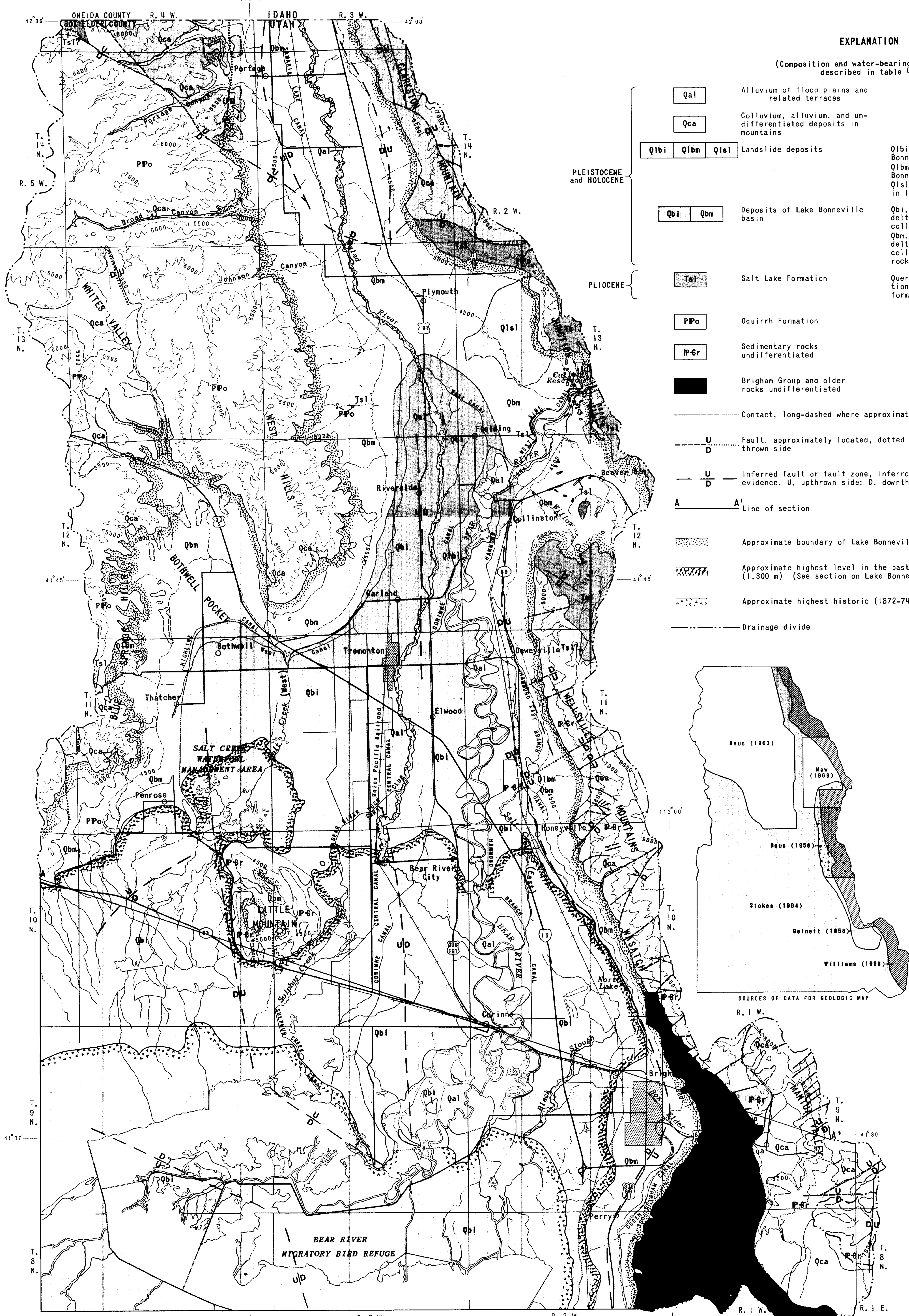


EXPLANATION

(Composition and water-bearing properties described in table 4)

PLEISTOCENE and HOLOCENE — Quaternary

- **Qal** — Alluvium of flood plains and related terraces
- **Qca** — Colluvium, alluvium, and undifferentiated deposits in mountains
- **Qlbi, Qlbm, Qlsl** — Landslide deposits. Qlbi, indicates interior deposits of Lake Bonneville basin involved in landslide. Qlbm, indicates marginal deposits of Lake Bonneville basin involved in landslide. Qlsl, indicates Salt Lake Formation involved in landslide
- **Qbi, Qbm** — Deposits of Lake Bonneville basin. Qbi, interior deposits: lake-bottom sediments, delta deposits, and interbedded alluvium and colluvium. Qbm, marginal deposits: lakeshore, fan, and delta deposits and interbedded alluvium and colluvium. Small outcrops of underlying older rock are not mapped

PLIOCENE — Tertiary

- **Tsl** — Salt Lake Formation. Queried where assignment to Salt Lake Formation is questionable. (Some rocks of the formation may be older than Pliocene.)

- **PPo** — Oquirrh Formation — Pennsylvanian and Permian
- **P-Cr** — Sedimentary rocks undifferentiated — Cambrian to Pennsylvanian
- Brigham Group and older rocks undifferentiated — Precambrian and Cambrian

Contact, long-dashed where approximately located, short-dashed where gradational

U/D Fault, approximately located, dotted where concealed. U, upthrown side; D, downthrown side

U/D Inferred fault or fault zone, inferred from geophysical or indirect geologic evidence. U, upthrown side; D, downthrown side

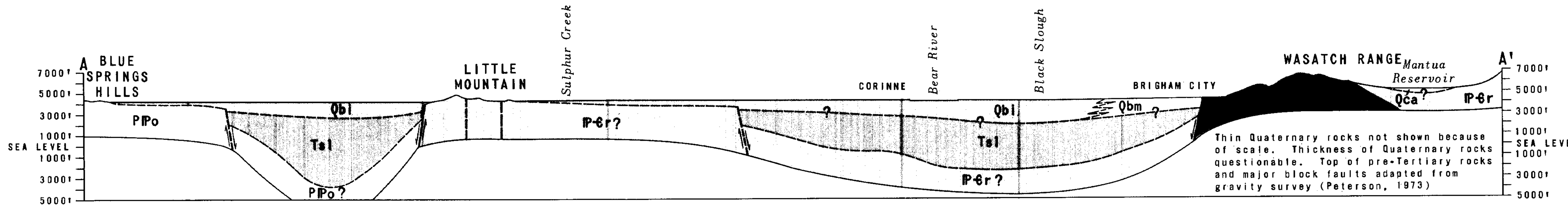
A — A' Line of section

Approximate boundary of Lake Bonneville at its highest level

Approximate highest level in the past 7,000 years; altitude about 4,260 feet (1,300 m) (See section on Lake Bonneville basin in text)

Approximate highest historic (1872-74) lake stand of Great Salt Lake

Drainage divide



GEOLOGIC MAP AND SECTION, LOWER BEAR RIVER DRAINAGE BASIN, BOX ELDER COUNTY, UTAH

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

STATE OF UTAH
DEPARTMENT OF NATURAL RESOURCES

TECHNICAL PUBLICATION NO. 44
PLATE 2 1974

EXPLANATION

4350 — 4340
Water-level contour
Approximate altitude of potentiometric surface of the principal ground-water system. Dashed where control is poor. Arrow indicates general direction of ground-water movement. Contour interval 10 and 50 feet (3 and 15 meters); datum is mean sea level

4350 — 4340
Water-level contour
Approximate altitude of potentiometric surface of the shallow unconfined ground-water system. Arrow indicates general direction of ground-water movement. Contour interval 10 and 50 feet (3 and 15 meters); datum is mean sea level

P 4375

Principal system (except as noted) Shallow unconfined system
Well used for control
Number is altitude of water level, in feet above mean sea level; P, indicates perched water level that is not contoured

Spring

Natural discharge area
Shows approximate area of general natural discharge from principal ground-water system

Drainage divide

CONVERSION UNITS

Feet	Meters
4220	1286
4230	1289
4240	1292
4250	1295
4260	1298
4270	1301
4280	1304
4290	1307
4300	1310
4310	1313
4320	1316
4330	1319
4340	1322
4350	1325
4360	1328
4370	1331
4380	1335
4390	1338
4400	1341
4410	1344
4420	1347
4430	1350
4440	1353
4450	1356
4500	1371
4550	1386
4600	1402
4650	1417
4700	1432

MAP SHOWING WATER-LEVEL CONTOURS, DIRECTION OF GROUND-WATER MOVEMENT, AND DISCHARGE AREAS, LOWER BEAR RIVER DRAINAGE BASIN, BOX ELDER COUNTY, UTAH, MARCH 1971

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

STATE OF UTAH
DEPARTMENT OF NATURAL RESOURCES

TECHNICAL PUBLICATION NO. 44
PLATE 3 1974

MAP SHOWING RELATION OF WATER LEVELS TO LAND SURFACE IN THE LOWER BEAR RIVER DRAINAGE BASIN, BOX ELDER COUNTY, UTAH, MARCH 1971

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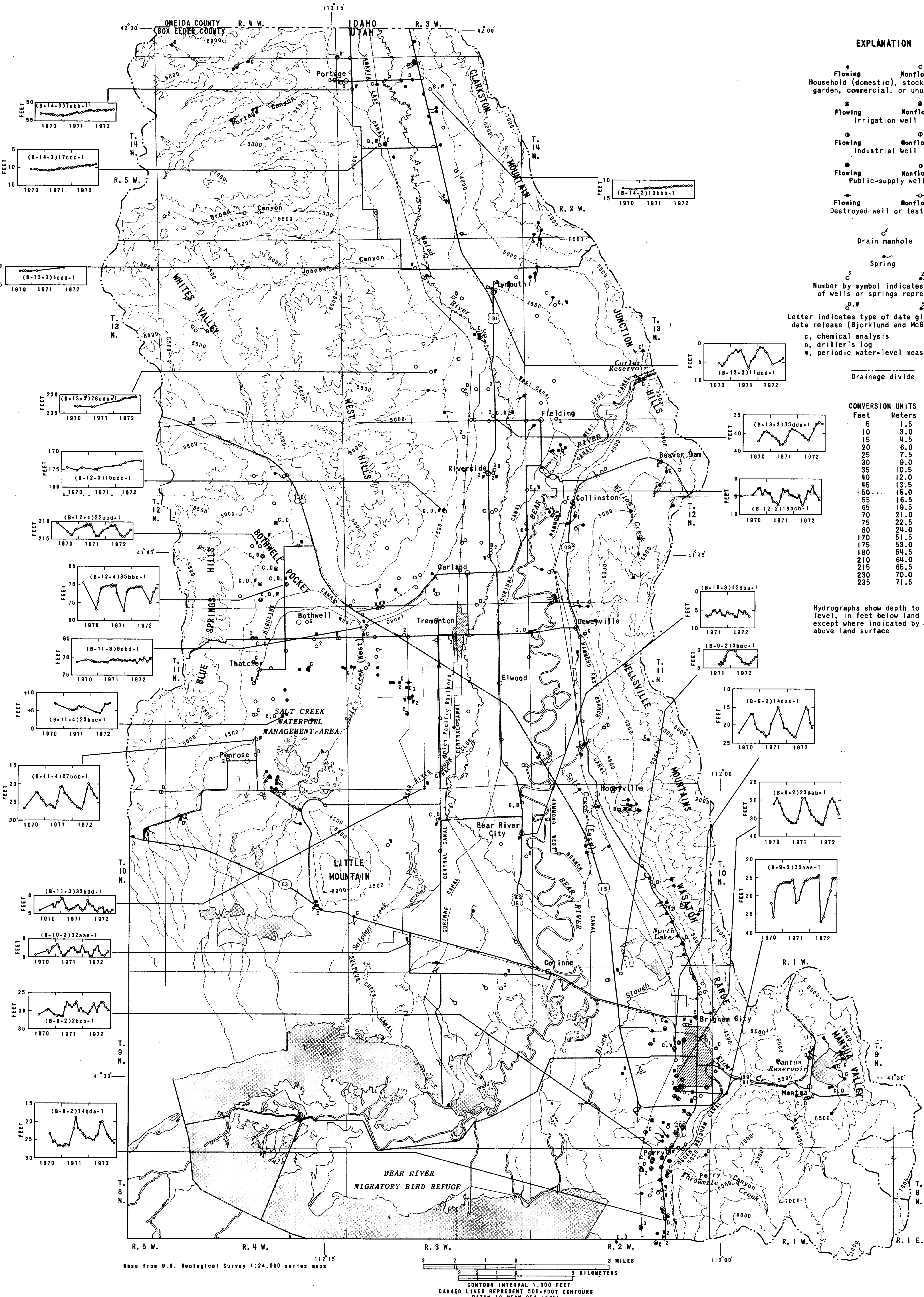
GEOLOGICAL SURVEY

STATE OF UTAH
DEPARTMENT OF NATURAL RESOURCES

TECHNICAL PUBLICATION NO. 44
PLATE 4 1974



EXPLANATION

Flowing / Nonflowing
Household (domestic), stock, lawn or garden, commercial, or unused well

Flowing / Nonflowing
Irrigation well

Flowing / Nonflowing
Industrial well

Flowing / Nonflowing
Public-supply well

Flowing / Nonflowing
Destroyed well or test hole

Drain manhole

Spring

Number by symbol indicates number of wells or springs represented

Letter indicates type of data given in basic-data release (Bjorklund and McGreevy, 1973):
c, chemical analysis
D, driller's log
W, periodic water-level measurements

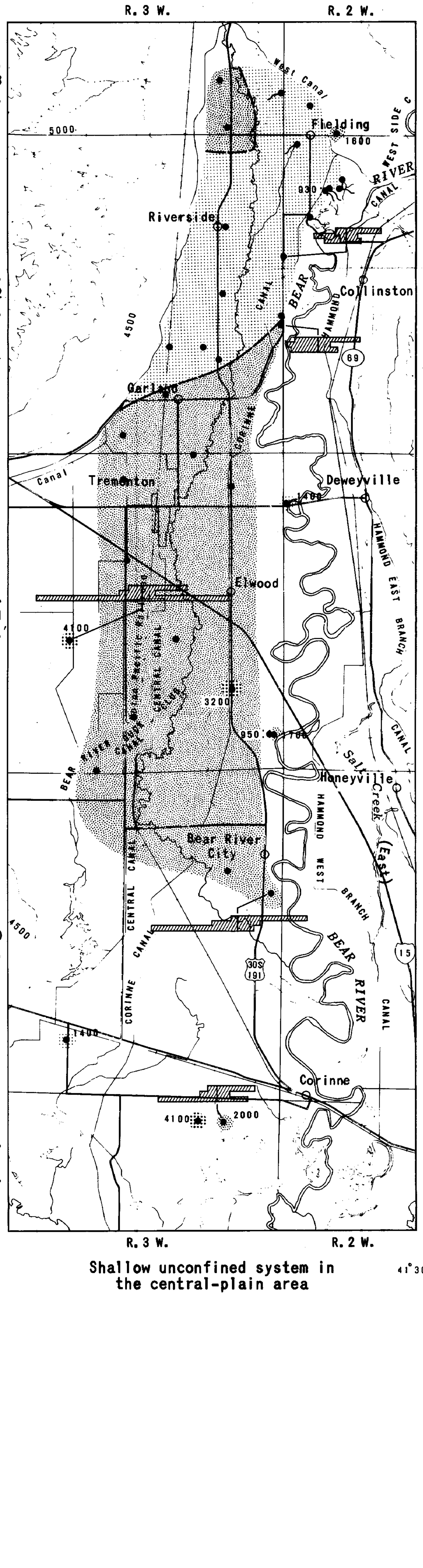
Drainage divide

CONVERSION UNITS

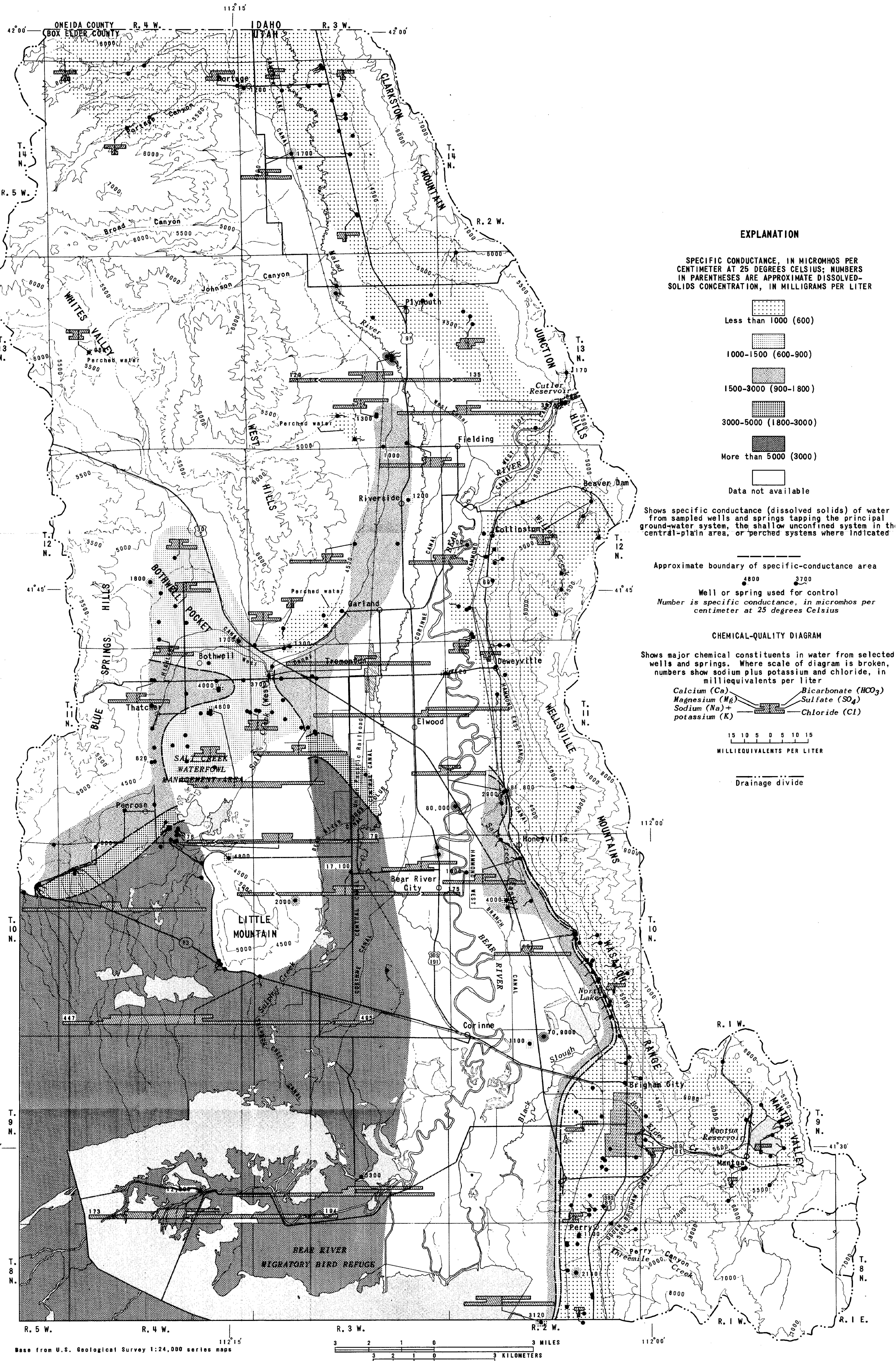
Feet	Meters
5	1.5
10	3.0
15	4.5
20	6.0
25	7.5
30	9.0
35	10.5
40	12.0
45	13.5
50	15.0
55	16.5
65	19.5
70	21.0
75	22.5
80	24.0
170	51.5
175	53.0
180	54.5
210	64.0
215	65.5
230	70.0
235	71.5

Hydrographs show depth to water level, in feet below land surface, except where indicated by + is above land surface

MAP SHOWING LOCATIONS OF SELECTED WELLS AND SPRINGS AND HYDROGRAPHS OF SELECTED WELLS, LOWER BEAR RIVER DRAINAGE BASIN, BOX ELDER COUNTY, UTAH



Shallow unconfined system in the central-plain area



EXPLANATION

SPECIFIC CONDUCTANCE, IN MICROMHOS PER CENTIMETER AT 25 DEGREES CELSIUS; NUMBERS IN PARENTHESES ARE APPROXIMATE DISSOLVED-SOLIDS CONCENTRATION, IN MILLIGRAMS PER LITER

- Less than 1000 (600)
- 1000-1500 (600-900)
- 1500-3000 (900-1800)
- 3000-5000 (1800-3000)
- More than 5000 (3000)
- Data not available

Shows specific conductance (dissolved solids) of water from sampled wells and springs tapping the principal ground-water system, the shallow unconfined system in the central-plain area, or perched systems where indicated

Approximate boundary of specific-conductance area

4800 3700

Well or spring used for control

Number is specific conductance, in micromhos per centimeter at 25 degrees Celsius

CHEMICAL-QUALITY DIAGRAM

Shows major chemical constituents in water from selected wells and springs. Where scale of diagram is broken, numbers show sodium plus potassium and chloride, in milliequivalents per liter

Calcium (Ca) — *Bicarbonate (HCO_3)*
Magnesium (Mg) — *Sulfate (SO_4)*
Sodium (Na) + potassium (K) — *Chloride (Cl)*

15 10 5 0 5 10 15

MILLIEQUIVALENTS PER LITER

Drainage divide

Principal ground-water system

MAP SHOWING CHEMICAL QUALITY OF GROUND WATER IN THE PRINCIPAL GROUND-WATER SYSTEM AND IN THE SHALLOW UNCONFINED SYSTEM IN THE CENTRAL-PLAIN AREA, LOWER BEAR RIVER DRAINAGE BASIN, BOX ELDER COUNTY, UTAH

STATE OF UTAH
DEPARTMENT OF NATURAL RESOURCES

Technical Publication No. 44

GROUND-WATER RESOURCES OF THE LOWER BEAR RIVER DRAINAGE BASIN, BOX ELDER COUNTY, UTAH

by

L. J. Bjorklund and L. J. McGreevy
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Prepared by
the United States Geological Survey
in cooperation with
the Utah Department of Natural Resources
Division of Water Rights

1974

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GROUND-WATER RESOURCES OF THE LOWER BEAR RIVER DRAINAGE BASIN, BOX ELDER COUNTY, UTAH

by

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Hydrologists, U.S. Geological Survey

ABSTRACT

The lower Bear River drainage basin consists of about 730 square miles (1,890 km^2) in north-central Utah, north of and adjacent to Bear River Bay of the Great Salt Lake. An average of about 1,180,000 acre-feet (1,460 hm^3) of surface water entered the basin annually during 1960-71; most of this water entered in the Bear River and in canals diverted from the Bear River. Several streams develop from springs within the drainage basin and both the Bear and Malad Rivers gain considerably in flow within the drainage basin, mostly from ground-water discharge. An average amount of about 972,000 acre-feet (1,200 hm^3) of surface water leaves the drainage basin annually and flows toward the Great Salt Lake.

Structurally, the study area is a complex of faulted blocks modified by erosion. A gravity survey indicates a maximum depth of valley fill (Cenozoic rocks) of about 8,000 feet (2,440 m). Rocks exposed in the area are of Precambrian, Paleozoic, and Cenozoic age.

The type and distribution of Quaternary deposits and the chemical quality of the ground water have been greatly affected by the succession of deep lakes and intervening lake recessions that occurred in the Lake Bonneville basin during Quaternary time. Marginal deposits (Quaternary) of the Lake Bonneville basin, mostly sand and gravel, and fractured limestone and sandstone of the Oquirrh Formation (Pennsylvanian and Permian) are the most productive water-bearing units. Water from most wells and springs tapping the marginal deposits contains from about 250 to 1,000 mg/l (milligrams per liter) of dissolved solids; yields are as much as 1,500 gal/min (gallons per minute) (95 l/s) to wells and as much as 1,600 gal/min (100 l/s) to springs. Water from most wells tapping the Oquirrh Formation contains about 800 mg/l of dissolved solids; yields are as much as 1,450 gal/min (91 l/s). Water from springs tapping the Oquirrh Formation contains from about 300 to 10,000 mg/l of dissolved solids; yields are as much as 10,000 gal/min (630 l/s). Interior deposits (Quaternary) of the Lake Bonneville basin, mostly silt and sand, generally yield smaller quantities of water of poorer quality, but the interior deposits are the only water-bearing unit in a large part of the area.

Ground water occurs in a principal ground-water system under both confined and unconfined conditions, in a shallow unconfined system, and in perched systems. The average annual change in ground-water storage is small; thus, total recharge to and discharge from the ground-water

reservoir is approximately equal and is estimated to be 315,000 acre-feet (389 hm^3) per year.

The ground water is derived from three sources: (1) precipitation within the basin, (2) surface water that enters the basin and is used for irrigation, and (3) subsurface inflow. Ground-water discharge to springs and drains amounts to about 210,000 acre-feet (259 hm^3) anually. About 270,000 acre-feet (333 hm^3) of surface and ground water is discharged annually by evapotranspiration from mudflats and phreatophyte areas; of this, about 100,000 acre-feet (123 hm^3) is ground water. An estimated 1,000 acre-feet (1.23 hm^3) per year of ground water moves out of the area as subsurface outflow. About 4,000 acre-feet (4.93 hm^3) of water was discharged from wells in 1971. Ground-water levels fluctuate seasonally but have changed little on a long-term basis since the mid-1930's.

Chemical analyses indicate that dissolved solids in ground water range from about 88 to 122,000 mg/l; observed ground-water temperatures ranged from 3.0° to 74.0°C, but most wells and springs tap water that has a temperature of 10.5°-15.0°C. Calcium, magnesium, and bicarbonate are predominant ions in the generally dilute water in and near the edges of the mountains. Sodium and chloride are predominant ions in the brine and very saline water at depth in the lower parts of the valley. The source of dissolved solids is commonly from solution of the rocks that contain the water, but in the project area most of the dissolved solids are the result of the accumulation of soluble minerals in a closed basin where the soluble minerals have been accumulating for at least a hundred thousand years. Dissolved-solids concentration and water temperature generally increase with depth. The ground-water system contains water of significantly different densities because of the wide range of disolved-solids concentrations and water temperatures.

The lower Bear River drainage basin is divided into 12 ground-water areas, which are discussed separately. The areas indicate where ground-water conditions are generally similar or where ground-water conditions can conveniently be discussed together.

Water for irrigation supply is derived mostly from surface-water sources. Ground water pumped from wells supplies almost all the irrigation needs in the Bothwell Pocket and supplements the surface-water supply in the Brigham City-Perry area. Shallow wells in the central-plain area supply water for many lawns and gardens. All the public-water supplies are from ground-water sources. Some of the distribution systems cover large rural areas because ground water in much of the area is not satisfactory for public or domestic use.

A water-budget analysis of the upstream area north of State Highway 83 (68 percent of the study area) indicates that during 1960-71 about 1,700,000 acre-feet (2,100 hm^3) of water annually entered the area by streamflow, ground-water flow, and precipitation and left the area by streamflow, ground-water flow, and evapotranspiration. A supplementary water-budget analysis of the downstream area south of State Highway

83 indicates that about 1,400,000 acre-feet (1,730 hm^3) of water per year entered and left that area during the same period.

INTRODUCTION

Purpose and scope of the study

This report is intended to aid public officials and water users in the lower Bear River drainage basin to develop, conserve, and administer their water resources. Although the report is primarily about ground water, it describes the relation of ground water to surface water and presents a general water-budget analysis. It discusses the sources, occurrence, availability, quantity, movement, chemical quality, and development of the ground water and the effects of climate, geology, and development on the ground water. The appendix of the report describes the well- and spring-numbering system and defines some units and terms.

For those readers interested in using the metric system, metric equivalents of English units of measurements are given in parentheses following the English units. For additional information and a conversion table, refer to the section "Use of metric units" in the appendix.

Selected hydrologic data collected for the study are in a separate release (Bjorklund and McGreevy, 1973), which contains information regarding selected wells and springs, including water levels, chemical quality of water, and drillers' logs of wells. Both the data release and this report were prepared by the U.S. Geological Survey in cooperation with the Utah Department of Natural Resources. Fieldwork for the investigation began in July 1970 and continued through June 1972.

Location and general features

The lower Bear River drainage basin in north-central Utah (fig. 1) is at the downstream end of the Bear River drainage basin and is in the Basin and Range physiographic province (Fenneman, 1931). The project area consists of about 730 square miles (1,890 km^2), of which about two-thirds is valley terrain and about one-third is mountains. At the Utah-Idaho State line, the north boundary of the project area, the basin is about 10 miles (16 km) wide and the valley 4 miles (6 km) wide. The basin and valley both widen southward to about 25 and 18 miles (40 and 29 km), respectively. The north-south length of the project area is about 40 miles (64 km).

The study area is a north-south trending valley along the Malad and Bear Rivers bounded by mountains on the east and west. The south-central and southwestern parts of the area are mudflats, lagoons, and marshes adjacent to the Bear River Bay of the Great Salt Lake. The valley ranges in altitude from about 4,200 to 5,200 feet (1,280-1,585 m) above mean sea level. Topographic features of the valley include terraces, bars, spits, and deltas of ancient Lake Bonneville, flood plains, and alluvial fans and cones. East of the valley a narrow ridge, mostly 3 to 7 miles (5-11 km) wide at the base, is formed by Clarkston Mountain, Junction Hills, and the Wasatch Range, which includes the Wellsville

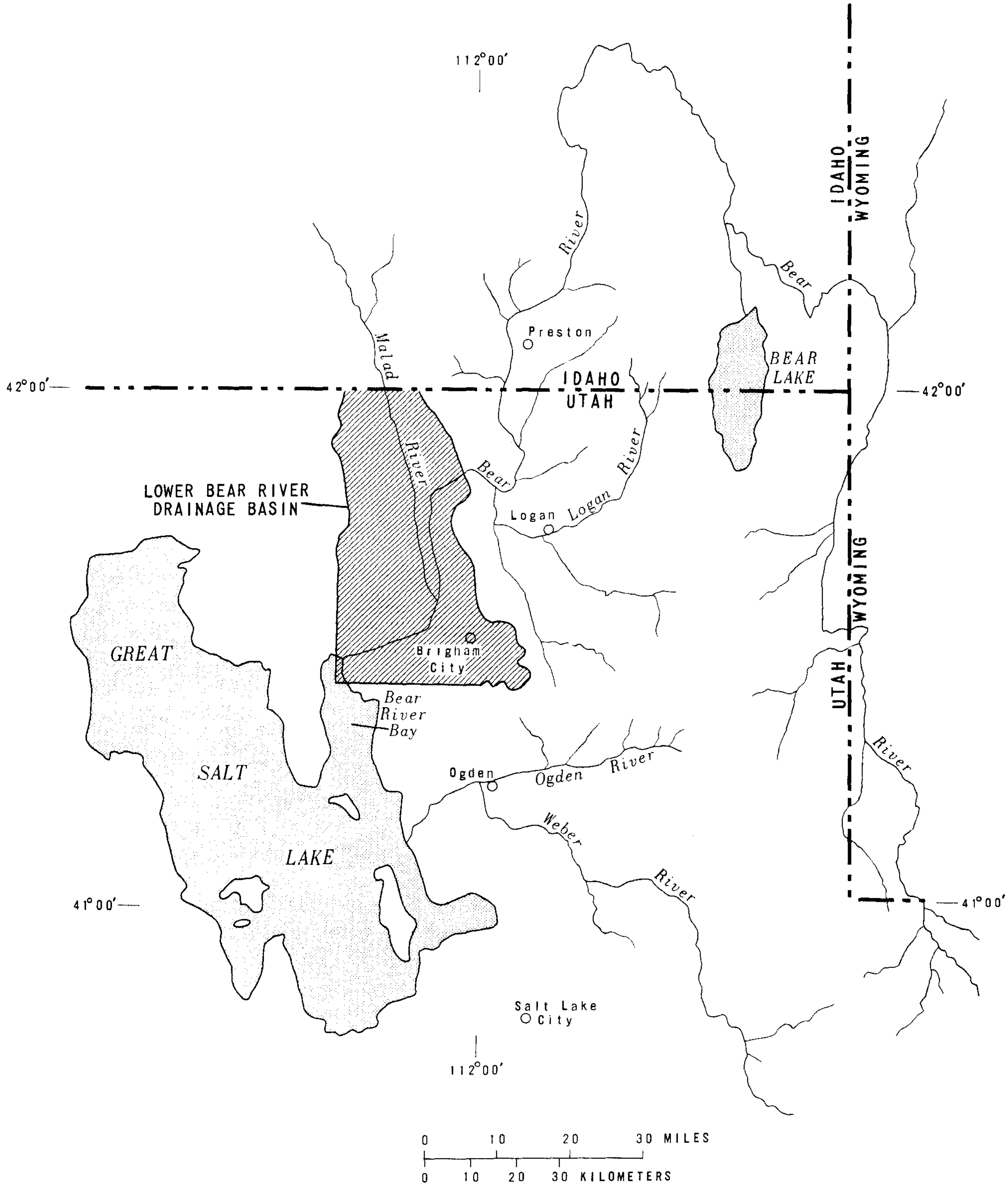

Figure 1.— Location of the lower Bear River drainage basin.

Mountains; crests are mostly at altitudes of 7,000 to 9,000 feet (2,134-2,743 m), but several peaks are above 9,000 feet (2,743 m). West of the valley the West Hills and the Blue Springs Hills form a dissected plateau 5 to 12 miles (8-19 km) wide; altitudes of crests are mostly 6,000 to 7,000 feet (1,829-2,134 m), and one peak is at 7,196 feet (2,193.3 m). Little Mountain, isolated in the south-central part of the valley, reaches an altitude of 5,607 feet (1,709.0 m).

Moderate to meager precipitation, large daily temperature changes, moderately cold winters, and warm dry summers are characteristic of the lower Bear River drainage basin. Most of the area normally receives less than 20 inches (508 mm) of precipitation annually. The highest parts of the mountains east of the valley receive less than 40 inches (1,016 mm), and the mountains west of the valley receive less than 25 inches (635 mm) (fig. 16). Most of the precipitation results from humid air masses that move southeastward from the North Pacific Ocean during fall, winter, and spring; much of it falls as snow in the mountains. Snow usually covers the valley floor during parts of December, January, and February. Runoff from the spring snowmelt reaches its maximum in May or June. Since 1947, the frost-free or growing season--the number of consecutive days above -2°C (28°F)--has averaged 162 days in Brigham City, 144 days in Garland, and 139 days in Corinne.

Climatological data are collected by the National Weather Service (formerly U.S. Weather Bureau) at weather stations at Brigham City, Corinne, and Garland. Normal monthly precipitation and temperature at Brigham City and Corinne and average monthly precipitation and temperature at Garland are given in table 1. Graphs showing relation of annual precipitation at Corinne (the longest record of precipitation in Utah), cumulative departure from the 1931-60 normal annual precipitation at Corinne, and ground-water levels in selected wells are shown in figure 2.

Approximately 24,000 people live within the project area. Brigham City (pop. 1970, 14,007) and Tremonton (pop. 1970, 2,794) are the principal towns and business centers. Agriculture, the principal industry, is devoted mainly to livestock, dairy products, sugar beets, small grains, corn, alfalfa, and tomatoes. South of Brigham City, along the Wasatch mountain front, agriculture is devoted mainly to fruits and vegetables. Most farms are irrigated, but small grains, particularly wheat, are grown on dry farms. Migratory bird-refuge and waterfowl-management areas are maintained on low marshy lands in the south-central and southwestern parts of the project area.

Previous investigations and acknowledgements

Ground-water resources of the lower Bear River drainage basin were discussed by Carpenter (1913, p. 37-50) in a reconnaissance report on ground water in Box Elder and Tooele Counties, Utah. Included were 104 chemical analyses (field assays) of water from wells and springs. Streamflow data since 1889 and water levels in wells since 1935 have

Table 1.--Normal monthly precipitation and temperature for 1931-60 at Brigham City and Corinne, and average monthly precipitation and temperature for 1913-26 and 1943-69 at Garland

	Brigham City		Corinne		Garland	
	Precipitation (inches)	Temperature (°F)	Precipitation (inches)	Temperature (°F)	Precipitation (inches)	Temperature (°F)
January	2.02	26.4	1.57	24.3	1.17	22.7
February	1.62	31.4	1.36	29.5	1.25	28.8
March	1.81	39.4	1.54	38.5	1.55	37.4
April	2.12	50.1	1.72	48.8	1.51	47.3
May	1.80	59.2	1.78	57.5	1.89	56.6
June	1.32	67.6	1.04	65.5	1.22	64.8
July	.40	76.4	.44	74.4	.63	73.8
August	.59	73.9	.47	72.2	.68	71.4
September	.99	64.5	.79	62.9	1.18	61.8
October	1.50	53.0	1.14	51.4	1.22	49.8
November	1.80	38.5	1.46	36.9	1.20	37.0
December	1.76	31.0	1.65	29.3	1.34	27.5
Annual	17.73	51.0	14.96	49.3	14.84	48.2

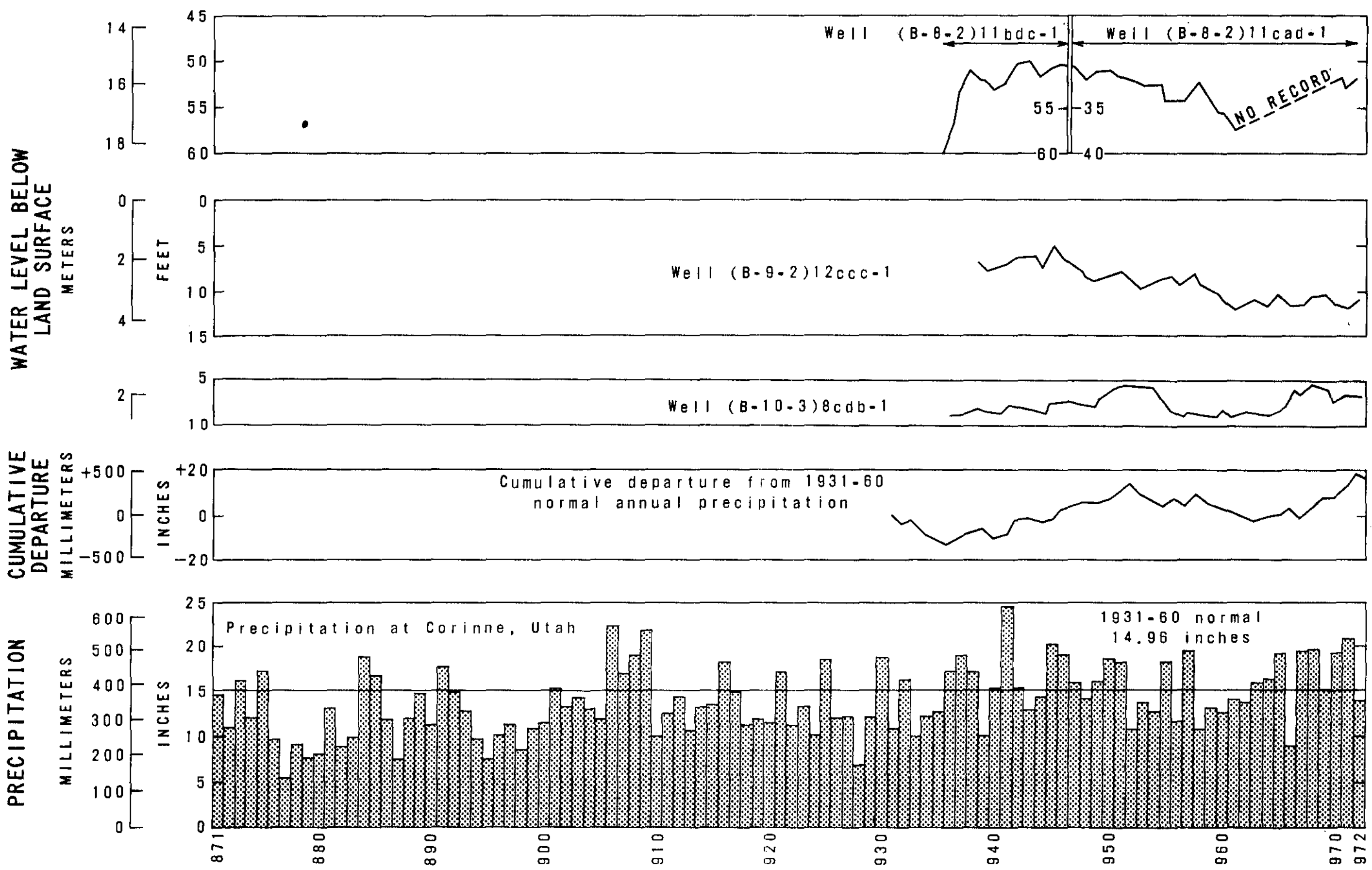

Figure 2.- Relation of annual precipitation, cumulative departure from the 1931-60 normal annual precipitation, and water levels in selected wells.

been collected by the U.S. Geological Survey (1936-55, 1960, 1963, 1966a-71a, 1966b-71b, and 1970). Data on chemical quality of water were compiled by Conner, Mitchell, and others (1958, p. 38-41, 257-258). Chemical-quality and streamflow data for the lower Bear River drainage basin are included in a study of dissolved-mineral inflow to Great Salt Lake (Hahl and Mitchell, 1963; Hahl and Langford, 1964; and Hahl, 1968). Waddell (1970, p. 42-57) and Waddell and Price (1972) evaluated the chemical quality of surface waters as part of a study of the Bear River basin. A specific-conductance survey of the Malad River was done by McGreevy (1972). Geologic data are available from various sources including the geologic map of Utah compiled by Stokes (1964). (See selected references for other sources of hydrological and geological data.)

The cooperation of the residents and public officials in the project area and of irrigation companies and other water users who gave information and permitted observations at wells and springs is gratefully acknowledged. Information and assistance were also furnished by the Utah Water Research Laboratory, Utah State University, Utah Power and Light Co., Utah-Idaho Sugar Co., and others.

SURFACE WATER

An average amount of about 1,180,000 acre-feet (1,460 hm^3) of water entered the lower Bear River drainage basin annually in the 1970-71 water years (table 2). About 96 percent of the water entered the valley in the Bear River and the West Side and Hammond Canals, which divert water from the river at Cutler Reservoir. About 3 percent of the inflow is in the tributary Malad River and the Samaria Lake Canal, which cross the Utah-Idaho State line near Portage. About 1 percent of the inflow is diverted from the Ogden River about 15 miles (24 km) south of the project area and transported in the Ogden-Brigham Canal to the Brigham City-Perry area. A flow diagram of average surface-water discharge is shown in figure 3.

Streams that originate at springs in and near the mountains bordering the valley discharge a total of more than 50,000 acre-feet (61.7 hm^3) of water annually. These streams include Box Elder Creek, which drains Mantua Valley, Salt Creek (west) which heads at Salt Creek Spring at the south end of West Hills, Salt Creek (east) which heads at Crystal Springs near Honeyville, and several smaller streams.

Streams that develop on the valley floor from small springs, sloughs, and drains include Black Slough, Sulphur Creek, and several smaller streams. The flow of several streams, including Salt Creek (west) and Sulphur Creek, is increased greatly at times by direct spilling from the irrigation canal system; much of the water in all the streams on the valley floor is irrigation return. Flow in Sulphur Creek is augmented also by diversion from Malad River via the Bear River Duck Club Canal.

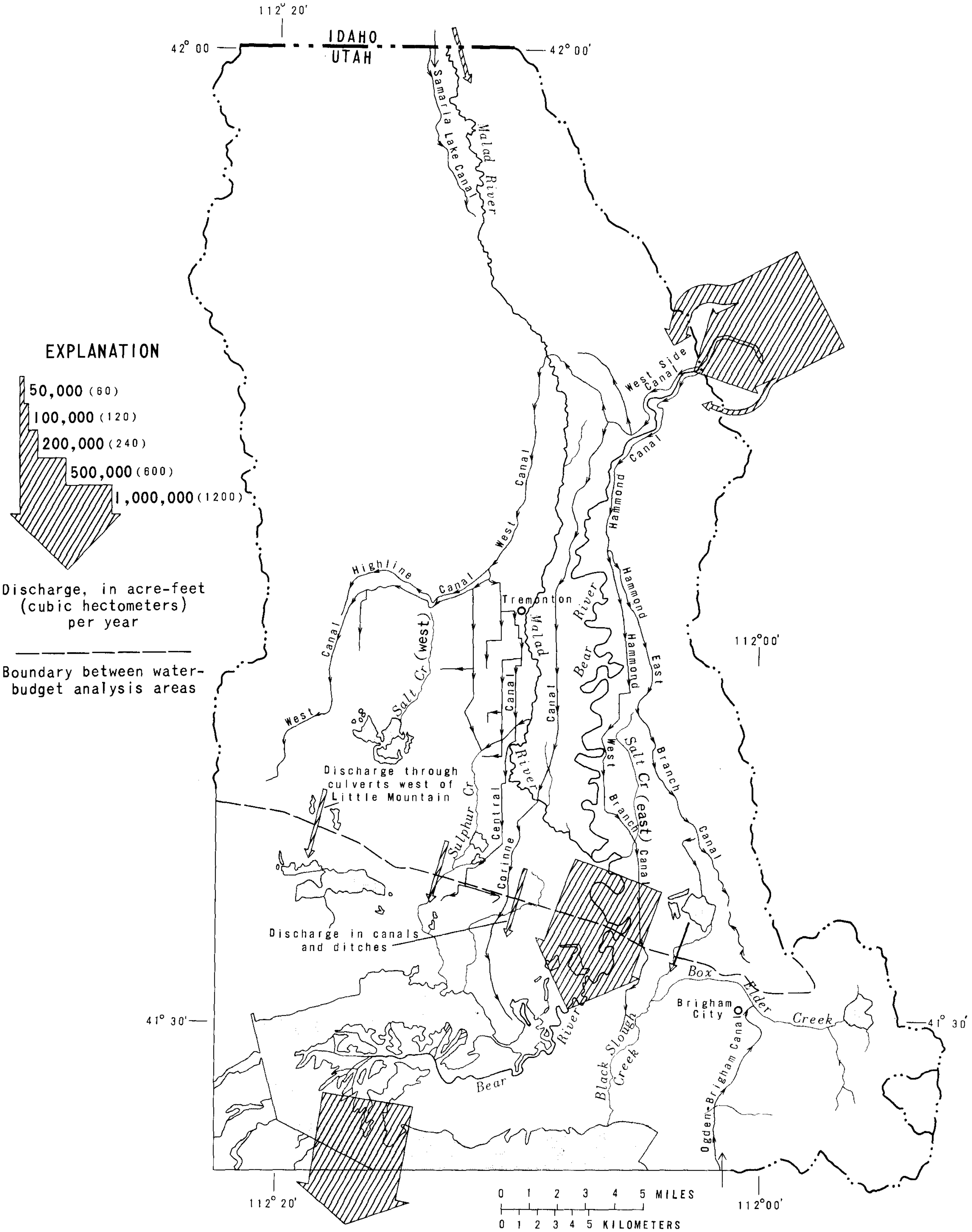

Figure 3.— Flow diagram showing streams, canals, and average annual discharge of principal streams crossing boundaries of water-budget analysis areas, water years 1960-71.

Table 2.--Discharge of the Bear and Malad Rivers and of canals entering lower Bear River drainage basin, 1960-71 water years

(Thousands of acre-feet)

[Data from U.S. Geological Survey (1963, 1966a-1971a, 1966b-1971b, 1970)]

	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	Average
Bear River near Collinston, Utah	530	364	808	576	832	1,074	1,018	942	874	1,046	729	1,992	899
West Side Canal near Collinston, Utah	214	200	172	184	164	193	219	176	194	218	205	190	194
Hammond (east side) Canal near Collinston, Utah	46	43	37	37	35	41	46	35	38	42	41	35	40
Malad River at Woodruff, Idaho	26	20	53	27	38	41	41	31	32	45	31	47	36
Samaria Lake Canal[1]	2	2	2	2	2	2	2	3	2	2	3	2	2
Ogden-Brigham Canal[2]	9	9	9	9	9	9	9	8	9	10	10	8	9
Total	827	638	1,081	835	1,080	1,360	1,335	1,195	1,149	1,363	1,019	2,274	1,180

[1]Discharge for 1967-70 from miscellaneous measurements and estimates by U.S. Geological Survey, Idaho Falls, Idaho; discharge for other years assumed equal to average for 1967-70.

[2]Discharge for 1966-71 estimated as 80 percent of flow gaged 3 miles south of Willard (Richard Bird, Weber-Box Elder Conservancy District, oral commun., 1972); discharge for other years assumed equal to average for 1966-71.

Both Bear River and Malad River gain in discharge within the project area. The average annual gain in discharge of the Bear River in the 18-mile (29 km) reach between the stations near Collinston and near Corinne during water years 1964-71 was 116,000 acre-feet (143 hm^3) or 13 percent of the average annual discharge near Collinston. The gain was from Malad River and Salt Creek (east), the principal tributaries within the reach, from local precipitation, and from ground-water discharge. During 1966-70, the Malad River gained an average of about 26,000 acre-feet (32.1 hm^3) annually in its 27-mile (43 km) reach between Woodruff, Idaho, 2 miles (3.2 km) north of the Utah-Idaho State line, and the Bear River Duck Club Canal diversion, 4 miles (6.4 km) upstream from the confluence of the Malad and Bear Rivers. The gain in the Malad River in this reach was 72 percent of its discharge at Woodruff, Idaho. A significant part of this gain was from ground-water discharge.

An average amount of about 972,000 acre-feet (1,200 hm^3) of surface water flows annually from the project area toward the Great Salt Lake. Most of this water is from the Bear River, but water is contributed also from Black Slough, Sulphur Creek, many unnamed streams crossing State Highway 83 west of Little Mountain, and several canals and ditches (fig. 3 and table 3). The water collects in lagoons and marshes south of State Highway 83 and then flows toward the Great Salt Lake in several independent channels. The quantity of surface water leaving the project area was estimated by a water-budget analysis of the area south of Highway 83. (See section on water-budget analysis and table 12.)

Table 3.--Discharge of streams in the lower Bear River drainage basin crossing Utah State Highway 83, 1960-71 water years

(Thousands of acre-feet)

[Data from U.S. Geological Survey (1966b-1971b, 1970)]

	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	Average
Bear River near Corinne	619[1]	436[1]	913[1]	668[1]	936	1,182	1,154	1,054	1,059	1,215	876	2,068	1,015
Black Slough												18	18[2]
Sulphur Creek												44	44[2]
Other streams east of Little Mountain												1	1[2]
Streams west of Little Mountain												40	40[2]
Canals and ditches												42	42[2]
Total												2,213	1,160

[1]Based on correlation with discharge near Collinston by U.S. Bureau of Reclamation (written commun., January 1967.)
[2]Average for 1960-71 assumed to be about the same as data for 1971.

The predominant use of surface water in the lower Bear River drainage basin is for irrigation; it is also used for livestock, to generate hydroelectric power, and to form lagoons and marshes in migratory bird-refuge and hunting areas. About 250,000 acre-feet (308 hm^3) of water is diverted annually from streams to irrigate about 96,000 acres (38,900 hm^2). The principal canals in the irrigation system are shown in figure 3. Some of the irrigation water returns to Bear River and its tributaries by spilling from canals, by wastewater from fields, and by discharge from sloughs, springs, and drains.

Surface water is stored at Cutler Reservoir on the Bear River for hydroelectric power and for irrigation in the lower Bear River drainage basin. Water is also stored in Mantua Reservoir, tributary to Box Elder Creek, for hydroelectric power and for irrigation near Brigham City. Lagoons and marshes in bird-refuge and hunting areas are maintained by the Federal Government, State of Utah, and private clubs; most of these are in natural pond or wet areas, enlarged by dikes.

GROUND WATER

Geologic setting

The types and structures of the rock units determine the occurrence and availability of ground water. Geologic units are described in table 4 and are shown on plate 1.

Rocks exposed in the project area are of Precambrian, Paleozoic, and Cenozoic age. Rocks of Mesozoic age are not exposed and probably are not present.

Regional thrust faulting (predominantly horizontal movement) was followed in mid-Tertiary time by normal faulting (nearly vertical movement) that is still active. A thrust fault is exposed at the south edge of the study area south of Perry, and thrust faults probably exist at depth under most of the area. Normal faulting has formed a complex of blocks that have a maximum vertical displacement of probably more than 10,000 feet (3,000 m). Faults with relatively minor displacement are common within the major blocks.

A gravity survey was made in 1970 to determine the approximate thickness of Cenozoic rocks in the valley and the gross structure of underlying pre-Cenozoic rock. The Bouguer gravity anomaly map from that study (Peterson, 1973) is shown in figure 4. Major faulting inferred from the gravity map is shown on plate 1.

The gravity map shows differences in gravity that are due largely to differences in density of the rocks underlying the area. Precambrian and Paleozoic rocks are more dense than the overlying Cenozoic rocks. A general interpretation of the gravity map is that the lower Bouguer gravity values indicate a greater thickness of less dense rocks and thus a greater depth to pre-Cenozoic bedrock, but the correlation is only approximate. Figure 4 shows the gross structure of the valley in much the same way as do contours on the bedrock surface, and steep gravity gradients (closely spaced contours) indicate probable faults or fault zones.

Interpretations of the depth to pre-Cenozoic bedrock were made from the gravity data by Peterson (written commun., 1971) along a profile across the valley, which is integrated into the section on plate 1. Peterson emphasizes that gravity interpretations are inherently ambiguous and the interpreted thickness of Cenozoic rocks may differ substantially from the actual thickness if the assumed density contrasts and regional gradient are not approximately correct. Maximum thickness of Cenozoic rocks interpreted on the profile is about 8,000 feet (2,400 m).

The type and distribution of Quaternary deposits in the study area and the quality of the ground water have been greatly affected by the lakes in the Lake Bonneville basin--the basin occupied by Lake Bonneville at its highest level. Great Salt Lake is a remnant of Lake Bonneville, the last of a succession of deep lakes that occupied the Lake Bonneville basin during Quaternary time (Morrison and Frye, 1965, figs. 2 and 5). At its highest level, Lake Bonneville had a maximum depth of about 1,100 feet (335 m) and a surface area of about 20,000 square miles (52,000 km^2) (Crittenden, 1963, p. E1). Great Salt Lake at its lowest recorded level (altitude about 4,191 feet or 1,277.4 m in 1963) had a maximum depth of about 24 feet (7.3 m) and a surface area of about 940 square miles (2,435 km^2) (Hahl and Handy, 1969, p. 8; Handy and Hahl, 1966, p. 138-140).

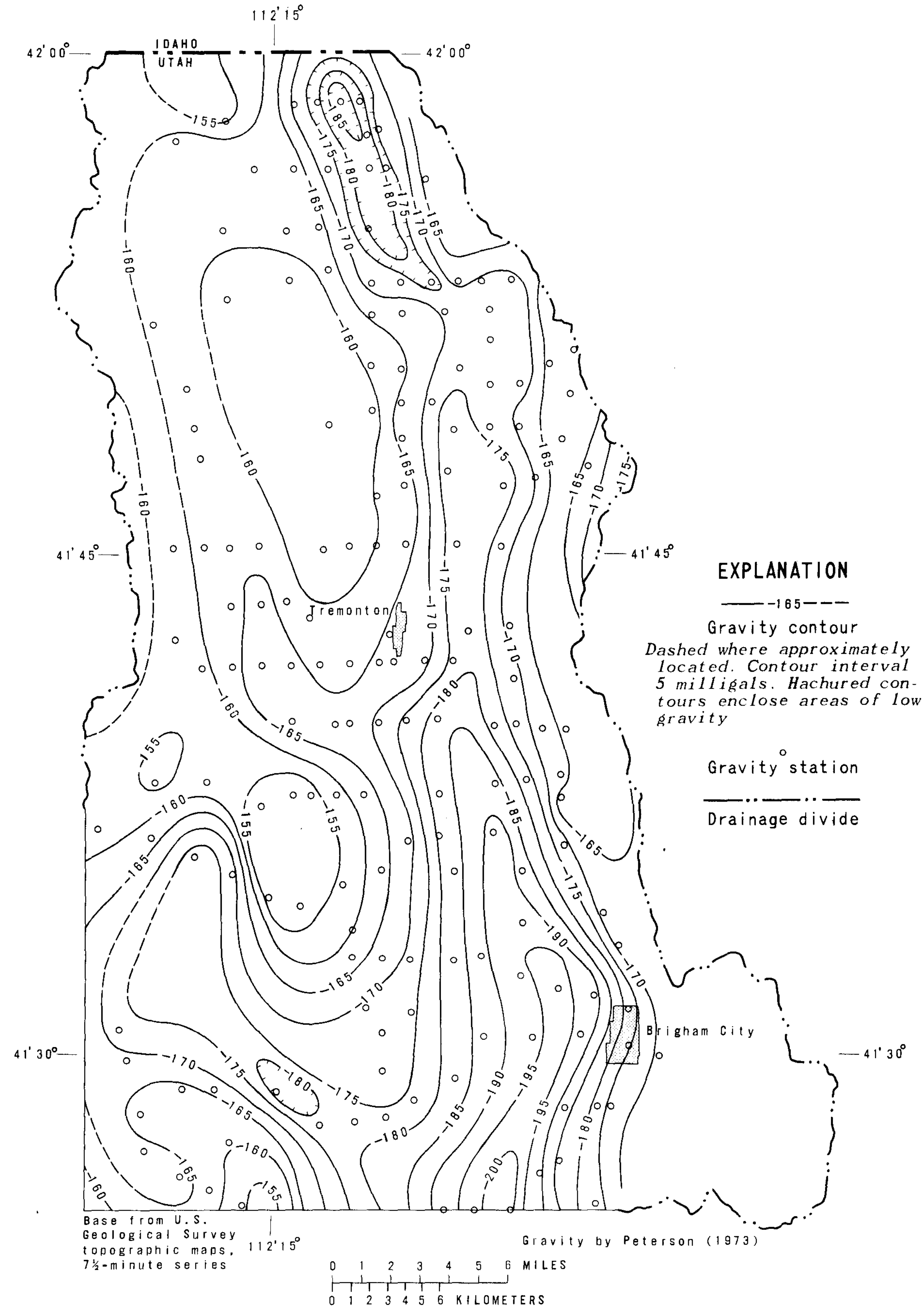

Figure 4.– Bouguer gravity anomaly map of the lower Bear River drainage basin.

Shoreline features are prominent at several levels within the study area. The highest shoreline, the Bonneville level, is at an altitude of about 5,200 feet (1,585 m). The approximate trace of the highest shoreline is shown in figure 4. Also shown on plate 1 is the approximate trace of the level of the Great Salt Lake during 1872-74; the average level was at an altitude of about 4,211 feet (1,284 m) and is the highest historic lake stand. Presently (1972) the lakeshore is near the south boundary of the study area at an altitude of about 4,200 feet (1,280 m).

The highest lake stand in the last 7,000 years was at an altitude of about 4,245 to 4,260 feet (1,294-1,298 m); this lake stand occurred sometime between 3,800 and 750 years ago (Morrison, 1966, p. 88, 92-93). Two miles (3.2 km) west of Bear River City the principal alluvial terrace of the Malad River inner valley grades to about this altitude range. Shoreline features of this stand in the study area are mostly obscure, but the 4,260-foot (1,298 m) contour is shown on plate 1 to represent the approximate level of this stand. This lake stand is thought to have had a significant effect on ground-water quality. Saline water, which entered sediments while the lake was at this level, probably has not been completely flushed out.

Geologic units and their general hydrologic characteristics

Geologic units and their general hydrologic characteristics are described in table 4. The Oquirrh Formation and the marginal deposits of the Lake Bonneville basin are the most productive water-bearing units. The interior deposits of the Lake Bonneville basin generally yield smaller quantities of water to wells but are important because they are the only water-bearing unit in a large part of the area.

The relative ease with which water can move through rocks depends on the permeability[1] (the ability of the rocks to transmit fluids) which depends on the size, number, and interconnection of the spaces in the rock. The most productive aquifer materials are generally well-sorted sand and gravel or rocks whose permeability has been increased by fracturing or solution. Clay and silt or consolidated rocks with little or no interconnected space have low permeability and do not readily yield water.

Ground-water systems

Ground water in the lower Bear River drainage basin occurs (1) in a principal ground-water system, (2) in a shallow unconfined system in the central-plain area (fig. 10), and (3) in perched systems. The principal ground-water system includes most of the ground water in all geologic units in the project area (table 4). The principal system is

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[1]A dimensionless qualitative concept. The term hydraulic conductivity is used in a quantitative sense for ground water at the prevailing viscosity. See p. 58 for definition.

Table 4.--Geologic units and their general hydrologic characteristics

Era	System	Series	Geologic unit	Lithology and thickness	General hydrologic characteristics
CENOZOIC	Quaternary	Pleistocene and Holocene	Alluvium of flood plains and related terraces	Sand, silt, clay, and some gravel; includes some travertine along Malad River. Unit probably is less than 30 feet (9 m) thick.	Permeability low to high. Would yield supplies adequate for stock in most of area. Wells are not known to tap the unit, but springs are numerous. Little is known about the chemical quality of the water, but along the Bear River the ground water probably contains from 500 to 1,500 mg/l of dissolved solids and along the Malad River the ground water probably contains from 500 to 2,500 mg/l of dissolved solids.
			Colluvium, alluvium, and undifferentiated deposits in mountains	Unconsolidated rocks of all sizes; well to poorly sorted. Maximum thickness is near Mantua where more than 500 feet (150 m) of deposits are reported.	Permeability low to high. Yields as much as 1,900 gal/min (120 l/s) to wells near Mantua; elsewhere probably would not yield more than 100 gal/min (6.3 l/s). Concentration of dissolved solids probably ranges from about 100 to 1,000 mg/l. Water in some areas is perched; some of the deposits are dry.
			Landslide deposits	Rubble derived principally from Quaternary and Tertiary units.	Permeability low to high. Water-bearing properties generally similar to those of principal units involved. Well (B-13-2) 17bbc-1, which probably taps landslide deposits derived from Tertiary conglomerate, yields 13 gal/min (0.82 l/s) of water containing 633 mg/l of dissolved solids.
			Interior deposits of Lake Bonneville basin	Clay, silt, sand, and some gravel. Includes lake-bottom sediments, delta deposits, and interbedded alluvium and colluvium. Grades laterally to generally coarser marginal deposits of Lake Bonneville basin. Maximum thickness unknown, but greater than 1,000 feet (300 m).	Permeability mostly low to moderate, but contains some zones of high permeability. Most wells yield less than 50 gal/min (3.2 l/s); maximum known yield is 450 gal/min (28 l/s). Most springs yield less than 300 gal/min (19 l/s); maximum known yield is 700 gal/min (44 l/s). Water from most wells and springs contains from about 500 to 2,500 mg/l of dissolved solids, but concentrations range from about 200 to 40,000 mg/l.
			Marginal deposits of Lake Bonneville basin	Boulders, cobbles, gravel, sand, silt, clay, travertine, and conglomerate; well to poorly sorted. Includes lakeshore, fan, and delta deposits and interbedded alluvium and colluvium. Grades laterally to generally finer interior deposits of Lake Bonneville basin. Maximum thickness unknown, but greater than 1,000 feet (300 m).	Permeability mostly moderate to high, but contains some zones of low permeability. Wells yield as much as 1,500 gal/min (95 l/s). Springs yield as much as 1,600 gal/min (100 l/s). Water from most wells and springs contains from about 250 to 1,000 mg/l of dissolved solids, but some concentrations are as much as about 2,200 mg/l.
	Tertiary	Pliocene	Salt Lake Formation1/	Tuff, and mostly tuffaceous and calcareous siltstone, sandstone, conglomerate, bentonite, limestone, and marl; white and light shades of gray, green, brown, yellow, and tan. (Some rocks of the formation may be older than Pliocene.) Maximum thickness unknown, but probably several thousand feet.	Permeability generally low; however, some sandstone and conglomerate have moderate to high permeability and some tuff and siltstone have moderate fracture permeability. Few wells and springs tap the formation. They discharge as much as 52 gal/min (3.3 l/s) of water which contains from about 400 to 700 mg/l of dissolved solids. Well (B-13-3)11dac-1 was abandoned when water temperature rose to 29°C (84°F) during test pumping. Chemical quality of the warm water is not known.
PALEOZOIC	Pennsylvanian and Permian		Oquirrh Formation	Limestone, sandstone, quartzite, and siltstone; mostly gray. Maximum thickness probably about 6,000 feet (1,800 m).	Permeability low to high. Sandstone has low to moderate permeability, but permeability of formation is mostly due to fractures and to solution openings. Wells yield as much as 1,450 gal/min (91 l/s). Springs yield as much as 10,000 gal/min (630 l/s). Concentrations of dissolved solids range from about 300 to 10,000 mg/l. Most wells yield water that contains about 800 mg/l of dissolved solids, but at greater depths the formation probably contains saline water in much of the area west of the Malad River.
	Cambrian to Pennsylvanian		Sedimentary rocks undifferentiated	Limestone and dolomite predominant; some quartzite, sandstone, siltstone, shale, and mudstone; mostly gray. Maximum thickness probably 15,000-20,000 feet (4,600-6,100 m).	Permeability mostly due to fractures and to solution openings in carbonate rocks; high permeability locally as a result of solution along fractures and bedding planes. Water from oil test (B-10-4)3bb-1 contained 122,000 mg/l of dissolved solids. Springs near Little Mountain yield as much as 450 gal/min (28 l/s); the water from four springs contains from about 6,000 to 37,000 mg/l of dissolved solids. Crystal Hot Spring, (B-11-2)29dad-S1, yields about 1,600 gal/min (100 l/s); the water contains 43,500 mg/l of dissolved solids. Water from most springs on Clarkston and Wellsville Mountains and in Mantua Valley contains less than 300 mg/l of dissolved solids; yields are as much as 4,300 gal/min (270 l/s). A few springs west of Portage yield as much as 100 gal/min (6.3 l/s); the water contains about 350 mg/l of dissolved solids.
PALEOZOIC / PRECAMBRIAN	Cambrian		Brigham Group and older rocks undifferentiated	Quartzite, phyllite, and tillite(?).	Permeability is low because of cementation, compaction, or crystallization. Permeability increases somewhat locally where fractured or weathered. Yields water to a few small springs in the mountains, but prospects of wells are poor. Little is known about the chemical quality of the water, but in outcrop areas, most of the water probably contains less than 200 mg/l of dissolved solids.

1/ Conglomerate with red sand matrix exposed about 2 miles (3.2 km) east of Deweyville may be older than the Salt Lake Formation (Williams, 1962, p. 132-133). Conglomerate, gravel, and sandstone at northwest corner of study area may be younger than the Salt Lake Formation.

complex and includes both confined and unconfined ground water. The shallow unconfined ground-water system exists in the central-plain area in materials near the land surface that are part of the interior deposits of Lake Bonneville basin. Unconfined ground water occurs in similar materials elsewhere in the valley, but the separation from the principal system is generally less distinct. Perched ground-water systems[1] occur mostly in the marginal deposits of Lake Bonneville basin; in colluvium, alluvium, and undifferentiated deposits in the mountains; and in the Oquirrh Formation.

Although perched systems are important sources of water locally, they are generally small and discontinuous and they are not discussed in detail in this report. Perched ground water occurs locally along the west side of the Wellsville Mountains and is common in the West Hills and the Blue Springs Hills. One or more perched ground-water systems occur along most of the east side of the West Hills and several perched systems occur west of Garland at the south end of the West Hills. Blind Springs, (B-12-4)10dab-S1, and nearby wells in secs. 10 and 11, T. 12 N., R. 4 W., tap perched water. Wells in the upper reaches of Broad Canyon (sec. 31, T. 14 N., R. 4 W.) and in Whites Valley probably tap perched water. The driller's log of well (B-13-4)32ccc-1 indicates perched water at depths of 90 and 148 feet (27 and 45 m) in unconsolidated rock and at a depth of 699 feet (213 m) in the underlying Oquirrh Formation. Some perched water levels are shown on the water-level contour map (pl. 2).

Aquifer characteristics

The transmissivity and storage coefficient of some of the water-bearing materials in the lower Bear River drainage basin were determined from pumping and recovery tests. Results are in table 5, and the terms are defined in the appendix. The tests were evaluated using methods described by Ferris and others (1962, p. 91-103), Cooper (1963, p. C43-C55), and Lohman (1972, p. 11-21, 30-34).

Source and recharge

Ground water in the lower Bear drainage basin is derived from precipitation within the basin, from surface water that enters the basin and is used for irrigation, and from water that moves into the basin as subsurface inflow.

The total annual recharge, assuming it is equal to discharge, is about 315,000 acre-feet (389 hm^3) (see section on discharge). Recharge should approximately equal discharge because the annual change in ground-water storage is small, as indicated by small average changes of water level in wells.

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[1]Ground water is said to be perched if it is separated from an underlying body of ground water by unsaturated rock (Meinzer, 1923, p. 40).

Table 5.--Results of pumping and recovery tests

Geologic unit: PIPo, Oquirrh Formation; Qbi, interior deposits of Lake Bonneville basin: Qbm, marginal deposits of Lake Bonneville basin.

Pumped well	Observation well	Radius and direction from pumped well	Date	Length of test (minutes)	Transmissivity (ft^2/d)	Storage coefficient	Discharge (gal/min)	Maximum drawdown (feet)	Water-bearing material	Geologic unit	Saturated section open to well (feet)	Rating of test
RECOVERY TESTS												
(B-8-2)2bcb-1			8/ 3/72	80	20,000	-	525	21	Sand and gravel	Qbm	85	Fair
(B-12-2)18bcb-1			7/14/71	300	2,000	-	9	1.7	Sand and silt	Qbi	10	Fair
PUMPING TESTS												
(B-12-4)22aac-1			3/31/71	630	-	-	1,000	-	Limestone Gravel	PIPo Qbm	373 63	-
	(B-12-4)22ccd-1	4,800 ft,S 33° W			140,000	-		-	-	PIPo1/		Fair
(B-12-4)27dbd-1			5/26-5/28/71	3,200	13,000	-	615	16	Gravel	Qbm	295	Fair
	(B-12-4)35bbc-1	3,230 ft,S 33° E			20,000	0.0006		1.3	Sand and gravel	Qbm	198	Good

1/ Principal water-bearing unit in nearby wells in Oquirrh Formation.

The amount of recharge was also estimated by evaluating the sources and quantities of water available for recharge as follows:

	Acre-feet per year
Availability	
Precipitation on recharge areas	548,000
Surface-water inflow diverted for irrigation on recharge areas (table 2)	245,000
Subsurface inflow	27,000
	820,000
Disposal	
Evapotranspiration in recharge areas	494,000
Runoff from recharge areas (estimated maximum)	10,000
Recharge (water available less evapotranspiration and runoff)	316,000
	820,000

Both methods of estimating total annual recharge give approximately the same result. A value of 315,000 acre-feet (389 hm^3) per year is used.

Recharge directly from precipitation occurs mostly in and near the mountains at places where rain or snowmelt enters permeable materials. This recharge is indicated in various ways. (1) Springs discharging from bedrock on the slopes of the Wasatch Range indicate recharge from precipitation on the rocks at higher altitudes. (2) The absence of well-developed drainage channels from West Hills and Whites Valley, which receives 16 to 20 inches (406-508 mm) of precipitation annually, indicates high permeability of the surface materials and hence recharge. (3) Perhaps the most striking evidence of recharge from precipitation is in the mountains east and southeast of Mantua Valley, where closed basins containing sinkholes conduct runoff from precipitation and snowmelt into solution channels in the limestone.

Infiltration from streams where they flow from canyons onto permeable materials is an important source of recharge in the project area. Much of such recharge is from perennial streams but considerable recharge also comes from many smaller intermittent and ephemeral streams that commonly lose all their flow in the alluvial slopes at the base of the mountains.

The principal streams on the valley floor, including Bear River, Malad River, Black Slough, Sulphur Creek, Salt Creeks (east and west), and the many smaller streams and drains, do not contribute water directly to the ground-water reservoir. They all flow through the lower part of the valley, which is an area of ground-water discharge (pl. 2); consequently, they are gaining streams. Bear River does contribute water indirectly, however, through infiltration of water diverted for irrigation.

Recharge to the ground-water reservoir in the area has been increased substantially by diverting water from streams for irrigation. An estimated average amount of 248,000 acre-feet (306 hm^3) of water was diverted annually from streams during 1960-71 (table 9) to irrigate about 96,800 acres (39,200 hm^2). (See irrigated area in fig. 11.) Because the land-surface materials are quite permeable, between one-fourth and one-half of this water probably infiltrated to the ground-water reservoir. Annual rises of water levels in observation wells, due principally to recharge by irrigation, averaged about 6 feet (1.8 m). (See hydrographs of wells (B-8-2)14bda-1, (B-9-2)14dac-1, (B-9-2)23dab-1, (B-12-2)18bcb-1, (B-13-3)35dda-1, and (B-11-4)27bcb-1, pl. 4.) If the estimated effective porosity of the water-bearing materials is 0.15, the annual change of 6 feet (1.8 m) in the irrigated area would amount to at least 85,000 acre-feet (105 hm^3) annually, which is about one-third of the water diverted for irrigation.

A total ground-water inflow into the project area of 27,000 acre-feet (33.3 hm^3) per year is required for balance when all items in the water-budget analyses (tables 11 and 12) are considered. As accumulated errors in the water budgets could be of this same magnitude, the estimate based on the budgets should be considered as only a best available approximation.

The subsurface inflow occurs in three general areas: (1) Some ground water crosses the Utah-Idaho State line through the valley fill in the Malad River valley and through the rocks in the West Hills. (2) Comparison of water-level contours in the Blue Creek area (Bolke and Price, 1972, pl. 1) with those on plate 2 indicates that some ground water enters the project area across the western boundary north of State Highway 83. (3) The ground-water divide in the Wellsville Mountains is probably somewhat east of the surface-drainage divide, thus some ground water probably enters the project area across the eastern boundary in the Wellsville Mountains.

Movement and potentiometric surface

The general direction of ground-water movement can be inferred from the water-level contour, or potentiometric-surface, map (pl. 2); movement is perpendicular to the contours as indicated by the arrows on the map. In addition to the lateral movement indicated on plate 2, the direction of movement is partly downward in recharge areas and partly upward in discharge areas.

The direction of ground-water movement is generally from the mountains toward the valley and then south and southwest toward the lowest parts of the basin. An exception is in the southern part of the West Hills, where water moves from the valley toward the West Hills and then generally toward Salt Creek Springs, (B-11-3)6dcc-S1, about 2 miles (3 km) southeast of Bothwell.

The potentiometric surface of the principal ground-water system includes the water table in areas where the principal system is unconfined and the imaginary surface defined by the head of the water in areas where it is confined; both are shown by one set of contours on plate 2. The second set of contours on plate 2 shows the configuration of the water table in the shallow unconfined ground-water system in the central-plain area.

The relation of water levels to land surface is indicated on plate 3. Water-level data (Bjorklund and McGreevy, 1973, table 1) show a range from 28 feet (8.5 m) above to 745 feet (227 m) below land surface, but water levels at most wells are between 10 feet (3 m) above and 200 feet (60 m) below land surface.

Fluctuations of water levels

Water levels were measured monthly in 32 wells and annually (in March) in approximately 160 wells during this investigation. The measurements at five of these wells were a continuation of water-level measurements going back more than 30 years. Periodic water-level measurements at 50 wells, including the above wells and at 13 wells measured prior to this investigation, are published in a basic-data release (Bjorklund and McGreevy, 1973). Hydrographs of 23 selected wells and the locations of the wells are shown on plate 4. Hydrographs of annual water levels showing long-term trends and their relations to precipitation are shown in figure 2.

Seasonal fluctuations

Water levels rise during the summer in areas irrigated with surface water and decline between irrigation seasons. Irrigated areas are shown in figure 11, and principal parts of the irrigation-water distribution systems are shown in figure 3. The rise of water levels during the irrigation season is indicated on plate 4 by the hydrographs of wells (B-8-2)2bcb-1, (B-8-2)14bda-1, (B-9-2)14dac-1, (B-9-2)23dab-1, (B-11-4)23bcc-1, (B-11-4)27bcb-1, (B-12-2)18bcb-1, and (B-13-3)35dda-1. The rise is less apparent in the hydrographs of wells (B-10-3)12dba-1, (B-10-3)32aaa-1, and (B-11-3)33cdd-1, which are also in irrigated areas, because the water level in these wells is near the land surface and discharge by springs, drains, and evapotranspiration lessens the fluctuations.

Water levels decline during the summer in the Bothwell Pocket (see fig. 10) where almost all the irrigation water is pumped from wells and in parts of the Brigham City-Perry area where ground water is used to supplement the surface-water supply. The water levels rise between pumping seasons. The hydrographs of wells (B-12-4)22ccd-1 and (B-12-4)35bbc-1 show the effect of pumping for irrigation in the Bothwell Pocket. In the Brigham City-Perry area the hydrographs of wells (B-8-2)2bcb-1 and (B-9-2)26aaa-1 show declines due to pumping from wells for irrigation superimposed on rises due to irrigation by surface water. On the other hand, the hydrographs of other pumped irrigation wells in the same general area, (B-8-2)14bda-1, (B-9-2)14dac-1, and (B-9-2) 23dab-1, do not show any effects from pumping because they are masked by rises due to irrigation with surface water.

A depressed water level, due primarily to evapotranspiration, and a recovery during the colder parts of the year when evapotranspiration is minimal, is indicated by the hydrographs of wells (B-9-2)3bbc-1 and (B-13-3)11dad-1. Such fluctuations are typical of some areas where the water table is near the land surface, such as much of the lowlands in the southern half of the project area, particularly the area south of State Highway 83. Well (B-9-2)3bbc-1 was dug 5 feet (1.5 m) deep into compact silt and fine sand on the mudflats near the Brigham City airport to observe water-level fluctuations. The hydrograph of the well indicates that evapotranspiration lowered the water surface to about 4 feet (1.2 m) beneath the mudflats during the summer of 1972. The recovery of water level to near the land surface during cooler parts of the year is due mostly to reduced rate of evapotranspiration and partly to increased recharge from precipitation. Most of the seasonal decline of water level at well (B-13-3)11dad-1 was caused by evapotranspiration in the vicinity of the well, although part of the decline was due to reduced recharge during the summer and to occasional pumping from the well.

The hydrographs of four wells in the valley northwest of Plymouth indicate fairly uniform water-level fluctuations in an area of about 25 square miles (65 km^2). These wells, (B-13-3)4cdd-1, (B-14-3)7abb-1, (B-14-3)10bbb-1, and (B-14-3)17cdc-1, tap sand and gravel in the valley fill. The hydrographs show little seasonal fluctuation compared with most other wells in the project area, and they all show rises of less than 2 feet (0.6 m) during 1970-72. The effects of pumping and recharge from irrigation are not noticeable in the hydrographs. Pumpage during the period of investigation was small, and recharge from irrigation was minor because most of the irrigated land is in a ground-water discharge area.

Three wells, (B-11-3)6bdb-1, (B-12-3)15cdc-1, and (B-13-3)28ada-1, which tap the Oquirrh Formation along the flanks of the West Hills, have hydrographs that show little seasonal fluctuation. The water level in well (B-11-3)6bdb-1 remained at about the same altitude during 1970-72, because levels in the vicinity are controlled by nearby Salt Creek Springs, (B-11-3)6dcc-S1, but the water level in the other two wells rose about 2 feet (0.6 m) during the period. The effect of pumping is not noticeable in the hydrographs, although well (B-12-3)15cdc-1 was pumped for irrigation during each of the years. This suggests that the aquifer has high transmissivity and that the ground-water reservoir is large.

Fluctuations caused by well interference

Water-level fluctuations caused by interference between wells occurs widely in the Bothwell Pocket and to a lesser extent in other parts of the project area. Well interference takes place when a decline of water level is induced in a well by discharging water from another well. Such fluctuations in the Bothwell Pocket are indicated by the hydrograph of well (B-12-4)22ccd-1 (pl. 4), which is not pumped. Water-level declines during the pumping season are caused by pumping from wells half a mile or more away. Mutual interference between pumped wells in the Bothwell Pocket was observed also during an aquifer test in May 1971, when well (B-12-4)27dbd-1 was pumped, and declines were observed in wells up to 1 mile (1.6 km) away (table 5).

Interference of wells along the Wasatch Range south of Brigham City is indicated in the hydrograph of well (B-9-2)26aaa-1. This well is relatively deep, 412 feet (126 m), and taps a confined aquifer that is also tapped by other irrigation wells. Shallow wells in the area, however, such as wells (B-9-2)14dac-1 and (B-9-2)23dab-1, do not show interference effects because (1) recharge from irrigation by surface water during the pumping season counteracts drawdown effects in the shallow aquifer; and (2) most of the shallow irrigation wells tap unconfined gravel deposits, and drawdown effects spread much more slowly in an unconfined aquifer than in a confined aquifer.

Long-term fluctuations and trends

Records of water-level measurements in five wells in the lower Bear River drainage basin indicate little long-term change in the water level since records began in the mid-1930's (Bjorklund and McGreevy, 1973, table 3). Changes in water level in response to changes in annual precipitation are indicated in figure 2 by comparing the hydrograph of well (B-10-3)8cdb-1 and the graph showing cumulative departure from normal annual precipitation. This well is on dryfarm land where water levels are not affected by irrigation or pumping. In most of the project area the natural change of water levels in response to changes in precipitation is modified by the recharge effect of irrigation with surface water or by the discharge effect of pumping, or by a combination of the two. The hydrograph of well (B-9-2)12ccc-1 and the combined hydrographs of wells (B-8-2)11bdc-1 and (B-8-2)11cad-1 correlate poorly with the graph of cumulative departure from normal annual precipitation (fig. 2). These wells are in an area that is irrigated by surface water which is supplemented by ground water.

Hydrographs of five wells in the Bothwell Pocket, (B-12-4)22ccd-1, 23cdd-1, 34bbd-1, 34cbd-1, and 35bbc-1, are given in figure 5. These hydrographs show only March-April water-level measurements to point out trends, which could have been induced by pumping. Pumping from wells for irrigation started in 1955 with two heavily pumped wells and increased to three wells in 1967, four in 1969, five in 1970, and six in 1971. All the hydrographs show very little change in water level during the 6-year period covered; however, water-level measurements should be continued annually to observe the future effects of pumping.

Discharge

Ground water is discharged in the lower Bear River drainage basin by springs, drains, wells, evapotranspiration, and subsurface outflow. The average ground-water discharge in the basin is estimated to be about 315,000 acre-feet (389 hm^3) per year. Major areas of natural ground-water discharge from the principal ground-water system are shown on plate 2.

Springs and drains

Springs and drains discharge about 210,000 acre-feet (259 hm^3) of ground water annually. The locations of selected springs for which data were collected are shown on plate 4. The data are given in a basic-data release by Bjorklund and McGreevy (1973, table 2).

About 21,000 acre-feet (26 hm^3) of fresh water is discharged annually from eight large springs in Mantua Valley. These springs discharge from Paleozoic limestone or from unconsolidated rocks near outcrops of Paleozoic limestone, suggesting that water is conducted to the springs through solution channels or fractures in the limestone.

A hydrograph of a typical spring in Mantua Valley--Big Dam Spring, (B-9-1)15adc-S1--for the period 1961-72 and a graph showing cumulative departure from the 1931-60 normal annual precipitation at Corinne are presented in figure 6. The spring-discharge data are based on monthly weir readings made during 1961-70 by W. H. Griffiths of Brigham City and during 1971-72 by the Geological Survey. Figure 6 indicates that (1) the spring discharge increased during extended periods of above-normal annual precipitation, and (2) the effects of above-normal precipitation extended into following years (although the precipitation in 1966 was considerably below normal, the discharge at the spring remained about the same because precipitation during 1965 was considerably above normal). This kind of relation between spring discharge and departure from normal annual precipitation probably is true for all the large-discharge springs in Mantua Valley.

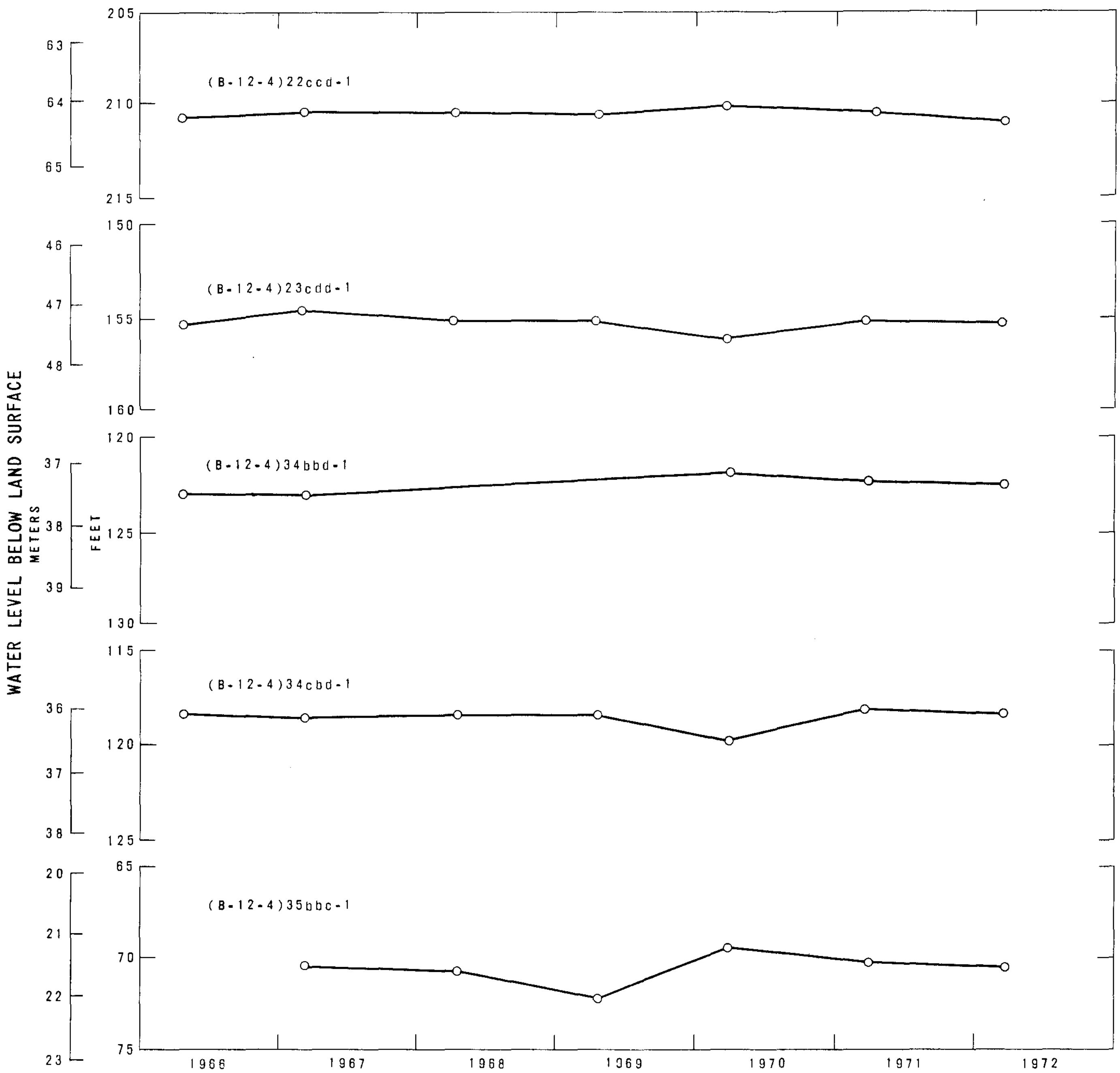

Figure 5.- Water-level trends in the Bothwell Pocket, 1966-72.

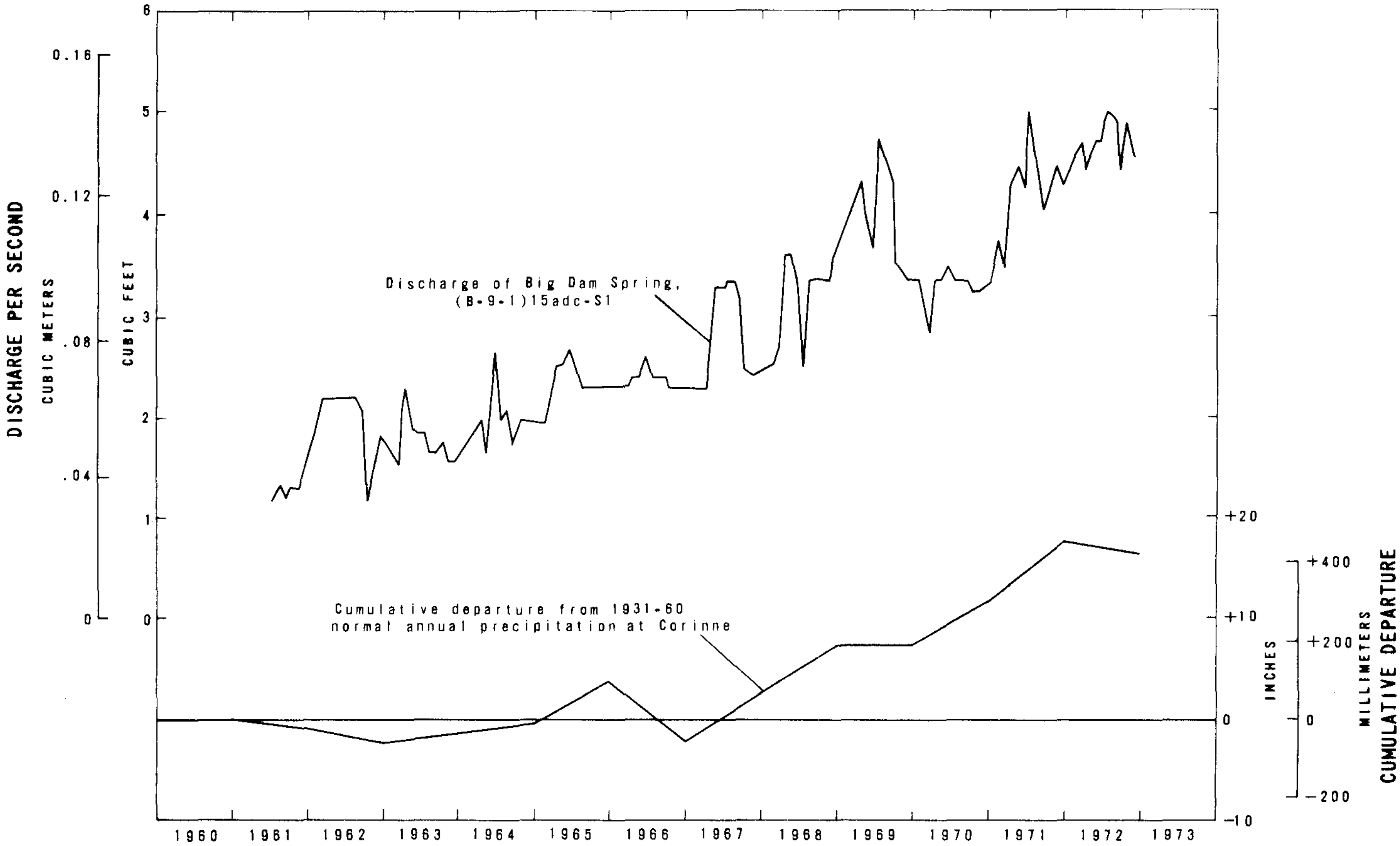

Figure 6.- Relation of discharge of Big Dam Spring, (B-9-1)15adc-S1, to cumulative departure from the 1931-60 normal annual precipitation at Corinne.

About 30,000 acre-feet (37 hm^3) of slightly saline to briny water is discharged annually from springs near West Hills, Blue Springs Hills, and Little Mountain. The water discharges from Paleozoic limestone or from unconsolidated sediments nearby. Springs are near the south ends of the mountain masses. The largest of these springs is Salt Creek Springs, (B-11-3)6dcc-S1, which discharges about 22 ft^3/s (cubic feet per second) (0.6 m^3/s).

At least 30,000 acre-feet (37 hm^3) of water is discharged annually from springs along the west side of the Wasatch Range and Clarkston Mountain. About one-third of this water is fresh and about two-thirds is slightly saline. Most of the springs issue either from bedrock on the mountain slopes or from the lower parts of alluvial slopes. Most of the springs from Deweyville northward and springs in the mountains or high on the abutting alluvial slopes south of Deweyville discharge fresh water. Most of the springs on the lower parts of alluvial slopes south of Deweyville discharge slightly saline water. About 4 ft^3/s (0.11 m^3/s) of brine is discharged from Crystal Hot Spring, (B-11-2)29dad-S1, which discharges from the base of an alluvial slope and in a major fault zone.

Seepage and conductance surveys of Salt Creek (east), which heads at Crystal Hot Spring, were made in July and November 1971 to determine the location and amount of ground-water accretion and the source and amount of salt load in the stream. Details of these surveys are presented in tables 6 and 7. Crystal Hot Spring, (B-11-2)29dad-S1, discharges approximately 4 ft^3/s (0.11 m^3/s) of brine, containing about 470 tons (445 t) of dissolved solids per day. The seepage and conductance surveys showed that other springs along the stream added water that ranged in dissolved solids from about 900 to 2,400 mg/l (milligrams per liter) and averaged about 1,500 mg/l at a rate of 15.4 ft^3/s (0.44 m^3/s) during the July survey and 9 ft^3/s (0.25 m^3/s) during the November survey. This added about 75 and 44 tons (68 and 40 t) of dissolved solids per day, respectively; however, the data did not indicate a consistent downstream gain in salt load. The saltload data are regarded as only approximate because the mixing of the brine and slightly saline water is probably not complete at the sampling points. Also, some of the dissolved solids, especially the carbonates, may precipitate in the stream and become part of the bedload. It is apparent from the surveys that Crystal Hot Spring supplies the bulk of the salt load in Salt Creek (east).

At least 130,000 acre-feet (160 hm^3) of water is discharged annually from springs and drains on the valley floor. Of this amount, about 126,000 acre-feet (155 hm^3) of fresh to slightly saline water is discharged into the Bear and Malad Rivers from springs and drains along the bluffs bordering the inner valleys of the two streams. Some additional spring discharge does not reach the streams because it is consumed by evapotranspiration. About 4,000 acre-feet (4.9 hm^3) of moderately saline water is discharged into the Malad River in the vicinity of Udy Hot Springs, (B-13-3)23bad-S1.

Accretion of ground water to Malad River and its relation to the chemical quality of the water is discussed by McGreevy (1972). According to his report the accretion to the stream between the Utah-Idaho State line and the diversion into the Bear River Duck Club Canal, about 25 miles (40 km) downstream, was 33 ft^3/s (0.93 m^3/s) of slightly saline water and 5 ft^3/s (0.14 m^3/s) of moderately saline water on August 12-13, 1971.

Evapotranspiration

About 270,000 acre-feet (333 hm^3) of water is discharged annually by evapotranspiration from mudflats and phreatophyte areas on 165 square miles (427 km^2) of lowland. (See fig. 11.) The average rate of evapotranspiration was calculated to be 30.2 inches (767 mm) per year, based on a modified Blaney-Criddle formula as used by Hill and others (1970, p. 17-19). Of the water consumed, approximately 14 inches (356 mm), or about 124,000 acre-feet (153 hm^3) per year, is derived from local precipitation. The remainder, about 146,000 acre-feet (180 hm^3) per year, is derived from the combined ground-water reservoir, springflow, and diverted surface water. As the amount of springflow and diverted surface water that is used by phreatophytes is not known, the amount of water consumed directly from the ground-water reservoir in the mudflats and phreatophyte areas cannot be calculated.

Table 6.--Approximate discharge of dissolved-solids load of Salt Creek (east), July 15, 1971

Discharge: E, estimated; M, measured.
Dissolved solids in the streamflow: A, calculated from analysis; B, calculated from conductance

Location and description of measuring station	Distance from head of stream at Crystal Hot Spring along streambed (miles)	Water temperature		Specific conductance (micromhos/cm at 25°C)	Dissolved solids (mg/l)	Discharge (ft^3/s)		Dissolved solids in the streamflow (tons per day)	Remarks
		°C	°F			Creek	Tributary to creek		
Crystal Hot Spring (B-11-2)29dad-S1	0	55.5	132	58,600	43,500	4E	-	470A	Estimates of total discharge at Crystal Springs area are based on observations made at the springs on 11-7-70.
Crystal Cold Spring (B-11-2)29dac-S1	0	16.5	62	2,000	1,170	-	4E	13A	
Spring (B-11-2)32aab-S1	.4	20.5	69	2,800	-	-	.01E	Neg.	
Salt Creek below Crystal Springs in box culvert at UPRR crossing, SE¼SW¼ SE¼ sec. 29, T. 11 N., R. 2 W.	.4	28.0	82	27,400	-	9.1M	-	400B	
Spring (B-10-2)5adb-S1	2.2	14.0	57	1,500	-	-	.1M	Neg.	
Salt Creek upstream from highway bridge, near Honeyville, SW¼SE¼NE¼ sec. 5, T. 10 N., R. 2 W.	2.3	24.0	75	19,200	-	18.3M	-	570B	
Drain, NE¼NE¼NE¼ sec. 17, T. 10 N., R. 2 W.	4.2	22.0	72	4,000	-	-	.7E	4B	
Drain, SE¼NE¼NE¼ sec. 17, T. 10 N., R. 2 W.	4.4	22.0	72	2,500	-	-	.5E	2B	
Spilling from canal, SE¼NE¼ NE¼ sec. 17, T. 10 N., R. 2 W.	4.5	-	-	-	-	-	.2E	-	
Salt Creek upstream from Call's Fort Road, SE¼SE¼ NE¼ sec. 17, T. 10 N., R. 2 W.	4.6	23.0	73	18,400	-	21.2M	-	630B	
Spilling from flume over creek, NW¼SE¼NE¼ sec. 20, T. 10 N., R. 2 W.	5.5	-	-	-	-	-	.4E	-	
Salt Creek downstream from canal flume crossing, NW¼ SE¼NE¼ sec 20, T. 10 N., R. 2 W.	5.6	23.0	73	17,100	9,770	19.4M	-	510A	
Confluence of Salt Creek with Bear River	6.4	-	-	-	-	-	-	-	

Wells

Approximately 4,000 acre-feet (4.94 hm^3) of water (table 9) was discharged from wells in the project area during 1970-71. About 1,600 acre-feet (1.97 hm^3) was pumped from six irrigation wells in the Bothwell Pocket area, the principal area where irrigation water is supplied almost exclusively by wells. About 1,100 acre-feet (1.36 hm^3) of water was pumped from wells near Brigham City for public supply and irrigation. About 1,100 acre-feet (1.36 hm^3) was also pumped from other public-supply and irrigation wells. About 200 acre-feet (0.247 hm^3) was pumped from many small-discharge wells for domestic and stock use and to irrigate some lawns and small gardens. Records of 346 representative wells are given in a separate basic-data release (Bjorklund and McGreevy, 1973).

Table 7.--Approximate discharge of dissolved-solids load of Salt Creek (east), Nov. 5, 1971

Discharge: E, estimated; M, measured.
Dissolved solids in the streamflow: A, calculated from analysis; B, calculated from conductance.

Location and description of measuring station	Distance from head of stream at Crystal Hot Spring along streambed (miles)	Water temperature		Specific conductance (micromhos/cm at 25°C)	Dissolved solids (mg/l)	Discharge (ft^3/s)		Dissolved solids in the streamflow (tons per day)	Remarks
		°C	°F			Creek	Tributary to creek		
Crystal Hot Spring (B-11-2)29dad-S1	0	55.5	132	58,600	43,500	4E	-	470A	Estimates of total discharge at Crystal Springs area are based on observations made at the springs on 11-7-70.
Crystal Cold Spring (B-11-2)29dac-S1	0	16.5	62	2,000	1,170	-	4E	13A	
Salt Creek below Crystal Springs in box culvert at UPRR crossing, SE¼SW¼ SE¼ sec. 29, T. 11 N., R. 2 W.	.4	23.5	74	32,800	-	10.5M	-	560B	
Salt Creek upstream from highway bridge near Honeyville, SW¼SE¼NE¼ sec. 5, T. 10 N., R. 2 W.	2.3	14.5	58	24,000	-	10.5M	-	410B	
Salt Creek upstream from Call's Fort Road, SE¼SE¼ NE¼, sec. 17, T. 10 N., R. 2 W.	4.6	11.5	53	22,800	-	13.4M	-	490B	
Salt Creek downstream from canal flume crossing, NW¼ SE¼NE¼ sec. 20, T. 10 N., R. 2 W.	5.6	11.0	52	21,800	-	13.0M	-	460B	
Confluence of Salt Creek with Bear River	6.4	-	-	-	-	-	-	-	

Subsurface outflow

An estimated 1,000 acre-feet (1.23 hm^3) per year of water moves out of the project area as subsurface outflow in the vicinity of the Bear River Migratory Bird Refuge. Movement across the western boundary of the project area south of State Highway 83 and across the southern boundary on the alluvial slope south of Brigham City is assumed to be negligible, as the ground-water gradient is about parallel to the boundary. Movement across the southern boundary probably occurs over a length of about 15 miles (24 km) from the southwestern corner of the project area eastward. The transmissivity in the area of outflow is estimated to be about 3,000 $ft^3/d/ft$ (cubic feet per day per foot) (279 $m^3/d/m$) and the gradient about 3 ft/mi (feet per mile) (0.9 m/km). Using these values, the estimated outflow is about 1,000 acre-feet (1.23 hm^3) per year.

Chemical quality

Data on the chemical quality of ground water that were collected for this study are presented in the basic-data release (Bjorklund and McGreevy, 1973). Much of that information is shown in generalized form on illustrations in this section. Representative chemical analyses are in table 8. The units used to express the quality of water are defined in the appendix.

The chemical quality of surface water in the study area and in the Bear River drainage as a whole has been reported in some detail by Waddell (1970) and by Waddell and Price (1972). A specific-conductance survey of the Malad River was made by McGreevy (1972). Data on the chemical quality of Salt Creek (east) are in tables 6 and 7.

Table 8.--Representative chemical analyses of water from selected wells and springs

Location: Description of numbering system in appendix.
Sodium and potassium: An entry of C in potassium column indicates that sodium and potassium are calculated and reported as sodium.
Nitrate: An entry of C after nitrate value indicates analysis of nitrate plus nitrite, reported as nitrate.
Agency making analysis: GS, U.S. Geological Survey; SH, Utah State Department of Health.

Location	Depth of well (feet)	Date of collection	Temperature (°C)	Milligrams per liter																		Specific conductance (micromhos/cm at 25°C)	pH	Sodium-adsorption ratio (SAR)	Agency making analysis
				Silica (SiO_2)	Iron (dissolved) (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$	Dissolved solids: Residue at 180°C	Dissolved solids: Sum of determined constituents				
(B-9-1)14cdc-S1	-	4-22-69	-	4.0	0.00	42	28	9.0	1.0	233	1	11	20	0.1	3.5	0.13	220	29	224	235	450	8.0	0.3	SH
19bcc-1	412	8-28-69	-	12	.00	50	21	10	1.0	242	1	16	20	.2	4.5	.07	210	13	256	255	490	7.7	.3	SH
(B-9-2)15daa-1	465	5-17-71	16.5	19	.28	2.0	1.2	150	1.8	351	22	5.5	16	.7	.1C	.00	10	0	-	395	593	8.7	21	GS
(B-9-3)2add-1	11	8- 6-71	14.5	43	.06	45	50	320	.4	556	0	140	260	.3	10C	.41	320	0	-	1,140	2,000	8.1	7.8	GS
(B-10-3)4ddd-1	510	9-25-70	25.5	80	-	94	45	3,900	160	452	0	170	6,200	1.2	.1	.80	420	49	-	10,800	17,100	7.7	82	GS
(B-10-4)24ccc-S1	-	5-11-71	42.0	28	.80	630	230	13,000	450	400	0	500	22,000	1.5	1.6C	4.5	2,500	2,200	-	37,000	-	7.0	113	GS
(B-11-2)29dac-S1	-	5-17-71	16.5	14	.01	70	32	310	15	293	0	45	530	.2	6.2C	.08	310	66	-	1,170	2,000	7.9	7.7	GS
29dad-S1	-	11- 2-66	53.0	27	.11	810	190	14,000	670	382	-	460	23,000	2.0	.9	3.2	2,800	2,500	-	39,700	58,100	7.3	110	GS
(B-11-3)6dcc-S1	-	6-25-71	19.5	20	.07	52	21	660	29	350	0	67	960	.2	5.8C	.38	220	0	-	1,990	3,670	8.1	20	GS
17dba-1	335	5-13-71	14.0	61	.02	52	19	400	9.7	166	0	48	670	.6	.1C	.00	210	72	-	1,340	2,310	8.3	12	GS
(B-11-4)3ccc-1	430	9- 9-69	-	20	-	87	49	270	C	250	0	42	540	-	2.8	-	420	210	1,180	1,130	2,000	8.1	5.8	GS
23bcc-1	393	9-25-70	-	70	-	68	33	130	9.4	229	0	110	200	.7	.4	.15	300	120	743	740	1,230	7.5	3.2	GS
(B-12-2)11dcb-S1	-	8-27-71	-	54	.20	98	27	46	5.0	321	0	41	81	.5	7.8C	.07	360	93	-	519	816	7.8	1.1	GS
18bcb-1	14	7-14-71	9.5	51	.00	54	95	100	42	504	0	130	120	.3	42C	.24	530	110	-	882	1,480	8.1	1.9	GS
(B-12-3)15cdc-1	277	7-20-71	-	23	.12	31	9.9	310	28	399	0	83	270	.3	7.5C	.31	120	0	-	960	1,660	8.0	12	GS
(B-12-4)34bbd-1	306	9- 9-69	-	22	-	89	39	170	C	250	0	51	340	-	5.8	-	380	180	870	836	1,470	7.9	3.7	GS
(B-13-3)35dda-1	237	8-25-64	-	47	.18	66	35	440	28	485	2	220	470	.9	2.2	.44	310	0	1,560	1,550	2,390	7.8	11	SH
(B-14-3)5cdc-1	-	5-12-71	11.0	36	.01	39	20	64	4.8	256	0	20	74	.3	1.5C	.03	180	0	-	386	621	8.2	2.1	GS
27dcb-S1	-	9-13-71	13.0	25	.06	63	34	18	4.0	323	0	25	17	.1	17C	.08	300	32	-	362	599	7.6	.5	GS
(B-14-4)9dcc-S1	-	5-13-71	11.5	14	.01	81	13	24	.9	261	0	19	41	.2	6.6C	.00	260	42	-	328	525	7.9	.7	GS

Concentration of dissolved solids

Chemical analyses of ground water in the lower Bear River drainage basin indicate that the concentration of dissolved solids ranges from about 88 to 122,000 mg/l. Terms used in this report to classify water according to the concentration of dissolved solids are as follows (adapted from Hem, 1970, p. 219):

		Dissolved solids (mg/l)	Approximate specific conductance (micromhos/cm at 25°C)
Fresh water		Less than 1,000	Less than 1,700
	Slightly saline	1,000- 3,000	1,700- 5,000
Saline water	Moderately saline	3,000-10,000	5,000-17,000
	Very saline	10,000-35,000	17,000-58,000
Brine		More than 35,000	More than 58,000

Specific conductance, which is a measure of the ability of water to conduct an electrical current, is related to the concentration of dissolved solids. The relation depends on the particular constituents in solution but is generally consistent in a particular area or aquifer. The relation in the lower Bear River drainage basin, as determined by chemical analyses, is shown graphically in figure 7. The concentration of dissolved solids, expressed in milligrams per liter, is near 60 percent of the specific conductance, expressed in micromhos per centimeter at 25°C, but ranges from about 50 percent to about 80 percent. A line representing the 60 percent relation is shown in figure 7. The specific conductance of ground water in the lower Bear River drainage basin is shown on plate 5.

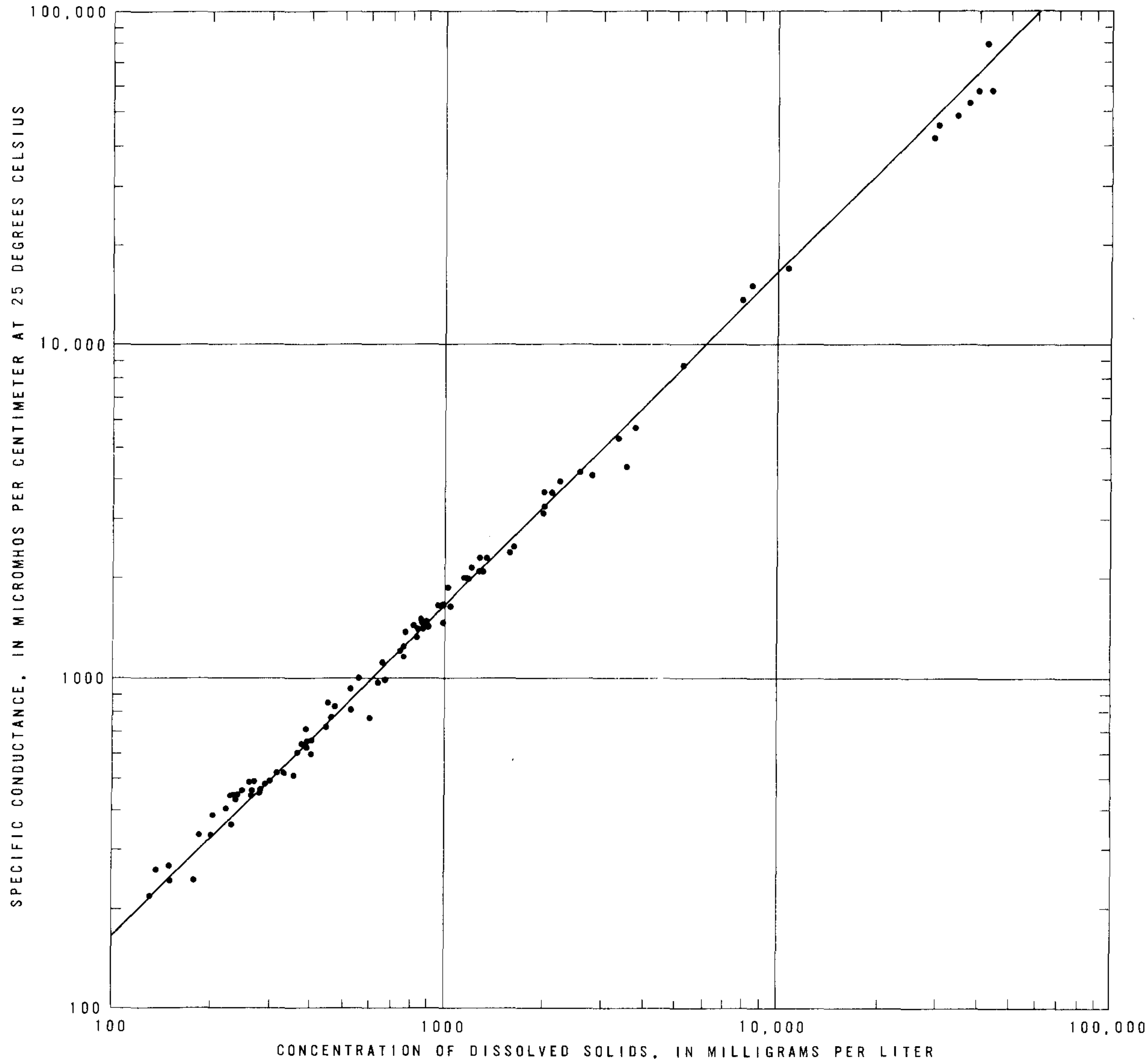

Figure 7.--Relation of specific conductance to the concentration of dissolved solids in ground water in the lower Bear River drainage basin.

Major constituents

The concentration of major chemical constituents in ground water in the project area is indicated by diagrams on plate 5. The water varies from dilute bicarbonate water in the mountains to chloride brine at depth in the lower parts of the area. Calcium and magnesium are the predominant cations in most bicarbonate water in and near the edges of the mountains, but sodium is the predominant cation in the bicarbonate water in the lower parts of the area. Note the change in cations indicated by diagrams representing bicarbonate water near Brigham City (pl. 5). Diagrams representing sodium bicarbonate water from wells (B-9-2) 15daa-1 and (B-11-2)6ccc-1 indicate that both cation exchange and sulfate reduction have probably occurred. Sodium is the predominant cation in most of the chloride water.

Sulfate is the predominant anion in only one water sample, that from well (B-11-4)11ddc-1. This water differs from that of nearby wells in both type and concentration, so it does not represent the general quality of the ground water in the area.

The source of dissolved solids in ground water is commonly from solution of the rocks that contain the water, but in the project area most of the dissolved solids are the result of the accumulation of soluble minerals in the basin. The lower Bear River drainage basin is part of a closed basin where soluble minerals have been accumulating for at least a hundred thousand years, and a large amount of accumulated minerals have entered the rocks with water and have contaminated a large part of the ground-water system. As a result, rocks at depth in the valley that are composed mostly of calcium, magnesium, silicate, and carbonate contain sodium chloride water with as much as 40,000 mg/l sodium and 70,000 mg/l chloride.

Quality in relation to use

Water quality is evaluated according to the intended use. Generally, the lower the concentration of dissolved solids, the better the quality of the water; however, for some uses, the concentration of particular substances in water may be more significant than the total concentration of dissolved solids.

Hardness of water is a consideration for domestic use and for many industrial uses. Hardness is that property of a water that causes soap to form an insoluble curd and is the major contributor to the scale that forms in boilers and pipes. Hem (1970, p. 224-226) presents a discussion of hardness and a classification of water with respect to hardness as follows:

Classification	Hardness as $CaCO_3$ (mg/l)
Soft	0 - 60
Moderately hard	61 -120
Hard	121 -180
Very hard	More than 180

Most ground water in the lower Bear River drainage basin is classified as hard or very hard.

Quality standards for potable water used by public carriers and by others subject to Federal quarantine regulations have been established by the U.S. Public Health Service (1962). These standards concern bacteria, radioactivity, and chemical constituents that may be objectionable in a water supply. The following is a list of the standards that pertain to those constituents for which analyses are given in this report:

> "The following chemical substances should not be present in a water supply in excess of the listed concentrations where * * * other more suitable supplies are or can be made available." (U.S. Public Health Service, 1962, p. 7.)

Substance	Recommended limit (mg/l)
Chloride (Cl)	250
Fluoride (F)	1.3[1]
Iron (Fe)	.3
Nitrate (NO_3)	45
Sulfate (SO_4)	250
Dissolved solids	500

[1]Based on the annual average of maximum daily air temperature of 61°F at Garland, Utah for 1957-71.

Ground water from those areas shown on plate 5 where the specific conductance is less than 1,000 micromhos per cm generally contains concentrations of the listed substances that are below the recommended maximum limits. Most public-supply systems in the lower Bear River drainage basin obtain water from these areas. Ground water obtained from other parts of the lower Bear River drainage basin generally exceeds the recommended limit for dissolved solids and for some of the individual constituents. The recommended limit for dissolved solids is influenced primarily by considerations of taste (U.S. Public Health Service, 1962, p. 34), and water exceeding the limit is used in many homes for domestic purposes without problems related to the concentration of dissolved solids. If the dissolved-solids limit is greatly exceeded, however, the concentration of individual constituents will exceed their recommended limits.

Water-quality requirements for industrial use differ widely according to the particular use. Criteria for evaluating water for many industrial uses are given in McKee and Wolf (1963, p. 92-106).

McKee and Wolf (1963, p. 112-113) discuss some of the criteria that have been used to evaluate water for livestock use and Beath and others (1953) suggest the following classification as a guide:

Classification	Dissolved solids (mg/l)
Good	Under 1,000
Fair (usable)	1,000 to 3,000
Poor (usable)	3,000 to 5,000
Very poor (questionable)	5,000 to 7,000
Not advisable	Over 7,000

Among the principal factors determining the suitability of water for irrigation are the concentration of boron, the concentration of dissolved solids, and the proportion of sodium to calcium and magnesium. Boron in more than trace concentrations is toxic to plants, but except for brines, few analyses of ground water in the study area show a boron concentration exceeding permissible limits for sensitive crops (1.0 mg/l) given by Hem (1970, p. 329). The concentration of dissolved solids (salinity hazard) affects plant growth by limiting the ability of the plant to take in water. The proportion of sodium to calcium and magnesium (sodium hazard) affects the extent to which soil minerals will adsorb sodium from the water. The adsorption of sodium breaks down the flocculation of the soil and makes it gummy, less permeable, and less fertile. An index to the sodium hazard is the sodium-adsorption ratio (SAR); it is expressed as:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$$

where the concentrations of the ions are expressed in milliequivalents per liter.

The sodium and salinity hazards of ground-water from selected wells and springs in the project area were classified according to the method of the U.S. Salinity Laboratory Staff (1954, p. 79-81). In this classification it is assumed that an average quantity of water will be used under average conditions of soil texture, salt tolerance of crops, climate, drainage, and infiltration. The areal distribution of the sodium and salinity hazards of water from the principal ground-water system is shown by figure 8. Water from the shallow unconfined ground- water system in the central-plain area has a high- to very high-salinity hazard; the sodium hazard is low from Tremonton northward and medium to very high south of Tremonton. Sparse data indicate that water from perched ground-water systems in the West Hills has a low-sodium hazard and a medium- to high-salinity hazard. Most irrigation wells in the project area tap ground water that has a low-sodium hazard and a low- to high-salinity hazard.

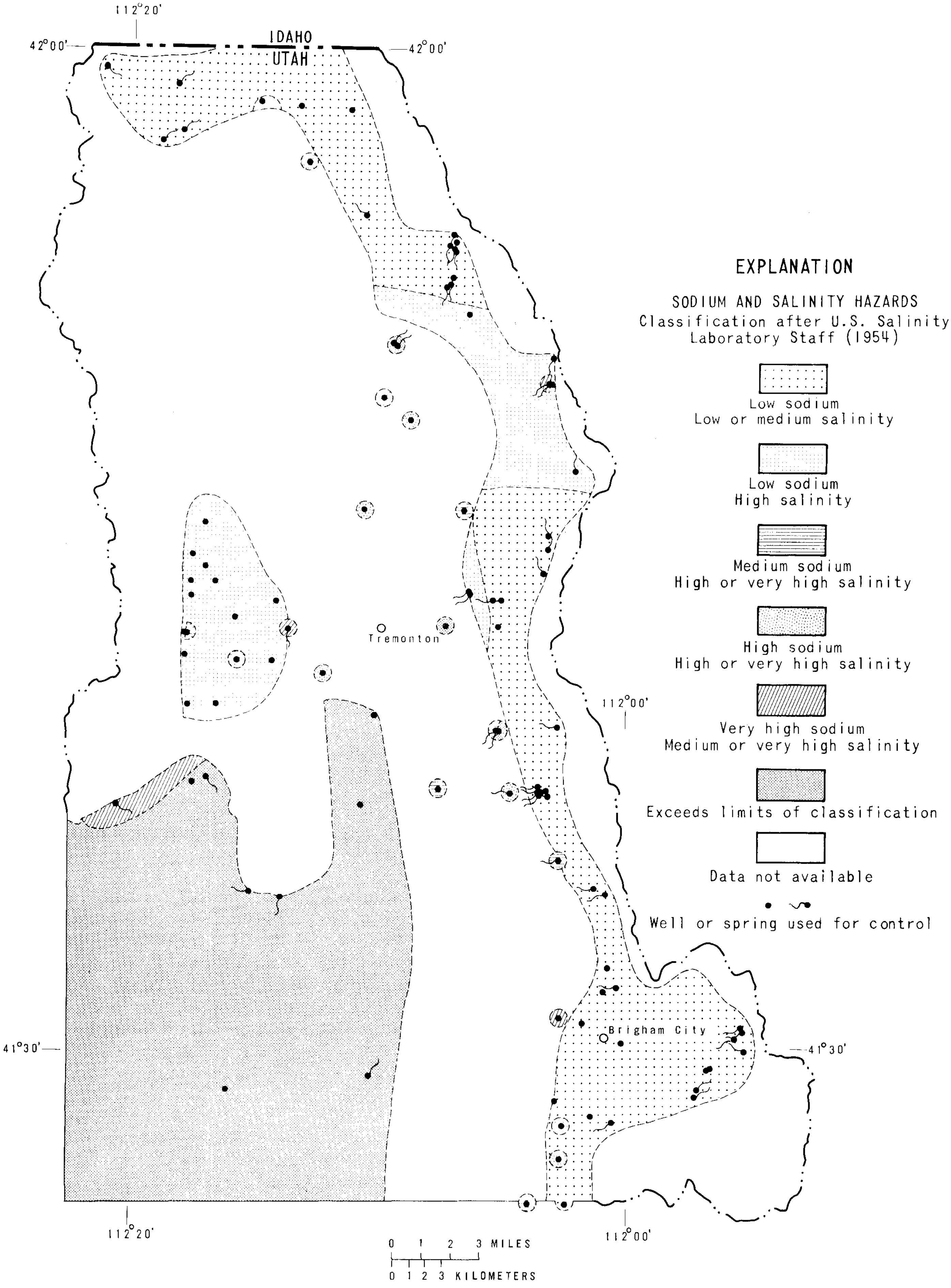

Figure 8.— Areal distribution of sodium and salinity hazards of water from the principal ground-water system.

Although the brine in the Great Salt Lake and underlying sediments is not a uniform body of water, the relation of the brine to fresher water in adjacent sediments in the study area is similar to the relation of sea water to fresh ground water in coastal areas. (See Todd, 1959, p. 277-296, or Kashef, 1967, p. 235-258, for discussion of the effects of density differences of water in coastal areas.) Because of its lower density, fresh water tends to float above heavier brine, and the brine tends to move beneath the fresh water. The result in the study area is the occurrence of relatively fresh ground water to some depth. Below this depth the fresh water and brine are mixed, and the concentration of dissolved solids generally increases with depth. The maximum concentration of dissolved solids in the ground water is not known, but it is probably much less than the maximum concentration of the Great Salt Lake brine. The highest known concentration of dissolved solids in ground water in the vicinity of the study area is 142,000 mg/l at a depth equivalent to about 3,700 feet (1,128 m) below mean sea level in an oil-test well in the SE¼ sec. 18, T. 11 N., R. 5 W., about 4 miles (6.4 km) west of the study area. Within the study area, the highest known concentration is 122,000 mg/l at a depth equivalent to 726 feet (221 m) above mean sea level in oil-test well (B-10-4)3bb-1. The maximum concentration of the Great Salt Lake brine is about 360,000 mg/l (after Handy and Hahl, 1966, p. 146).

The theoretical minimum thickness of the layer of fresh ground water can be calculated if it is assumed that the maximum density of the brine is that of the Great Salt Lake brine, or about 1.2 grams per cubic centimeter. The minimum depth of fresh ground water below the altitude of the lake (about 4,200 feet or 1,280 m above mean sea level) is about five times the head of the ground water above the lake altitude. However, saline ground water also occurs above this theoretical minimum depth. The shallower saline water derives its high dissolved-solids concentration from sources other than density flow from the area of the Great Salt Lake, such as: (1) saline water that entered the sediments during higher lake stands (particularly the 4,245-4,260 foot or 1,294-1,298 m stand) and which has not been completely flushed out, (2) soluble minerals in the sediments, (3) concentration by evapotranspiration, and (4) upward flow of saline ground water from greater depth.

Development and use

Water from wells and springs is used in the lower Bear River drainage basin mainly for irrigation, public supply, livestock, and domestic purposes. The locations of 346 selected wells and 138 selected springs are shown on plate 4. Data about these wells and springs are given in a separate release (Bjorklund and McGreevy, 1973). The estimated annual use of water for irrigation, public, domestic, and stock supplies are in table 9. Industrial use of water in the basin is negligible.

Wells provide water for irrigation in some parts of the project area, although most of the area is irrigated with surface water. Both drilled and dug wells in the Brigham City-Perry area derive water from alluvial gravels to irrigate orchards and small farms. The water from these wells supplements water from the Ogden-Brigham Canal. Flowing wells on the lower parts of alluvial slopes provide supplemental water for meadowlands used for pasture. Six drilled wells in the Bothwell Pocket provide irrigation water for about 1,600 acres (648 hm^2). A well north of Garland, (B-12-3)15cdc-1, provides water to sprinkle irrigate about 180 acres (73 hm^2). A well north of Portage, (B-15-3)31ccc-1, has been used for irrigation, but it was not used during the period of investigation. Many drilled and dug wells with small yields are used to irrigate lawns and gardens.

Table 9.--Estimated average annual use of water for irrigation, public, domestic, and stock supplies, in acre-feet

	Pumped wells 1970-71	Flowing wells 1970-71	Springs 1970-71	Surface water diversions 1960-71	Totals (rounded)
Irrigation	2,600	80	13,000 [1]	248,000 [2]	264,000
Public supply	1,000	-	8,000	-	9,000
Domestic and stock	200	20	50	-	300
Totals (rounded)	4,000	100	21,000	248,000	273,000

[1] One half the flow of springs that are used mainly for irrigation.
[2] Includes diversions from Bear River, discharge in Samaria Lake and Ogden-Brigham Canals (table 2), and estimated diversions from Box Elder Creek.

Twenty-two communities in the lower Bear River drainage basin have public water-supply systems. Two other communities that use mostly individually owned wells are planning a joint system. All of the systems derive water from ground-water sources, mostly from springs in or near the mountains along the eastern side of the valley. Some of the public-supply systems are urban and some are rural; they annually distribute about 9,000 acre-feet (11 hm^3) of water to about 24,000 people residing in a combined area of about 100 square miles (260 km^2). The public-supply systems also furnish water for livestock and dairy use. The location and approximate area covered by each system and its principal sources of water are shown in figure 9 and detailed information about the systems is given in table 10.

Table 10.--Public water-supply systems and sources of the water

Specific conductance: E, estimated from dissolved-solids concentration; F, measured in field; L, measured in laboratory.

Name	Population (1970)	Approximate area served (square miles)	Number of service connections	Source of water	Location number of principal springs and(or) wells	Approximate amount of water used in 1970 (acre-feet)	Specific conductance of water (micromhos per cm at 25°C)	Chemical analysis in Bjorklund and McGreevy (1973, table 5): Well or spring	Chemical analysis in Bjorklund and McGreevy (1973, table 5): Composite	Remarks
Bear River City	445	2.0				75	390E		X	
				2 springs	(B-10-2)3dca-S1 (Honeyville Spring)					On share basis with Honeyville.
					3dcb-S1 (Honeyville Spring)					Do.
Beaver Dam										
East system	10	.1	3	Spring	(B-12-2)14ddb-S1	2	680F			
Middle system	25	.1	6	Spring	14bac-S1	4	780F			
West system	50	.2	13	Spring	11dcb-S1	9	750F	X		
Bothwell	300	2.8	73			70				
				Spring	(B-12-3)32bcc-S1		620F	X		
				3 wells	(B-11-4)3ccc-1		2,000F	X		
					4ddd-1		2,200E	X		Emergency only.
					(B-12-3)31ccd-1		1,400E	X		
Box Elder Campground	100	.3		Spring	(B-9-1)28adb-S1	100	130F			
Brigham City	14,007	11	3,622			6,130				
				5 springs	(B-9-1)14cdc-S1 (Jensen Spring)		450F	X		
					15cdc-S1 (West Halling Spring)		425L	X		
					23baa-S1 (East Halling Spring)		450L	X		
					23bcb-S1 (Knoll Spring)		450L	X		
					23cda-S1 (Rock Spring)		450L	X		
				5 wells	(B-9-1)14cdd-1		235L	X		
					18cbc-1		445L	X		
					19bcc-1		490L	X		
					27bcd-1		245L	X		
					27bdc-1		220L	X		
Corinne	471	1.0	160	Spring	(B-10-2)25bba-S1 (Yates Canyon Spring)	67	420E	X		
Cutler	15	.1	12			5				
				2 springs	(B-13-2)22dda-S1		1,170L	X		
					27dac-S1		830L	X		Emergency only.
Deweyville	248	7.0				60				
				Spring	(B-11-2)27daa-S1 (Coldwater Spring)		270E	X		On share basis with Elwood.
				Well	8aaa-1		337L	X		
Elwood	294	6.8				70	443		X	
				Spring	(B-11-2)27daa-S1 (Coldwater Spring)		270E	X		On share basis with Deweyville.
				Well	28abc-1					
Garland	1,187	1.0				350	690E		X	
				3 springs	(B-11-2)4cbd-S1 (Garland Spring)					
					(B-12-2)31dda-S3 (Garland Spring)					
					(B-12-3)28ddc-S1 (Garland West Side Spring)		770F			
Honeyville	640	12	276			190	406L		X	
				9 springs	(B-10-2)3cab-S1					
					3cac-S1					
					3cac-S2					
					3cca-S1					
					3cdb-S1					
					3cdb-S2					
					3dbc-S1					
					3dca-S1 (Honeyville Spring)					On share basis with Bear River City.
					3dcb-S1 (Honeyville Spring)					Do.
				Well	(B-10-2)4dda-1					
Mantua	413	3.3				70	150E		X	
				2 springs	(B-9-1)33aac-S1					
					33acd-S1		95F			
North Deweyville	30	.1		Spring	(B-11-2)5abd-S1	6	500F	X		
Perry	909	5.4				200				
				2 wells	(B-8-2)1bbb-1		480E	X		
					(B-9-2)35ddd-1					
Plymouth	203	.5				50	467L		X	
				8 springs	(B-13-2)6abb-S1		500F			
					6abb-S2					
					6cdd-S1					
					7bad-S1					
					7bca-S1					
					(B-14-2)31caa-S1					
					31cdc-S1					
					31dcb-S1					
				Well	(B-13-3)12adb-1		660F			Emergency only.
Portage	144	2.3				40				
				Spring	(B-14-4)10cbd-S1		620E	X		
				Well	(B-14-4)1dad-1		800F	X		
Riverside-North Garland (proposed)	500	9.0		Well	(B-14-3)35ccb-1	100				Estimated use.
Thatcher Water Co.	20	.2		Well	(B-11-4)9dad-1		2,000F	X		

Table 10.--Public water-supply systems and sources of the water - Continued

Name	Population (1970)	Approximate area served (square miles)	Number of service connections	Source of water	Location number of principal springs and(or) wells	Approximate amount of water used in 1970 (acre-feet)	Specific conductance of water (micromhos per cm at 25°C)	Chemical analysis in Bjorklund and McGreevy (1973, table 5): Well or spring	Chemical analysis in Bjorklund and McGreevy (1973, table 5): Composite	Remarks
Tremonton	2,794	2.3				845	1,010L		X	
				5 springs	(B-11-2)4bbc-S1 (Limekiln Spring)		510E	X		
					(B-12-2)31dda-S1 (Tremonton North Spring)		730E	X		
					31dda-S2 (Tremonton Middle Spring)		820F	X		
					31ddd-S1 (Tremonton South Spring)					
					(B-12-3)32acd-S1 (Tremonton West Spring)					
Ukon Water Co.	530	2.6				120	659L		X	
				4 springs	(B-12-2)22baa-S1 (Hansen Spring)					
					22dcd-S1					
					27acd-S1					
					34bad-S1					
Washakie	10	-		Well	(B-14-3)17dca-1	2	1,700F	X		
West Corinne	1,000	37	270	Spring	(B-10-2)25acb-S1 (Baker Spring)	462	438L	X		
Willard (north)	200	.5	50	Spring	Outside of project area	40	271L		X	Estimated data for part of system in project area.
				2 wells	do.					

Extended drought conditions could have an adverse effect on some of the public-water supplies, especially those depending on springs in the mountains. Many of the springs are high above the valley and tap ground-water reservoirs existing at higher elevations. The size of the recharge area and the amount of ground water in storage that is available to a spring generally decreases with increasing altitude. Consequently, the discharge from springs on mountain slopes depends more on recent precipitation and less on carryover of ground-water storage. The most dependable springs used for public supply in the area are the large springs in Mantua Valley that supply Brigham City and the large springs near the Bear River east of Tremonton that supply Tremonton and Garland. Both of these spring areas are topographically low in respect to their surroundings, and apparently both have relatively large recharge areas and ground-water reservoirs.

In the areas not served by public water-supply systems, water for domestic and stock use is generally obtained from privately owned wells and springs.

Ground-water areas

The ground-water areas shown in figure 10 were chosen to indicate areas where ground-water conditions are generally similar, or areas where ground-water conditions can conveniently be discussed together. None of the areas are independent of other areas, and the boundary lines are arbitrary.

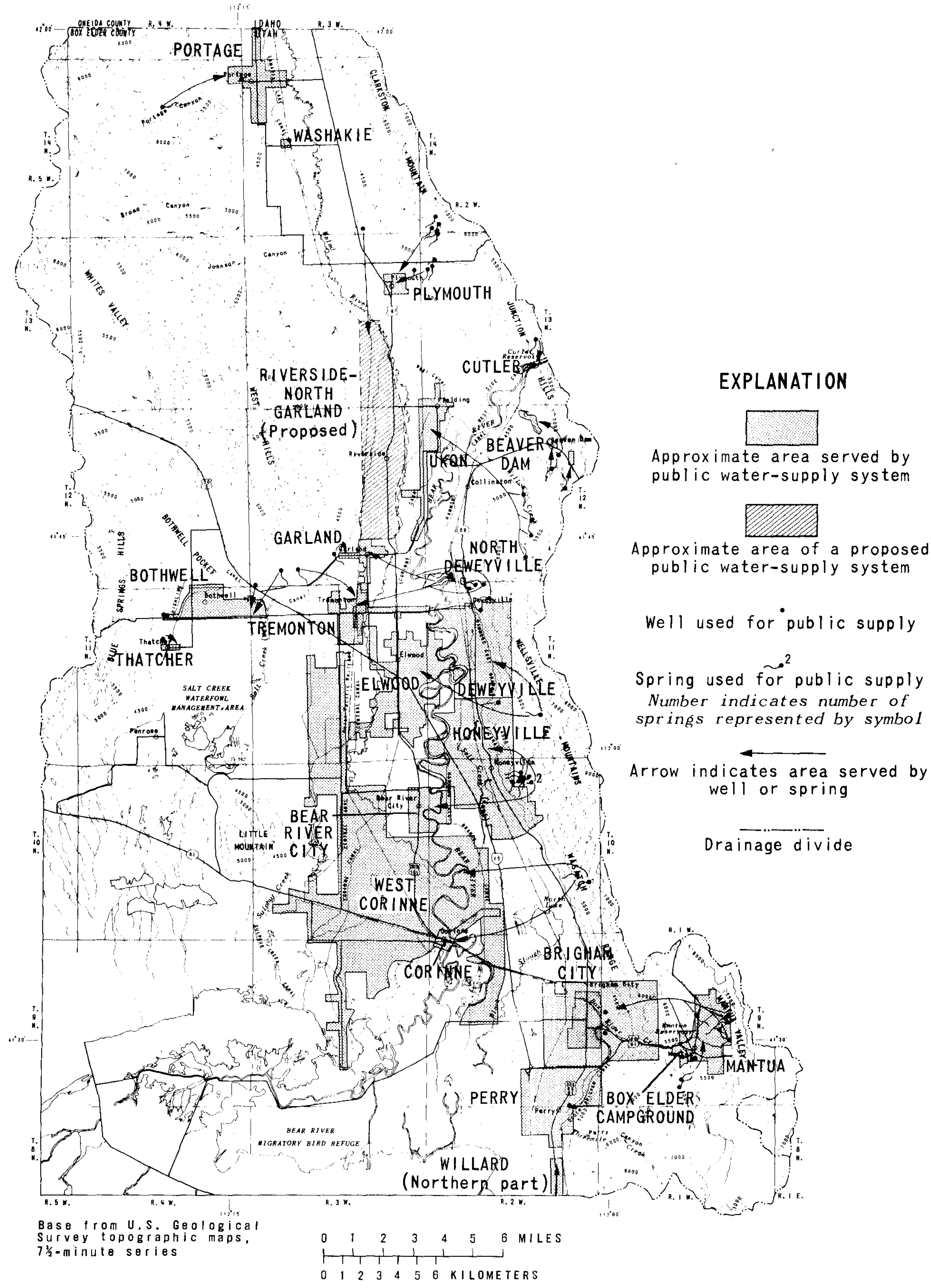

Figure 9.— Areas in the lower Bear River drainage basin served by public water-supply systems and sources of the water.

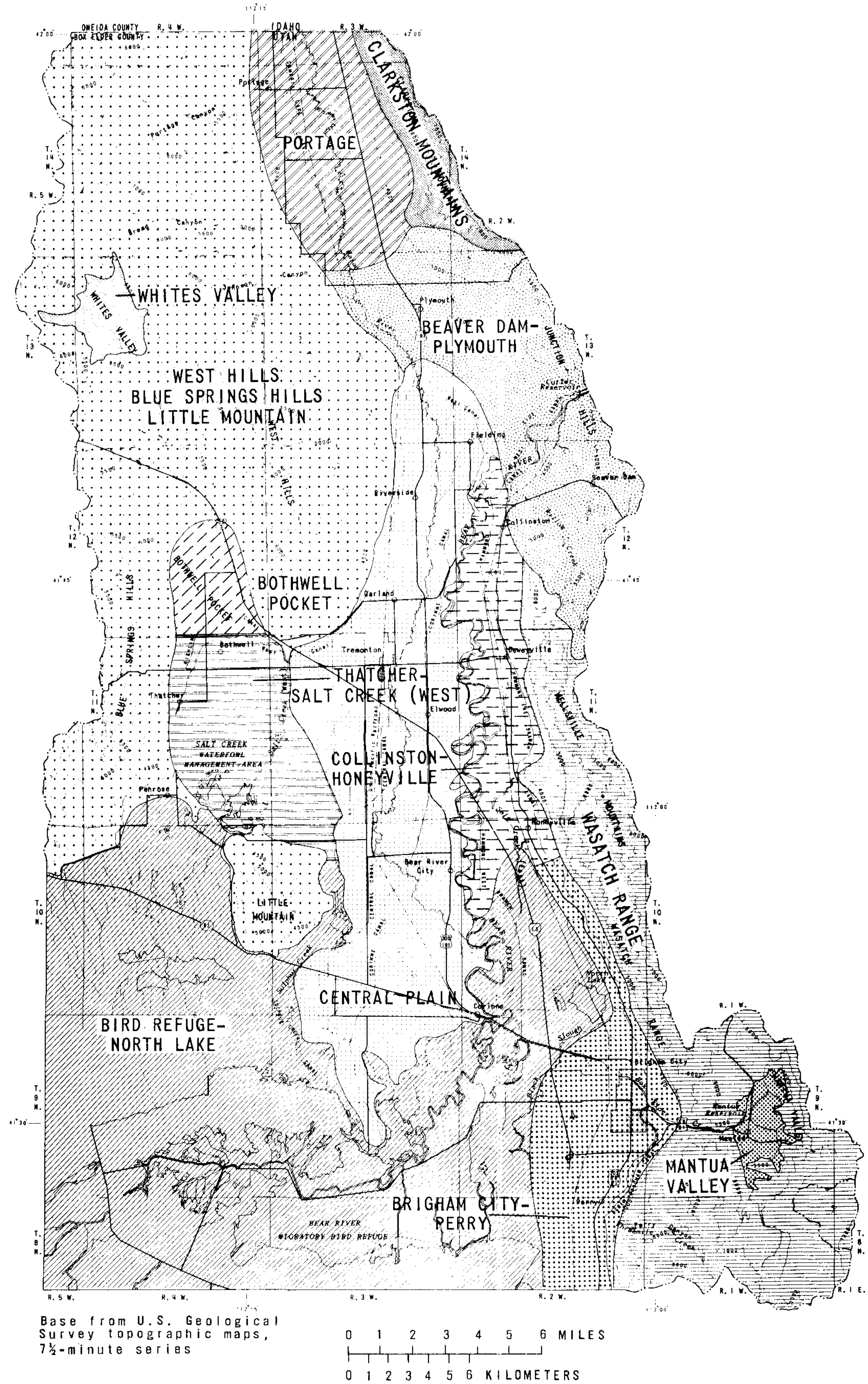

Figure 10.— Ground-water areas in the lower Bear River drainage basin.

For the discussions in this section, yields are defined as: small, less than 15 gal/min (1 l/s); moderate, 15 to 150 gal/min (1 to 10 l/s); and large, more than 150 gal/min (10 l/s).

Brigham City-Perry

The largest amount of ground-water development and the largest potential for future development is in the area from Brigham City southward to the project boundary. Alluvial and delta deposits at and south of Brigham City contain several hundred feet of saturated highly permeable gravel and sand. Dissolved-solids concentration of the ground water is low near the mountains, but the water becomes more mineralized toward the west (pl. 5) and with depth. Salty water, probably only slightly saline, has been reported in a few wells of moderate depth. Both shallow unconfined and deeper confined ground water are tapped by wells. Records since 1935 indicate that ground-water pumpage has caused no decline in water level (fig. 2). Ground water supplements surface water for irrigation, and recharge from irrigation is adequate to compensate for ground-water pumpage. Ground water discharges by evapotranspiration and from springs along the base of the alluvial slopes, and a large part of the spring discharge is used for irrigation. Possible effects on springs of increased pumpage by new wells should be considered in plans for future development.

North of Brigham City, ground water occurs in a narrow band of alluvial fans along the mountains. Possibilites for additional development are limited to wells of small to moderate discharge. Quality varies in a short distance from fresh water high on the alluvial fans to slightly saline water near their bases. Northward-flowing currents in ancient lakes evidently stripped most of the unconsolidated deposits from along the mountains from north of Brigham City to near Honeyville, carried them northward, and deposited them in the Collinston-Honeyville area. This is indicated by large accumulations of gravel on the north side of mountain spurs and outliers.

Mantua Valley

Unconsolidated valley-fill deposits in Mantua Valley are as much as 500 feet (152 m) thick and consist largely of saturated sand and gravel. Paleozoic rocks, primarily limestone, underlie the valley fill and bound it on the north, east, and south: Cambrian and Precambrian rocks, primarily quartzite, phyllite and tillite(?), bound the valley fill on the west. Large springs discharge from the undifferentiated Cambrian to Pennsylvanian sedimentary rocks around the margins of the valley and large-discharge wells tap the valley fill. Dissolved-solids concentration of the ground water is low, and much of the water is used for public supply for Brigham City. Mantua Valley is a discharge area for a large part of the mountains east of Brigham City; included is drainage from large sinkholes southeast of Mantua Valley. The Cambrian and Precambrian rocks west of the valley have generally low permeability and restrict westward drainage of ground water. Instead, the ground water discharges in Mantua Valley and flows out of the valley in Box Elder Creek. Additional development by large-discharge wells is possible, but the effects on the flow of the springs and on Box Elder Creek should be considered.

Clarkston Mountain-Wasatch Range

In most of the Clarkston Mountain-Wasatch Range area, Paleozoic and Precambrian rocks crop out or are only thinly covered by unconsolidated Quaternary deposits. This is primarily a recharge area where precipitation is high. Springs discharge small to moderate amounts of water that has a low concentration of dissolved solids. Many public supplies in the lower Bear River drainage basin are derived from these springs.

Collinston-Honeyville

In the Collinston-Honeyville area, water-bearing sand, gravel, and conglomerate occur in lake terraces and bars and in alluvial fans and cones. The materials, which are mostly derived from the Wellsville Mountains, thicken and become generally finer grained toward the west. Large amounts of calcium carbonate were deposited from ancient lakes as tufa and as cement in conglomerate. Several springs have large yields from gravel and conglomerate, but most wells and springs have small to moderate yields. Additional development of wells with small to moderate yields is possible in most of the area, and wells with high yields are possible in a few places.

Ground-water quality varies from fresh to briny. The ground water is generally fresh in the north and slightly saline in the south (pl. 5). Crystal Hot Spring, (B-11-2)29dad-S1, yields hot brine and well (B-11-2)31bab-1, about 1½ miles (2.4 km) to the west, reportedly yields brine. Crystal Hot Spring and Crystal Cold Spring, (B-11-2)29dac-S1, which yields slightly saline water, occur near each other at the junction of a major north-trending fault zone and a relatively minor northeast-trending fault that cuts the Wellsville Mountains block. Most of the water from the hot springs is from considerable depth, and the water presumably rises through a permeable zone along the major fault zone. Hot brine rising along the fault zone probably has contaminated some adjacent sediments and is probably the source of the brine at well (B-11-2)31bab-1. Most of the water from Crystal Cold Spring is from the Wellsville Mountains. The water moves to the spring through a zone of high permeability along the northeast-trending fault, either in the fault zone itself or in permeable materials along the fault.

Beaver Dam-Plymouth

In the Beaver Dam-Plymouth area, the Salt Lake Formation generally underlies unconsolidated Quaternary deposits at depths near the land surface to about 100 feet (30.5 m) and both units contain ground water. Most of the Quaternary materials are reworked from the Salt Lake Formation and most are fine-grained sand and silt, although some gravel is present. A huge slide area north of the Bear River (pl. 1) contains much conglomerate from the Salt Lake Formation. Small to moderate yields from wells and springs are derived from the coarser Quaternary materials and from conglomerate and sandstone of the Salt Lake Formation. Additional development of wells with discharge as much as 50 gal/min (3 l/s) is possible, but development of wells with large yields is not likely. The ground water is generally fresh except for hot saline springs along the Malad River in sec. 23, T. 13 N., R. 3 W., and warm saline springs in the Bear River channel near Cutler Reservoir (pl. 5).

Portage

Gravity data indicate that Quaternary valley fill in the Portage area probably is several hundred feet thick. The valley fill contains a large amount of saturated sand and gravel. Most of the ground water is fresh; however, the Malad River, which flows through the area, is moderately saline at low flow. Most of the low flow is derived from Woodruff Warm Springs, about 4 miles (6.4 km) north of the State line in Idaho (McGreevy, 1972). The potentiometric surface of the ground water is above the level of the Malad River and the area near the river is a ground-water discharge area (pl. 2), thus ground-water quality is generally not affected by the river quality. Possiblities for development of large discharge wells in the Portage area are good, but if the area is developed enough to lower ground-water levels below the river surface, recharge from the river will be induced, and ground-water quality will deteriorate.

The potentiometric surface is essentially flat (pl. 2) in most of the Portage area, and water levels fluctuate very little (pl. 4). The potentiometric surface slopes westward from Clarkston Mountain, which indicates recharge from the mountain. The transmissivity decreases sharply at the south end of the area where the valley fill becomes thin and where the Salt Lake Formation underlies the valley fill. Because southward movement of ground water is restricted by the low transmissivity in that direction, ground water may move to the southwest into the Oquirrh Formation, which may have a higher transmissivity than that of the valley fill. Data are sparse, however, and the relation between ground water in the valley fill and in the Oquirrh Formation is not clear.

Central plain

The shallow unconfined ground-water system overlies the principal ground-water system throughout the central-plain area. Water-bearing materials in the shallow unconfined system are generally less than 50 feet (15 m) thick and are composed mostly of sand and silt. The water table in the central-plain area is generally less than 20 feet (6 m) below the land surface (pl. 3). The ground water is mostly fresh north of Garland and slightly saline south of Garland (pl. 5). Recharge is mostly from irrigation, and water-level fluctuations depend mostly on irrigation practices.

Wells are generally used for stock or for lawn and garden irrigation. Small to moderate yields are possible from the shallow unconfined ground-water system in most of the central-plain area.

Unconsolidated deposits of clay, silt, sand, and gravel that underlie the shallow sand and silt in the central-plain area are part of the principal ground-water system. The maximum thickness of unconsolidated materials is probably more than 1,000 feet (305 m). Generally, the water in the known parts of the principal ground-water system is fresh to slightly saline north of Tremonton and slightly saline to very saline south of Tremonton (pl. 5). North of Tremonton the principal ground-water system is recharged by downward leakage from the shallow unconfined system, but south of Tremonton the shallow system is recharged by upward leakage from the principal system. The water-level map (pl. 2) suggests that some water moves westward from the unconsolidated deposits in the northern part of the central-plain area into the Oquirrh Formation in the West Hills. Moderate yields are possible from the principal ground-water system in most of the central-plain area, but development possibilities are generally poor because of the inferior water quality.

Bird refuge-North Lake

Quaternary valley-fill deposits in the bird refuge-North Lake area are mostly fine sand, silt, and clay with some carbonaceous materials. The deposits are almost completely saturated with water. Maximum thickness of the Quaternary materials is probably more than 1,000 feet (305 m). The Salt Lake Formation underlies the valley fill in parts of the area. Paleozoic rocks probably underlie the valley fill at moderate depth in some places south of Little Mountain and near the Blue Springs Hills, but the maximum depth to Paleozoic rocks is probably near 8,000 feet (2,438 m). (See section, pl. 1.) Some wells in the valley fill yield gas (probably methane). Ground water in the area is generally saline (pl. 5) and some is briny; the water is generally warm or hot. The potentiometric surface of the ground water is above the land surface, and ground-water discharge occurs throughout the area. Most of the discharge is evapotranspiration from wetlands and open-water surfaces (pl. 2). Although wells of small to moderate yields would be possible in much of the area, development possibilities are poor because of the generally poor chemical quality and high temperature of the ground water.

Bothwell Pocket

Highly fractured limestone and sandstone of the Oquirrh Formation and sand, gravel, and conglomerate in the Quaternary valley fill provide large yields of fresh water to wells in the Bothwell Pocket. The valley fill varies greatly in thickness, and the maximum thickness is more than 668 feet (204 m). The valley-fill deposits are mostly sand and gravel, but they also contain silt, clay, tufa, and partly cemented conglomerate. Most irrigation wells tap both the valley fill and the Oquirrh Formation. The altitudes of water levels in most wells in the

Bothwell Pocket differ by less than 1.6 feet (0.5 m); this and all other data indicate a generally high transmissivity. (See table 5.)

Bothwell Pocket may be an area of potential overdevelopment of ground water where excessive pumping could cause water levels to decline and water quality to deteriorate. To date (1972) water levels have changed very little (fig. 5); however, the increase in pumpage during the past few years has been rapid and the ultimate magnitude of the total effect on the ground-water reservoir is uncertain. The small amount of land available for irrigation may place a natural limit on development that is sufficient to prevent overdevelopment, but periodic water-level measurements should be continued. A large general decline in water level of 20 to 30 feet (6-9 m) could reverse the gradient of the potentiometric surface sufficiently to bring saline water northward into the Bothwell Pocket area; however, declines of this magnitude are unlikely because of the high transmissivity and an apparently large reservoir. A more likely source of saline water is from depth. Salinity is believed to increase with depth in the area, and when the potentiometric surface is drawn down in the pumping area, some of the water moving into the drawdown area is from below. In this way, large drawdowns that occur during the pumping season could cause saline water from depth to rise and to enter the wells. To date (1972), significant changes in chemical quality have not been detected, but continued monitoring is advisable.

Thatcher-Salt Creek (west)

In the Thatcher-Salt Creek (west) area, aquifers in the unconsolidated Quaternary valley fill consist mostly of moderately permeable sand and gravel on the north and west and of less permeable sand, silt, and clay toward the south and east. Maximum thickness of the valley fill is probably more than 500 feet (152 m). The ground water is fresh to slightly saline in most of the area (pl. 5), but in the south and southeast parts some of the water is probably moderately saline. Moderate yields to wells are possible in most of the area, and large yields probably are available in the northern part of the area.

West Hills-Blue Springs Hills-Little Mountain

West Hills and Blue Springs Hills are composed mostly of Oquirrh Formation, and Little Mountain is composed mostly of older Paleozoic rocks. Alluvial and colluvial deposits, which have a maximum thickness of probably less than 100 feet (31 m), occur in stream valleys and on slopes. Lacustrine deposits, which contain a large amount of gravel and conglomerate and have a maximum thickness of several hundred feet, cover most of the hillsides below the Bonneville level (pl. 1). Alluvial, colluvial, and lacustrine deposits contain perched fresh water in many places, particularly along the south and east margins of the West Hills. Small to moderate yields are available from the perched ground-water systems.

Limestone, dolomite, sandstone, shale, and quartzite that are older than the Oquirrh Formation occur north of a major fault in the north part of the West Hills (pl. 1). Vegetation changes across the fault indicate a change in hydrologic character of the rocks. Juniper north of the fault suggests retention of water near the surface; the lack of juniper and other trees south of the fault suggests that the water from precipitation moves more quickly to a deeper level. This change in vegetation implies a higher general permeability and a greater recharge from precipitation in the area of the Oquirrh Formation than in the area of older rocks. A similar conclusion is drawn from the general lack of springs and of well-defined drainage channels in most of the area of the Oquirrh Formation.

The Oquirrh Formation is mostly limestone and sandstone that is highly fractured and permeable in most of the West Hills and Blue Springs Hills. The regional water level in the formation is deep, but possibilities are good for development of large yields of fresh to slightly saline water in a narrow band along the margins of the West Hills where the depth to water is less than about 300 feet (91 m). Possibilities for development of large yields are also good along the margins of the Blue Springs Hills, but in the southern part of the Blue Springs Hills, the water probably is slightly to moderately saline. Shallow wells near the south end of the Blue Springs Hills and on the flanks of Little Mountain may yield small to moderate amounts of fresh to slightly saline water in some locations where ground water from local recharge does not mix thoroughly with the more saline water in the reservoir and "floats" above it, as at well (B-10-4)5bbc-1.

Springs occur along the south end of the West Hills, Blue Springs Hills, and Little Mountain. Salt Creek Springs, (B-11-3)6dcc-S1, discharge from the Oquirrh Formation at the south end of the West Hills. These springs are a major drain for the West Hills and yield warm, slightly saline water. Valley-fill materials south of the Blue Springs Hills and Little Mountain have lower permeability than the material in the hills and retard the movement of ground water; consequently, many springs discharge along the south end of the hills. The elevation of most of the springs is about the same, about 4,250 feet (1,295 m) above mean sea level. Water from these springs is slightly saline to briny and is mostly warm to hot.

Whites Valley

Unconsolidated Quaternary deposits in Whites Valley are probably less than 100 feet (31 m) thick and overlie the Oquirrh Formation. Fresh ground water is perched in the unconsolidated deposits and provides small to moderate yields to a few wells. The regional water level is probably several hundred feet below the land surface in the underlying Oquirrh Formation.

WATER-BUDGET ANALYSES

The quantity of water entering the lower Bear River drainage basin is equal to the quantity of water leaving the basin plus or minus the change in storage within the basin. Water enters the basin by streamflow, ground-water flow, and precipitation; it leaves the basin by streamflow, ground-water flow, and by evapotranspiration. As there were no practicable means of directly determining the outflow from the lagoons at the downstream end of the project area, a principal water-budget analysis area was selected with the downstream end mostly at State Highway 83, where streamflow could be determined. The principal analysis area comprises 68 percent of the project area; the analysis is shown in table 11. Areas of farmland, rangeland, wetland, and open water (where evapotranspiration occurs), water-budget analysis areas, and the 1931-60 normal annual precipitation are shown in figure 11.

Table 11.--Water-budget analysis of area north of State Highway 83

	Thousands of acre-feet per year	
Inflow		
Streams (table 2)		
Bear River	899	
West Side Canal	194	
Hammond Canal	40	
Malad River	36	
Samaria Lake Canal	2	
Total streams (rounded)		1,200
Precipitation[1]		460
Ground-water inflow		
Southern boundary[2]	12	
Other boundaries[3]	27	
Total ground-water inflow (rounded)		40
Total inflow (rounded)		1,700
Outflow		
Streams crossing State Highway 83 (rounded) (table 3)		1,200
Evapotranspiration[4]		
Irrigated farmland[5]	188	
Nonirrigated farmland[6]	73	
Rangeland and mountains[7]	156	
Wetland (mudflats and phreatophyte areas)[8]	72	
Open water[9]	15	
Total evapotranspiration (rounded)		500
Ground-water outflow[10]		3
Total outflow (rounded)		1,700
Change in surface-water storage	Negligible	
Change in ground-water storage	Negligible	

[1] The average annual precipitation on the area was estimated from the 1931-60 normal annual precipitation map of Utah (U.S. Weather Bureau, 1963). (See fig. 11.)

[2] Ground water flows northward across the budget boundary near Brigham City between Black Slough and the Wasatch Range. Estimated subsurface flow is based on estimated ground-water discharge north of the boundary that is attributable to flow across the boundary. This value agrees in magnitude with a rough estimate of the flow based on assumed transmissivity and gradient along the boundary.

[3] See discussion of subsurface inflow in section on source and recharge.

[4] Evapotranspiration values for various land classifications were developed with the assistance of the Utah Water Research Laboratory, Utah State University, on the basis of a modified Blaney-Criddle formula (Hill and others, 1970, p. 17-19).

[5] Average annual evapotranspiration = 28.15 inches.

[6] Average annual evapotranspiration at altitudes of 4,000-5,000 feet = 13.76 inches and at altitudes of 5,000-6,000 feet = 15.31 inches.

[7] Average annual evapotranspiration at altitudes of 4,000-5,000 feet = 13.13 inches; 5,000-6,000 = 13.59 inches; 6,000-7,000 = 13.72 inches; 7,000-8,000 = 12.43 inches; 8,000-9,000 = 13.36 inches; and 9,000-10,000 = 10.24 inches.

[8] Average annual evapotranspiration = 30.24 inches.

[9] Average annual evapotranspiration = 48.77 inches.

[10] Ground water flows southward across State Highway 83 west of Black Slough. Estimated average transmissivity for the valley-fill materials is 3,000 $ft^3/d/ft$, the estimated average gradients is 3 ft/mi, and the length of the underflow section is about 17 miles. Using these values, flow through valley-fill materials is about 1,300 acre-feet per year. Paleozoic rocks underlying the boundary west of Black Slough have a higher transmissivity than valley-fill materials, but the gradient is much lower. Flow though the Paleozoic rocks is assumed to be about the same amount as through the valley fill.

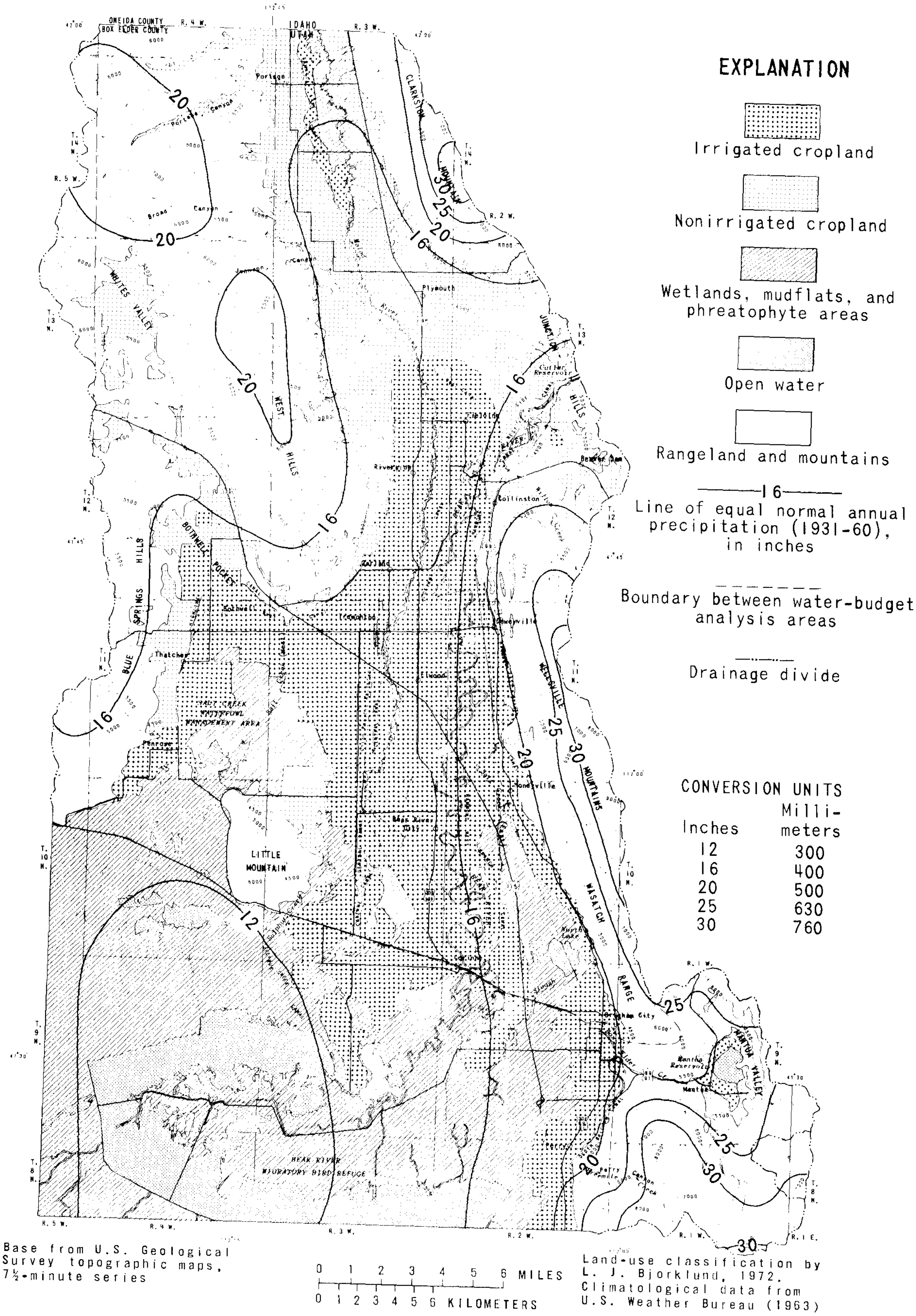

Figure 11.– Map showing land use, wetlands, open water, water-budget analysis areas, and 1931-60 normal annual precipitation.

A supplementary water-budget analysis of the area south of State Highway 83 was made to estimate the quantity of water moving out of the project area. (See table 12.) Surface- and ground-water outflow items for the analysis area north of Highway 83 were used as part of the inflow items. The average evapotranspiration rates developed for various land uses north of Highway 83 were used because conditions were considered to be similar. The analysis indicates that an average of about 970,000 acre-feet (1,200 hm^3) of surface water leaves the project area annually.

Table 12.--Water-budget analysis of area south of State Highway 83

	Thousands of acre-feet per year	
Inflow		
Streams		
Streams crossing State Highway 83 (table 3)	1,160	
Ogden-Brigham Canal (table 2)	9	
Total streams (rounded)		1,200
Precipitation (rounded)[1]		200
Ground-water inflow[2]		3
Total inflow		1,400
Outflow		
Evapotranspiration		
Irrigated farmland[3]	38	
Nonirrigated farmland[4]	2	
Rangeland and mountains[5]	34	
Wetland (mudflats and phreatophyte areas)[6]	193	
Open water[7]	123	
Total evapotranspiration		390
Ground-water outflow		
Northward across the budget boundary[8]	12	
Southward toward Great Salt Lake[9]	1	
Total ground-water outflow		13
Streams (Total inflow less evapotranspiration and ground-water outflow) (fig. 3) (rounded)[10]		970
Total outflow (rounded)		1,400
Change in surface-water storage	Negligible	
Change in ground-water storage	Negligible	

[1]The average annual precipitation on the area was estimated from the 1931-60 normal annual precipitation map of Utah (U.S. Weather Bureau, 1963). (See fig. 11.)

[2]Ground water flows southward across State Highway 83 west of Black Slough. Estimated average transmissivity for the valley-fill materials is 3,000 $ft^3/d/ft$, the estimated average gradient is 3 ft/mi, and the length of the underflow section is about 17 miles. Using these values, flow through the valley-fill materials is about 1,300 acre-feet per year. Paleozoic rocks underlying the boundary west of Black Slough have a higher transmissivity than valley-fill materials, but the gradient is much lower. Flow through the Paleozoic rocks is assumed to be about the same amount as through the valley fill.

[3]Average annual evapotranspiration = 28.15 inches.

[4]Average annual evapotranspiration at altitudes of 4,000-5,000 feet = 13.76 inches and at altitudes of 5,000-6,000 feet = 15.31 inches.

[5]Average annual evapotranspiration at altitudes of 4,000-5,000 feet = 13.13 inches; 5,000-6,000 = 13.59 inches; 6,000-7,000 = 13.72 inches; 7,000-8,000 = 12.43 inches; 8,000-9,000 = 13.36 inches; and 9,000-10,000 = 10.24 inches.

[6]Average annual evapotranspiration = 30.24 inches.

[7]Average annual evapotranspiration = 48.77 inches.

[8]Ground water flows northward across the budget boundary near Brigham City between Black Slough and the Wasatch Range. Estimated subsurface flow is based on estimated ground-water discharge north of the boundary that is attributable to flow across the boundary. This value agrees in magnitude with a rough estimate of the flow based on assumed transmissivity and gradient along the boundary.

[9]See section on subsurface outflow.

[10]Outflow from lagoons in Bear River Migratory Bird Refuge.

SUMMARY AND CONCLUSIONS

The lower Bear River drainage basin is hydrologically complex. It is an area of transition from cold, fresh ground water at the upstream end and at the higher altitudes to generally warm, very saline ground water at the downstream end near the Great Salt Lake. A wide range of hydrologic conditions exists that differ both areally and vertically.

An average amount of about 1,200,000 acre-feet (1,480 hm^3) of water entered the basin annually in streams and canals during 1960-71.

The Bear and Malad Rivers gain in flow through the basin. Most of the water consumed in the basin is by evapotranspiration. It is estimated that about 970,000 acre-feet (1,200 hm^3) of surface water leaves the basin annually.

Ground water occurs in the valley fill and in the bedrock under both confined and unconfined conditions. Perched ground water occurs locally. Total recharge to, and discharge from, the ground-water reservoir is estimated to be about 315,000 acre-feet (389 hm^3) per year. Ground-water levels have changed little on a long-term basis since records began in the mid-1930's. The chemical quality of ground water ranges from excellent for public, domestic, irrigation, and stock supply to water unfit for any of the mentioned uses because of salinity.

Surface-water sources supply most of the water used for irrigation. Ground water supplies almost all the irrigation needs in the Bothwell Pocket and supplements the surface-water supply in the Brigham City-Perry area. Shallow wells in the central-plain area supply water for many lawns and gardens. All the public-water supplies are from wells and springs. Some of the distribution systems cover large rural areas because ground water in much of the area is not satisfactory for public or domestic use.

A water-budget analysis of the area north of State Highway 83 indicates that during 1960-71 about 1,700,000 acre-feet (2,100 hm^3) of water annually entered the area by streamflow, ground-water flow, and precipitation, and left the area by streamflow, ground-water flow, and evapotranspiration. A supplementary water-budget analysis of the area south of State Highway 83 indicates that about 1,400,000 acre-feet (1,730 hm^3) of water per year entered and left that area during the same period.

Moderate additional ground-water development is feasible from the marginal deposits along the west side of the Wasatch Range near Brigham City and Perry and in the Portage area, and from the Oquirrh Formation along the east side of West Hills. Additional development is feasible also from the shallow materials of the central-plain area where water usable for irrigation discharges into drains and springs along the Bear and Malad Rivers.

Continued monitoring of water levels and chemical quality of the water is advisable, particularly in the Bothwell Pocket and Portage areas, where lowering of water levels might induce inflow of saline water.

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APPENDIX

Well- and spring-numbering system

The system of numbering wells and springs in Utah is based on the cadastral land-survey system of the U.S. Government and is illustrated in figure 12. The number, in addition to designating the well or spring, describes its position in the land net. The State is divided into four quadrants by the Salt Lake base line and meridian, and these quadrants are designated as: A, northeast; B, northwest; C, southwest; and D, southeast. Numbers designating the township and range (in that order) follow the quadrant letter, and all three are enclosed in parentheses. The number after the parentheses indicates the section; it is followed by letters indicating the quarter section, the quarter-quarter section, and the quarter-quarter-quarter section (in that order). The letters indicate: a, the northeast; b, the northwest; c, the southwest; and d, the southeast quarters of each subdivision. The number after the letters is the serial number of the well or spring within the indicated tract; the letter "S" preceding the serial number denotes a spring. Thus, well (B-11-3)17caa-1 is in the NE¼NE¼SW¼, sec. 17, T. 11 N., R. 3 W., and is the first well constructed or visited in that tract. (See fig. 12.) Similarly, (B-13-3)9aac-S1 designates a spring in the SW¼NE¼NE¼ sec. 9, T. 13 N., R. 3 W.

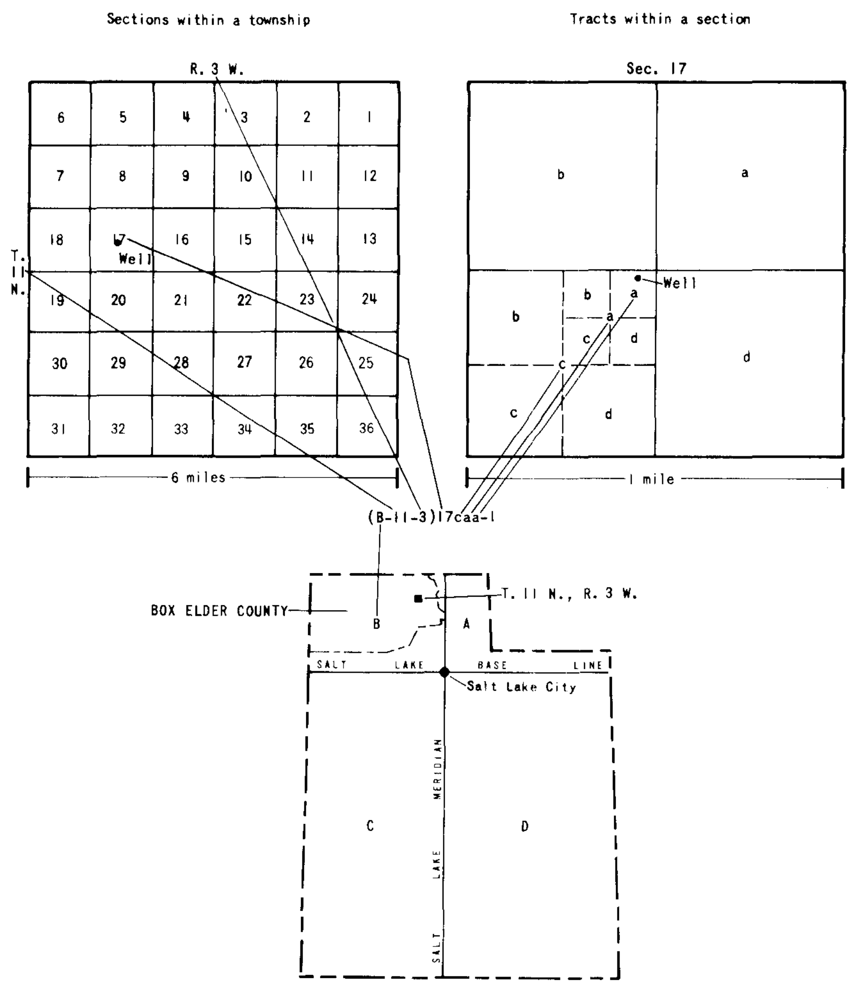

Figure 12.– Well- and spring-numbering system.

Use of metric units

Most numbers are given in this report in English units followed by metric units in parentheses. The conversion factors used are:

English Units (Multiply)	Abbreviation	(by)	Metric Units (to obtain)	Abbreviation
Acres	acres	0.4047	Square hectometers	hm^2
Acre-feet	acre-ft	.0012335	Cubic hectometers	hm^3
Cubic-feet	ft^3	.02832	Cubic meters	m^3
Feet	ft	.3048	Meters	m
Gallons	gal	3.7854	Liters	l
Inches	in	25.4	Millimeters	mm
Miles	mi	1.6093	Kilometers	km
Square miles	mi^2	2.59	Square kilometers	km^2
Tons	ton	.90718	Metric tons	t

Chemical concentration and water temperature are given in metric units. Chemical concentration is given in milligrams per liter (mg/l). For concentrations less than 7,000 mg/l, the numerical value is about the same as for concentrations in the English unit, parts per million.

Chemical concentration in terms of ionic interacting values is given in milliequivalents per liter (meq/l). Milliequivalents per liter is numerically equal to the English unit, equivalents per million.

Water temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit by the following equation: $°F = 1.8(°C) + 32$ or by use of the following table:

Temperatures in °C are rounded to nearest 0.5 degree. Underscored temperatures are exact equivalents. To convert from °F to °C where two lines have the same value for °F, use the line marked with an asterisk (*) to obtain equivalent °C.

°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F
-20.0	-4	-10.0	14	0.0	32	10.0	50	20.0	68	30.0	86	40.0	104
-19.5	-3	-9.5	15	+0.5	33	10.5	51	20.5	69	30.5	87	40.5	105
-19.0	-2	-9.0	16	1.0	34	11.0	52	21.0	70	31.0	88	41.0	106
-18.5	-1	-8.5	17	1.5	35	11.5	53	21.5	71	31.5	89	41.5	107
-18.0 *	0	-8.0 *	18	2.0 *	36	12.0 *	54	22.0 *	72	32.0 *	90	42.0 *	108
-17.5	0	-7.5	18	2.5	36	12.5	54	22.5	72	32.5	90	42.5	108
-17.0	1	-7.0	19	3.0	37	13.0	55	23.0	73	33.0	91	43.0	109
-16.5	2	-6.5	20	3.5	38	13.5	56	23.5	74	33.5	92	43.5	110
-16.0	3	-6.0	21	4.0	39	14.0	57	24.0	75	34.0	93	44.0	111
-15.5	4	-5.5	22	4.5	40	14.5	58	24.5	76	34.5	94	44.5	112
-15.0	5	-5.0	23	5.0	41	15.0	59	25.0	77	35.0	95	45.0	113
-14.5	6	-4.5	24	5.5	42	15.5	60	25.5	78	35.5	96	45.5	114
-14.0	7	-4.0	25	6.0	43	16.0	61	26.0	79	36.0	97	46.0	115
-13.5	8	-3.5	26	6.5	44	16.5	62	26.5	80	36.5	98	46.5	116
-13.0	9	-3.0	27	7.0	45	17.0	63	27.0	81	37.0	99	47.0	117
-12.5	10	-2.5	28	7.5	46	17.5	64	27.5	82	37.5	100	47.5	118
-12.0 *	10	-2.0 *	28	8.0 *	46	18.0 *	64	28.0 *	82	38.0 *	100	48.0 *	118
-11.5	11	-1.5	29	8.5	47	18.5	65	28.5	83	38.5	101	48.5	119
-11.0	12	-1.0	30	9.0	48	19.0	66	29.0	84	39.0	102	49.0	120
-10.5	13	-0.5	31	9.5	49	19.5	67	29.5	85	39.5	103	49.5	121

Terms describing aquifer characteristics

The capacity of an aquifer to transmit and store water is described by the transmissivity and the storage coefficient of the aquifer. The transmissivity is equal to the product of the aquifer thickness and the average hydraulic conductivity.

Transmissivity (T) is the rate at which water of the prevailing viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient. The units for T are cubic feet per day per foot which reduces to ft^2/d. The term transmissivity replaces the term coefficient of transmissibility, which was formerly used by the U.S. Geological Survey and which was reported in units of gallons per day per foot. To convert a value for coefficient of transmissibility to the equivalent value of transmissivity, divide by 7.48; to convert from transmissivity to coefficient of transmissibility, multiply by 7.48.

The *hydraulic conductivity (K)* of a water-bearing material is the volume of water of the prevailing viscosity that will move through a unit cross section of the material in unit time under a unit hydraulic gradient. The units for K are cubic feet per day per square foot which reduces to ft/d. The term hydraulic conductivity replaces the term field coefficient of permeability, which was formerly used by the U.S. Geological Survey and which was reported in units of gallons per day per square foot. To convert a value for field coefficient of permeability to the equivalent value of hydraulic conductivity, divide by 7.48; to convert from hydraulic conductivity to field coefficient of permeability, multiply by 7.48.

The *storage coefficient (S)* of an aquifer is the volume of water it releases from or takes into storage per unit surface area of the aquifer per unit change in head. S is a dimensionless number. Under confined conditions, S is typically small, generally between 0.00001 and 0.001. Under unconfined conditions, S is much larger, typically from 0.05 to 0.30.

Terms describing thermal springs

A *thermal spring* is one whose temperature is appreciably (about 5.5°C, 10°F) above the mean annual air temperature. A *hot spring* is a thermal spring with a temperature above that of the human body, thus a spring with a temperature of 37.0°C (99°F) or above would be *hot*. A *warm spring* is a thermal spring with a temperature below that of a hot spring. (After Meinzer, 1923, p. 54-55.)

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