an artesian well of unknown depth which probably reaches gravel 230 to 280 feet below the surface. Wells in the immediate vicinity are used primarily for industrial purposes, and their discharge is more nearly constant throughout the year than where the draft is chiefly for irrigation. On the hydrograph the rise from March to June 1947 is attributed to the effect of recharge, and the slight rise in April 1946 may be due to the same cause. The effects of well discharge during the irrigation season are most clearly shown from May to August 1946, but they are much less pronounced than in the Williams well and in the Mann well described below.

The Mann well (B-2-1)24bad-5 is an artesian well about 120 feet deep, in an area of closely spaced domestic and irrigation wells. The daily fluctuations of pressure head and the major seasonal fluctuations in this well are due to the operation of those wells, and any effect of recharge is completely masked. During the irrigation season the diurnal fluctuation amounts to as much as 2 feet, as shown in the hydrograph. Ordinarily the season of irrigation by wells in this area begins in mid-April and continues through September, and thus is somewhat longer than in the vicinity of the Williams well farther north. The pressure head in the Mann well begins to decline as the irrigation wells are opened and reaches its minimum for the year in July. Thereafter there is a pronounced rise as nearby wells are closed for the season, and beginning in November a more gradual rise which continues until the following February or March. Many wells may be closed in the midst of the irrigation season because of rainfall, and the pressure in observation wells rises as a result. Effects of the storms of May 29-30, 1946, and June 2-12, 1947, are shown especially in the hydrographs of the Williams, Cheney, and Mann wells. It is noteworthy also that the fluctuations in the Mann well due to discharge of irrigation wells are reflected faintly in the Wasatch Oil Co. well, which is south of the area of greatest well density.

In the southern group of wells, the Hansen well (B-2-1) 36adc-1, drilled 126 feet deep, extends about 40 feet below the water table. It is about half a mile west of the upper Bonneville canal and less than a quarter of a mile from the channel of North Canyon, but more than a mile from Mill Creek. The water level in the well changes little during the winter and early spring and rises appreciably from May to September, probably because of seepage from North Canyon and later from land irrigated by the Bonneville canal. The hydrograph of the Parkin well (B-2-1)36bad-2, a nonflowing artesian well 85 feet deep, exhibits the same general trend during 1947 as that of the Hansen well. In 1946, however, its trend is more nearly parallel with that of the Lemon well.

The Lemon well (B-2-1)36bbd-1 is near the upper, eastern edge of the area of artesian flow. As shown in figure 11, the water level in this well is markedly affected by operation of adjacent wells, and the decline in May and the rise in November 1946 are attributed respectively to the starting and stopping of irrigation wells. The effect of recharge is also very pronounced in some years, as will be shown subsequently. The Whitecar well (B-2-1-)26dda-2, 300 feet deep, is close to a group of irrigation wells of large yield. Each summer the pressure head of this well declines 9 feet or more from its maximum in April, commonly reaches a minimum in late July of August, and then rises as adjacent wells are closed. The Hart well (B-2-1)34ada-3, about a mile farther west and in a region of relatively less discharge from wells, has a similar hydrograph, but the seasonal decline is less and the recovery in the autumn more gradual. Most wells in that region flow the year around.

In general the fluctuations due to recharge, whether from streams or the Bonneville canal, are greatest in the wells east of the area of artesian flow, and progressively less in wells to the west. In these western wells, particularly in the areas of most intensive ground-water development, the fluctuations due to discharge of wells are the dominant features of each hydrograph. Even in these wells, however, the changing rate of recharge to the ground-water reservoir from year to year has a marked effect upon artesian pressure, which can be discriminated on hydrographs covering many years of record.

Long-term fluctuations

Measurements of water level or artesian pressure have been made periodically in one well in the Bountiful district since 1931,

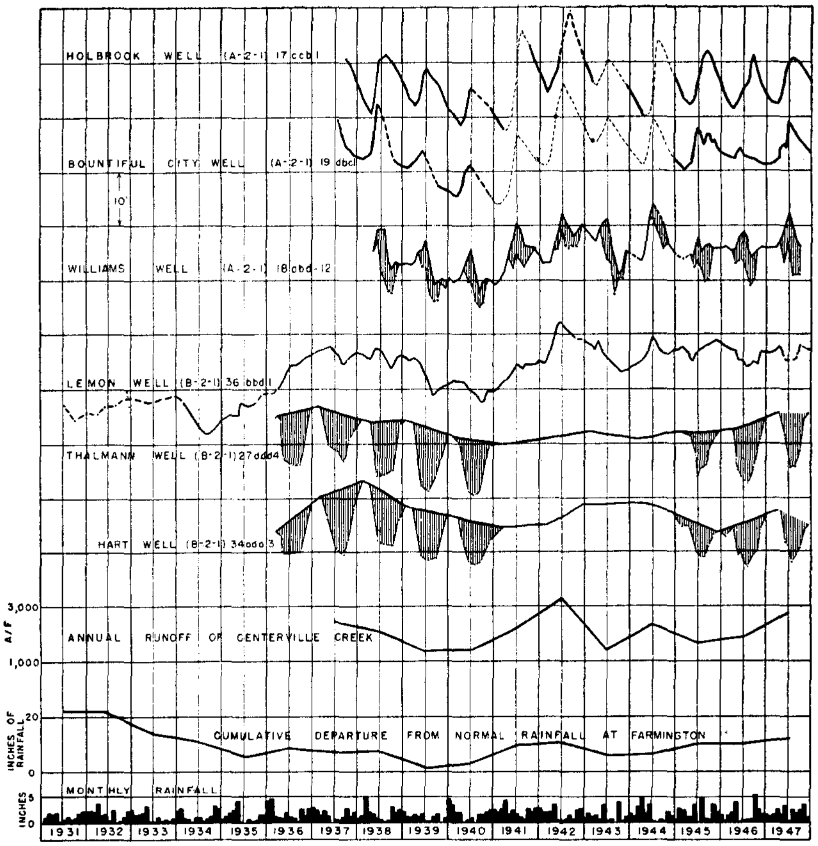


Figure 13.—*Fluctuations of water level or artesian pressure in six wells from* 1931 *to* 1947.

and in several other wells since 1935. The fluctuations shown by these measurements represent the composite effects of the several forces that influence the water level or pressure head of each well, and thus show the balance between the recharge to the groundwater reservoir from streams, irrigation, precipitation, and other sources, and the discharge therefrom by wells, tunnels, springs, evaporation, transpiration, and any other methods of disposal. Hydrographs of six wells in the Bountiful district for the years 1931 to 1947 are assembled in figure 13, based on these measurements. Curves showing cumulative departure from normal precipitation at Farmington and annual runoff of Centerville Creek afford bases for comparison of water-level fluctuations with precipitation and stream flow.

The upper two hydrographs are for the Holbrook and Bountiful City wells, which are east of the area of artesian flow. The other four hydrographs are for wells within the area of artesian flow, of which the Williams and Lemon wells have already been described in the discussion of seasonal fluctuations. The hydrographs for these wells are based on recorded pressure head at the end of each month except during irrigation seasons, when the maximum and minimum monthly pressure heads are plotted. The projected record of the Lemon well prior to 1934 is based on measurements in the Farmers State Bank well (B-2-1)36ccb-1, which has a nearly parallel hydrograph. The Thalmann and Hart wells are in the western part of the area of artesian-well development; their hydrographs are based on the maximum pressure head measured each winter, and the seasonal fluctuation caused by operation of irrigation wells is shown by shading.

The hydrographs of all six wells show good correlation with the curves of precipitation and runoff. Beginning in 1935 there is an upward trend of water levels until 1937 or 1938, then a downward trend until 1940 or 1941, a sharp rise in 1942, and a decline in 1943, and then several years with comparatively little change. The fluctuations in the westernmost wells generally lag behind those of wells farther east and because of the effects of well discharge may not be observed until the following year.

The record for the year 1942 indicates that the water levels or artesian pressures in observation wells are more closely related to stream flow than to total precipitation. In that year the precipitation at Farmington was approximately normal, but the runoff of Centerville Creek was the highest of the 11-year period of record (p. 120). In that year, also, the water levels in the Holbrook, Williams, and Lemon wells were the highest recorded in the period. The maximum pressure head each year in the Williams well (on the Centerville Creek fan) shows an especially close correlation with the flow of Centerville Creek. In 6 of the 10 years of record the maximum pressure head has varied with the total runoff so that a maximum head of 22 feet may be expected in a year when the runoff is 1,500 acre-feet, and this maximum increases about 1 foot with every additional 250 acre-feet of runoff. Discharging wells are also known to produce a marked effect on the pressure head of the Williams well, and are considered to account for the variations in the other 4 years of record. In 1943, 1944, and 1947 the rainfall in June was more than three times the average for the month, with the result that most irrigation wells remained closed, and the maximum pressure head in the Williams well was 3 to 4 feet higher than might have been expected from the runoff in those years. On the other hand, the spring rainfall in 1940 was less than half of normal, wells were opened earlier than usual, and the maximum pressure head was 1 foot lower than might be expected from the runoff of Centerville Creek.

The hydrographs of the four wells in the area of artesian flow, and particularly of the Lemon well, show the beneficial effects of the program of conservation started in 1935, when the State Legislature enacted a law requiring the capping of wells not being used beneficially. The parallelism of the hydrograph of the Lemon well with the precipitation curve extends back only to 1936. Throughout 1935 there was a pronounced upward trend in the hydrograph although the precipitation in that year was 5½ inches below normal. As a result, the water level in the well from 1937 to 1939 was 5 to 10 feet higher than from 1932 to 1934, although the precipitation at Farmington during the two 3-year periods was approximately the same. The higher water levels in the latter period are ascribed to the effect of closing many wells when not in use, in compliance with the 1935 ground-water law.

Piezometric surfaces

The great majority of wells in the area west of the upper Bonneville canal yield water that is confined under artesian pressure. As shown by the logs of wells and by their range in depth, there are several of these artesian aquifers in the Bountiful district at varying depths below the land surface. The piezometric surfaces of the individual aquifers are separate and distinct, as shown by differences in the head of adjacent wells of different depth.

Differential head of wells in aquifers of different depths

The water level or pressure head of wells of different depths indicates the comparative positions of the piezometric surfaces of the aquifers tapped by the wells. As a general rule, deep wells have a higher pressure head than adjacent shallower wells, indicating that the piezometric surfaces of the deeper aquifers are commonly higher than those of shallow aquifers; this, in turn, indicates that the deeper aquifers crop out and receive recharge at higher elevations than the shallower aquifers. In some pairs of wells the head of the deeper well is markedly higher than that of the shallower well even though the reported depths of the wells differ by only 15 or 20 feet. Some wells reported to be of identical depths show marked differences in head, and in some such instances the reported depth is questionable.

Although it is the general rule, it is not universally true that deep wells have a higher head than adjacent shallow wells. In the southern part of the district, notably in secs. 26, 35, and 36, T. 2 N., R. 1 W., wells ranging in depth from 160 to 220 feet have approximately the same head as nearby wells reported to be 250 to 600 feet deep. Thus the piezometric surfaces of the shallow and intermediate artesian aquifers coincide in this area.

Near Centerville many wells less than 50 feet deep have a higher pressure head than adjacent deeper wells that reach pre-Lake Bonneville beds. In this area the shallowest artesian wells reach aquifers within the Lake Bonneville beds.

It has been shown in the description of fluctuations that the pressure head in a well may be affected by the opening and closing of nearby wells. The effect of discharging wells is generally most pronounced in nearby wells of similar depth, but may be discriminated even in wells of different depths. When wells are opened the head of wells in the same aquifer is lowered, and the differential head between those wells and wells reaching other aquifers is modified. The differential head between adjacent wells thus may vary from day to day and from season to season. This variation is shown in figure 14. The upper hydrographs are for the Gull and Mann wells, 150 feet apart, in an area where flowing irrigation wells are closely spaced. Most of these irrigation wells obtain water from the shallow artesian aquifer (less than 200 feet deep), and the effect of this greater draft is clearly shown by comparison of the hydrographs; the differential head is as little as 13 feet in the winter months, and increases to as much as 23 feet during July of each year. During the summer of 1947 the pressure in the Gull (deep) well declined only 4½ feet from the spring maximum, whereas in 1946 the seasonal decline was more than 6 feet. In the Mann well, the seasonal fluctuations in these two years were respectively 10 and 14 feet, not including the diurnal fluctuations due to discharging wells, which commonly amount to a foot or more in the midst of the irrigation season.

The other two groups of hydrographs on figure 14 represent wells respectively half a mile south and a mile southwest of the Mann and Gull wells. As shown by periodic measurements in

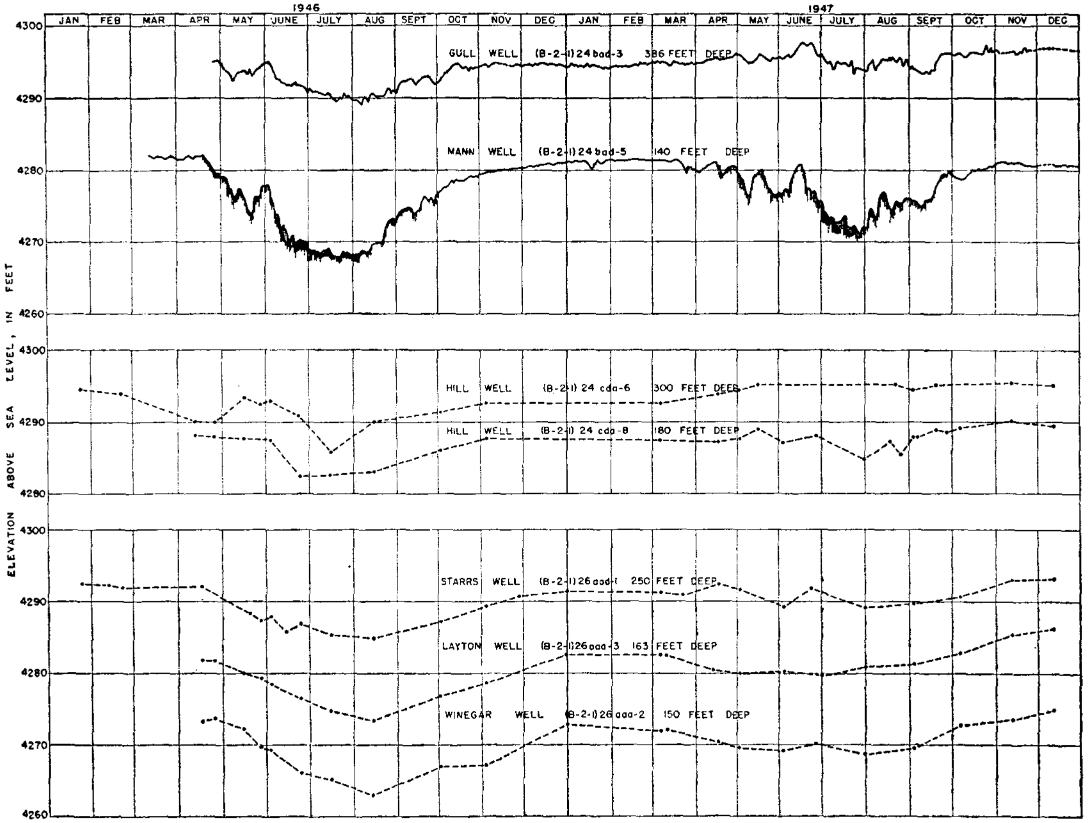


Figure 14.—*Differential head in three groups of artesian wells.*

these wells, the fluctuations of pressure head are more nearly parallel than in the Mann and Gull wells, although there is a slightly greater decline of head in wells tapping the shallow aquifer. The Layton well consistently has a pressure head 8 to 12 feet higher than that of the Winegar well 40 feet to the north, although its reported depth is only 13 feet greater.

Piezometric surfaces of Lake Bonneville beds

Water is confined under slight artesian pressure in the uppermost layers of sand and silt within the Lake Bonneville beds. In 27 holes bored in the area west of the Warm Springs fault, water was encountered in sandy or silty material below clay, and rose 0.1 foot to 2.0 feet within 10 minutes after the hole was bored; the average rise was 0.7 foot. The piezometric surface, as defined by the water levels in these bore holes, was approximately parallel with the land surface in July 1947, and had a gradient of 5 to 20 feet per mile. At that time the piezometric surface was within 6 feet of the land surface throughout the area west of the Warm Springs fault except in parts of the Jordan River delta, and over most of that area it was less than 3 feet below the land surface. Subsequent measurements of water level indicate that this piezometric surface declined a few inches by late August or September 1947 and then rose 1 to 3 feet in the following 4 to 6 months.

Water is also confined in the gravel and sand layers at greater depths within the Lake Bonneville beds. Some of the oldest wells in the area obtained water under sufficient artesian pressure to flow at the surface from gravel horizons 30 to 50 feet deep in the vicinity of Centerville, and slightly deeper to the west and south. About 50 flowing wells still yield water from these zones. Generally the pressure head in these wells is less than 5 feet above the land surface, and fluctuates through a range of only 1 to 2 feet in a year.

The piezometric surface of the water confined in these Lake Bonneville beds is commonly lower than that of the shallow artesian aquifer of the pre-Lake Bonneville beds, according to data obtained from the few existing wells. Exceptionally, however, as near the eastern margin of the lake-bottom sediments of the Lake Bonneville beds in the vicinity of Centerville, the piezometric surface defined by wells in the Lake Bonneville beds is higher than that defined by wells in the shallow pre-Lake Bonneville artesian aquifer. It is believed that the higher piezometric surface is that of water in tongues of permeable Lake Bonneville shore material that are bounded above and below by lake-bottom sediments.

Piezometric surfaces of pre-Lake Bonneville alluvium

Shallow artesian aquifer

The piezometric surface of the shallow artesian aquifer as of April 1946 is shown on plate 2. The isopiestic lines below the altitude of 4,300 feet on this map are based on determinations of pressure head in about 150 wells, ranging in depth from 60 to 200 feet in the northern part of the district, and from 80 to 250 feet in the southern and western parts. (Observation wells east of that isopiestic line were used to derive the form of the water table east of the upper Bonneville canal, as described on page 152).

The form of the piezometric surface is similar to that of the land surface to the extent that both have a general westward slope toward Great Salt Lake. Whereas the land surface has the least slope near the lake and a progressively increasing gradient eastward, the piezometric surface is most nearly flat in the vicinity of Woods Cross, where it has a broad terracelike form with a gradient of less than 5 feet in a mile. This terrace becomes narrower to the north and south and is not discernible beyond Centerville and North Salt Lake; it is located upon the coalescing alluvial fans of the three largest streams in the district: Stone, Barton, and Mill Creeks. West of this terrace the piezometric surface has a rather steep gradient of 50 to 75 feet per mile, and then near the western edge of the district, where there are very few wells, a slope approximately parallel with the nearly flat land surface. From Centerville north there are not enough wells to show the detailed form of the piezometric surface; in that area there may be small terracelike surfaces on each of the alluvial fans analogous to that shown near Woods Cross, but no such features are apparent from available data.

Low-pressure "valleys" are indicated by most of the isopiestic lines, which produce a scalloped edge in the "terrace" described above. For the most part these "valleys" result from interference of wells discharging at the time of the measurement of pressure head, or from partial recovery in an observation well that had been flowing prior to measurement. From Centerville north, however, similar indentations may mark areas of relative impermeability between the water-bearing materials of the several individual but closely spaced alluvial fans.

There is no clear evidence on plate 2 that the Warm Springs fault constitutes a barrier to ground-water movement in the shallow artesian aquifer. Especially in sec. 26, T. 2 N., R. 1 W., the piezometric surface continues across the line of the fault, and it is inferred that the permeable zones in the aquifer do likewise. To the north and south, the piezometric surface slopes steeply across the trace of the fault. This gradient doubtless results chiefly from the increasing fineness of water-bearing materials to the west, but it may be enhanced in the vicinity of the fault by juxtaposition of aquifers with strata of lesser permeability.

The form of the piezometric surface in April 1946 is representative of its form throughout most of the nonirrigation season, judging by the fluctuations of water level observed in selected wells, but changes in detail can be expected because of intermittent discharge from wells. This form is representative also of the nonirrigation seasons of other years, but the position of the surface is higher in some years than in others, as suggested by figure 13.

During each irrigation season the majority of wells in the district are discharging either continuously or intermittently. The piezometric surface is irregular and changes markedly in response to this discharge, so that even an approximate delineation would require detailed observations in a very large number of wells. The extent of these seasonal changes is suggested in profiles of the piezometric surfaces. Figure 15 is an east-west profile showing the relative positions of the piezometric surfaces of the shallow and intermediate aquifers in April 1946, as depicted on plate 2 and figure 17. Also shown is the position of each surface at the end of the irrigation season in October, after most irrigation wells had been closed. At that time the piezometric surface in the vicinity of Bountiful was higher than it had been in April, owing to the recharge from irrigation. Throughout the area of artesian flow the piezometric surface in October was 1 to 5 feet below its position in April, and the greatest decline was near the Warm Springs fault, where the density of wells is great. The north-south profile along the Woods Cross road (fig. 16) shows the comparative positions of the piezometric surfaces of shallow and intermediate aquifers in April 1946, and the amount of decline of each by July, when most irrigation wells were flowing. There was little change in the position of the piezometric surfaces at either end of the profile, where there are few wells; but the piezometric surface of the shallow artesian aquifer was lowered

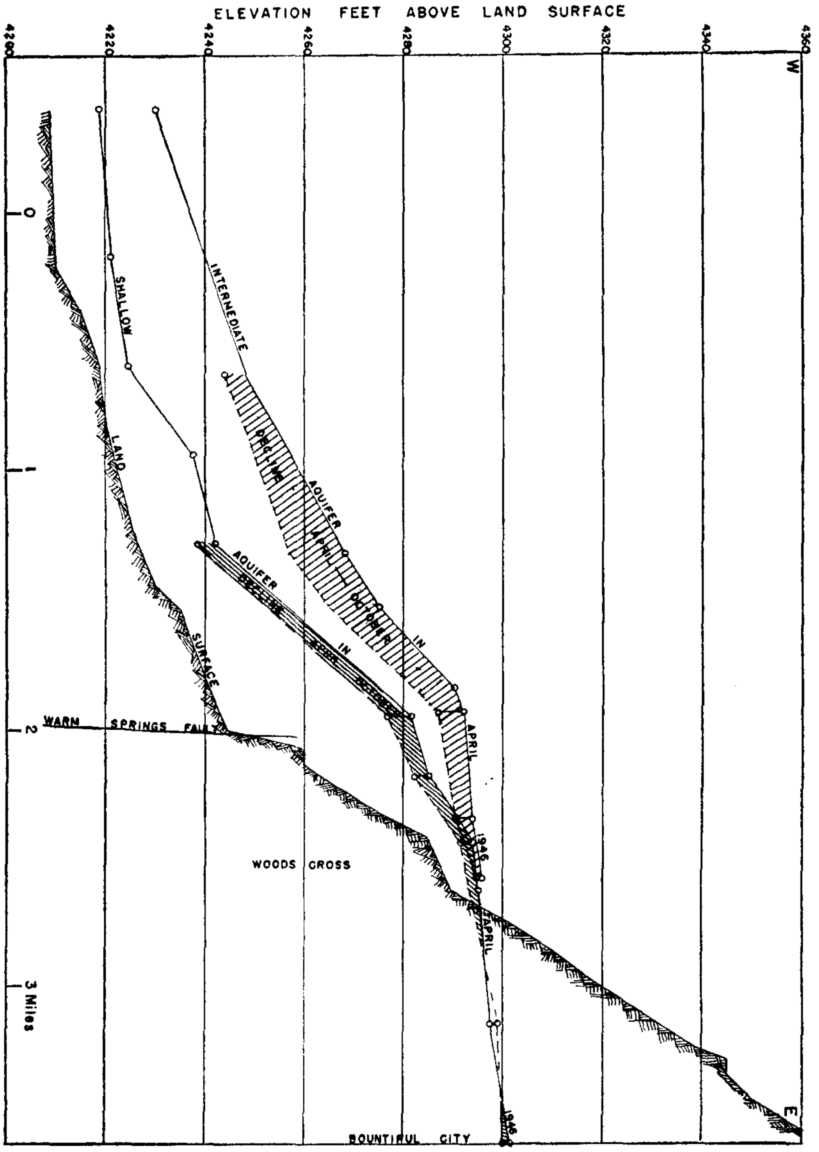


Figure 15.—*Profiles of piezometric surfaces west from Bountiful in 1946.*

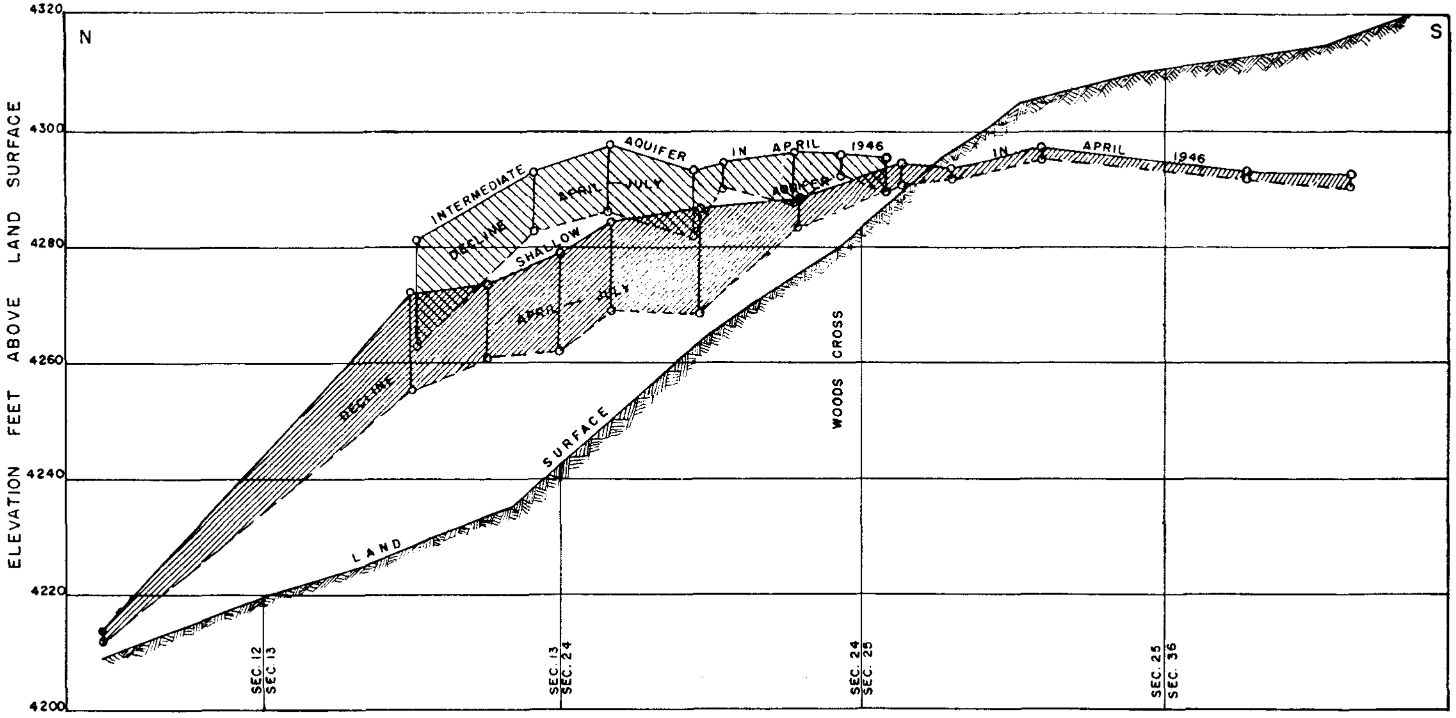


Figure 16.—*Profiles of piezometric surfaces along Woods Cross road in* 1946.

as much as 18 feet in the area of greatest well density. Thus both profiles show that the form of the piezometric surface changes from season to season; in the summer it is slightly lower than in the preceding spring in marginal areas where there is little discharge by wells, but it declines considerably more in the areas where withdrawal from wells is large.

Intermediate artesian aquifer

The piezometric surface of the intermediate artesian aquifer in April 1946 (fig. 17) is based on measurements of pressure head in about 100 wells 250 to 500 feet deep. The form of this surface is similar to that of the shallow artesian aquifer and it exhibits a similar gentle gradient in the vicinity of Woods Cross, with steeper gradients to the southwest, west, and northwest. The surface is somewhat smoother and more regular than that of the shallow aquifer, chiefly because there were fewer wells discharging from this aquifer at the time. In secs. 27 and 34, T. 2 N., R. 1 W., reentrants in the isopiestic lines show the effect of discharge of wells, and similar effects are shown to a less extent in secs. 23, 24, and 26 of that township.

The piezometric surface of the intermediate aquifer is as much as 20 feet higher than that of the shallow aquifer, and is generally 10 to 15 feet higher throughout the area of the Stone-Barton-Mill Creek alluvial fan, north and west of Woods Cross. South of that town, however, the two surfaces appear to converge, and would coincide over much of the southern part of the district if it were not for the effects of wells discharging from the respective aquifers. Wells on opposite sides of the Warm Springs fault have comparable head, and there is no indication that that fault constitutes a barrier to movement of water in the intermediate aquifer.

Measurements of pressure head in selected wells indicate that the piezometric surface of the intermediate aquifer throughout the nonirrigation season in 1946, as well as in other years, has a form similar to that in April 1946, but that its position may be higher in some years than in others. Seasonal changes in form of this piezometric surface are similar to those described for the piezometric surface of the shallow artesian aquifer, and are likewise due chiefly to discharge from wells. However, because fewer wells obtain water from this aquifer, there is less change in form from winter to summer (figs. 15 and 16).

Deep artesian aquifer

About a dozen wells in the artesian reservoir are reported to be more than 500 feet deep, but most of them are uncased or are perforated at intermediate levels and thus permit entry of water from the intermediate artesian aquifer. The Woolley well (B-2-1)13bbb-3 and the Hepworth well (B-2-1)23bdd-1 evidently obtain water only from the deep artesian aquifer of the pre-Lake Bonneville beds, at depths 600 to 800 feet below the land surface. The pressure head in the Hepworth well is about 25 feet higher than that of adjacent wells reaching the intermediate aquifer, but there is insufficient information to define the position and form of the piezometric surface of the deep aquifer. That surface is perhaps 20 to 25 feet above that of the intermediate aquifer in the western part of the district, as shown by differential head in wells in secs. 13, 23, and 27, T. 2 N., R. 1 W. On the other hand, measurements made during the drilling of the Wasatch Oil Co. well (B-2-1)24cdd-10 showed no difference in pressure head of the intermediate aquifer at 275 feet and the deep aquifer at 525 feet. Measurements during drilling operations are of questionable value, but it is possible that the two piezometric surfaces converge in this area, where there is a predominance of gravel and sand in the pre-Lake Bonneville beds.

Average annual changes of water level as indicative of changes in storage

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 Bountiful district, and very little is known as to porosity, except that it is probably 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 can be made of the change in storage from year to year, just as comparative storage in a surface reservoir can be determined from changes of reservoir level, without knowledge of the total volume of the reservoir. The several artesian aquifers in the Bountiful district are clearly interconnected, as shown by parallel fluctuations of pressure head in wells of different depths (fig. 14) and by interference between wells that reach different aquifers (p. 180). Thus the ground water is considered to occur in a single reservoir, in which the strata that separate the aquifers are not continuous enough or impervious enough to cause true separation, although they have pronounced local effects on the movement of water. The changes in storage in that reservoir are indicated by changes in water level or artesian pressure in selected wells. A wide variety of fluctuations has been observed in wells, as shown graphically in figures 11 to 14. Many of these fluctuations are of short duration and are local in character, caused by discharge of nearby wells or recharge from adjacent streams or irrigated lands. Changes of storage are best determined when these pronounced fluctuations are at a minimum, which is during the months from December to March.

Winter measurements in observation wells during 1946 and 1947 show that there are consistent changes in the water level from year to year in the recharge area and in the eastern part of the area of artesian flow. The water level rose in 35 wells in these areas between December 1946 and December 1947, the rise ranging from 1.2 feet to 3.7 feet. The average rise in the 35 wells was 2.3 feet, and in 27 wells the rise was within half a foot of this average. The wells range in depth from 45 to 450 feet and tap shallow and intermediate aquifers of the pre-Lake Bonneville beds. They are distributed over the alluvial fans of Barnard, Parrish, Stone, Barton, Mill, and North Canyon Creeks. Most of the wells are in the area where the piezometric surface is nearly flat during the nonirrigation season, and it is inferred that the valley fill in this area is sufficiently permeable that the effects of local discharge or accretion are quickly distributed throughout the aquifers, so that this portion of the artesian reservoir is analagous to a surface reservoir. Changes of water levels in the 35 wells are considered to be indicative of changes in storage in the artesian reservoir.

By contrast, the fluctuations of pressure head in the westernmost artesian wells are quite irregular, because of the pronounced interference effects of other wells, some of which flow throughout the year. Sometimes these changes in pressure head are similar to those in wells farther east, but they cannot be counted on as indicative of changes in storage. Similarly, the changes in the position of the steeply sloping water table east of the upper Bonneville canal may or may not correspond to changes in storage in the artesian reservoir, for the ground water in that area has not yet entered the artesian reservoir.

Periodic measurements of water level have been made since 1935 in eight of the 35 wells mentioned above, and the annual changes of water level, based on December measurements, are tabulated below. Three of these wells are on the alluvial fan of Centerville Creek, three on the coalescing fans of Stone, Barton, and Mill Creeks, and two west of the mouth of North Canyon. The changes of water level in all eight wells have been in the same general range each year, but generally there has been a greater rise in wet years such as 1941, and a greater decline in dry years such as 1939 and 1943, in the easternmost wells than in the area of artesian flow. In the 12-year period the net rise in the area of artesian flow has been 3.3 feet greater than the average rise in the easternmost wells, probably because of slower recovery from the effect of the 1931-35 dry cycle. The average water level in the eight wells is ordinarily somewhat lower in March than in the preceding December, indicating little if any recharge during the winter. However, the change in storage as indicated by comparative water levels in March are ordinarily very close to those shown by measurements in the preceding December.

A few indications as to changes in storage prior to 1935 can be obtained from reports of well owners. In the vicinity of Centerville several wells are reported to have flowed when drilled, and to have ceased flowing during the 1930's. The pressure head in most of these has increased sufficiently in the past decade to produce artesian flow again, and in the others the water level is generally within 5 feet of the land surface. Farther south, however, there are numerous wells which formerly flowed, in which the water level in recent years has been more than 5 feet below the land surface. The greatest decline is reported in Hyrum Parkin's well (B-2-1)36bad-2 (fig. 13), which flowed intermittently until 1928, and in which the water level since 1936 has been 12 to 23 feet below the land surface. W. S. Lemon's well (B-2-1)36bbd-1 is reported to have flowed at the rate of 65 gpm in September 1925 and 11 gpm in September 1928, and to have ceased flowing in July 1931. Since that date the water level has ranged from 5 feet below the land surface to 13 feet above the surface. In several other wells in secs. 25 and 36, T. 2 N., R. 1 W., which had ceased flowing prior to 1935, the water levels in April 1946 were 5 to 10 feet below the land surface. In this area of exceptional decline water was drawn from wells more rapidly than it could be replaced by the small amount of recharge from North Canyon and Mill Creek. Elsewhere the wells near the east margin of the area of artesian flow indicate that recharge, although varying with climatic conditions, in the long run has been adequate to offset withdrawals.

The relation among changes of storage, inflow to the reservoir, and discharge from the reservoir are discussed in a subsequent section.

Interference among wells

The forms of the piezometric surfaces have been derived, and changes in storage have been discussed on the basis of water levels and artesian pressures in wells during the winter. As has been previously pointed out, however, the greatest changes in pressure head in most wells occur during the months from April to August when irrigation wells are in continuous or intermittent operation. Well owners are chiefly concerned with the pressure head of their wells in the irrigation season, because the yield of the wells is closely related to the artesian pressure.

As soon as an artesian well begins discharging water, a hydraulic gradient is established toward the well, and the piezometric surface is lowered around it and assumes the form of an inverted cone with its apex at the well. When discharge begins most of the water comes from the sediments close to the well, but as discharge continues the cone of depression expands until a condition of steady flow and essentially constant gradient is established, first in the vicinity of the well and more gradually at greater distance. Within the area in which the piezometric surface is lowered by the discharging well there will be a reduction of pressure head in other wells, and the discharging well is said to interfere with them. The amount of interference depends upon the distance from the discharging well, the rate and period of discharge, and the permeability of the materials penetrated by the wells. If one of these nearby wells is permitted to flow, it in turn may reduce the pressure and therefore the flow from the well previously opened. Under these conditions of mutual interference the discharge from each well will be less than if the other well had not been flowing.

Interference is a controlling factor in the flow of closely spaced artesian wells, and it is of particular importance to the owners of wells in the areas of greatest development in the Bountiful district. Because of interference the flow of a well may be reduced as much by discharge from another well as if there had been an overdraft on the artesian reservoir amounting to thousands of acre-feet. Yet the adjacent well may be discharging only a few gallons a minute, and soon after that discharge ceases the pressure head or flow of the affected well may be the same as if no discharge had occurred from the adjacent

Annual change of water level, in feet, in observation wells in the Bountiful district, based on measurements in December[1]

Well number	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947
Wells in the recharge area												
(A-2-1) 17ccb-1			+0.3	—5.0	—1.3	+8.2	+2.1	—5.9	+2.8	—0.9	—2.1	+1.4
19dbc-1			—1.6	—4.9	—1.5	+7.3	(+2.0)	(—4.5)	(+3.0)	+2.1	—3.6	+2.4
(B-2-1) 36bad-2	(+6.7)	+0.4	—1.0	(—5.0)	(—0.9)	+5.5	+4.8	(—5.0)	(+2.3)	+0.4	—3.4	+3.7
Average	+6.7	+0.4	—0.8	—5.0	—1.2	+7.0	+3.0	—5.1	+2.7	+0.5	—3.0	+2.5
Wells in the eastern part of the area of artesian flow												
(A-2-1) 18abd-12				—2.8	+0.2	+5.6	+4.0	—4.6	+0.5	+2.0	—1.3	(+2.0)
18baa-1	+9.1	+0.5	—0.6	—5.1	+1.0	+6.7	+2.3	—5.1	+1.9	+1.1	—2.7	(+2.5)
(B-2-1) 25bad-2	+6.9	—0.1	—0.7	—4.4	—1.1	+5.2	+3.6	—4.0	+2.3	+0.8	—2.1	+2.5
26aad-1	+6.2	+1.0	—0.9	—5.1	—1.0	+4.4	+4.4	—4.3	+2.1	+0.9	—2.0	+2.4
36bbd-1	+7.6	+0.6	—0.5	—5.1	—0.9	+4.5	+4.2	—4.5	+3.0	+1.7	—2.2	(+1.9)
Average	+7.5	+0.5	—0.7	—4.5	—0.4	+5.3	+3.7	—4.5	+2.0	+1.3	—2.1	+2.3
Average for 8 wells	+7.3	+0.5	—0.8	—4.7	—0.7	+5.9	+3.4	—4.7	+2.2	+1.0	—2.4	+2.4
Changes as shown by water levels in March of following year	+7.0	+0.2	—0.6	—4.0	—0.4	+5.4	+2.9	—5.0	+1.6	+1.0	—0.8	

---

[1] Figures enclosed in parentheses are interpolated from measurements at other times or in nearby wells.

well. Also, the discharge of a well may be reduced by interference at a time when water levels in wells throughout the recharge area show increased storage in the artesian reservoir.

In order to determine the extent and degree of interference among wells in the Bountiful district, several tests have been made during the present study. These tests have been conducted during the spring when most wells are not operating, so that the effects of individual wells could be specifically identified.

Test of the Security Investment Co. well (B-2-1) 13acd-1

The Security Investment Co. well, of unknown depth, had a pressure head 46 feet above land surface on March 11, 1946, comparable to that in nearby wells that reach the shallow artesian aquifer 120 to 200 feet beneath the surface. The well discharged 42 gpm when opened on March 11, at 2:30 p.m., and 35 gpm prior to closing on March 14, at 2:05 p.m. The average discharge in this 71.6-hour period was about 37 gpm. The pressure head in six wells within a radius of 2,220 feet was lowered by the discharge of the Security Investment Co. well, as shown in the following table:

Interference caused by well (B-2-1) 13acd-1

Well number	Reported depth (feet)	Decline in pressure head between Mar. 11 and 14, 1946 (feet)	Distance (in feet) and direction from well tested
(B-2-1) 13dba-3	300	1.6	680 SE
(B-2-1) 13acc-1	187	1.4	770 W
(B-2-1) 13acc-2	180	1.3	830 W
(B-2-1) 13dab-4	168	1.1	1,190 SE
(B-2-1) 13daa-2	165	0.9	1,360 SE
(B-2-1) 13cab-1	157	0.2	2,220 SW
(B-2-1) 24abb-4	160	None	3,040 SW
(B-2-1) 24baa-9	180	None	3,210 SW
(B-2-1) 13caa-2	227	None	1,230 SW

The lowering of pressure head amounted to a foot or more in wells within a radius of a quarter of a mile of the discharging well, and measurable interference occurred in wells within a radius of half a mile. The reported depth of well (B-2-1) 13dba-3 is questioned, because the pressure head and amount of interference indicate that this well reaches only the shallow aquifer. On the other hand, well (B-2-1) 13caa-2 clearly taps the intermediate aquifer, as shown by its pressure head and by the absence of any indication of interference during the test, although the well is within a quarter of a mile of the discharging well.

Test of the Smith well (B-2-1) 13ccd-2

The Smith well is a 3-inch irrigation well reported to be 307 feet deep, thus reaching the intermediate artesian aquifer. The well had a pressure head 53.4 feet above land-surface datum on April 23, 1946. The well was opened on April 23 at 4:12 p.m. and allowed to flow for 44.9 hours; its average discharge was 106 gpm.

The pressure head of eight wells within a radius of half a mile was lowered by the discharge of the Smith well. Interference in wells reaching the intermediate aquifer ranged from 0.7 foot half a mile from the Smith well to more than 10 feet within a hundred feet of the discharging well. The interference in well (B-2-1)24bad-3, which reaches a deeper part of the intermediate aquifer than does the Smith well, was appreciably less than in wells of depth comparable to that of the Smith well.

The discharge of the Smith well also caused interference in wells that reach the shallow artesian aquifer, but the interference amounted to only about one-tenth of that measured in wells tapping the intermediate aquifer at comparable distances from the Smith well.

Interference caused by well (B-2-1) 13cdd-2

Well number	Reported Depth (feet)	Decline in pressure head between April 23 and 25, 1946 (feet)	Distance (in feet) and direction from Smith well
(B-2-1)13cdd-6	327	10.7	100 W
(B-2-1)24baa-1	310	5.1	660 S
(B-2-1)24aab-3	[1]600	1.6	1,760 SE
(B-2-1)24aaa-7	268	0.9	2,600 SE
(B-2-1)24baa-9	180	0.7	440 S
(B-2-1)24bad-3	386	0.4	1,470 S
(B-2-1)13cda-1	150	0.3	790 N
(B-2-1)24baa-6	160	0.3	890 S
(B-2-1)24abb-4	160	None	970 SE
(B-2-1)24bad-5	-	None	1,520 S
(B-2-1)24aab-1	150	None	1,760 SE
(B-2-1)13caa-2	180	None	2,140 N
(B-2-1)13acc-2	227	None	2,350 N

[1] Reported to have been perforated by dynamite between 300 and 400 feet.

Test of the Burnham wells (B-2-1) 26bdd-1 and 2

The Burnham wells are reported to be respectively 643 and 350 feet deep. The wells, 60 feet apart, are known to interfere with each other, and the pressure head in both wells on March 6, 1947, was 52.5 feet above land surface. Accordingly it is believed that the deeper well has been perforated opposite the intermediate aquifer and may obtain little or no water from greater depths. The two wells were opened on March 7 and flowed for 75.4 hours, the combined discharge gradually declining from

480 to 395 gpm. By the end of this period the pressure head had been lowered in 24 wells within a radius of 1¼ miles of the Burnham wells, as shown below.

Interference was greatest in wells more than 200 feet deep, and the pressure head dropped a foot or more in those wells within half a mile of the discharging wells. The discharging wells also caused measurable interference in wells that reach the shallow artesian aquifer, but the drop in pressure head in those wells was commonly less than half of that recorded in nearby wells reaching the intermediate aquifer. The interference recorded in wells north and northeast of the discharging wells was less than in wells of similar depth at a comparable distance to the east, southeast, and southwest.

Interference caused by wells (B-2-1)26bdd-1 and 2

Well number	Reported Depth (feet)	Distance (feet)	Decline in head (feet)
	Wells reaching the intermediate aquifer		
(B-2-1)26bdd-5	400	310 N	4.2
26cda-3	400	1,340 S	3.1
26dca-3	272	1,980 SE	1.7
26dda-2	300	2,950 SE	1.4
26cdd-2	343	2,200 S	1.3
26dcd-2	300	2,950 SE	1.3
26cda-5	400(?)	1,340 S	1.2
26add-2	248	2.750 E	.9
35abd-1	230	3,480 S	.8
35bcb-1	272	4,600 SW	.5
26aad-1	250	3,320 NE	.4
25bbc-2	247	3,720 NE	.3
27ddd-4	500	3,260 SW	.3
26abb-1	278	2,160 N	.2
	Wells reaching the shallow aquifer		
(B-2-1)26dcd-1	200	2,380 SE	1.1
26adc-2	189	1,910 E	.7
26dad-4	160	2,490 E	.7
25cbc-2	108	3,020 E	.4
35dad-1	100	5,320 SE	.4
25bbc-3	-	3,740 NE	.3
34ada-3	-	4,840 SW	.2
36bbd-1	167	5,240 SE	.2
26aaa-2	150	3,690 NE	None
26aaa-3	163	3,670 NE	.1

Miscellaneous tests

In addition to the tests described above, in which the discharge was from a single aquifer, and the amount of interference was determined both in wells reaching the same aquifer and wells reaching different aquifers, several groups of wells of different depths which are ordinarily operated together were tested to determine the extent of the interference by each group as a whole.

In May 1936 five wells owned by the Salt Lake Union Stockyards were tested by increasing the discharge from 105 to 340 gpm. These five wells—numbers (B-2-1)26ddd-1, 361 feet deep; 26ddd-7, 180 feet deep; 26ddd-9, 248 feet deep; 26ddd-7, 261 feet deep; and 26ddd-8, 180 feet deep—flow into a single collecting line for industrial use. The first three wells had been flowing prior to the test, and the total discharge was increased by pumping from the last two wells mentioned. As a result of the increased discharge over a 48-hour period, the pressure head was lowered in 18 of 20 observation wells within a radius of a mile from the pumped wells. Interference occurred with wells ranging in depth from 74 to 500 feet, and the pressure head was lowered more than half a foot in wells within a radius of 500 feet of the pumped wells.

Also in May 1936, the discharge of seven wells owned by Roy Cahoon was reduced in order to determine the extent of interference that had been caused by them. The seven wells had been discharging a total of 640 gpm, and the flow was reduced to 200 gpm for a period of 96 hours. Four of the wells reach the shallow artesian aquifer and the others reach the intermediate aquifer, if the reported depths are correct: (B-2-1)-26cda-2, 400 feet; 26cda-3, 400 feet; 26cda-5, 400 (?) feet; 26dca-1, 170 feet; 26dca-2, 220 feet; 26dca-3, 190 feet; 26dcd-1, 200 feet. The reduction in flow resulted in an increase in pressure head of more than 3 feet in wells within a radius of 2,000 feet, and caused a measurable increase in head in 13 of 16 observation wells within a radius of 4,500 feet of the discharging wells. The greatest effect was observed in wells reaching the shallow aquifer and ranging in depth from 112 to 208 feet, but wells as deep as 267 feet showed some effect. The pressure head in wells less than 90 feet or more than 300 feet deep apparently was not influenced by the reduction in discharge or by the increased discharge at the end of the test.

The several tests here described, and others undertaken during the course of the investigation, show that each discharging well causes interference over an extensive area, the interference being greatest in wells of similar depth, but extending also to wells of other depths. Where wells are closely spaced the pressure head in all wells may be reduced several feet by wells discharging throughout the irrigation season, and, in addition, may fluctuate through a daily range of 1 to 3 feet, owing to intermittent operation of other wells, as shown in figure 12. The cause of each individual fluctuation in a well can be identified if the periods of discharge of other wells are watched closely, and this has been done in many instances in the case of the Lemon well (fig. 11), where the effects of operations of wells 112 to 343 feet deep and 200 to 4,400 feet from the observation well have been discriminated. The amount of regional interference is not correlated with the storage of water in the artesian reservoir, but it is commonly greater in years of low storage than in years of abundant supplies.

Sources of ground water

The ground water in the artesian reservoir of the Bountiful district, which includes the area west of the upper Bonneville canal and, farther north, the area west of the frontal Wasatch fault, is derived from several sources: (1) Underground movement from the area farther east; (2) seepage from the streams that drain the Wasatch Range; (3) seepage of water diverted from those streams and from the Jordan River, and applied for irrigation; (4) precipitation upon the area; and (5) upward movement along the Warm Springs fault.

The water moving underground from the area east of the upper Bonneville canal, derived from precipitation and seepage from streams and irrigated lands in that area, has been shown to move generally westward (p. 153). The deeper wells in the artesian reservoir yield water similar in chemical characteristics to the waters in that area to the east and the stratigraphy indicates that the principal source of the water in those deep wells is the area east of the canal. Although that area is thus the principal recharge area for intermediate and deep artesian aquifers, water near the surface there may contribute also to the shallow artesian aquifer of the pre-Lake Bonneville beds.

Seepage from the channels of the streams draining the Wasatch Range is known to be considerable. Judge J. W. Rigby,, of Centerville, has described tests made by the Ricks Creek Irrigation Company in which it was determined that there are no measurable losses in that creek in the canyon, but large losses occur as the stream crosses the frontal fault and flows over alluvial debris to the west. Fluctuations of water level in wells within a few hundred yards of the major stream channels indicate that water reaches shallow aquifers by seepage from the stream channel; generally these aquifers are gravel and sand layers within the Lake Bonneville beds, but water also enters the pre-Lake Bonneville beds east of the margin of the Lake Bonneville "clay."

Irrigation of lands by water diverted from these streams and from the Jordan River contributes appreciably to the water in the artesian reservoir—doubtless a greater total volume than the seepage from the stream channels themselves, inasmuch as a large proportion of the surface water is diverted for this purpose. Water from the Jordan River, pumped into the Bonneville canals and used for irrigation as far north as Stone Creek, has been shown to enter the shallow artesian aquifer of the pre-Lake Bonneville alluvium. Thus, the recharge area for this aquifer must include at least a part of the area irrigated by that water. The western limit of this recharge area coincides with the eastern margin of the lake-bottom deposits of the Lake Bonneville beds (pl. 1) and it is thus seen that the lower Bonneville canal does not serve land in the recharge area. Water seeping from irrigated lands below the lower Bonneville canal may reach gravel and sand beds within the Lake Bonneville beds, and would then be encountered in wells less than 80 feet deep.

A considerable contribution to the water in the shallow artesian aquifer in the vicinity of Bountiful is suggested by the isopiestic lines of plate 2. Water moves in the direction of maximum hydraulic gradient, which is perpendicular to the isopiestic lines. Water crossing the 4,300-foot isopiestic line is thus continuing approximately down the topographic slope in the same direction as established farther east. The broad arch of the 4,295-foot contour, however, indicates that water is moving outward from the vicinity of Bountiful, and it is inferred that there has been appreciable contribution to the reservoir in that vicinity. This addition may come from streams, irrigated lands, and precipitation upon the area.

Precipitation upon the recharge areas for the several artesian aquifers—that is, upon the area east of the margin of the lake-bottom sediments of Lake Bonneville—may contribute to the artesian reservoir. It has been shown that water from precipitation reaches the ground-water reservoir east of the upper Bonneville canal when there is no soil-moisture deficiency. Under similar conditions, usually during the winter and spring, precipitation upon the recharge areas for the shallow artesian aquifer may enter the ground-water reservoir. Precipitation upon the lake-bottom deposits of Lake Bonneville in the western part of the area contributes to the surficial ground water, bringing it practically to the surface in the winter and early spring.

It is inferred from temperature gradients and chemical constitutents of water in certain wells that some water rises from deep sources along the Warm Springs fault within the Bountiful district. In comparison with the brine that rises along this fault at Becks Hot Springs, the affected well waters have a low mineral content and low temperature and thus indicate that only a small fraction of water comes from the deep source. As this warm water is of a quality unfit for use, it is fortunate that the contribution is no larger.

Movement and natural discharge of ground water

Ground water in the Bountiful district moves generally from the sources enumerated above and toward Great Salt Lake. This westward movement is characteristic of the water in all permeable strata in the valley fill. The direction of movement of water in the principal artesian aquifers is shown in some detail on plate 2 and figure 17, for water moves in the direction of maximum hydraulic gradient and perpendicular to the isopiestic lines.

In the description of geology it has been shown that the valley fill in the artesian reservoir comprises a succession of permeable gravels and sands interbedded with less permeable beds of finer texture; the coarse deposits are commonly thicker and more extensive near the mountains, and the proportion of less permeable fine material increases lakeward. Subsequently it has been shown that water within each permeable layer is confined by the relatively less permeable materials above and below, and that it moves in that aquifer with a hydraulic gradient that may differ markedly from that of water in deeper or shallower aquifers. On the other hand, interference tests have shown that these confining layers either are not truly impermeable or are discontinuous, because wells discharging from one aquifer may cause a reduction of pressure in a different aquifer. Thus, water moves not only within the aquifers but also around or through the less permeable sediments, the low permeability resulting in a much reduced rate of movement.

The piezometric surfaces of the several artesian aquifers show hydrologic characteristics in conformity with the geologic conditions. The very low gradients in the vicinity of Woods Cross are in the area where coarse materials have accumulated on the alluvial fans of the three largest streams, and they indicate an underground reservoir in permeable materials. The piezometric surfaces have low gradients for some distance south of the Mill Creek fan, and suggest that aquifers in the alluvial fans of small streams like North Canyon are also moderately permeable. These alluvial beds were derived largely from outcrop areas of the conglomerate of the Wasatch (?) formation, which produces better-sorted materials than do the crystalline rocks that form the Wasatch Range farther north. The closely spaced isopiestic lines farther west are in the area where silt and sand predominate in most aquifers; they indicate the increased hydraulic gradient required for movement in these materials of lesser permeability.

The average rate of movement in the artesian aquifers has been estimated to be about a foot a day (p. 140) and probably ranges from about 10 feet a day near the upper Bonneville canal (p. 150) to a few inches a day in the western part of the district. The westernmost wells may be discharging water now which entered the artesian reservoir half a century ago. Changes in the artesian flow of these wells occur within a few months of marked changes in precipitation and runoff because the effect of marked changes in storage in the recharge area is quickly transmitted to all parts of the reservoir by changes in artesian pressure.

Any movement of water through the relatively impermeable beds that separate the aquifers would be in the direction of decreased pressure, which is generally westward and toward the land surface. Such movement, the possibility of which is indicated by interference between wells of different depths, is also suggested by the slight artesian pressure under which water is confined in very shallow Lake Bonneville beds. Israelsen[46] has shown that there is upward movement of water through clay beds overlying artesian aquifers in other areas of Utah, and it is presumed that such movement occurs wherever the confining beds are not truly impermeable.

No data are available as to the quantity of water that may be transferred from deeper to shallower aquifers through materials of low permeability that separate them within the Bountiful district. Only the water moving upward from the artesian aquifers and through the lake-bottom deposits of Lake Bonneville to the surface would be lost naturally from the artesian reservoir by this movement. In much of the area west of the Warm Springs fault, surficial ground water is within 5 feet of the land surface during August and September, and rises 0.3 foot to 3.0 feet during the next 4 to 6 months. This rise may be due in part to precipitation upon the land surface, but it coincides also with a general rise of artesian pressure in the underlying pre-Lake Bonneville aquifers as wells are closed at the end of the irrigation season.

The water moving westward in the artesian reservoir is discharged chiefly by flowing wells (p. 194). Also, some is discharged naturally by springs and by evapo-transpiration, or leaves the dis-

---

[46] Israelsen, O. W., and McLaughlin, W. W., Drainage of land overlying an artesian ground-water reservoir: Utah Agr. Exper. Sta. Bull. 259, p. 5, 1935.

trict by movement westward in aquifers that extend under Great Salt Lake.

Several springs and seeps along the Warm Springs fault discharge water during the non-irrigation season. An outflow of 660 gpm. from the larger openings was measured in March 1947, and it is estimated that total flow from all springs is of the order of 900 gpm. during the winter. Most springs cease flowing in the summer and the annual yield of all springs and seeps along this fault probably has been not more than 1,000 acre-feet in recent years. Some of this water may be discharged from sand and silt layers within the Lake Bonneville beds, but most of it rises along the fault from the shallow artesian aquifer of the pre-Lake Bonneville beds. Long-time residents report that the discharge from these spring areas was greater formerly than it has been in recent years, and this is confirmed by the size of the channels draining the areas and by the hardpan deposited in some areas near the orifices.

Large quantities of ground water are discharged by evaporation and transpiration in the area west of the Warm Springs fault, where water is less than 5 feet beneath the surface throughout the year. On the basis of studies in the Escalante Valley in southern Utah, White[47] estimated that in areas covered by salt grass and associated plants where the depth to water is less than 5 feet, ground water is discharged at the rate of 1 acre-foot per acre per year. At this rate the ground-water discharge from this portion of the Bountiful district is of the order of 9,000 acre-feet annually, of which at least a portion is probably derived by upward movement of water from artesian aquifers beneath the Lake Bonneville beds.

The westernmost wells in the Bountiful district reach aquifers that yield water under artesian pressure, and it is probable that some aquifers extend even farther west and carry water underneath Great Salt Lake. Whether some of this water is discharged by springs or by gradual upward movement through the clays is not known. The wells in sec. 21 and 28, T. 2 N., R. 1 W., have low yields (5 to 20 gpm.), and the piezometric surface of the shallow artesian aquifer has a gradient less than 5 feet per mile in this area. In the few thin sand beds that extend west of the district the rate of movement is judged to be slow and the loss from the Bountiful district through them to be a very small proportion of the amount discharged by other means. Thus most of the water entering the ground-water reservoir of the Bountiful district is discharged within that district by natural and artificial means.

---

[47] White, W. N., A method of estimating ground-water supplies based on discharge by plants and evaporation from soil: U. S. Geol. Survey Water-Supply Paper 659-A, pp. 84-87, 1932.

GROUND-WATER DEVELOPMENT

History

Well construction

The early records of the settlement of the southern part of Davis County in 1848[48] state that water supplies from streams were quite limited and that it was necessary to go into the canyons for culinary supplies, particularly in late summer when the streams were likely to be dry below the canyon mouths. It is probable that dug wells were utilized for culinary supply soon after these first settlers arrived, although there are no records of this early development.

The first artesian wells were constructed about in 1885, according to available reports. Mr. Ancel Hatch states that his well (B-2-1)22ddd-5 was the first flowing well in the Bountiful district. It was bored with a large soil auger to a depth of 58 feet by Mr. Frank Yager and next morning was found to be yielding about 8 gpm. by artesian flow. The well was cased with 10-inch wood-stave casing, and subsequently several other wells were bored by the same apparatus; a few of these wells are still in existence. Soon afterward, according to Mr. Hatch, iron pipe of 1¼-inch to 2-inch diameter was obtained and used for well casing.

The earliest records concerning artesian wells in the Bountiful district are those submitted by owners in response to inquiries for the 1891 Census of Irrigation. Reports were received for 40 wells in Bountiful precinct (which included Woods Cross) and for 13 wells in Centerville precinct. At that time all wells were 1¼ inches to 2 inches in diameter, except for one owned by John Wayman, which had a 3-inch casing . The average yield was about 40 gpm, but 6 wells flowed 100 gpm. or more. West of Bountiful the wells ranged from 75 to 375 feet in depth, but only five had a depth greater than 170 feet. Near Centerville the wells were 30 to 85 feet deep.

In February 1904, Richard Stringham in a letter to the Geological Survey described the area of artesian flow as follows: "The flowing well belt here ranges from the Woods Cross P. O. to the Centerville P. O., a distance of a little over three miles long and one to two miles wide. There are many flowing wells in the belt. I counted on one quarter section 30 flowing wells running 20 to 100 gallons a minute from 2-inch casings, which are driven to a depth of from 100 to 175 feet. Water will flow over the pipe from

---

[48] Tullidge, Histories of Utah, vol. 2, pp. 58-60, 1889.

1 to 12 feet above the surface of the ground. We find where a great many wells are driven in a small area the wells are affected if all are kept running. Water is used for both culinary and irrigation purposes, and some wells are flowing that have been driven nearly 20 years."

The State ground-water law of March 22, 1935, provided that (1) all waters of the State, including ground water, belong to the public, subject to existing rights; (2) these rights are based on the principle that first in time is first in right; (3) claimants of rights to the use of ground water must file notices of such claims with the State Engineer; (4) new rights can be initiated only upon application to the State Engineer; and (5) the State Engineer is responsible for administrative supervision of all public waters. The "underground water claims" submitted in response to these provisions by the owners of wells used prior to March 1935 are in many instances based on memory without supporting records. The reported dates of construction, especially of the older wells, are therefore only approximate and may be in error by several years. In the Bountiful district dates of construction are indicated for 1,058 of the 1,179 wells reported to be in existence in 1935.

More than 20 artesian wells are reported, on these claims, to have been completed prior to 1880, of which seven are claimed to date back to 1850. Because other evidence places the date of the first flowing well as subsequent to 1880, it is believed that these claims are in error, or that the owners are claiming priority on the basis of dug wells that previously existed in the vicinity. Including these wells with those claimed to have been completed during the 1880's, well construction in the Bountiful district is reported to have been as follows:

Construction of wells in the Bountiful district
(as reported on claims filed by well owners)

Period	Number of wells constructed in		Total	Cumulative total
	T. 2 N., R. 1 E.	Tps. 1 and 2 N., R. 1 W.		
1880-89	39	118	157	157
1890-99	60	150	210	367
1900-09	69	105	174	541
1910-19	101	117	218	759
1920-29	94	105	199	958
1930-32	22	19	41	999
1933-35	27	32	59	1,058
1936-39	11	31	42	1,100
1940-47	36	53	89	1,189
Total reported	459	730	1,189	
Total in valley				1,310

This tabulation indicates that there were three times as many wells in the district in 1890 as were reported for the 1891 census, but many of those reports implied the existence of numerous additional wells. In August 1932 the Utah Agricultural Experiment Station, under the direction of William Peterson, recorded 1,086 wells during a survey of the district, of which nearly 200 were artesian wells that had ceased to flow. Judging by the table, many of these "dry" wells were subsequently abandoned. It is evident from the table that the greatest activity in ground-water development occurred prior to 1900 in the western part of the area, and somewhat later in the vicinity of Centerville. In the district as a whole, nearly half the wells were drilled prior to 1910. However, the use of ground water east of the artesian area was begun for the most part after 1900. Only half a dozen drains were completed prior to that year, and two-thirds of the existing drains and tunnels were constructed between 1900 and 1920. Pumped wells, likewise, were rare early in the century, and the majority have been developed in the last 25 years.

Annual discharge from wells

Well-discharge measurements

The discharge of the majority of artesian wells has been measured in each of six irrigation seasons since 1932, commonly with the valves opened to the position normally used by the owners. In addition, the discharge from wells in a part of the area was measured in April 1936, and measurements or estimates were made of the discharge during the winter months of 1946 and 1947. For comparison, estimates have been made of the discharge of wells in 1890, based on reports by the owners of about 55 of the wells then in existence. These estimates are presented in the following table.

It is evident that the rate of discharge has fluctuated appreciably from year to year, and also that there is a marked decline in discharge in the course of a single irrigation season, as might be expected from the fluctuations in artesian pressure. Comparisons of the late-season discharge are available for August of six years, and the total has ranged from 16,400 gpm in 1946 to 12,750 gpm in 1940. It is estimated that in each year since 1932 the rate of discharge from the reservoir has been two to three times as great as in 1890, when there were about one-fifth as many wells.

Discharge, in gallons per minute, of artesian wells in the Bountiful district

Township	Section	[a]Rept. 1890	[b]Aug. 1932	[c]Apr. 1936	[d]Aug. 1937	[d]June 1938	[d]Aug. 1938	[d]Aug. 1939	[d]Aug. 1940	[c]Mar. 1946	[c]Aug. 1946	[c]Dec. 1946
2 N., R. 1 E.	6		260		510	795	570	460	460	15	580	60
	7		1,160		1,020	1,395	1,035	810	970	60	810	30
	18		1,425		1,980	2,410	1,775	1,450	1,530	85	1,895	180
	19		105		390	350	300	300	300	0	650	0
	Total	1,800	2,950		3,900	4,950	3,680	3,020	3,260	160	3,935	270
1. N., R. 1 W.	2		5		10	10	10	10	10	85	85	85
	3				5	5	5	5	5	5	5	5
	Total		5		15	15	15	15	15	90	90	90
2 N., R. 1 W.	1				5	5	5	5	5	5	5	5
	12		10		10	10	10	10	10	10	10	10
	13		940		1,430	1,920	1,430	1,470	1,100	185	1,505	235
	14		20		25	25	25	35	20	25	25	25
	21		20		15	15	15	15	15	15	15	15
	22		85		65	80	70	55	55	15	70	80
	23		130		755	965	795	850	630	50	950	150
	24		6,250		3,925	6,415	4,580	3,930	3,700	500	4,610	500
	25		590	540	625	925	680	705	460	30	365	75
	26		2,610	3,360	2,055	2,675	2,220	2,385	2,245	320	3,150	325
	27		305	550	265	365	285	260	270	180	465	170
	28				15	15	15	20	15	15	15	15
	34		700	900	285	600	360	335	425	290	330	395
	35		540	1,410	660	1,240	835	750	630	325	795	350
	36		100	60	90	170	90	60	45	5	65	30
	Total	4,500	12,300		10,225	15,425	11,415	10,885	9,480	1,970	12,375	2,380
District	Total	6,300	15,250		14,140	20,390	15,110	13,920	12,750	2,220	16,400	2,740

[a] Estimate based on statements of owners concerning discharge of one-third of the wells in the district.

[b] By Utah Agricultural Experiment Station.

[c] By Geological Survey.

[d] "Diversion and use" survey by Utah State Engineer.

In each year the rate of discharge is probably greatest when irrigation wells are first opened and declines gradually as artesian pressure declines during the summer. For example, in June 1938 the rate of discharge of all wells was one-third greater than in August of the same year. A high rate of discharge was also noted in the sections covered by the survey of April 1936. Wells that are permitted to flow in the winter, when the majority of irrigation wells are closed, yield at a greater rate than in the summer, with the result that in sec. 34, T. 2 N., R. 1 W., as an example, the winter discharge in 1946 exceeded the discharge of a larger number of wells during the preceding irrigation season. The discharge from wells in the district during the winter of 1946-47 amounted to about 15 percent of the discharge during the preceding August. The water appeared to be largely wasted.

Estimates of the total quantity yielded by the ground-water reservoir can be only rough approximations, because the periods of discharge of individual wells are not known. A few wells flow continuously throughout the year. Some others are opened soon after April 1 and are permitted to flow continuously until November 1, as authorized by the State Engineer. On the other hand, particularly in sec. 24, T. 2 N., R. 1 W., and in sec. 18, T. 2 N., R. 1 E., where well density is greatest, most wells are used only intermittently, many being closed each night, many remaining closed during rainy periods, and some flowing for only a few days each week. Many wells discharge ordinarily through hose connections, and are rarely opened to capacity. The fluctuations due to well discharge (pp. 155-163) indicate that there is considerable variation in operation from place to place within the district, as well as from month to month and from year to year.

As a basis for arriving at some estimate of the number of acre-feet discharged annually by artesian wells, it has been assumed that the average length of irrigation season is 4 months, and that the average rate of discharge in that period is 10 percent greater than the rate measured in August. It is also assumed that the rate of discharge during the other 8 months of each year since the State law went into effect has been 15 percent of the August rate in that year. With these assumptions, the discharge from the artesian reservoir is estimated to have been approximately 10,600 acre-feet in 1937, 11,300 acre-feet in 1938, 10,400 acre-feet in 1939, 9,500 acre-feet in 1940, and 12,200 acre-feet in 1946.

Relation of well discharge to change in storage and to total surface inflow

Changes of the water level in certain wells have been shown to be an indication of the changes in storage of water in the artesian reservoir (p. 172). Correlation between the average water levels in these wells and the computed discharge from all wells is evident in the years for which some discharge records are available, as shown in the following tabulation:

Water levels in wells at beginning of years for which total well discharge has been computed

Year	Average water level in eight wells at beginning of year, in feet above assumed datum.	Computed annual discharge, acre-feet
1946	14.4	12,200
1938	12.8	11,300
1937	12.3	10,600
1939	12.0	10,400
1940	7.3	9,500

This direct relation between storage and discharge exists also in other artesian basins in Utah, and is in contrast to that in many ground-water basins where water must be pumped, and where discharge is inversely proportional to relative storage because of increased demand for water during dry years when storage is low. The relationship is only a rough approximation, because many instances can be cited of well owners using their wells very little in years when there is much ground water in storage, because of adequate stream supplies, and drawing heavily on wells when surface supplies and ground-water storage are low. The fact that there is even a rough direct correlation indicates that most wells are open for approximately the same periods year after year, and that discharge is therefore dependent largely on artesian pressure, which in turn is determined by the quantity of water in storage.

The relation of well discharge to changes in storage and to the quantity of water available for recharge of the artesian reservoir is shown diagrammatically in figure 18. The annual surface inflow includes the quantities contributed by streams and the Bonneville canals, as listed in the table on page 125, the inflow prior to 1937 being estimated on the basis of the flow of City Creek, which has a drainage basin adjacent to Mill Creek. Most of this water reaches the district in the spring or summer.

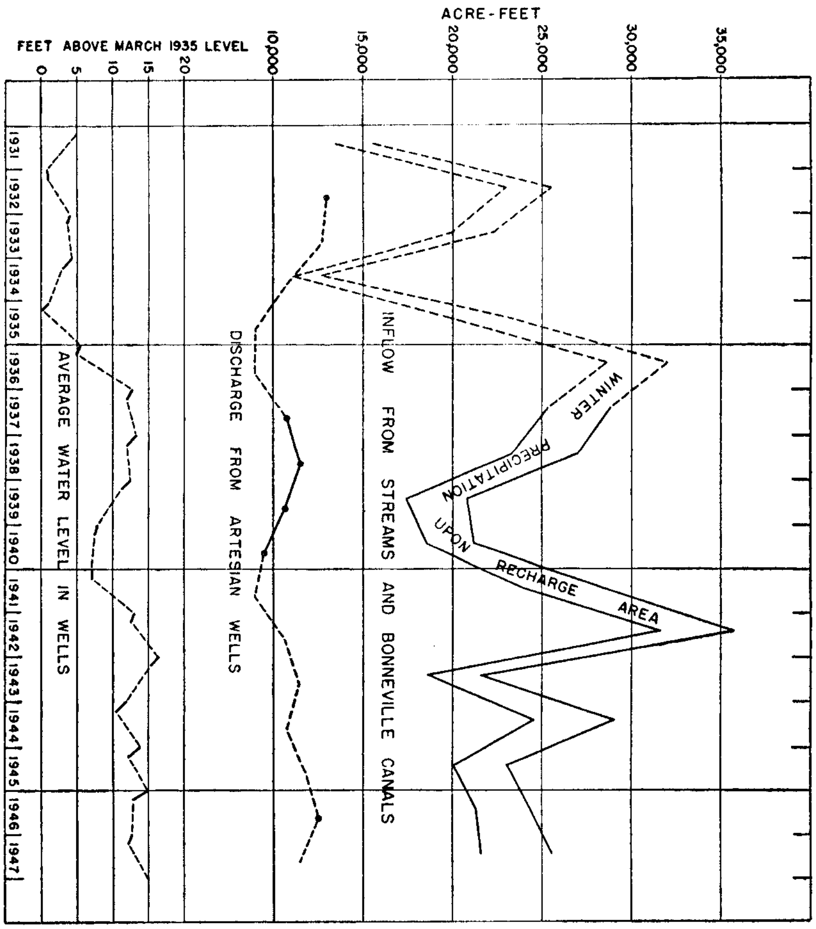


Figure 18.—*Relation of recharge opportunity and well discharge to storage in the artesian reservoir.*

In computing the quantity of water available from precipitation for recharge of the artesian reservoir, it has been assumed that most of the precipitation above an altitude of 4,600 feet is likely to contribute to the drains, tunnels, and wells tapping the shore deposits of the Provo stage, rather than to the artesian wells. Therefore the estimates are limited to the most favorable recharge area for artesian aquifers, which is an area of about 4 square miles below this altitude; the quantity is estimated from the precipitation at Farmington during the months of October to May of each year, when the soil-moisture deficiency is likely to be least. This quantity, added to the estimated annual inflow, gives the total considered to be available for recharge of the artesian reservoir. Recharge opportunity is shown to have been greatest in 1942, 1936, and 1944, and least in 1934, 1931, 1939, and 1943. The quantity available for recharge apparently has been more than twice as great as the discharge from wells in all years since 1934.

The storage in the artesian reservoir is indicated in figure 18 by a composite hydrograph based on the average position of water levels in the eight wells used to indicate the changes in water level shown on page 176. Solid portions of this hydrograph are based on December and March determinations of the water levels, and the hydrograph is dashed through the remainder of each year. In every year there is a downward trend of water level between December and March, suggesting that there is relatively little recharge at that time of year, and that pressure gradients are decreasing from those developed during the irrigation season by infiltration in the recharge area and well discharge farther west. The major trends of the composite hydrograph correlate with the changing quantities available for recharge. In the winter following a year of increased inflow and precipitation the water levels in wells have been higher, as in 1935, 1941, 1942; after a year of decreased inflow the water levels have been lower, as in 1939 and 1943. However, the full effect on the artesian reservoir of surface inflow and precipitation may be delayed for more than a year, as shown by the trends of water levels in 1937, 1940, 1945, and 1946.

The estimates of well discharge are based upon inadequate data and may be in error by considerably more than 20 percent. In consideration of the probability of large error in these estimates, the apparent correlation between well discharge and the available ground-water storage may be fortuitous, and certainly is closer than might be expected. The dashed line for years when no well-discharge measurements were made follows the trend of the composite hydrograph, with slight modifications based on field observations and precipitation records. For instance, during the rainy months of June and August of 1945 and 1947, many wells were closed for extended periods, and the annual discharge is considered to have been substantially less than in 1946, when there were no effective summer storms. Heavy rainfall in June of 1941, 1943 and 1944 is known to have delayed the opening of many irrigation wells, and the total discharge in those years is presumed to have been substantially reduced. In 1942 the storage in the artesian reservoir and the distribution of precipitation were similar to those in 1937, and well discharge is assumed to have been comparable also. The pronounced upward trend of water level in 1935 and 1936 is regarded as due in part to increased efforts at conservation (p. 163). The total discharge from wells in those years is estimated to have been less than in earlier years when a larger proportion of wells were permitted to flow throughout the year.

Considering now the entire ground-water reservoir in the Bountiful district in the 10-year period 1937 to 1946, inclusive, the average annual inflow of tributary streams has been estimated to be about 18,000 acre-feet, and the pumpage into the Bonneville canals about 4,000 acre-feet additional (p. 125). Average precipitation at Farmington from October to May in those years has been 16.4 inches, and over the recharge area of about 7,300 acres the water available for recharge from this source may have been of the order of 9,000 acre-feet annually. These estimates would give a total of about 31,000 acre-feet of water available for irrigation and for ground-water recharge in an average year.

The average annual discharge from artesian wells in the 10-year period is estimated to have been about 11,000 acre-feet, and the discharge from wells, drains, and tunnels east of the artesian reservoir about 2,000 acre-feet additional. The total annual draft upon the ground water reservoir by wells, drains, and tunnels has thus averaged about 13,000 acre-feet.

At the end of 1946 the water levels in observation wells were very nearly the same as at the end of 1936, and storage of water in the artesian reservoir is inferred to have been practically the same at the beginning and end of the 10-year period, a period during which the precipitation at Farmington was about average (p. 127). The difference between the average quantity available for recharge and that discharged from the ground-water reservoir by wells, drains, and tunnels — 18,000 acre-feet—represents the average quantity used for irrigation from streams and canals, plus the quantities wasting in streams toward Great Salt Lake and those lost from the ground-water reservoir by natural discharge. The following table, summarizing these rough approximations, is intended merely to show the comparative magnitude of the several methods of disposal of the water that enters the Bountiful district.

Estimated disposition of water in the Bountiful district

(Annual average for the 10-year period 1937-1946)

Water entering the recharge area:	*Acre-feet*
Inflow from tributary streams	18,000
Pumpage from Jordan River	4,000
Precipitation upon the recharge area, October to May	9,000
	31,000
Disposal:	
Surface-water irrigation of about 5,000 acres	10,000-12,000
Discharge from wells and drains in irrigation season	11,000
Discharge from wells in nonirrigation season	2,000
Discharge from springs along Warm Springs fault	1,000
Stream outflow toward Great Salt Lake	3,000
Other losses, including evapo-transpiration	4,000-2,000
	31,000

Relation of well discharge to natural discharge

No records are available concerning the water levels and artesian pressures in years prior to 1931, but the claims to underground water filed by well owners since 1935 show that most wells which produced artesian flows when drilled have been flowing in recent years. Storage in the northern part of the artesian reservoir during the past 10 years has been nearly as great as during the years prior to 1931, but there has been appreciable lowering south of Barton Creek. It is inferred that in those years, particularly when abundant stream flow and precipitation gave ample opportunity for recharge, water entered the artesian reservoir in quantities comparable to those estimated for recent years. In early years when there were few wells, each well doubtless discharged at a greater rate than it would today, but the total discharge from wells was necessarily less than that measured in recent years, and it is inferred that there was a correspondingly greater amount of natural discharge. Prior to the construction of wells, of course, the only discharge from the underground reservoir was through springs and seeps and by evapo-transpiration.

There is ample evidence in reports of residents and in geological data that the springs along the Warm Springs fault formerly discharged at greater rates than in recent years. Discharge from artesian aquifers by upward movement in the low western part of the district also was probably greater at that time. The development and utilization of water from wells, springs, tunnels, and drains has been largely at the expense of this natural discharge, and as the total amount taken from the underground reservoir has increased the natural discharge is inferred to have declined a corresponding amount and there has been no great decrease in storage in the reservoir.

Status in 1946

In 1946 there were about 1,310 wells and 130 water tunnels and drains in the Bountiful district, of which 930 were used principally for irrigation, 200 for domestic purposes, 4 for municipal supplies, 40 for industrial supplies, and 50 for stock. About 1,040 wells had sufficient artesian pressure to flow at the surface. About 680 of the wells had diameters of 2 inches or less, 520 had diameters of 2½ to 4 inches, and 20 cased wells had diameters of 5 to 12 inches. There were also about 90 dug wells, mostly in the eastern part of the district. Practically all the wells less than 5 inches in diameter had been constructed by the hydraulic jetting method, and the drilled wells of larger diameter were constructed by cable-tool rigs.

The irrigated areas within the Bountiful district are shown on figure 19, which is based on a reconnaissance of the area aided by aerial photographs taken in August 1946. About 5,200 acres were irrigated in 1946 by wells; 3,600 by streams and the Bonneville canals; and 1,500 by streams, supplemented by wells, drains and tunnels — making a total irrigated area of about 10,000 acres.

In 1946 the discharge from artesian wells was greater than in preceding years when similar measurements were made. The artesian reservoir was capable of this high rate of discharge for, as shown by water levels in wells, storage at the beginning of the year was greater than in any year since 1931, except for 1943. There was less precipitation in the summer of 1946 than in any year since 1935, and the high yield of wells was doubtless welcomed by all who used wells for irrigation. In part the increased discharge from the reservoir resulted from the construction of about 75 additional wells since 1940, when the last previous survey had been made of the well discharge, but comparison of measurements in the two years shows that the discharge of most wells was greater in 1946 than in 1940, and this increase is attributed to the increased storage in the reservoir.

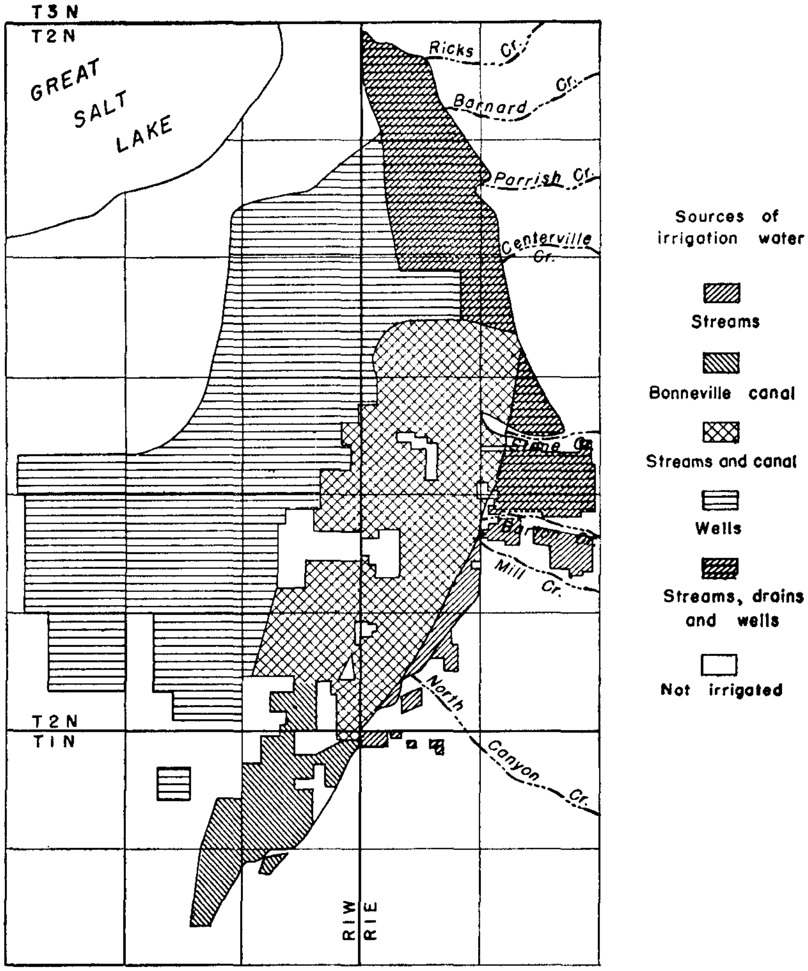


Figure 19.—*Irrigated areas in the Bountiful district.*

The status in 1946 and the history of ground-water utilization in the preceding decade indicate that the ground-water reservoir is not overdeveloped, and that when precipitation and runoff are normal the wells of the district can maintain a yield comparable to that in 1946. During drought periods such as that from 1931 to 1935, however, recharge is greatly diminished and discharge from flowing wells is correspondingly reduced. In such dry years, when the need for irrigation water is even greater than in normal years, the owners of flowing wells may not be able to obtain sufficient supplies without installing pumps.

Water supplies for future requirements

The influx of population to the Bountiful district has resulted in a need for additional water supplies, and in recent years several new wells have been constructed east of the area of artesian flow. Most of these are drilled wells with high pumping lift and low specific capacity. The drilling of the deep well (A-2-1)29cab-1 for the city of Bountiful (p. 89) indicates that the valley fill to a depth of 775 feet near that town is predominantly unsorted torrential debris, which is not sufficiently permeable to yield satisfactory quantities of water to wells. Farther south, in the Val Verda area, the valley fill includes several moderately permeable water-bearing strata, but the streams tributary to that area are so small that recharge is insufficient for development of any large water supply from wells.

Additional water supplies are also being sought for expansion of industries within the Bountiful district, and it is certain that the assurance of an adequate water supply would attract new industries to the area. The most favorable industrial sites are near the major transportation facilities and within the area of artesian flow, but artesian flow is inadequate for present industries, and some of the water is pumped. Increased draft upon the artesian reservoir for industrial supplies will require increased pumping not only of industrial wells but also of nearby wells affected by interference.

Most of the owners of existing wells do not look with favor upon any increase in the number of wells drawing from the ground-water reservoir. The effect of interference has long been recognized (p. 187), and it is realized that each new well will probably reduce the flow of nearby wells. The State Engineer, assuming that the ground-water reservoir has been approaching the limit of economic development in recent years, has discouraged the drilling of large new wells for irrigation and industrial purposes, although he has permitted the drilling of new domestic wells in the area.

The present study indicates that the Bountiful district is indeed putting to beneficial use a high proportion of the water that enters the area by stream flow and precipitation. However, some loss occurs from the ground-water reservoir, and there is some stream flow toward Great Salt Lake. The possibilities of increasing the water supplies of the district by utilizing some of this water that is now lost are discussed in succeeding sections.

Reduction of waste and natural losses

The discharge from irrigation wells during the winter is estimated to range from 1,800 to 2,200 acre-feet per year, of which at least 1,000 acre-feet is discharged from wells that leak around the casing. The plugging of these wells would cause an increase in pressure head, which in the following irrigation season would result in greater yield of wells in the vicinity, and especially of the wells so controlled.

The natural loss from the artesian reservoir by springs along the Warm Springs fault and by upward movement and evapotranspiration in the area farther west has been estimated to be at least 2,000 acre-feet annually, and may be more than twice as great. This natural loss has been reduced in historic time by construction of wells in the area, with resultant lowering of the artesian pressure that has caused the water to rise to the surface. By further lowering of the piezometric surface of the shallow artesian aquifer the natural loss can be further reduced. If that piezometric surface is lowered by pumping to a position below the land surface, the natural discharge can be eliminated over substantial areas and the water brought to the surface instead by the pumps, whence it can be diverted to beneficial use.

In order to attain the greatest reduction in natural loss it would be necessary to install pumps in the area where the natural loss occurs, west of the fault. In this area the aquifers are prevailingly of sand, and the yields of pumped wells would be less than farther east, but each pump would achieve a greater lowering of the piezometric surface per unit of discharge because of the lesser permeability of the strata. Experimental pumping is recommended for that area, under close control, to determine the extent of the lowering of the piezometric surface in the vicinity of the pumped well and in the productive area farther east. It is possible that locations could be selected where pumping from wells less than 200 feet deep would reduce water-logging of the surface and yet not seriously reduce the artesian pressure of the wells east of the fault. Year-round pumping for industrial use might be found to be especially effective in reducing natural discharge along the Warm Springs fault.

Pumped wells in the area of artesian flow east of the Warm Springs fault would tap permeable aquifers and yield good water supplies. Substantial pumping here, however, would reduce artesian pressure to the extent that all well owners would be forced to install pumps. It is concluded from this study that the sediments in the recharge area are not highly permeable, and that water does not move freely into the artesian reservoir. Reduction of storage in that reservoir, although it would increase somewhat the hydraulic gradient and westward movement of water into the reservoir, would not insure a substantial increase in natural recharge from streams and other sources. Thus it is possible that pumping would remove substantial quantities of water from storage without achieving any appreciable increase in the perennial yield of the reservoir unless recharge to the reservoir were increased by artificial means.

Artificial recharge

The water that flows down the channels of the streams tributary to the Bountiful district and continues across the district constitutes an appreciable proportion of the total water available to the district. Most of this water traverses the district during the spring freshet, when stream flow is greater than can be used for irrigation. Some water undoubtedly seeps from the stream bed into the ground-water reservoir at this time, but this natural recharge takes only a part of the water. There are no suitable reservoir sites which could be developed economically for storage and subsequent use of the comparatively small quantities of water that flow down each of the several streams. However, diversion of this surplus water for artificial recharge of the ground-water reservoir would increase the total ground-water supplies of the district.

Two noteworthy experiments in artificial recharge have been conducted within the past 10 years in the Bountiful district, and they show a way in which surplus waters may be stored in ground-water reservoirs for future use in other parts of Utah and throughout the arid Western States. The first of these experiments was conducted under superviison of the Intermountain Forest and Range Experiment Station of the U. S. Forest Service. The writers are indebted to Messrs. R. W. Bailey, G. W. Craddock, and A. R. Croft of that station for much of the data as to that experiment, which was undertaken on the Provo terrace south of Centerville Creek.

During 1937 a spreading basin was constructed on that terrace, with a length of half a mile and a maximum width ot about 75 feet. Beginning in December 1937, water was diverted through a 10-inch pipe to this basin during the winter and spring, the quantities being determined by Parshall flume and water-stage recorder. The period of diversion and quantity of water diverted each year are shown in the following table.

Artificial recharge in Centerville Creek spreading basin

Year ending Sept. 30	Period of diversion	Quantity of water diverted (acre-feet)
1938	Dec. 23-June 7	372
1939	Oct. 21-May 26	415
1940	Oct. 27-May 31	355
1941	Jan. 10-May 18	344
1942	Feb. 22-July 19	345
1943	Nov. 4-May 18	300
1944	Apr. 5-July 18	257
1945	Apr. 23-June 30	253
1946	Mar. 15-June 23	269
1947	Mar. 26-June 27	185

During the first few years the spreading basin absorbed the water as rapidly as it could be delivered by the 10-inch pipe, a maximum rate of 3.0 cfs. Gradually, however, silt and fine sand particles accumulated in the basin and the rate of percolation diminished until in some years there was flow over the spillway at the south end of the basin. The diversions into the spreading basin have been decreased in the years ince 1942 for this reason.

The spreading basin is located about 1,400 feet east of the escarpment of the Wasatch frontal fault. The steep slope between the scarp and the basin has a thin cover of talus, lake-shore gravel, and alluvial debris, through which project outcrops of the pre-Cambrian bedrock near the south end of the basin. None of the water was observed to come to the surface on this slope or along the frontal fault, although there was some seepage through the constructed embankment near the center of the basin.

After the diversion of water into the spreading basin in 1937, several wells on the Centerville Creek alluvial fan, that had ceased flowing several years before, began to flow again. However, as shown in preceding discussion, there was a general rise of artesian pressure in wells throughout the Bountiful district from 1936 to 1938, and available data are inadequate to discriminate the beneficial effect of the artificial recharge in this general rise. Careful study of the hydrograph of the Williams well (figs. 12 and 13) gives no evidence that artificial recharge had any effect upon the artesian pressure in that well. The Williams well, however, is located within 50 feet of the channel of Centerville Creek, and its pressure head is clearly related to flow in that stream (p. 162). In order to prove that this artificial recharge reached the artesian aquifers it would be necessary to know in detail the positions and changes of the piezometric surfaces of the respective aquifers under natural conditions, prior to 1937. This information is not available, and the beneficial effect must be inferred from the reports of several well owners that the flow of their wells was increased after the water spreading, together with the indication that the water did not appear as seeps, springs, or surficial ground water that would tend to waterlog the area below the spreading basin.

Beginning in 1941, the city of Bountiful has diverted part of the flow of Barton Creek into a spreading area north of the stream channel and a quarter of a mile east of the Provo shore line. The spreading canal is about 1,200 feet long, and water flows through 11 outlets into an area covered by oak brush. The oak brush area is highly absorptive, and there has been no evidence of silting in 7 years of water-spreading operations. Quantities diverted each year are tabulated below, based on weir measurements in 1946 and 1947, and on estimates prior to those years.

Artificial recharge by the Bountiful spreading canal

Year	Period of diversion	Quantity diverted, acre-feet
1941	May-June 5	75
1942	April 14-June 18	180
1943	April 14-May 13, June 5-18	130
1944	January-May	300
1945	February 9-May	400
1946	February 20-June 10	450
1947	February 21-June 5	425

The purpose of the water spreading, as stated by the city of Bountiful in its application (No. A-18224) filed with the State Engineer, was to allow the water to percolate into the underground supply to mix with natural waters of the basin. This water was then to be exchanged for a like quantity diverted by means of wells 1½ to 2 miles farther west and below the Provo shore terrace.

Observations in artesian wells give no evidence that the water spreading resulted in increased storage in the artesian reservoir, but water levels in wells in the shore deposits of the Provo stage rose appreciably and the discharge from adjacent drains increased in response to the artificial recharge. It is concluded that most of this water moved westward only as far as the permeable beds of the Provo shore deposits and was discharged from those aquifers by wells and drains east of the area of artesian flow. The results of this experiment confirm the existence of a belt of relatively impermeable pre-Lake Bonneville beds of torrential origin under the shore deposits of Lake Bonneville, as shown in the log of the Bountiful City well (A-2-1)29cab-1 (p. 89).

The discharge from the Bountiful City water tunnel (A-2-1) 20caa-T was more than doubled as a result of the artificial recharge, and the yield of many other drains was similarly increased. The water recharged by the city of Bountiful affords a basis for a claim for permission to increase its water supply by constructing additional tunnels to capture the water in excess of that discharged under natural conditions in the area. By this development water spread during the spring would issue from the ground-water reservoir in the summer when municipal supplies are critically short.

The water applied for irrigation from the upper Bonneville canal, although it was not diverted as an experiment in artificial recharge, serves to mark the area where artificial recharge would be most beneficial to the artesian reservoir. This water, because of its chemical composition, can be traced as conclusively as if it were loaded with fluorescein dye, and it clearly has reached the shallow artesian aquifer. Thus, as shown in figure 20, artificial recharge to be of greatest benefit to the shallow artesian aquifer should be in the area between this canal and the eastern limit of the lake-bottom sediments of Lake Bonneville. For artificial recharge of deeper aquifers, water should be spread somewhat farther east, perhaps in areas as high as 4,600 feet in altitude. These areas include much of the city of Bountiful and the residential areas farther south, near Val Verda. Water spreading in the part of the recharge area above the 4,600-foot altitude will serve chiefly to increase the water supplies available from the Provo shore gravel, as shown by the experiment of the city of Bountiful. Excess ground water in this area would probably move westward, however, and into the area where conditions are more favorable for recharge of the artesian reservoir.

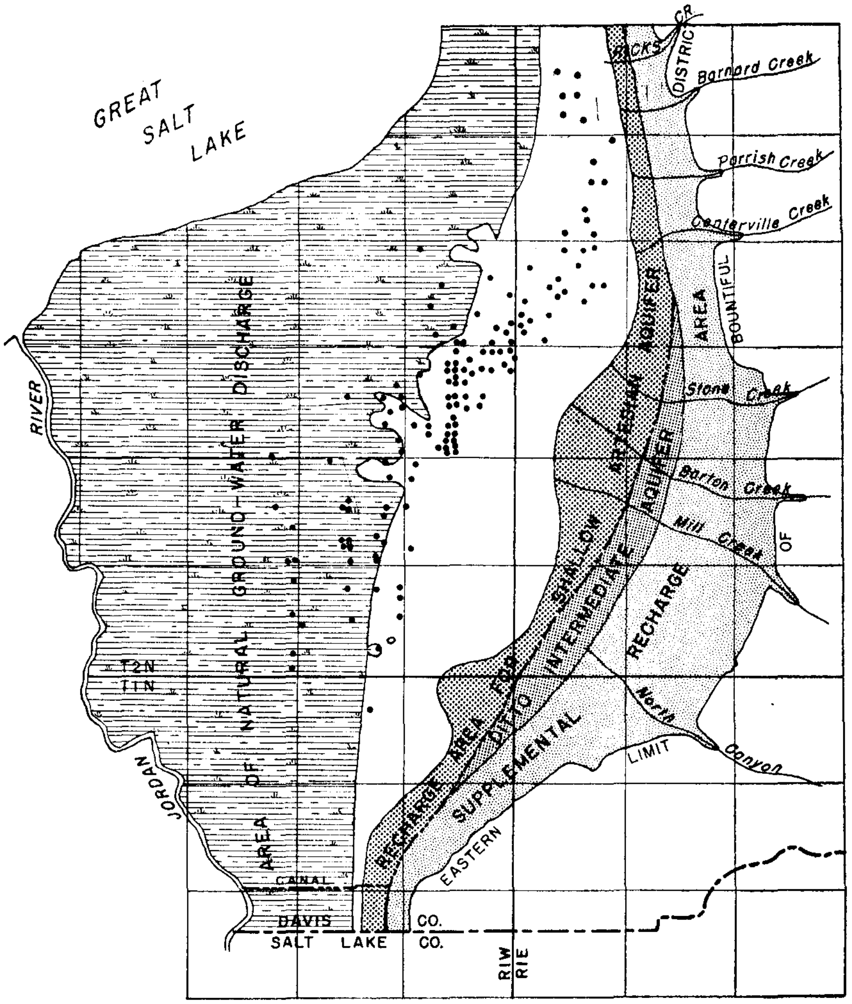


Figure 20.—*Areas of recharge and discharge of ground water.* (*Each dot represents discharge of* 100 *g.p.m. from flowing wells in August* 1946)

It may be concluded from the experience in the Bountiful district that, where the purpose of artificial recharge is to promote the public welfare and increase ground-water storage in general, the operation may be deemed successful if there is evidence that the water seeps into the spreading ground and produces no harmful effects by appearing at the surface or waterlogging land below that spreading ground. Where artificial recharge is for the specific purpose of storing water that is to be diverted subsequently from a certain aquifer by means of wells, however, it is essential that proof be obtained that the water spread does reach that aquifer. This proof requires an adequate knowledge of geologic and hydrologic conditions, and it can be obtained only by detailed observations of the effects of the artificial recharge. The City of Bountiful wisely made provisions for obtaining this evidence, and thus has a basis for modifying its program of artificial recharge so that it will best serve its needs.

Importation of water

The preceding sections have included suggestions for increasing the utilization of water available within the Bountiful district by reduction of waste from flowing wells, pumping to reduce natural losses from the artesian reservoir, and diversion of surplus stream flow to recharge the ground-water reservoir. Actually, however, the Bountiful district is already putting to beneficial use in an average year perhaps 70 percent of the water that enters the district from tributary streams or that falls on the ground-water recharge area as precipitation. Conservation measures cannot be expected to eliminate all natural losses of water within the Bountiful district, and even with outstanding success will probably increase the total water supply of the district by not more than 20 percent, or perhaps 5,000 acre-feet in an average year.

It has been the experience of Utah cities that a family of four or five commonly uses about an acre-foot of water (325,000 gallons) a year for domestic purposes, and the water that is now being wasted could if conserved supply the needs of the increasing population probably for several years. During 1946 and 1947 the city of Bountiful has anticipated these needs by filing applications for 4,500 acre-feet of additional water, and 45 other applicants have requested water to supply more than 300 new homes. It is evident that the conservation measures recommended in preceding sections will be necessary in the very near future to insure the newcomers as well as older appropriators have an adequate water supply.

For additional water supplies the Bountiful district must look beyond the drainage basin that is tributary to it, and seek to import water from river systems that carry a surplus. Importation of water is not new to the district, for the water pumped from the Jordan River has played an important part in the present development of the area south of Stone Creek, and the 4,000 acre-feet pumped annually is an essential part of the water resources of the district. The Jordan River water, however, is of poor quality, with a high mineral content that includes a large proportion of sodium and a high degree of bacterial contamination. Rather than introduce more of this water into a residential area where municipal and domestic use is important, water of better quality could be imported, not only to meet additional requirements but to replace the Jordan River water now being used. Plans are under consideration by the Federal Bureau of Reclamation for bringing surplus water of the Weber River system into the Bountiful district to augment its water supplies for irrigation.

Additional water supplies for irrigating the land east of the area of artesian flow can also serve to recharge the artesian reservoir and make it possible to increase the withdrawal from artesian wells. Within the area of artesian flow the use of imported water would reduce the draft on the artesian reservoir for irrigation, thus permitting increased use of water from artesian wells for domestic and industrial purposes. Finally, the diversion of imported water to lands now irrigated from mountain streams and by water tunnels and drains east of Bountiful would make it possible to develop a municipal supply from those sources, which yield water of very low mineral content. Until importation of additional water to the Bountiful district is assured, any large additional ground-water development in the future should be predicated on the requirement that the water be recovered from that currently lost to the district by stream flow to Great Salt Lake or by natural discharge or waste of ground water.

PLATE I

GEOLOGIC MAP OF BOUNTIFUL DISTRICT
DAVIS CO., UTAH

EXPLANATION

QUATERNARY

RECENT

Qht
Historic torrential deposits
(Unsorted, partly permeable alluvium)

Qd
Alluvium and delta deposits of Jordan River
(Silt, clay, and fine sand)

Qg
Deposits of Great Salt Lake
(Clay, silt, and salines deposited in Great Salt Lake)

Qt
Post-Lake Bonneville torrential deposits
(Unsorted, partly permeable alluvium)

PLEISTOCENE

Lake Bonneville beds

Qlr
Recessional shore deposits
(Permeable sand and gravel)

Qlp
Shore deposits of Provo stage
(Permeable gravel and sand)

Qlb
Shore deposits of Bonneville stage
(Permeable gravel and sand)

Qli
Shore deposits of "Intermediate" stage
(Permeable sand and silt)

Qld
Lake-bottom deposits
(Impermeable clay, sand, and silt; dashed pattern indicates cover of later deposits)

PLEISTOCENE and PLIOCENE (?)

Qpb
Pre-Lake Bonneville alluvium
(Partly permeable unsorted torrential deposits to the east, permeable gravel and sand interbedded with less permeable silt and clay farther west.)

TERTIARY

EOCENE (?)

Tw
Wasatch (?) formation
(Conglomerate, limestone and shale, less permeable than younger unconsolidated deposits.)

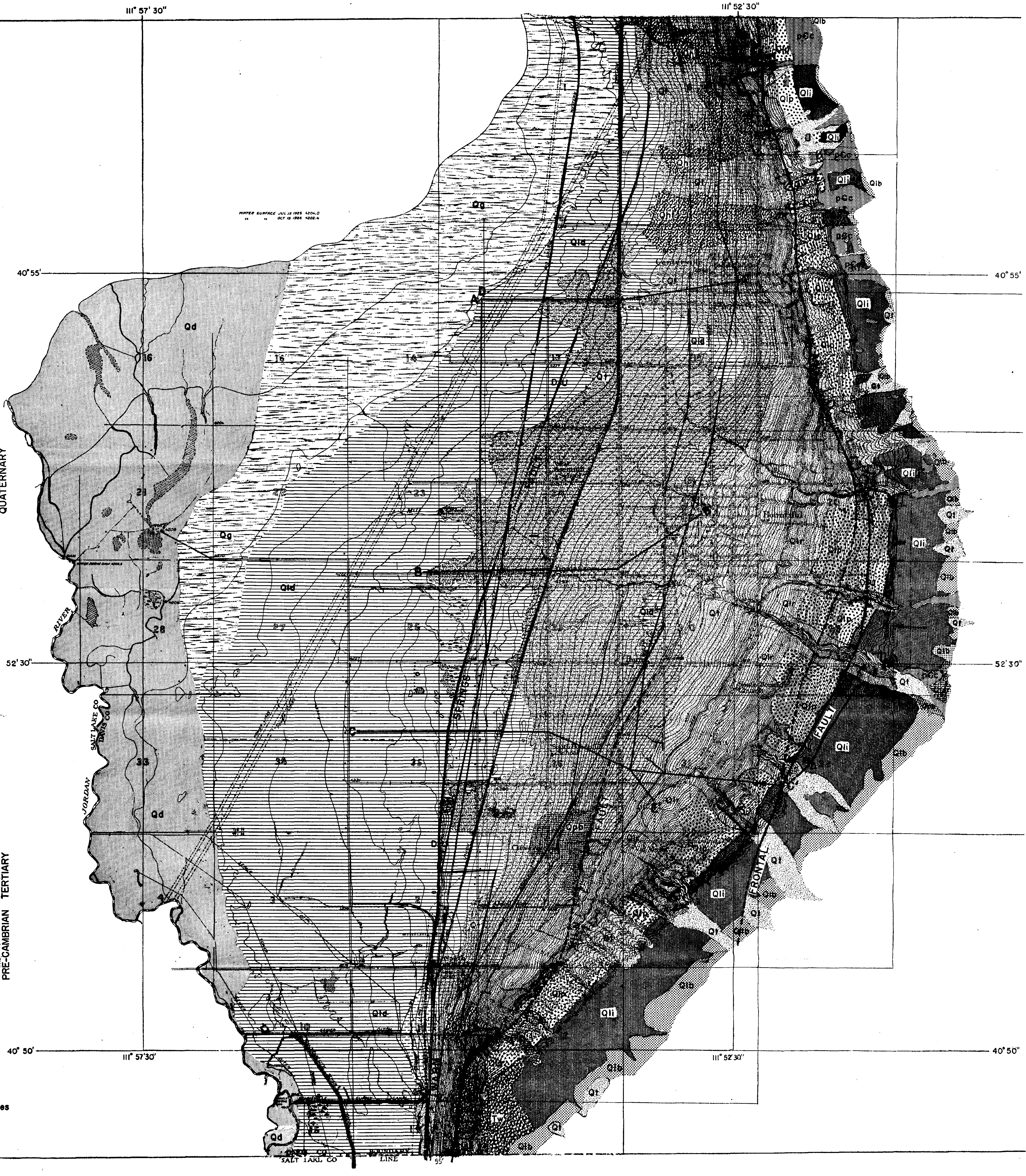
PRE-CAMBRIAN

pCc
Crystalline rocks
(Impermeable gneiss, schist, and pegmatite—The Farmington Canyon complex of Eardley.)

D/U FAULT

A———A'
Geologic section (fig. 4-8)

SCALE
0 0.5 1 2 Miles



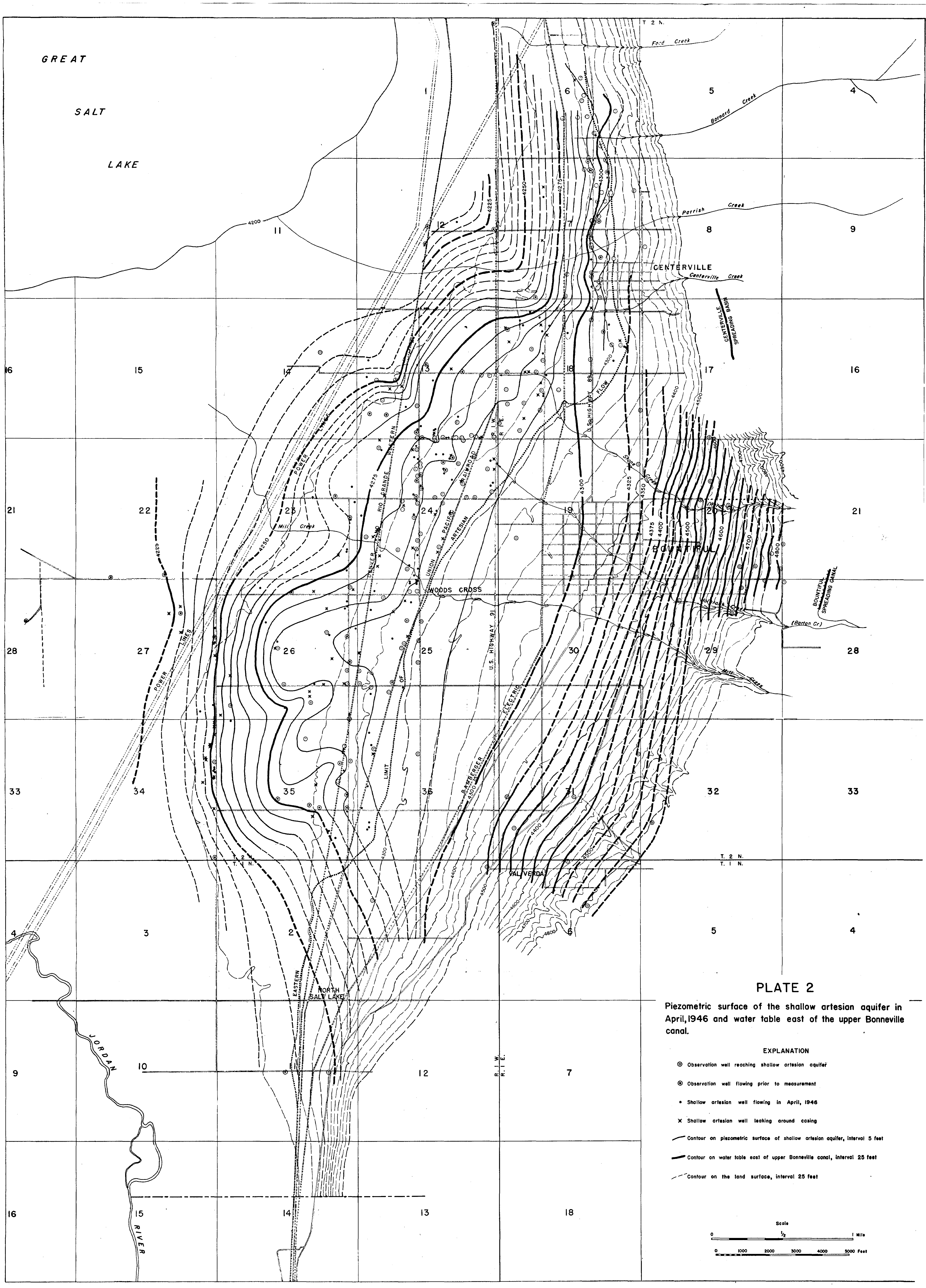


PLATE 2

Piezometric surface of the shallow artesian aquifer in April, 1946 and water table east of the upper Bonneville canal.