WATER-RESOURCES BULLETIN 2
1963

UTAH GEOLOGICAL AND MINERALOGICAL SURVEY
affiliated with
THE COLLEGE OF MINES AND MINERALS INDUSTRIES
University of Utah, Salt Lake City, Utah

GROUND - WATER CONDITIONS

in the Southern and Central Parts
of the East Shore Area, Utah
1953 - 1961

Prepared by
The United States Geological Survey
in cooperation with
The State Engineer of Utah

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UTAH GEOLOGICAL AND MINERALOGICAL SURVEY

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Address:

UTAH GEOLOGICAL AND MINERALOGICAL SURVEY
103 Civil Engineering Building
University of Utah
Salt Lake City 12, Utah

DIRECTORS :

William P. Hewitt, 1961-

Arthur L. Crawford, 1949-1961

WATER-RESOURCES BULLETIN 2

GROUND - WATER CONDITIONS IN THE SOUTHERN AND CENTRAL PARTS OF THE EAST SHORE AREA, UTAH, 1953 - 1961

by Ralph E. Smith and Joseph S. Gates
Geologists, U. S. Geological Survey

Photograph of a small-diameter flowing well in Woods Cross.

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UTAH GEOLOGICAL AND MINERALOGICAL SURVEY

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Geologists, U. S. Geological Survey

ABSTRACT

The East Shore area is in north-central Utah between the Wasatch Range and Great Salt Lake, and it has been divided into the Bountiful, Weber Delta, and Brigham ground-water districts, from south to north. The area described in this report includes the Bountiful and Weber Delta districts and the southernmost part of the Brigham district. Long-term mean annual precipitation at Ogden is 17.07 inches, and the average annual temperature over the area is about 50°F. The population of the project area increased by 54 per cent from 1950 to 1960 and should increase rapidly in the future.

The major aquifers in the area are artesian and consist of permeable stream and lake deposits of sand and gravel of Quaternary age interbedded with fine-grained deposits. The aquifers are commonly discontinuous and lenticular or elongate, and their interrelations are complex. The aquifers are recharged in a zone 1 to 2 miles wide adjacent to the west face of the Wasatch Range. The sources of recharge are the Weber and Ogden Rivers as they emerge from the Wasatch Range, the streams draining the western front of the mountains, and seepage from the bedrock of the mountain mass, and precipitation and irrigation in the recharge area.

In the project area during 1959 about 40,000 acre-feet of water was discharged by flowing wells and by small-diameter wells pumped for domestic use, and about 13,000 acre-feet was discharged by large-diameter pumped wells. The quantity of ground water used did not change significantly during the period 1955-59. Total water use in the area increased, however, because of large quantities of surface water made available to the area by the Weber Basin Project of the U.S. Bureau of Reclamation. Ground-water use will probably increase to help meet the growing needs of the area.

Since 1953 water levels have declined in most of the observation wells in the project area. December water levels in the Bountiful district and in the Hill Air Force Base and North Ogden-Plain City areas of the Weber Delta district declined 5 to 27 feet during the period 1953-59. Most of

the decline was caused by pumping, but the below-normal precipitation since 1953 also has been a factor. The decline of water levels is an unavoidable effect of water development, and it actually leads to more efficient use of water by reducing waste.

Ground water in the project area is of the calcium magnesium bicarbonate, sodium bicarbonate, and sodium chloride types. Each type generally is found in fairly well-defined areas. Most of the wells periodically sampled show little change in quality of water, and the changes observed in a few wells are not obviously related to ground-water development.

INTRODUCTION

Location and Extent of the Area

The East Shore area is in north-central Utah between the west face of the Wasatch Range and the east shore of Great Salt Lake, and it includes parts of Davis, Weber, and Box Elder Counties. Thomas and Nelson (1948, p. 63) defined the East Shore ground-water area as lying between the lake and the mountains from the Davis County-Salt Lake County line to the lower Bear River Valley. They divided the area into three districts: the Bountiful district, which is in the southern part of the area in Townships 1 and 2 North, in Davis County; the Weber Delta district, which is in the central part of the area in Townships 3 through 7 North, in Davis, Weber, and Box Elder Counties; and the Brigham district, which is in the northern part of the area extending north from Bear River Bay to the lower Bear River Valley in Box Elder County. The boundaries of these districts are shown on plates 1 and 2. The northern limit of the area included in this study (fig. 1) is the section line north of the town of Willard, and the southern limit is the Davis County-Salt Lake County line. (See pl. 1.) The project area includes the Bountiful and Weber Delta ground-water districts and the southernmost part of the Brigham ground-water district of the East Shore area. The area is generally flat, but the elevation and relief increase eastward from the salt flats adjacent to the lake to the foothills of the Wasatch.

Purpose and Scope of the Investigation

In February 1957 the U.S. Geological Survey, in cooperation with the Utah State Engineer, began a study of ground-water conditions in the project area. Fieldwork was completed in July 1961.

This investigation was not a comprehensive areal study of ground water in the southern and central East Shore area, but a study of water-level and quality-of-water data collected during the period 1953-61. Two more comprehensive studies of ground water have been made in the Bountiful district (Thomas and Nelson, 1948) and in the Weber Delta district (Feth and others, written communication, 1961) of the East Shore area. The latter report is being readied for publication.

The East Shore is an area of rapidly increasing population and growing industry, and the use of water in the area also is increasing. The limits of future development of the area depend to a large extent on the amount of water available, and continuing evaluations of the water supply are needed to insure that the maximum amount of water is obtained without overdevelopment.

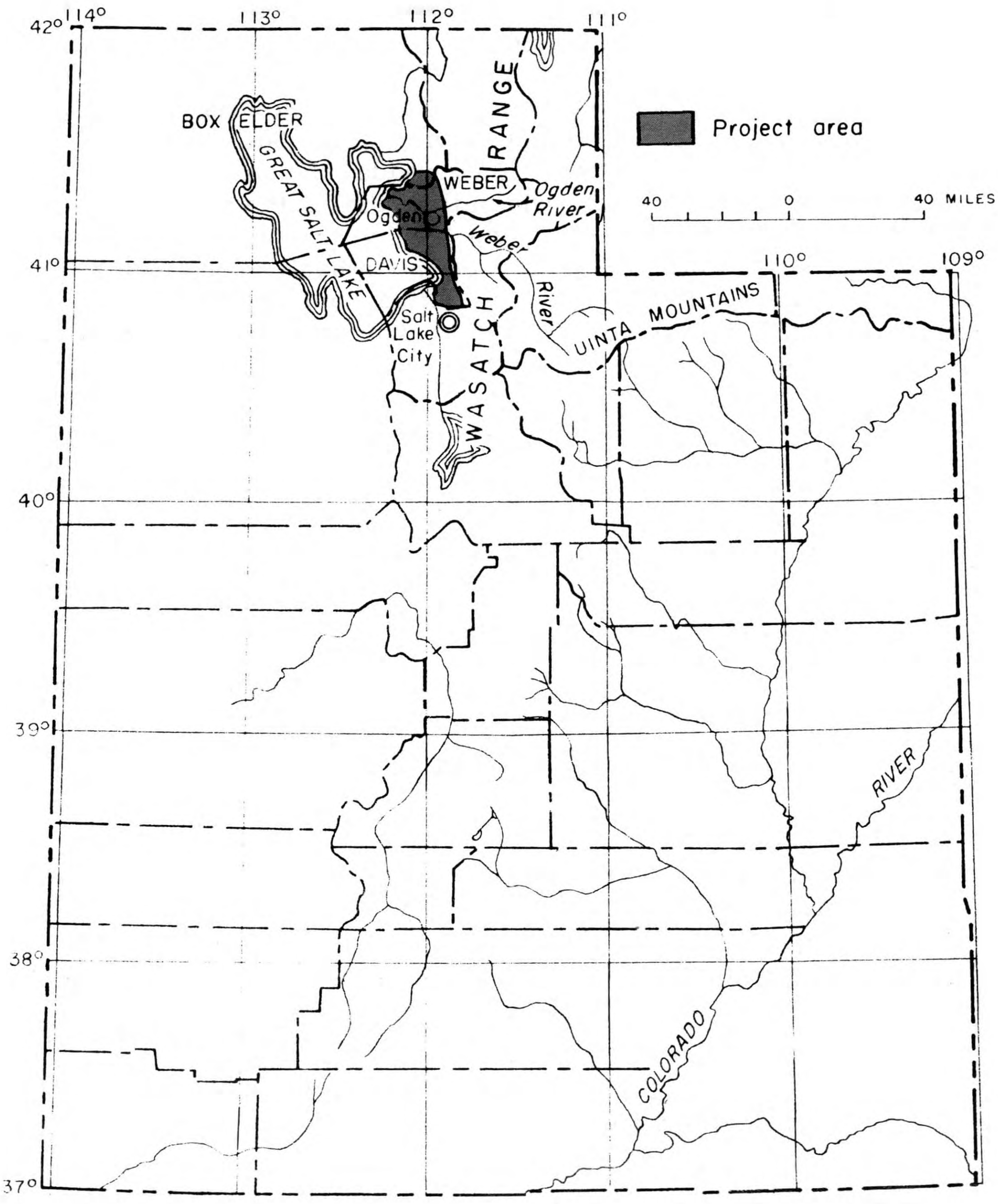

Figure 1. Index map of Utah showing the location of the area described in this report.

The water-level and quality-of-water data collected during the period 1953-61 and selected earlier data were released as Utah Basic-Data Report No.1 (Smith, 1961). Basic-Data Report No. 1 includes records for 194 wells; measurements of water levels and artesian pressures in 141 wells, 13 of which were equipped with recording gages; chemical analyses of water from 41 wells; and a well-location map. The present report is based on these data, on estimates of pumpage from 57 large-diameter wells in 1955 and 1959, and on other data from Geological Survey files.

The senior author collected the basic data during the study and largely prepared the report. The junior author assisted in interpretation of data and preparation of the report. The study was carried out under the supervision of H. A. Waite and H. D. Goode, successively district geologist and acting district geologist of the Ground Water Branch of the Geological Survey in Utah.

Methods of Investigation

In 1935 the Geological Survey began periodic measurements of water levels in 23 wells in the East Shore area. The number of observation wells increased to about 160 by 1946 and then decreased to 31 by 1951. During the period 1952-56 the U.S. Bureau of Reclamation participated in the water-level measurement program and the number of observation wells was increased from about 100 in 1952 to about 240 in 1956. During 1957-61 the Bureau and the Geological Survey, in cooperation with the State of Utah, each measured water levels in 60 wells.

Smith prepared hydrographs of most of the wells, and Basic-Data Report No. 1 (Smith, 1961) includes the 36 hydrographs most representative of water-level fluctuations in the project area. All or parts of 11 of these hydrographs are included in this report (figs. 4, 5, and 7). Graphs of cumulative departure from the average October-through-April precipitation at local weather stations for the period 1936-60 were prepared and compared with hydrographs of April water levels in wells to determine the effect of precipitation on water levels. Areas in which water levels had declined most in the period 1953-59 were outlined in a contour map of decline in December water levels (pl. 1).

The Geological Survey, the Bureau of Reclamation, and the Utah State Engineer obtained estimates of pumpage from owners or users of large-diameter pumped wells. These data and data from Feth and others (written communication, 1961) were used to estimate the total quantity of water withdrawn during 1959 from all wells in the project area.

Connor, Mitchell, and others (1958) report chemical analyses of ground-water samples collected in the East Shore area prior to 1957 by the Geological Survey, the Bureau of Reclamation, and the Utah State Department of Public Health. Water-quality data for the present study were collected during the period 1958-61 from 41 wells, 32 of which had been sampled prior to 1957. The 1958-61 data were collected to add new information on quality of water in the area and to note any changes in quality of water since the previous period of sampling. Smith (1961, table 3) presents these data and analyses of a few 1957 samples from Hill Air Force Base and other locations. Most of the available data were used to prepare a map delineating areas that produce different chemical types of water (fig. 8). This map is in part after a similar illustration by Feth and others (written communication, 1961).

Acknowledgments

Private, municipal, industrial, and military well owners allowed the collection of water-level data and water samples from their wells and furnished information on the wells and on pumpage. The Weber Basin Project Office of the Bureau of Reclamation made most of the water-level measurements in wells in the Ogden-Clearfield-Hooper area since 1952, and G. M. Ross, in charge of ground-water investigations for the Project Office, was especially helpful in providing these and other data. The Utah State Engineer's office provided a large part of the information in the well table in Basic-Data Report No. 1 (Smith, 1961).

Population

The East Shore area is about the northern half of the Wasatch Front, which is the 15-20 mile-wide strip of valley land bordering the west side of the Wasatch Range. The Wasatch Front is the most heavily populated area in Utah because of its good water supply, climate, and soil. Industry in the area is growing, and largely for this reason the Wasatch Front can be expected to lead the state in future economic and population growth.

The population of the project area was estimated to be 113,000 in 1950; it increased by 54 per cent to 175,000 by 1960. In contrast, the population of Utah as a whole increased only 29 per cent during the same period. Davis County had the greatest increase, from 30,867 to 64,760, largely because it has become a residential area for people employed in Salt Lake City. Some of the increases for the 1950-60 period for the largest cities and for the fastest growing cities are as follows: Bountiful - 6,004 to 17,039, Layton - 3,456 to 9,027, Ogden - 57,112 to 70,197, and Roy - 3,723 to 9,239.

The East Shore area is semiarid with a normal precipitation of from 12 to 20 inches and an average annual temperature of about 50°F. According to records of the U.S. Weather Bureau, the long-term mean annual precipitation at Farmington is 19.39 inches, at Ogden (Sugar Factory) 17.07 inches, and at Brigham City, 6 miles north of Willard, 17.93 inches. The October through April precipitation at these stations ranges from 70 to 73 per cent of the annual precipitation (table 1). The long-term mean monthly temperatures range from 28.1°F in January to 75.6°F in July at Farmington, from 26.2°F in January to 75.4°F in July at Ogden (Sugar Factory), and from 25.9°F in January to 76.3°F in July at Brigham City.

Table 1. Long-term mean monthly precipitation and other precipitation data in in the East Shore area.

(From records of the U. S. Weather Bureau. Means based on the period 1931 - 55.)

	Farmington	Ogden (Sugar Factory)	Brigham City		Farmington	Ogden (Sugar Factory)	Brigham City
October	1.69	1.67	1.59	May	1.76	1.55	1.74
November	1.89	1.64	1.86	June	1.41	1.31	1.41
December	2.04	1.82	1.80	July	.45	.56	.46
January	2.28	1.70	1.98	August	1.02	.79	.58
February	1.79	1.45	1.60	September	.69	.83	.97
March	2.05	1.59	1.81	May-September	5.33	5.04	5.16
April	2.32	2.16	2.13				
October-April	14.06	12.03	12.77	Annual	19.39	17.07	17.93

Well-Numbering System Used in Utah

The well numbers used in this report indicate the well location by land subdivision according to a numbering system that was devised cooperatively by the Utah State Engineer and G. H. Taylor of the Geological Survey about 1935. The system is illustrated in figure 2. The complete well number comprises letters and numbers that designate consecutively the quadrant and township (shown together in parentheses by a capital letter designating the quadrant in relation to the base point of the Salt Lake Base and Meridian, and numbers designating the township and range); the number of the section; the quarter section (designated by a letter); the quarter of the quarter section; the quarter of the quarter-quarter section; and, finally, the particular well within the 10-acre tract (designated by a number). By this system the letters A, B, C, and D designate, respectively, the northeast, northwest, southwest, and southeast quadrants of the standard base and meridian system of the Bureau of Land Management, and the letters a, b, c, and d designate, respectively, the northeast, northwest, southwest, and southeast quarters of the section, of the quarter section, and of the quarter-quarter section. Thus, the number (B-2-2)12dcd-2 designates well 2 in the SE1/4 SW1/4 SE1/4 sec. 12, T. 2 N., R. 2 W., the letter B showing that the township is north of the Salt Lake Base Line and the range is west of the Salt Lake Meridian; and the number (D-3-2)34bca-1 designates well 1 in the NE1/4 SW1/4 NW1/4 sec. 34, T. 3 S., R. 2 E. In part of the Uinta basin the land subdivision is based on the Uinta Special Base and Meridian. Coordinates of wells in that area are preceded by the letter U; a typical well number is U(D-1-1)23abd-1.

GENERAL HYDROLOGY

The source of most of the water in the East Shore area is from streams fed by precipitation in the mountains to the east, the Wasatch Range and the Uinta Mountains. In northern Utah, precipitation increases roughly in proportion to altitude, and figure 3 shows that the maximum October-April precipitation in the Wasatch Range is almost three times the corresponding precipitation in most of the project area. The precipitation in the mountains contributes more water to the East Shore area than precipitation in the East Shore area because of its greater quantity and because less of it is evaporated or transpired. Evapotranspiration in the mountains is much less than it is at lower elevations, and in the higher parts of the Wasatch Range it was estimated by Feth and others (written communication, 1961) to be as little as one-fourth of the annual precipitation in the same area. In contrast, the average annual class A pan evaporation in the East Shore area is about 55 inches (Kohler, Nordenson, and Baker, 1959, pl. 1), which is about three times the average annual precipitation in the same area.

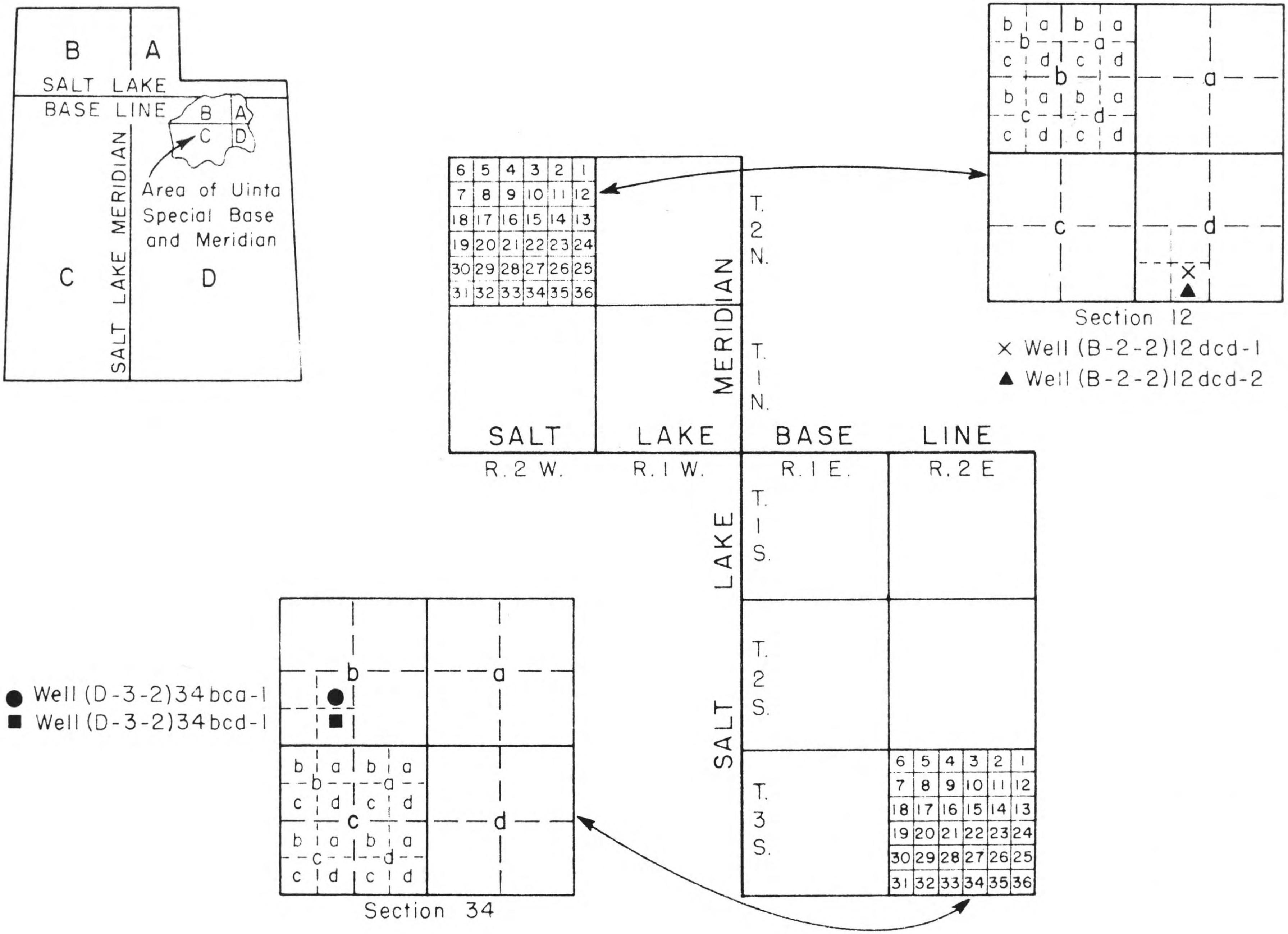

Figure 2.-- Well-numbering system used in Utah.

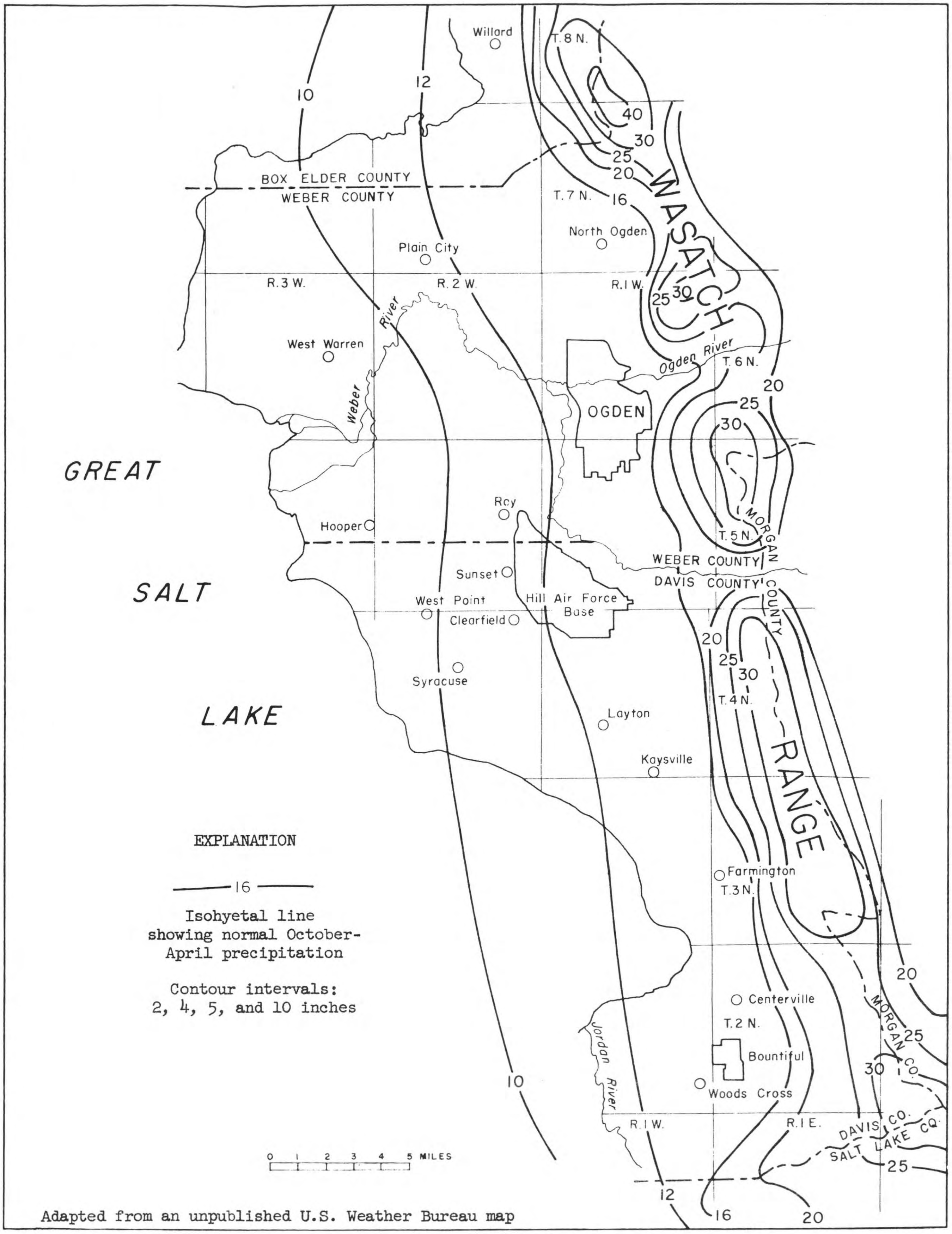

Figure 3. Map of the project area and adjacent mountains, showing the normal October-April precipitation for the period 1921 - 1950.

Approximately 70 per cent of the precipitation in northern Utah is during the period October through April. In addition, evapotranspiration is much less during this period than in the period May through September. Precipitation in the mountains during the period October through April falls as snow, which collects until rising temperatures in the spring start snowmelt and runoff. The peak flows of the mountain streams are from April through July and generally are several times as large as the late summer flows.

Most of the water used in the project area is taken from the Weber and Ogden Rivers, which originate in the Uinta Mountains and Wasatch Range and in the Wasatch Range, respectively. Feth and others (written communication, 1961) stated that during the period 1928-47 an annual average of 360,000 acre-feet of water in the Weber River and 160,000 acre-feet in the Ogden River entered the Weber Delta district. The shorter streams draining the west slopes of the Wasatch Range furnished about 35,000 acre-feet per year to the Weber Delta district during the same period. Using later Geological Survey records, the average annual discharge of the Weber River to the Weber Delta district during 1948-60 was calculated as 407,000 acre-feet and the average annual discharge of the Ogden River during 1948-58 was 190,000 acre-feet. Thomas and Nelson (1948, p. 123-126) estimated that surface flow from mountain-front streams in the Bountiful district averaged 18,500 acre-feet per year for the period 1937-46. Using later Geological Survey records and the same method of estimation as Thomas and Nelson, the average annual surface flow for the period 1950-59 was estimated as 16,700 acre-feet.

The ground-water reservoir in the Bountiful and Weber Delta ground-water districts has been described by Thomas and Nelson (1948) and Feth and others (written communication, 1961), and the following discussion is a summary of their conclusions. The project area is underlain by several thousand feet of unconsolidated and semiconsolidated material, mostly of Quaternary age, which was deposited by streams, mud-rock flows, and similar processes and in lakes. The stream deposits, which are bedded and partly sorted, generally are discontinuous and elongated bodies of boulders, gravel, sand, and clay. Mud-rock-flow deposits are unsorted and contain clay, sand, and larger fragments. Lacustrine deposits include fairly continuous and well-sorted bodies of clay, silt, sand, and gravel. Many of the coarser lake beds were deposited by near-shore currents as elongate bodies parallel to shorelines. Lacustrine and subaerial conditions of deposition alternated many times in the history of the basin. The best aquifers, or water-yielding deposits, in the basin are the coarser and better sorted materials, usually stream-channel or lake-shore deposits.

Ground water occurs as local bodies of perched water above the main saturated zone, under unconfined (or water-table) conditions in shallow aquifers, and under confined (or artesian) conditions in several deeper aquifers. The artesian aquifers, which contain most of the ground water in the area, are permeable beds between fine-grained beds of lower permeability. The fine-grained beds confine the water under pressure in the permeable beds. Although the various artesian aquifers generally are separated by fine-grained beds, enough hydraulic connection exists between them so that in many aspects they can be studied as a single system.

According to Feth and others (written communication, 1961), the artesian aquifers in the Weber Delta district are recharged in a zone of coarse material as wide as 1 1/2 miles just west of the mountain front.

Feth and others (written communication, 1961) estimated that almost half the recharge to the ground-water reservoir in the Weber Delta district is seepage from the bedrock of the Wasatch Range, slightly less than one-quarter of the recharge is infiltration from the Weber River, and the remainder includes infiltration from precipitation, infiltration from irrigation, infiltration from the short streams draining the mountain front, and infiltration from the Ogden River.

Thomas and Nelson (1948) do not discuss the recharge area of the Bountiful district in detail, but from their geologic map and discussion of recharge it can be determined that the recharge area at the mountain front in the southern East Shore area ranges from 3/4 to 2 miles in width. Most of the recharge probably is seppage from the bedrock of the mountain front, and the remainder includes infiltration from the mountain-front streams, infiltration from irrigation, and perhaps a minor amount from infiltration of precipitation in the recharge area.

GROUND - WATER CONDITIONS

Discharge from Wells in 1955 and 1959

Wells in the project area can be classified into three types based on well diameter and type of water use; flowing wells used principally for domestic needs, stock, and irrigation; small-diameter (generally less than 6 inches) wells pumped for domestic use; and large-diameter wells pumped for municipal, industrial, military, or irrigation supply.

The amount of water discharged by wells of the first two types was virtually the same in 1959 as in 1955 (F. M. Warnick, U.S. Bureau of Reclamation, oral communication, September 1960), when it was estimated that flowing wells and wells pumped for domestic use produced 13 billion gallons, or about 40,000 acre-feet, of water.

The quantity of water produced by large-diameter pumped wells in the project area during 1955 and 1959 is shown in table 2, and the wells that produced significant amounts of water and the estimated amount of water each produced in 1959 are shown on plate 2. The main centers of use of water from large-diameter wells are the Bountiful district and the area around Hill Air Force Base. The accuracy of the pumpage estimates from the various wells used to prepare table 2 differs considerably. The estimates from some of the wells were accurate to three significant figures, whereas other estimates were not accurate to one significant figure and only indicate an order of magnitude. Totals for the two years are given for each county (Davis, Weber, and Box Elder) and for each type of water use. The totals for each year and the subtotals for each county and type of use did not change significantly from 1955 to 1959.

Table 2. Summary of estimated pumpage from large-diameter wells in the project area in 1955 and 1959.

	Pumpage in millions of gallons, acre-feet in parentheses; (totals rounded to degree of accuracy)	
	1955	1959
Totals by counties		
Davis County	3,130 (9,600)	3,860 (11,800)
Weber County	920 (2,800)	300 (900)
Box Elder County	60 (200)	60 (200)
Total for project area	4,110 (12,600)	4,220 (12,900)
Totals by use		
Public supply (includes any water for industrial use that is supplied by municipalities)	1,840 (5,600)	2,090 (6,400)
Industry	1,330 (4,100)	1,260 (3,900)
Military	900 (2,800)	830 (2,500)
Irrigation	40 (100)	40 (100)

Although the annual discharge from wells in the project area showed little change from 1955 to 1959, starting in 1957 the total water use in the area increased considerably because an additional supply of surface water was brought in from reservoirs of the Weber Basin Water Conservancy District in the mountains to the east. The use of ground water will increase if the local use of water ever exceeds the surface supply available to the Conservancy District. Furthermore, F. T. Mayo of the State Engineer's Office (oral communication, Oct. 18, 1962) stated that in areas where water of good quality is available; pumpage from wells for public and industrial supply will probably increase as long as the cost of developing and producing ground water is less than the cost of treated Weber Basin Project water.

Changes in amounts of water produced from large-diameter wells around the main centers of use from 1955 to 1959 do not show up in table 2. In the Bountiful district annual pumpage increased about 560 million gallons (1,700 acre-feet), whereas in the area around Hill Air Force Base annual pumpage decreased about 470 million gallons (1,400 acre-feet). More water from the Weber Basin Water Conservancy District was substituted for well water by owners of large-diameter wells in the Hill Air Force Base area than by owners of wells in the Bountiful district. The city of Ogden, for example, began using Weber Basin Project water in 1957 and by 1959 had reduced the annual use of ground water by about 430 million gallons (1,300 acre-feet).

Complete and accurate data for the discharge of ground water will be needed in future evaluations of the ground-water supply of the East Shore area. Withdrawals from large-diameter wells should be measured by meters or by some other relatively accurate method.

Water-Level Fluctuations

Water levels in wells fluctuate principally in response to changes in recharge to or discharge from the ground-water reservoir. When recharge exceeds discharge, the ground water in storage increases and water levels rise. When discharge exceeds recharge, storage decreases and water levels decline. In addition, minor fluctuations are caused in artesian wells by changes in atmospheric pressure, temporary aquifer loading, or by earthquakes. In the East Shore area, the water-level fluctuations useful for interpretation of the changes produced by recharge and discharge of ground water can be classified as either annual or long-term fluctuations.

Annual Changes

Water levels in both artesian and water-table wells in the East Shore area generally fluctuate through a yearly cycle. The fluctuations can be caused mostly by changes in recharge, mostly by changes in discharge, or by both.

Water levels in most artesian wells, the most numerous type of well in the area, are highest in the spring or early summer. They decline during the summer, reaching their lowest point in the early fall before starting to rise to the next spring maximum. Levels are highest in the spring because at that time recharge is greatest and because the discharge from wells has been at a minimum during the winter and early spring. During the summer water levels decline because of diminishing recharge and increased discharge. Near the mountain front variations in recharge are the major cause of fluctuations of water levels, whereas farther from the mountains variations in discharge probably are the main cause.

Water levels are highest in most water-table wells in irrigated areas in the late summer because during the irrigation season the shallow unconfined aquifers are recharged by irrigation water. In water-table wells along stream channels, however, the highest water levels correspond with the greatest runoff of the stream, usually during the spring or early summer.

Figure 4 shows hydrographs of three wells in the East Shore area in which water-level fluctuations are caused by recharge. Figure 4A is a hydrograph of an artesian well, (B-8-2)23cdb-1, which is close to the mountain front in the town of Willard. The water level reaches a yearly high in the early summer, at the time of greatest recharge from the mountain front, and is lowest just before recharge begins. Thus, the fluctuations are caused largely by recharge. Figure 4B is a hydrograph of well (B-7-1)30abb-1, which is a water-table well in an irrigated area west of North Ogden. The yearly high water level is in the late summer at the end of the irrigation season, and the low is in the winter when the land is not irrigated. Recharge to the shallow aquifer by irrigation is the major cause of the water-level fluctuations in this well. Figure 4C is a hydrograph of well (B-5-1)27abd-1, which is a water-table well 75 feet deep and less than a mile north of the Weber River. The yearly high water level coincides with the yearly peak discharge of the river, indicating that the flucuations are caused by recharge to shallow aquifers from the river.

Figure 5 shows the hydrographs of three artesian wells in which water-level fluctuations result partly or mostly from variations in discharge and the hydrograph of an artesian well in which fluctuations are only minor. Water levels that are influenced by discharge fluctuate more irregularly than those influenced mostly by recharge. (Compare the hydrographs of figs. 4 and 5.) Flowing wells are often closed at various times of the year, most commonly in the winter, and pumped wells are often used only part of a day. The consequent irregularities in discharge are the major cause of the large irregularities in water-level changes. Figure 5A is a hydrograph of well (B-2-1)34ada-3, which is west of

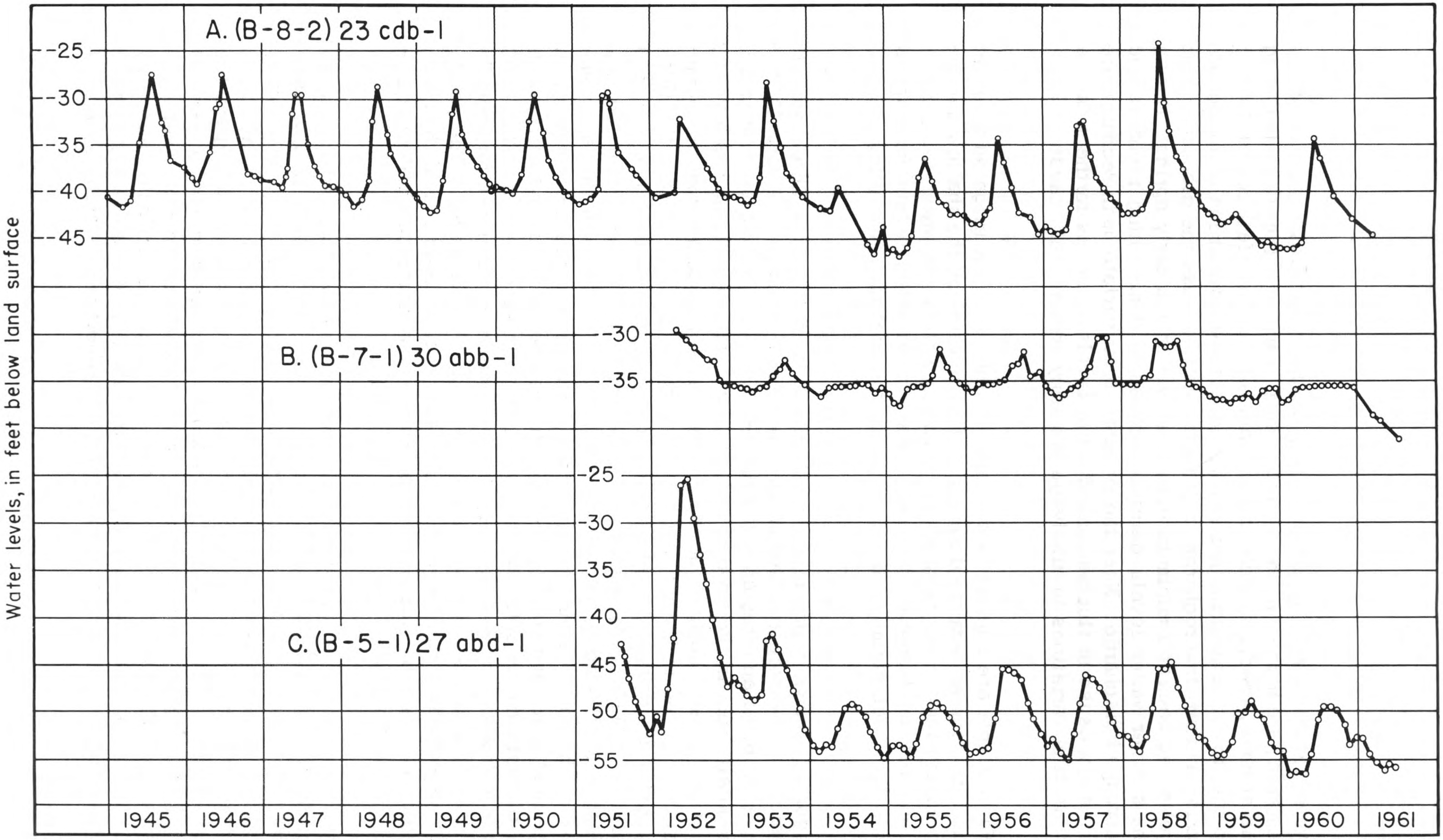

Figure 4. Hydrographs of an artesian well and two water-table wells that show fluctuations due to recharge.

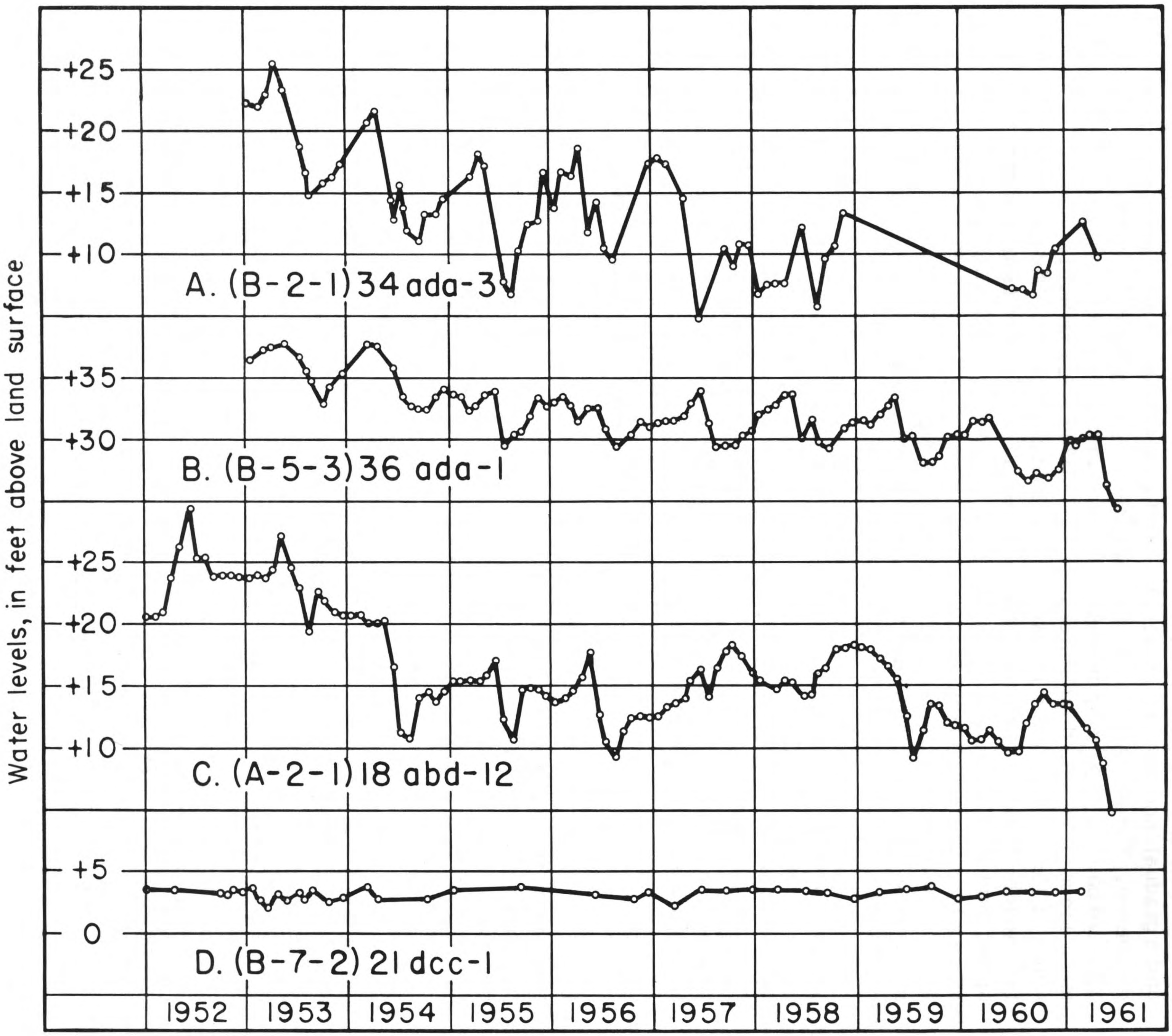

Figure 5. Hydrographs of selected artesian wells that show fluctuations due to discharge and a hydrograph of an artesian well that shows little fluctuation.

Woods Cross and 4 miles west of the mountain front. The high spring water levels in this well are probably a result of both spring recharge and a gradual increase in pressure during the winter because of decreased discharge. The low water levels are in the late summer, and they probably are caused largely by discharge of wells in the area during the summer. Figure 5B is a hydrograph of well (B-5-3)36ada-1, which is 2 miles south of Hooper and 11 miles west of the mountain front. This well is far enough from the recharge area so that the high water levels in the spring and low water levels in the late summer probably are caused mostly by variations in discharge from nearby flowing wells. Figure 5C is a hydrograph of well (A-2-1)18abd-12 in Centerville. The hydrograph shows several sharp downward fluctuations that are caused by the discharge of nearby wells.

Figure 5D is a hydrograph that shows only minor water-level fluctuations. The well, (B-7-2)21dcc-1, is a mile north of Plain City in an area where there are few other wells. It is far enough from the mountain front so that recharge has no noticeable effect on the water level, and the discharge of nearby wells evidently is not great or variable enough to cause large fluctuations of the water level.

Long-Term Fluctuations

Long-term fluctuations, or trends, of water levels are caused by long-term trends in recharge or discharge or both. Trends in water levels are best observed by comparing the position of water levels at a certain time each year for a period of years. The time of year selected should be when fluctuations caused by discharge are at a minimum, commonly during the winter or early spring.

Recharge comes directly or indirectly from precipitation, and therefore water levels fluctuate in response to changes in precipitation. Thomas and Nelson (1948, p. 161-162 and fig. 13) recognized that long-term trends in water levels in the East Shore area correlate with long-term trends in precipitation.

The correlation between precipitation and trends in water levels has been close during recent years. The cumulative departure from the average October through April precipitation for 1935-60 at Farmington (table 3) and a hydrograph of April water levels in artesian well (B-4-1)30bba-1 for the same period are shown on figure 6. From 1935 to April 1944 precipitation was above average, with cumulative peaks in 1942 and 1944. From April 1944 to April 1948 precipitation was below average, and from April 1948 to April 1953 precipitation was above average, reaching a cumulative peak in 1953. From April 1953 to April 1960 precipitation was below average. The April water level in well (B-4-1)30bba-1 had a slight upward trend from 1935 to April 1943 and a slight downward trend from April 1943 to April 1948. From April 1948 to April 1953 the water level rose sharply, reaching its highest point for the 1935-60 period in April 1953, corresponding to the peak in cumulative precipitation for the period. The water level generally declined from April 1953 to April 1960, although a small rise matched a rise in precipitation from April 1957 to April 1958.

Table 3. October-April precipitation at Farmington, Utah, for the period 1935-60.

(From records of the U. S. Weather Bureau)

Year	October-April precipitation (inches)	Year	October-April precipitation (inches)
1935	13.42	1948	13.02
1936	14.68	1949	16.15
1937	16.29	1950	14.48
1938	15.70	1951	14.65
1939	13.90	1952	19.28
1940	15.08	1953	15.92
1941	17.98	1954	7.74
1942	17.00	1955	14.63
1943	11.36	1956	11.88
1944	17.06	1957	14.18
1945	10.98	1958	16.76
1946	11.39	1959	10.73
1947	16.29	1960	9.93
1935-60 Average			14.25

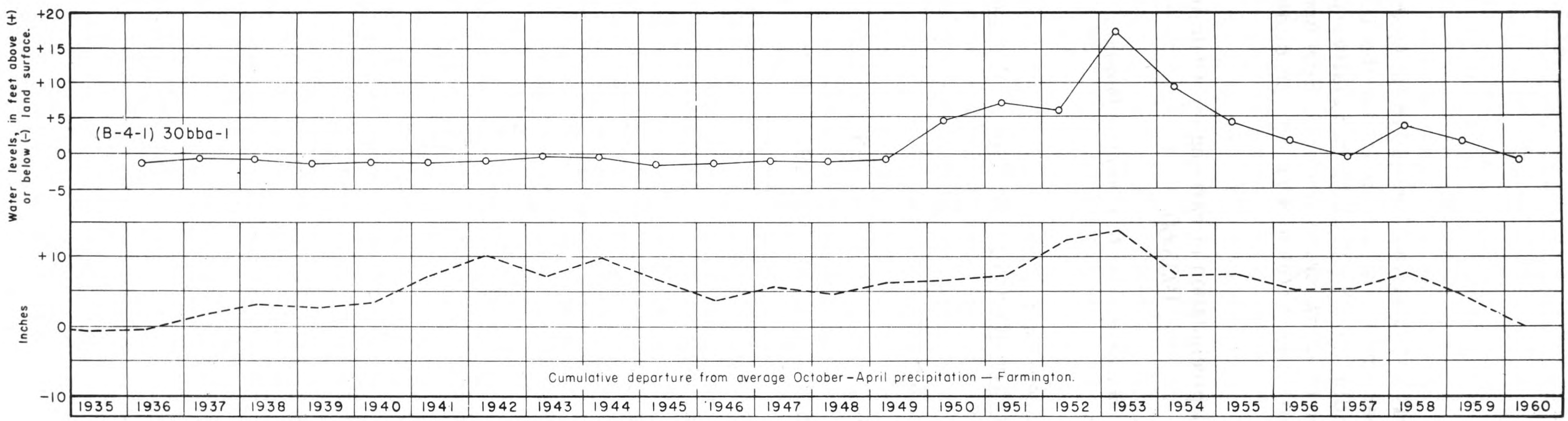

Figure 6. Cumulative departure from average October-April precipitation at Farmington, Utah, and a hydrograph of April water levels in artesian well (B-4-1)30bba-1 for the period 1935 - 60.

In the observation wells in the East Shore area for which records are available, the above-average precipitation in 1941-42 was matched by high water levels in 1942 and (or) 1943 in 18 of 24 wells. The above-average and following below-average precipitation in 1951-53 was matched by a similar rise and fall of water levels in 31 of 43 wells. The above-average precipitation in 1958 produced a rise in water level in 1958 in 48 of 104 wells. Deviations from the correlation between water levels and precipitation occurred mostly during the period 1942-51 when precipitation was roughly average and probably were caused largely by other influences.

Long-term trends in discharge also cause long-term changes in water levels. Recharge and discharge are balanced in an untapped ground-water reservoir. When wells are drilled, the resulting discharge of water disturbs the balance and water levels will decline until recharge and and discharge again are equal. This balance can be restored either by an increase in recharge or a decrease in natural discharge. If increases in recharge or decreases in natural discharge cannot compensate for the increases in discharge from wells, water is drawn from storage and water levels will decline continuously. A period of a few years during which water levels decline usually is not a sufficient length of time to determine whether the imbalance between recharge and discharge is temporary or permanent.

The effects of pumped wells and flowing wells on water levels differ somewhat. Water levels in any area will decline if discharge from wells increases because of increases in withdrawals from individual wells or because of added withdrawals from new wells. In an area of pumped wells, however, long-term declines can be caused by a steady rate of discharge that, in combination with natural discharge, exceeds recharge. In contrast, the water levels of a group of wells flowing at some initial rate will become relatively stable at a lower head and lesser discharge if no new wells are drilled. The water level and discharge of a flowing well are directly proportional; thus a decline in water level causes a decline in discharge, which in turn causes the rate of decline in water level to lessen.

Figure 7 shows the hydrographs of representative artesian wells in the Bountiful district (fig. 7A) and in the Weber Delta district (figs. 7B, 7C, and 7D) that show long-term water-level changes. The dashed lines of figures 7A, 7B, and 7C represent the trend of year-end water levels, and the dotted line of figure 7D represents the trend of spring maximum water levels. The hydrographs indicate that water levels in the project area did not show any significant upward or downward long-term trend from 1936 to 1953. From 1953 to 1960, the hydrographs show a definite downward trend. Although this decline in water level was not observed in all wells in the project area, it was common enough to indicate a general decrease in the pressure head of the artesian aquifers.

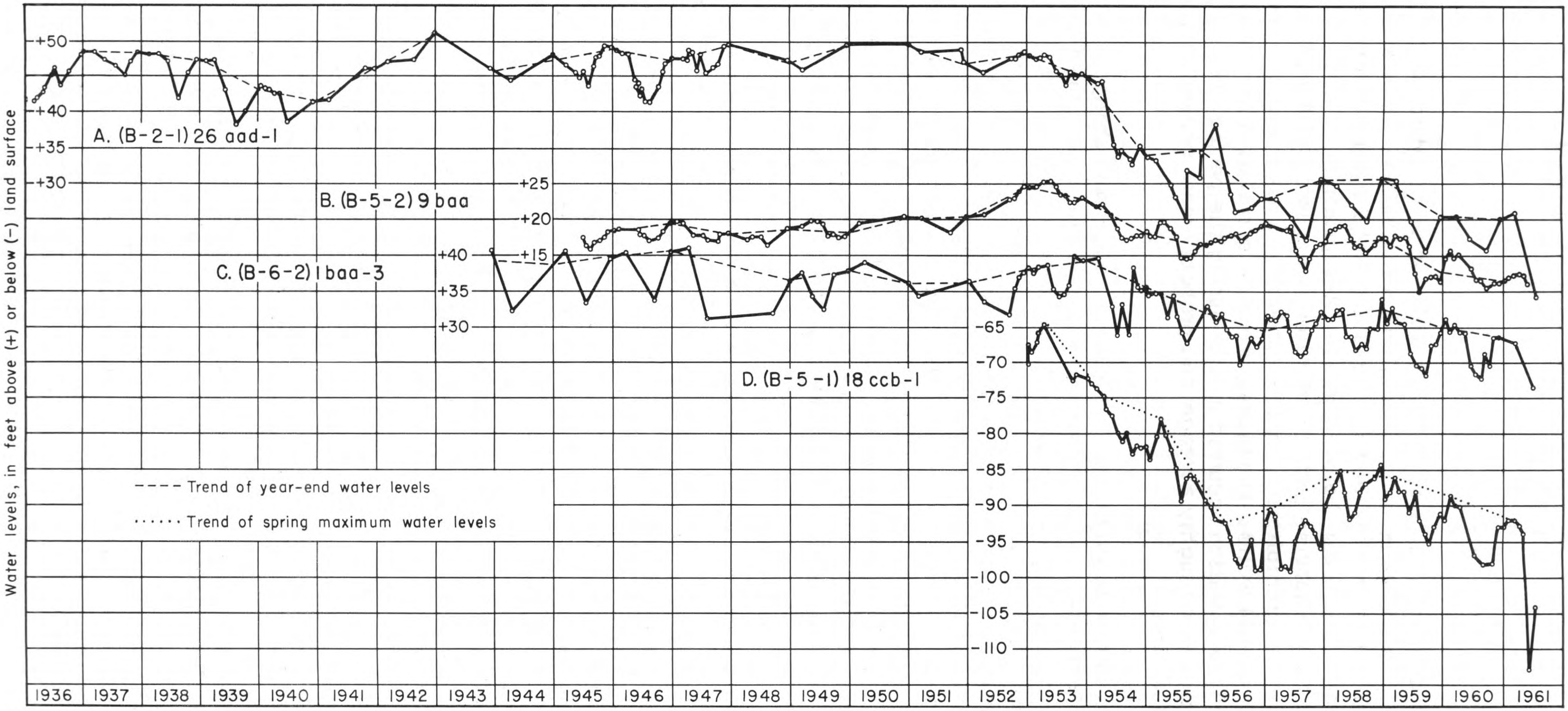

Figure 7. Hydrographs of selected artesian wells that show long-term trends (dashed and dotted lines) in water levels.

Areas of Significant Water-Level Decline 1953 - 1959

From December 1953 to December 1959 water levels in observation wells in the project area declined most in the Bountiful district and the Hill Air Force Base area of the Weber Delta district and to a lesser extent in the North Ogden-Plain City area of the Weber Delta district (pl. 1). The areas of significant decline generally coincide with areas that contain concentrations of pumped or flowing wells or both, and the two areas of greatest decline coincide with the two areas that contain concentrations of pumped wells. (See pl. 2.) This indicates that the greatest part of the decline of water levels was caused by withdrawal of water from wells, and the largest declines were caused by pumping large-diameter wells.

Large-diameter pumped wells discharge about one-quarter of the water yielded to wells in the project area. The apparently greater effect of pumped wells on water levels in the East Shore area is an example of the difference between the effects of pumped and flowing wells on water levels. A steady rate of discharge from a constant number of pumped wells will cause continuous decline of water levels or after a period of time result in relatively stable water levels. On the other hand, discharge from a constant number of flowing wells will not cause continuous decline but only will result in relatively stable water levels because the discharge changes in response to changes in pressure head.

Because water levels over much of the project area declined at least 5 feet during the period 1953-59 (pl. 1), perhaps 5 or as much as 10 feet of the decline was caused by the deficiency in precipitation during the period 1953-59. Although the below-average precipitation doubtless has had an effect on the water level of nearly all wells in the East Shore area, it is not possible to determine the exact amount of effect on each. The below-average precipitation probably indirectly helped cause the large water-level decline by resulting in an increase in pumping during 1953-59.

The decline of water levels has caused only minor changes in pumping methods or quantities of water produced by wells. In the Bountiful district most of the wells still flow, and in the Hill Air Force Base area the water levels during pumping are about 80 feet above the highest perforated zones in the wells.

Bountiful district. Water levels declined 5 to 21 feet in an area that includes more than 10 square miles around the towns of Bountiful, Woods Cross, and Centerville in the Bountiful district (pl. 1). The center of greatest decline was near Woods Cross. The area of water-level decline coincides with an area in which there is a concentration of both pumped and flowing wells (pl. 2). The withdrawal of water from pumped wells is considered to be the major cause of decline of water levels.

Water levels declined more in the earlier part of the 1953-59 period than in the later part (figs. 5C and 7A). The water level in well (B-2-1) 26dda-2, as an additional example, declined 14.4 feet from December 1953 to December 1955 and only 6.3 feet from December 1955 to December 1959. Few pumpage data are available for the Bountiful district during the earlier part of the 1953-59 period, and there are no data available on yields of flowing wells during the whole period. Withdrawals from pumped wells probably increased significantly during 1953-55, thereby causing the water-level decline for that period. Available data indicate that annual pumpage from large-diameter wells increased by about 560 million gallons (1,700 acre-feet) during the period 1955-59. This rate of increase may have been considerably less than that during the period 1953-55. Moreover, the decline in artesian pressure in flowing wells during the 1953-59 period probably resulted in a decrease in the discharge of these wells. This decrease in discharge may have helped to lessen the rate of decline of water levels during the latter part of the period.

Weber Delta district.

Hill Air Force Base area--The Hill Air Force Base area includes more than 30 square miles around Hill Air Force Base and the towns of Sunset, West Point, and Clearfield (pl. 1). This area includes much of the Weber Delta subdistrict of the Weber Delta district, as defined by Feth and others (written communication, 1961). Water levels declined 15-27 feet in this area during the period 1953-59, with centers of greatest decline at the Air Force Base and West Point. The Hill Air Force Base area is about in the center of a larger area, bounded roughly by Ogden on the northeast, Hooper on the northwest, and Kaysville on the southeast, in which the decline of water levels exceeded 5 feet. The area in which the decline of water level exceeds 15 feet coincides roughly with one of the two areas in which large-diameter pumped wells are concentrated (pl. 2), and most of the decline is probably caused by pumping.

The largest part of the decline in many of the wells was from 1953 to 1955, and the rate of decline decreased, or water levels rose, from 1955 to 1959 (figs. 7B and 7D). Few pumpage data are available for the period 1953-55, but during the period 1955-59, the annual pumpage around Hill Air Force Base decreased by about 470 million gallons. A significant increase in pumpage during the period 1953-55 probably caused the decline of water levels during that period.

North Ogden-Plain City area--The North Ogden-Plain City area includes more than 10 square miles from North Ogden to Plain City (pl. 1). This area includes parts of the North Ogden and Ogden-Plain City subdistricts of the Weber Delta district, as defined by Feth and others (written communication, 1961). Water levels declined from 5 to 14 feet in this area, with centers of greatest decline at North Ogden, southwest of North

Ogden, and south of Plain City. Differences in rates of decline during the early and late parts of the 1953-59 period are not great, although water levels declined most in some wells southwest of North Ogden during 1953-56 (fig. 7C).

No large-diameter, heavily pumped wells were in the North Ogden-Plain City area during the 1953-59 period. Many flowing wells are scattered throughout the area, however, and a concentration of flowing wells is in North Ogden. Discharge of water from the flowing wells drilled prior to 1953 probably was not the major cause of decline of water levels in the area. However, any new wells drilled during the 1953-59 period lowered the artesian pressure and contributed to the decline in water levels. Estimating the amount of decline caused by new wells is difficult, but the decline probably is from 5 to 10 feet. Below-average recharge resulting from deficiency in precipitation probably caused the remainder of the decline.

CHEMICAL QUALITY OF GROUND WATER

Precipitation in the mountains to the east is the source of most of the ground water in the East Shore area, and precipitation on inland mountainous areas generally contains only minor amounts of dissolved mineral matter. The mineral matter in ground water is dissolved from the rocks and soil with which the water has been in contact. The amount and kind of mineral matter in ground water depends on the composition and solubility of the material through which the water passes, the temperature, pressure, amount of time spent in transit, and the minerals already in solution in the recharge water. Study of chemical analyses of ground-water samples indicates sources of the water and types of rock through which the water has moved.

Suitability of water for various uses can be determined from chemical analysis. In general, water containing less than about 500 ppm (parts per million) dissolved solids is satisfactory for most uses unless it has more than 200 ppm hardness. Water containing from 500 to 1,000 ppm dissolved solids is commonly usable, but water with more than about 1,000 ppm is likely to be unsuitable for domestic uses because of taste, hardness, corrosiveness, or other reasons.

The chemical analyses of water from the 41 wells in table 3 of Smith (1961) are considered to be typical of ground-water quality in the East Shore area. Of these 41 wells, 30 yield water containing less than 500 ppm dissolved solids, 9 yield water containing 500-1,000 ppm dissolved solids, and 23 yield water with less than 200 ppm hardness.

The collection of water-quality data during this study was essentially a continuation of work done by Thomas and Nelson (1948) and Feth and others (written communication, 1961). Feth's study, especially, determined the broad patterns of occurrence of water of various chemical types in the report area.

Types of Water

Feth and others (written communication, 1961) classified the ground water of the Weber Delta district into three major chemical types, and they prepared a map showing the areas in which these types of water occur. The analyses used to prepare the map were of samples from wells generally less than 800 feet deep. Data on the quality of deeper water are sparse, but they indicate that below 1,300 feet the water is saline.

The three major types of water are calcium magnesium bicarbonate (in this report includes calcium bicarbonate water), sodium bicarbonate, and sodium chloride. Calcium magnesium bicarbonate water was described by Feth and others (written communication, 1961) as the chemical type typical of the water entering the project area in the Weber and Ogden Rivers, in the mountain-front streams, and as seepage from the mountain front; thus, this type is typical of most of the ground-water recharge to the area. Sodium bicarbonate water is considered to be derived from calcium magnesium bicarbonate water by cation exchange (Feth and others, written communication, 1961). The calcium and magnesium ions in calcium magnesium bicarbonate water exchange with sodium ions as the water moves through fine-grained sediments. At least part of the sodium chloride water probably rises from deep sources along fault zones in the report area. Some sodium chloride water, however, may result from the movement of calcium magnesium bicarbonate water through sediments containing salt or brine (Feth and others, written communication, 1961). Some parts of the project area contain mixtures of some or all of the major types of water.

Figure 8 is a map of the project area showing occurrence of chemical types of ground water. This map is mainly adapted from a larger scale map by Feth and others (written communication, 1961), but it differs in detail from the earlier map because somewhat different criteria were used to classify the water types and because additional data were used in its preparation. Figure 8 was prepared by determining, from most of the available analyses, the chemical type of ground water according to the following classification:

Cation	
Chemical type	Percentage of equivalents per million of cations
Calcium magnesium (CaMg)	Calcium plus magnesium is greater than 50 per cent. Calcium and magnesium are each less than 50 per cent, and either calcium or magnesium must be at least 5 per cent greater than sodium.
Calcium (Ca) (subtype)	Calcium is greater than 50 per cent and at least 5 per cent greater than sodium.
Sodium (Na) (includes minor amounts of potassium)	Sodium is greater than 50 per cent and at least 5 per cent greater than either calcium or magnesium.
Mixed	No one cation is greater than 50 per cent; or, if calcium plus magnesium is greater than 50 per cent, then both calcium and magnesium are less than 5 per cent greater than sodium; or, if sodium is greater than 50 per cent, then sodium is less than 5 per cent greater than either calcium or magnesium.

Anion	
Chemical type	Percentage of equivalents per million of anions
Bicarbonate (HCO_3)	Bicarbonate is greater than 50 per cent and at least 5 per cent greater than any other anion.
Chloride (Cl)	Chloride is greater than 50 per cent and at least 5 per cent greater than any other anion.
Mixed	No one anion is greater than 50 per cent; or, if bicarbonate is greater than 50 per cent, then bicarbonate is less than 5 per cent greater than any other anion; or, if chloride is greater than 50 per cent, then chloride is less than 5 per cent greater than any other anion.

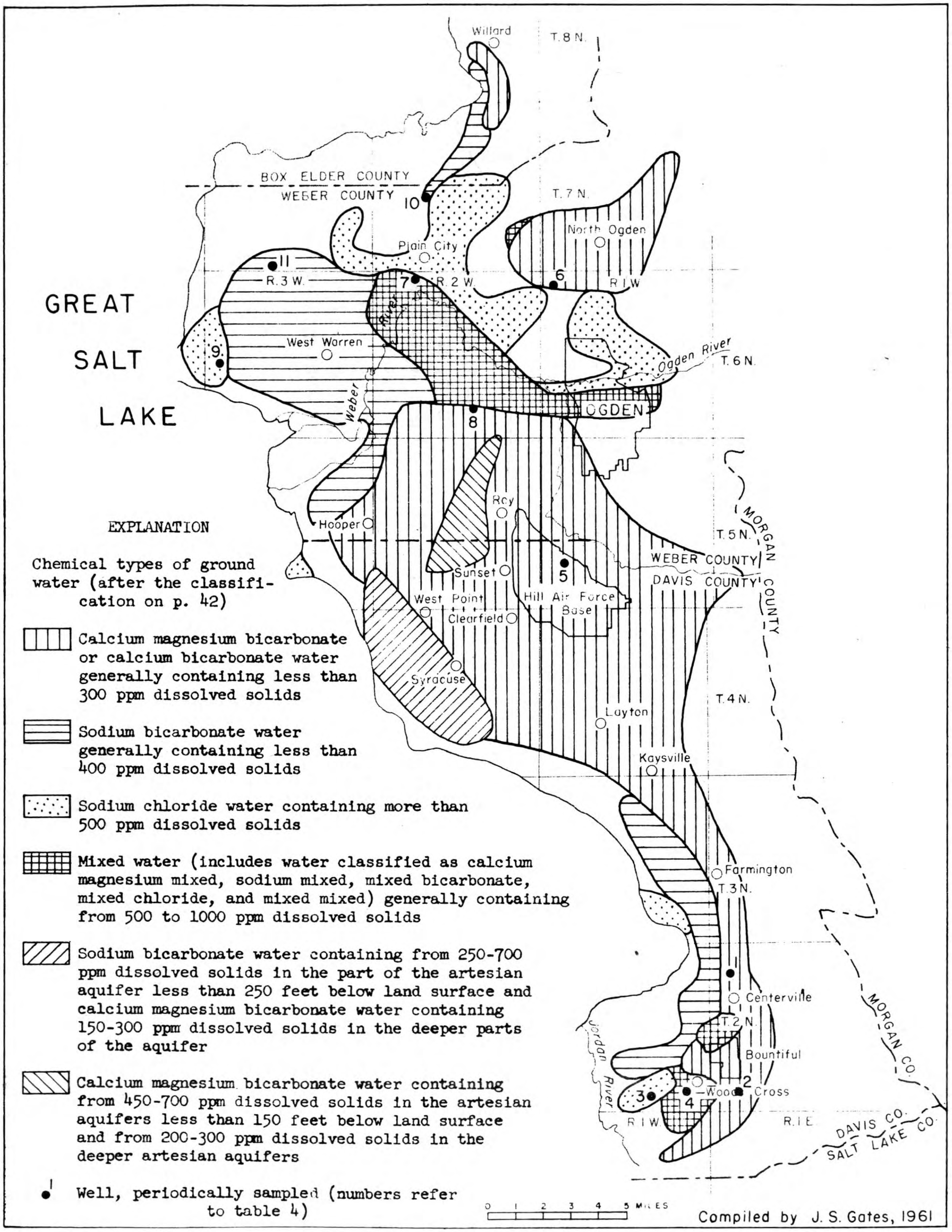

Figure 8. Map of the project area showing generalized occurrence of chemical types of ground water.

The areas yielding calcium magnesium bicarbonate water commonly also yield the water lowest in dissolved solids (less than 300 ppm), although this water generally contains more than 100 ppm hardness. Water from the areas yielding sodium bicarbonate water is commonly as low in dissolved solids as the calcium magnesium bicarbonate water and is softer. Water from areas yielding sodium chloride or mixed water commonly contains more dissolved solids than that from the other areas, generally more than 500 and from 500 to 1,000 ppm, respectively.

Areas in which wells yield water of similar chemical type are designated on figure 8 by the predominant type of ground water in the area; all wells in the area will not necessarily yield water of that chemical type. Areas that yield water of mixed type or water of various types, with no type predominant, are termed mixed. Blank spaces on figure 8 represent places where data are insufficient to determine the chemical type.

West of Syracuse, wells less than 250 feet deep yield sodium bicarbonate water with dissolved solids ranging from 250 to about 700 ppm. Deeper wells yield calcium magnesium bicarbonate water with dissolved solids ranging from 150 to 300 ppm. This change in quality of water with depth is considered by Feth and other (written communication, 1961) to result from upward movement of water from deep to shallow zones in the underlying aquifer. As water moves upward it exchanges calcium and magnesium for sodium and also dissolves additional material.

West of Roy, an artesian aquifer less than 150 feet below the land surface yields calcium magnesium bicarbonate water containing from 450 to 700 ppm of dissolved solids. Deeper artesian aquifers yield calcium magnesium bicarbonate water that contains 200 to 300 ppm of dissolved solids. The shallow aquifer probably is recharged locally by precipitation and irrigation on the benchlands east of Roy (Feth and others, written communication, 1961). The recharge area of the shallow aquifer is irrigated, whereas the recharge area of the deeper aquifers probably is near the mountain front and is largely uncultivated. The difference in recharge areas probably accounts for the difference in quality of water. Possibly there are more salts available to be dissolved by water seeping through cultivated soil than through uncultivated soil. Shallow aquifers, both artesian and water table, that yield water containing more dissolved solids than do deeper aquifers may occur in other parts of the project area. Data available are sufficient only to indicate that such a shallow aquifer exists west of Roy.

Figure 8 is a composite of conditions in the various aquifers of the project area, and water-type boundaries are approximate. Boundaries generally were determined without regard to depth of water sources, and probably the actual boundaries in specific aquifers do not coincide exactly with the boundaries in figure 8. Boundaries between water types probably interfinger to some degree, and changes from one type to another are probably gradual. Relations are especially complex in the areas of sodium chloride and mixed waters in the Bountiful-Woods Cross and Ogden-Plain City areas, and the collection of additional data may require that some changes of the boundaries be made. In spite of its limitations, figure 8 is useful for presenting general relations, and it can be used as a starting point in future quality-of-water studies.

Changes in Quality

Feth and others (written communication, 1961) proposed that a program of collection of ground-water samples for chemical analysis be made permanent and that this program have two functions. Samples should be taken, preferably from new wells, in areas where chemical-quality data are lacking, to increase the accuracy of location of chemical-type boundaries. In addition, samples should be collected periodically from a few wells at or near chemical-type boundaries to observe any boundary migrations that may occur. Changes in pressure in aquifers caused by water use could cause movements of water-type boundaries that would be important. If it were discovered that water use in an area of water of good quality had lowered the water table or artesian pressure enough to cause movement of water of poor quality into the area, corrective steps could be taken before the problem became serious.

In general, the study of chemical quality for this report followed the proposals of Feth and others (written communication, 1961). Selected analyses of samples of water from 11 of the 32 wells that were sampled several times during the period 1943-61 are given in table 4, and the locations of the 11 wells are shown on figure 8. The significance of the analyses in table 4 is discussed in the following paragraphs.

Well 1, (A-2-1)7aba-4, is north of Centerville in an area yielding calcium magnesium bicarbonate water just east of an area yielding sodium bicarbonate water. Water-levels did not decline in the immediate vicinity of well 1 during the 1953-59 period. In the 12-year period 1947-59, water from this well changed from calcium ~~magnesium~~ bicarbonate type to a mixed (tending toward sodium) bicarbonate water. The calcium content of the water decreased 43 per cent, and the sodium and potassium content increased 37 per cent. Cation exchange in this water, tending to soften it, probably has caused at least part of the change.

Well 2, (A-2-1)31ada-1, is south of Bountiful in an area yielding calcium magnesium bicarbonate water. The well is on the east edge of an area in which water levels declined significantly during the period 1953-59 (pl. 1). Water from the well is of calcium bicarbonate type, and it showed little change in chemical composition during the 1947-60 period. This indicates that development in the Bountiful district is not causing any major change in water quality. However, periodic checks on the quality of water from a well nearer the center of the area of maximum water-level decline would give a better indication of any change.

Well 3, (B-2-1)34ada-3, is southwest of Woods Cross near a boundary between areas yielding sodium chloride water and mixed water, both of which commonly yield water containing more than 500 ppm of dissolved solids. The dissolved solids in the water from this well have increased about 360 ppm during the 13-year period 1947-60. The quantity of most dissolved constituents increased, and the water changed from a sodium mixed water to a sodium chloride water. The sodium content increased about 50 per cent, the chloride content almost tripled, while the bicarbonate content decreased about 20 per cent. This well is outside a nearby area of water-level decline, and thus the change in quality of water is not related obviously to any decline in water level. Thomas and Nelson (1948, p. 139) stated that four wells and a spring in the southern part of the Bountiful district yield sodium chloride waters that evidently are derived from deep sources and probably from the Warm Springs fault that trends north-south east of these wells. Well 3 is near these wells that yield sodium chloride water and for unknown reasons evidently now is producing a higher proportion of water from deep sources.

Well 4, (B-2-1)36bbc-2, is south of Woods Cross in an area yielding water of mixed type in which water levels declined more than 20 feet during the 1953-59 period (pl. 1). During the period 1954-60, water from this well increased about 100 ppm in dissolved solids, with increases in content of sodium and bicarbonate. The water type changed from calcium magnesium mixed to mixed mixed (no constituent is predominant in either the cation or anion content). The large decline of water level in the immediate area may be a factor in the deterioration of water quality in this well. Although the water still can be used for most purposes, continuing checks on the quality of water should be made.

Well 5, (B-5-1)30add-1, is in Hill Air Force Base near the center of a large area that yields water of calcium magnesium bicarbonate type which commonly contains less than 400 ppm of dissolved solids. The well is in an area in which water levels declined more than 25 feet during the period 1953-59 (pl. 1). Smith (1961, table 3) reports 13 analyses of water from well 5 during the period 1943-60. The analyses show only changes that are due probably to the short-term effects of pumping rather than representing a long-term trend. Table 4 of this report includes the oldest and most recent analyses as well as the analyses having the lowest and highest content of dissolved solids. The difference in dissolved solids between the 1943 and 1960 analyses is

Table 4. Chemical analyses of water from 11 selected wells in the project area

Analysis by: GS — U. S. Geological Survey BR — U. S. Bureau of Reclamation

Number on figure 8	Well-coordinate number	Depth of well	Date collected	Temperature (°F)	Specific conductance (micromhos/cm at 25°C)	Chemical constituents in parts per million (ppm) Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Sodium and potassium (Na+K)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (calculated)	Hardness as $CaCo_3$	pH	Percent sodium	Sodium-adsorption ratio	Analysis by:
1.	(A-2-1)7aba-4	450	9- 8-47	62	338	23	-	30	7.9	-	23	-	140	16	18	-	2.1	189	108	-	32	1.0	GS
			12-12-58	63	271	21	0.00	17	7.3	-	32	-	131	11	14	-	3.1	169	72	7.6	49	1.6	GS
			11-18-59	60	271	19	-	17	7.1	-	31	-	126	13	13	-	2.8	165	71	7.6	48	1.6	GS
2.	(A-2-1)31ada-1	195	8- 8-47	-	588	14	-	75	22	-	22	-	296	37	30	-	1.9	348	278	7.6	15	.6	GS
			10-10-58	-	597	15	-	79	18	-	26	-	296	37	28	-	6.6	356	270	7.6	17	.7	GS
			12- 6-60	-	578	15	.00	78	19	21	-	1.6	288	33	26	0.1	6.7	342	272	7.9	14	.6	GS
3.	(B-2-1)34ada-3	-	5- 9-47	60	958	8.9	-	36	10	-	161	-	264	55	141	-	10	552	131	-	73	6.1	GS
			10-10-58	62	1610	16	-	74	21	-	241	-	212	63	390	-	9.0	918	272	7.7	66	6.4	GS
			11-10-60	62	1660	13	.00	74	22	238	-	3.4	208	68	384	.3	6.7	912	276	8.0	65	6.2	GS
4.	(B-2-1)36bbc-2	501	10-11-54	-	952	19	-	70	33	68	-	3.9	234	84	136	.0	10	539	312	-	32	1.7	BR
			10-10-58	60	1070	17	-	93	27	-	96	-	314	86	140	-	11	624	344	7.5	38	2.3	GS
			11-10-60	59	1100	15	.00	87	29	105	-	3.3	310	91	152	.1	11	645	334	8.0	40	2.5	GS
5.	(B-5-1)30add-1	900	4- 9-43	52	564	-	-	64	19	-	40	-	1/324	20	24	.2	2.7	2/342	238	-	27	1.1	GS
			9- 9-54	53	569	12	.03	71	20	21	-	2.0	298	29	20	.0	6.4	328	259	7.5	15	.6	GS
			4-25-55	54	898	25	.10	84	26	80	-	6.8	504	5.4	55	.2	.4	531	316	7.4	35	2.0	GS
			5-10-60	54	609	12	.01	83	18	26	-	2.1	338	32	21	.1	.4	361	280	7.6	17	0.7	GS
6.	(B-6-1)6caa-1	640	4-14-43	-	262	-	-	32	10	-	14	-	3/170	4.0	6.0	.2	.3	-	121	-	21	.6	GS
			2-24-56	-	275	-	-	32	10	11	-	2.3	156	5.8	9.6	-	-	4/175	121	-	16	.4	BR
			11-17-59	60	272	18	-	32	8.8	-	14	-	161	6.0	5.5	-	.5	164	116	7.9	21	.6	GS
7.	(B-6-2)5acb-2	850	3- 4-54	-	507	24	-	17	5.2	90	-	2.3	271	1.4	30	.4	1.5	305	65	-	74	4.8	BR
			10- 9-58	63	492	20	-	19	4.9	-	92	-	270	2.7	30	-	.3	302	68	7.9	75	4.8	GS
			11- 4-59	60	493	20	-	19	5.8	-	89	-	272	2.3	28	-	1.5	300	72	8.1	73	4.6	GS

8.	(B-6-2)27dcd-2	625	10- 7-54	-	453	22	-	40	8.7	37	-	3.9	5/193	6.7	49	0.0	0.1	262	137	-	36	1.4	BR
			11- 4-58	68	455	21	-	40	12	-	39	-	196	7.6	48	-	.8	264	151	7.9	36	1.4	GS
			11-18-59	68	459	19	-	42	10	-	41	-	193	9.1	48	-	.4	264	147	7.8	38	1.5	GS
9.	(B-6-3)19abc-1	220	7-26-55	-	574	-	-	7.4	4.0	114	-	9.0	279	8.6	41	.0	-	4/337	35	-	84	8.4	BR
			10 -9-58	66	588	23	-	9.6	3.9	-	123	-	284	1.4	52	-	.4	353	40	7.8	87	8.5	GS
			11- 5-59	65	551	20	-	8.8	3.4	-	117	-	283	2.3	37	-	4.5	332	36	7.8	88	8.5	GS
			11-16-60	64	538	21	0.02	8.8	5.4	111	-	6.6	282	1.6	38	.6	4.3	337	44	8.2	82	7.3	GS
10.	(B-7-2)20daa-1	150	3- 4-54	56	1290	22	.48	12	9.6	238	-	34	418	1.2	205	.9	1.0	731	70	8.0	82	15	GS
			10- 9-58	57	1280	21	-	11	6.8	-	268	-	416	3.7	208	-	1.4	725	56	7.8	91	16	GS
			11- 4-59	56	1270	24	-	10	7.8	-	265	-	412	.0	210	-	1.2	721	58	7.5	91	15	GS
11.	(B-7-3)33cdd	399	5-26-54	-	653	27	-	6.8	2.9	139	-	9.0	378	4.3	31	.2	.1	406	29	-	88	11	BR
			10- 9-58	66	421	26	-	10	3.9	-	83	-	232	1.6	21	-	.3	260	42	7.8	81	5.5	GS
			11- 4-59	68	424	23	-	11	3.2	-	84	-	234	.0	21	-	.3	258	40	7.7	82	5.7	GS
			12- 2-60	68	409	24	.05	10	3.9	76	-	8.0	228	1.4	23	.4	.3	259	42	7.5	76	5.1	GS

1/ Includes equivalent of 14 ppm CO_3

2/ Calculated by estimating 12 ppm silica

3/ Includes equivalent of 12 ppm CO_3

4/ Residue on evaporation

5/ Includes equivalent of 11 ppm CO_3

only about 20 ppm, but the difference between the analyses that are lowest (1954) and highest (1955) in dissolved solids is about 200 ppm. The differences result largely from a change in bicarbonate content, which may have been caused by changes in duration or rate of pumping or in methods of sampling.

Well 6, (B-6-1)6caa-1, is southwest of North Ogden near the boundary between an area yielding calcium magnesium bicarbonate water, which commonly contains less than 300 ppm of dissolved solids, and an area yielding sodium chloride water, which commonly contains more than 500 ppm of dissolved solids. The well is in an area in which water levels declined more than 10 feet during the period 1953-59 (pl. 1). During the period 1943-59 well 6 yielded calcium bicarbonate water of fairly constant composition. Although this indicates that the present development is not causing any movements of the boundary, future checks on water quality should be made. Extensive development of water north of the boundary might cause movement of the sodium chloride water into the water of better quality.

Well 7, (B-6-2)5acb-2, is south of Plain City near a boundary between areas yielding mixed water and sodium chloride water. The well is in an area in which water levels declined more than 10 feet during the period 1953-59 (pl. 1). The water from well 7 is of sodium bicarbonate type, and the analyses show little change from 1954 to 1959. The development of water locally, therefore, has not caused any significant change in water quality.

Well 8, (B-6-2)27dcd-2, is west of Ogden at the boundary between a large area yielding water of the calcium magnesium bicarbonate type and an area yielding mixed water. The mixed water commonly contains more dissolved solids than the calcium magnesium bicarbonate water. Well 8 is in an area in which water levels declined from 5 to 10 feet during the period 1953-59 (pl. 1). The water from the well is of the calcium magnesium bicarbonate type, and it showed little or no change for the 1954-59 period.

Well 9, (B-6-3)19abc-1, is west of West Warren in an area yielding predominantly sodium chloride water, near the boundary between this area and an area to the east that yields sodium bicarbonate water. The well is not within any area of significant water-level decline. Water from the well is of the sodium bicarbonate type, and it changed little in chemical quality during the 1955-60 period.

Well 10, (B-7-2)20daa-1, is north of Plain City in an area yielding sodium bicarbonate water, just west of an area yielding sodium chloride water. The December water level in the well declined only 0.1 foot in the period 1953-59. Water from the well is of the sodium bicarbonate type, and it changed little in chemical quality during the period 1954-59.

Well 11, (B-7-3)33cdd, is west of Plain City in an area yielding sodium bicarbonate water and is not near any ground-water development. During the period 1954-60 the dissolved solids in the water from this well decreased about 150 ppm. The water is of the sodium bicarbonate type, and the change was due chiefly to decreases in sodium and bicarbonate content. The reason for this decrease is not known.

Most of the analyses for the 41 wells in table 3 of Smith (1961) show little long-term change in quality of water. Analyses for several of the 11 wells discussed above show changes in water quality, but no apparent relation exists between development of water and changes in quality. Future changes in water quality caused by increased water use are possible, however, and in areas where changes might be expected, the quality should be checked periodically.

Thomas and Nelson (1948, p. 131-143) discussed the quality of ground water in the Bountiful district and stated that the upper Bonneville canal, which trends northeast-southwest from North Salt Lake through the southeast part of Bountiful, was recharging shallow aquifers to the west. The canal carried water from the Jordan River that contained more dissolved solids than the water in the shallow aquifers. Thus the canal water was contaminating the aquifers. Use of the canal, which had decreased gradually during the period 1948-56, decreased rapidly during the period 1957-58 because of the availability of water of better quality from the Weber Basin Project. The canal has not been used since 1958, and presumably the quality of water in the shallow aquifers west of the canal has improved. The areas of mixed water in the Bountiful district (fig. 8) probably resulted from mixing of canal water with water in the shallow aquifers. If or when these areas will be flushed by the more dilute calcium magnesium bicarbonate water to the east or by the irrigation water of better quality now used is not known.

FUTURE DEVELOPMENT

Feth and others (written communication, 1961) discussed future development of ground water in the Weber Delta district and a summary of some of their discussion is presented in this report because of its importance to water users in the area. They stated that tens of thousands of acre-feet of water are wasted annually by transpiration from nonbeneficial vegetation, evaporation from saturated land surfaces and water surfaces, and leakage from aquifers into Great Salt Lake, They consider it desirable to lower the pressure head in the aquifers in the Weber Delta district to eliminate some of this waste.

These opinions are shared by Marsell (1961, p. 52-53), who stated that maximum yield from an artesian aquifer is obtained when pumpage approaches average annual recharge. These conditions can be obtained only by eliminating pressure effects and thus eliminating flowing wells. Marsell estimated that the maximum yield of an artesian reservoir commonly is several times as great as the yield during the early stages of development, when most wells flow.

The decline of water levels in the project area, although it may be harmful to some water users and may lead to legal problems between water users, is leading to more efficient overall use of the area's ground-water supply.

Feth and others (written communication, 1961) also suggested that artificial recharge of the ground-water reservoirs in the area be started. Recharge to the reservoirs from the Weber River will be reduced after full development of the Weber Basin Project because the flow of the downstream part of the river, including that part crossing the recharge area, will be reduced. This reduction in recharge could at least be partly offset by spreading water over the recharge area during times of excess flow in the river.

The construction of housing developments in the areas of recharge, which is already extensive in the Bountiful district, may reduce the amount of water entering the ground-water reservoirs, but the magnitude of such a reduction is not known.

CONCLUSIONS

The East Shore area is growing rapidly in population, and the use of water is increasing. Since 1953 water levels in the project area have trended downward, with the largest declines in the Bountiful district and in the Hill Air Force Base and North Ogden-Plain City areas of the Weber Delta district. Most of the decline was caused by withdrawals of water, although below-normal precipitation for the period was a significant factor. The decline of water levels has caused only minor changes in pumping methods or quantities of water produced by wells. No apparent relation exists between development of water and changes in quality of water.

An increase in annual precipitation during a few years might decrease the rate of water-level decline, but with the expected continued increase in water use, no long-term rise in water levels would occur. The rate of water-level decline probably will increase if at some future date the pumpage of ground water increases because the supply of water from the Weber Basin Project is insufficient to meet the needs of the area or if ground water is used as an alternate source of supply. The decline of water levels caused problems of interference between wells in 1961 and will cause additional problems of interference in the future; but it is a necessary effect of efficient water development.

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36 - Directory of Utah Mineral Resources and Consumers Guide, by Alfred M. Buranek and C. E. Needham, 1949, 95 p., 1 pl. ______ $1.00

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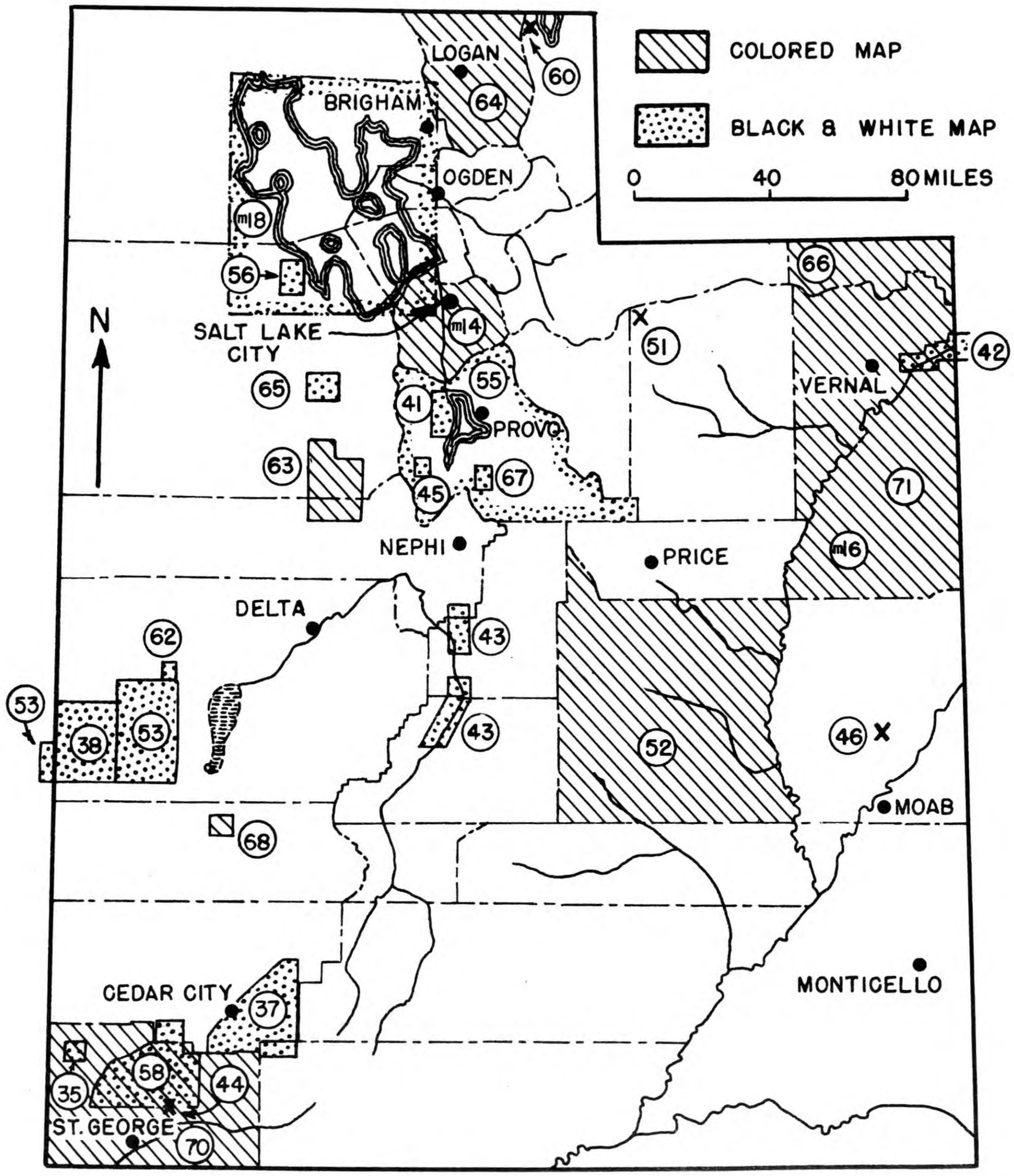
INDEX MAP TO PUBLICATIONS OF THE UTAH GEOLOGICAL AND MINERALOGICAL SURVEY



MAPS

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Maps 2, 10, and 11 are out-of-print.

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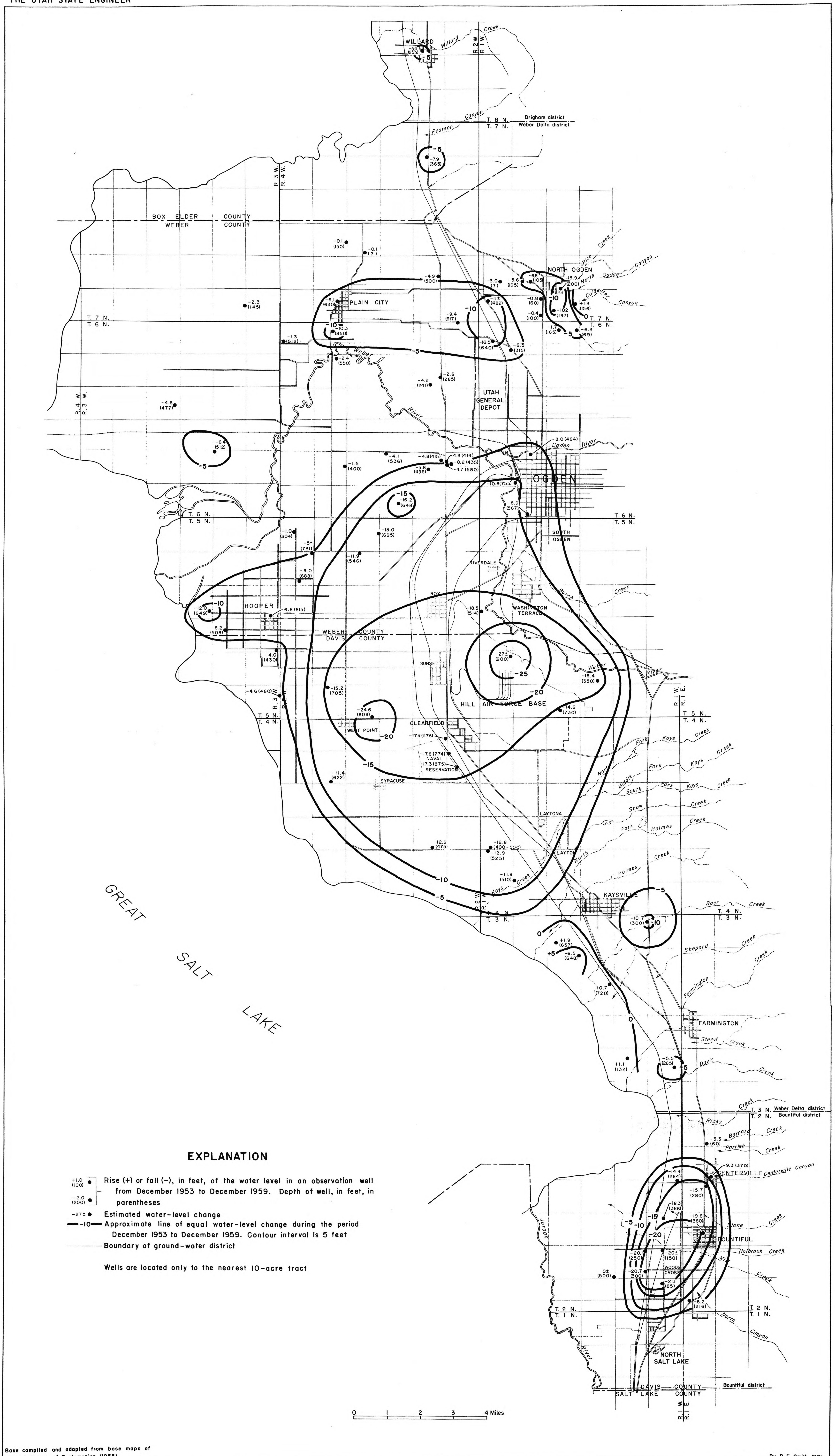
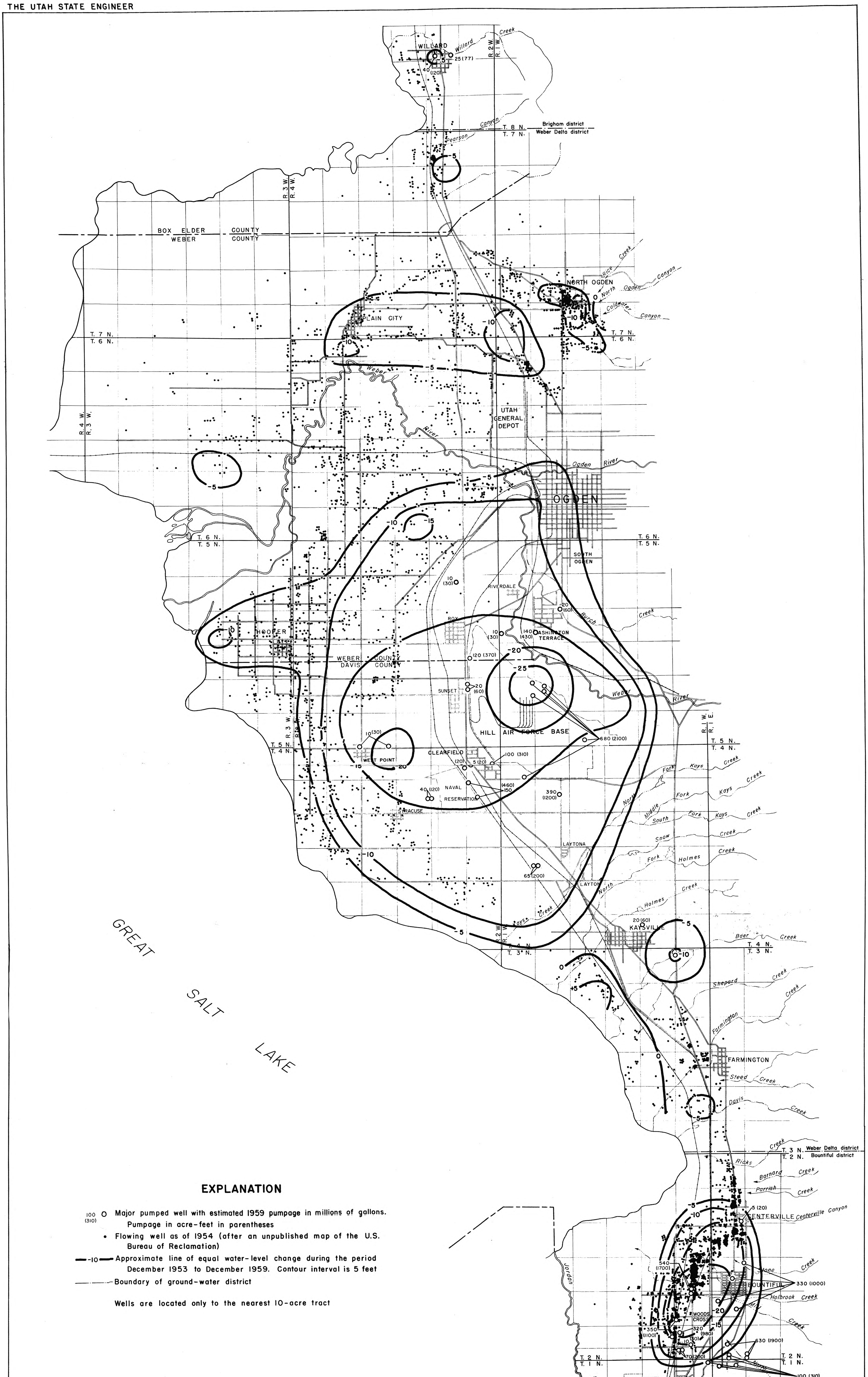


MAP OF THE PROJECT AREA SHOWING THE CHANGE IN WATER LEVELS FROM DECEMBER 1953 TO DECEMBER 1959 IN OBSERVATION WELLS PENETRATING ARTESIAN AQUIFERS MORE THAN 60 FEET BELOW LAND SURFACE



MAP OF THE PROJECT AREA SHOWING THE PUMPED WELLS HAVING SIGNIFICANT YIELDS AND THEIR ESTIMATED PUMPAGE IN 1959, FLOWING WELLS AS OF 1954, AND LINES OF EQUAL WATER-LEVEL CHANGE DURING THE PERIOD DECEMBER 1953 TO DECEMBER 1959