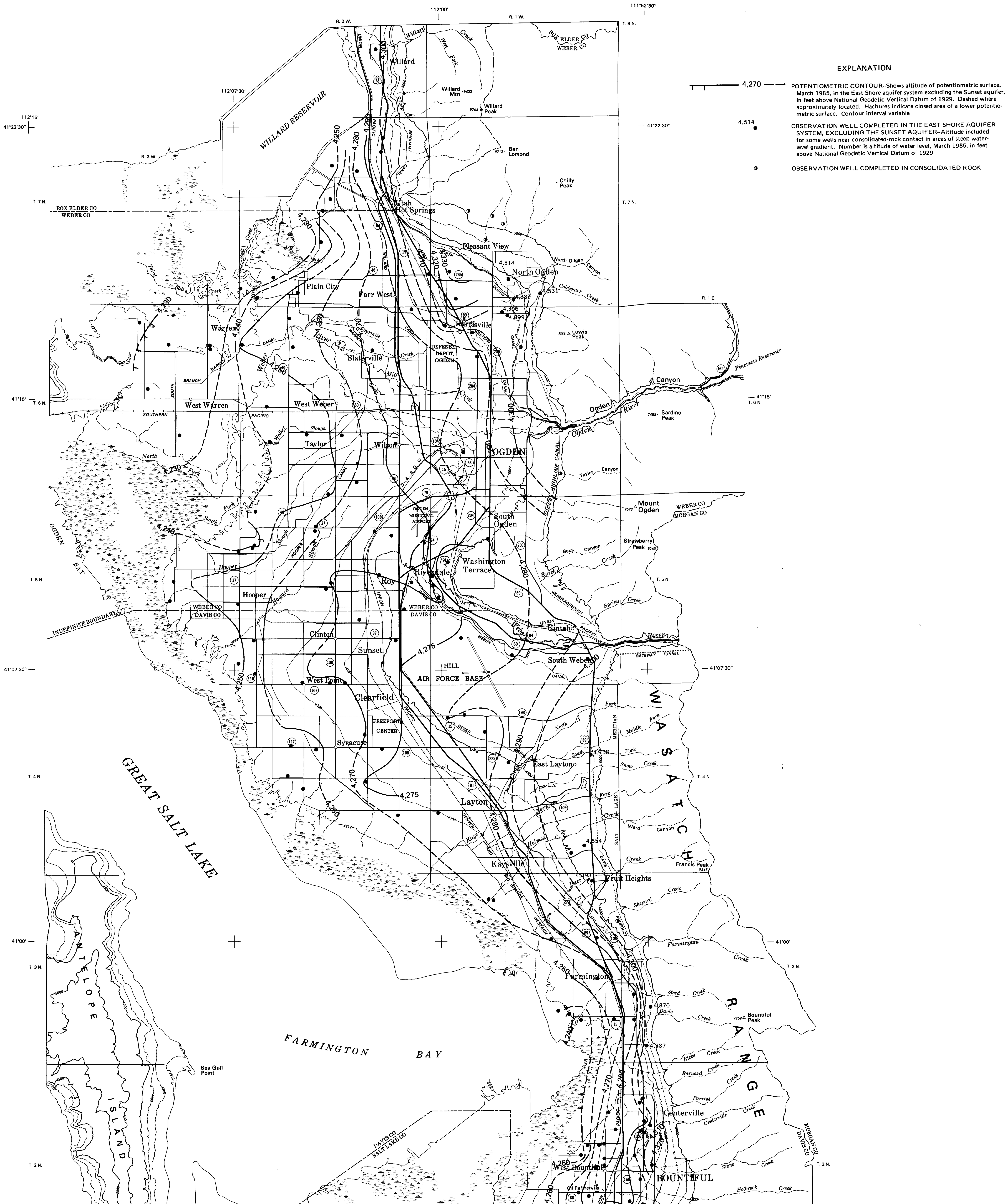
UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Prepared in cooperation with the
STATE OF UTAH
DEPARTMENT OF NATURAL RESOURCES

TECHNICAL PUBLICATION NO. 93
1990 PLATE 1



POTENTIOMETRIC SURFACE OF THE EAST SHORE AQUIFER SYSTEM, EXCLUDING THE SUNSET AQUIFER, MARCH 1985

STATE OF UTAH
DEPARTMENT OF NATURAL RESOURCES

Technical Publication No. 93

GROUND-WATER RESOURCES AND SIMULATED EFFECTS OF WITHDRAWALS IN THE EAST SHORE AREA OF GREAT SALT LAKE, UTAH

By

David W. Clark, Cynthia L. Appel,

Patrick M. Lambert, and Robert L. Puryear

Prepared by the
United States Geological Survey
in cooperation with the
Utah Department of Natural Resources
Division of Water Rights

1990

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CONVERSION FACTORS AND RELATED INFORMATION

For readers who prefer to use metric units, conversion factors for inch-pound units used in this report are listed below:

Multiply inch-pound units	By	To obtain metric units
acre	0.4047	hectare
	4,047	square meter
acre-foot	0.001233	cubic hectometer
cubic foot per second	0.02832	cubic meter per second
cubic foot per day	0.02832	cubic meter per day
cubic mile	4.168	cubic kilometer
foot	0.3048	meter
foot per acre	0.7532	meter per hectare
foot per day	0.3048	meter per day
foot per mile	0.1894	meter per kilometer
foot squared per day	0.0929	meter squared per day
gallon per minute	0.06309	liter per second
inch	25.40	millimeter
	2.540	centimeter
mile	1.609	kilometer
square mile	2.590	square kilometer

Chemical concentrations and water temperatures are given in metric units. Chemical concentration is given in milligrams per liter (mg/L) or micrograms per liter (μg/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter of water). One thousand micrograms per liter is equivalent to 1 milligram per liter. For concentrations less than 7,000 mg/L, the numerical value is about the same as for concentrations in parts per million.

Chemical concentration in terms of ionic interacting values is given in milliequivalents per liter (meq/L). Meq/L is numerically equal to equivalents per million.

Water temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the following equation:

$$°F = 1.8\ (°C) + 32$$

National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Sea Level Datum of 1929".

GROUND-WATER RESOURCES AND SIMULATED EFFECTS OF WITHDRAWALS

IN THE EAST SHORE AREA OF GREAT SALT LAKE, UTAH

By David W. Clark, Cynthia L. Appel,

Patrick M. Lambert, and Robert L. Puryear

U.S. Geological Survey

ABSTRACT

The ground-water resources in the East Shore area of Great Salt Lake, Utah, were studied to better define the ground-water system; to document changes in ground-water levels, quality, and storage; and to simulate effects of an increase in ground-water withdrawals. The East Shore aquifer system is in basin-fill deposits, and is primarily a confined system with unconfined parts near the mountain front.

Recharge to and discharge from the East Shore aquifer system were estimated to average about 160,000 acre-feet per year during 1969-84, with minor amounts of water being removed from storage during that period. Major sources of ground-water recharge are seepage from surface water in natural channels and irrigation canals, and subsurface inflow from consolidated rock to the basin-fill deposits. Discharge of ground water is primarily to wells, water courses, springs, and as diffuse seepage to Great Salt Lake. Average annual surface-water inflow to the study area was estimated to be 860,000 acre-feet for the period 1969-84. Annual withdrawal of ground water for municipal and industrial use increased from about 10,000 acre-feet in 1960 to more than 30,000 acre-feet in 1980 to supply a population that increased from 175,000 in 1960 to 290,000 in 1980.

Long-term trends of ground-water levels indicate a steady decline at most observation wells since 1952, despite near normal or increased precipitation since the late 1960's. Water levels declined as much as 50 feet near the principal pumping center in the east-central part of the study area. They declined as much as 35 feet more than five miles from the pumping center. The increase in withdrawals and subsequent water-level declines have caused about 700 wells within 30 square miles to cease flowing since 1954.

A numerical model of the East Shore aquifer system in the Weber Delta area was constructed and calibrated using water-level data and changes in ground-water withdrawals for 1955-85. Predictive simulations were made based on doubling the 1980-84 rate of municipal and industrial withdrawals for 20 years, and using both average and below-average recharge rates. The simulations indicated water-level declines of an additional 35 to 50 feet near the principal pumping center; a decrease in natural discharge to drains, evapotranspiration, and Great Salt Lake; and a decrease in ground-water storage of 80,000 to 115,000 acre-feet after 20 years.

INTRODUCTION

Increased ground-water withdrawal by municipal and military users in the East Shore area of Great Salt Lake has caused widespread water-level declines. Water levels have declined as much as 50 feet in some areas since 1952. State and local water managers and water users needed an updated evaluation of ground-water conditions and a tool with which to simulate effects of future changes in recharge and discharge of ground water.

Purpose and Scope

During 1983-85, the U.S. Geological Survey evaluated the ground-water resources of the East Shore area of Great Salt Lake, Utah. The study was done in cooperation with the Utah Department of Natural Resources, Division of Water Rights. Objectives of the study were to add to the understanding of the area's ground-water hydrology, to determine changes in ground-water conditions since the 1960-69 study by Bolke and Waddell (1972), and to simulate effects of potential future ground-water withdrawals on ground-water levels, discharge, and storage.

Information collected during this study included discharge from wells; water levels in wells; drillers' logs of wells; water samples for chemical analysis; seepage losses from or gains to canals, streams, and drains; and hydraulic properties of aquifers. A digital-computer model of the ground-water system was constructed on the basis of this and other information.

This report emphasizes ground water in the basin-fill deposits of the East Shore area, referred to as the East Shore aquifer system. The report describes ground-water conditions, including recharge, movement, and discharge, water levels, water quality, and volumes of water in storage. In addition, the report describes a computer simulation of the aquifer system in the Weber Delta area (fig. 1), including simulated effects of potential changes in ground-water recharge and discharge. A separate report (D.W. Clark, U.S. Geological Survey, written commun., 1990) includes a computer simulation of the aquifer system in the Bountiful area (fig. 1). The results and interpretations presented here are based primarily on data presented by Plantz and others (1986). Their report contains records of water quality, discharge, water levels, and drillers' logs for wells in the area.

Location and Physiography

The East Shore area is a valley or basin lowland north of Salt Lake City between the western margin of the Wasatch Range and the eastern shore of Great Salt Lake (fig. 1). It is at the eastern edge of the Basin and Range physiographic province (fig. 1), and is a densely populated urban-industrial-suburban area. The largest city is Ogden, which had a population of about 64,000 in 1980 (U.S. Department of Commerce, 1980). Hill Air Force Base (fig. 1), the area's largest employer, includes about 10 square miles of the study area.

The study area is about 40 miles long and from 3 to 20 miles wide. It includes all of Davis County, about one-half of Weber County, and a small part of southern Box Elder County. The southern boundary is the Davis-Salt Lake County line, and the northern boundary is about 1 mile north of the town of

Willard. The eastern boundary is the consolidated rock of the Wasatch Range and the western boundary is several miles west of the Great Salt Lake shoreline.

The East Shore study area includes two somewhat separate hydrologic areas, the Bountiful area and the Weber Delta area. The Bountiful area is between the Salt Lake-Davis County line and the line between Townships 2 and 3 North. The Weber Delta area is considered in this report to start at the northern end of the Bountiful area and continue to the north edge of the study area.

The total amount of land within the study area fluctuates with the level of Great Salt Lake. During this study, the level of the lake rose at an unprecedented rate, inundating large tracts of lowlying land near its eastern shore. During 1969-82 the level of the lake was at an average altitude of about 4,199 feet, but during 1983-84 the lake rose rapidly to an altitude of about 4,209 feet. At a lake level of 4,199 feet, the study area is about 430 square miles, whereas at a lake level of 4,209 feet, the study area is about 330 square miles.

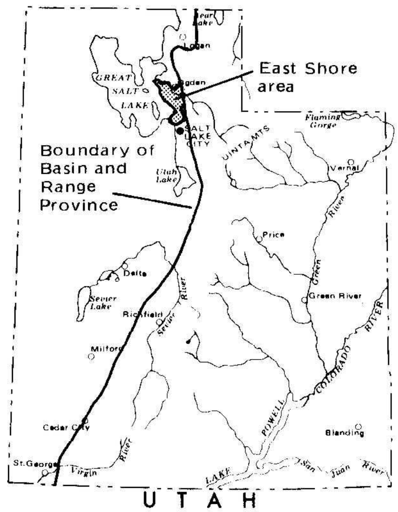
The study area contains two distinct physiographic units. The eastern unit is composed of benches (terraces) adjacent to the Wasatch Range that extend westward in a series of large steplike units (fig. 2). These terraces, formed by Pleistocene Lake Bonneville (Gilbert, 1890) have since been dissected by closely spaced mountain-front streams. The second unit is a valley-lowland plain with minor topographic relief that extends from the western edge of the terraces to the shores of Great Salt Lake (fig. 2). The valley-lowland plain ranges in width from 1 or 2 miles south of Farmington and near Willard to about 14 miles north of Ogden, but this width varies with changing levels of Great Salt Lake.

The altitude of the valley floor ranges from about 5,000 feet near the Wasatch Range to about 4,200 feet at the eastern margin of Great Salt Lake, depending on the lake level. The crest of the Wasatch Range is about 4,000-5,000 feet above the valley floor; the altitude of the highest peaks are more than 9,700 feet.

Geohydrologic Setting

The East Shore aquifer system lies within an elongate graben formed by normal faulting along the Wasatch fault zone to the east and an undefined fault zone near the shore of Great Salt Lake to the west (fig. 2). Displacement along the Wasatch fault zone may be as much as 10,000 feet (Feth and others, 1966, p. 21). A major fault is inferred to trend southward just east of the consolidated rocks exposed at Little Mountain and toward Hooper Hot Springs (fig. 3)(Feth and others, 1966, p. 22). This fault corresponds to the western edge of the graben near the shore of Great Salt Lake (Cole, 1982, p. 592).

The Wasatch Range is composed of metamorphic and sedimentary rocks that range from Precambrian to Tertiary in age. The rocks in the Wasatch Range south of the Ogden River primarily are Precambrian gneiss, schist, and quartzite, whereas north of the river the Wasatch Range also contains



EXPLANATION FOR FIGURE 1

STUDY AREA

Bountiful area

Weber Delta area

4,200 TOPOGRAPHIC CONTOUR--Shows altitude of land surface. Dashed contour represents historic high water elevation of Great Salt Lake. Contour interval, in feet, variable. National Geodetic Vertical Datum of 1929

CLIMATOLOGIC STATIONS

1 Bear River Refuge

2 Ogden Sugar Factory

3 Ogden Pioneer Powerhouse

4 Pineview Dam

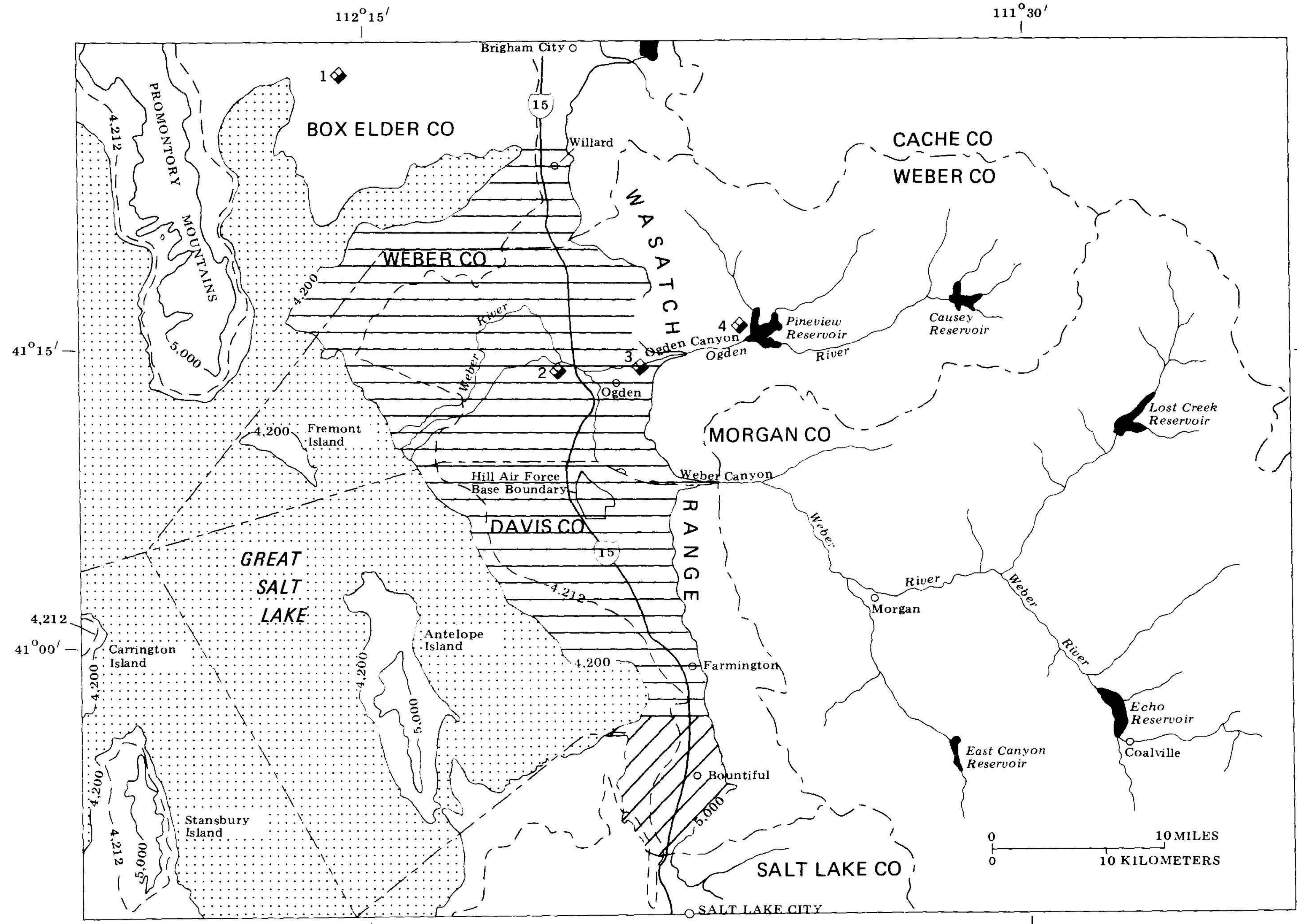


Figure 1.--Location of the East Shore area of Great Salt Lake.

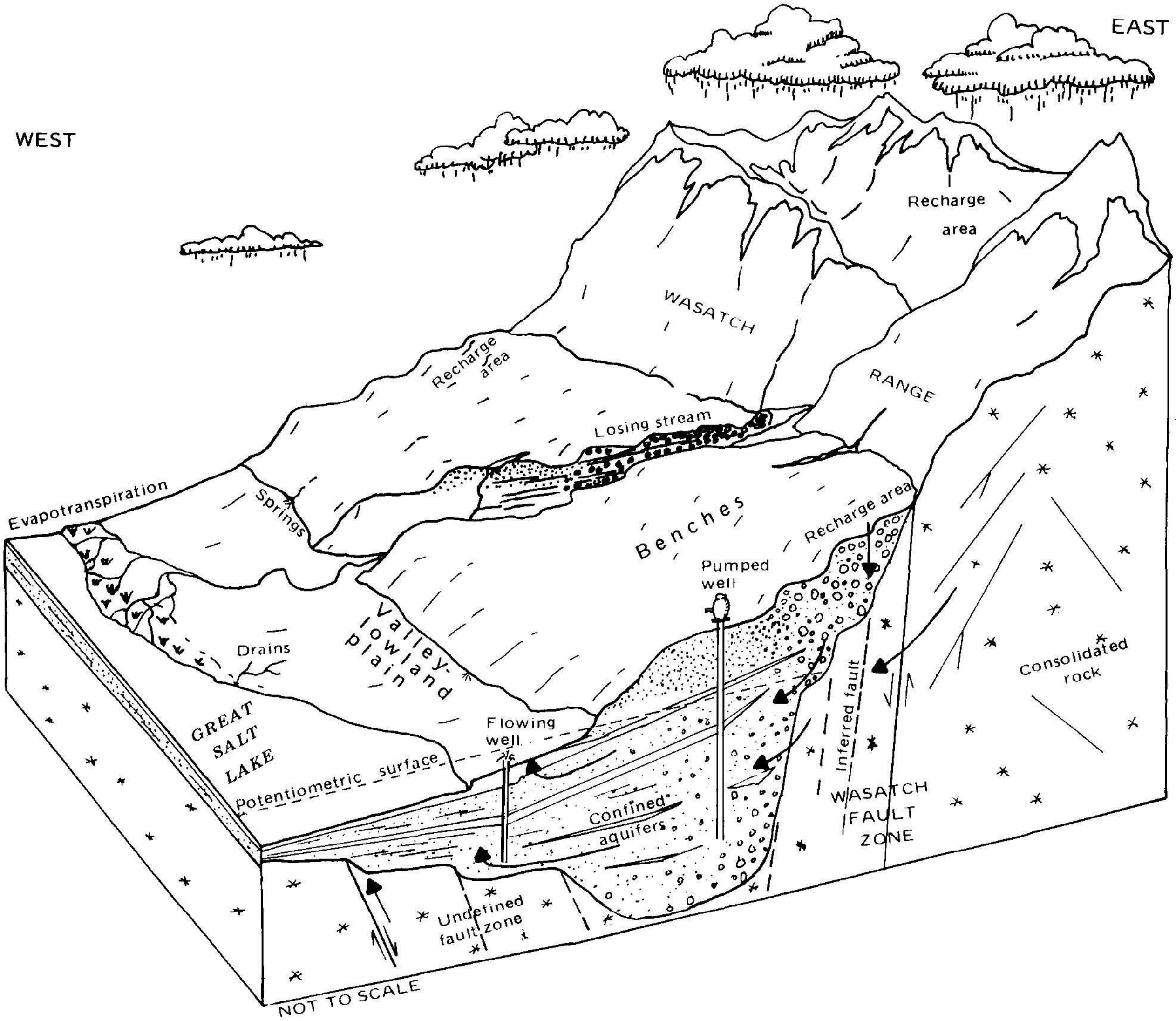


Figure 2.--Generalized block diagram showing water-bearing formations, probable directions of ground-water movement (arrows), and areas of recharge and discharge.

Paleozoic limestones, dolomites, shales, and quartzites. Tertiary conglomerates are exposed in the area south of Bountiful.

Basin-fill deposits comprising the East Shore aquifer system were eroded from the mountains and deposited in the grabens during Pleistocene Lake Bonneville and pre-Lake Bonneville time. The basin fill is composed of unconsolidated and semi-consolidated sediments in a series of interbedded alluvial and lacustrine deposits. Most of the sediments are coarse grained near the mountains, particularily near the mouths of canyons, where delta, alluvial-fan, and mudflow materials predominate. Fine-grained sediments predominate toward the western edge of the graben, where most of the deposits are lacustrine. The total thickness of the basin fill generally is unknown, but is estimated to be approximately 6,000 to 9,000 feet thick in the Weber Delta area (Feth and others, 1966, p. 22). On the basis of shallow seismic-reflection surveys, the total thickness may be as much as 6,300 feet near the Weber River in T. 5 N., R. 2 W. south of Slaterville (fig. 3)(Feth and others, 1966, p. 28); on the basis of gravity data, the thickness may be as much as 7,500 feet under Hill Air Force Base (Glenn and others, 1980, p. 37-47). The thickness of basin-fill deposits decreases substantially toward the western edge of the graben. The thickness of the basin fill in the Bountiful area is unknown; however, the deepest well in the area was completed in unconsolidated material at a depth of 1,985 feet (Thomas and Nelson, 1948, p. 86).

Further description of the geology of the East Shore area can be found in Feth and others (1966) and Thomas and Nelson (1948). In addition to subsurface geology, paleontology, and structure, Quaternary and surficial geology are detailed in those reports.

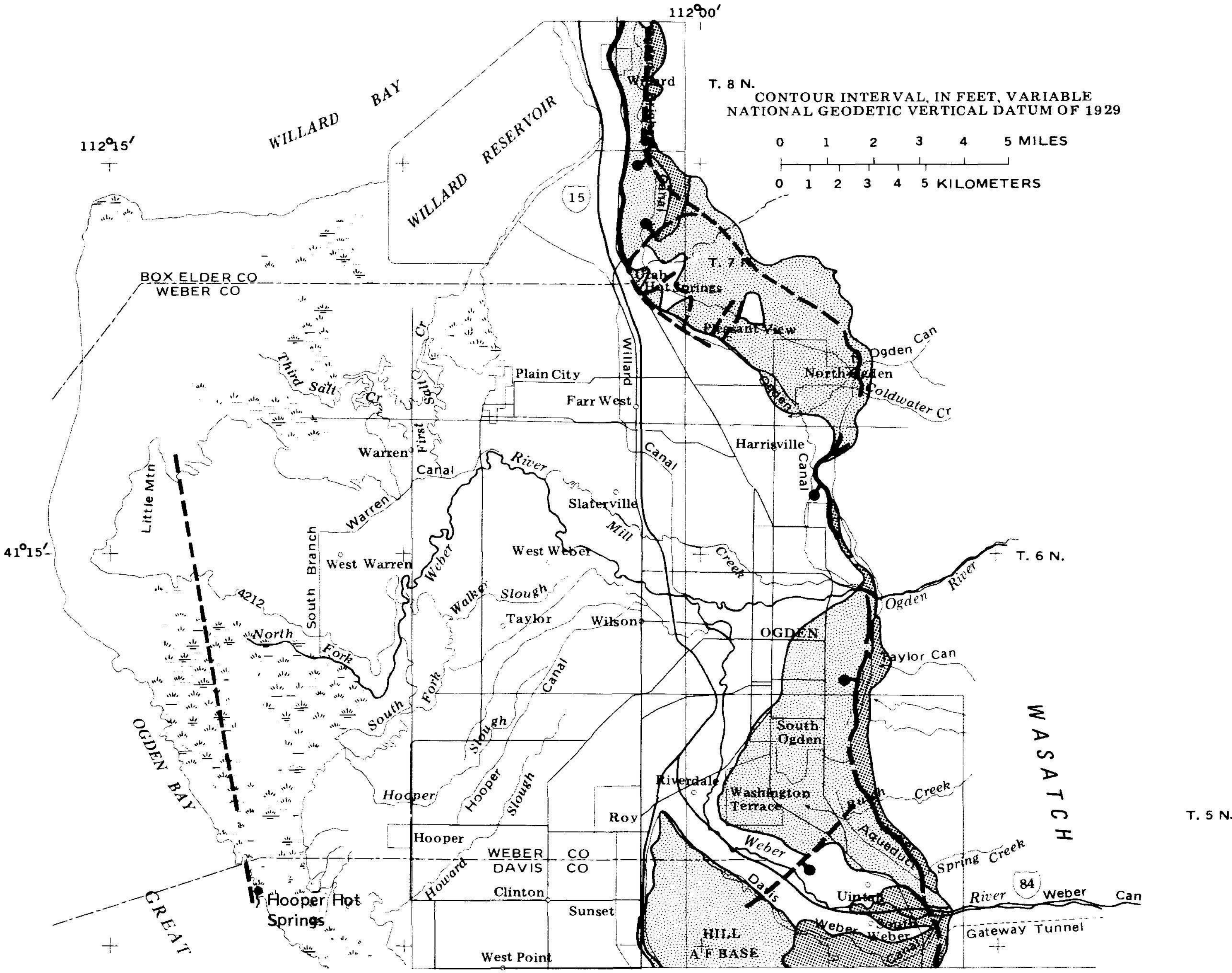
Climate

The climate of the East Shore area is temperate and semiarid with a typical frost-free season from May to mid-October. Precipitation increases from west to east across the valley lowland and on the adjoining mountains as altitude increases (table 1); the mean annual temperature differs little with altitude. The normal annual precipitation ranges from less than 12 inches near Great Salt Lake to more than 20 inches near the mountain front. During 1983, however, precipitation was more than twice the normal quantity (National Oceanic and Atmospheric Administration, Environmental Data Service, 1984).

Population and Land Use

The East Shore area is one of the fastest-growing regions in the United States; its population has increased about 66 percent since 1960. The 1980 population was about 290,000; about 260,000 people lived within incorporated areas (table 2). The population has increased everywhere except within the city of Ogden; in many places the population has doubled or tripled since 1960. The increase in population has occurred primarily in the southern part of the area, and in suburban areas, which have expanded onto former agricultural lands.

The 1968-85 change in land use from irrigated cropland and natural vegetation to urban is shown in figure 4. There was an increase of about 12,000 acres of land classified as urban, of which 75 percent was formerly



112°00′
112°15′
41°15′
T. 8 N.
T. 7 N.
T. 6 N.
T. 5 N.
CONTOUR INTERVAL, IN FEET, VARIABLE
NATIONAL GEODETIC VERTICAL DATUM OF 1929
0 1 2 3 4 5 MILES
0 1 2 3 4 5 KILOMETERS
WILLARD BAY
WILLARD RESERVOIR
15
BOX ELDER CO
WEBER CO
WEBER CO
DAVIS CO
Utah Hot Springs
Pleasant View
Ogden Can
North Ogden
Coldwater Cr
Plain City
Farr West
Willard
Canal
Harrisville
Third Salt Cr
First Salt Cr
Warren
Canal
Warren
Little Mtn
South Branch
West Warren
River
Weber
Slaterville
Mill
Creek
West Weber
Walker
Slough
Taylor
Wilson
Ogden River
OGDEN
Taylor Can
4212
North Fork
South Fork
Canal
Slough
South Ogden
Washington Terrace
Riverdale
Roy
Hooper
Hooper Slough
Hooper
Howard
Clinton
Sunset
West Point
Weber
Davis
Aqueduct
Creek
Spring Creek
84
River
Weber
Can
Uintah
Weber
Canal
Gateway Tunnel
HILL A F BASE
WASATCH
OGDEN BAY
GREAT
Hooper Hot Springs

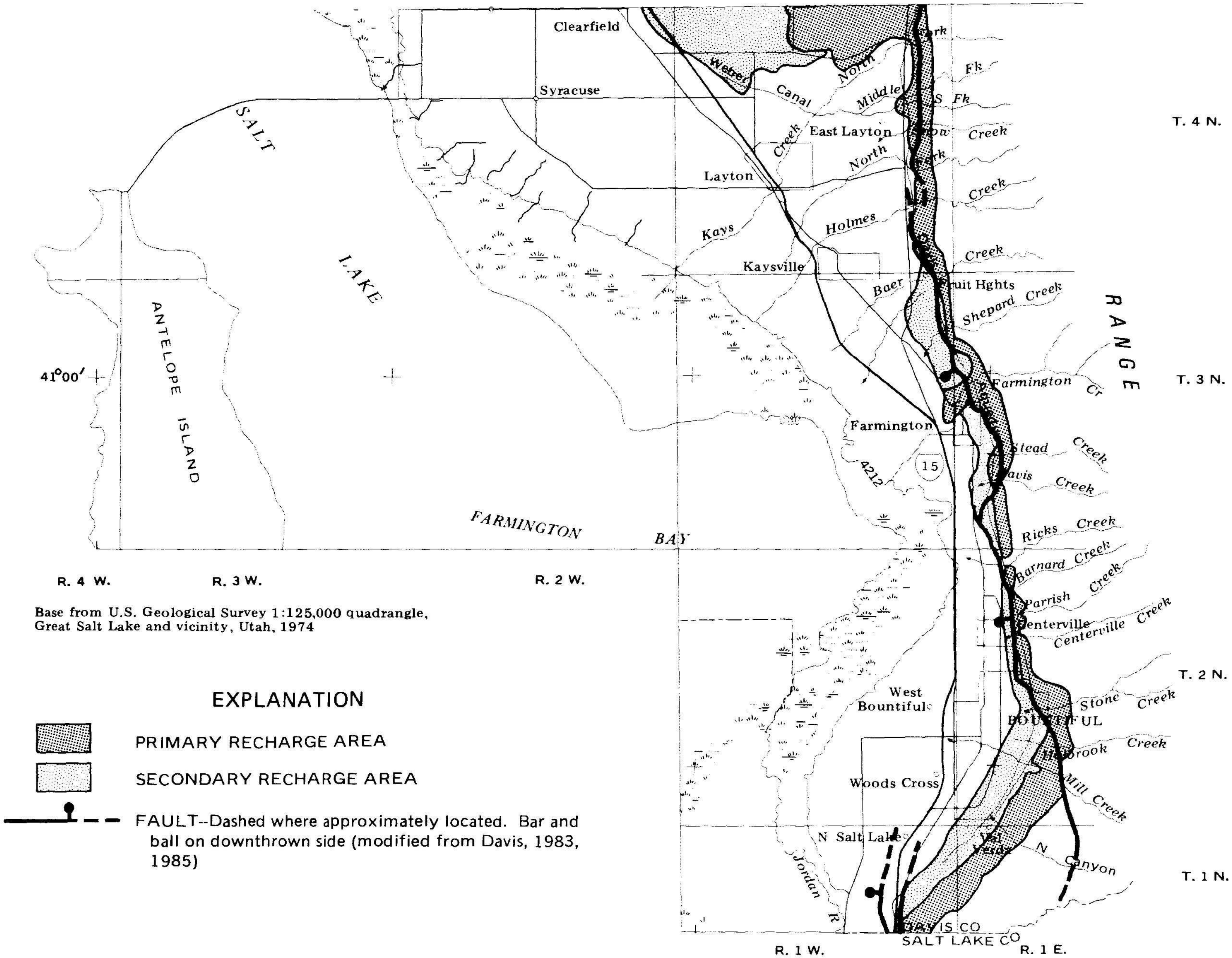


Figure 3.--Recharge areas and major fault zones.

Table 1.--Normal monthly precipitation for 1951-80 at Bear River Refuge, Ogden Sugar Factory, Ogden Pioneer Powerhouse, and Pineview Dam climatologic stations

(Data from National Oceanic and Atmospheric Administration, Environmental Data Service, 1983)

Month	Bear River Refuge (altitude 4,210 feet)	Ogden Sugar Factory (altitude 4,280 feet)	Ogden Pioneer Powerhouse (altitude 4,350 feet)	Pineview Dam (altitude 4,940 feet)
	Precipitation (inches)			
Jan.	1.16	1.52	2.36	3.83
Feb.	.98	1.27	1.90	3.11
Mar.	.89	1.41	2.05	3.06
Apr.	1.40	2.06	2.52	3.05
May	1.31	1.71	2.14	2.68
June	1.16	1.43	1.58	1.72
July	.35	.50	.65	.71
Aug.	.64	.72	.98	1.09
Sept.	.87	1.10	1.20	1.46
Oct.	1.05	1.27	1.58	2.11
Nov.	1.03	1.36	1.73	2.76
Dec.	.96	1.30	1.89	3.21
Annual	11.80	15.65	20.58	28.79

Table 2.—Population in the East Shore area
(Data from U.S. Department of Commerce, Bureau of Census, 1971 and 1980)

Location	1980 census	Percent change 1970-80	1970 census	Percent change 1960-70	1960 census	Percent change 1960-80
East Shore Area	289,280	29.0	224,203	28.3	174,782	65.5
Box Elder County						
Willard City	1,242	18.9	1,045	28.4	814	52.6
Davis County	146,360	47.8	99,024	52.9	64,760	126.0
Bountiful	32,978	18.4	27,853	63.5	17,039	93.5
Centerville	8,041	146.1	3,268	38.4	2,361	240.6
Clearfield	17,937	34.7	13,316	50.8	8,833	103.1
Clinton	5,781	227.0	1,768	72.5	1,025	464.0
East Layton	3,537	363.6	763	71.8	444	696.6
Farmingtion	4,692	85.7	2,526	29.5	1,951	140.5
Fruit Heights	2,731	241.4	800	357.1	175	1,460.1
Kaysville	9,804	58.3	6,192	71.6	3,608	171.7
Layton	22,603	66.2	13,603	50.7	9,027	150.4
North Salt Lake City	5,588	160.8	2,143	29.5	1,655	237.6
South Weber	1,580	47.3	1,073	180.9	382	313.6
Sunset	5,739	-8.4	6,268	48.0	4,235	35.5
Syracuse	3,692	100.3	1,843	73.7	1,061	248.0
West Bountiful	3,559	185.6	1,246	31.9	945	276.6
West Point	2,168	112.5	1,020	70.3	599	261.9
Woods Cross	4,274	36.8	3,124	184.5	1,098	289.3
Weber County	141,678	14.1	124,130	13.7	109,208	29.7
Harrisville	1,376	83.7	749	—	—	—
North Ogden	9,316	77.2	5,257	100.6	2,621	255.4
Ogden	64,444	-7.2	69,478	-1.0	70,197	-8.2
Plain City	2,374	53.9	1,543	33.9	1,152	106.1
Pleasant View	3,997	97.1	2,028	118.8	927	331.2
Riverdale	3,840	3.7	3,704	100.4	1,848	107.8
Roy	19,718	37.4	14,356	55.4	9,239	113.4
South Ogden	11,358	13.7	9,991	34.9	7,405	53.4
Uintah	720	80.0	400	16.3	344	109.3
Washington Terrace	8,217	13.5	7,241	12.4	6,441	27.6
Total for incorporated areas	261,302	29.0	202,598	30.3	155,426	68.1
Total for unincorporated areas	27,978	29.5	21,605	11.6	19,356	44.5

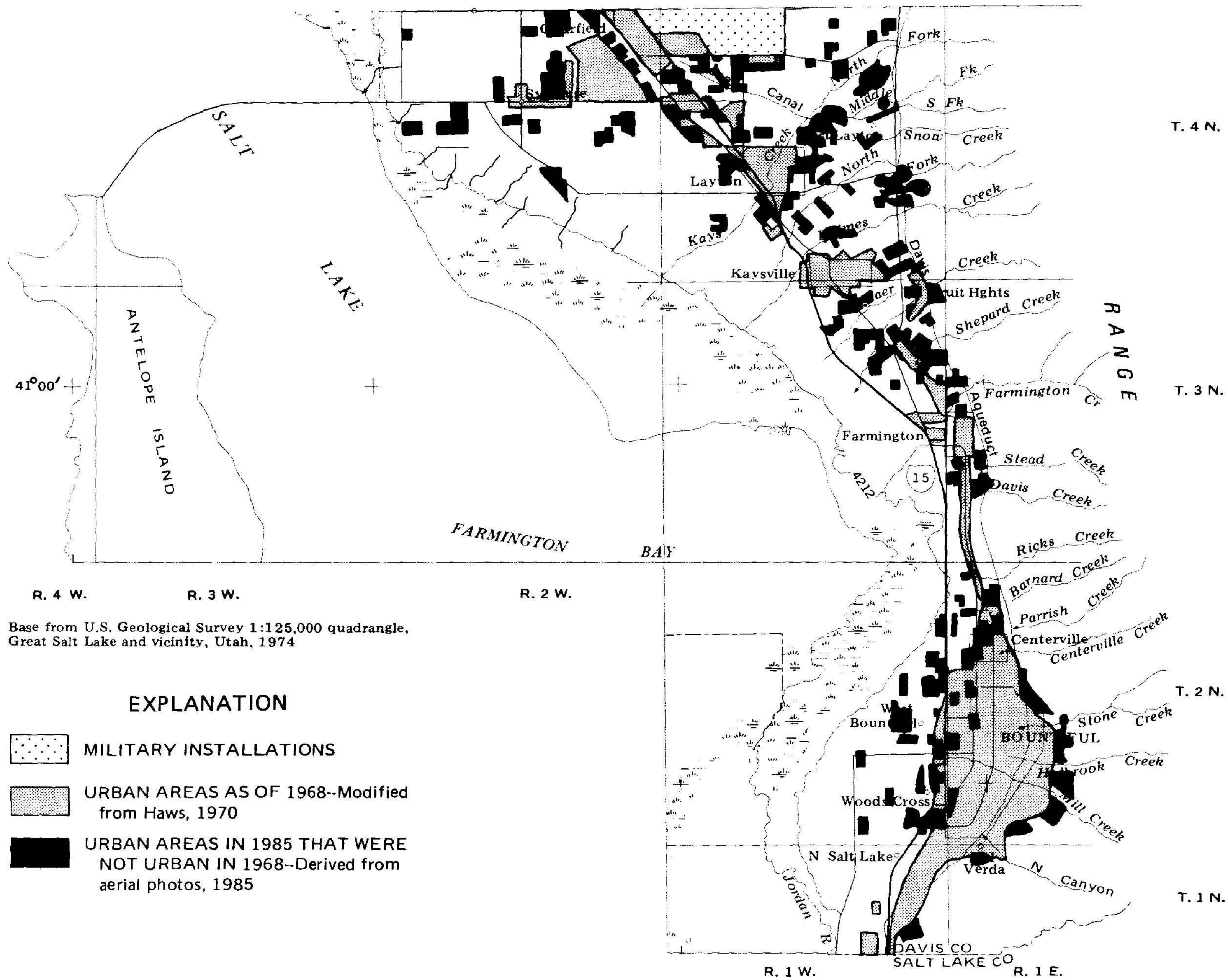


Figure 4.--Land use and land-use change, 1968-85.

classified as irrigated cropland. Total acres of irrigated cropland and natural vegetation in the project area decreased by about 10 percent during 1968-85.

Previous Investigations

Thomas and Nelson (1948) conducted a comprehensive study during 1946-48 of the hydrology of the Bountiful area at the southern end of the East Shore area. Their study included water-level and discharge measurements at more than 400 wells. Feth and others (1966) studied the geology and hydrology of the Weber Delta area, which includes the northern part of the East Shore area. Their report includes a discussion of ground-water conditions for 1953-56 and a potentiometric map for December 1955. Smith and Gates (1963) conducted a study of the East Shore area to determine changes in water levels and ground-water quality from 1953 to 1961. Bolke and Waddell (1972) reported on water levels and changes in ground-water quality in the East Shore area during 1960-69; they compiled a generalized map of ground-water quality. A map series of ground- and surface-water resources and geology of the Wasatch Front (Price and Jensen, 1982a, 1982b; Price and LaPray, in press; Davis, 1983, 1985) have recently been completed.

Well-Numbering System Used in Utah

The system used to number wells in Utah is based on the cadastral land-survey system of the U.S. Government. The number, in addition to designating the well, describes its position in the land net. By the land-survey system, the State is divided into four quadrants by the Salt Lake Base Line and Meridian, and these quadrants are designated by A, B, C, and D, indicating respectively the northeast, northwest, southwest, and southeast quadrants. 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, and it is followed by three letters indicating the quarter section, the quarter-quarter section, and the quarter-quarter-quarter section—generally 10 acres[1]; a, b, c, and d indicate, respectively, the northeast, northwest, southwest, and southeast quarters of each subdivision. The number after the letters is the serial number of the well within the 10-acre tract. If a well cannot be located within a 10-acre tract, one or two location letters are used and the serial number is omitted. Thus, (B-7-1)30dca-1 designates the first well constructed or visited in the NE¼SW¼SE¼, sec. 30, T. 7 N., R. 2 W. The numbering system is illustrated in figure 5.

Acknowledgments

Special acknowledgments are extended to the residents, the officials of various cities and towns, irrigation companies, conservancy districts,

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[1]Although the basic land unit, the section, is theoretically 1 square mile, many sections are irregular. Such sections are subdivided into 10-acre tracts, generally beginning at the southeast corner, and the surplus or shortage is taken up in the tracts along the north and west sides of the section.

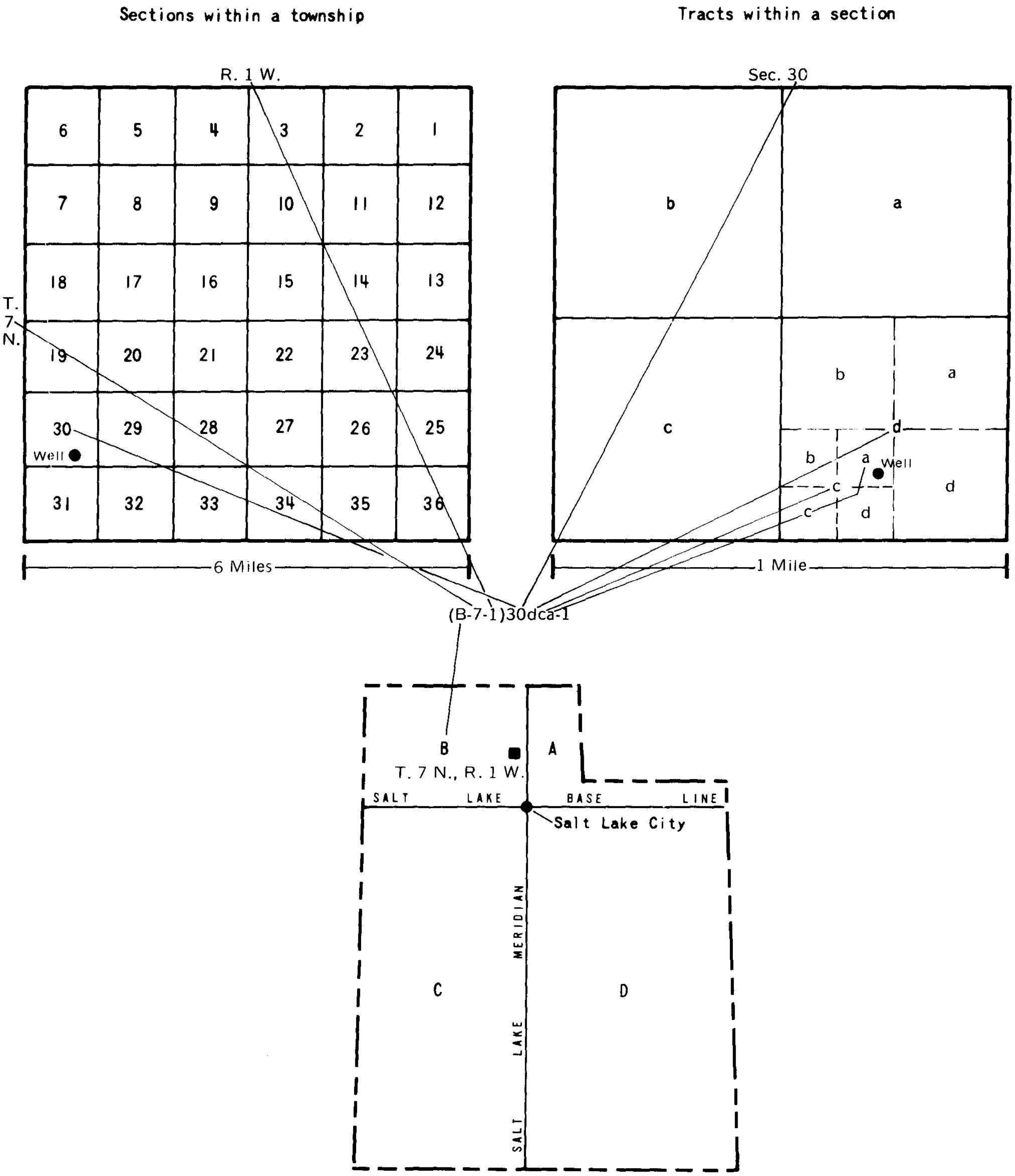

Figure 5.--Well-numbering system used in Utah.

and industries in the East Shore area who gave permission for the use of their wells for water-level measurements and aquifer testing and who provided other useful information for this study. The cooperation of officials of the State of Utah and Box Elder, Davis, and Weber Counties was helpful and is appreciated.

SURFACE WATER

Surface water is the primary source of irrigation water in the East Shore area, and it is also used extensively by municipalities and industries as part of their water supply. Average annual (1969-84) surface-water inflow to the East Shore area from all sources, but mostly from nine major streams, is estimated to be about 860,000 acre-feet. The estimated surface-water inflow from the nine streams for water years[1] 1969-84 is shown in table 3. The inflow for 1928-47 is given in Feth and others (1966, p. 34), and the inflow for 1948-60 is given in Smith and Gates (1963, p. 15).

Calculations of inflow from major streams are based on continuous records of water stage at some stations and partial records at other stations, which were correlated to long-term records from nearby streams. The estimated flow of Holmes, Ricks, Parrish, Stone, and Mill Creeks for 1969-84 is based on records of annual flow available from 1950 to 1968, which were correlated with long-term records of flow for City Creek in northern Salt Lake County. The estimated flow for 1972-75 and 1980-84 for Farmington Creek was based on annual flow from 1950-71 and 1976-79 correlated with flow of City Creek. The estimated flow for Centerville Creek for 1981-84 is based on records of annual flow for 1950-80 correlated with flow of City Creek. Flow of the Ogden River was estimated from the commissioner's reports of the Ogden River distribution system for 1969-81 (Barnett, 1969-77, Berghout, 1978-81) by combining the flow of the river at a gage downstream from Pineview Reservoir, flow at the Pioneer powerhouse, and flow in the Ogden-Brigham and Ogden Highline canals. Flow for 1982-84 was estimated by adding the total releases from Pineview Reservoir (Pineview Reservoir personnel, written commun., 1985) and the flow at the gaging station on Wheeler Creek. The estimates for the Ogden River do not include flow from several other small streams downstream from the gaging station. Total flow of the Weber River was estimated from records of flow at the gaging station near Gateway and from records of flow diverted to the Gateway Tunnel contained in the commissioner's reports of the Weber River distribution system (Johnson, 1969-84).

The estimated average annual inflow to the East Shore area from perennial, ephemeral, and intermittent streams for which there are no records of flow is about 47,000 acre-feet (table 4). The streams with mean annual flow greater than 1,000 acre-feet generally are perennial upstream from the canyon mouths, and water often reaches the valley lowland during periods of high flow. Most of the water in ephemeral and intermittent streams seeps into alluvial fans or high benchlands where the definable channels terminate.

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[1]All surface-water records in this report are given by water year. A water year is the 12 months ending September 30 and designated by the year in which it ends.

Table 3.--Estimated inflow to East Shore area from major streams, water years 1969-84

[Flow in thousand acre-feet]

Water year	Ogden River	Weber River	Holmes Creek	Farmington Creek	Ricks Creek	Parrish Creek	Centerville Creek	Stone Creek	Mill Creek	Total
1969	233	617	4	13.3	2	2	2.4	4	8	886
1970	196	403	3	10.4	2	2	2.4	3	7	629
1971	232	561	4	14.4	3	2	3.4	4	9	833
1972	270	611	4	13	2	2	3.1	4	7	916
1973	203	501	3	12	2	2	2.8	3	7	736
1974	245	610	4	15	3	2	3.6	5	9	897
1975	241	641	5	17	3	2	3.5	5	11	929
1976	188	431	3	9.0	2	1	2.2	3	6	645
1977	62	166	2	5.8	1	1	1.3	1	2	242
1978	179	448	4	14.8	3	2	3.3	4	8	666
1979	198	373	3	9.5	2	1	1.8	2	4	594
1980	271	565	3	10	2	1	2.5	3	5	862
1981	84	303	2	8	1	1	2	2	4	407
1982	236	609	4	14	3	2	3	4	9	884
1983	329	996	4	16	3	2	3	5	10	1,368
1984	468	1,052	4	14	3	2	3	4	8	1,558
Average annual	227	555	4	12	2	2	3	4	7	816

Table 4.--Estimated inflow to East Shore area from ungaged perennial, intermittent, and ephemeral streams, water years 1969-84

Stream	Drainage area (A) (square miles)	Mean drainage altitude (E) (thousands of feet)	Mean annual flow (Q) (cubic feet per second)	Mean annual flow (acre-feet per year)
Willard Creek	4.1	7.39	4.0	2,900
Holmes Canyon	.7	7.05	.7	510
Pearsons Canyon	.8	6.97	.8	580
Unnamed SW. of Willard Peak	1.6	7.07	1.5	1,100
Maguire Canyon	1.3	6.74	1.0	720
Pine and Ridge Canyons	1.1	6.55	.8	580
Barrett Canyon	1.3	6.69	1.0	720
Unnamed E. of Barrett Canyon	1.0	6.90	.9	650
Unnamed S. of Chilly Peak	2.0	6.71	1.5	1,100
North Ogden Canyon	3.0	6.53	1.9	1,400
Coldwater Canyon	2.0	6.76	1.5	1,100
One Horse Canyon	.8	6.50	.6	430
Garner Canyon	.7	6.10	.4	290
Jumpoff Canyon	1.5	6.85	1.2	870
Unnamed S. of Jumpoff Canyon	.4	6.10	.3	220
Unnamed NW. of Johnson Draw	.6	6.37	.4	290
Unnamed W. of Johnson Draw	.4	6.04	.2	140
Johnson Draw	.8	6.29	.5	360
Dry Canyon	1.1	6.50	.8	580
Goodale Creek	3.4	6.62	2.2	1,600
Unnamed E. of Sardine Canyon	.7	5.89	.4	290
Cold Water Canyon	1.9	6.36	1.2	870
Warm Water Canyon	.6	6.04	.3	220
Hidden Valley	.4	6.25	.3	220
Taylor Canyon	2.4	6.79	1.8	1,300
Waterfall Canyon	1.2	7.21	1.2	870
Strongs Canyon	1.4	7.07	1.3	940
Beus Canyon	1.5	6.70	1.1	800
Burch Creek	2.5	7.47	2.7	2,000
Dry Canyon	1.0	6.23	.6	430
Spring Creek	2.1	6.62	1.5	1,100
Corbett Creek	1.8	6.53	1.2	870
North Fork of Kays Creek	1.6	6.82	1.3	940
Middle Fork of Kays Creek	2.0	7.35	2.1	1,500
South Fork of Kays Creek	1.9	7.24	1.9	1,400
Snow Creek	1.0	6.66	.8	580
North Fork of Holmes Creek	2.5	7.11	2.2	1,600
Baer Creek	4.3	7.09	3.5	2,500
Shepard Creek	2.8	6.94	2.2	1,600
Rudd Creek	1.2	6.16	.7	510
Steed Creek	3.1	7.05	2.6	1,900
Davis Creek	2.3	6.42	1.4	1,000
Unnamed N. of Ricks Creek	1.0	6.12	.6	430
Barnard Creek	1.7	6.73	1.3	940
Unnamed S. of Centerville Canyon	.5	5.75	.2	140
Unnamed N. of Stone Creek	1.0	6.19	.6	430
Holbrook Creek	4.9	7.16	4.1	3,000
North Canyon	2.4	6.26	1.3	940
Hooper Canyon	1.2	5.80	.6	430
Unamed SW. of Hooper Canyon	3.6	5.01	0.9	650
			Total (rounded)	47,000

The flow in the streams listed in table 4 was computed by the equation:

$$Q = 7.69 \times 10^{-4} (A)^{0.883} (E)^{3.65} \quad (1)$$

where:

Q = mean annual flow, in cubic feet per second;

A = drainage area, in square miles; and

E = mean altitude of the drainage basin, in thousands of feet.

Equation 1 was derived from long-term flow records for 25 streams in the Wasatch Range with similar drainage-area size and mean altitude. The average standard error of estimate was 28 percent and the correlation coefficient was 0.95.

During the water years 1969-84, an average of 64 percent of the total inflow to the East Shore area was from the Weber River and 91 percent of the total inflow was from the Ogden and Weber Rivers combined. Greater than normal precipitation for most of 1969-84 resulted in the annual flow in the two rivers being about 140 percent of the average annual flow during 1928-61.

The seasonal fluctuation of flow is extremely large; the largest flows are caused by spring snowmelt. The hydrograph of flow in the Weber River (fig. 6) is considered typical of streams in the area, even though the river is regulated by reservoirs. Fluctuation in total annual flow can also be extremely large, as indicated by the flow in the Weber River for the drought year of 1977 and the flood years of 1983 and 1984. The largest mean monthly flow for 1983 and 1984 was ten times greater than the largest mean monthly flow of 1977. During 1983-84, total annual surface-water inflow to the East Shore area in major streams averaged 1,463,000 acre-feet.

During 1969-84, an average of about 350,000 acre-feet of surface water was diverted annually from about 60 irrigation systems into irrigation canals, pipelines, and other aqueducts for irrigation use (Johnson, 1969-84; Barnett, 1969-77; Berghout, 1978-81). This amount is about 40 percent of the total surface-water inflow to the area during 1969-84. The remaining 60 percent of surface-water flow was used for other purposes or occurred during October through June, when there is little or no demand for irrigation use. A tabulation of the estimated amount of surface water used in the East Shore area follows:

Use	Average annual use, acre-feet	Percent of annual surface-water inflow
Irrigation	350,000	40
Powerplants	85,000	10
Wildlife habitat	57,000	7
Municipal or industrial	40,000	5
Unused or unaccounted for	328,000	38
Total	860,000	100

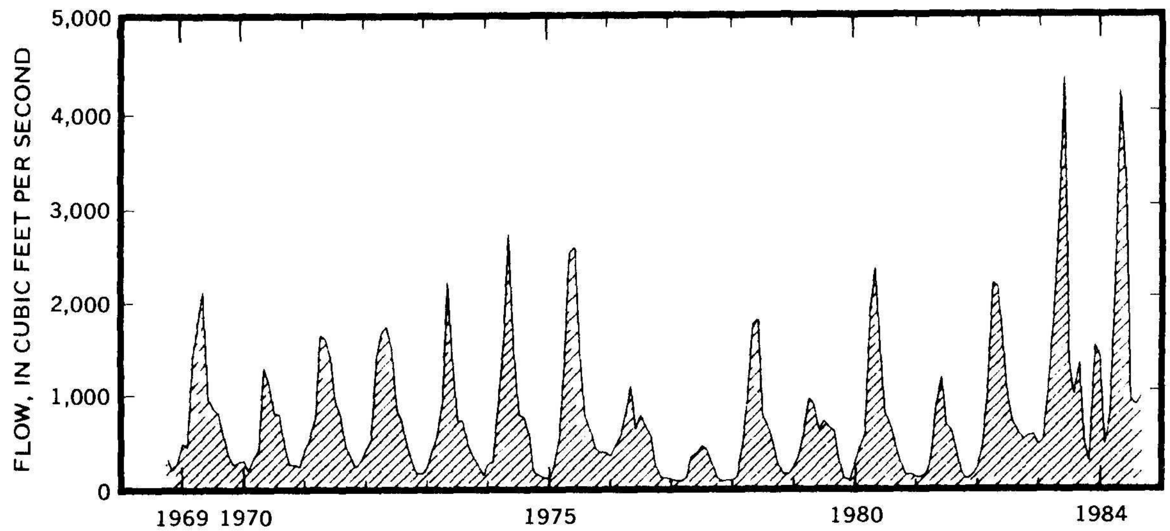


Figure 6.--Monthly mean flow of the Weber River at Gateway, Utah, 1969-84.

Surface-water inflow to Great Salt Lake from the East Shore area is estimated to be about 650,000 acre-feet per year for 1969-84, or about 75 percent of the total surface-water inflow to the area. This total was calculated from data for 1971-76 in a report on total inflow to Great Salt Lake (Waddell and Barton, 1980, p. 37-40), and data for the same period from tables 3 and 4 in this report. Some of this inflow is return or unused irrigation water, or ground water that seeped into natural channels or irrigation canals.

GROUND WATER

The East Shore aquifer system is defined as consisting of saturated alluvial deposits between the Wasatch Range and Great Salt Lake and which includes artesian aquifers plus a deep unconfined aquifer along the mountain front. The shallow water-table zone in the topographically low parts of the area is part of the overall ground-water system of the East Shore area but is not considered part of the East Shore aquifer system as defined in this report. The shallow water-table zone was not included because of lack of data on recharge to the zone by infiltration of precipitation, large amounts of seepage from irrigation, and infiltration of urban runoff and water from urban activities, and a similar lack of data on discharge from the zone.

Geology and Hydraulic Properties of the East Shore Aquifer System

The East Shore aquifer system is primarily confined with some unconfined parts along the mountain front. The consolidated rocks in the mountains contain water, but they are considered to be only a source of recharge to the East Shore aquifer system.

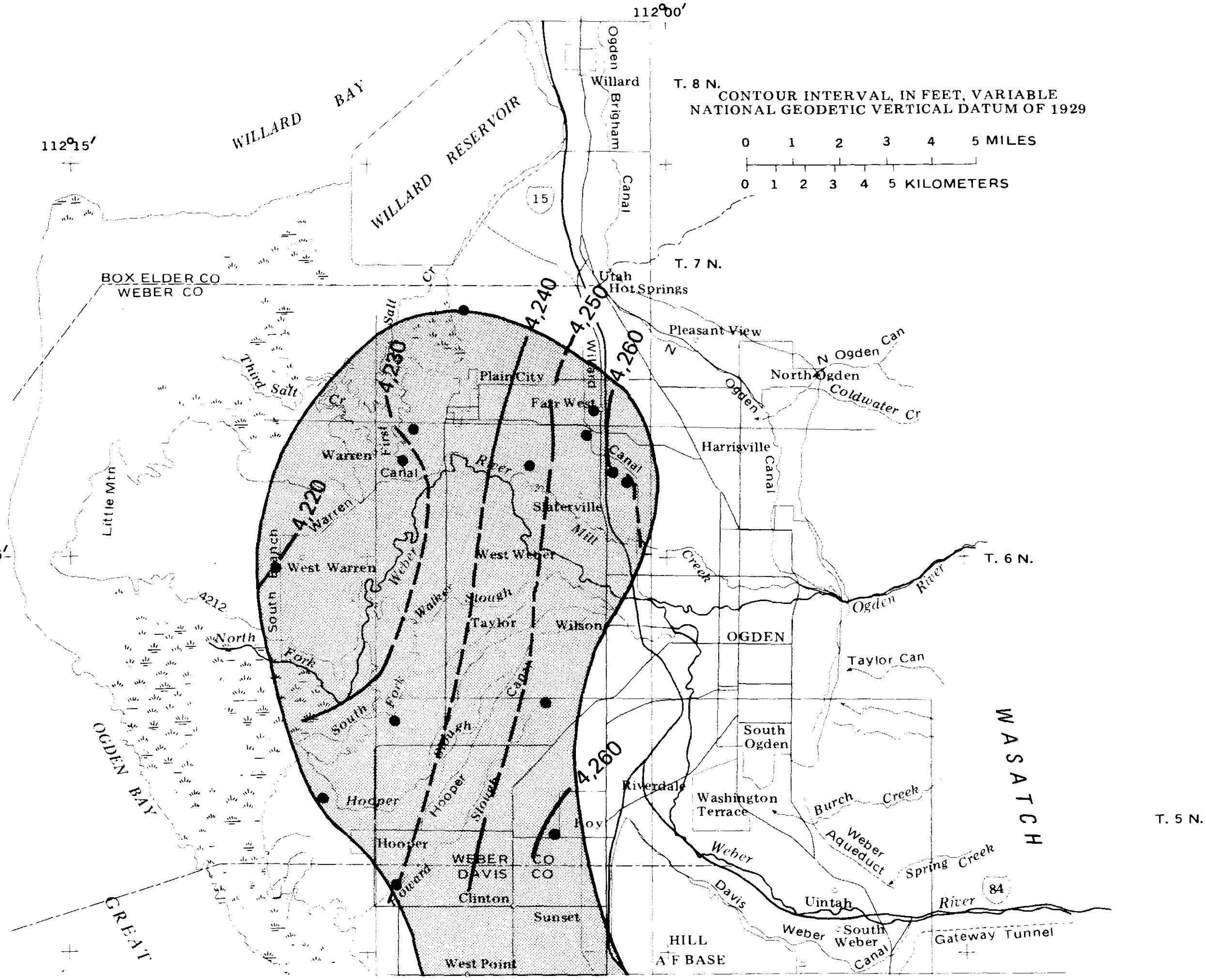
Feth and others (1966, p. 36-37) described the Weber Delta area and Thomas and Nelson (1948, p. 167-172) the Bountiful area of the East Shore aquifer system. The Weber Delta area was described as containing two confined aquifers, the Sunset and Delta, and locally unnamed parts of those aquifers. The Bountiful area was described as containing shallow, intermediate, and deep artesian aquifers. In this report, however, the East Shore aquifer system is defined as the saturated sediments between the Wasatch Range and the study area's western boundary, excluding the shallow water-table zone in the topographically low parts of the area but including the Sunset and Delta aquifers.

The East Shore aquifer system contains individual confined aquifers that have previously been defined and named, unconfined laterally-upgradient extensions of those aquifers, multiple confined zones within the individual aquifers, and confined and unconfined zones of the aquifer system outside of the areas where individual aquifers have previously been defined. The individual confined aquifers, as previously defined, typically are separated by predominately fine-grained layers several feet to several hundred feet thick which can cause a substantial difference in the hydraulic head (which generally increases with depth in the topographically lower parts of the East Shore area) between the aquifers. Where confining layers are thin or more permeable, ground water easily moves vertically through them from one aquifer to another. This is evident when a well completed in a deep aquifer zone is pumped and water-level declines are observed in wells completed in a shallower aquifer zone. The water-level declines in the shallower aquifer zone are a result of leakage through the confining layers separating the zones. However, where confining layers are tens to hundreds of feet thick and less permeable, little vertical movement takes place, and pumping a well in a deep aquifer zone results in only small water-level declines in an overlying aquifer zone.

The Sunset and Delta aquifers, as defined by Feth and others (1966), were delineated in the central part of the Weber Delta area from about Kaysville north to Plain City and from the western part of Hill Air Force Base west to Hooper (fig. 7). Near Great Salt Lake the aquifers are composed of thin alternating layers of silt, clay, and sand, and are difficult to differentiate. Within each aquifer, alternating layers of fine and coarse-grained materials occur. Within the central part of the Weber Delta area, wells completed at depths from 200 to 400 feet were considered to be completed in the Sunset aquifer, and wells completed at a depth greater than 400 feet were considered to be completed in the Delta aquifer. In all areas outside of the central part of the Weber Delta area, no delineation of indiviual aquifers within the East Shore aquifer system was made.

The top of the Sunset aquifer is as shallow as 200 feet below land surface in some locations, but is more typically between 250 and 400 feet below land surface (Feth and others, 1966, p. 37). The aquifer is composed of sand; mixtures of gravel, sand, and clay; or sand and clay. The thickness of the aquifer ranges from 50 to 200 feet. The Sunset aquifer is less permeable than most of the rest of the East Shore system and consequently fewer wells are completed in the Sunset. The material composing the aquifer becomes progressively finer grained toward Great Salt Lake.

The Delta aquifer, which is assumed to underlie most of the Weber Delta part of the East Shore aquifer system, is mostly composed of deltaic deposits of the Weber River that extend westward from the mouth of Weber Canyon. The top of the aquifer is from 500 to 700 feet below land surface in most locations (Feth and others, 1966, p. 36). The aquifer is estimated to be between 50 and 150 feet thick. The total thickness has been penetrated by few wells, and thus is unknown in many places. The Delta aquifer primarily is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BOX ELDER CO
WEBER CO
WEBER CO
DAVIS CO
Ogden Brigham Canal
Willard
15
84
Utah Hot Springs
Pleasant View
N Ogden Can
North Ogden
Coldwater Cr
Harrisville
Canal
Plain City
Farr West
Warren
West Warren
West Weber
Slaterville
Taylor
Wilson
OGDEN
Taylor Can
South Ogden
Riverdale
Washington Terrace
Roy
Hooper
Clinton
Sunset
West Point
HILL AF BASE
Uintah
South Weber
Gateway Tunnel
Weber Aqueduct
Burch Creek
Spring Creek
Weber River
Ogden River
Mill Creek
Davis Weber Canal
Third Salt Cr
Salt Cr
First Canal
Warren Canal
South Branch
North Fork
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Walker Slough
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Hooper Slough
Howard Slough
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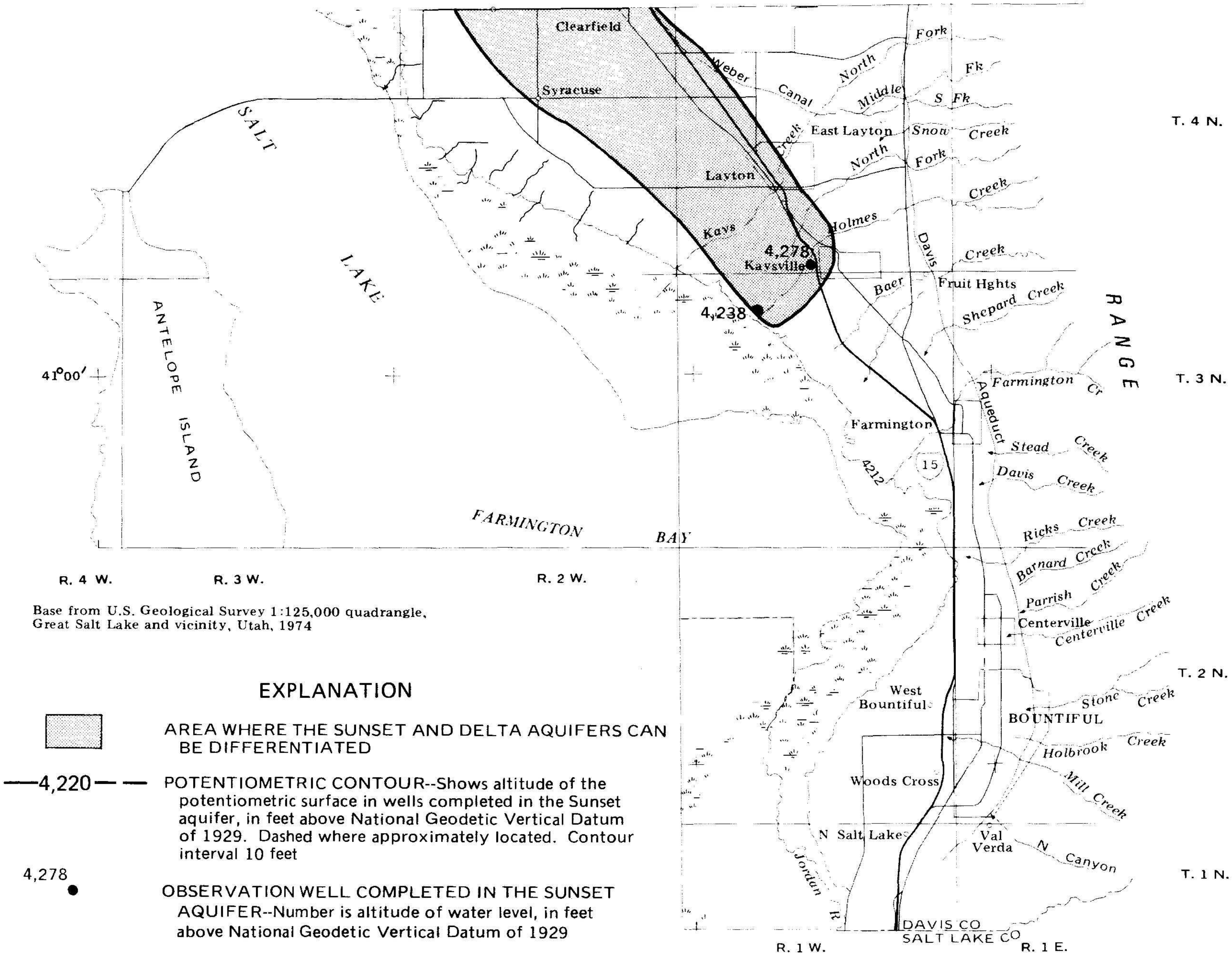


Figure 7.--Area where the Sunset and Delta aquifers of the East Shore aquifer system can be differentiated, and the potentiometric surface of the Sunset aquifer, March 1985.

composed of mixtures of gravel, sand, and silt. The aquifer material becomes progressively finer grained toward Great Salt Lake.

In the Bountiful area, all wells greater than 100 feet deep were considered to be completed in the East Shore aquifer system. Near the mountain front, the aquifer system is composed of either mudflow deposits which are poorly sorted and only slightly permeable, or sediments deposited at the mouths of the major stream channels, which are coarse grained and more permeable. Farther from the mountains, the sediments consist of alternating layers of gravel, sand, and clay. Thomas and Nelson (1948, p. 167) defined the shallow artesian aquifer as being from 60 to 250 feet below land surface, the intermediate artesian aquifer as being from 250 to 500 feet below land surface, and the deep artesian aquifer as being at depths greater than 500 feet. In this report, these aquifers were not differentiated because they have neither substantial lithologic differences or large vertical head differences.

Unconfined parts of the East Shore aquifer system generally are present only as lateral extensions of the confined aquifers upgradient in a small area near the mountain front within the recharge area (fig. 3). The sediments in these parts of the aquifer system typically are coarse grained; finer grained confining layers are thin or absent. Unconfined ground water that is not part of the East Shore aquifer system as defined in this report is present in flood-plain deposits along stream channels, in isolated perched water-table aquifers on the bench areas, and throughout the valley lowlands within a few feet of land surface.

Transmissivity and storage coefficient were determined from aquifer tests and by reanalyzing aquifer tests conducted prior to this study. The results of the tests are given in table 5.

Values of transmissivity determined from aquifer tests range from 150 to 30,000 feet squared per day. The smallest values generally are from wells nearer the western edge of the valley lowland where the aquifers are predominately fine-grained and thinly bedded, and from some wells finished in unfractured rock or in mudflow deposits near the mountain front. The largest values of transmissivity generally are from wells finished in thick coarse-grained alluvium near the center of the valley, under the benchlands, or near river or stream channels.

The values in table 5 do not necessarily represent the full range of transmissivity in the study area. Values estimated from other methods including specific-capacity data (Theis and others, 1963, p. 331-340), lithologic data from drillers' logs, and previously published results of aquifer tests, indicate that transmissivity may be much larger in the area south of Ogden and near Hill Air Force Base.

Values of storage coefficient for the confined parts of the East Shore aquifer system are fairly consistent throughout the study area. The values range from about 3×10^{-6} to 1×10^{-4} with an average value of about 9×10^{-5}.

Table 5.—Results of aquifer tests

Location: P, pumped well; F, flowing well: I, injection well.
Methods of analysis: HM, Hantush modified method (Hantush, 1960)); SLM, Straight-line solution method (Jacob and Lohman, 1952); IM, Injection method (Cooper and others, 1967, p. 264, 265)

Location: Well tested	Location: Observation well	Date	Discharge (gallons per minute)	Transmissivity (T) (feet squared per day): Drawdown	Transmissivity (T) (feet squared per day): Recovery	Storage coefficient (S): Drawdown	Storage coefficient (S): Recovery	Method of analysis
(A-2-1)7dca-1 P		10-47	400		1,800			SLM
20cdd-1 P		10-47	26		6,700			SLM
28bca-1 P		4-76	1,500		5,000			SLM
32ccb-2 P		2-58	1,000		30,000			SLM
34cdb-1 P		7-81	240		600			SLM
34dcc-1 P		7-76	1,250		1,000			SLM
(B-2-1)13acd-1 F		3-47	38		200			SLM
13cdd-2 F		4-47	105		1,700			SLM
26bdd-2 F		3-47	250		2,000			SLM
26cdd-1 F		5-36	53		1,000			SLM
26dca-3 F		3-47	275		7,100			SLM
(B-3-1)5dda-1 F		3-85	200		4,000			SLM
15aab-1 I		5-85	33		150			IM
(B-4-1)19daa-1 P	(B-4-1)19cd 20cbb-1 30bba-1	10-53	1,800		10,000		2.6×10^{-4}	HM
(B-4-2)12bbb-1 P	(B-4-2)2dad 12bdc	4-53	1,330		17,000		1.2×10^{-4}	HM
(B-4-2)14baa-1 P		3-85	275		7,700			SLM
(B-5-2)3baa-1 P	(B-5-2)3baa-2	3-85	550	5,100	5,300	1.5×10^{-4}	1.4×10^{-4}	HM
(B-5-2)16daa-2 P	 (B-5-2)16dcd-1	8-85	1,800		16,700 13,100		 4.4×10^{-5}	SLM HM
(B-5-2)22dcd-1 P	 (B-5-2)11aac-1 14bdc-1 16dcd-1 26daa-1 36bcc-1	6-84	1,680	 3,500	23,500 3,800	 5.6×10^{-5}	 2.9×10^{-6}	SLM HM
(B-6-1)4bbd-1 P	 (B-6-1)5cdb-1 (B-7-1)33dbd-1	8-68	750	4,300 700		 3.1×10^{-4}		SLM HM
(B-6-2)25 P	(B-6-2)25bbc-1 25bbc-3 25bca-1 25bcb-1	4-54	80		1,300		1.2×10^{-4}	HM
(B-6-2)30ada-1 F		3-85	100		2,500			SLM
(B-7-3)31daa-4 P	 (B-7-3)31aac-1 32cbb-1	12-69	120	 1,600	1,300	 7.3×10^{-5}		SLM HM
(B-7-3)31dab-1 P	(B-7-3)31dac-1	12-69	54	380		4.4×10^{-5}		HM
(B-7-3)31d P	(B-7-3)31daa-1	12-69	35	1,500		1.4×10^{-5}		HM

Recharge

Annual recharge to the East Shore aquifer system is estimated to have averaged about 153,000 acre-feet during 1969-84 (table 6). The ultimate source of most of the recharge water is precipitation in the mountainous areas of numerous basins that drain to the East Shore area. The aquifer system is recharged by seepage of water from streams, canals, irrigated fields, lawns and gardens, by infiltration of precipitation, and by subsurface inflow from consolidated rock of the Wasatch Range to basin-fill deposits.

Table 6.--Summary of recharge to the East Shore aquifer system

Source	Estimated annual recharge (acre-feet)
Seepage from natural channels and irrigation canals	60,000
Seepage from irrigated fields	5,000
Seepage from lawns and gardens	3,000
Infiltration from precipitation	10,000
Subsurface inflow	75,000
Total	153,000

Recharge Area

Recharge to the East Shore aquifer system was calculated only for the area near the front of the Wasatch Range, where the surficial and underlying sediments are permeable enough to transmit water downward to the alluvial aquifers. The zone of permeable sediments extends as far as 7 miles west of the mouth of Weber Canyon to less than one-fourth of a mile west of the mountain front in areas north of Ogden and south of Farmington (fig. 3). The recharge area consists of two parts (fig. 3) that have different potential for accepting recharge by downward movement. The primary recharge area is nearest the mountain front; it is underlain by predominately permeable sands and gravel that enhance infiltration of recharge water. The secondary recharge area is farther from the mountains; it is underlain by some finer grained sediments that partially impede downward movement and therefore probably accepts direct infiltration less readily than areas closer to the mountain front (Feth and others, 1966, p. 39). Although no direct relation was known for infiltration rates between the recharge areas, for the purpose of calculating recharge, it was assumed that the rate of infiltration in the secondary recharge area was one-half of the rate of the primary area.

Seepage from Natural Channels and Irrigation Canals

The average annual recharge during 1969-84 by seepage from natural channels and irrigation canals that cross the recharge areas was estimated to be about 60,000 acre-feet, primarily as seepage from channels of major streams. In areas where the streams enter the valley lowland, the natural channels contain gravel, boulders, and larger sized material that are permeable and susceptible to seepage. Fluctuations of water levels in some wells near stream channels show a relation to fluctuations in annual streamflow. The relation between the highest water level in a well and the annual flow in Centerville Creek for the water years 1950-84 is shown in figure 8 and indicates possible recharge from the stream upgradient from the well.

Weber River

The average annual recharge by seepage from the Weber River during 1969-84 was estimated to be 26,000 acre-feet. Seepage losses were estimated to range from about 12,000 acre-feet in the drought year of 1977 to about 38,000 acre-feet per year during the high water and flood years of 1983 and 1984. The estimates are based on a series of flow measurements made during this and other projects including a concurrent study on canal and river losses (Herbert and others, 1986). Losses from the river occur in the river channel for about 1½ to 2 miles downstream from the mouth of Weber Canyon (fig. 3). The river channel contains large boulders and cobbles and is entrenched within a flood plain about one-quarter mile wide. Even during high flow the river generally stays within its channel and does not spill onto the flood plain. Losses from the river at the mouth of Weber Canyon were estimated to range from about 3 percent of the flow during high flow to about 20 percent of the flow during low or base flow. These estimates are based on seepage measurements made during this and other studies during moderate and low flows. The total monthly flow of the river at the mouth of Weber Canyon was determined by subtracting the total diversions from the river downstream from the gaging station near Gateway from the flow near Gateway. Estimated losses during four high-flow months (March-June) account for one-half of the estimated total annual losses. Losses during low-flow periods are estimated to be about 20 cubic feet per second, whereas average losses during high-flow periods are estimated to be about 60 cubic feet per second.

The sediments in and underlying the river channel near the canyon mouth are extremely permeable. They apparently are at least hundreds of feet thick and there is no evidence of finer grained layers to impede downward movement of recharge water.

West of the primary recharge area (fig. 3), however, there is evidence in drillers' logs of shallow wells of a perched zone near and probably underlying the river. Feth and others (1966, p. 41) reported possible eastward movement of water toward the mountains in this shallow zone. Although all seepage studies conducted on the river during this study show substantial gains in the flow of the river in this area, these gains are most likely water moving from perched zones on the adjacent benchlands and flood plains into the river channel. They are not believed to be return flow from upstream river losses (Feth and others, 1966, p. 41).

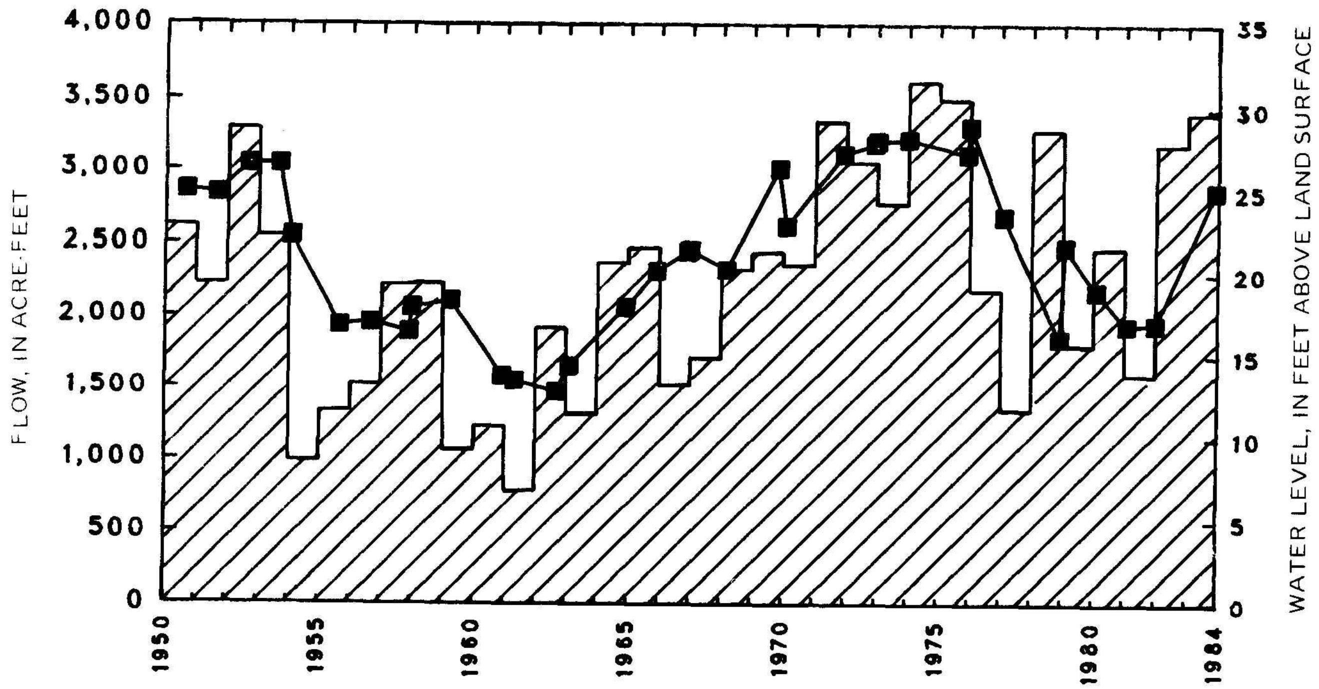


Figure 8.--Relation between annual flow of Centerville Creek and highest water level in well (A-2-1)18abd-12, water years 1950-84.

Ogden River

Annual recharge from the Ogden River is a small percentage of the total annual flow of the river. The annual recharge is estimated to average about 3,000 acre-feet and to range from 2,000 to about 4,000 acre-feet. These estimates are based on the average monthly flow at the mouth of Ogden Canyon for 1969-81 and on results of seepage measurements made during this and previous studies. Seepage losses are estimated to average about 3 cubic feet per second (Feth and others, 1966, p. 41) and are estimated to range from about one to five percent of the flow. The area near the mouth of Ogden Canyon appears similar to the area near the mouth of Weber Canyon in topography and in the composition of the riverbed deposits; however, only minimal recharge to the East Shore aquifer system is estimated from this major source of surface water.

Other major streams

The average annual recharge from the other major streams, listed in table 3, is estimated to total about 8,500 acre-feet. This estimate is based on records and estimates of monthly flow and seepage measurements made on three streams assumed to be representative of the other major streams.

Measurements to detect seepage losses were made on Mill, Parrish, and Holbrook Creeks during high flows in June 1985. Each stream was divided into three sections, the uppermost section starting where the stream is entrenched in consolidated rock, and the lower section generally ending at the west boundary of the primary recharge area (fig. 3). Measurable losses of flow in all three streams, were fairly consistent, ranging from about 10 to 20 percent of the flow. Seepage losses occurred in the middle section generally between altitudes of about 4,800 and 4,600 feet.

Average annual recharge for 1969-84 from Mill Creek was estimated to be 1,800 acre-feet by assuming a seepage loss of 15 percent at high flow, based on measurements, and a maximum of 50 percent loss during low flow, based on information from local residents and observations. Total annual recharge is about 25 percent of the total annual flow.

Using similar procedures, average annual recharge was estimated to be 430 acre-feet from Parrish Creek and 750 acre-feet from Holbrook Creek. Total annual seepage loss is about 25 percent of the total annual flow of these two streams.

Estimates of the average annual recharge from other streams for 1969-84, based on a 25 percent seepage loss, are: Holmes Creek, 880 acre-feet; Ricks Creek, 580 acre-feet; Centerville Creek, 680 acre-feet; and Stone Creek, 880 acre-feet. The recharge from Farmington Creek was decreased to about 20 percent of the annual flow, or about 2,500 acre-feet per year for 1969-84, because of summertime diversions from the stream upstream of the recharge area.

Ungaged perennial, ephemeral, and intermittent streams

Recharge from smaller streams generally is by seepage into alluvial fans near the mouths of canyons and is estimated to total about 12,500 acre-feet per year. No accurate estimates of losses are available for most of these streams. For this study, it was assumed that seepage losses from these streams range from 25 to 50 percent of the total annual flow, depending on the location of the stream and the estimated amount of annual flow. Seepage measurements indicate larger losses in the primary recharge area than in the secondary area. Therefore, streams that cross only the secondary recharge area (fig. 3) were assumed to have no more than a 25-percent seepage loss, whereas most of the streams that cross the primary recharge area were assumed to have an annual loss of 50 percent of their total flow. Streams that cross the primary recharge area and have an estimated annual flow of about 1,500 acre-feet or greater (table 4) were assumed to have a loss of about 25 percent of the total annual flow on the basis of measurements of Holbrook and Parrish Creeks. The streams listed in table 4 that are tributaries to the Ogden River between the gage below Pineview Reservoir and the mouth of the canyon are not included in these estimates.

Irrigation canals

Irrigation canals within the recharge area range in size from small ditches to the Davis-Weber Canal, which annually transports about 70,000 acre-feet of water. Most of the major canals in the recharge area are lined with concrete and, therefore, lose little if any water by seepage.

The Davis-Weber Canal system has been in operation for many years; its concrete lining is cracked and in poor condition in places. Seepage measurements made on 9 reaches of the canal during summer 1985 as part of a concurrent study (Herbert and others, 1986) indicated losses near the head and end reaches of the canal, with little evidence of losses from the middle reaches. A major part of the canal system lies within the recharge area, and most losses from the canal are considered to recharge the East Shore aquifer system. The average annual recharge from the canal is estimated to be about 10,000 acre-feet.

The other canals and ditches in the recharge area are either lined and have small or no seepage losses, or are small, unlined ditches that carry a minimal amount of water. Losses from these canals were assumed to be minimal when compared to losses from applied irrigation water and were, therefore, not estimated.

Infiltration from Irrigated Fields, Lawns, and Gardens

The average annual recharge from approximately 6,000 acres of irrigated cropland in the recharge areas is estimated to be 4,500 acre-feet. About 75 percent, or 4,500 acres, of the irrigated cropland is in the secondary recharge area. The amount of recharge from applied irrigation water depends on several factors including the quantity of water applied, the type of application, consumptive use by crops, and the permeabilty of the soils. On the basis of other studies (Feth and others, 1966, p. 43; Clark and Appel, 1985, p. 29; and U.S. Bureau of Reclamation 1967 and 1968, 1969) it was estimated that 4 feet of water per year was applied to all cropland. In the primary recharge area, where permeable materials occur at the surface, about 30 percent of the applied water, or 1,800 acre-feet, was estimated to recharge the East Shore aquifer system. If 15 percent of the applied water infiltrated to the East Shore aquifer system in the secondary recharge area, where the surface materials are less permeable, the estimated recharge there was 2,700 acre-feet.

The average annual recharge from lawns and gardens in the recharge areas is estimated to be 3,000 acre-feet. Approximately 16,000 acres of land under predominately urban (and some suburban) use (including streets and buildings) is in the recharge area. This total includes about 12,500 acres in the secondary recharge area and 3,500 in the primary recharge area. The water applied to these predominately urban areas is from treated municipal supplies and from canals and pipelines. The amount of water applied annually to these areas is unknown but was estimated based on seasonal municipal water-use records to be about 1 foot per acre, or a total of 16,000 acre-feet. The seepage loss from this applied water is estimated to be the same as that for irrigated fields, or 30 percent in the primary recharge area (about 1,000 acre-feet) and 15 percent in the secondary recharge area (about 2,000 acre-feet).

Direct Infiltration from Precipitation

The average annual recharge by direct infiltration of precipitation in the recharge areas is estimated to be about 10,000 acre-feet; but it may vary considerably from one year to the next depending on amount, intensity, season, and type of precipitation. The average annual precipitation in the recharge area is estimated to be about 20 inches, based on records at the Ogden Pioneer Powerhouse station (table 1). The recharge area includes about 45,000 acres, of which 13,000 acres is in the primary recharge area and the remaining 32,000 acres is in the secondary recharge area. On the basis of previous estimates (Feth and others, 1966, p. 43), it was assumed that 20 percent of the average annual precipitation infiltrates in the primary recharge area and 10 percent infiltrates through the less permeable sediments in the secondary recharge area.

Subsurface Inflow

Subsurface inflow to the East Shore aquifer system from consolidated rocks is estimated to be about 75,000 acre-feet per year as described in the following sections. Most of the inflow is assumed to be by direct water movement from fissures and joints and along faults in the consolidated rock of the Wasatch Range to the unconsolidated basin-fill deposits (fig. 2). In the southern two-thirds of the study area, the Wasatch Range is primarily composed of thick sequences of Precambrian metamorphic rocks, which in some areas have been extensively faulted and fractured. Water is assumed to enter the rock from seepage of snowmelt percolating down through the mountain soils into fractures or into the weathered mantle overlying the rock.

Evidence of inflow

The occurrence of subsurface recharge cannot be directly measured, and estimates are based on only limited available data and assumptions; however, indirect evidence exists of subsurface inflow from consolidated rock to the basin-fill deposits. The indirect evidence includes data from wells completed in consolidated rock; springs in consolidated-rock areas; differences in the chemical quality of water from wells, streams, and springs; and comparison of hydraulic heads between wells completed in rock and in basin fill where there are only small amounts of recharge from other sources.

Numerous wells have been completed at or near the surficial contact between the basin fill and consolidated rock, and data from these wells indicate that in some areas the rock is permeable and that water does move from consolidated rock to alluvium. Some wells completed in consolidated rock near North Ogden and from Farmington to Bountiful discharge freshwater in quantities of about 50 gallons per minute by artesian flow, indicating that some of the consolidated rock is capable of transmitting substantial quantities of water. Wells near Bountiful generally are more productive when completed in "fractured" rock or near faults indicating the fractured metamorphic rock is transmitting water that may be recharging the downgradient basin fill. Water levels in some wells that are completed in the alluvium near the mountain front, yet distant from sources of surface water, fluctuate seasonally, probably in response to recharge by seepage from snowmelt moving into the alluvium from consolidated rock. For example, the water level in a well penetrating consolidated rock east of Ogden declined at least 46 feet from September 1984 to April 1985 and rose at least 36 feet in the next 2 months, probably due in part to recharge to consolidated rock.

The occurrence of springs discharging from consolidated rock, water flow into the Gateway Tunnel, and gains in flow in the Weber River where it flows on rock are evidence that consolidated rock in the Wasatch Range contains water in substantial quantities. Feth and others (1966, p. 42) reported on the discharge of springs near the mouth of Weber Canyon, which indicates rocks in the Wasatch Range are capable of contributing appreciable volumes of water to the basin fill. When the Gateway Tunnel was drilled through the Wasatch Range, considerable water was encountered at various places (Feth and others, 1966, p. 42). The flow into the tunnel was measured for 2 years and ranged from about 0.5 to 1.0 cubic foot per second. The hydrograph of the flow (Feth and others, 1966, pl. 7) indicates that fractures and fissures in metamorphic rocks receive recharge from snowmelt, which normally would flow to the basin fill or the Weber River if it had not been intercepted by the tunnel. Flow measurements made on the Weber River near the mouth of Weber Canyon during this study were compared with records of flow at the Gateway gaging station several miles upstream. The comparison indicates that the river consistently gains as much as 25 cubic feet per second, or about 10 percent of the total flow, during low-flow periods in that reach. Only minor tributaries join the Weber River in the reach between the measurement sites; therefore, the gain is probably ground-water inflow from consolidated rock.

Springs that discharge from consolidated rock in the Wasatch Range annually supply a total of about 4,000 acre-feet of water for municipalities near the mountains. These springs generally supplement the available surface water and have a reasonably predictable annual discharge.

Calculation of inflow

In order to estimate the subsurface inflow from the consolidated rock to the unconsolidated basin fill, the following variation of the Darcy equation was used to estimate subsurface flow from all sources topographically higher than the cross section:

$$Q = TIL \qquad (2)$$

where:

Q = discharge, in cubic feet per day;

T = transmissivity, in feet squared per day;

I = hydraulic gradient (dimensionless); and

L = length, in feet, of the cross section through which flow occurs.

The flow was computed through a cross section that follows a line along the eastern flank of the valley as close to the basin fill-rock contact as available data would permit. The line was divided into 13 segments based on differences in hydraulic properties and available data. The location of the cross section line segments is shown in figure 9, and the estimated flow across those segments is given in table 7.

The total annual flow of about 130,000 acre-feet computed through the section includes about 55,000 acre-feet per year of recharge from other sources upgradient of the section. It is assumed that all recharge from natural channels, about 50,000 acre-feet, occurs near the mouths of the canyons upgradient from the section. In addition, about 3,500 acre-feet of recharge directly from precipitation, 1,000 acre-feet from irrigated fields, and 500 acre-feet from lawns and gardens is assumed to occur upgradient of the section on the basis of land use there. The adjusted total recharge from subsurface inflow, therefore, is estimated to be about 75,000 acre-feet per year.

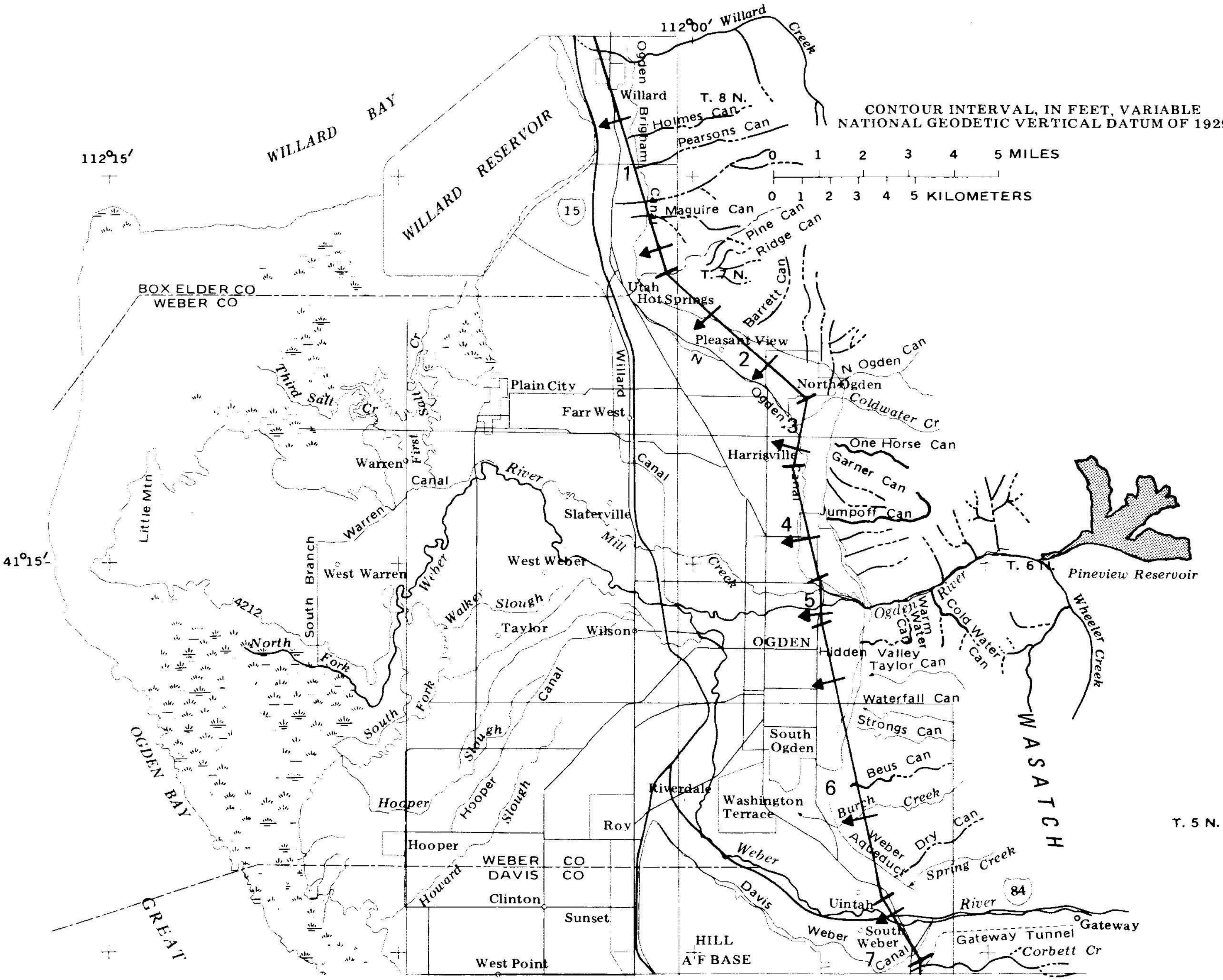
Table 7.--Estimated annual subsurface inflow from consolidated rock to basin fill

Line segment numbers for cross section (see fig. 9)	Transmissivity (T) (feet squared per day)	Hydraulic gradient (I) (dimensionless)	Length of segment (feet)	Discharge (Q)	
				Cubic feet per day (rounded)	Acre-feet per year (rounded)
1	10,000	0.0029	28,700	830,000	7,000
2	1,500	.046	21,800	1,500,000	13,000
3	3,000	.032	8,300	800,000	6,700
4	2,000	.017	13,200	450,000	3,800
5	5,000	.025	5,600	700,000	5,900
6	1,000	.032	33,000	1,100,000	9,200
7	25,000	.019	8,200	3,900,000	33,000
8	1,000	.05	44,500	2,200,000	18,000
9	1,500	.067	7,900	790,000	6,600
10	1,000	.043	13,500	580,000	4,900
11	1,000	.03	15,500	460,000	3,900
12	2,000	.06	12,900	1,500,000	13,000
13	500	.06	20,800	620,000	5,200
				Total (rounded)	130,000

Less recharge within the recharge areas upgradient from computation line (fig. 9)

Streams	50,000
Direct precipitation	3,500
Irrigated fields	1,000
Lawns and gardens	500
Subtotal	55,000

Total subsurface inflow from consolidated rock....75,000


CONTOUR INTERVAL, IN FEET, VARIABLE
NATIONAL GEODETIC VERTICAL DATUM OF 1929
0 1 2 3 4 5 MILES
0 1 2 3 4 5 KILOMETERS
112°00′
112°15′
41°15′
WILLARD BAY
WILLARD RESERVOIR
Willard Creek
Willard
T. 8 N.
Holmes Can
Pearsons Can
Ogden Brigham Canal
15
Maguire Can
Pine Can
Ridge Can
T. 7 N.
Barrett Can
Utah Hot Springs
Pleasant View
N Ogden Can
North Ogden
Coldwater Cr
BOX ELDER CO
WEBER CO
Third Salt Cr
First Salt Cr
Plain City
Farr West
Willard Canal
N Ogden Canal
Harrisville
One Horse Can
Garner Can
Jumpoff Can
Warren
Canal
River
Slaterville
Mill Creek
Little Mtn
South Branch
Warren
West Warren
Weber
West Weber
T. 6 N.
Pineview Reservoir
Wheeler Creek
Ogden River
Warm Water Can
Cold Water Can
4212
North Fork
Walker Slough
Taylor
Wilson
OGDEN
Hidden Valley
Taylor Can
Waterfall Can
WASATCH
South Fork
Canal
Strongs Can
South Ogden
Beus Can
OGDEN BAY
Slough
Hooper Slough
Hooper
Riverdale
Washington Terrace
Burch Creek
Roy
Weber Aqueduct
Dry Can
T. 5 N.
Hooper
WEBER CO
DAVIS CO
Howard Slough
Spring Creek
Weber
84
Clinton
Davis
Uintah
River
Sunset
Weber
South Weber Canal
Gateway
Gateway Tunnel
Corbett Cr
GREAT
HILL AF BASE
West Point
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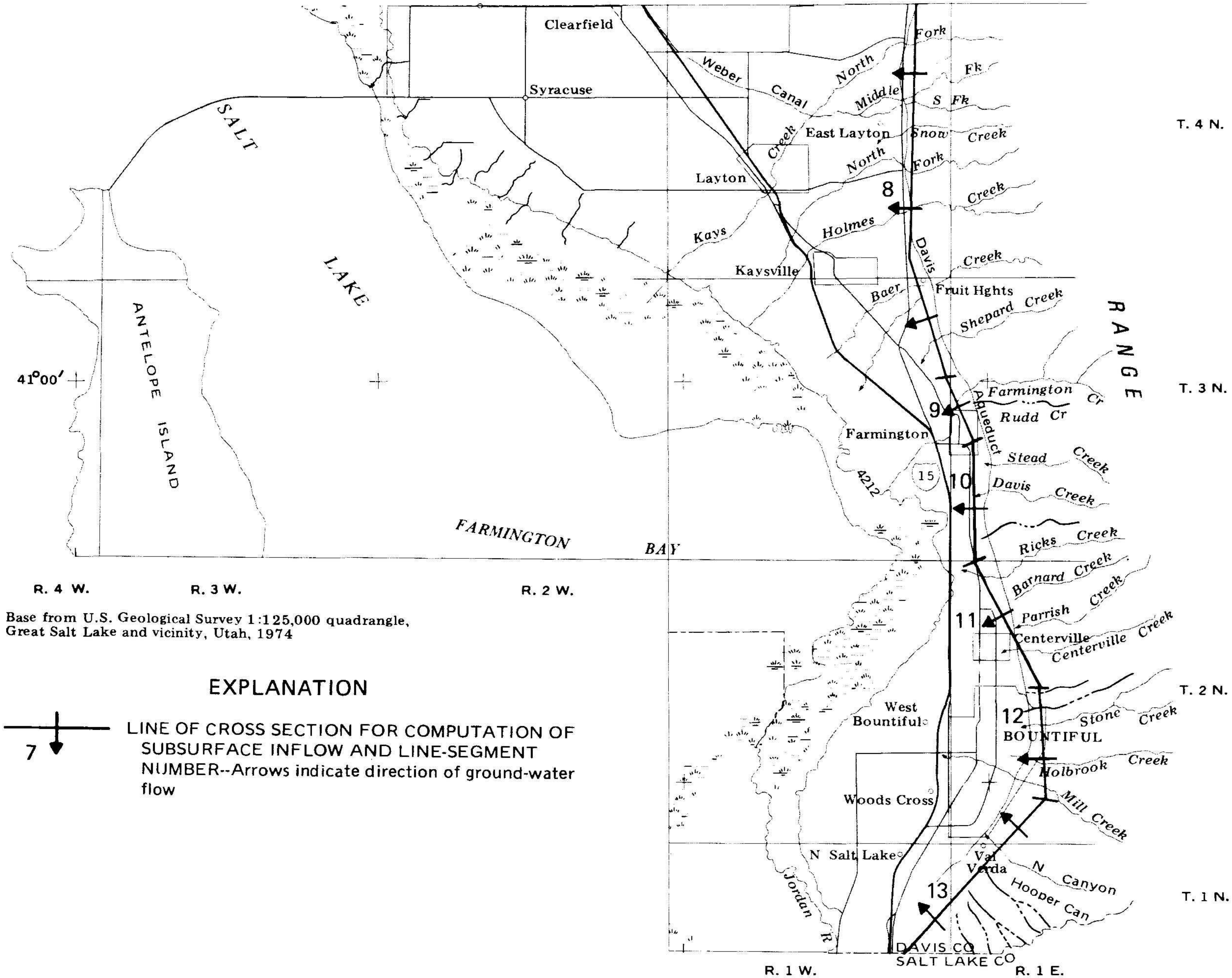


Base from U.S. Geological Survey 1:125,000 quadrangle, Great Salt Lake and vicinity, Utah, 1974

EXPLANATION

7 — LINE OF CROSS SECTION FOR COMPUTATION OF SUBSURFACE INFLOW AND LINE-SEGMENT NUMBER--Arrows indicate direction of ground-water flow

Figure 9.--Location of perennial, ephemeral, and intermittent streams and cross-section lines used to compute subsurface inflow.

Movement

Ground water in the East Shore aquifer system generally moves westward from the mountain front toward Great Salt Lake (pl. 1, fig. 7). A downward component of movement exists throughout the recharge area near the mountain front (fig. 2) where heads decrease with depth. An upward component of movement exists where water is confined and heads increase with depth; water moves upward through confining beds from deeper parts of the aquifer system to shallower parts of the system. The hydraulic connection within the aquifer system depends on the thickness of the clay layers and other fine-grained sediments between separate parts of the aquifer system. Generally, where the clay or other fine-grained deposits are thick, the hydraulic connection within the aquifer system is less.

The upward hydraulic gradient may be reversed locally because of large-scale withdrawals of water from wells. This may occur seasonally as well as during a period of years. Near Warren and Little Mountain, hydraulic heads in the Sunset aquifer and the deeper part of the East Shore aquifer system indicate downward movement of ground water from the shallow to the deep parts of the aquifer system. Water levels in wells near South Weber and Hill Air Force Base have declined to below the confining layer(s) between aquifers, and thus, water-table conditions now exist where artesian conditions were previously present.

Potentiometric-surface maps were prepared for the East Shore aquifer system based on water levels measured in March 1985. A map of the Sunset aquifer (based on water levels from wells completed at depths from 200 to 400 feet) was prepared for the central Weber Delta area where that aquifer had been delineated (fig. 7). A separate map was prepared for the remainder of the East Shore aquifer system, including the Delta aquifer and excluding water levels from wells in the Sunset aquifer (pl. 1). The potentiometric-surface maps and ground-water movement in the East Shore aquifer system are described in the following paragraphs.

Water in the Sunset aquifer generally moves from east to west, perpendicular to the contours shown in figure 7. The hydraulic gradient is about 0.001 (5 feet per mile) and is consistent throughout much of the area west of Ogden. Near Kaysville the gradient may be steeper, however, the water-level altitude is known for only two wells.

The configuration of the potentiometric surface for the rest of the East Shore aquifer system, including the Delta aquifer and excluding the Sunset, is shown on plate 1. Movement of ground water generally is perpendicular to the contours shown. The map includes water levels in wells drilled deeper than 400 feet in the central part of the Weber Delta area and water levels in all other wells outside of this area, including wells completed in the unconfined parts of the East Shore aquifer system and all wells completed at depths greater than 100 feet in the Bountiful area. Some of the irregularities in the potentiometric surface may be caused by the decline of water levels due to large-scale withdrawal of water from wells or by differences in hydrostatic head due to differences in the depth of the wells.

Near the mountain front, water levels are affected primarily by recharge from streams and from subsurface inflow. In the North Ogden area, a large amount of the recharge occurs by subsurface inflow from consolidated rock, as indicated by the configuration of the potentiometric contours. This recharge, possibly together with a thinner section of basin fill or possibly lower permeability downgradient, causes the altitude of the potentiometric surface to be higher than in the rest of the Weber Delta area; in this area, wells completed at relatively shallow depths flow.

In the Bountiful area, the shape of the water-level contours, which generally bulge westward from the mountain front, reflect recharge from Mill and Holbrook Creeks and recharge by subsurface inflow from consolidated rock. The potentiometric surface in the Bountiful area may also have been affected by withdrawal of water from wells.

The potentiometric contours of the East Shore aquifer system near Riverdale are concave to the west along the Weber River. The water levels are most likely affected by recent large-scale ground-water pumpage in the immediate area.

Near Great Salt Lake, water moves from the deepest parts of the East Shore aquifer system by upward leakage into overlying deposits. The water levels near West Weber and Taylor, south of Harrisville, near Hooper Slough, and southwest of Farmington are affected by discharge, probably by upward leakage to drains and evapotranspiration. The water levels at the southern end of the East Shore area indicate possible movement of water toward the Jordan River.

The gradient of the potentiometric surface ranged from about 0.00017 (1 foot per mile) west of Hooper to about 0.012 (65 feet per mile) near West Bountiful. In 1985, the gradient from South Weber to the center of Hill Air Force Base was 0.001 (5 feet per mile) which is about the same as in 1960. Farther west however, the gradient has become less steep since 1960. In 1985, the gradient from Riverdale to Hooper was 0.00086 (4 feet per mile) compared to 0.0014 (7 feet per mile) in 1960. This change in gradient is probably a result of the withdrawals from wells near the mouth of Weber Canyon. The gradient typically steepens near the edge of the benches where aquifer zones thin, sediments become more fine-grained, and transmissivity decreases. The gradient toward Great Salt Lake is quite steep in the area between Farr West and Willard where it is about 0.0045 (24 feet per mile) and also in the area between Farmington and Bountiful where it is about 0.0052 (28 feet per mile).

The vertical gradient within the East Shore aquifer system varies with depth and location, and in 1985 ranged from -0.096 to 0.104 (table 8). The negative gradients indicate downward movement of ground water, which is normal in recharge areas, whereas the positive gradients indicate upward movement, which is normal in discharge areas. A large positive vertical gradient generally indicates a less permeable confining layer between water-bearing zones, whereas a small gradient may indicate a more permeable confining layer and, therefore, perhaps more discharge by upward leakage to drains and evapotranspiration. The gradients shown in table 8 were calculated based on the difference in the altitudes of the potentiometric heads in pairs of wells divided by the difference in depth of the wells or top of perforations of the wells.

Table 8.--Vertical gradients between water-bearing units of different depths in the East Shore area, 1985

Well number	Altitude of potentiometric surface (feet)	Depth of well (D) or top of perforations (P) (feet)	Gradient (dimensionless) [(-) downward gradient, (+) upward gradient]
(A-2-1) 7dca-1	4,289	355 (P)	
(A-2-1) 7ddd-1	4,302	220 (P)	-0.096
(A-2-1)18abd-7	4,307	90 (D)	
(A-2-1)18abd-12	4,304	280 (D)	+.016
(B-3-1) 5dda-1	4,278	873 (P)	
(B-3-1) 5ddb-2	4,238	328 (P)	+.073
(B-3-1) 5dda-1	4,278	918 (D)	
(B-3-1) 5ddb-3	4,271	655 (D)	+.027
(B-3-1) 5ddb-2	4,238	338 (D)	
(B-3-1) 5ddb-3	4,271	655 (D)	+.104
(B-5-2) 3aab-2	4,255	272 (P)	
(B-6-2)34dbb-1	4,267	648 (P)	+.032
(B-5-2) 6bdd-2	4,228	75 (P)	
(B-5-2) 6bdd-4	4,233	285 (P)	+.024
(B-5-2) 6bdd-3	4,248	609 (D)	
(B-5-2) 6bdd-4	4,233	303 (D)	+.049
(B-5-2) 6bdd-2	4,228	83 (D)	
(B-5-2) 6bdd-3	4,248	609 (D)	+.038
(B-5-2)30baa-1	4,241	306 (P)	
(B-5-2)30caa-2	4,258	614 (P)	+.055
(B-6-1) 4bbd-5	4,306	1,133 (D)	
(B-6-1) 4bda-1	4,399	165 (D)	-.096
(B-6-2) 6dbc-5	4,224	299 (P)	
(B-6-2) 7bbc-6	4,251	848 (P)	+.049

Unconfined ground water that is not considered part of the East Shore aquifer system, as defined in this report, is present locally in perched zones on the bench areas near Hill Air Force Base, South Ogden, and Bountiful. Water in these areas probably moves to the edge of the benches where it discharges to the Weber River, to springs, seeps, and drains, or by evapotranspiration. Some of the water moves into surface deposits in the valley lowlands. Minor quantities of this perched water may move downward to the East Shore aquifer system.

Water-Level Fluctuations

Water levels fluctuate in response to changes in the quantity of ground water in storage, which varies according to the amount of water added to or removed from the system. The fluctuations can be short term, diurnal, seasonal, and long term. Water-level data have been collected in the East Shore area intermittently since 1935 at a few wells, annually since 1963 in about 35 wells, and continually at a few wells equipped with water-level recorders since 1936. Water levels in about 50 wells were measured twice monthly during 1984-85. The location of wells for which water-level hydrographs were compiled for this study are shown in figure 10.

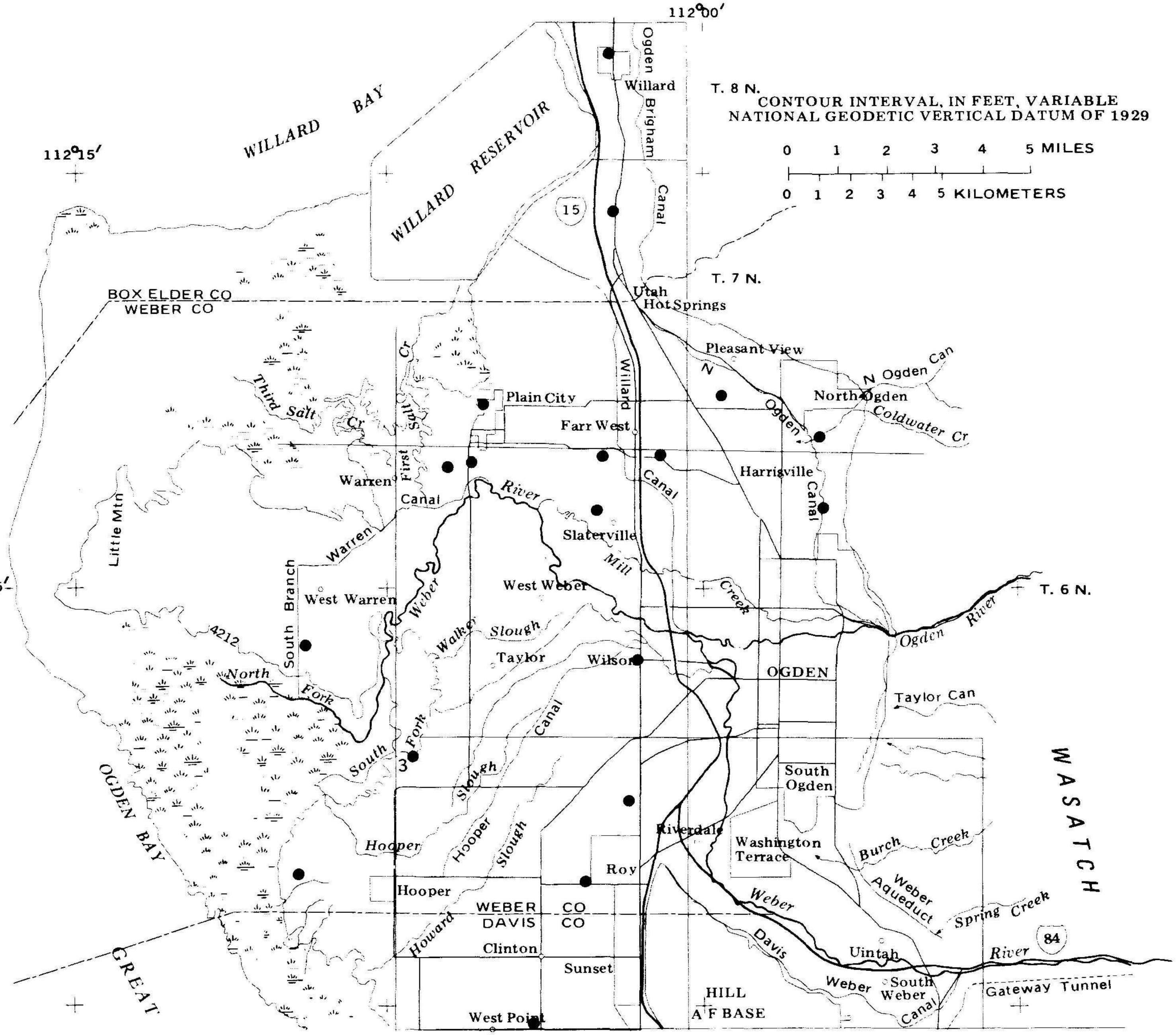
Seasonal Fluctuations

The major factors controlling seasonal fluctuations of water levels in wells are recharge by seepage from streams and discharge by withdrawal of water from wells. Other factors causing fluctuations include recharge by infiltration of precipitation and irrigation water and discharge by evapotranspiration. The magnitude of seasonal fluctuations varies from year to year, and the greatest fluctuations are near distinct areas of recharge or discharge. The magnitude of seasonal fluctuations may also depend on the depth of the well. The greatest fluctuations are in wells completed at the same depth as wells from which large amounts of water are withdrawn. Hydrographs showing seasonal fluctuations are shown in figures 11 to 26, and the primary reasons for the fluctuations are summarized in table 9.

The magnitude of the seasonal water-level fluctuation has increased since the late 1950's in almost all wells with long-term records (figs. 11 to 18). In some of the wells, water levels do not recover at the end of the summer to the previous spring high, and thus, long-term water-level trends reflect a general decline. An exception is well (B-3-1)25dab-1 (fig. 12) in which the water level was higher in the fall than in the spring of 1985.

The water levels in wells (B-7-2)11baa-3, (B-4-1)13bbc-1, and (B-6-1)9adb-2 (figs. 18-20), which are near the mountain front yet not near a surface-water source, show large seasonal changes in water levels. These changes appear to be a response to recharge from spring snowmelt as subsurface inflow from consolidated rock. The high water levels in 1984 in well (B-7-2)11baa-3 (fig. 20) are in response to greater than normal precipitation, which resulted in larger amounts of subsurface inflow.

The effects of withdrawals for municipal use on seasonal water-level fluctuations are shown in figures 11 and 22. The effects of proximity to a pumping center are indicated by comparing well (B-2-1)27ddd-4 (fig. 22), about 2 miles from the major pumping area in Bountiful, to well (B-2-1)26aad-1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T. 8 N.
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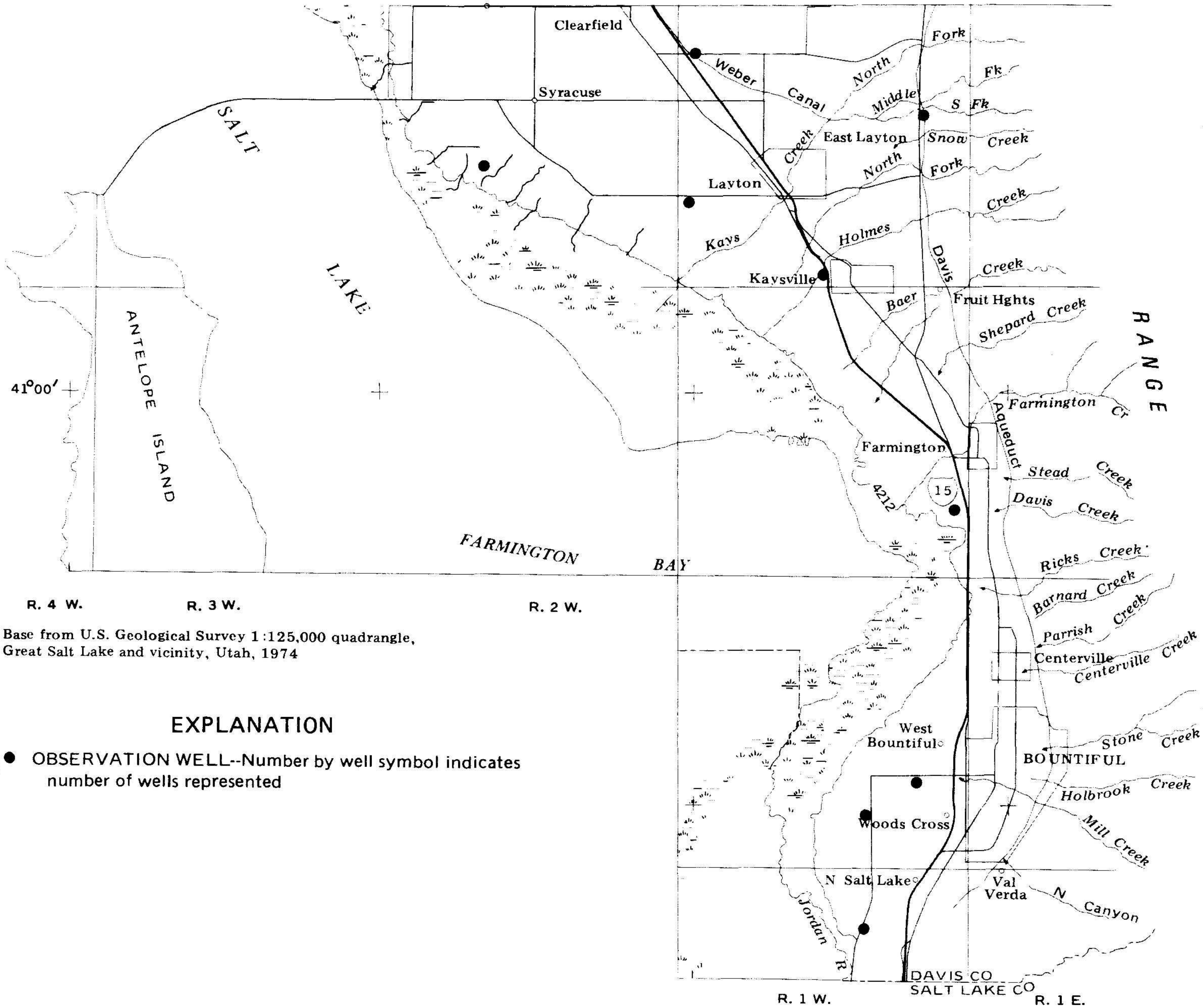
CONTOUR INTERVAL, IN FEET, VARIABLE
NATIONAL GEODETIC VERTICAL DATUM OF 1929
0 1 2 3 4 5 MILES
0 1 2 3 4 5 KILOMETERS
WILLARD BAY
WILLARD RESERVOIR
15
Ogden Brigham Canal
Willard
Utah Hot Springs
BOX ELDER CO
WEBER CO
Pleasant View
N Ogden Can
North Ogden
N Ogden
Coldwater Cr
Willard Canal
Plain City
Farr West
Harrisville
Canal
Third Salt Cr
First Salt Cr
Warren
Canal
River
Slaterville
Mill Creek
Warren
Little Mtn
South Branch
West Warren
Weber
West Weber
Ogden River
4212
Walker Slough
Taylor
Wilson
OGDEN
North Fork
Taylor Can
South Fork
Canal
Slough
South Ogden
WASATCH
OGDEN BAY
Hooper
Hooper Slough
Riverdale
Washington Terrace
Burch Creek
Weber Aqueduct
Roy
Spring Creek
Hooper
Howard
WEBER CO
DAVIS CO
Weber
Davis
Uintah
River
84
Clinton
Sunset
South Weber
Weber
Canal
Gateway Tunnel
HILL A F BASE
West Point
GREAT



Base from U.S. Geological Survey 1:125,000 quadrangle, Great Salt Lake and vicinity, Utah, 1974

EXPLANATION

3● OBSERVATION WELL--Number by well symbol indicates number of wells represented

Figure 10.--Location of wells for which hydrographs are shown in figures 11-26.

Table 9.—Primary reason for water-level fluctuations in observation wells

(Hydrographs for the wells are shown in figures 11-26)

Figure number	Well number	Depth (feet)	Primary reason for seasonal water-level fluctuations
11	(B-2-1)26aad-1	250	Withdrawal for public supply and irrigation
22	27ddd-4	500	Withdrawal for public supply and irrigation
12	(B-3-1)25dab-1	265	Withdrawal for public supply
13	(B-4-1) 7baa-1	902	Withdrawal for public supply
19	13bbc-1	127	Infiltration of snowmelt
14,23	30bba-1	525	Withdrawal for public supply
23	34cbc-3	350	Withdrawal for public supply and reduced upward leakage
15	(B-4-2)20ada-1	600	Withdrawal for public supply
24	(B-5-2) 6bdd-2	83	Reduced upward leakage due to withdrawals for public supply
24	6bdd-3	609	Withdrawal for public supply
24	6bdd-4	303	Withdrawal for public supply and reduced upward leakage
25	11aac-1	540	Withdrawal for public supply
25	15ddd-2	278	Withdrawal for public supply and reduced upward leakage
16	(B-5-3)15dda-1	649	Withdrawal for public supply
20	(B-6-1) 9adb-2	189	Recharge from infiltration of snowmelt
21	(B-6-2)11bcb-1	949	Withdrawal for public supply
17	26ada-1	600	Withdrawal for public supply
26	(B-7-1)30dca-1	180	Withdrawal for irrigation and public supply and reduced upward leakage
26	33dbd-2	636	Withdrawal for public supply
18	(B-7-2)11baa-3	365	Recharge from infiltration of snowmelt

(fig. 11), less than 1 mile from the pumping center. The seasonal water-level decline in well (B-2-1)26aad-1 was about 14 feet in 1985, whereas in well (B-2-1)27ddd-4 it was only about 5 feet. Seasonal water-level fluctuations generally are larger in deep wells than in shallow wells and are also larger in wells in areas near deep production wells (figs. 23-26).

Long-Term Fluctuations

Long-term fluctuations of water levels generally reflect either long-term trends in precipitation or changes in withdrawals from wells, or both. A comparison of the cumulative departure from average annual precipitation, withdrawal from municipal and industrial wells, and water levels in wells is shown in figure 27. Long-term hydrographs for representative wells in the East Shore area are shown in figure 28.

In the Weber Delta area, water-level trends in most wells for which hydrographs are shown closely follow the trend of the cumulative departure from normal precipitation until the late 1960's (fig. 27). Water levels were fairly stable from 1936 to about 1952 (fig. 28) when they began a decline that lasted until 1982. From 1982 to 1985 water levels rose slightly in most wells in response to much greater than normal precipitation. Precipitation was approximately normal from 1937 to 1952 and less than normal from 1952 until the early 1960's. Precipitation, as indicated by the departure line, was approximately normal from the mid-1960's until it began to increase in the late 1970's. The continued decline in water levels in the mid 1960's, despite the increase in precipitation, was due to the continued large-scale withdrawals for municipal and industrial use. The largest water-level declines are in wells near, and of the same depth as, wells that are pumped

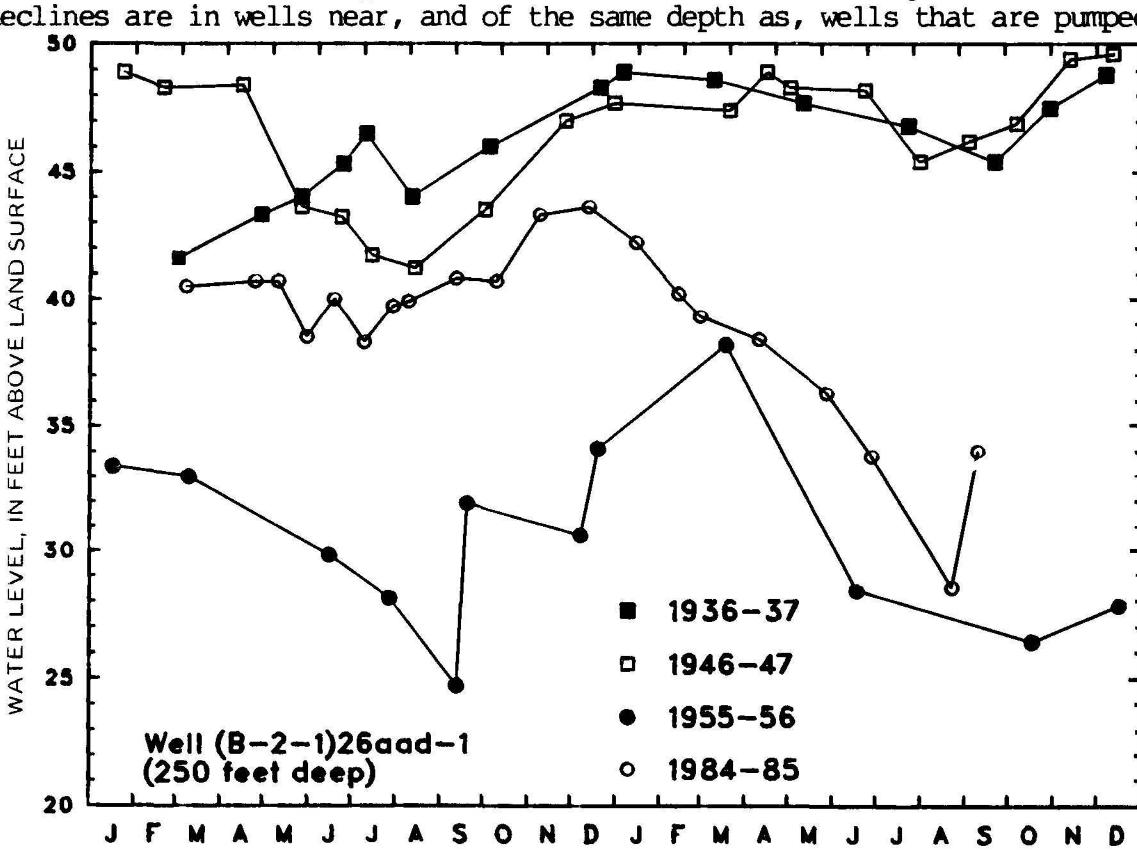


Figure 11.--Water levels in a well near Woods Cross, 1936-37, 1946-47, 1955-56, and 1984-85.

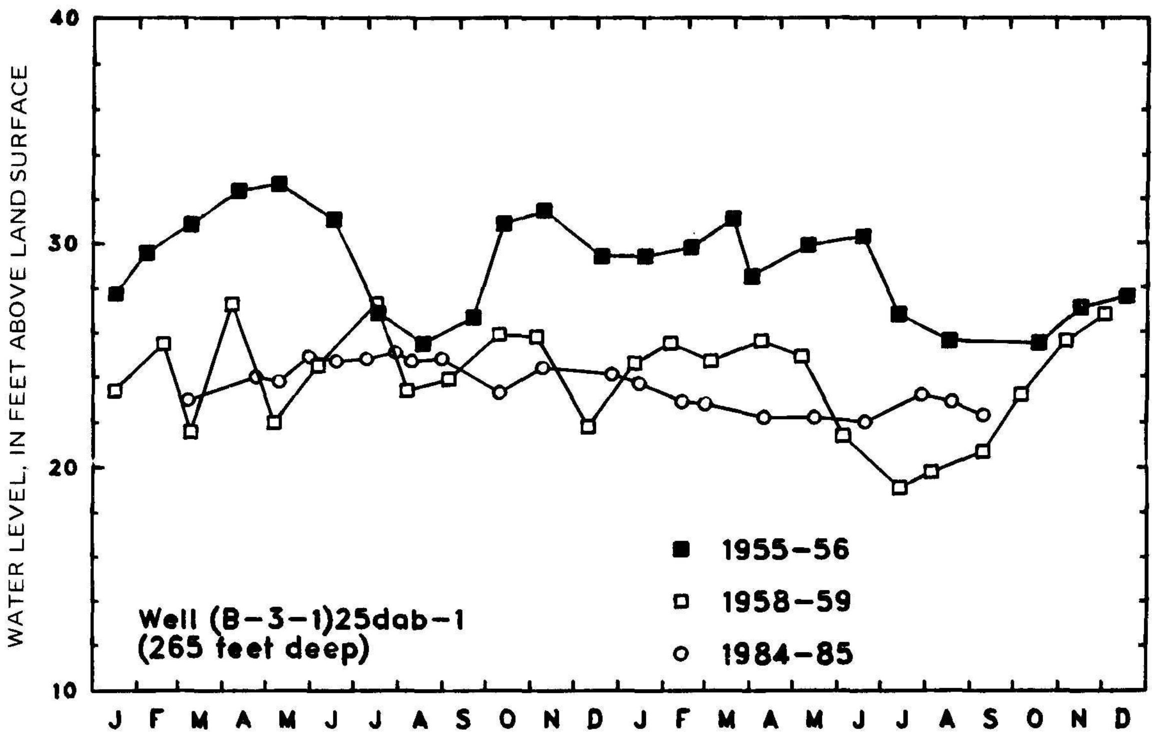


Figure 12.--Water levels in a well southwest of Farmington, 1955-56, 1958-59, and 1984-85.

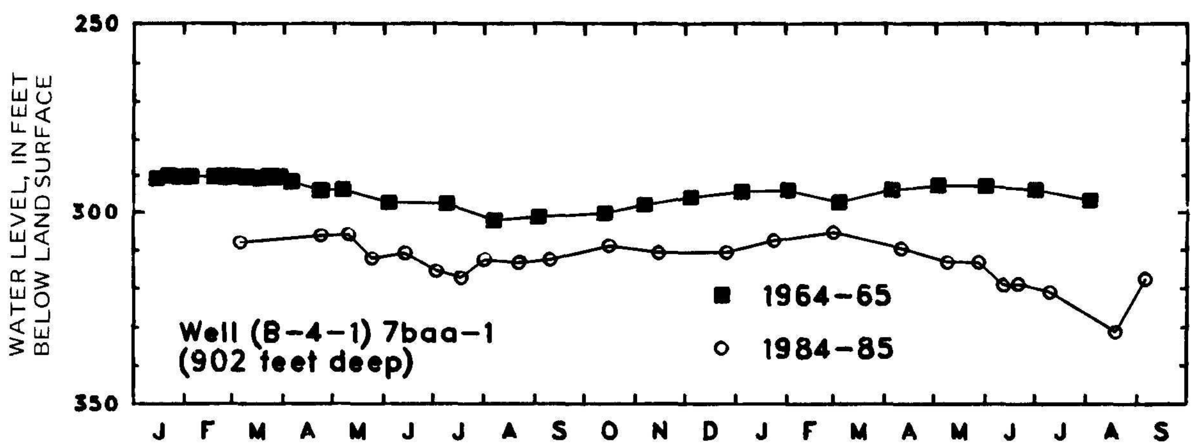


Figure 13.--Water levels in a well near Hill Air Force Base, 1964-65 and 1984-85.

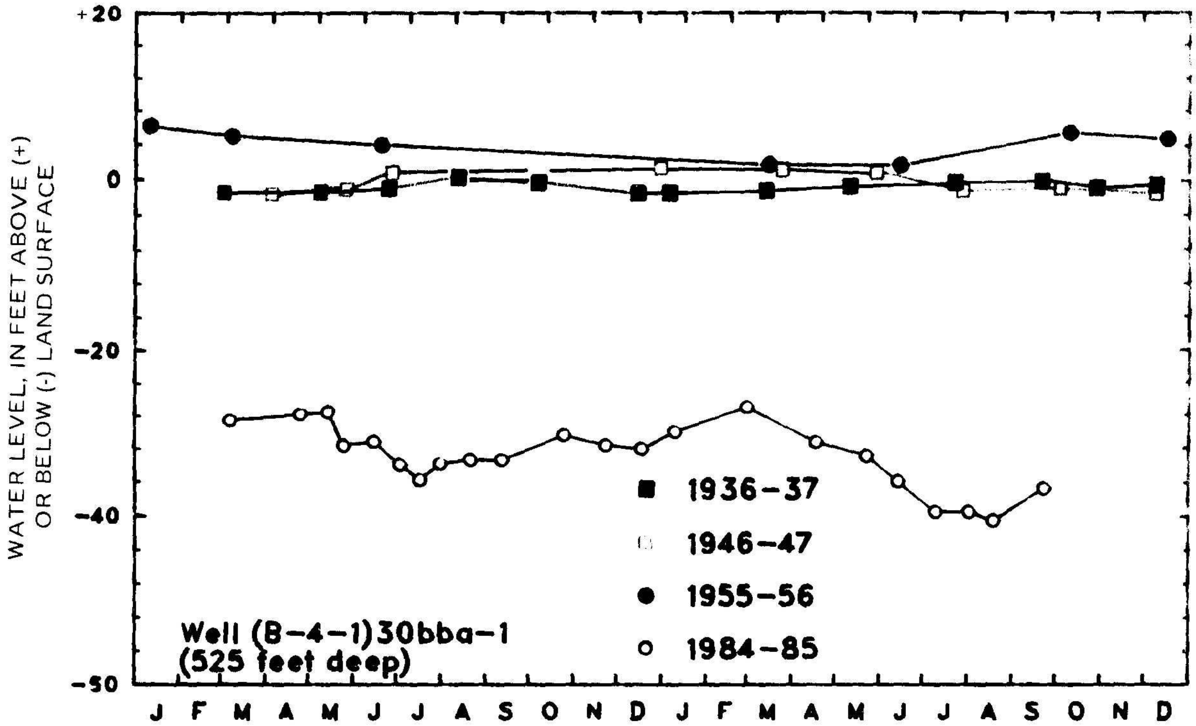


Figure 14.--Water levels in a well near Kaysville, 1936-37, 1946-47, 1955-56, and 1984-85.

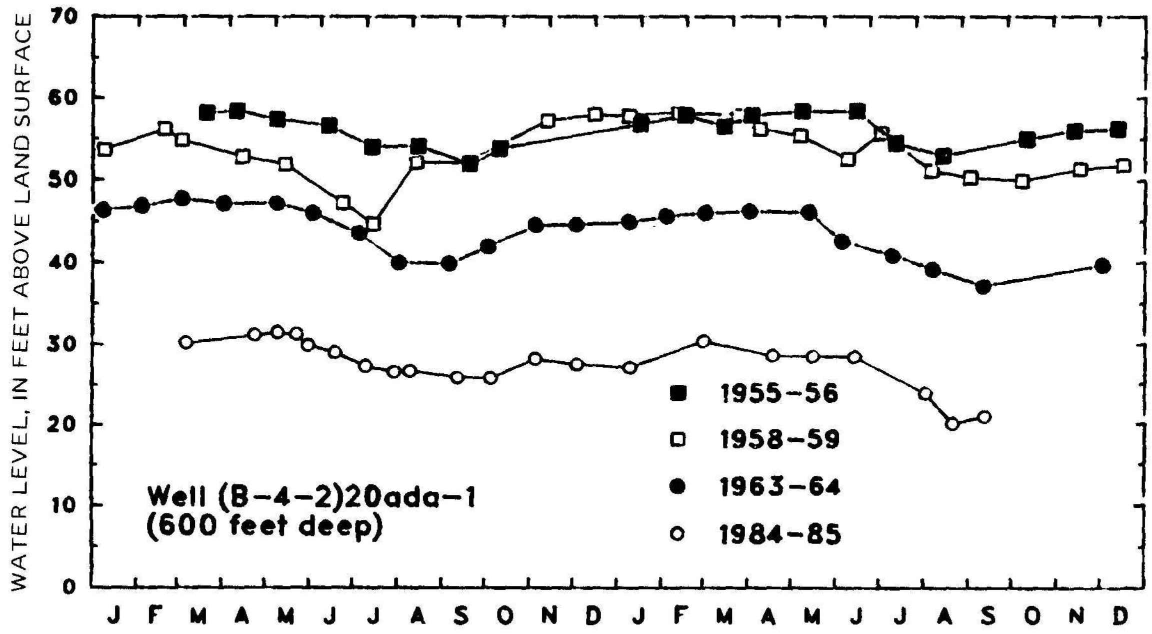


Figure 15.--Water levels in a well near Great Salt Lake, 1955-56, 1958-59, 1963-64, and 1984-85.

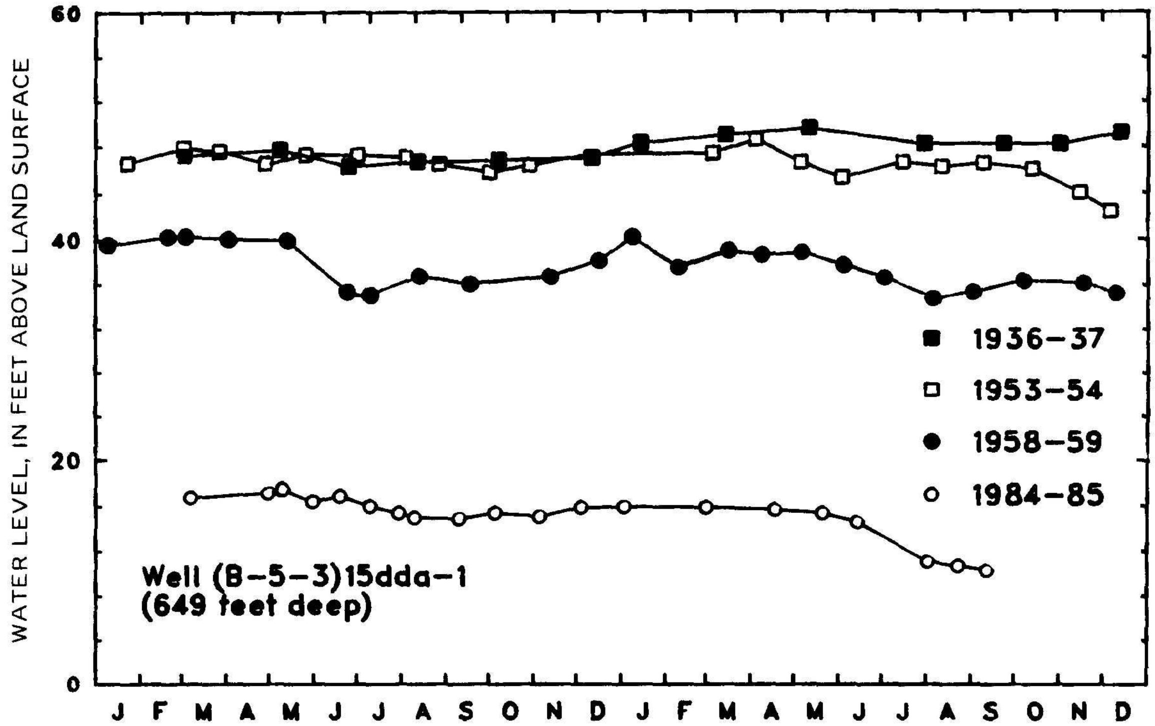


Figure 16.--Water levels in a well near Great Salt Lake, 1936-37, 1953-54, 1958-59, and 1984-85.

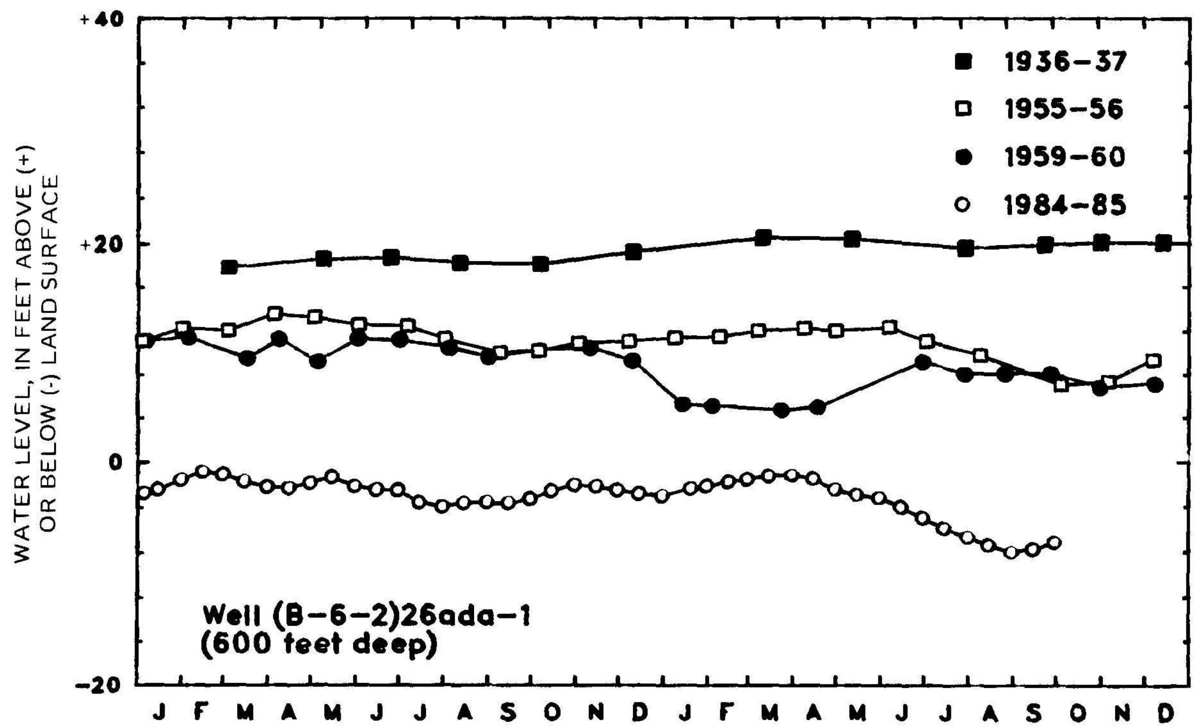


Figure 17.--Water levels in a well near Wilson, 1936-37, 1955-56, 1959-60, and 1984-85.

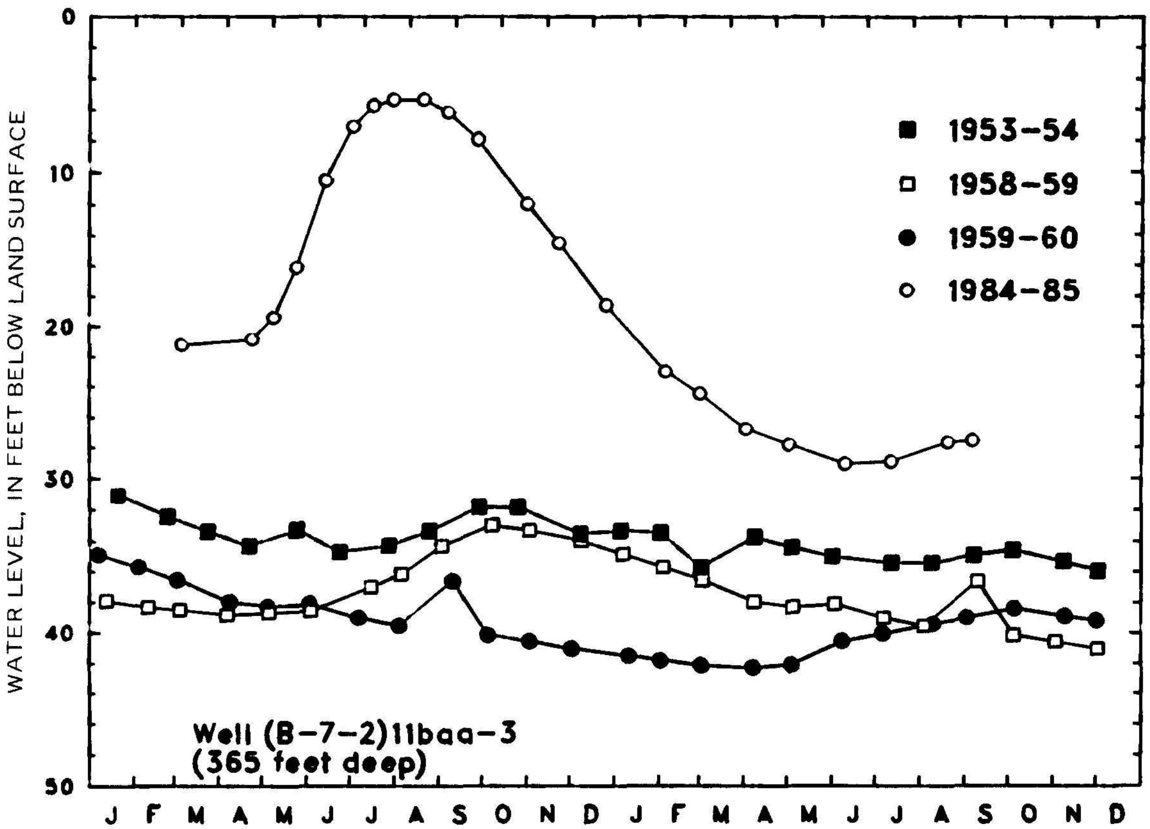


Figure 18.--Water levels in a well south of Willard, 1953-54, 1958-59, 1959-60, and 1984-85.

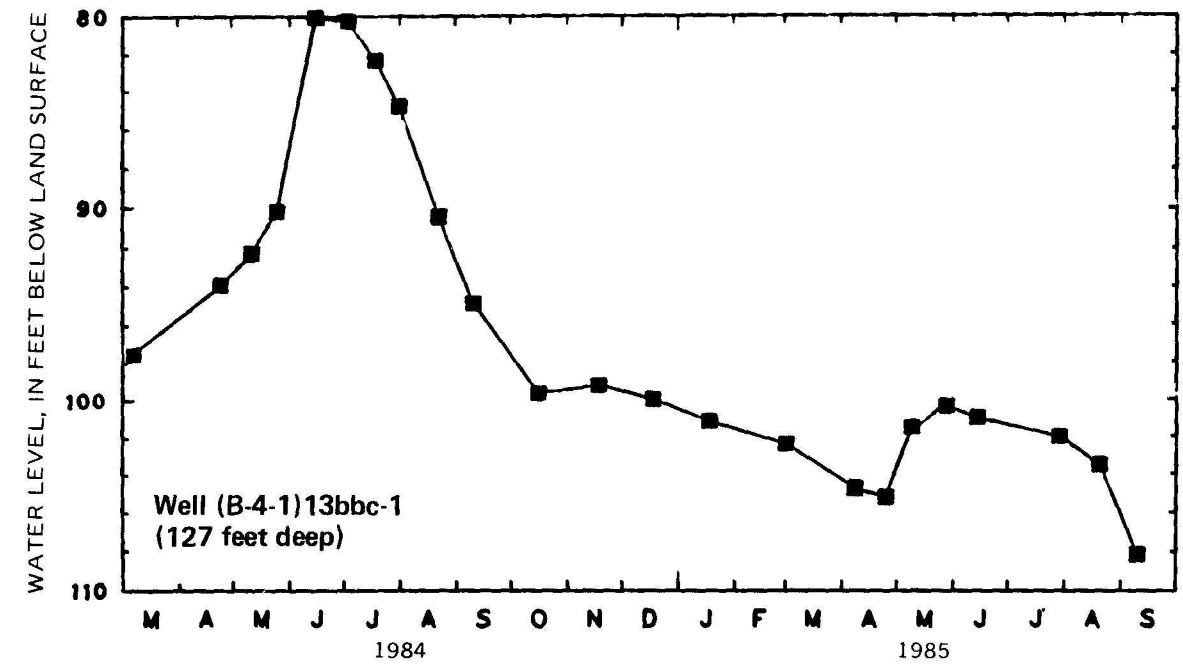


Figure 19.--Water levels in a well near East Layton, 1984-85.

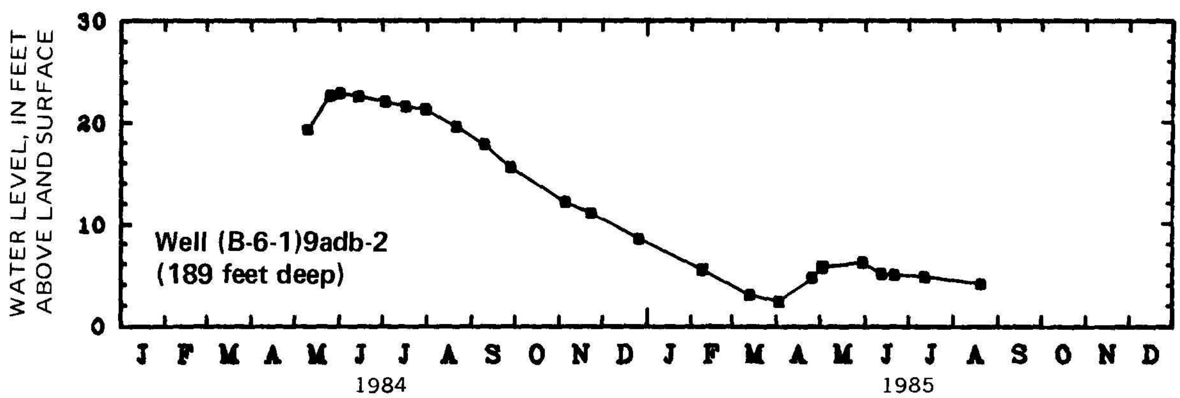


Figure 20.--Water levels in a well completed in consolidated rock near Harrisville, 1984-85.

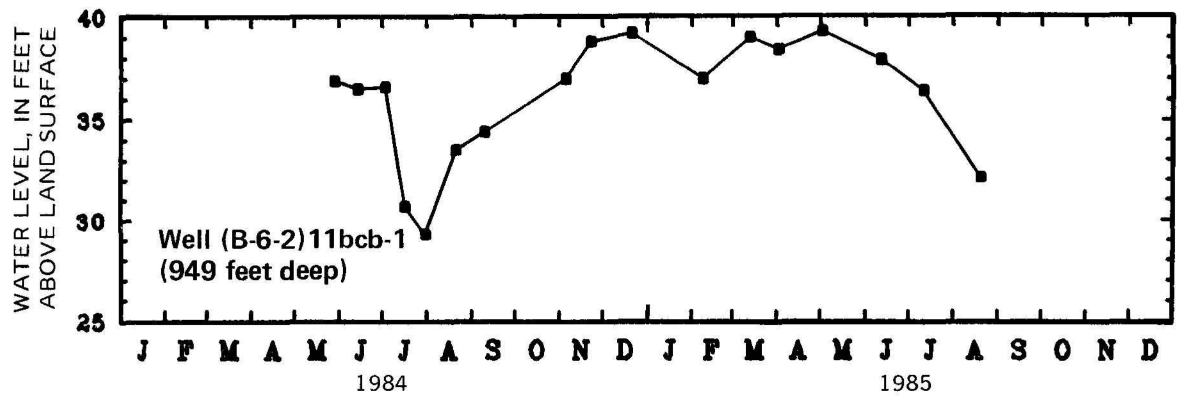


Figure 21.--Water levels in a well north of Slaterville, 1984-85.

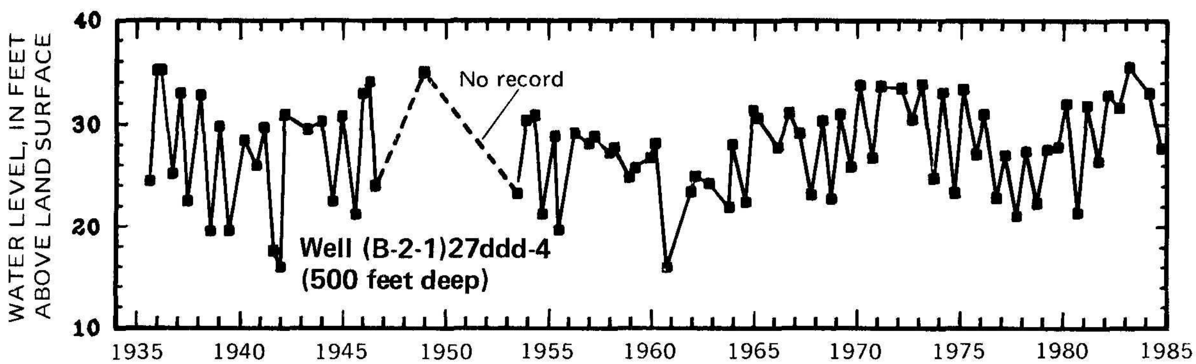


Figure 22.--Water levels in a well west of Woods Cross, 1936-85.

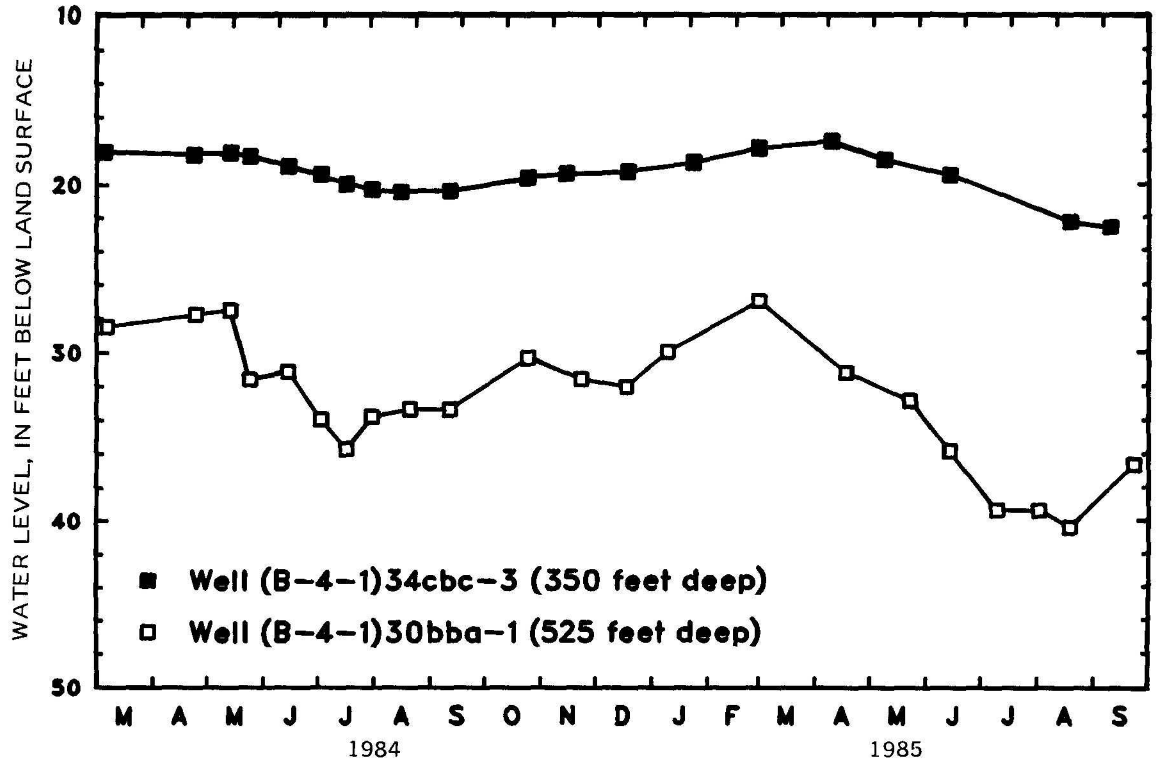


Figure 23.--Water levels in wells near Kaysville, 1984-85.

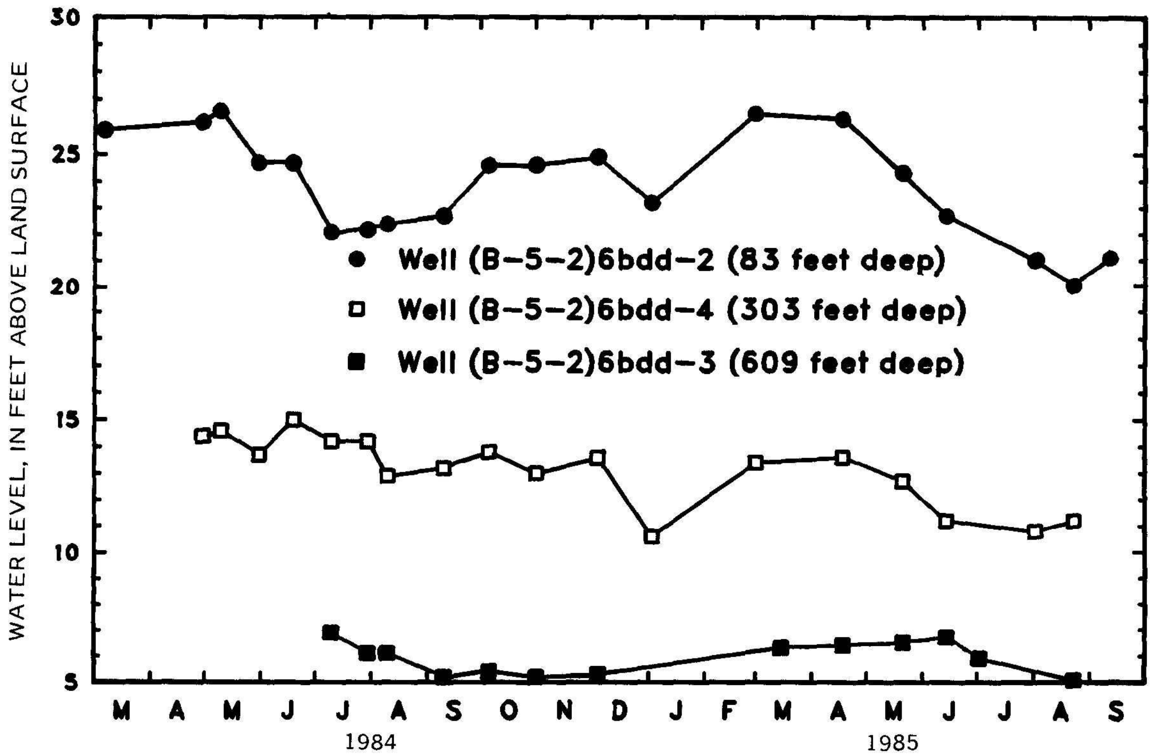


Figure 24.--Water levels in wells near Great Salt Lake, 1984-85.

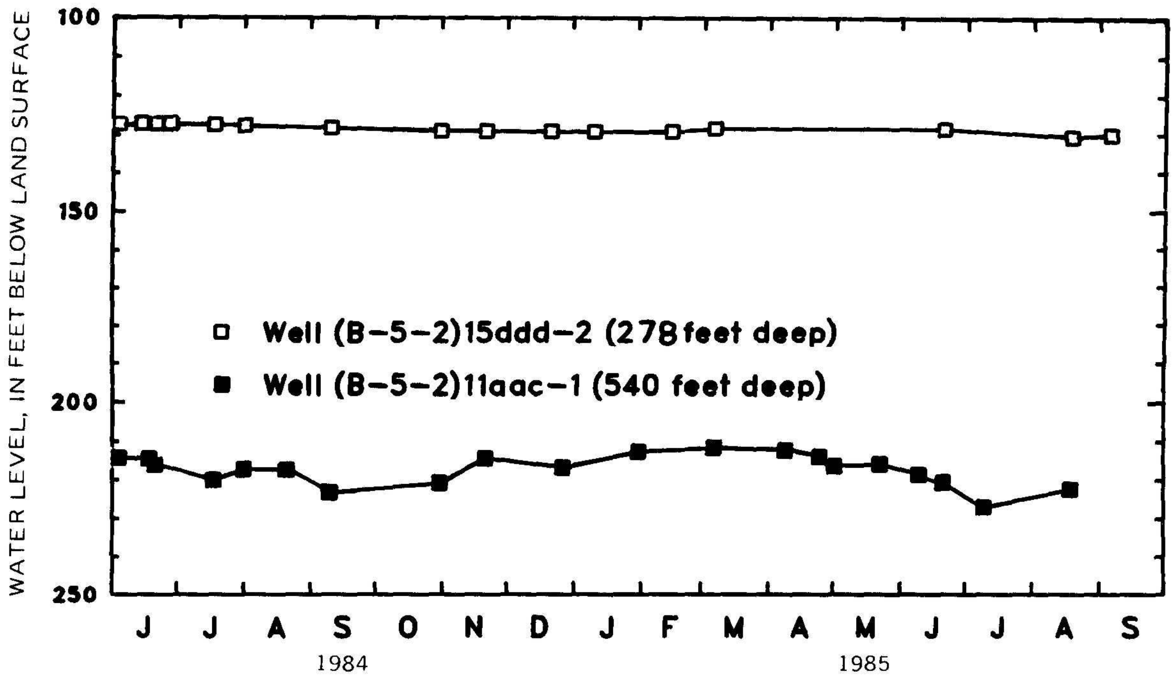


Figure 25.--Water levels in wells north of Roy, 1984-85.

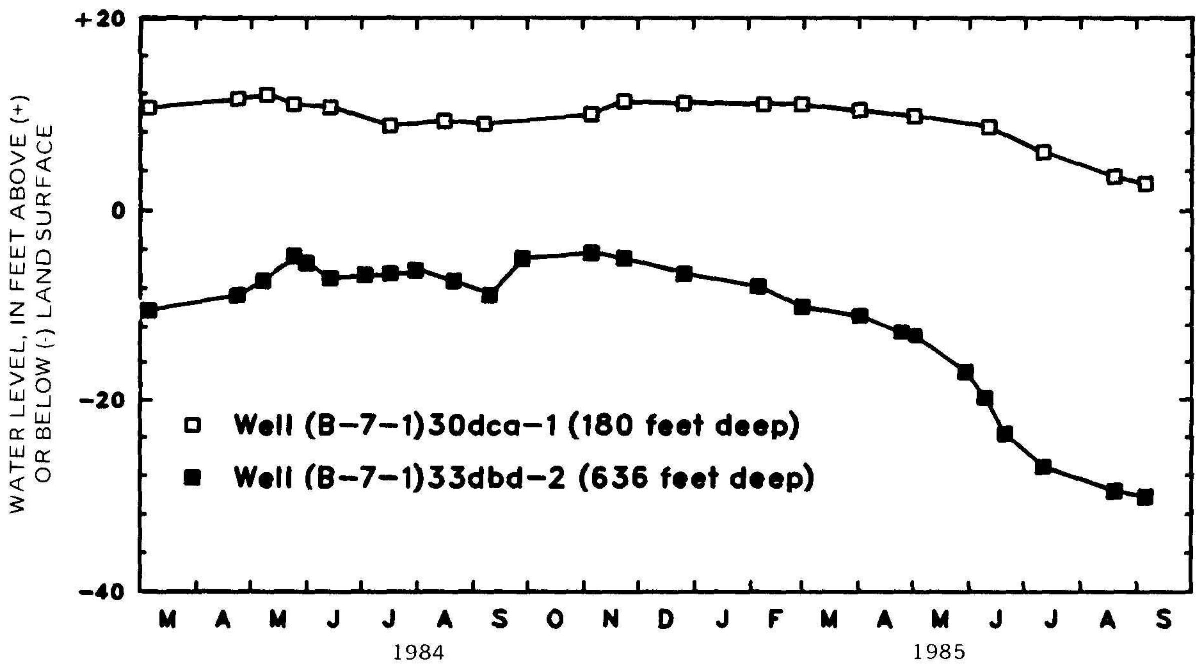
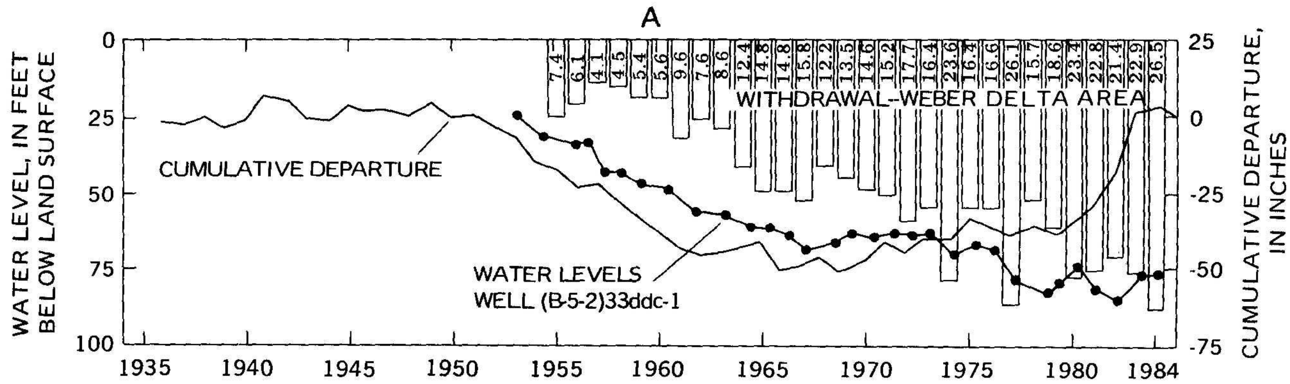


Figure 26.--Water levels in wells near Pleasant View, 1984-85.



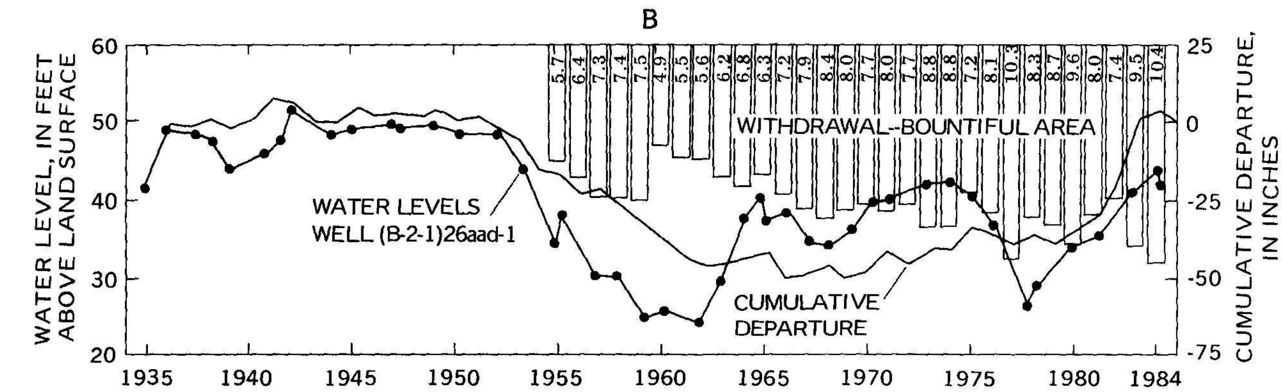


Figure 27.--Comparison of cumulative departure from the average annual precipitation at the Ogden Pioneer Powerhouse to: a) water levels in well (B-5-2)33ddc-1 and withdrawal from wells for municipal and industrial use in the Weber Delta area; and b) water levels in well (B-2-1)26aad-1 and withdrawal from wells for municipal and industrial use in the Bountiful area. [Number inside withdrawal histogram is discharge in thousands of acre-feet.]

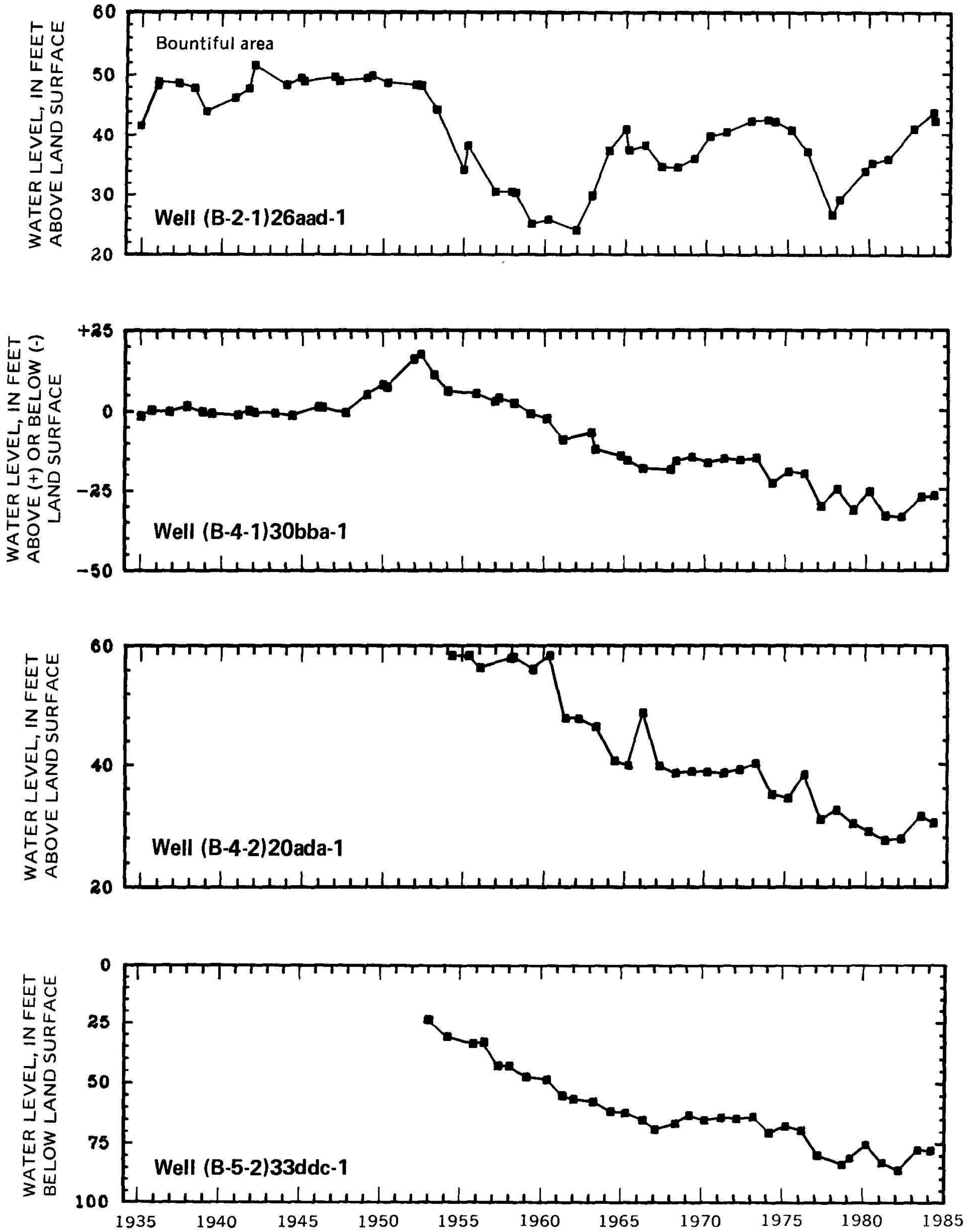


Figure 28.--Water levels in selected wells, 1936-85. All wells are in Weber Delta area except where indicated.

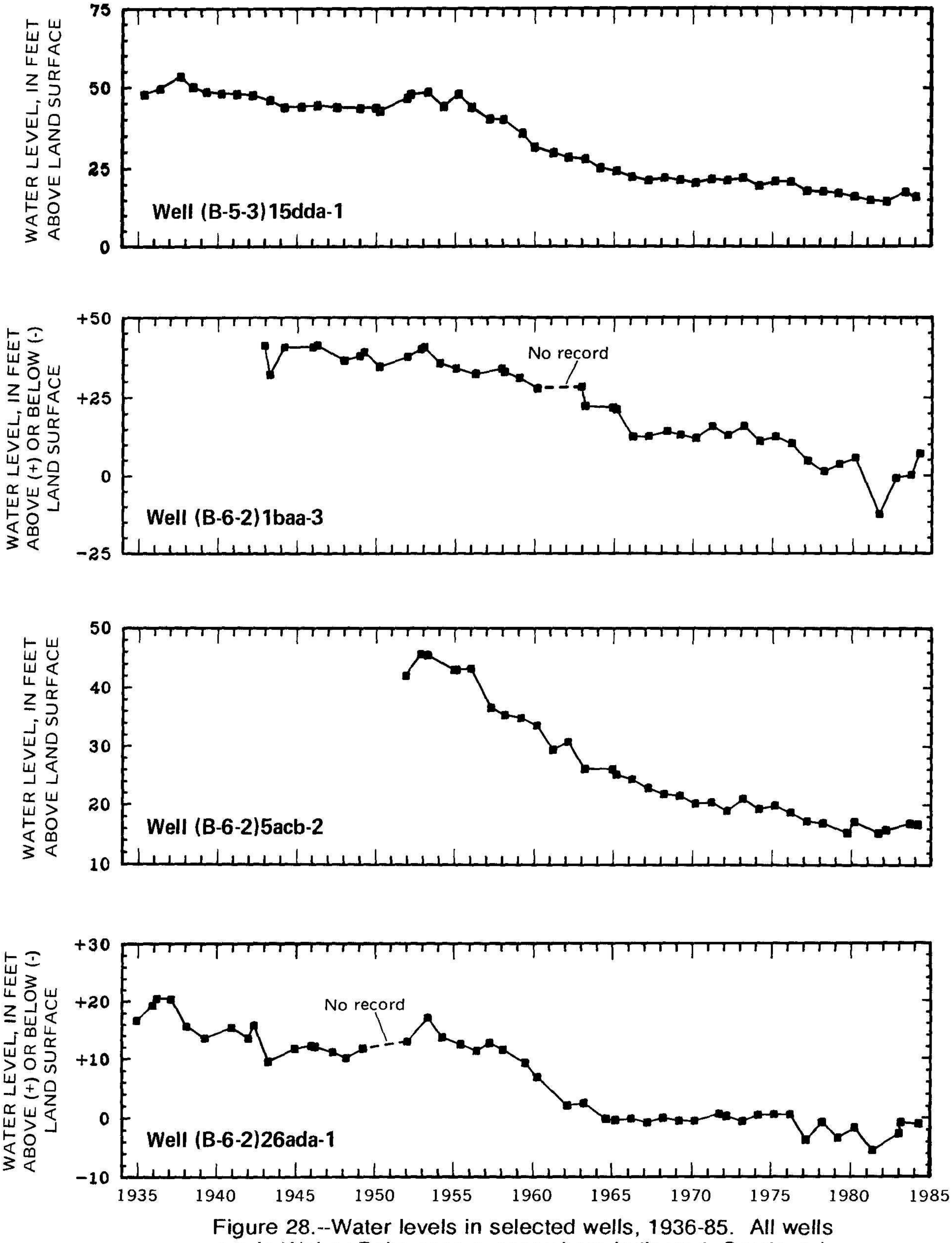


Figure 28.--Water levels in selected wells, 1936-85. All wells are in Weber Delta area except where indicated--Continued.

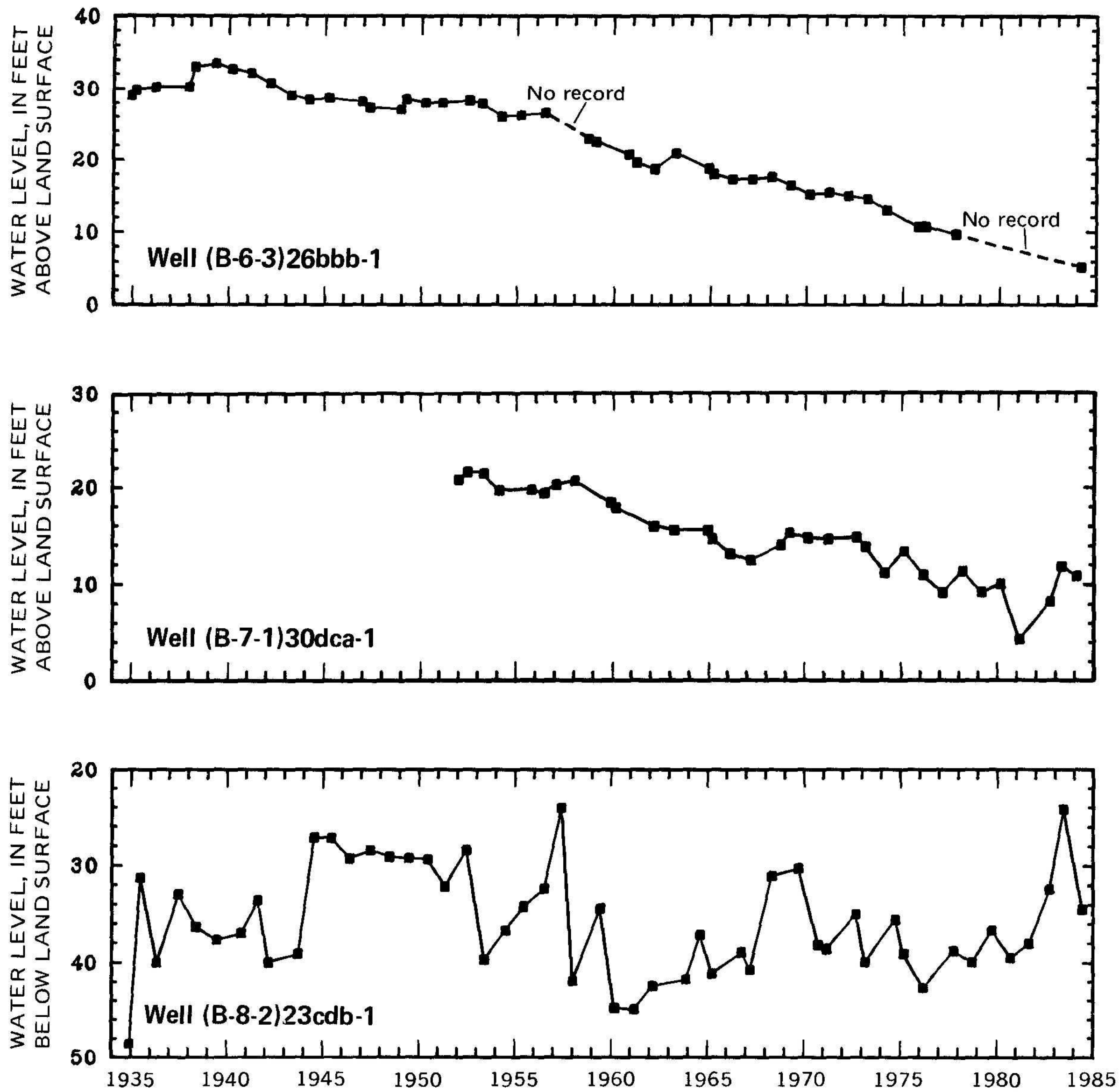


Figure 28.--Water levels in selected wells, 1936-85. All wells are in Weber Delta area except where indicated--Continued.

for municipal and industrial use. Since 1953, water levels have declined as much as 50 feet in well (B-5-2)33ddc-1, which is near the principal pumping center, defined as the general area near Hill Air Force Base, along the Weber River from Uintah to Riverdale, and from Roy south to Clearfield. More than five miles from that pumping center, water levels have declined as much as 35 feet in well (B-5-3)15dda-1.

In the Bountiful area, long-term water-level trends generally followed the trend of the culmulative departure from normal precipitation (fig. 27) from 1935 until about 1962 when water levels began to rise. This rise was due to approximately normal precipitation with less than average withdrawal of water from wells from 1960 to 1962. The less than average withdrawals were due to importation of Weber River water by the Davis Aqueduct. Water levels generally declined from 1965 to 1970 in response to an increase in withdrawal of water from wells. From 1970 to 1975 precipitation was slightly greater than normal while withdrawals remained fairly stable; thus, water levels remained fairly stable. In the late 1970's withdrawals again increased causing water levels to decline. Water levels generally have risen since 1979 in response to an increase in precipitation despite an increase in withdrawals. The slight decline in water levels in 1984, however, was due to a large increase in withdrawals in 1983 and 1984.

Water-Level-Change Maps

Water-level-change maps, which show the distribution and magnitude of water-level changes in the East Shore aquifer system from one point in time to another, were drawn for three time periods: 1946-47 to 1985, 1953-55 to 1985, and 1969 to 1985. The maps are composites that include all aquifers or zones within the East Shore aquifer system, as long-term water-level changes were similar throughout the aquifer system. The change map for the 1946-47 to 1985 period is only for the Bountiful area. The three time periods are based on years during which previous investigations were conducted.

1946-47 to 1985

Water levels in wells in the East Shore aquifer system in the Bountiful area generally declined from 1946-47 to 1985 (fig. 29). The water-level changes ranged from a rise of 5.4 feet west of Val Verda to a decline of 9.1 feet northeast of Woods Cross. The largest declines generally were near the mountains from Centerville to south of Bountiful. These declines probably were due to increased withdrawals for municipal use.

1953-55 to 1985

A water-level-change map for the entire East Shore aquifer system was constructed using the earliest available water level in the spring during 1953-55 to determine the water-level change between 1953-55 and 1985 (fig. 30). The change map was drawn using spring 1953 water levels where available and spring 1955 water levels in areas where there were no 1953 levels. Water levels declined throughout the study area from 1953 to 1955 due to the beginning of large ground-water withdrawals and less than normal precipitation in 1954. Between 1953 and 1955, water levels in some wells declined from as much as 15 feet in the Bountiful area to less than 1 foot near North Ogden, and the declines averaged about 7 feet. In general, the largest declines were near pumping centers, whereas the smallest declines were some distance from pumping centers. Given these circumstances, the contours shown in figure 30 represent a maximum water-level change for 1953-55 to 1985 where they are based on 1953 water levels, but probably do not represent maximum change where based on 1955 water levels.

Between 1953-55 and 1985, water levels generally declined in the area from Plain City south to Bountiful (fig. 30), with declines ranging from less than 1 foot in a well south of Farmington to about 57 feet in a well near Washington Terrace, and averaging about 27 feet in the Weber Delta area. The largest declines were in wells between Riverdale and Clearfield, generally west of the principal pumping center, with the amount of decline decreasing with increasing distance from the pumping center. Water levels rose from North Ogden to Willard and near Great Salt Lake in the Bountiful area, ranging from about 1 to 11 feet and averaging 6 feet in the North Ogden-Willard area.

1969 to 1985

Water levels in wells declined in most of the East Shore aquifer system from 1969 to 1985 (fig. 31). The maximum decline was about 21 feet in a well southeast of Taylor. The water-level declines were due to continued large-scale withdrawals of water from wells for municipal and industrial use. The largest declines were in areas where the most water is withdrawn. Water levels generally rose in wells near the mountains between Willard and North Ogden and from Kaysville to North Salt Lake, primarily because of greater than average precipitation from 1983-85, with a maximum rise of about 12 feet.

Storage

The quantity of water contained in the East Shore aquifer system could be determined if the total volume of the saturated unconsolidated sediments and the porosity of those sediments were known. However, with the available data only an approximation can be made. Although the maximum thickness of the sediments has been estimated to be 6,000 feet (Feth and others, 1966, p. 30), data from the deepest well in the area, well (B-5-2)16ddc-1 which is 3,008 feet deep, indicate moderately saline water below a depth of about 1,500 feet. Therefore, for the purpose of calculating the quantity of water in the system, it was assumed that the average thickness of sediments in the East Shore aquifer system that contain freshwater is 1,500 feet. The area for which the total quantity is calculated depends somewhat on the level of Great Salt Lake. During this project, the size of the study area was about 330 square miles, corresponding to a lake level of about 4,209 feet. When the lake was at 4,200 feet, the size of the project area was 430 square miles. For calculations of water in storage, the area is considered to be 330 square miles with a thickness of 1,500 feet; thus, the volume of saturated material is about 100 cubic miles. The smaller area was used because the western limit of the freshwater aquifers under Great Salt Lake is unknown, and little of the area inundated by the rising lake has had any ground-water development. In addition, the ground water in this area is slightly saline and generally nonpotable, and well yields are small. Therefore, the amount of freshwater in the area inundated by the lake is not considered to be significant, although the following value for the total volume of ground water in the system is considered to be a minimum.

The amount of water contained in saturated sediments is only a small percentage of the total volume of those sediments, and the quantity of water that can be removed from those sediments by wells is an even smaller percentage. For example fine-grained sediments such as clay may contain more than 50 percent water, whereas a saturated gravel layer may contain only about 20 to 35 percent water. The clay will yield only about 5 percent of the contained water to wells, whereas the gravel may yield 25 percent.

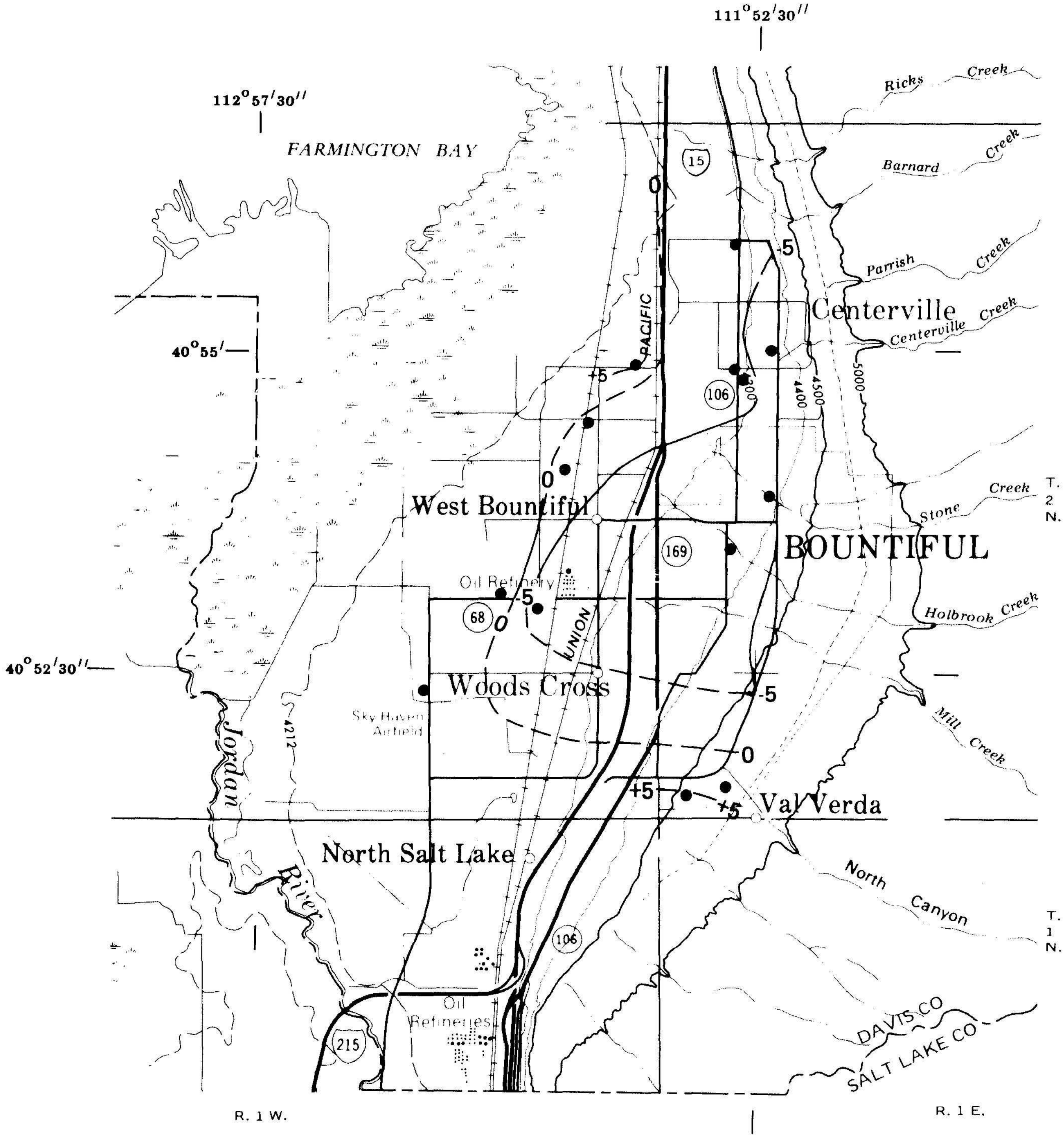
An estimate of average water content (porosity) and specific yield of the sediments in the East Shore aquifer system was made from drillers' logs of about 50 of the deepest wells in the area. The values of water content and specific yield for alluvial sediments are assumed to be the same as those used in Northern Utah Valley (Clark and Appel, 1985, p. 69). Those values (largely from Johnson, 1967, p. D49-D57) are as follows:

Lithologic material from drillers' logs	Estimated water content (percent)	Specific yield (percent)
Clay..	50	5
Clay and sand; sand and clay; sandy clay....	40	10
Sand..	30	20
Gravel..	30	25
Sand and gravel...............................	25	20
Hardpan; all other cemented material........	15	10

EXPLANATION FOR FIGURE 29

———5——— LINE OF EQUAL WATER-LEVEL CHANGE, IN FEET--Dashed where approximately located. Interval variable. + indicates rise in water level, - indicates decline in water level

● OBSERVATION WELL



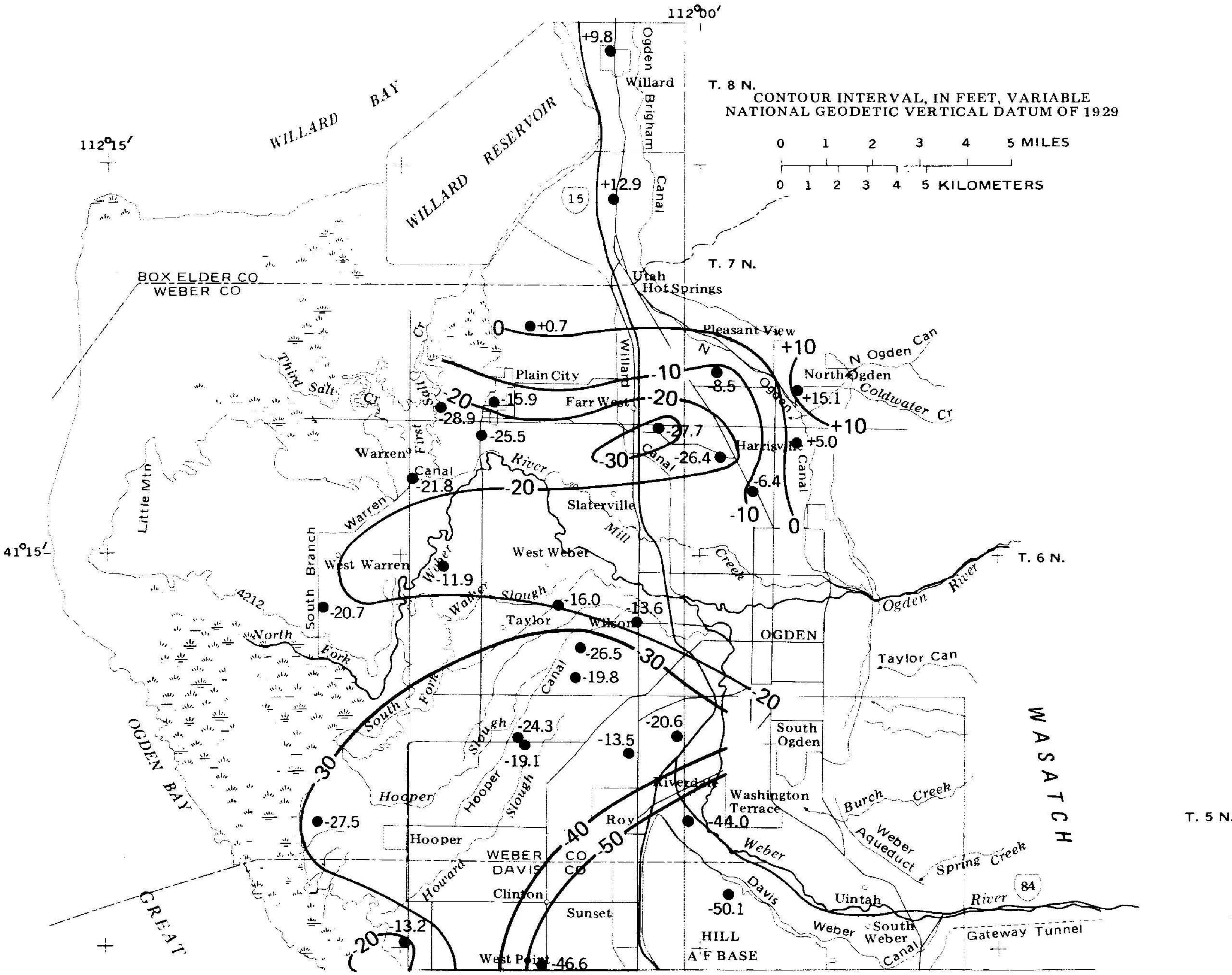
Base from U.S. Geological Survey 1:125,000 quadrangle,
Great Salt Lake and vicinity, Utah, 1974

0 1 2 MILES

0 1 2 KILOMETERS

CONTOUR INTERVAL, IN FEET, VARIABLE
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Figure 29.--Change in water levels in the East Shore aquifer system, Bountiful area, 1946-47 to 1985.



112°00′
112°15′
41°15′
T. 8 N.
T. 7 N.
T. 6 N.
T. 5 N.
CONTOUR INTERVAL, IN FEET, VARIABLE
NATIONAL GEODETIC VERTICAL DATUM OF 1929
0 1 2 3 4 5 MILES
0 1 2 3 4 5 KILOMETERS
WILLARD BAY
WILLARD RESERVOIR
BOX ELDER CO
WEBER CO
WEBER CO
DAVIS CO
OGDEN BAY
GREAT
WASATCH
Willard
Ogden Brigham Canal
Utah Hot Springs
Pleasant View
North Ogden
N Ogden Can
Coldwater Cr
Plain City
Farr West
Harrisville
Warren
West Warren
Slaterville
West Weber
Taylor
Wilson
OGDEN
South Ogden
Riverdale
Washington Terrace
Roy
Hooper
Clinton
Sunset
West Point
HILL A F BASE
Uintah
South Weber
Little Mtn
Third Salt Cr
First Salt Cr
Canal
Warren Canal
South Branch
Weber River
Mill Creek
Ogden River
Walker Slough
North Fork
South Fork
Hooper Slough
Howard Slough
Taylor Can
Burch Creek
Weber Aqueduct
Spring Creek
Davis Weber Canal
Gateway Tunnel
4212
15
84
+9.8
+12.9
+0.7
-8.5
+15.1
+5.0
-15.9
-28.9
-25.5
-27.7
-26.4
-6.4
-21.8
-11.9
-20.7
-16.0
-13.6
-26.5
-19.8
-24.3
-19.1
-13.5
-20.6
-27.5
-44.0
-50.1
-13.2
-46.6
0
+10
-10
-20
-30
-40
-50

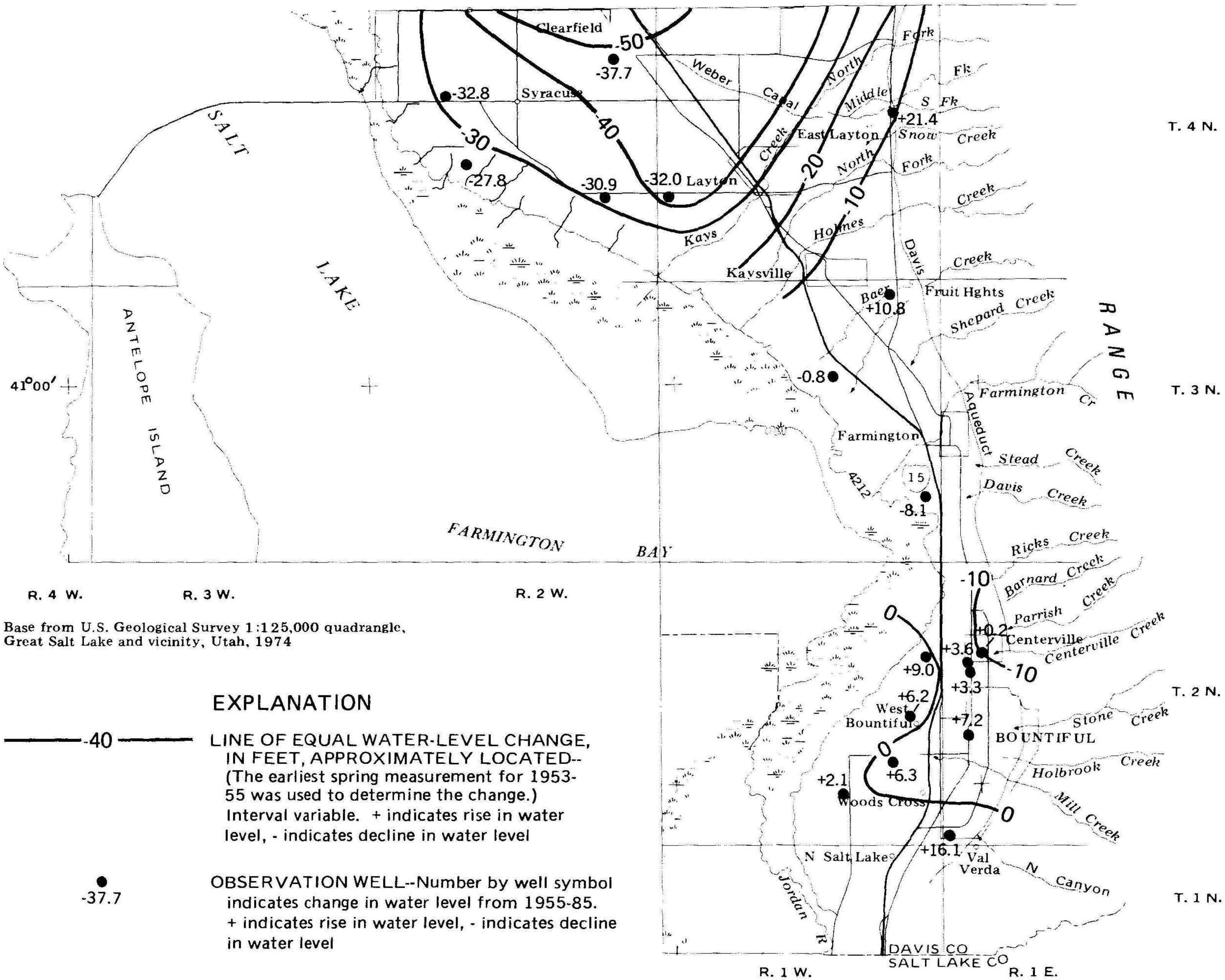
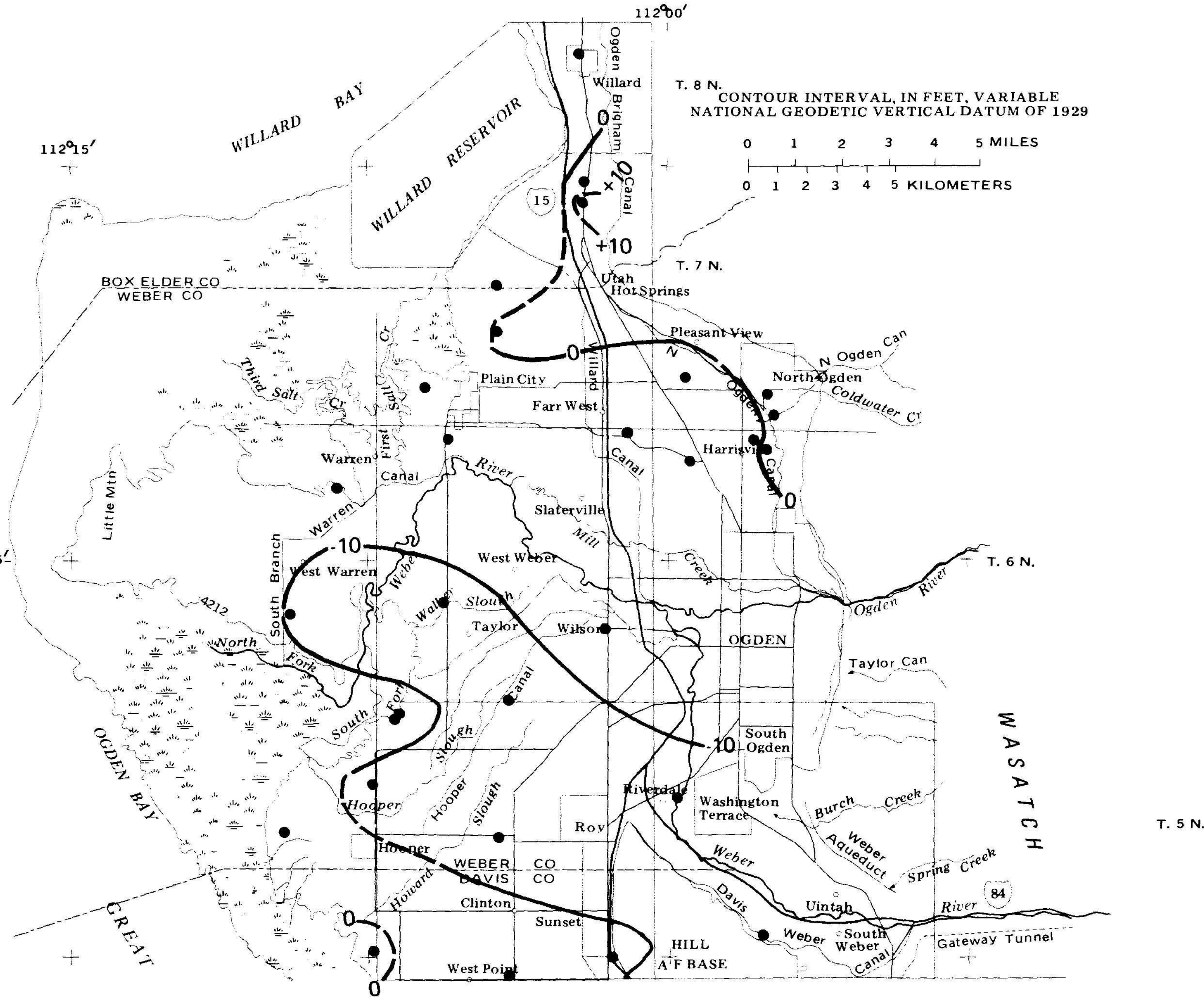


Figure 30.--Change in water levels in the East Shore aquifer system, 1953-55 to 1985.


112°00′
112°15′
41°15′
CONTOUR INTERVAL, IN FEET, VARIABLE
NATIONAL GEODETIC VERTICAL DATUM OF 1929
0 1 2 3 4 5 MILES
0 1 2 3 4 5 KILOMETERS
T. 8 N.
T. 7 N.
T. 6 N.
T. 5 N.
WILLARD BAY
WILLARD RESERVOIR
Willard
Ogden Brigham Canal
15
Utah Hot Springs
BOX ELDER CO
WEBER CO
Pleasant View
N Ogden Can
North Ogden
Coldwater Cr
N Ogden Canal
Harrisville
Plain City
Farr West
Willard Canal
Third Salt Cr
First Salt Cr
Warren
Canal
Warren
Little Mtn
River
Slaterville
Mill Creek
West Weber
West Warren
South Branch
Weber
Walker Slough
Taylor
Wilson
OGDEN
Ogden River
Taylor Can
4212
North Fork
South Fork
Canal
Slough
Hooper Slough
Hooper
South Ogden
Riverdale
Washington Terrace
Burch Creek
Weber Aqueduct
Spring Creek
WASATCH
Roy
Hooper
WEBER CO
DAVIS CO
Howard
Clinton
Sunset
Weber
Davis
Uintah
River
84
HILL A F BASE
Weber
South Weber
Canal
Gateway Tunnel
West Point
OGDEN BAY
GREAT
0
+10
-10

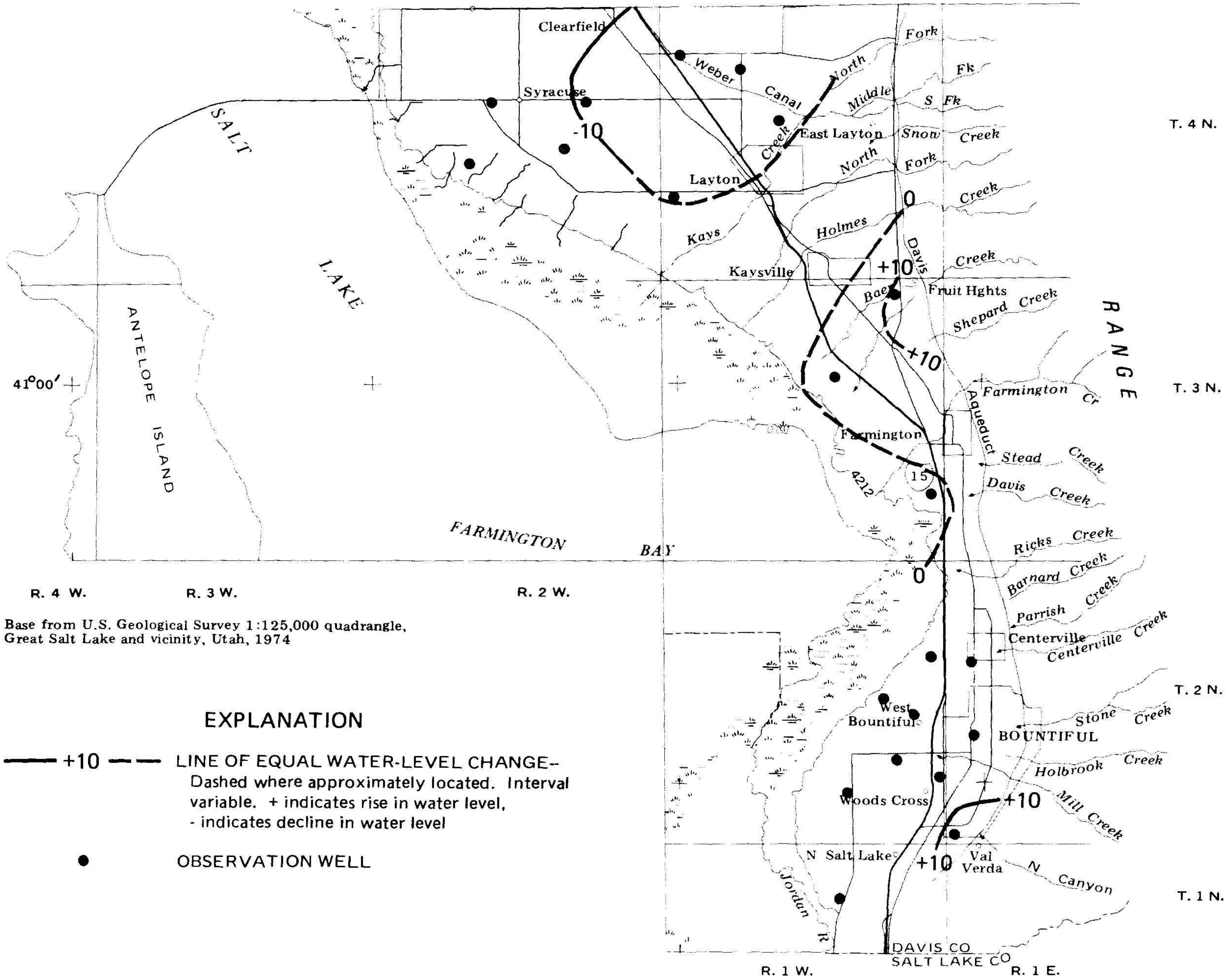


Figure 31.--Change in water levels in the East Shore aquifer system, 1969 to 1985.

Average values of specific yield and water content were estimated from drillers' logs of wells for various types of lithologies in the study area, ranging from thick sequences of clay and sandy clay near Great Salt Lake to the coarse-grained material beneath the high benchlands and river floodplains. The average estimated water content for the area is 40 percent, and the average specific yield is 11 percent. An estimate of the total volume of ground water recoverable from storage was made assuming that water levels could be drawn down enough so that the confined part of the system would be dewatered, and therefore, a specific yield representing water-table conditions would be valid. The total volume of ground water in the system was estimated to be 135 million acre-feet. An estimate of the total recoverable water in storage, based on the specific yields of the water-bearing zones, the area, and the lithology of the zones, is estimated to be about 37 million acre-feet. This amount is considered to be a maximum because it assumes all available water could be removed from the system. However, the extent of dewatering that could occur without undesirable side effects such as water levels declining to depths from which water cannot be pumped economically, potential movement of nonpotable water to wells, and land subsidence, is not known.

The quantity of water that can be removed from storage by lowering water levels in an aquifer depends on whether the aquifer is under confined or unconfined conditions. Water-table conditions exist in about 5 square miles near the mouth of Weber Canyon, about 3 square miles near the benches of the Bountiful area, and about 10 additional square miles in a narrow band along the mountain front. Ground water in the East Shore aquifer system in the remainder of the study area is confined. From 1953 to 1985 water levels declined as much as 57 feet in the study area (fig. 30), with an average decline estimated to be about 27 feet for approximately 200 square miles underlain by confined aquifers. The storage coefficient of the confined part of the East Shore aquifer system ranges from 3×10^{-6} to 1×10^{-4}; therefore, about 350 to 1,700 acre-feet of water was removed from storage as a result of these water-level declines, assuming the water was derived from elastic compaction of the aquifer system. Declines in water levels in the unconfined part of the aquifer system near the mouth of Weber Canyon are assumed to have been at least 40 feet during the same time period. The specific yield of the unconfined part of the aquifer system is assumed to be about 0.1; thus, about 13,000 acre-feet of water was removed from storage in the 5-square-mile area. Between 1969 and 1985 about 100 to 500 acre-feet of water was removed from storage in the confined part of the East Shore aquifer system and about 3,000 acre-feet was removed from storage in the unconfined part of that aquifer system.

Discharge

Discharge from the East Shore aquifer system is to wells and drainageways (drains, ditches, and streams) and by springs, evapotranspiration, and diffuse seepage to Great Salt Lake. The average annual discharge for 1969-84 was estimated to be 182,000 acre-feet.

Wells

Approximately 5,900 wells have been constructed in the East Shore area, varying from municipal wells with large diameter and large discharge to small-diameter flowing wells used to supply stock water. The discharge from these wells was estimated to average about 54,000 acre-feet per year during 1969-84. The number of wells in the East Shore area was determined from drillers' logs of wells filed with the Utah Division of Water Rights and published data from previous investigations conducted in the area. Arnow and others (1964, p. 16) reported that 5,000 wells were in the area in 1962, Bolke and Waddell (1972, p. 7) reported that about 430 wells were drilled during 1962-69, and 444 wells have been drilled since 1969. This makes a total of about 5,900 wells in the East Shore area in 1985.

Most well discharge in the East Shore area is from about 200 wells that supply municipal and industrial users. The average annual discharge from these wells during 1955-84 for the Weber Delta and Bountiful areas is shown in figure 32. The annual discharge was about 16,000 acre-feet during 1955-68, but during 1969-84 it was about 28,000 acre-feet. Most of this increase was in the Weber Delta area, whereas withdrawal in the Bountiful area remained fairly constant (fig. 32). The discharge from municipal and industrial wells was determined from records provided by the municipalities, industrial users, and by Weber Basin Water Conservancy District, which supplies large quantities of water for municipal and industrial use.

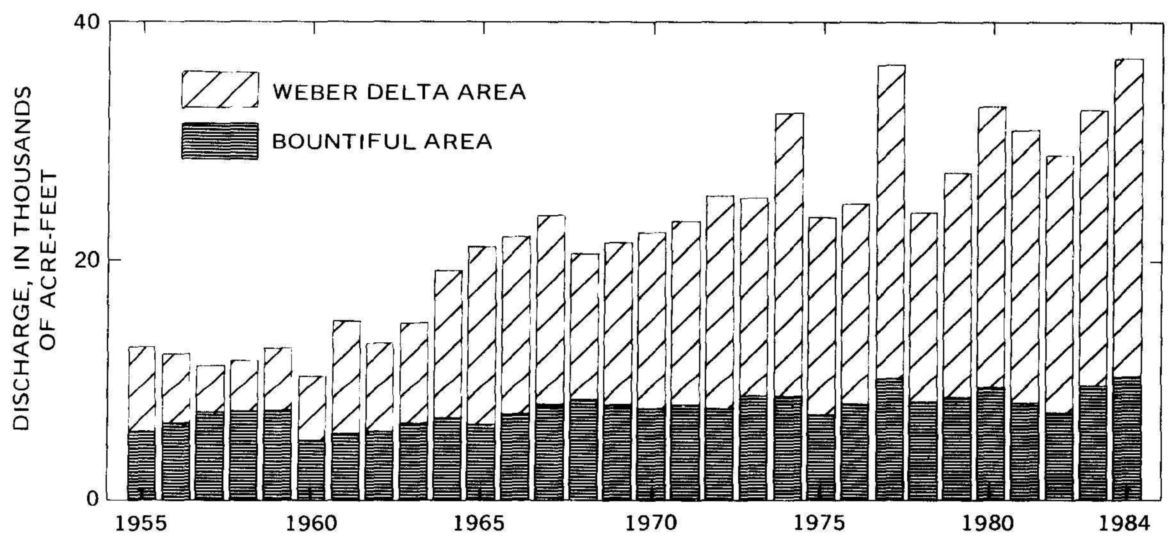


Figure 32.--Withdrawal from wells for municipal and industrial use, 1955-84.

The approximate area of flowing wells (area in which most wells flow under artesian pressure) in 1954 and 1985 is shown in figure 33. The flowing-well area boundary fluctuates seasonally and over periods of several years, and is only an approximate boundary. The percentage of wells that are within the area of flowing wells was determined from drillers' logs of wells, previously published data, and data collected at 249 wells during 1985. Most of the 249 wells visited in 1985 are in five sections and had been inventoried in 1969 by Bolke and Waddell (1972, p. 7). According to Smith and Gates (1963, pl. 2), about 3,500 wells flowed in 1954. Available drillers' logs of wells indicate about 560 flowing wells were drilled during 1955-69, giving a total of about 4,160 flowing wells in 1969, which was about 77 percent of the total number of wells in 1969 (5,430). Since 1969 about 444 wells have been drilled, of which 340 were assumed to be flowing, for an estimated total of 4,500 flowing wells in 1985. Of the 249 wells visited during the summer of 1985, 39 percent were valved or pumped, 27 percent were flowing continuously, 16 percent no longer flowed, and 18 percent were plugged or unused but still within the area of flowing wells. These percentages were applied to the estimated total number of flowing wells (4,500) to determine the number of wells in each category discussed in the following paragraphs.

Using data from the 249 wells visited in 1985, it was estimated that of the approximate total of 4,500 flowing wells in 1985, about 1,800 wells in the flowing-well area have their discharge controlled by a pump or a valve. About 1,200 wells flow continuously, and about 800 wells have been plugged or are unused. Since 1954, about 700 wells within 30 square miles have ceased to flow for at least part of the year and many of these wells have not flowed for several years. Most of the non-flowing wells probably are in the area representing the difference between the flowing-well areas of 1954 and 1985, where wells have ceased to flow because of a decrease in artesian pressure. The decrease in pressure in the aquifers is in response to the large-scale withdrawals of water from wells for municipal and industrial use.

The 1,800 wells controlled by a pump or valve within the flowing-well area are assumed to each have the same annual discharge. The annual discharge from each of these wells is estimated to be from 1 to 2 acre-feet. This rate is based on a per-capita consumption of 250 gallons per day and a household unit of 4 persons (Utah Division of Water Rights, 1980; Wasatch Front Regional Council, 1986). Most of these wells are in rural areas and are used to irrigate large lots; therefore, the discharge from these 1,800 wells is estimated to range from 1,800 to 3,600 acre-feet per year.

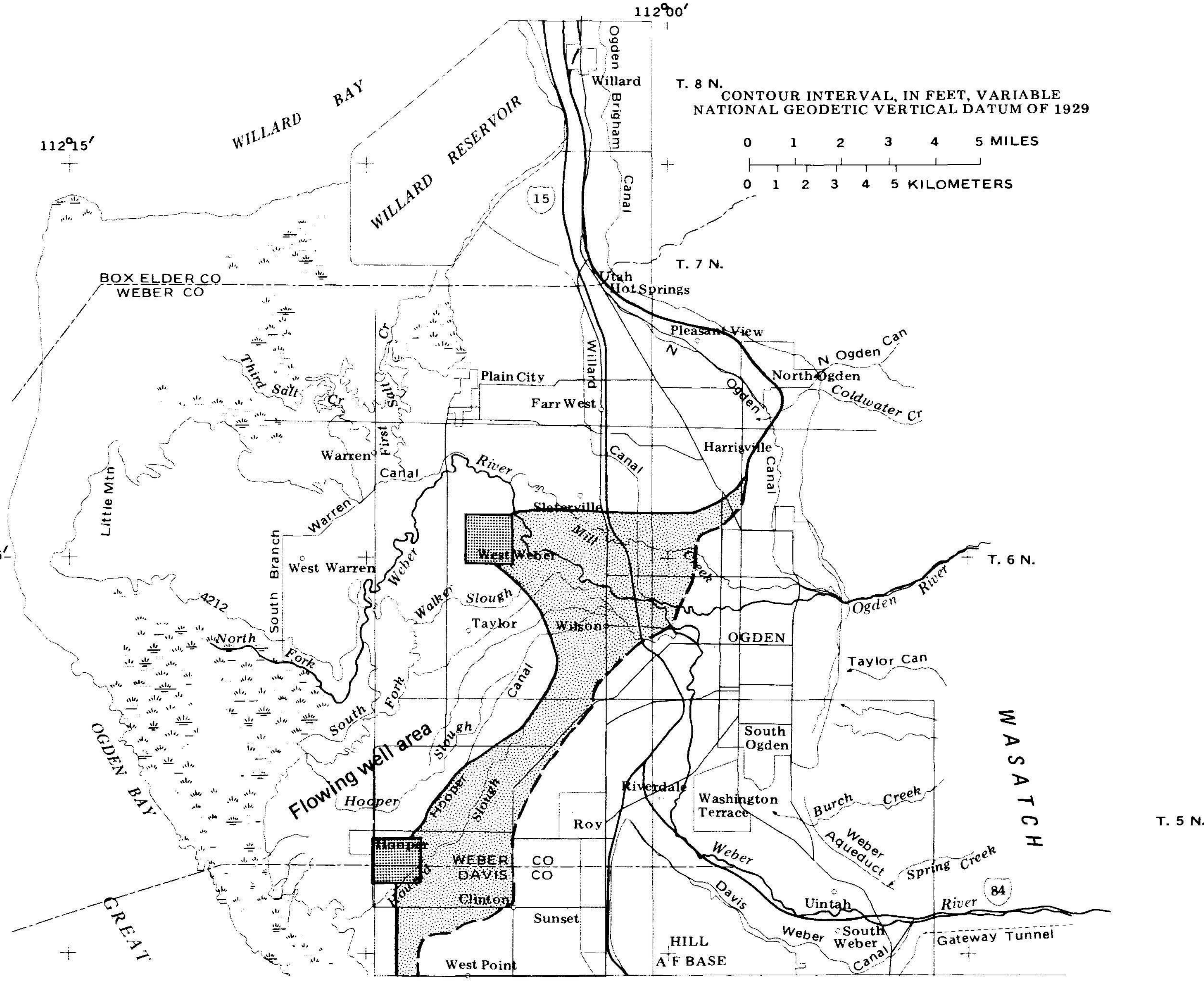
Discharge from continuously-flowing wells varies considerably, both annually and seasonally, depending primarily on the artesian pressure in the confined aquifers; discharge generally decreases as pressure decreases. Since 1963, shut-in water levels in flowing wells have generally decreased as has discharge from the same wells (figs. 34-36). Discharge in some wells can decrease even when water levels are rising (fig. 34), indicating the possibility that the well perforations are being blocked by sediment or mineral deposits, causing discharge to decrease even though artesian pressure increases. Seasonal water-level and discharge fluctuations are shown in figures 37 to 39. Figures 37 and 38 are for the same wells for which long-term fluctuations were illustrated in figures 34 and 35. The water levels and discharge generally decline during the summer due to increased use of water for irrigation.

The discharge from 1,200 continuously flowing wells was estimated to be 22,000 acre-feet in 1985. The estimate is based on measurements of discharge from 133 flowing wells during summer 1985. The average measured discharge from all wells with the same casing diameter is considered to be representative of the average flow from all wells with that diameter. The average discharge for all measured flowing wells with the same diameter was multiplied by the number of wells for each diameter within the area of flowing wells. The number of wells of each casing diameter was estimated by assuming that the percentage of wells of each diameter of the 133 wells visited could be applied to the total number of continuously flowing wells. The number of discharge measurements for wells of each diameter and the total discharge is shown in the following table:

Diameter of well casing (inches)	Number of wells measured	Average discharge (gallons per minute)	Standard deviation (gallons per minute)	Estimated number of wells with same diameter casing	Total discharge (acre-feet)
2	101	6.5	7.1	910	10,000
3	18	25	24	160	6,000
4	9	39	28	80	5,000
6	4	13	12	40	800
10	1	35	-	10	600
Total	133			1,200	22,000

The discharge from 27 wells throughout the flowing-well area has been measured annually since 1963 in order to estimate long-term changes in the total discharge of water from flowing wells. Since the early 1970's, a general decrease has been observed in the total measured discharge from these wells (fig. 40).

About 1,200 small-diameter wells are used for domestic, stock, and irrigation purposes outside of the flowing-well area. The annual discharge from each of these wells is estimated to be from 1 to 2 acre-feet, based on a per-capita consumption of 250 gallons per day and a household unit of 4 persons (Utah Division of Water Rights, 1980; Wasatch Front Regional Council, 1986). The discharge from these wells is estimated to range from 1,200 to 2,400 acre-feet per year.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CONTOUR INTERVAL, IN FEET, VARIABLE
NATIONAL GEODETIC VERTICAL DATUM OF 1929
0 1 2 3 4 5 MILES
0 1 2 3 4 5 KILOMETERS
WILLARD BAY
WILLARD RESERVOIR
WILLARD
Willard
Ogden Brigham Canal
15
BOX ELDER CO
WEBER CO
Utah Hot Springs
Pleasant View
N Ogden Can
North Ogden
Coldwater Cr
Ogden
Third Salt Cr
First Salt Cr
Plain City
Farr West
Willard Canal
Harrisville
Canal
Warren
Canal
River
Little Mtn
Warren
Slaterville
Mill Creek
West Weber
West Warren
South Branch
Weber
Ogden River
4212
Walker Slough
Taylor
Wilson
OGDEN
North Fork
Taylor Can
Canal
South Fork
Flowing well area
Slough
South Ogden
WASATCH
OGDEN BAY
Hooper
Hooper Slough
Riverdale
Washington Terrace
Burch Creek
Weber Aqueduct
Roy
Weber
Spring Creek
Hooper
WEBER CO
DAVIS CO
84
Davis
Uintah
River
Clinton
Sunset
GREAT
West Point
HILL A F BASE
Weber
South Weber
Canal
Gateway Tunnel

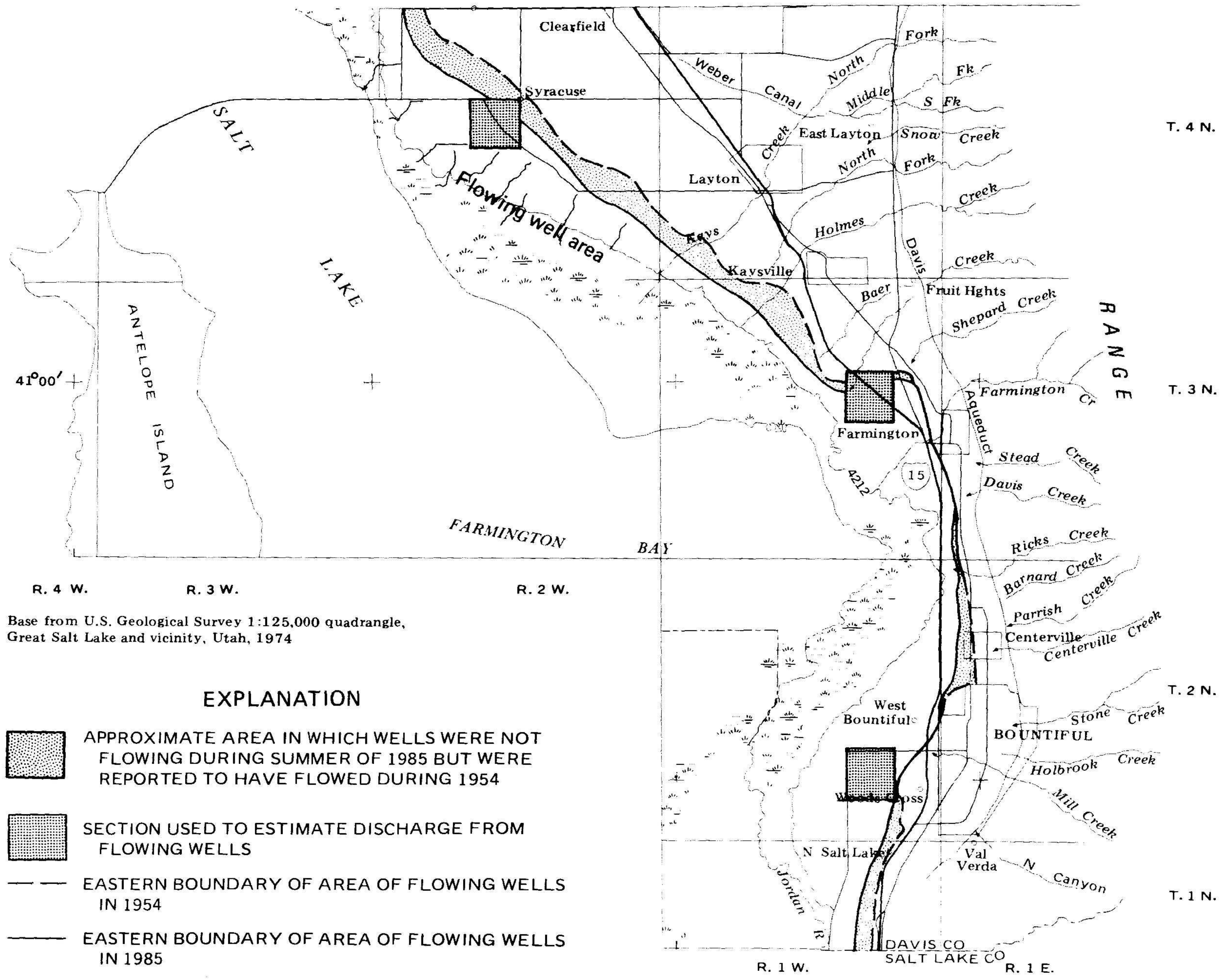


Figure 33.--Approximate boundary of flowing-well area, 1954 and 1985, and location of sections used to estimate discharge from flowing wells.

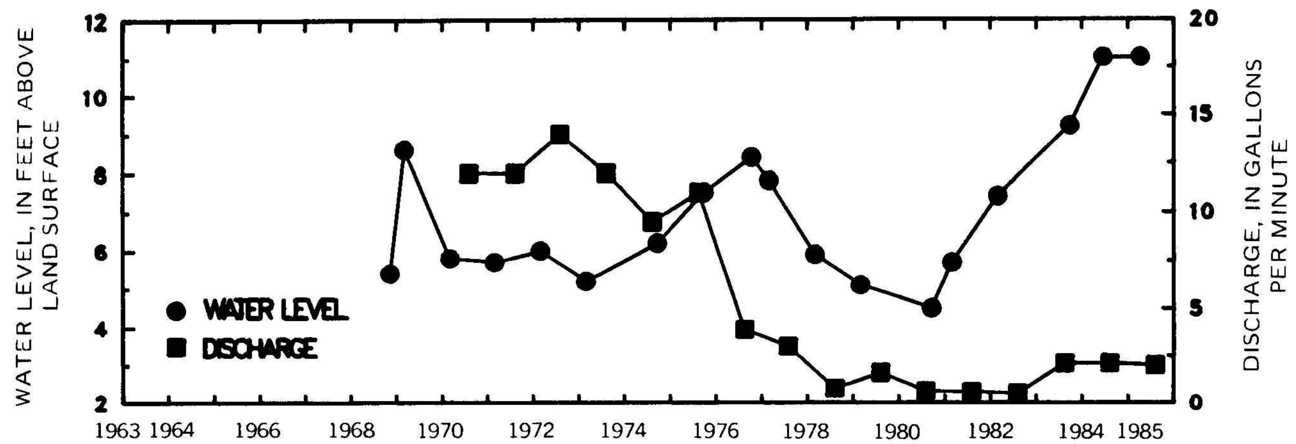


Figure 34.--Water level in and discharge from well (B-1-1)10aac-1, 1963-85.

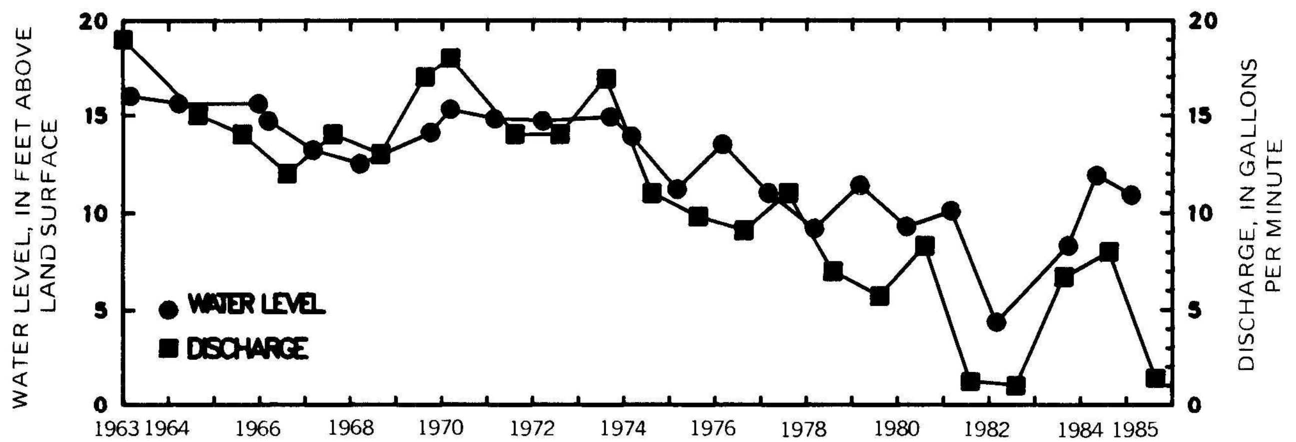


Figure 35.--Water level in and discharge from well (B-7-1)30dca-1, 1963-85.

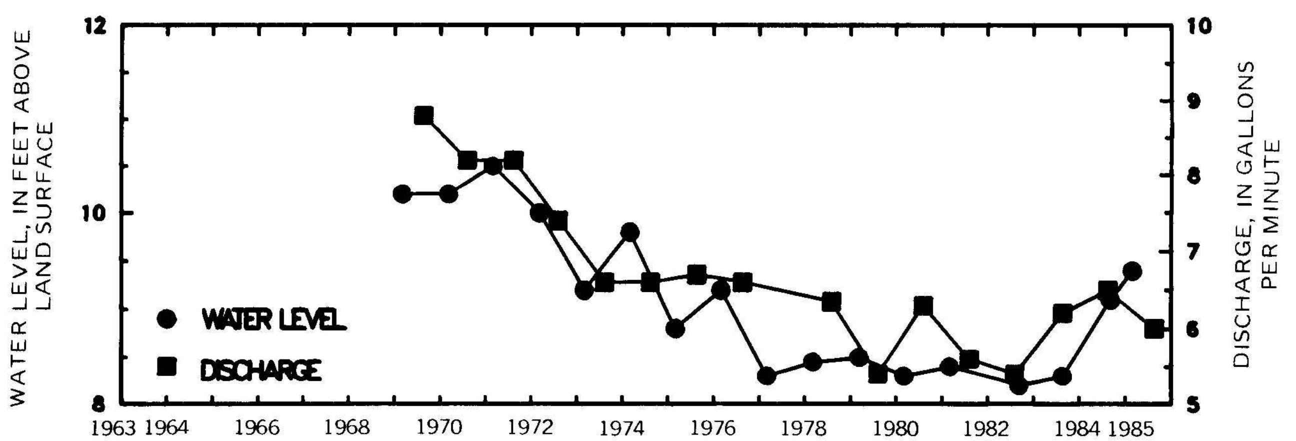


Figure 36.--Water level in and discharge from well (B-7-2)32bbb-1, 1963-85.

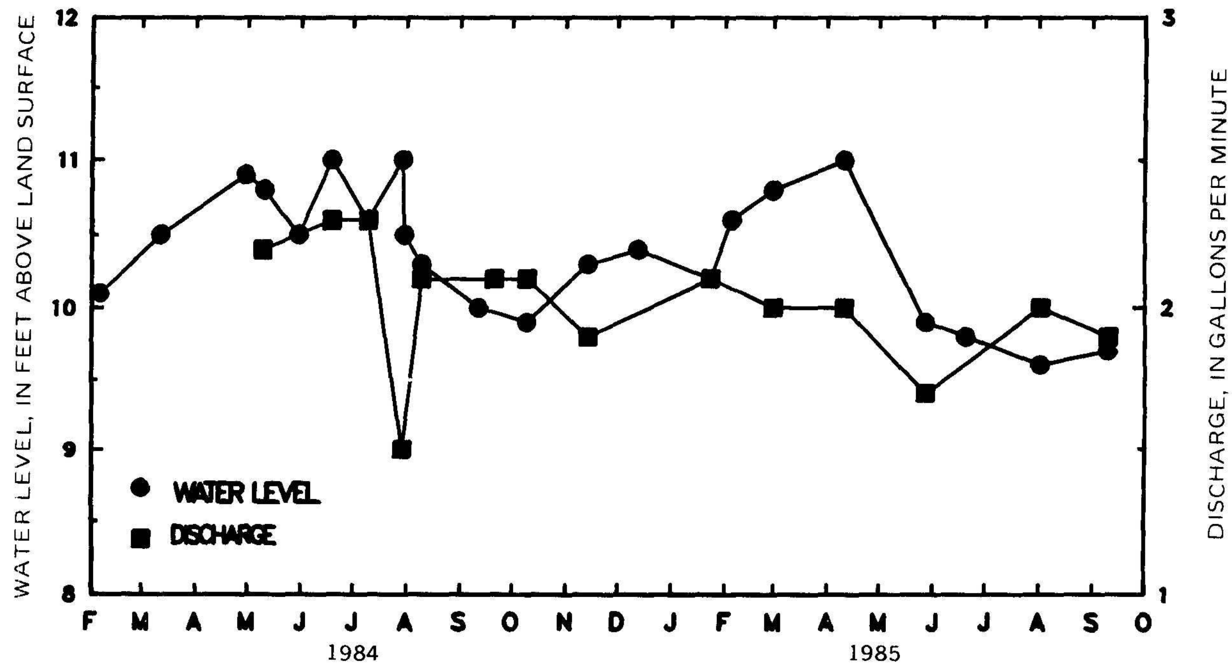


Figure 37.--Water level in and discharge from well (B-1-1)10aac-1, 1984-85.

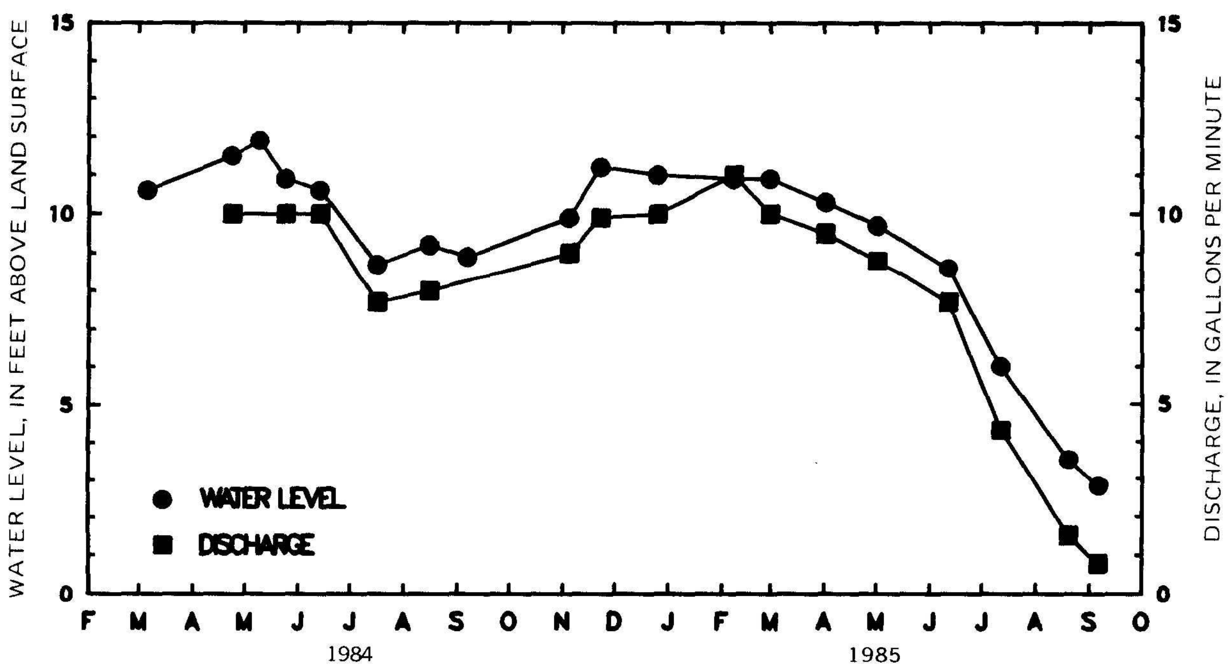


Figure 38.--Water level in and discharge from well (B-7-1)30dca-1, 1984-85.

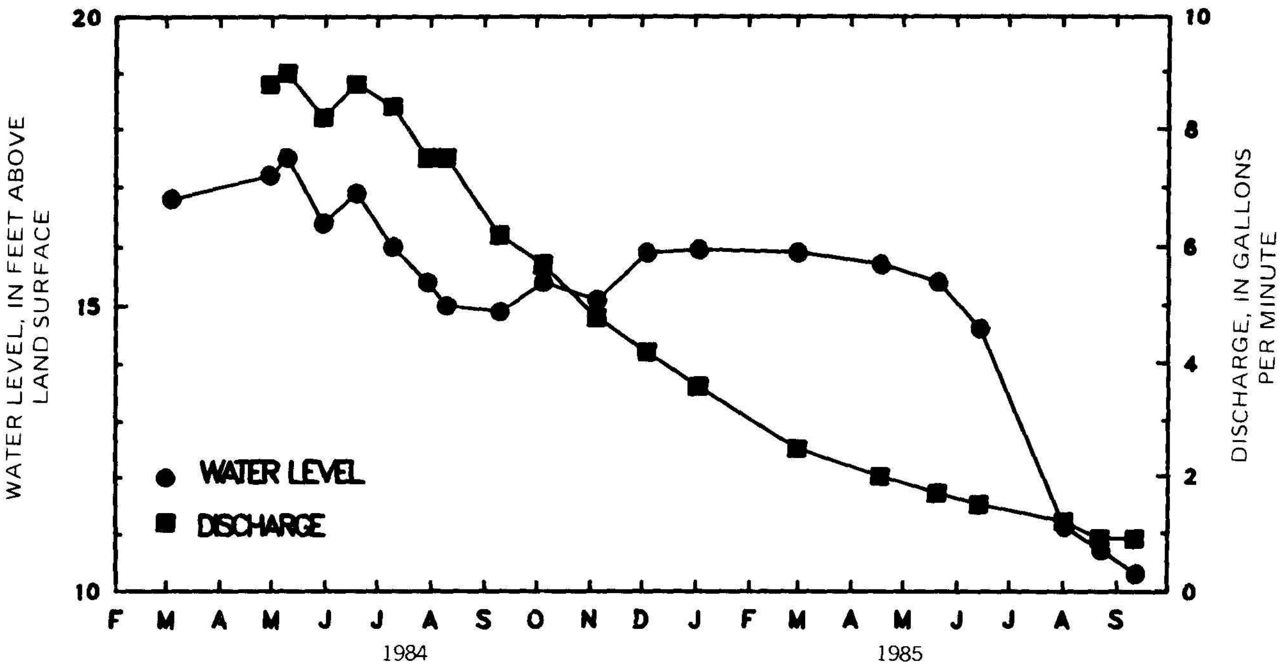


Figure 39.--Water level in and discharge from well (B-5-3)15dda-1, 1984-85.

The total estimated annual discharge from all wells is shown in the following table.

Type of well	Estimated annual discharge, in acre-feet (1969-85)
Municipal and industrial	28,000
Controlled flowing wells	1,800-3,600
Small-diameter pumped wells	1,200-2,400
Continuously flowing wells	22,000
Total average discharge	54,000

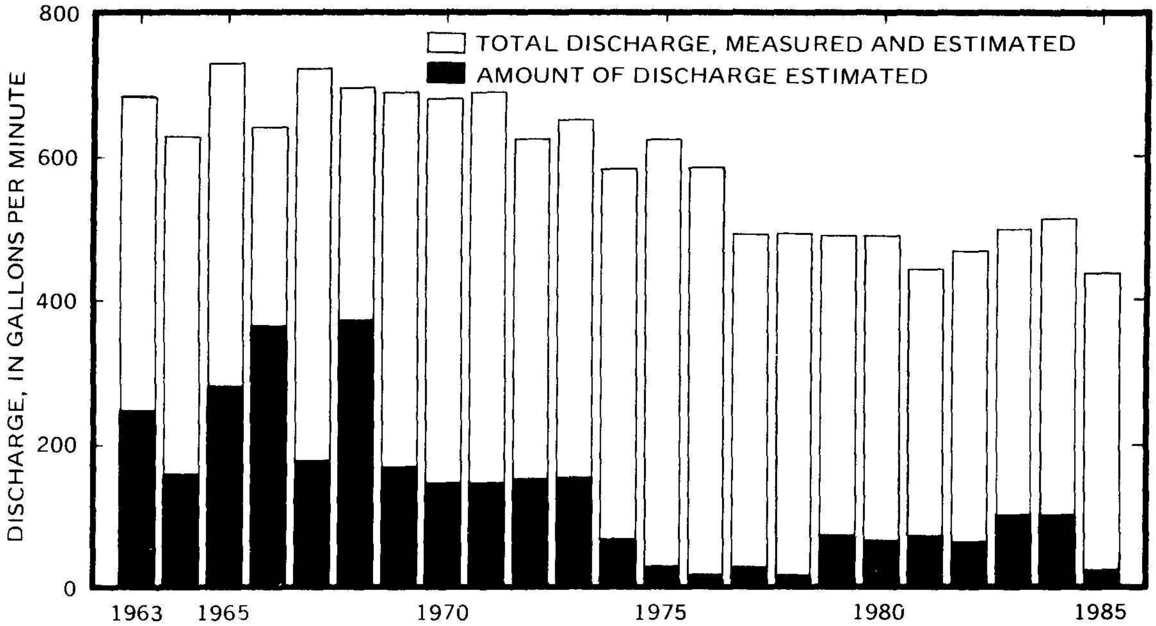


Figure 40.--Total discharge from 27 selected flowing wells, 1963-85.

Waterways and Springs

Discharge from the East Shore aquifer system to drainageways (drains, ditches, and streams) and by seeps and springs is estimated to have ranged from 61,000 to 84,000 acre-feet per year during 1969-84, or an average of about 70,000 acre-feet per year. This estimate of discharge is based primarily on 175 measurements or estimates made during spring 1985. The measurements were made on all known drains and are assumed to represent total drain discharge within the study area. The measurements were made before the irrigation season and after the previous season's irrigation water had drained off, and were, therefore, assumed to be representative of base-flow conditions, which includes mainly ground water derived from upward leakage from the East Shore aquifer system. Precipitation and surface runoff were greater than average during 1984-85; thus, drain discharge during the spring of 1985 may also have been greater than the 1969-84 average. All known points of discharge to drainageways and by springs were located and the discharge measured where possible. The proportion of water in the drains, ditches, seeps, and springs that is discharge from the East Shore aquifer system was estimated in the field where possible, or by using water quality to differentiate surface water from ground water by comparing specific conductance and chemical characteristics to those of water from nearby surface-water sites and wells. Some of the drainageways are used to distribute irrigation water in addition to being used as drains; thus, estimating the amount of water discharged by upward leakage from the East Shore aquifer system is difficult. On drainageways used as a part of irrigation systems, measurements were made upstream and downstream from points of suspected ground-water discharge to determine the amount of ground-water inflow.

The discharge from the East Shore aquifer system to drainageways and by springs originates primarily as upward leakage; it varies seasonally and annually depending on changes in the artesian pressure within the aquifer system, similar to discharge from flowing wells. Many of the springs and seeps, which are generally the headwaters of drainageways, are located where the altitude of the potentiometric surface is slightly higher than the land-surface altitude; thus, many spring locations correspond to the boundary of the area of flowing wells (fig. 33). The discharge by upward leakage typically is largest in the spring when ground-water levels are highest, and smallest in the fall when water levels are lowest. Discharge by upward leakage to drainageways and by springs generally is assumed to be greatest in areas where the confining layer overlying the upper artesian aquifer is more permeable or thinner than eleswhere.

Discharge to drainageways and by springs was determined as a total for specific drainage areas. Measurements were made throughout the drainage areas from the mouths of drains to the headwaters (spring and seep areas) to determine the discharge for each specific drainage area. Some of the discharge in the drainageways is from surface water, applied irrigation water, and other sources. This discharge was measured and subtracted from the total discharge for that drainage area. Total discharge for a specific drainage area was calculated. The discharge rates were determined by dividing the estimated total discharge by the area of the drainage basin. The individual drain rates were then combined into larger areas, and ranges of rates for those larger areas were determined.

The Bountiful-Farmington area includes 55 sites at which drain discharge ranged from 0.5 to 1.1 cubic feet per second per square mile, the largest average discharge in the East Shore area (fig. 41). The annual average drain discharge is estimated to range from 12,500 to 19,400 acre-feet in this area, which includes minor amounts of discharge to the Jordan River.

The area from Willard to Hooper includes 90 sites at which the drain discharge ranged from 0.5 to 0.9 cubic foot per second per square mile, and the average annual discharge in this area is estimated to range from 44,000 to 58,000 acre-feet. This includes an estimated annual discharge from the East Shore aquifer system of 12,000 acre-feet to Hooper and Howard Sloughs. The amount of discharge from the aquifer system to the sloughs was estimated by assuming the smaller discharge rate of 0.5 cubic foot per second per square mile for their 13.0 and 20.6 square-mile drainage areas. The contours of the potentiometric surface of the aquifer system near the headwaters of Walker, Hooper, and Howard Sloughs indicate potential ground-water discharge to the sloughs (pl. 1).

In the area west of Syracuse and Kaysville, which includes 24 sites, the discharge ranged from 0.3 to 0.4 cubic foot per second per square mile. The average annual discharge is estimated to range from 3,100 to 4,200 acre-feet per year.

Between Warren and Little Mountain, six sites were measured and the discharge ranged from 0.1 to 0.2 cubic foot per second per square mile, and the annual average discharge is estimated to range from 1,400 to 2,400 acre-feet. In part of this area, head differences in the confined parts of the aquifer system indicate a vertical gradient downward; thus, little discharge to drains in the area would be expected.

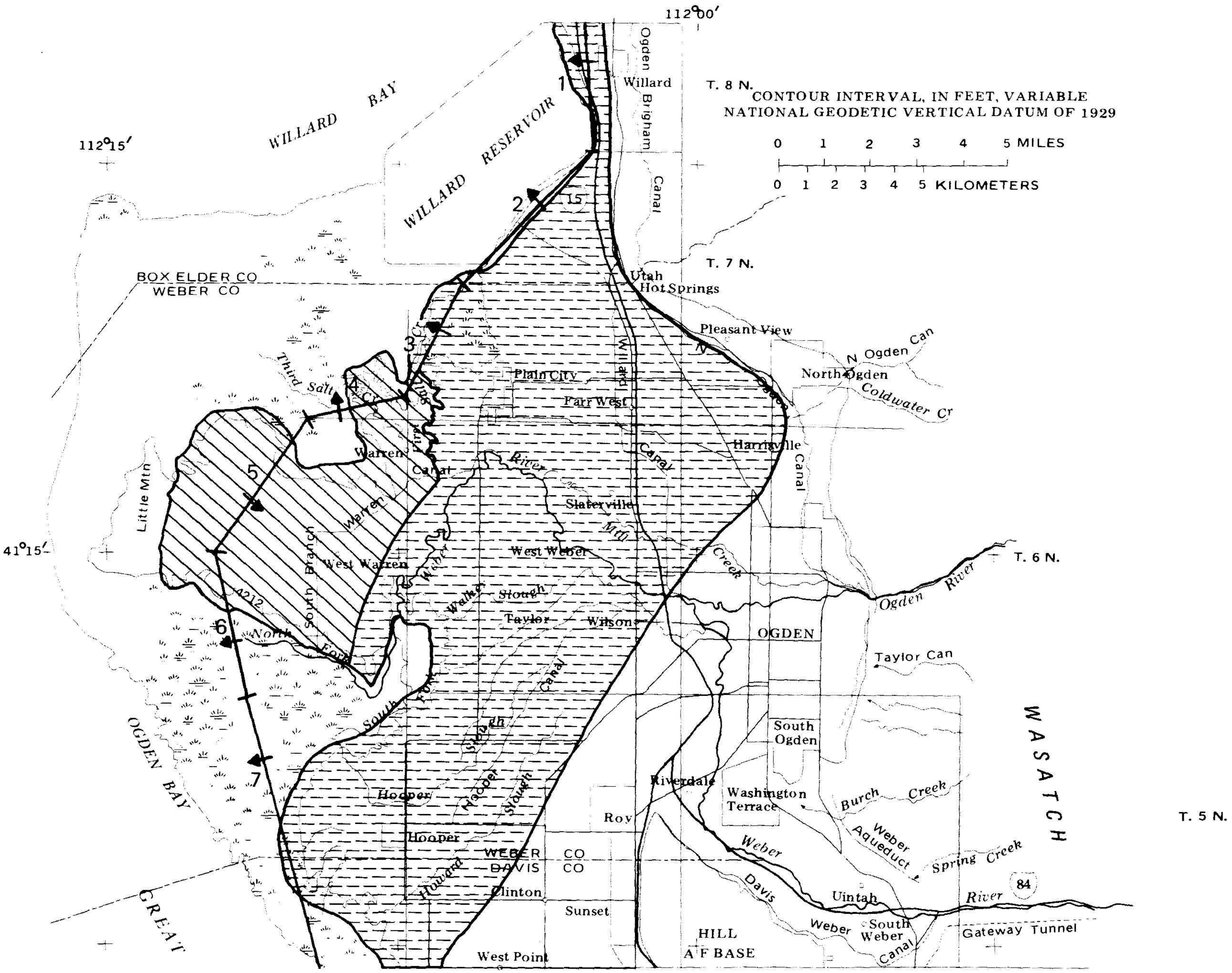
Some springs along the mountain front are thought to be associated with fault systems. The flow from these springs is not included in the water budget for the East Shore aquifer system because they discharge from consolidated rock. Some springs discharge water having temperatures as high as 46 degrees Celsius along the shore of Great Salt Lake. The water from these springs probably has followed a much deeper flow path than the water from the East Shore aquifer system.

Evapotranspiration

The East Shore area includes approximately 90,000 acres of land where upward leakage from the East Shore aquifer system is a source of water for evapotranspiration. This area is defined as the area where artesian pressure in the confined parts of the aquifer system is great enough to cause wells to flow. About 40,000 acres of this land is non-cropped, non-irrigated, vegetated areas and the remaining 50,000 acres is irrigated croplands. Water levels in the shallow water-table zone under the 40,000 acres of non-irrigated land are usually less than 10 feet below land surface and within reach of the roots of phreatophytes. Some of this shallow ground water, which originates as upward leakage from the East Shore aquifer system, is taken up by plants, evaporated to the atmosphere, or discharged to drains. The remaining water consumed by evapotranspiration is supplied by local precipitation, applied irrigation water from adjacent irrigated land, or from water in drainageways and streams.

The weighted annual average evapotranspiration rate of the phreatophytes in non-irrigated areas is estimated to be 2.5 feet per year. The estimate is based on the percentage of vegetation types in the area (Haws, 1970) and densities and rates of evapotranspiration of those vegetation types (Feth and others, 1966, p. 66-70). The annual evapotranspiration rates ranged from 1.4 feet for dryland vegetation to 5.1 feet for cattails (*Typha* spp.), rushes (*Juncus* spp.), and reeds. Other types of vegetation include saltgrass (*Distichlis spicata* sp.), greasewood (*Sarcobatus vermiculatus*), willow (*Salix* spp.), and cottonwoods (*Populus* spp.).

Of the total annual 2.5 feet of evapotranspiration, about 0.64 foot per year is from the effective precipitation, which was calculated from the April to October precipitation at the stations at Bear River Refuge and Ogden Sugar Factory for 1951-80. The annual evapotranspiration from sources other than precipitation from the 40,000 acres of non-irrigated land is about 1.9 feet or 76,000 acre-feet. The source of most of this water is excess applied irrigation water on the upgradient cropland, water in drainageways, and surface water in the sloughs and forks of the Weber River. The excess applied irrigation water was estimated to be about 65,000 acre-feet, based on a rate of 1.3 feet throughout the 50,000 upgradient acres. The 1.3-feet rate was calculated from an average consumptive use of 1.7 feet and an average applied irrigation rate of 3.0 feet for farms with less than 1,000 acres (U.S. Department of Commerce, 1982, p. 266). The average consumptive-use rate of 1.7 feet for croplands was calculated from a rate of 2.3 feet, based on percentage of crop types in the area (Haws, 1970) and the consumptive-use rate of the individual crops (Huber and others, 1982), minus the effective



112°00′
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CONTOUR INTERVAL, IN FEET, VARIABLE
NATIONAL GEODETIC VERTICAL DATUM OF 1929
0 1 2 3 4 5 MILES
0 1 2 3 4 5 KILOMETERS
T. 8 N.
T. 7 N.
T. 6 N.
T. 5 N.
WILLARD BAY
WILLARD RESERVOIR
Willard
Ogden Brigham Canal
BOX ELDER CO
WEBER CO
Utah Hot Springs
Pleasant View
N Ogden Can
North Ogden
Coldwater Cr
Plain City
Farr West
Harrisville
Canal
Slaterville
West Weber
Warren
West Warren
Third Salt Cr
Little Mtn
South Branch
Warren Canal
Willard Canal
Mill Creek
Ogden River
OGDEN
Taylor
Wilson
Taylor Can
Walker Slough
North Fork
South Fork
Weber River
Hooper Slough
Howard Slough
Hooper
Roy
Riverdale
South Ogden
Washington Terrace
Burch Creek
Weber Aqueduct
Spring Creek
WASATCH
WEBER CO
DAVIS CO
Clinton
Sunset
West Point
HILL A F BASE
Davis Weber Canal
Uintah
South Weber
Gateway Tunnel
OGDEN BAY
GREAT
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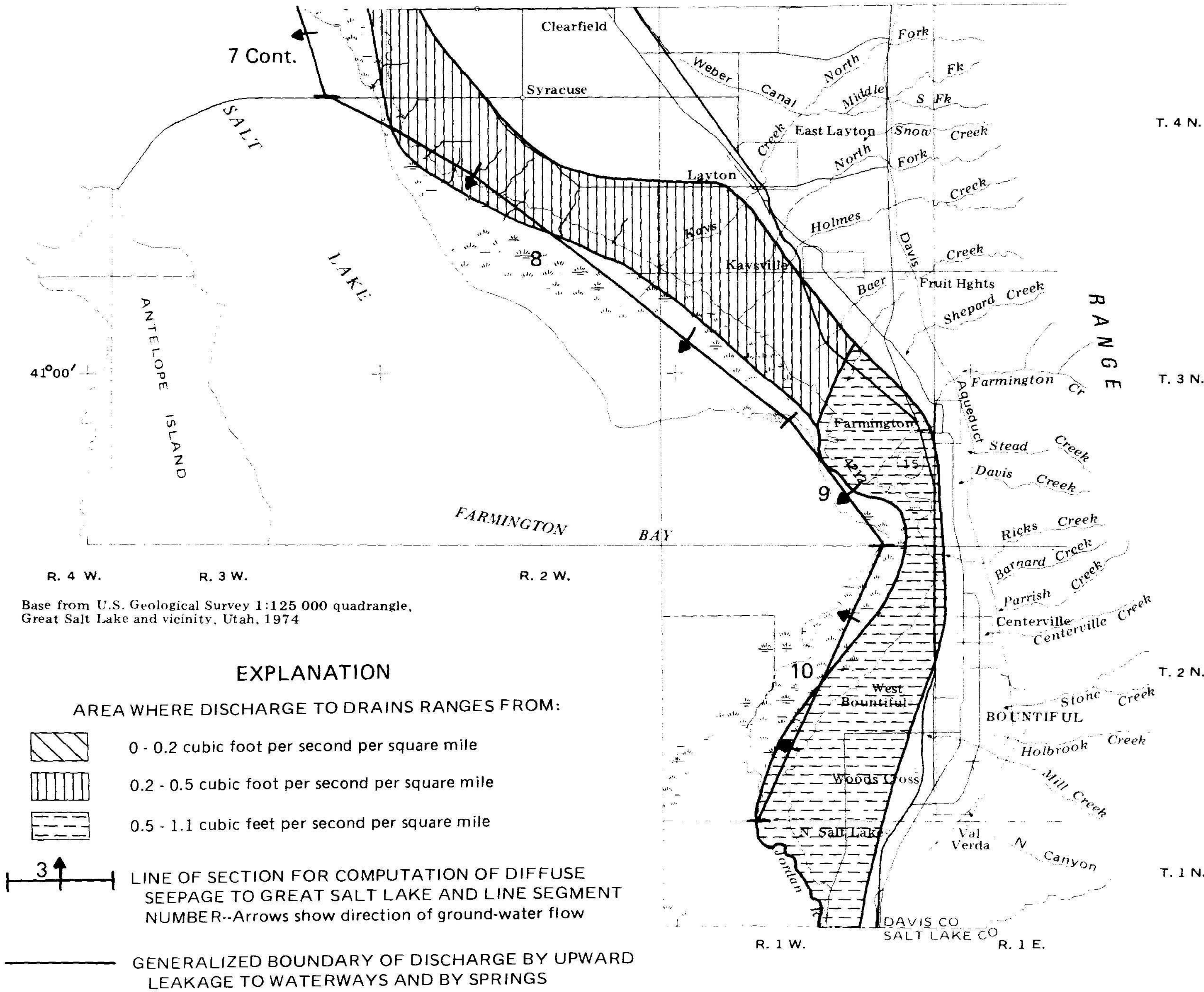


Figure 41.--Areas of different rates of drain discharge and computation lines used for estimating diffuse seepage to Great Salt Lake.

precipitation rate of 0.64 foot per year. Only a small part of the 76,000 acre-feet of evapotranspiration is supplied directly by upward leakage from the East Shore aquifer system. Part of the evapotranspiration from the non-irrigated area is from the 65,000 acre-feet of excess irrigation water. If all of this excess water moves to the non-irrigated area, the calculated evapotranspiration derived from excess irrigation water would be 65,000 acre-feet, and the remainder, or 11,000 acre-feet (76,000 - 65,000), would be supplied by upward leakage from the East Shore aquifer system. This estimate of 11,000 acre-feet is a maximum if some of the evapotranspiration is derived from other sources.

The areas of non-irrigated vegetation generally have little drain discharge, such as the area between Warren and Little Mountain (fig. 41). Feth and others (1966, table 15) reported a range of the annual rate of upward leakage in an area similar to the non-irrigated areas from 0.04 to 0.2 foot with an average rate of 0.1 foot, based on five experiments in 1954-55 on salt-crust barren lands near Great Salt Lake. If this average rate of evapotranspiration from upward leakage is assumed to represent a minimum rate for the 40,000 acres of non-irrigated vegetation, 4,000 acre-feet per year would represent the minimum evapotranspiration by upward leakage from the East Shore aquifer system.

Evapotranspiration of water from upward leakage in the irrigated croplands is assumed to be negligible because the water table in these areas generally is deeper than in the non-irrigated areas. The deeper water table is caused by the generally higher altitude and steeper land-surface gradient, and by the drains constructed to maintain the water table at a distance below the land surface such that plant roots are not in saturated soils. Therefore, it is assumed that the minimum annual evapotranspiration from upward leakage is about 4,000 acre-feet, the maximum amount is unknown but assumed to be about 11,000 acre-feet and the estimated average is 8,000 acre-feet.

Diffuse Seepage to Great Salt Lake

Ground water discharges by diffuse seepage from sediments under the east side of Great Salt Lake. The total annual ground-water discharge to the lake was estimated as the flow through a series of vertical cross-sectional areas—the locations of the sections are shown by the lines of section in figure 41. The necessary components of the Darcy equation (p. 32) to determine ground-water discharge into the lake are listed in table 10. Transmissivity was estimated with average aquifer hydraulic conductivity and thickness. The average hydraulic conductivity (K) was determined from lithologies described in drillers' logs of wells near the computation lines and hydraulic conductivity values used by Mower (1978, p. 16). The hydraulic gradient (I) was determined from water levels in wells near the lake. Where wells and water levels were not available very near the lake, it was assumed that the gradients nearest the lake were representative of gradients across the computation lines. Using the steeper gradients some distance from the lake probably overestimates discharge across some section lines. For the purpose of computing discharge, the saturated thickness of the aquifer system near the lake shore was assumed to be 1,000 feet.

Table 10.--Estimated discharge by diffuse seepage to Great Salt Lake

Section line (see fig. 41)	Hydraulic conductivity (K) (feet per day)	Hydraulic gradient (I) (dimensionless)	Length of section line (L) (feet)	Discharge (Q)[1] Cubic feet per day	Acre-feet per year (rounded)
1	40	0.0007	14,600	409,000	3,400
2	11	.0014	21,900	337,000	2,800
3	22	.0059	14,600	1,895,000	15,900
4	20	.0040	14,600	117,000	980
5	8	.0013	18,800	196,000	1,600
6	12	.00088	16,700	176,000	1,500
7	18	.0015	42,700	1,153,000	9,700
8	18	.00089	57,300	918,000	7,700
9	12	.0032	17,700	680,000	5,700
10	17	.0016	35,400	963,000	8,100
			Total (rounded)		57,000

Less discharge across section line 5 (see fig. 41) where flow is to the east 1,600
Less discharge to drains, seeps, and streams (see page 80) 3,000-5,000

Total discharge to Great Salt Lake at a lake altitude of about 4,200 feet (rounded) 50,000

[1]Based on an assumed saturated thickness of 1,000 feet for the aquifer system.

The total discharge calculated for 48 miles of lake shore is estimated to be 57,000 acre-feet per year. Discharge by drains near the lake and west of line segment line 3 (fig. 41) is estimated to range from 3,000 to 5,000 acre-feet per year and was subtracted from the total discharge by diffuse seepage to Great Salt Lake. Excluding the drain discharge (3,000-5,000 acre-feet) and ground-water flow to the east across line segment line 5 (1,600 acre-feet), the discharge from the East Shore aquifer system by diffuse seepage to the lake is estimated to be about 50,000 acre-feet per year (table 10).

Summary of the Hydrologic Budget for the East Shore Aquifer System

The hydrologic budget of the East Shore aquifer system is summarized in table 11. The budget components for recharge and discharge were calculated independently, and the totals are not equal. The difference between the totals for recharge and discharge primarily is due to lack of reliable data for calculating some of the individual budget components, particularly recharge from subsurface inflow, discharge to drainageways and springs, and diffuse seepage to Great Salt Lake, which are major parts of the total budget. However, it is likely that the discharge from the East Shore aquifer system was slightly larger than recharge during 1969-84 because a small part of the discharge from wells was derived from loss of aquifer storage rather than being entirely derived from recharge. Another source of discrepancy was the time periods during which data to calculate individual parts of the budget were collected. The value for each component of the budget is assumed to be an average value during 1969-84. However, data were not available for all components for the same time period, and the average values represent different periods of time and may represent hydrologic extremes. For instance, discharge to drainageways and springs was calculated based on data collected during 1984-85, a period following greater than normal precipitation; the calculated value may be larger than actual average value for 1969-84. A reasonable estimate of the long-term average for both recharge to and discharge from the East Shore aquifer system is about 160,000 acre-feet per year.

Chemical Quality and Temperature

The quality of ground water in the East Shore area has changed little since previous studies even though withdrawals have increased substantially. Chemical analyses of water from wells collected during this study and selected analyses from other studies are reported in Plantz and others (1986, table 5). Smith and Gates (1963) and Bolke and Waddell (1972) discussed the chemical quality of ground water in the entire area, whereas Feth and others (1966) discussed the quality of water in only the Weber Delta area. Additional information on the prevalent chemical types of ground water in the area can be found in those reports. Chemical analyses of ground water in the area indicates that in most of the area the water is potable; however, some areas are not extensively developed because the quality of the water is not suitable for some uses.

Table 11.—Approximate hydrologic budget for the East Shore aquifer system, 1969-84

Budget component	Acre-feet per year (rounded)
Recharge	
Seepage from rivers, streams, and irrigation canals	60,000
Infiltration from irrigated fields, lawns, gardens, and direct precipitation	18,000
Subsurface inflow from consolidated rocks	75,000
Total............	153,000
Discharge	
Wells	54,000
Waterways and springs	70,000
Evapotranspiration	8,000
Diffuse seepage to Great Salt Lake	50,000
Total.............	182,000

Relation to Hydrology and Geology

The chemical quality of the ground water in the East Shore area is directly related to the quality of its recharge water and the composition of the rocks and soil through which the water flows from points of recharge to points of discharge. The specific conductance of potential recharge water from streams is given in table 12. More than one-third of the recharge to the East Shore aquifer system is by seepage from surface water. The differences in quality between the streams primarily reflects the rock types in the drainage area and the rate of flow when the sample was taken. Most of the recharge by seepage occurs when the streams are at high flow and the specific conductance is relatively small. Specific conductance of water in the Gateway Tunnel, which was drilled through metamorphic rocks, and of freshwater springs near the mouths of Weber and Ogden Canyons is considerably smaller than that of most other surface water during low-flow periods. The water in the tunnel and the springs is assumed to be representative of the quality of water recharged from the same rock types along the Wasatch Front by subsurface inflow to the basin fill.

The East Shore area is bounded on the east by the Wasatch Fault zone and on the west by an inferred fault trending southeast from the Little Mountain area (fig. 3). The fault systems have a direct effect on the quality of

Table 12.--Specific conductance of water from streams at high and low flow, selected springs, and Gateway Tunnel

Name	Average specific conductance (microsiemens per centimeter at 25 degrees Celsius)		
	High flow	Low flow	
Ogden River	180	280	
Burch Creek	100	-	
Weber River	310	550	
Kays Creek	560	900	
Holmes Creek	350	630	
Baer Creek	230	500	
Farmington Creek	120	-	
Gateway Tunnel			200
Springs at the mouth of Ogden Canyon			150
Springs at the mouth of Weber Canyon			120

ground water near them. This effect is indicated by high temperatures and large concentrations of dissolved minerals in the water of Hooper Hot Springs on the west and Utah Hot Springs on the east. These waters are assumed to result from upward flow along the fault zones and are presumed to have circulated either deep in the alluvium or in the underlying consolidated rock where the water has been heated. Such circulation has been postulated based on data from analyses for stable isotopes (Cole, 1982). The increase in temperature increases the solubility and dissolution rate of rock minerals and causes an increase in the total concentrations of dissolved minerals (Hem, 1970, p. 42).

An example of how the water chemistry changes along flow paths between recharge and discharge areas is shown in figure 42. The specific conductance of water at selected sites along the flow path from the mouth of Weber Canyon northwest to near Little Mountain suggests recharge sources and indicates changes in water quality. Recharge water from the Weber River has a specific conductance ranging from about 310 to 550 microsiemens per centimeter at 25 degrees Celsius, whereas specific conductance of water from the Gateway Tunnel and springs in consolidated rock ranges from 120 to 200. Water from deep wells near Hill Air Force Base and the Weber River has values of specific conductance that are larger than the values of the Weber River at high flow and similar to values at low flow. This difference indicates that water that moves to these wells originated as seepage from the river, assuming some dissolution of rock minerals along the ground-water flow path. Farther along the flow path, the values of specific conductance are smaller than the values at the upgradient wells and for river water, indicating that at least some of the water that moves to these wells probably is from consolidated-rock sources that has circulated beneath the upgradient wells. The large values at the

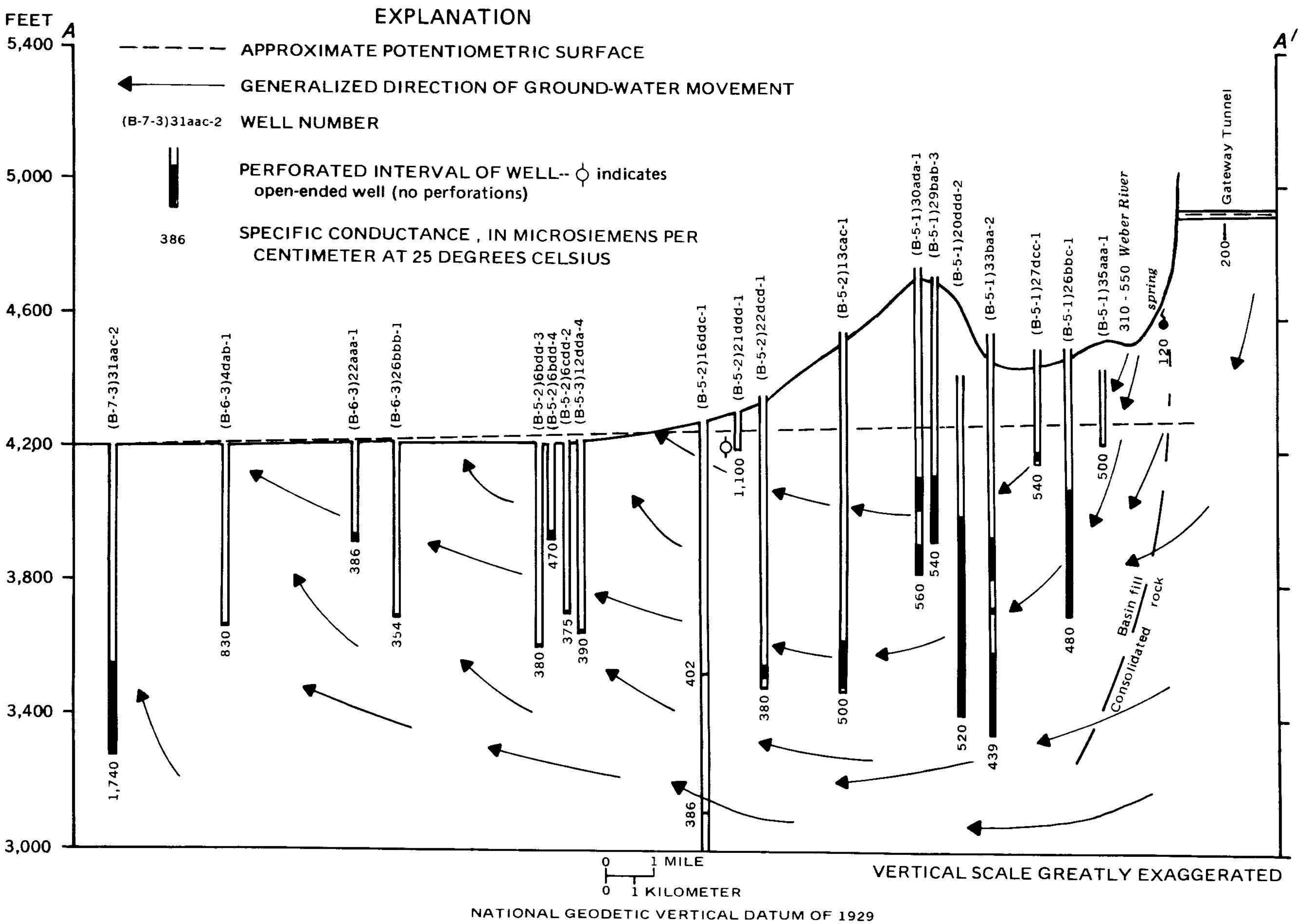


Figure 42.--Section from Weber Canyon to Great Salt Lake showing flow path of ground water and values for specific conductance. Trace of section is shown on figure 44.

western (down gradient) end of the section are related to vertical movement of warm saline waters along the steeply dipping faults.

Chemical Composition

The chemical makeup of the ground water in the East Shore area varies areally and with depth. The principal ions in the ground water are calcium, magnesium, sodium plus potassium, bicarbonate plus carbonate, sulfate, and chloride. The large variability in the chemical composition of ground water is shown by Stiff diagrams in figure 43. The Stiff diagram shows individual ion concentrations in milliequivalents per liter in a polygon shape that indicates water-composition differences and similarities. The chemical composition of ground water in the East Shore area is dominated by three principal types. Calcium magnesium bicarbonate type waters generally have the smallest dissolved-solids concentrations and occur in an area along the Weber River, along the recharge area south of the Weber River to Bountiful, and in the North Ogden area. Sodium bicarbonate waters generally occur in the discharge areas, and sodium chloride type waters are found associated with fault-related thermal waters and in an area from Ogden northwest toward Plain City (fig. 43).

In the East Shore area, the chloride concentration in water is an approximate indication of the quality of the water. Areas where the chloride concentration in ground water exceeds 25 and 250 milligrams per liter are shown in figure 44. The larger chloride concentration near Great Salt Lake probably is related to thermal water. This, however, is not believed to be the case with the larger chloride concentrations in the area between Ogden and Plain City. The reason for the larger chloride concentrations in the Ogden-Plain City area is not completely understood; however, there appears to be greater resistance to ground-water flow through the area. Feth and others (1966, p. 62) suggested that when sediments were being deposited in Lake Bonneville and preceding lakes, there may have been an embayment in the area which ponded water and restricted flow, and consequently, caused a larger proportion of fine-grained sediments to be deposited in this area. They also suggested that increased evaporation may have caused evaporite beds to be deposited. The combination of fine-grained sediments, which impede ground-water flow, and buried salt deposits may result in the large chloride concentrations in this nonthermal ground water. These suggestions are supported by drillers' logs of wells in the area, which indicate large sequences of fine-grained material and the presence of saline water in some areas.

Water in the deeper parts of the East Shore aquifer system generally contains smaller dissolved-solids concentrations than the water in the shallower parts of the aquifer system, especially in the topographically lower part of the basin. The primary reason for this difference is upward leakage from the deeper to the shallower parts of the aquifer system in which the water flows through fine-grained sediments and accumulates additional dissolved solids. The fine-grained sediments in the lower part of the basin contain soluble salts partly left by precipitation from past saline lakes and concentration of salts by evaporation as a part of past ground-water discharge. Another reason is deeper circulation of less mineralized recharge water from subsurface inflow from consolidated rock, as illustrated in figure 42. Water-quality data from a well drilled to more than 3,000 feet indicate that at depths greater than 1,200 feet, the trend reverses, that is, dissolved-solids concentration in the water increases with depth (fig. 43). Stiff diagrams for water from well (B-5-2)16ddc-1 at various depths (fig. 43) show that the water ranges from relatively small chemical concentrations of calcium magnesium bicarbonate water at 750 feet and sodium bicarbonate water at 1,160 feet to a non-thermal, sodium chloride water with a large dissolved-solids concentration below 1,600 feet. These data and data from a well drilled on Hill Air Force Base (Glenn and others, 1980) indicate that the average thickness of sediments containing water with relatively small concentrations of dissolved solids in the study area probably does not exceed about 1,500 feet. Below 1,500 feet in well (B-5-2)16ddc-1, most of the sediments are fine grained, and the water probably moves through these sediments at a slow rate and becomes more mineralized. Therefore, this mineralized, moderately saline, water is probably not directly related to water in the East Shore aquifer system above it.

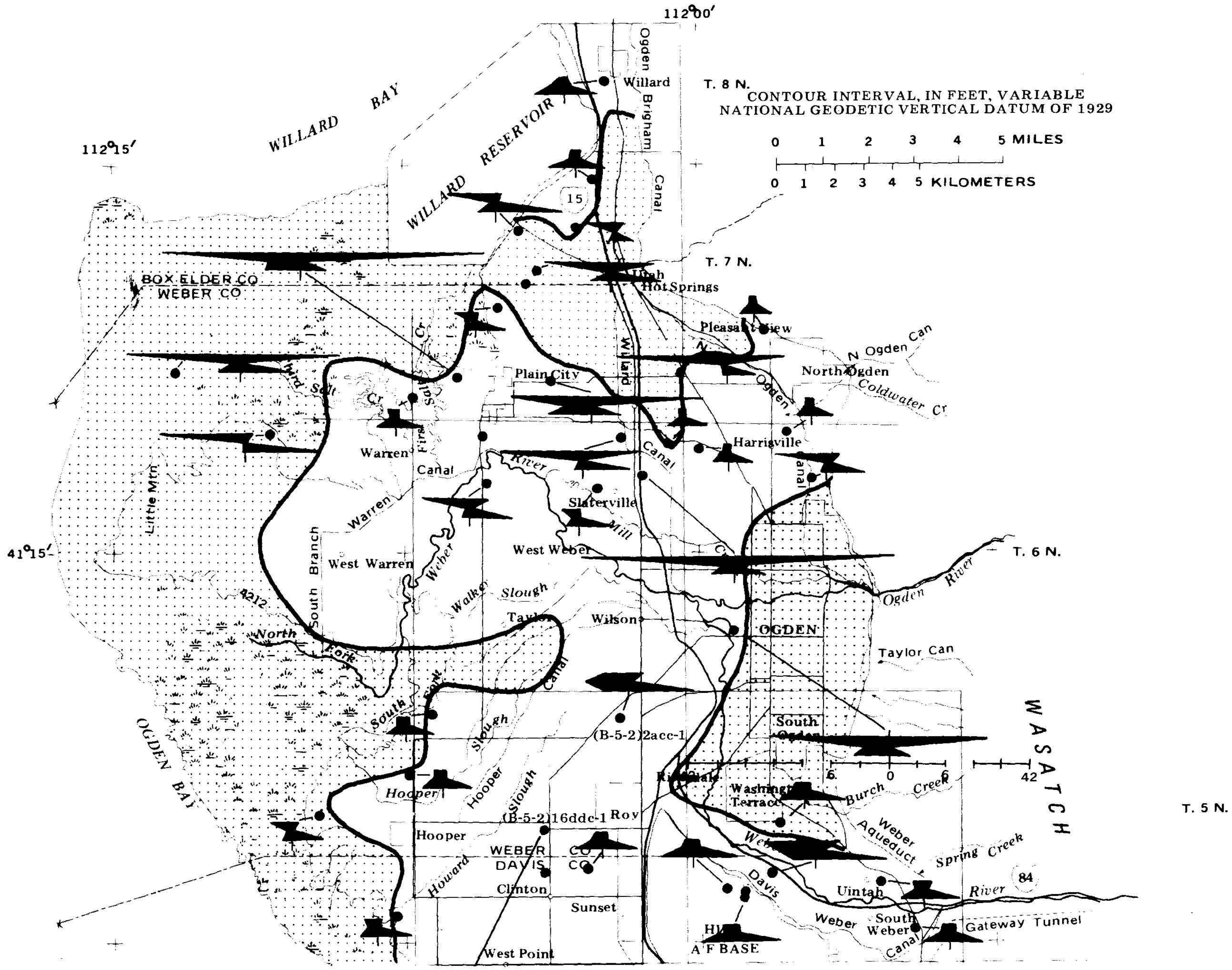
The water from well (B-5-2)2acc-1 (fig. 43), a shallow flowing well east of most flowing wells, is a magnesium bicarbonate type which is different from the water samples from other wells. The well probably obtains water from an aquifer that is locally recharged by infiltration of irrigation water on nearby benchlands, which may be the cause of the unique type of water.

Suitability for Use

The standards for suitability of water vary with the potential use of the water. The suitability of water for irrigation depends on the soil type and application procedures, as well as the dissolved-solids concentration and chemical type of the water. The recommended standards for inorganic chemical constituents for drinking water are based on maximum concentration limits for those constituents. The suitability of water for domestic and municipal use may also depend on the hardness of the water.

In general, the more suitable types of water for irrigation are the calcium, magnesium bicarbonate types, and water with small concentrations of dissolved solids. Sodium-type water and all water with dissolved-solids concentrations greater than 500 milligrams per liter are generally less suitable for irrigation and could lower the yields of some types of crops, depending on soil and drainage conditions.

Water that has a dissolved-solids concentration greater than about 500 milligrams per liter, or chloride concentration greater than about 250 milligrams per liter, generally exceeds the recommended limits for public supply (Utah Department of Health, 1984, p. 3-6). About 25 percent of the wells sampled in the East Shore area produced water with a dissolved-solids concentration that exceeded 500 milligrams per liter. Most of the ground water in areas where the chloride concentration exceeds 250 milligrams per liter generally is unused, used for stock water, or used for irrigation as a supplement to surface water.


112°00′
112°15′
41°15′
T. 8 N.
T. 7 N.
T. 6 N.
T. 5 N.
CONTOUR INTERVAL, IN FEET, VARIABLE
NATIONAL GEODETIC VERTICAL DATUM OF 1929
0 1 2 3 4 5 MILES
0 1 2 3 4 5 KILOMETERS
WILLARD BAY
WILLARD RESERVOIR
Willard
Ogden Brigham Canal
15
Utah Hot Springs
BOX ELDER CO
WEBER CO
Pleasant View
N Ogden Can
North Ogden
Coldwater Cr
Plain City
Willard
Harrisville
Canal
Warren
Canal
River
Slaterville
Mill
Little Mtn
Warren
South Branch
West Warren
Weber
West Weber
Walker
Slough
Taylor
Wilson
Ogden River
4212
North Fork
OGDEN
Taylor Can
WASATCH
OGDEN BAY
South Fork
Slough
Canal
(B-5-2)2acc-1
South Ogden
Hooper
Hooper
Slough
Riverdale
Washington Terrace
Burch Creek
Weber Aqueduct
Spring Creek
Hooper
(B-5-2)16ddc-1
Roy
WEBER CO
DAVIS CO
Howard
Clinton
Sunset
West Point
Davis
Uintah
84
River
South Weber
Weber Canal
Gateway Tunnel
HILL A F BASE
42

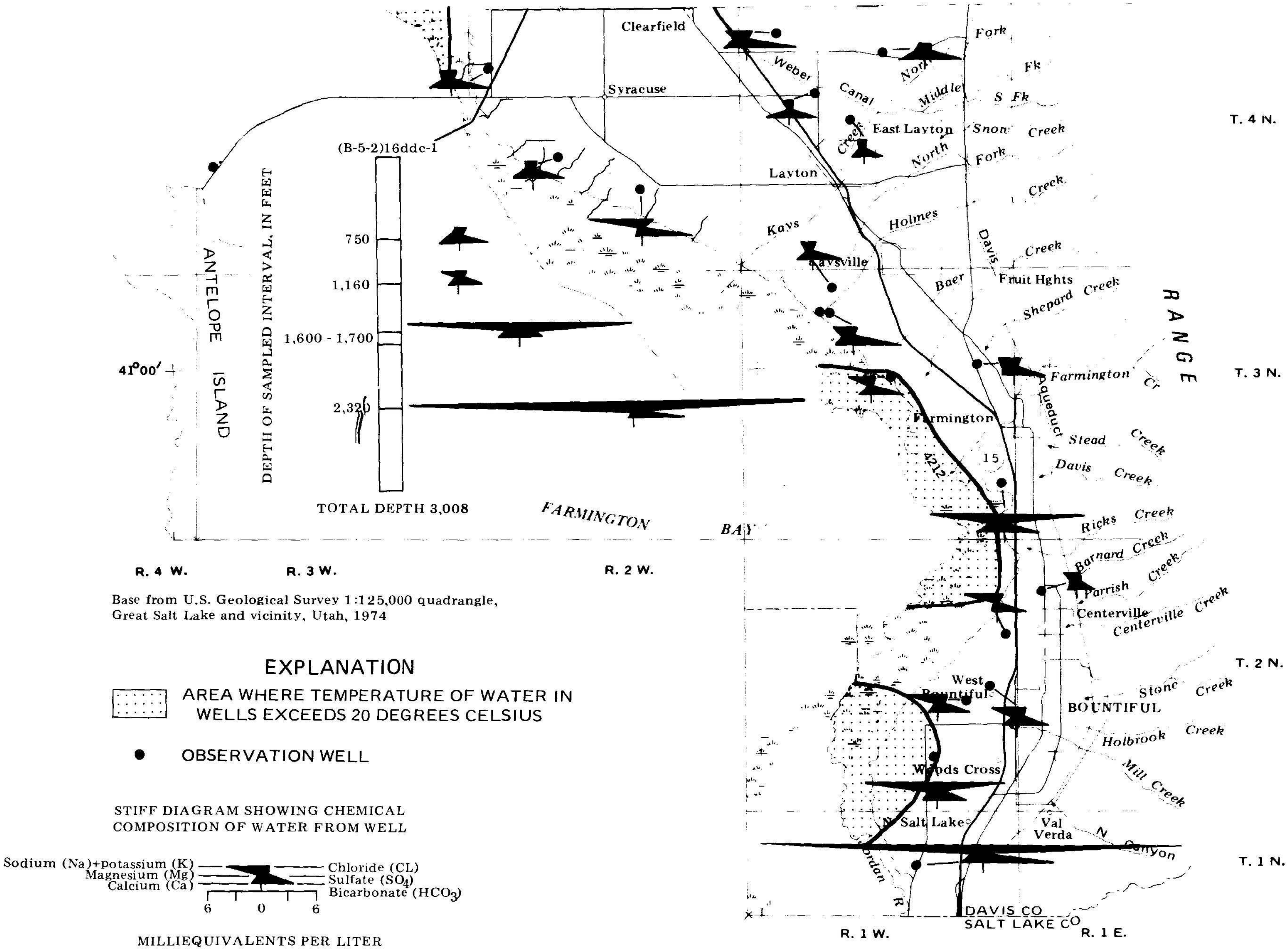
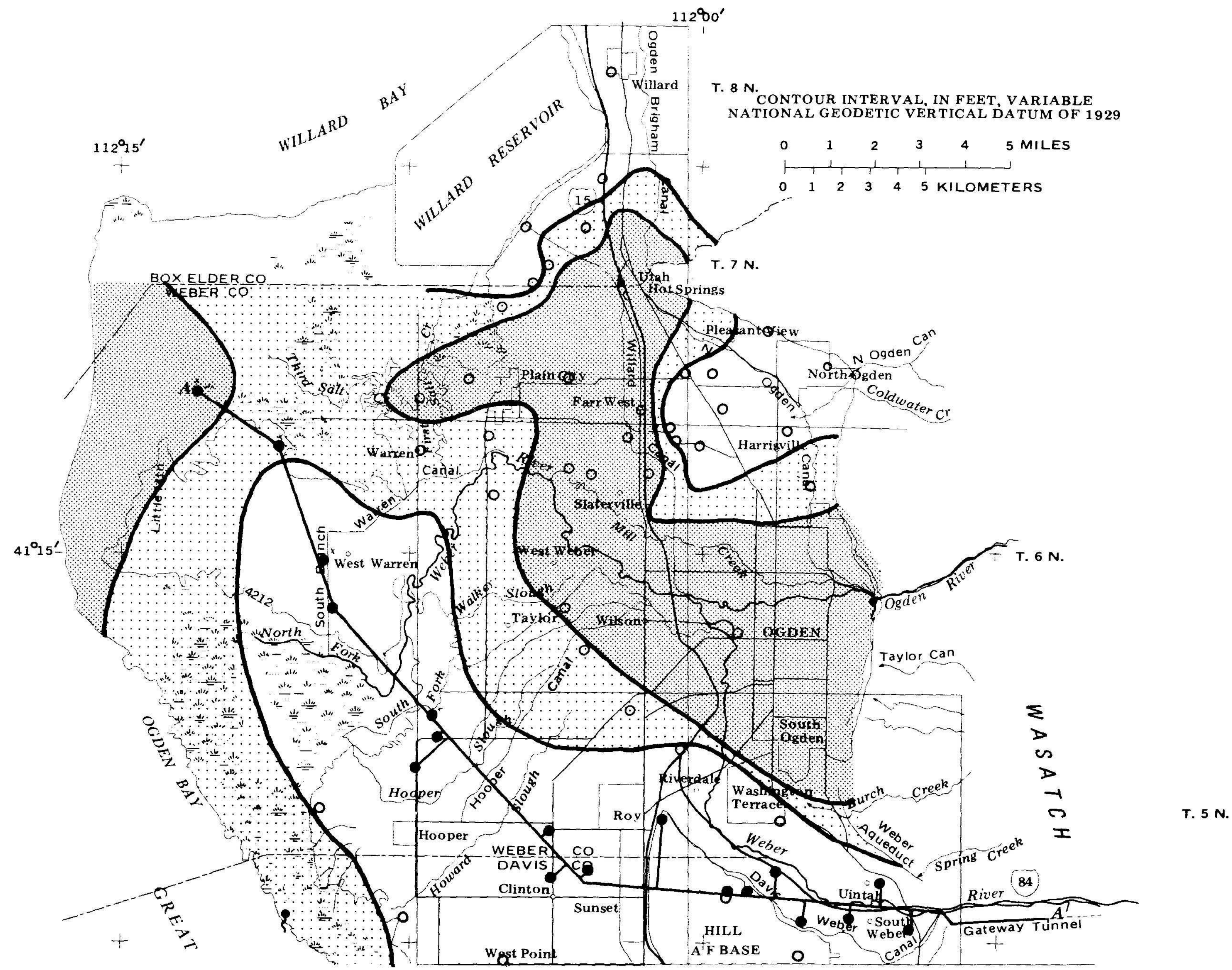
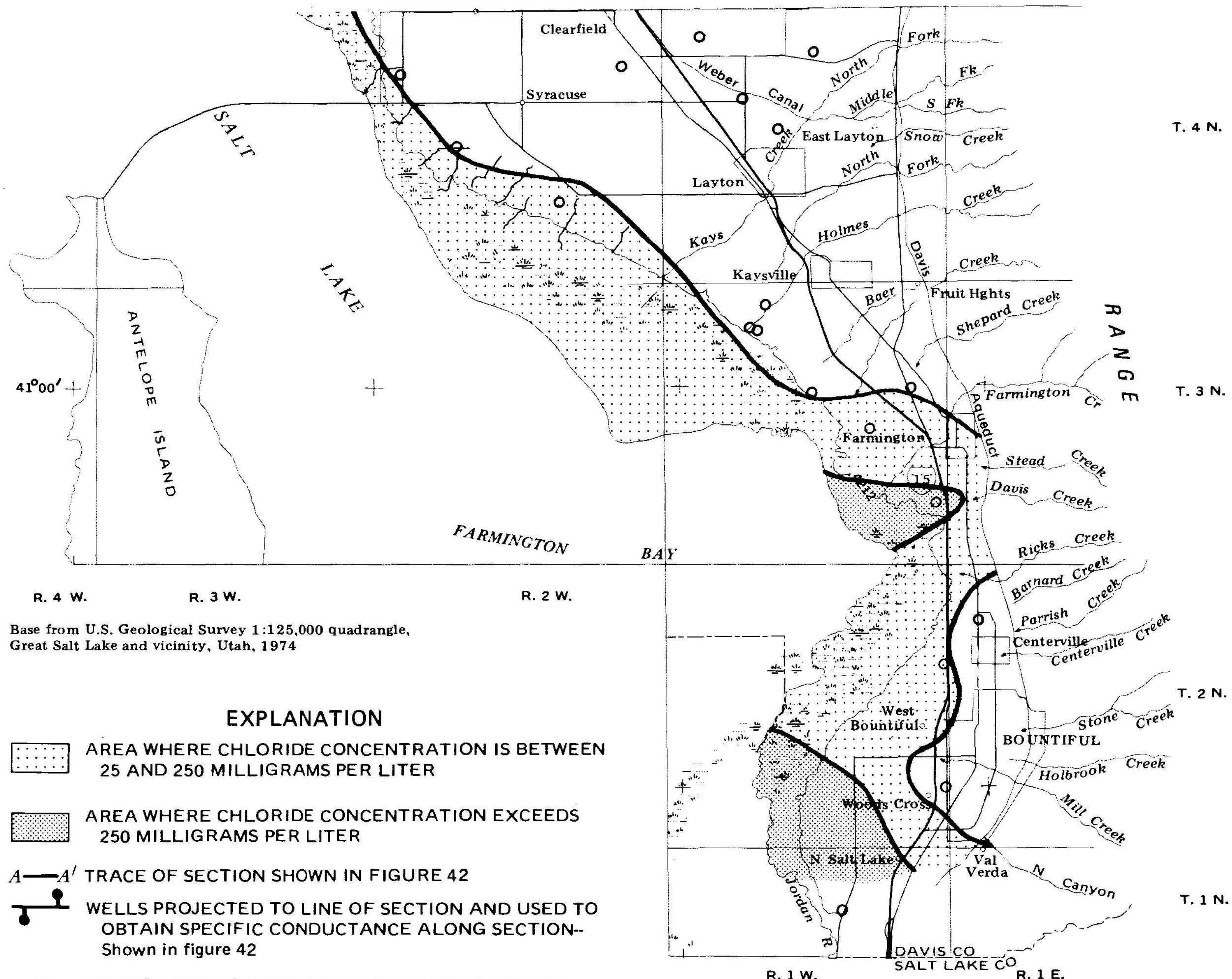


Figure 43.--Chemical composition of water from wells, and areas where temperature of water from wells exceeds 20 degrees Celsius.



112°00′
112°15′
41°15′
T. 8 N.
T. 7 N.
T. 6 N.
T. 5 N.
CONTOUR INTERVAL, IN FEET, VARIABLE
NATIONAL GEODETIC VERTICAL DATUM OF 1929
0 1 2 3 4 5 MILES
0 1 2 3 4 5 KILOMETERS
WILLARD BAY
WILLARD RESERVOIR
Willard
Ogden Brigham Canal
15
BOX ELDER CO
WEBER CO
Utah Hot Springs
Pleasant View
N Ogden Can
North Ogden
Coldwater Cr
Plain City
Farr West
Willard Canal
Harrisville
Ogden Canal
A
Third Salt
Warren
Canal
Slaterville
Mill Creek
Little Salt
Warren
West Warren
Weber
West Weber
South Branch
4212
North Fork
Walker Slough
Taylor
Wilson
OGDEN
Ogden River
Taylor Can
Canal
South Fork
Slough
South Ogden
WASATCH
OGDEN BAY
Hooper
Hooper Slough
Riverdale
Washington Terrace
Burch Creek
Roy
Weber Aqueduct
Spring Creek
Hooper
WEBER CO
DAVIS CO
Howard
Clinton
Sunset
Weber
Davis
Uintah
84
River
A′
GREAT
West Point
HILL A F BASE
Weber
South Weber
Canal
Gateway Tunnel



Base from U.S. Geological Survey 1:125,000 quadrangle, Great Salt Lake and vicinity, Utah, 1974

EXPLANATION

AREA WHERE CHLORIDE CONCENTRATION IS BETWEEN 25 AND 250 MILLIGRAMS PER LITER

AREA WHERE CHLORIDE CONCENTRATION EXCEEDS 250 MILLIGRAMS PER LITER

A——A′ TRACE OF SECTION SHOWN IN FIGURE 42

WELLS PROJECTED TO LINE OF SECTION AND USED TO OBTAIN SPECIFIC CONDUCTANCE ALONG SECTION--Shown in figure 42

SPRING USED FOR CONTROL POINT FOR CHLORIDE CONCENTRATION

WELL USED FOR CONTROL POINT FOR CHLORIDE CONCENTRATION

Figure 44.--Chloride concentration of water from wells and selected springs.

Changes in Water Quality

During previous studies in the East Shore area, a network of wells was established for water-quality sampling in order to determine if any changes in water quality occurred with time. The network was established because of the variety of water types in the area and because of the potential for unsuitable, mineralized water migrating toward areas of potable, less mineralized water with increasing ground-water development and resulting water-level changes. Smith and Gates (1963) and Bolke and Waddell (1972) described changes that had occurred at the time of those reports and identified areas of potential changes in ground-water quality due to increased development.

Thirty-three wells that were sampled prior to 1970 were resampled during this study to document any water-quality changes that may have occurred (table 13). Of the thirty-three wells resampled, water from only five had a greater than 10-percent increase in dissolved solids. Water from one well, (B-7-2)10dbd-1, had a large decrease in dissolved solids; water from another, (B-4-3)19cca-1, had large fluctuations in dissolved solids; and water from another, (B-7-3)31aac-2, had little or no change in dissolved-solids concentration, but did reflect a change in the chemical type. Because vertical stratification of water with different chemical types exists in the East Shore area, changes in chemistry of water produced by a given well may be a result of fluctuating proportions of water of different chemical types entering the well as a result of changes in the discharge rate or an increase in recharge. Change in chemical type of water probably does not reflect a widespread regional change in water chemistry.

The water from well (B-4-1)6adc-1, on Hill Air Force Base about 1 mile east of Clearfield, is a calcium bicarbonate type that has shown a greater than 10-percent increase in dissolved-solids concentration since 1967 (table 13). Bolke and Waddell (1972, p. 20) suggested that similiar changes in a nearby well were apparently due to different proportions of water being contributed by two zones within the deeper parts of the aquifer system. In those two zones, dissolved solids generally increase with depth; therefore, during periods of large withdrawals, a relatively larger amount of water is apparently contributed by the deeper zone. Even though some changes have occurred in the area near Hill Air Force Base, a degradation of the regional water quality due to increased withdrawals probably has not occurred.

The dissolved-solids concentration in water from well (B-6-1)29cbb-1 (table 13), which is a sodium chloride type (fig. 44), has increased more than 35 percent since 1960. In addition, the water temperature has decreased from 24 to 15.5 degrees Celsius. Even with the large increase in dissolved solids, the calcium concentration actually decreased, whereas the sodium, potassium, and chloride concentrations increased by more than 45 percent. A map by Bolke and Waddell (1972, pl. 3) indicates that the well is near a boundary between mixed and sodium chloride type water. Since the well was completed, it is possible that the lower temperature, sodium chloride water has migrated toward the well.

Table 13.--Chemical analyses of water from selected wells sampled before 1970 and after 1980

Location: See text for explanation of numbering system for wells.
Units: DEG C, degrees Celsius; µS/cm, microsiemens per centimeter at 25° Celsius; mg/L, milligrams per liter; Sodium: T, value is total of sodium plus potassium; Alkalinity: *, value converted from bicarbonate; Solids: R, value as dissolved solids residue at 180 °C.
Analyses for additional samples for some of these wells are in Plantz and others (1986), table 5.

Location	Date of sample	Specific conductance (µS/cm)	Temperature (DEG C)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Alkalinity, lab (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Solids, sum of constituents, dissolved (mg/L)	Hardness (mg/L as $CaCO_3$)
(A-2-1) 7aba-4	09-08-47	338	17.0	30	7.9	23 T	--	114	16	18	189	--
	12-12-58	271	17.0	17	7.3	32 T	--	107	11	14	169	--
	10-15-64	264	18.0	16	7.9	31 T	--	105	12	14	162 R	--
	08-05-82	265	16.0	20	8.3	31	1.6	103	18	15	180	84
(B-1-1)10aac-1	12-20-65	3,080	15.5	51	17	577 T	--	351 *	1.2	780	1,700	200
	11-13-68	2,920	16.0	45	20	570 T	--	355 *	6.2	760	1,700	190
	07-31-84	2,860	16.0	48	16	530	28	372	7.3	750	1,700	190
(B-2-1)13aab-1	05-09-47	380	--	12	3.5	80 T	--	168 *	15	30	260	44
	10-10-58	395	15.5	9.6	2.9	80 T	--	157 *	9.5	30	250	36
	05-05-69	395	15.0	9.6	1.9	80 T	--	158 *	8.2	28	240	32
	08-31-84	400	16.0	9.7	2.5	76	.70	160	6.0	26	240	35
24bad-3	08-12-74	470	16.0	28	6.5	64	1.0	--	21	--	280	97
	08-17-84	490	16.5	35	7.6	63	.90	169	26	30	280	120
(B-3-1) 5dda-1	11-14-68	300	24.0	25	7.3	32 T	--	131 *	3.2	18	200	92
	08-31-84	305	18.0	28	5.5	30	2.6	139	2.5	14	200	93
15bac-1	09-09-69	395	24.0	30	3.4	60 T	--	190 *	4.1	20	250	89
	08-04-81	320	20.5	29	3.6	59	2.2	180	1.0	17	250	87
25dab-1	08-20-68	1,320	18.0	65	17	180	2.3	176 *	1.0	320	700	230
	08-31-84	1,360	16.0	60	15	180	2.2	190	3.5	310	710	210
(B-4-1) 6adc-1	01-04-56	470	11.0	43	15	33	6.7	--	1.5	21	280	170
	05-10-60	475	12.5	45	14	36	6.0	--	2.1	20	280	170
	07-10-67	450	17.5	48	11	40 T	--	--	2.0	22	270	170
	09-19-84	565	12.5	50	17	44	7.1	264	1.0	24	320	190
8dcd-1	09-06-61	385	--	47	12	17	1.6	162 *	21	15	225 R	170
	08-22-84	370	14.0	49	11	15	1.3	158	16	13	220	170
(B-4-2)27aba-1	05-05-69	630	15.0	14	4.4	130	5.4	324 *	1.5	48	390	53
	08-02-77	600	13.5	15	4.5	130	5.8	--	6.8	48	410	56
	08-15-84	650	14.0	13	4.4	130	5.7	276	5.6	45	400	51
(B-4-3)19cca-1	08-04-69	1,180	24.0	46	25	160	4.4	156 *	8.8	290	660 R	220
	08-05-70	1,800	24.0	68	21	360	--	--	24	620	1,200	260
	08-02-77	1,150	23.5	48	11	170	5.0	--	11	290	660	170
	08-04-80	1,240	22.0	47	12	190	6.0	--	8.2	310	710	170
(B-5-1)17ddd-1	12-19-62	475	--	54	17	19	2.7	197 *	20	24	238 R	200
	09-12-84	515	21.0	56	17	20	2.9	218	22	21	290	210
20ddd-2	01-03-62	485	15.0	80	16	17	1.2	245 *	27	18	274 R	270
	08-22-84	520	14.5	64	16	17	2.0	213	24	20	280	230

Table 13.--Chemical analyses of water from selected wells sampled before 1970 and after 1980—Continued

Location	Date of sample	Specific conductance (µS/cm)	Temperature (DEG C)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Alkalinity, lab (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Solids, sum of constituents, dissolved (mg/L)	Hardness (mg/L as $CaCO_3$)
(B-5-1)29bdb-3	04-09-43	520	--	70	19	21	2.1	236 *	28	21	320	250
	04-14-52	560	11.5	73	19	20	1.7	242 *	30	18	320	260
	05-09-60	530	12.0	74	16	19	1.8	230 *	37	16	320	250
	07-24-69	540	16.0	71	27	--	--	234 *	31	20	300	290
	09-19-84	575	11.0	70	18	17	1.9	231	28	20	310	250
29bdc-1	04-14-52	600	11.5	76	20	24	2.6	262 *	36	20	350	270
	05-09-60	550	12.0	75	18	20	2.5	242 *	36	17	320	260
	07-25-69	580	18.0	77	21	18 T	--	363 *	34	12	330	280
	09-19-84	600	11.0	71	19	21	2.2	252	26	20	320	260
(B-5-2)30ada-1	06-19-50	580	12.0	75	19	23	1.3	260 *	33	20	340	270
	05-10-60	580	12.0	78	18	23	2.1	257 *	36	18	340	270
	07-18-68	540	14.0	65	22	22 T	--	235 *	32	18	320	250
	09-19-84	570	11.5	70	18	19	2.1	234	27	18	310	250
(B-5-2) 6bdd-3	08-29-68	360	19.0	36	9.7	23	3.1	156 *	8.2	18	210	130
	08-02-77	360	17.0	36	11	20	2.3	--	13	16	210	140
	08-15-84	380	17.5	42	11	22	2.5	156	15	12	220	150
6bdd-4	09-09-69	445	16.0	--	--	--	--	215 *	--	18	--	--
	08-02-77	450	14.5	36	15	37	7.8	--	5.2	18	280	150
	08-15-84	470	18.0	38	14	36	7.7	221	1.5	15	260	150
21ddd-1	11-18-68	1,090	12.0	46	49	130 T	--	429 *	1.8	110	640	320
	08-15-84	1,000	14.5	47	44	110	20	451	2.1	85	610	300
(B-5-3)15dda-1	05-14-69	380	24.0	--	--	--	--	134 *	--	29	--	84
	08-15-84	395	23.5	21	6.5	55	3.5	166	.9	22	220	140
25dcd-1	05-14-69	365	15.0	--	--	--	--	103 *	--	22	--	140
	08-15-84	390	16.0	36	11	29	1.6	180	.8	14	220	140
(B-6-1) 4bbd-5	11-22-67	245	--	28	8.0	14	1.2	117 *	5.3	7.8	140 R	100
	08-29-84	255	18.5	27	9.0	14	1.2	119	7.7	6.2	150	100
6caa-1	04-14-43	260	--	32	10	14 T	--	130 *	4.0	6.0	--	120
	02-24-56	275	--	32	10	11	2.3	128 *	5.8	9.6	180	120
	11-17-59	270	15.5	32	8.8	14 T	--	131 *	6.0	5.5	160	120
	10-16-64	265	15.0	31	9.1	15 T	--	131 *	5.4	6.6	170	110
	09-05-84	280	14.5	33	9.3	11	2.5	134	5.1	5.0	170	120
29cbb-1	12-27-60	3,150	24.0	96	31	480	41	127 *	8.2	900	1,760 R	370
	09-05-84	4,390	15.5	74	29	740	60	119	3.0	1,400	2,400	300
(B-6-2) 5acb-2	03-04-54	510	--	17	5.2	90	2.3	222 *	1.4	30	300	64
	11-04-59	495	15.5	19	5.8	89 T	--	223 *	2.3	28	300	71
	10-19-64	475	19.5	17	6.1	94 T	--	226 *	3.1	30	310	68
	09-05-84	495	16.5	19	4.8	86	3.0	226	1.8	27	300	67
(B-6-3) 4dab-1	10-09-68	820	21.0	4.0	3.4	200	4.8	411 *	4.2	28	520	24
	08-16-84	800	21.0	3.9	1.7	200	4.9	401	<.2	27	--	17

Table 13.--Chemical analyses of water from selected wells sampled before 1970 and after 1980--Continued

Location	Date of sample	Specific conductance (µS/cm	Temperature (DEG C)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Alkalinity, lab (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Solids, sum of constituents, dissolved (mg/L)	Hardness (mg/L as $CaCO_3$)
(B-7-2) 2cba-5	09-09-69	234	14.0	17	3.9	32 T	--	116 *	0.5	7.2	140	59
	08-09-77	340	13.0	50	6.6	11	1.1	--	12	14	200	150
	08-05-80	460	15.5	52	11	16	2.8	--	16	14	230	180
	08-14-84	420	13.5	58	9.2	11	1.4	159	17	18	220	180
10dbd-1	11-20-68	1,480	24.0	75	10	216 T	--	138 *	8.5	390	800	230
	08-21-84	360	23.5	10	1.0	65	3.2	109	8.0	41	210	29
16dcd-2	05-07-69	335	25.0	21	4.4	49	6.8	158 *	4.5	10	220	71
	08-10-79	340	26.5	20	3.7	51	7.1	--	7.4	7.9	220	65
	08-14-84	355	27.0	21	4.0	49	7.1	165	3.9	8.0	220	69
20daa-1	03-04-54	1,290	13.5	12	9.6	240	34	342 *	1.2	210	730	69
	10-19-64	1,240	13.5	10	9.7	269 T	--	340 *	1.6	220	740	65
	08-14-84	1,360	15.0	10	7.9	250	36	336	4.8	220	760	58
32bbb-1	11-20-68	2,360	18.0	66	45	335 T	--	105 *	1.5	680	1,200	350
	08-03-77	2,350	19.0	76	41	310	23	--	1.7	690	1,300	360
	08-14-84	2,450	19.0	73	41	330	22	140	1.1	690	1,300	350
(B-7-3)31aac-2	09-10-69	1,490	38.0	27	5.4	320	--	468 *	.5	230	930	90
	08-06-80	1,730	39.5	57	9.3	290	23	260	2.9	420	1,000	170
(B-8-2)26bcd-1	09-09-69	420	13.0	59	14	13 T	--	190 *	33	7.7	250	200
	08-14-84	490	13.0	62	18	7.8	2.1	197	36	9.6	270	230

Well (B-7-2)2cba-5 (table 13) is near a boundary between sodium bicarbonate and calcium bicarbonate waters (Bolke and Waddell, 1972, pl. 3). Water from the well has gradually increased in dissolved-solids concentration since 1969 and has changed from a sodium bicarbonate to a calcium bicarbonate type. The calcium bicarbonate waters extend into the recharge area. Increased recharge in the 1980's probably has caused these waters to extend farther west, into areas that prior to 1970 contained sodium bicarbonate waters.

The water from well (B-4-3)19cca-1 (table 13), near the causeway to Antelope Island, is a sodium chloride water. The water had a large increase in most major ions from 1969 to 1970; the concentrations in 1977 and 1980 were similar to those in 1969. The increase was probably a result of mixing of the various chemical types of water from the different perforated zones of the well.

The dissolved-solids concentration in the water from well (B-7-2)10dbd-1 (table 13), which is on the boundary between sodium chloride and sodium bicarbonate type water (Bolke and Waddell, 1972, pl. 3), decreased substantially between 1969 to 1984. In addition, the water type changed from sodium chloride to sodium bicarbonate. The probable explanation is that with rising water levels in the area since 1969 (fig. 31), a larger proportion of the water came from the upgradient, sodium bicarbonate water that has a smaller dissolved-solids concentration.

Between 1969 and 1980, the dissolved-solids concentration in water from well (B-7-3)31aac-2 (table 13) increased less than 10 percent, but the chemical type changed from sodium bicarbonate to sodium chloride. The most probable explanation is a gradual increase in the proportion of sodium chloride water entering the well from deeper zones. Sodium chloride water was reported to be at depth in this area by Bolke and Waddell (1972, pl. 3).

In general, the water-quality changes that have occurred in the East Shore area seem to be related primarily to areal and vertical variations of water quality within the East Shore aquifer system and to the effects of increased withdrawal from, or recharge to, the system. The changes in quality of water from some wells has been substantial, but widespread changes in quality have not occurred.

Temperature

The temperature of water from wells in the East Shore area varies from about 10 to 40 degrees Celsius. Water from hot springs associated with faults have temperatures approaching 60 degrees Celsius. Generalized areas where the temperature of ground water exceeds 20 degrees Celsius are shown in figure 43. The warmest water is assumed to be associated with hot water in the spring and fault areas, including water near Hooper and Utah Hot Springs, Little Mountain (fig. 3) and near the mouth of Ogden Canyon. No indication of thermal water at depth in the alluvium exists in areas distant from the hot spring and fault-zone areas.

SIMULATION OF THE EAST SHORE AQUIFER SYSTEM IN THE WEBER DELTA AREA

A major effort of this study was to simulate part of the aquifer system of the East Shore area using a digital-computer model. The part of the East Shore aquifer system that was simulated is from about 1 mile north of Centerville to the section line north of Willard (fig. 45), previously described as the Weber Delta area (p. 3), and the aquifer system in this area is referred to in this part of the report as "the East Shore aquifer system in the Weber Delta area". The shallow water-table zone in the topographically lowest part of the area, not included in the East Shore aquifer system as defined in this report, was included in the model as a layer because upward discharge of water into the water-table zone from the East Shore aquifer system was simulated by the model. However, recharge to the water-table zone by local precipitation and large amounts of seepage from irrigation and subsequent discharge of this water was not included in the model because few data on these processes were available.

The model was constructed and calibrated using available data on aquifer properties, historic water-level changes, and components of the hydrologic budget to learn more about the system and how it functions, and to improve the estimates of its hydrologic components. The calibrated model was then used to simulate changes in ground-water levels, discharge, and storage caused by projected increases in ground-water withdrawals by pumpage, and possible changes in recharge.

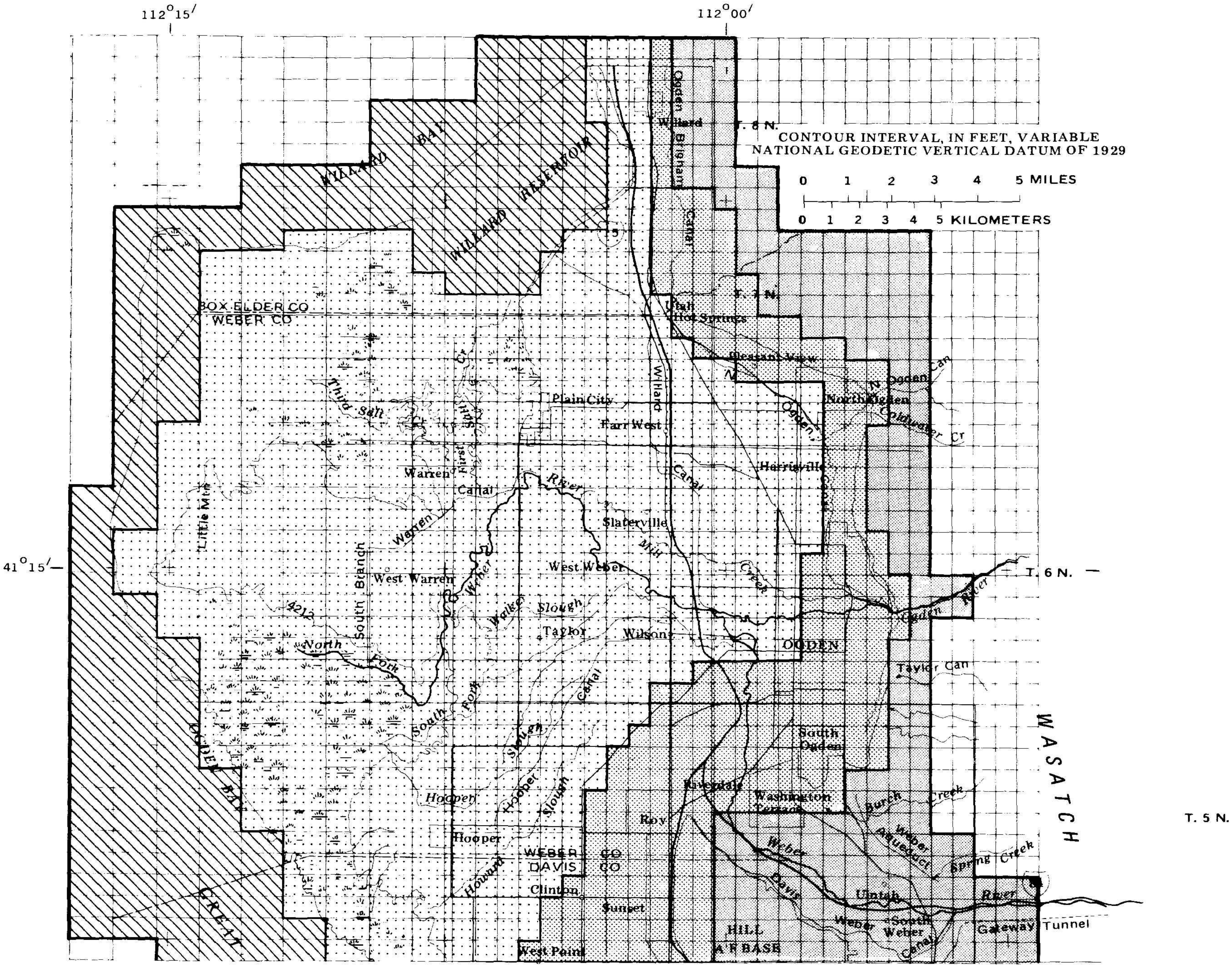
Design and Construction of the Digital-Computer Model

Data used to construct and calibrate the model were collected during hydrologic studies in the East Shore area that span about 50 years. Data from Feth and others (1966), Smith (1961), and from Smith and Gates (1963) were used for steady-state and transient-state calibration; data from Bolke and Waddell (1972) and Plantz and others (1986) were used for transient-state calibration; and data from previous sections of this report were used for various aspects of the model calibration.

General Description of the Model

The north and south boundaries of the model of the East Shore aquifer system in the Weber Delta area, from about 1 mile north of Centerville to the section line north of Willard, were based on the potentiometric surface as shown in plate 1 and on narrowing of the basin-fill area between the mountain front and Great Salt Lake. The potentiometric contours are closely spaced at both boundaries, and the configuration indicates most of the flow is directly from the mountains to the lake, so that little if any flow is across the boundaries. The boundaries were placed along flow lines which could be affected by potential pumping from wells near those boundaries.

The three-dimensional, finite-difference numerical model developed by McDonald and Harbaugh (1984) was used to simulate the Weber Delta part of the aquifer system. Most of the data used for the simulations represent average conditions, or were estimated where there was a lack of measurements. Therefore, the simulations are considered to be a simplification of the natural system, and the results should be applied with discretion.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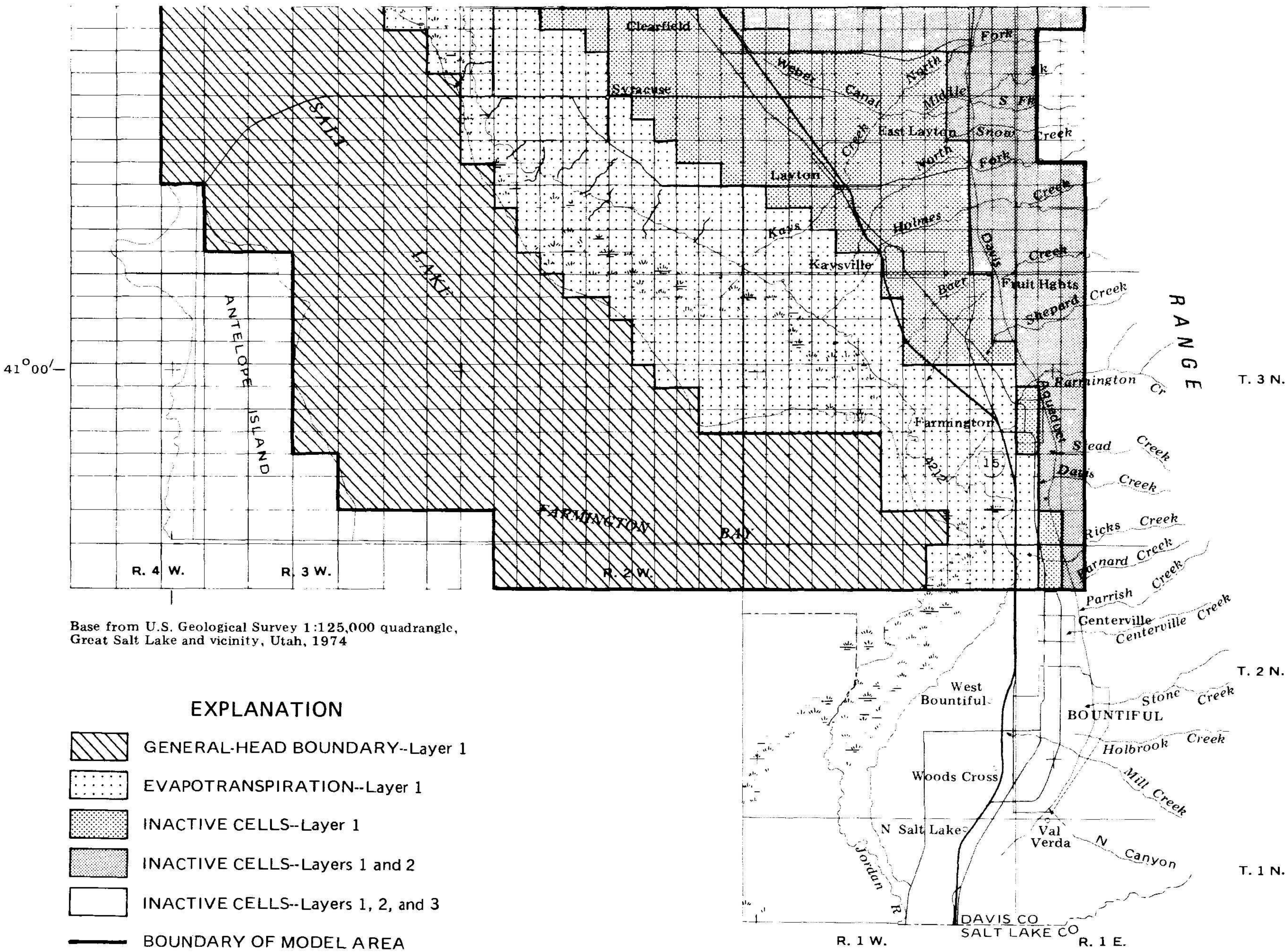


Figure 45.--Location of evapotranspiration, general-head boundary, and inactive cells in the model of the East Shore aquifer system.

The finite-difference model uses a series of rectangular blocks in which hydraulic properties are assumed to be uniform. The model calculates the hydraulic head at the point, or node, which is at the center of each block. With the calculated head values, the rate and direction of ground-water flow through the system can be determined. Input data used in the calculations include boundary conditions, initial heads, hydraulic properties of the aquifers and confining beds, and rates and distribution of recharge and discharge. The algorithm used as the matrix solver for the differential equations of ground-water flow in the model is SIP, or the strongly implicit procedure (McDonald and Harbaugh, 1984, p. 370).

Subdivision of the Weber Delta part of the East Shore Aquifer System

The aquifer system consists of complex, interconnected multiple aquifers in the basin-fill deposits. The system includes confined parts previously called the Sunset and Delta aquifers (Feth and others, 1966) and their lateral extensions, including the area along the mountain front where the system is unconfined. Further discussion of the aquifer system is in the previous section on "Geology and hydraulic properties of the East Shore aquifer system". The confined parts of the system vary in thickness, continuity, and lithology and in places it is not possible to delineate separate aquifers.

The model consists of three layers that represent the shallow water-table zone and two separate confined or unconfined intervals of the East Shore aquifer system in the Weber Delta area. The layers have different lateral extents as shown in figure 45. Layer 1, which is used to simulate discharge to the shallow water-table zone from the underlying aquifer system, is simulated only where the potentiometric surface is near or above land surface, roughly corresponding to the area of evapotranspiration in figure 45. Layer 1 is simulated only as it relates to the underlying layers, thus there is no recharge to, or discharge from layer 1 except the water that has moved upward from layer 2. Layer 2 represents the upper confined interval of the aquifer system where it is less than 400 feet deep, including the Sunset aquifer where it has been delineated. Layer 2 was not simulated in the area near Hill Air Force Base because the potentiometric surface there is greater than 400 feet deep. Layer 3 represents the confined parts of the aquifer system where it is deeper than 400 feet, including the Delta aquifer where it has been delineated. Layer 3 also represents the unconfined parts of the aquifer system near the mountain front. Layer 3 is simulated over the entire area of active cells shown in figure 45.

The confining layers between the aquifers were not simulated as separate layers, primarily because of a lack of data. It was assumed that the change in storage and horizontal flow in the confining layers was insignificant. Therefore, it was not essential to simulate the confining layers separately; however, vertical flow through the confining layers was simulated.

Model Grid

A block-centered grid with variable spacing was used to simulate the East Shore aquifer system in the Weber Delta area. A block-centered grid was formulated by dividing the model area with two sets of parallel lines perpendicular to each other. In the block-centered formulation the blocks formed by the sets of parallel lines are the cells, and the nodes are at the center of the cells. A node represents a prism of porous material within which the hydrologic properties are constant, so any value associated with a node is distributed over the volume of the cell (McDonald and Harbaugh, 1984, p. 10).

The grid consists of 36 columns and 67 rows. The largest active cells, 0.5 square mile, generally were used where data were sparse, primarily areas covered by Great Salt Lake. The smallest and most numerous cells were 0.25 square mile. These cells were used where required information, particularily ground-water discharge, historic water levels, recharge areas, or numerous well records warranted the smaller grid size. A total of 7,236 cells were used, 4,880 of which were active cells. Layer 3 contains 1,962 active cells, layer 2 has 1,644 active cells, and layer 1 has 1,274 active cells. Areas of inactive cells within the simulated area are shown in figure 45.

Boundary Conditions

The inactive cells, illustrated in figure 45, are simulated with transmissivities of zero, and therefore act as no-flow boundaries that surround the area of active cells. On the east, the model boundary represents the lower altitudes of the consolidated rock in the Wasatch Range, approximately one mile east of the contact between the basin-fill deposits and the consolidated rock. This boundary was chosen in order to simulate recharge from the consolidated rocks. On the west, a no-flow boundary was placed on the eastern sides of Antelope and Fremont Islands, and west of Great Salt Lake shoreline near Little Mountain. This was assumed to be the westernmost extent of ground-water flow from the study area. In actuality, there may be some ground-water flow across this boundary toward the west; however, any flow is assumed to be negligible. A no-flow boundary was placed under layer 3, on the assumption that there is no significant vertical interchange of water between layer 3 and deeper strata.

During steady-state calibration about 30 constant-head nodes were used to simulate recharge from sources for which no estimates of recharge rates had been made. The constant-head nodes were placed in areas where recharge from other sources could not easily be calculated, generally along streams within the Wasatch Range. The initial heads for these nodes were assumed to be the same or slightly higher than head values for those areas measured during this study. After steady-state calibration, flow rates from the constant-head nodes were used as constant-flux recharge rates during transient simulations, and the constant-head nodes were eliminated.

A general-head boundary was used to simulate inflow from the Weber Delta part of the East Shore aquifer system into Great Salt Lake. Constant heads were specified at boundary cells in layer 1 throughout the area covered by water when the lake was at an altitude of 4,200 feet. Layer 1 in this area is assumed to represent the lake bottom, and specified heads were set at 4,200 feet for steady-state calibration.

No-flow boundaries were placed at the northern and southern boundaries of the model area. The no-flow boundaries were placed along flow lines, perpendicular to the potentiometric surface in both areas.

Model Parameters

Initial Conditions

Ground-water withdrawal from wells in the East Shore aquifer system began about 1900 when numerous small-diameter wells were driven or jetted into the aquifers in the flowing-well areas. By 1954 total annual discharge from wells was estimated to be about 25,000 acre-feet (Feth and others, 1966, p. 49), which was considered to be a small part of the total ground-water discharge. Ground-water withdrawal prior to 1954, primarily from flowing wells, was assumed to not significantly affect water levels; thus water levels from 1955 or earlier were used as initial water levels for steady-state calibration in the areas where data were available (Feth and others, 1966, pl. 9). Many of the initial data used for simulations were from Feth and others (1966); however, in areas where data on historic water levels, recharge, discharge, or hydraulic properties were not available, calculations and data from this study were used to approximate initial conditions.

Recharge

The East Shore aquifer system is simulated by the model only in the Weber Delta area (p. 3), whereas recharge was calculated in the preceding parts of the report for the entire East Shore area. Recharge values specified in the simulations for individual parts of the Weber Delta area, therefore, do not necessarily correspond to values for the entire study area. However, values used as initial estimates for recharge were virtually the same as those calculated in preceding sections, when adjusted to represent the part of the aquifer system simulated by the model. The annual recharge at the end of steady-state calibration was simulated at about 109,000 acre-feet, or about 44,000 acre-feet less than estimated for the entire study area.

Recharge from the land surface was specified in the model using constant-flux recharge nodes as close as possible to the actual locations. The constant-flux recharge includes: seepage from the Weber and Ogden Rivers, the Davis and Weber Canal, ungaged perennial, ephemeral, and intermittent streams, irrigated areas, and infiltration directly from precipitation within the recharge area. The constant-flux recharge nodes were located in the uppermost active model layer.

Recharge by subsurface inflow from consolidated rock of the Wasatch Range to the basin-fill deposits of the aquifer system was simulated during steady-state calibration by constant-head nodes, primarily in layer 3. All calculated and estimated rates of recharge from other sources were independently measured or estimated for the model; therefore, the flow calculated by the model from the constant-head nodes was assumed to be from subsurface inflow. Initially, constant-head nodes were placed in most cells along the eastern boundary. However, when the independently-calculated recharge rates were added, the initial flow from many of these boundary cells became negligible, and the constant-head boundary at such cells was eliminated. Further discussion on how recharge was estimated is in the ground-water recharge section on pages 26-32.

Hydraulic Properties

The transmissivities of the East Shore aquifer system were estimated in part from data derived from aquifer tests (table 5); however, not enough aquifer-test data were available to adequately estimate transmissivities over the study area. Therefore, transmissivity was also estimated from specific-capacity values and average hydraulic conductivity and aquifer system thickness.

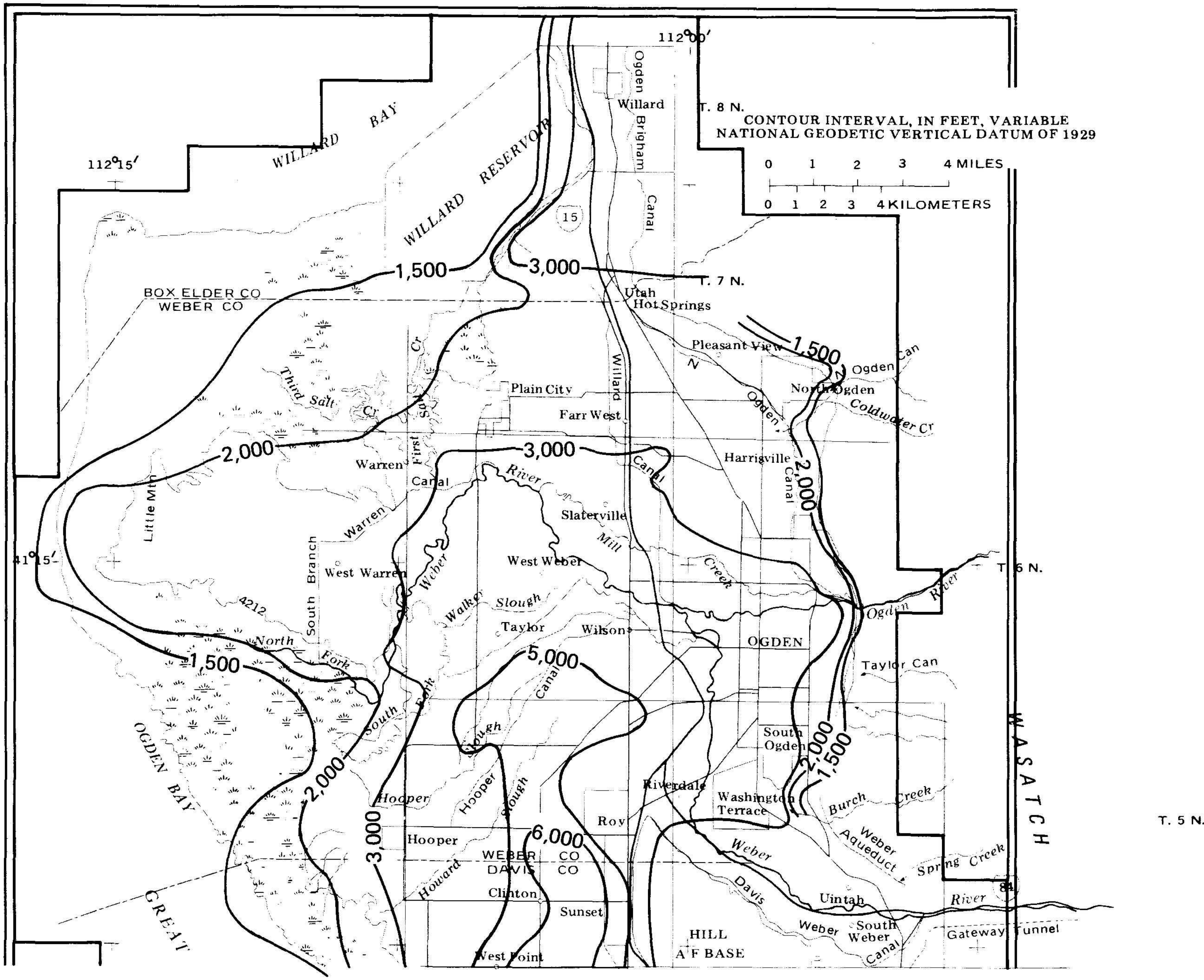
Specific-capacity values were obtained from records of about 100 wells. These values, and information about the well depth, diameter, and openings, were used to calculate transmissivity for the aquifer system.

Transmissivity was also estimated by multiplying the thickness of sediments described in drillers' logs by the hydraulic conductivity for that sediment type. Values of hydraulic conductivity were from values given by Clark (1984, p. 14), Mower (1978, p. 16), and from the calculated values of transmissivity in table 5. Information about lithologies and thickness of sediments (from logs of about 500 wells) was used to estimate the transmissivity of layers 2 and 3. The horizontal hydraulic conductivity of layer 1 was estimated from information in drillers' logs based on the lithologies of the upper 50 feet of sediments.

The transmissivity information was used to prepare contour maps for layers 2 and 3. The map for layer 2 (fig. 46), shows the largest values of transmissivity are in the area nearest the Weber Delta, where sediments are thick and relatively more permeable. Values in layer 2 range from less than 1,500 to greater than 6,000 feet squared per day. The map of layer 3 (fig. 47) shows the largest values, exceeding 100,000 feet squared per day, are in the area near Hill Air Force Base where there are extensive sequences of coarse-grained sediments deposited by the ancestral Weber River. The hydraulic conductivity used for layer 1 ranged from less than 20 feet per day near Great Salt Lake to greater than 150 feet per day near the eastern boundary of layer 1. The simulated thickness of layer 1 ranges from 30 to 59 feet and averages about 35 feet.

Vertical conductance between the aquifer layers was initially estimated from equations in the model documentation (McDonald and Harbaugh, 1984, p. 138-147), and from calculations and estimates based on aquifer tests during this study and studies in nearby areas. An initial average vertical hydraulic conductivity of approximately 1×10^{-3} feet per day was determined from these methods. The initial value was then altered during calibration to approximately reflect the areal pattern of vertical head gradients determined from Feth and others (1966, pl. 9). In the recharge areas near the mountain front, conductance values were assumed to be larger, in order to reflect the absence of confining layers in the area.

Initial values of storage coefficients required for transient-state calibration for the confined parts of the aquifer system were from table 5. Specific-storage values generally ranged from about 1×10^{-4} to 1×10^{-6} and the thickness of the individual parts of the aquifer system ranged from tens to hundreds of feet. Specific yield values for layer 1 were estimated to be 1×10^{-1} and values for unconfined parts of layer 3 were estimated to be 1×10^{-2}.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Harrisville
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Warren Canal
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Third Salt Cr
Little Mtn
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West Warren
South Branch
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Hooper Slough
Hooper Canal
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Howard Slough
South Ogden
Riverdale
Washington Terrace
Burch Creek
Weber Aqueduct
Spring Creek
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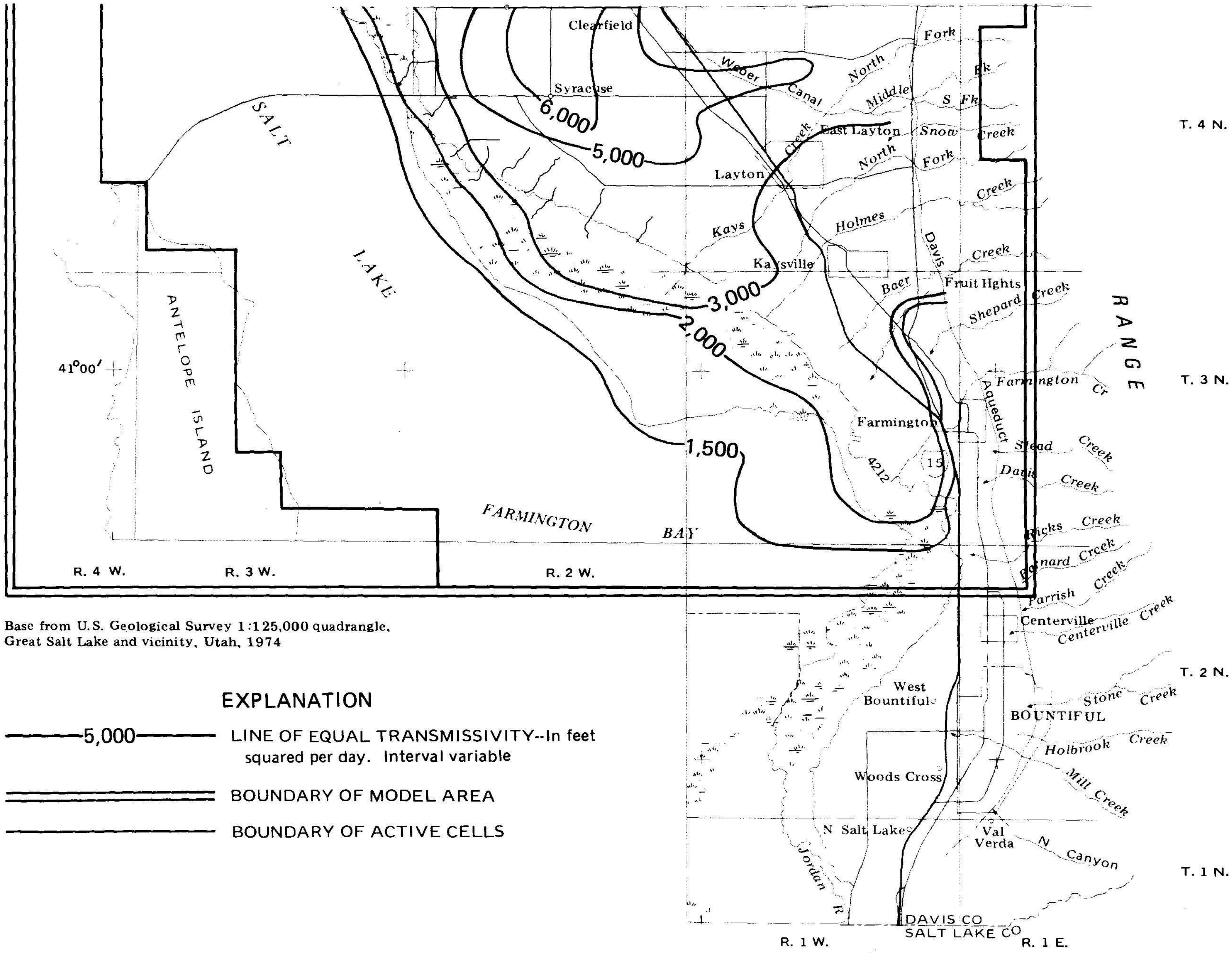
Sunset
West Point
HILL A F BASE
Davis Weber Canal
Uintah
South Weber Canal
Gateway Tunnel



Base from U.S. Geological Survey 1:125,000 quadrangle, Great Salt Lake and vicinity, Utah, 1974

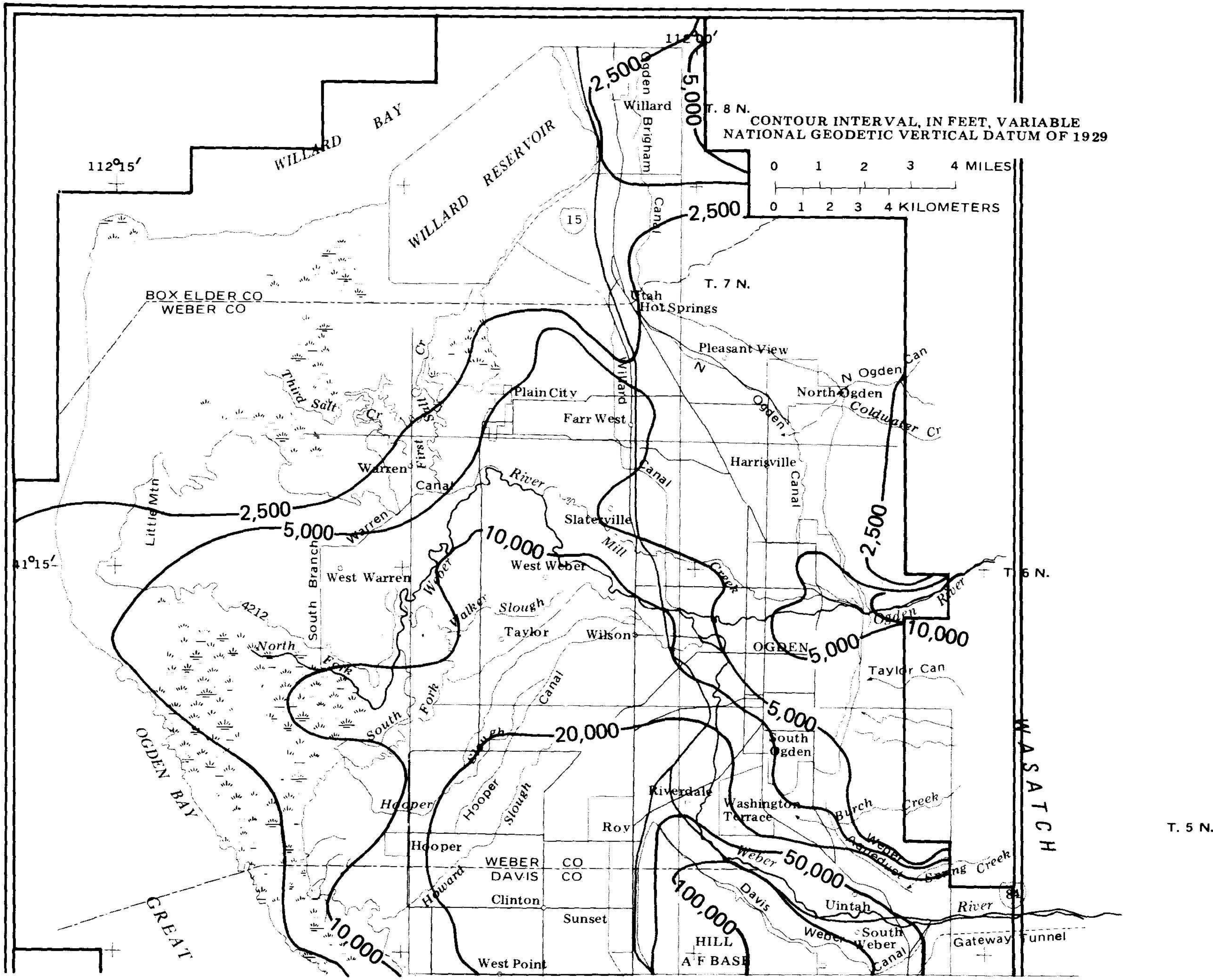
EXPLANATION

—5,000— LINE OF EQUAL TRANSMISSIVITY--In feet squared per day. Interval variable

BOUNDARY OF MODEL AREA

BOUNDARY OF ACTIVE CELLS

Figure 46.--Transmissivity of layer 2.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Davis Weber Canal
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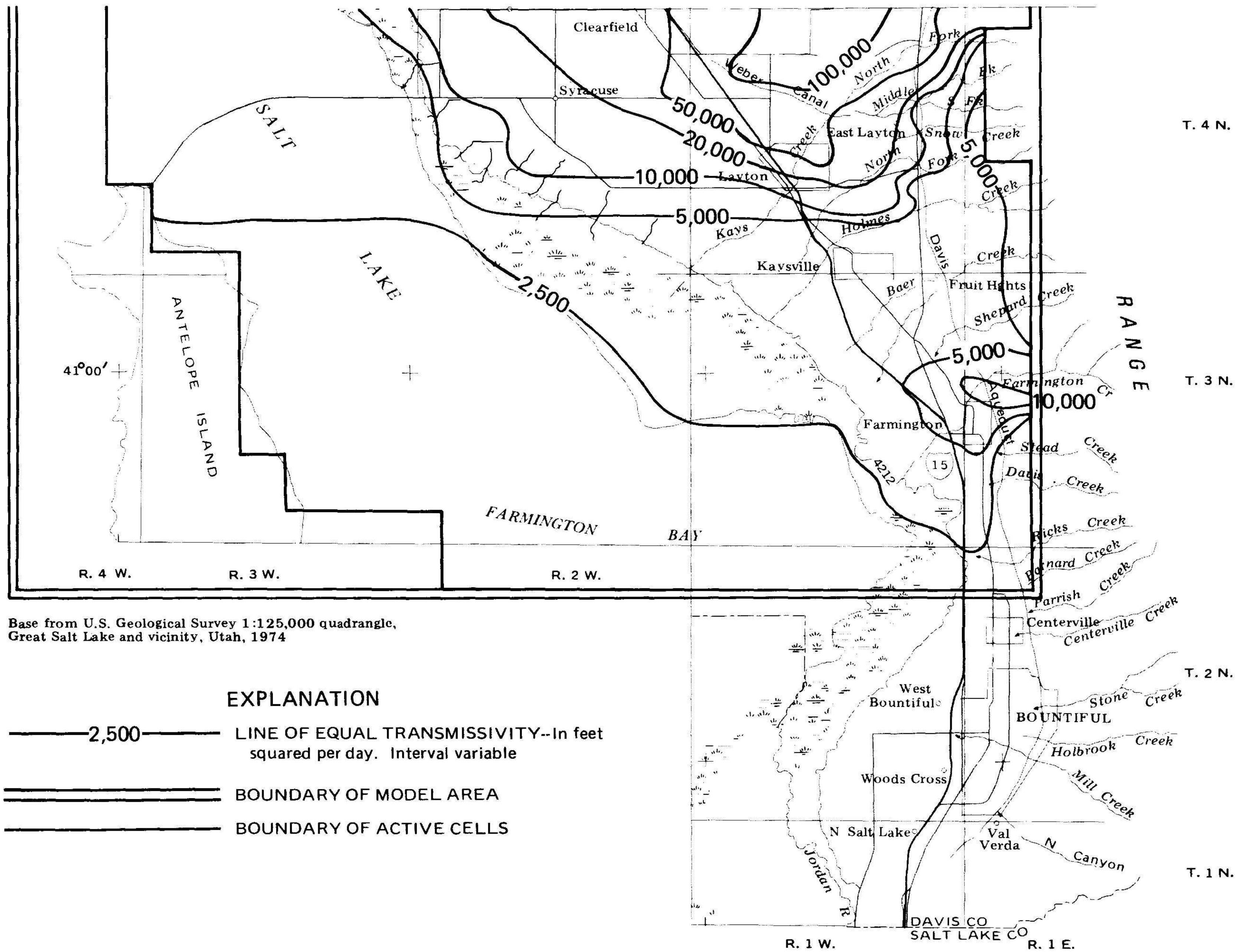


Figure 47.--Transmissivity of layer 3.

Discharge

Drain discharge was simulated in the model with the use of the "Drain" subroutine (McDonald and Harbaugh, 1984, p. 288), which requires information for the altitude of the water level in the drain, and a term for the conductance between the aquifer and the drain. The altitudes used for the water level in the drains were based on the altitudes of land surface and water levels, where available, in the same area. Drain cells were used in model layer 1. In this application, the conductance is defined as the product of the hydraulic conductivity and the area of the drain channel divided by the thickness of the material separating the drain from the aquifer. The area where drain discharge was simulated (fig. 48) is similar to the area of flowing wells and evapotranspiration (fig. 45).

Initially a constant term for conductance was used for all drain cells; however, it was evident from the early simulations that large changes were necessary. Conductance terms were varied to reproduce the observed water levels (heads), and vertical head gradients between the aquifers. Some areas were known to have relatively large discharge to drains (fig. 41), and in these areas the conductance term was generally made larger. Simulation of discharge to drains was based on water levels and associated vertical head gradients. The simulated discharge was not based on measured drain discharge in order that measured and simulated total drain discharge might be compared. At the end of steady-state calibration, the amount of discharge to drains, as simulated by the model, was close to the discharge measured during this study in the same area, and totaled about 58,000 acre-feet per year.

Initial values for discharge from wells were derived from previously published reports on the study area. Estimates of flowing- and pumped-well discharges for steady-state conditions were from Feth and others (1966, p. 50), and locations of the flowing wells were taken from Smith and Gates (1963, pl. 2). Discharge from flowing wells was apportioned based on the number of wells in a particular cell, the estimated discharge from wells per township (Feth and others, 1966, table 7), and the percentage of wells finished in either layer 2 or 3. The total annual discharge from flowing wells in each township was divided by the total number of flowing wells drilled before 1955 in that township to obtain discharge per well, based on the assumption that all wells in a given area discharged the same amount of water. It was determined from well records that approximately 60 percent of flowing wells drilled before 1955 were finished in layer 3 and the remaining 40 percent were finished in layer 2. Flowing-well discharge was apportioned to the layers according to those percentages. The initial value of discharge from wells was about 25,000 acre-feet per year.

A portion of the upward leakage from layer 2 to layer 1 discharges by evapotranspiration. Evapotranspiration from layer 1 was simulated in the model by a head-dependent option, which assumes a linear change between a maximum evapotranspiration rate, when the water level is at or above land surface, to no evapotranspiration when the water level is at or below a specified extinction depth of 15 feet (McDonald and Harbaugh, 1984, p. 316). Only a small part of the total evapotranspiration in the study area originates from the East Shore aquifer system, and at the end of steady-state calibration this amount was calculated by the model to be about 7,000 acre-feet per year. The cells where evapotranspiration was simulated are shown in figure 45.

Subsurface inflow to Great Salt Lake, as diffuse seepage, was simulated in the model with a general-head boundary by assuming that discharge was primarily by upward leakage from the underlying East Shore aquifer system. It was assumed that all ground-water flow past the shoreline eventually discharges into the lake, as diffuse seepage through the lake-bottom sediments, and possibly by springs under the lake. The general-head boundary was used so discharge to the entire area inundated by the lake could be simulated, and the specified heads (representing lake stage) could be changed, if necessary, as part of the transient-calibration process. The conductance terms between the external specified head (lake altitude) and the model cells were approximated based on vertical conductance terms used in simulated areas east of the lake.

Model Calibration

The model was first calibrated to steady-state conditions which were assumed to exist in 1952-55. The final water levels from steady-state calibration were then used as initial heads for the transient-state calibration. Withdrawals from, and recharge to, the Weber Delta part of the East Shore aquifer system were varied during the transient-calibration period from 1955 to 1984.

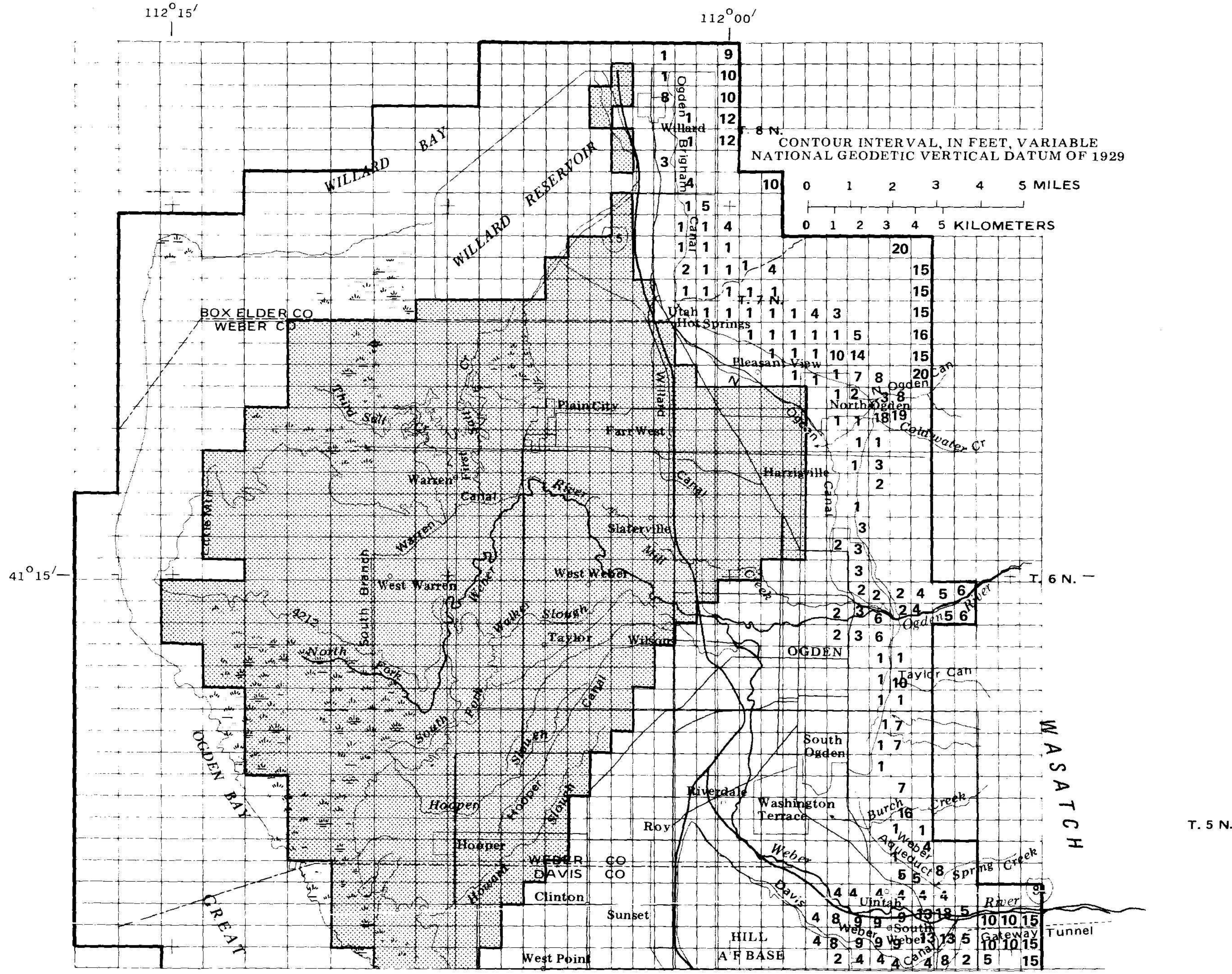
Steady-State Calibration

Calibration of the model to steady-state conditions involved the comparison of measured water levels for layers 2 and 3 with computer-generated water levels. The measured water levels were generally from the period 1952-55, depending on available data. If possible, water levels from 1954 or 1955 were used instead of those from the 1952-53 period, because 1952 and 1953 were years of well-above-normal precipitation, and water levels were generally higher than the average steady-state water levels. Ground-water withdrawals prior to 1955 were almost entirely from flowing wells. Since 1955, withdrawals for municipal and industrial use have steadily increased, and have been almost exclusively from large pumped wells east of the flowing-well area.

Water levels in most wells with long-term records show that from 1935 through the mid-1950's, water levels remained fairly constant with the exception of 1952-53 when there were large water-level rises (fig. 28). It was assumed that steady-state conditions existed until 1955 with minor fluctuations in water levels due to short-term changes in recharge, and that ground-water withdrawals prior to 1955 had little or no effect on water-level fluctuations.

To test the assumption that discharge from flowing wells prior to 1955 was part of the equilibrium state of the aquifer system, the estimated 17,700 acre-feet per year of discharge by flowing wells was decreased to about 10,000 acre-feet per year. This resulted in rises from the calibrated steady-state water levels of up to about seven feet, with an average of about 3 feet. When flowing-well discharge was decreased, discharge to drains, evapotranspiration, and Great Salt Lake increased by a nearly equal amount.

During the calibration to steady-state conditions, some values of system parameters were adjusted. Values that were most commonly adjusted were vertical conductance, drain conductance, and starting heads for constant-head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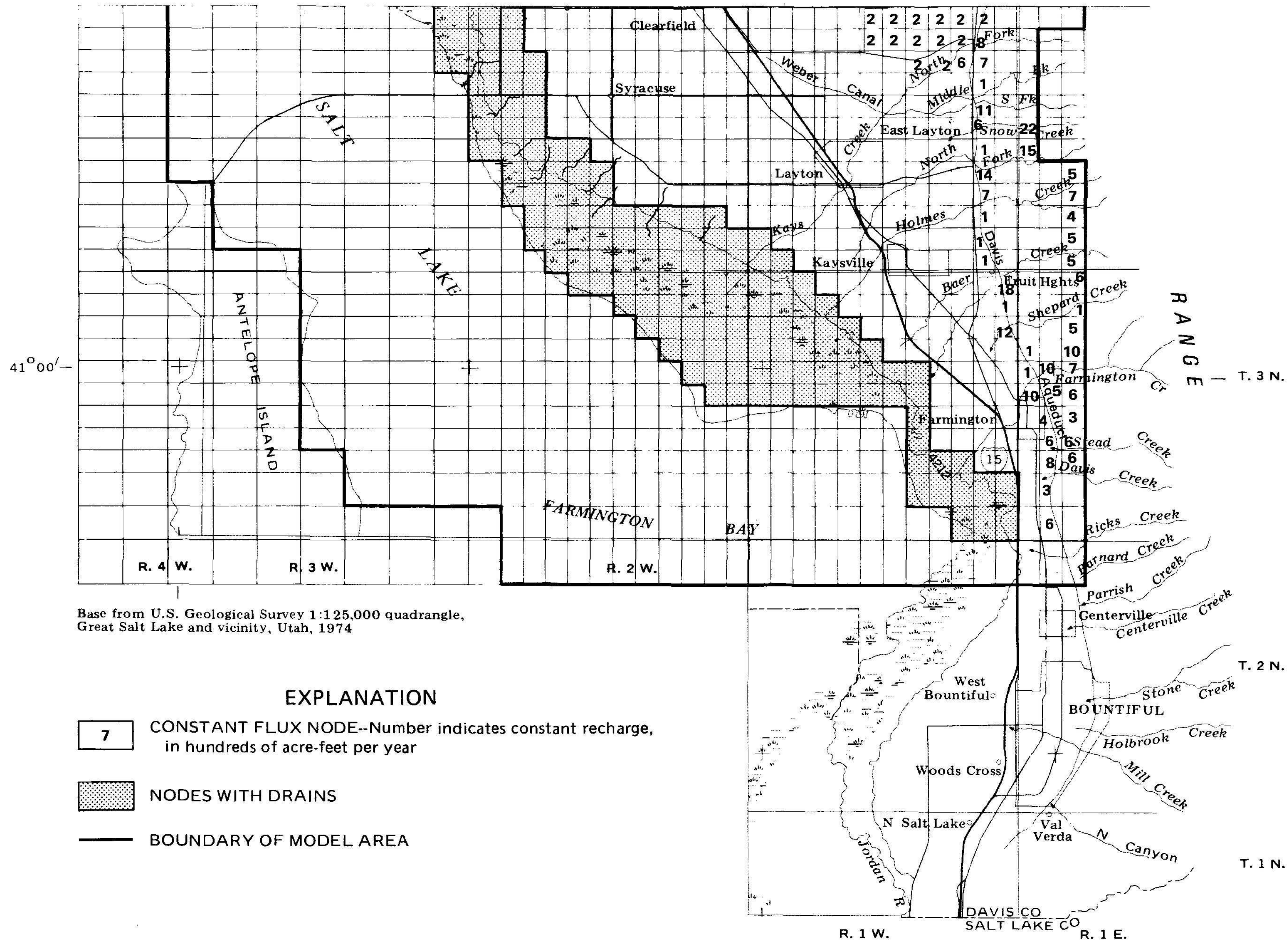


Base from U.S. Geological Survey 1:125,000 quadrangle, Great Salt Lake and vicinity, Utah, 1974

EXPLANATION

7 CONSTANT FLUX NODE--Number indicates constant recharge, in hundreds of acre-feet per year

NODES WITH DRAINS

BOUNDARY OF MODEL AREA

Figure 48.--Rate and location of constant recharge values and drain areas used for steady-state simulations in the model of the East Shore aquifer system.

nodes. Transmissivity values were changed only slightly as they were considered to be some of the most reliable data.

The vertical conductance terms for the general-head boundaries under Great Salt Lake were adjusted for various reasons: to calibrate to a known water level near the Antelope Island causeway, to calibrate to 1952-55 water levels near the shoreline, and to maintain known vertical-head gradients between the artesian aquifers. It was assumed that all discharge from the East Shore aquifer system in the Weber Delta area to the lake occurs to the east of Antelope and Fremont Islands. Total annual discharge to Great Salt Lake by diffuse seepage, as calculated by the model at the end of steady-state calibration, was about 19,000 acre-feet.

As part of the calibration process, computed water levels at specified nodes were compared with measured 1952-55 water levels. Of the 175 nodes at which the comparisons were made, 100 nodes were in layer 3 and 75 nodes were in layer 2. The location of the cells associated with these nodes are shown in figure 49, which illustrates that the data points were fairly evenly distributed across the area. A particular node or area was considered to be in calibration if the computed water level was within a preset range of the measured water level. The criteria for this range were determined from the location of the actual water level in the model cell and the contoured gradient across the cell. Therefore, near the mountains, where the gradient is steep, the acceptable range was large, up to 50 feet or greater.

Near Great Salt Lake a computed water level needed to be within 10 feet or less of the measured water level to be considered calibrated. The criteria set for calibration was not met at the end of the steady-state calibration at 13 of the 175 nodes. These 13 nodes (fig. 49) are generally either near the recharge areas where the gradient of the water surface is steep, or in the discharge areas near the lake where computed water levels were lower than the actual levels.

At the conclusion of the steady-state calibration, the flow rates for the constant-head nodes along the mountain front, as calculated by the model, were entered as recharge rates at specified-flux nodes, and the constant-head nodes were eliminated. These rates, which approximate at least part of the ground-water recharge by subsurface inflow, total about 45,000 acre-feet per year. The constant recharge rates for all sources of recharge applied to individual nodes at the end of steady-state calibration are shown in figure 48. The total recharge to these nodes is 109,000 acre-feet per year.

Comparison of water-level contours drawn using water levels measured in 1955 (Feth and others, 1966, pl. 1), and contours drawn using computed water levels for layers 2 and 3, at the end of steady-state calibration, are shown in figures 50 and 51. The contour patterns match fairly well in areas with sufficient historic data, and the computed water levels in those areas are generally within 10 feet of the measured levels. Differences between the shape of the contours generated from computed and measured data are a result of simplification and problems in defining the exact characteristics of the physical system. In general, however, the configuration of the contours and the resulting gradient of each set of contours are similar, indicating that the computed values are a good approximation of the steady-state conditions.

During the steady-state calibration process, it was difficult to match measured water levels in the North Ogden area, using the initial values for transmissivity, while staying within the estimated range of recharge and discharge for that area. It was necessary to significantly reduce the transmissivity in the area in order to match the actual steep hydraulic gradient in the area, and maintain reasonable rates of recharge and discharge. Calibration to measured water levels in the North Ogden area was difficult throughout the calibration process, primarily because of steep water-level gradients, and because simulated water levels were sensitive to small changes in recharge.

As a test of the sensitivity of the calibrated model, values of some hydraulic-property arrays were varied to determine the effects on the calibrated model. Values of transmissivity were assumed to be fairly accurate in most areas; therefore, changes that could be made in transmissivity values and still be within a realistic range of measured or estimated transmissivities were relatively small. Changes from the measured or estimated values of transmissivity for layer 3 ranged from about a 25 percent increase in the Sunset-Roy area to about a 25 percent decrease in the Ogden and Willard areas. Changes within these ranges of transmissivity resulted in relatively small water-level changes, except in areas with steep head gradients.

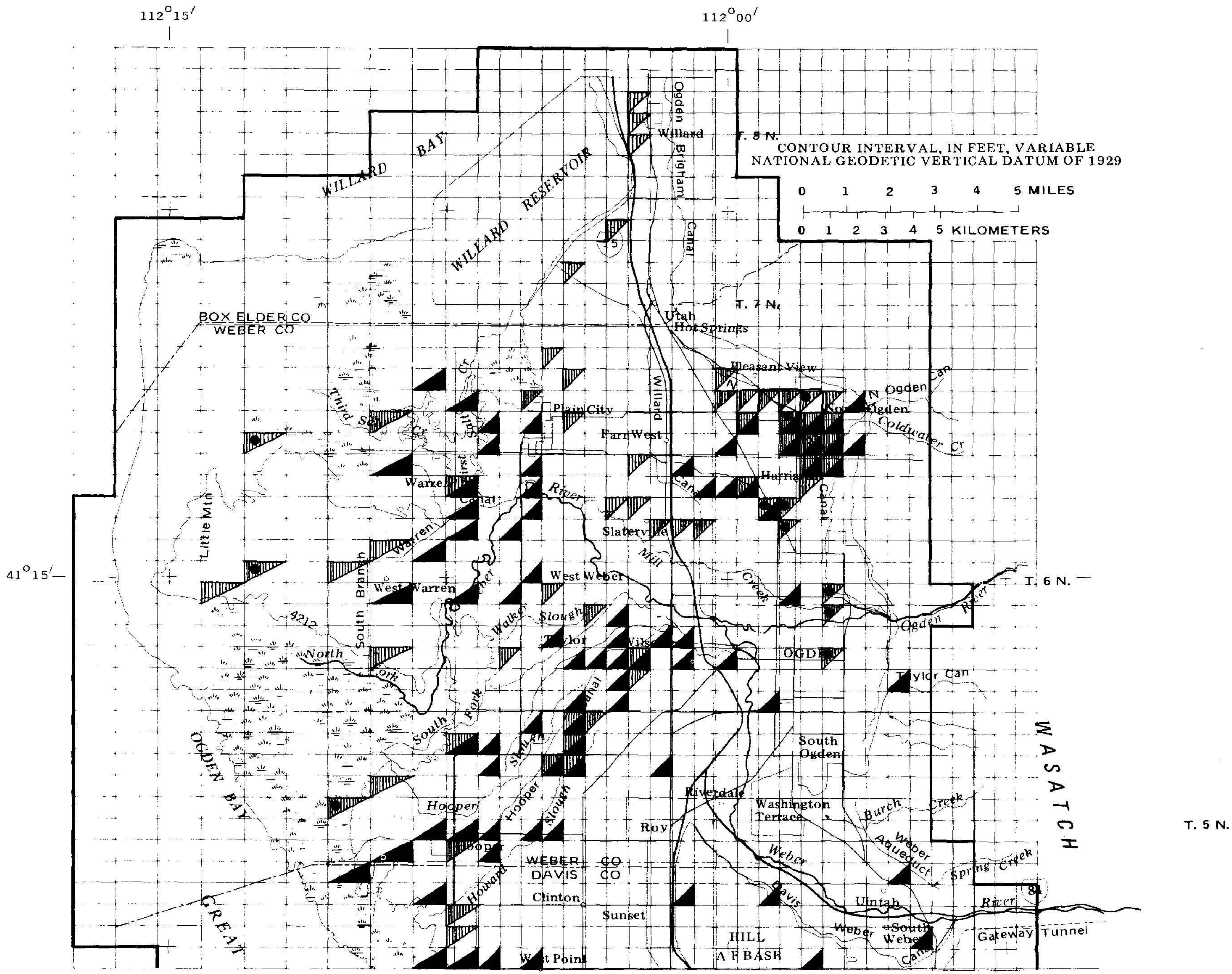
The values of vertical hydraulic conductivity are not well defined, and the range of realistic values could span at least two orders of magnitude. Changes in the vertical hydraulic conductivity within this range resulted in large water-level changes from the calibrated results, especially in areas with large vertical head gradients between layers. The final distribution of vertical hydraulic conductivity values ranged from about 1×10^{-3} foot per day in the recharge areas near the mountain front to about 3×10^{-6} foot per day in areas with the greatest vertical head differences. The average value was about 1×10^{-4} foot per day.

Changes in the conductance terms used in the "General-head boundary" subroutine (McDonald and Harbaugh, 1984) did not significantly affect either water levels or discharge from those cells unless the calibrated conductance term was changed by at least an order of magnitude. In areas of large discharge by drains, however, only minor changes in the drain conductance term resulted in significant changes in the drain discharge or water levels or both.

Transient-State Calibration

Calibration to transient-state conditions consisted of establishing data bases for the years 1955 to 1985. Data included (1) 1955-84 withdrawals from municipal, industrial, and flowing wells, and (2) 1956-85 water-level data.

Transient-state calibration was initiated by simulating withdrawals from wells for 1955-84 and comparing the resultant computed water levels with water levels measured during 1956-85. Water-level changes were computed at the end of each of the 30 one-year pumping periods during the 30-year transient calibration.


112°15′
112°00′
41°15′
CONTOUR INTERVAL, IN FEET, VARIABLE
NATIONAL GEODETIC VERTICAL DATUM OF 1929
0 1 2 3 4 5 MILES
0 1 2 3 4 5 KILOMETERS
T. 8 N.
T. 7 N.
T. 6 N.
T. 5 N.
WILLARD BAY
WILLARD RESERVOIR
Willard
Ogden Brigham Canal
BOX ELDER CO
WEBER CO
Utah Hot Springs
Pleasant View
N Ogden Can
Plain City
Farr West
Willard Canal
Coldwater Cr
Third Salt Cr
First Salt
Warren Canal
Little Mtn
Slaterville
Mill Creek
West Weber
West Warren
South Branch
North Fork
South Fork
Walker Slough
Taylor
Taylor Can
Ogden River
OGDEN BAY
South Ogden
Hooper Slough
Hooper
Riverdale
Washington Terrace
Burch Creek
Weber Aqueduct
Spring Creek
Roy
WEBER CO
DAVIS CO
Howard Slough
Clinton
Sunset
Weber River
Davis Weber Canal
Uintah
South Weber
Gateway Tunnel
HILL A F BASE
West Point
GREAT
WASATCH

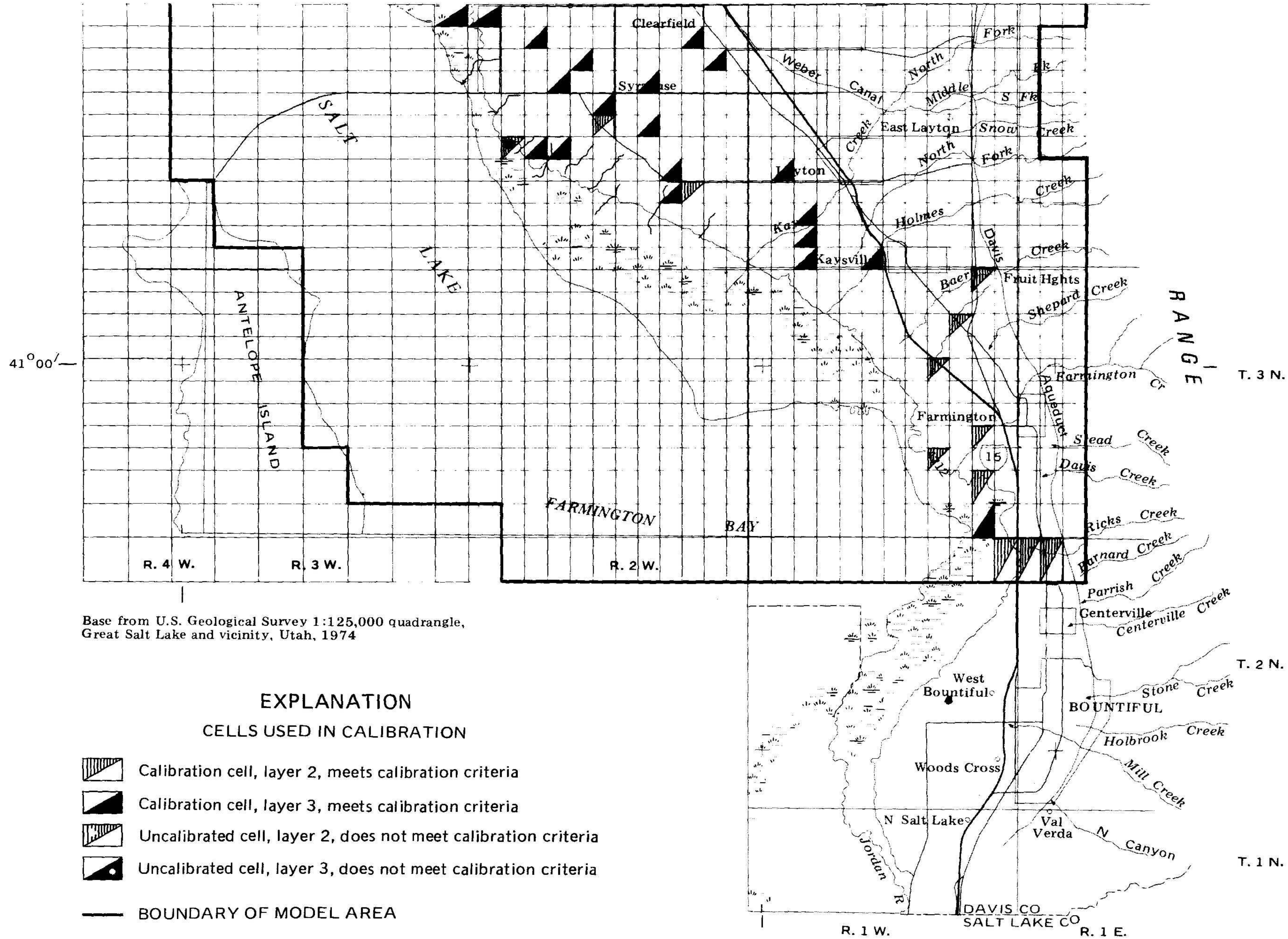
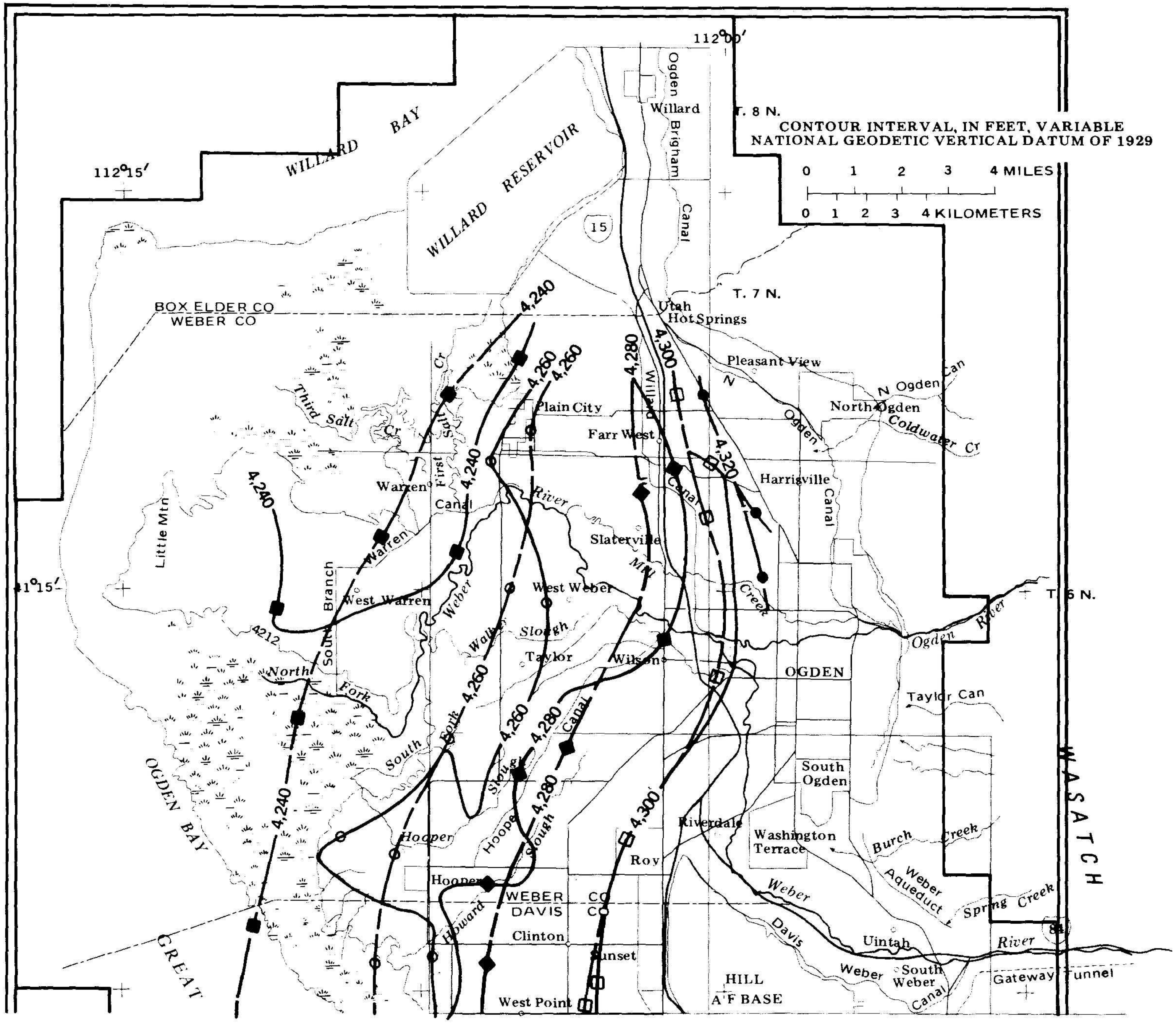


Figure 49.--Location of cells used in the calibration of the model of the East Shore aquifer system.



CONTOUR INTERVAL, IN FEET, VARIABLE
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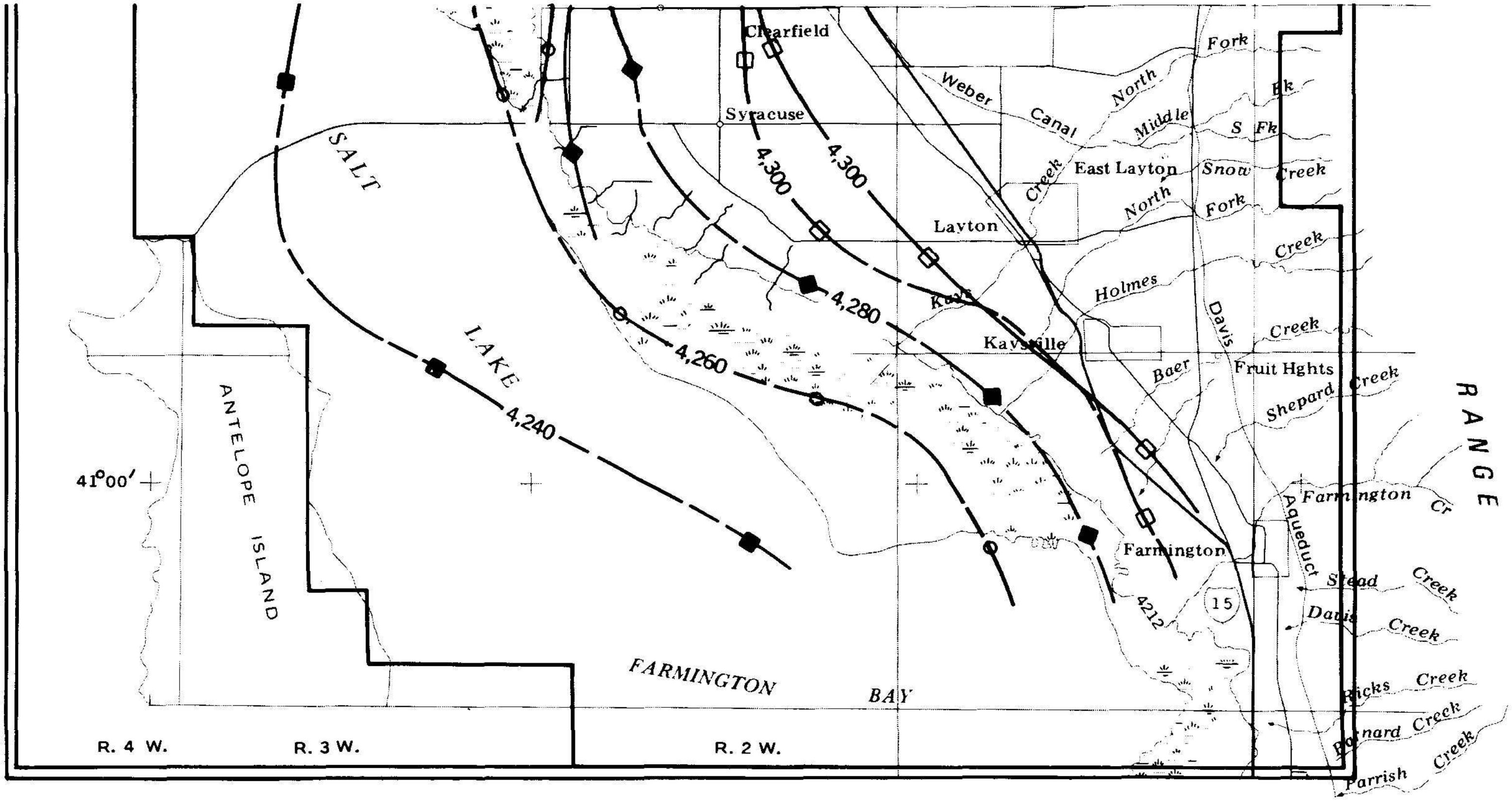
Ogden Brigham Canal
BOX ELDER CO
WEBER CO
Utah Hot Springs
Pleasant View
N Ogden Can
North Ogden
Coldwater Cr
Plain City
Farr West
Harrisville
Canal
Third Salt Cr
First Salt Cr
Warren
Canal
Warren
Little Mtn
South Branch
West Warren
Weber River
Slaterville
Mill Creek
West Weber
Walker Slough
Taylor
Wilson
OGDEN
Ogden River
Taylor Can
North Fork
South Fork
OGDEN BAY
GREAT
South Ogden
Riverdale
Washington Terrace
Burch Creek
Weber Aqueduct
Spring Creek
Hooper
Hooper Slough
Howard Slough
Roy
WEBER CO
DAVIS CO
Clinton
Sunset
West Point
HILL A F BASE
Davis Weber Canal
Uintah
South Weber
Gateway Tunnel
WASATCH
4,240
4,260
4,280
4,300
4,320
4212



Base from U.S. Geological Survey 1:125,000 quadrangle, Great Salt Lake and vicinity, Utah, 1974

EXPLANATION

POTENTIOMETRIC CONTOUR--Shows approximate altitude, in feet. National Geodetic Vertical Datum of 1929

4,240 CONTOUR FROM MEASURED DATA, 1955--Data from Feth and others (1966, plate 9)

4,240 COMPUTER-GENERATED CONTOUR

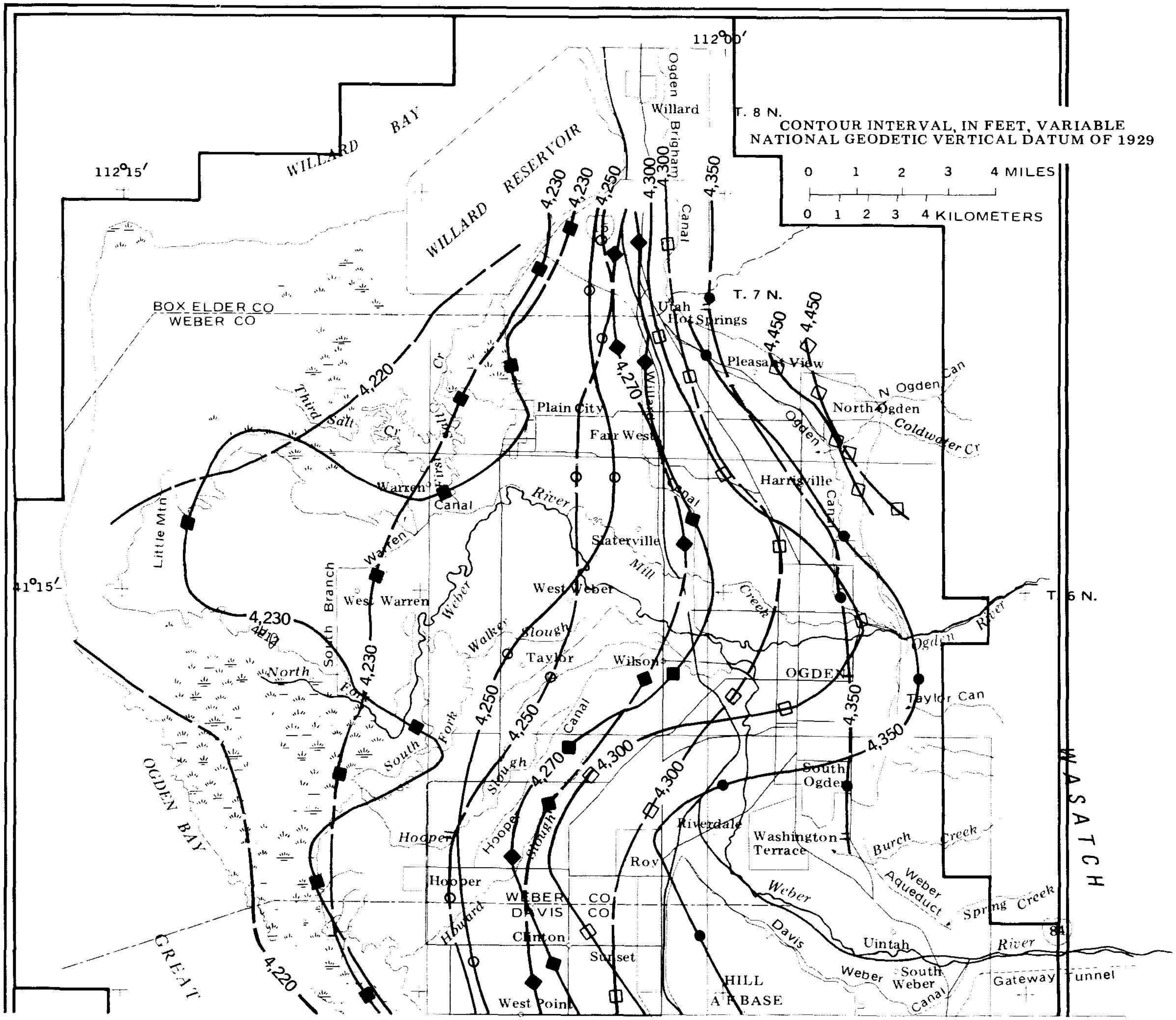
BOUNDARY OF MODEL AREA

BOUNDARY OF ACTIVE CELLS

LIKE SYMBOLS INDICATE EQUAL VALUES

4,240
4,260
4,280
4,300
4,320

Figure 50.--Comparison of potentiometric contours based on measured water levels for 1955 and contours of computed water levels, model layer 2.


CONTOUR INTERVAL, IN FEET, VARIABLE
NATIONAL GEODETIC VERTICAL DATUM OF 1929
0 1 2 3 4 MILES
0 1 2 3 4 KILOMETERS
112°00′
112°15′
41°15′
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T. 7 N.
T. 6 N.
T. 5 N.
WILLARD BAY
WILLARD RESERVOIR
BOX ELDER CO
WEBER CO
WEBER CO
DAVIS CO
OGDEN BAY
GREAT
WASATCH
Willard
Ogden Brigham Canal
Utah Hot Springs
Pleasant View
North Ogden
N Ogden Can
Coldwater Cr
Plain City
Fair West
Harrisville
Warren
Warren Canal
West Warren
Slaterville
West Weber
Taylor
Wilson
OGDEN
Ogden River
Taylor Can
South Ogden
Riverdale
Washington Terrace
Roy
Hooper
Clinton
Sunset
West Point
HILL AF BASE
Uintah
South Weber
Weber Aqueduct
Burch Creek
Spring Creek
Gateway Tunnel
Davis Weber Canal
Weber River
Mill Creek
Walker Slough
Hooper Slough
Howard Slough
Third Salt Cr
North Fork
South Fork
South Branch
Little Mtn
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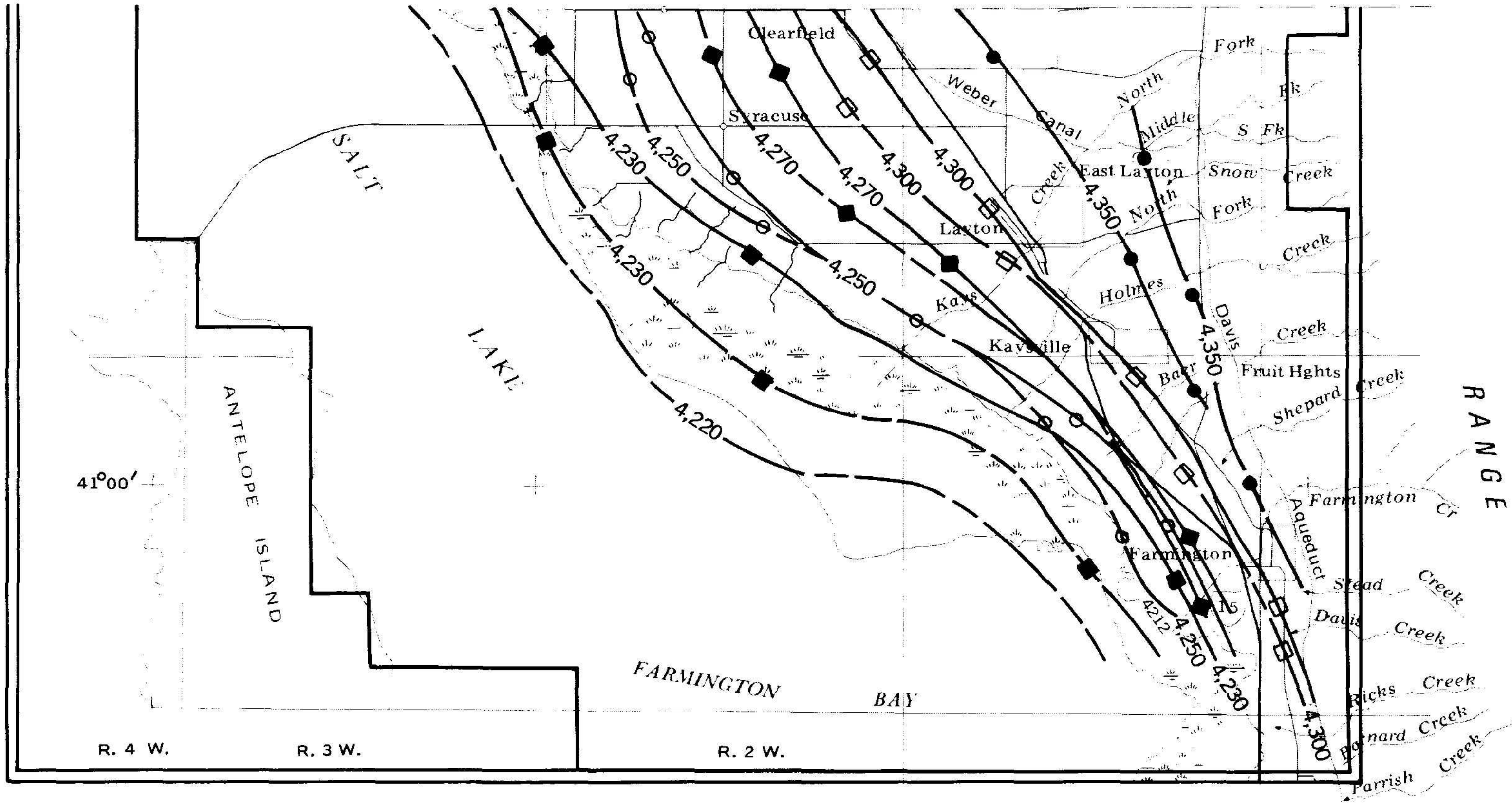
4,230
4,250
4,270
4,300
4,350
4,450



Base from U.S. Geological Survey 1:125,000 quadrangle,
Great Salt Lake and vicinity, Utah, 1974

EXPLANATION

POTENTIOMETRIC CONTOUR--Shows approximate altitude, in feet. National Geodetic Vertical Datum of 1929

4,230 CONTOUR FROM MEASURED DATA, 1955--Data from Feth and others (1966, plate 9)

4,220 COMPUTER-GENERATED CONTOUR

BOUNDARY OF MODEL AREA

BOUNDARY OF ACTIVE CELLS

LIKE SYMBOLS INDICATE EQUAL VALUES

No symbol 4,220
4,230
4,250
4,270
4,300
4,350
4,450

Figure 51.--Comparison of potentiometric contours based on measured water levels for 1955 and contours of computed water levels, model layer 3.

Records of withdrawals for municipal and industrial use are fairly complete from 1955-84. Most withdrawal records are given as a total for a user, and therefore, it was necessary to assume that total pumpage was divided equally among all wells owned by the user, unless information was available for individual wells. In the case of wells drilled during a year in which pumpage was estimated, it was assumed that the well went into production the following year.

Discharge from flowing wells and changes in this discharge through the 30-year calibration period were more difficult to estimate. Previous estimates of discharge from flowing wells, in acre-feet per year, varied from 17,700 in 1954 (Feth and others, 1966, p. 50), to 40,000 (including the Bountiful area) in 1955 (Smith and Gates, 1963, p. 16), to 12,000 in 1969 (Bolke and Waddell, 1972, p. 9), and to an average of 23,000 for 1969-84 (including the Bountiful area) during this study. Flowing-well discharge was increased from the steady-state rate of 17,700 acre-feet per year to 24,000 acre-feet per year in 1955, to more than 30,000 acre-feet per year in 1985. It was necessary to increase the flowing-well discharge in some areas to get computed water-level changes to approximate measured changes. The apparent increase in flowing-well discharge during the transient-state calibration period could be attributed to several factors, including discharge from new wells drilled in the flowing-well area between 1954 and 1985, inaccuracies in the discharge estimates made in 1954 or 1984, or that the discharge rate necessary to obtain transient-state calibration was greater than the actual flowing-well discharge. However, the increase in the total discharge from flowing wells used in the transient-state calibration was considered to be within a reasonable range of actual discharge from flowing wells. During the same period discharge from pumped wells increased from 7,700 to 26,500 acre-feet per year.

Water-level declines have caused the static water level in some areas to decline below land surface, thereby causing some wells to cease flowing. The discharge from wells in these areas was gradually decreased and eventually eliminated during transient-state calibration. Flowing-well discharge was considered to increase during the last few years of the calibration due to higher heads resulting from increased recharge.

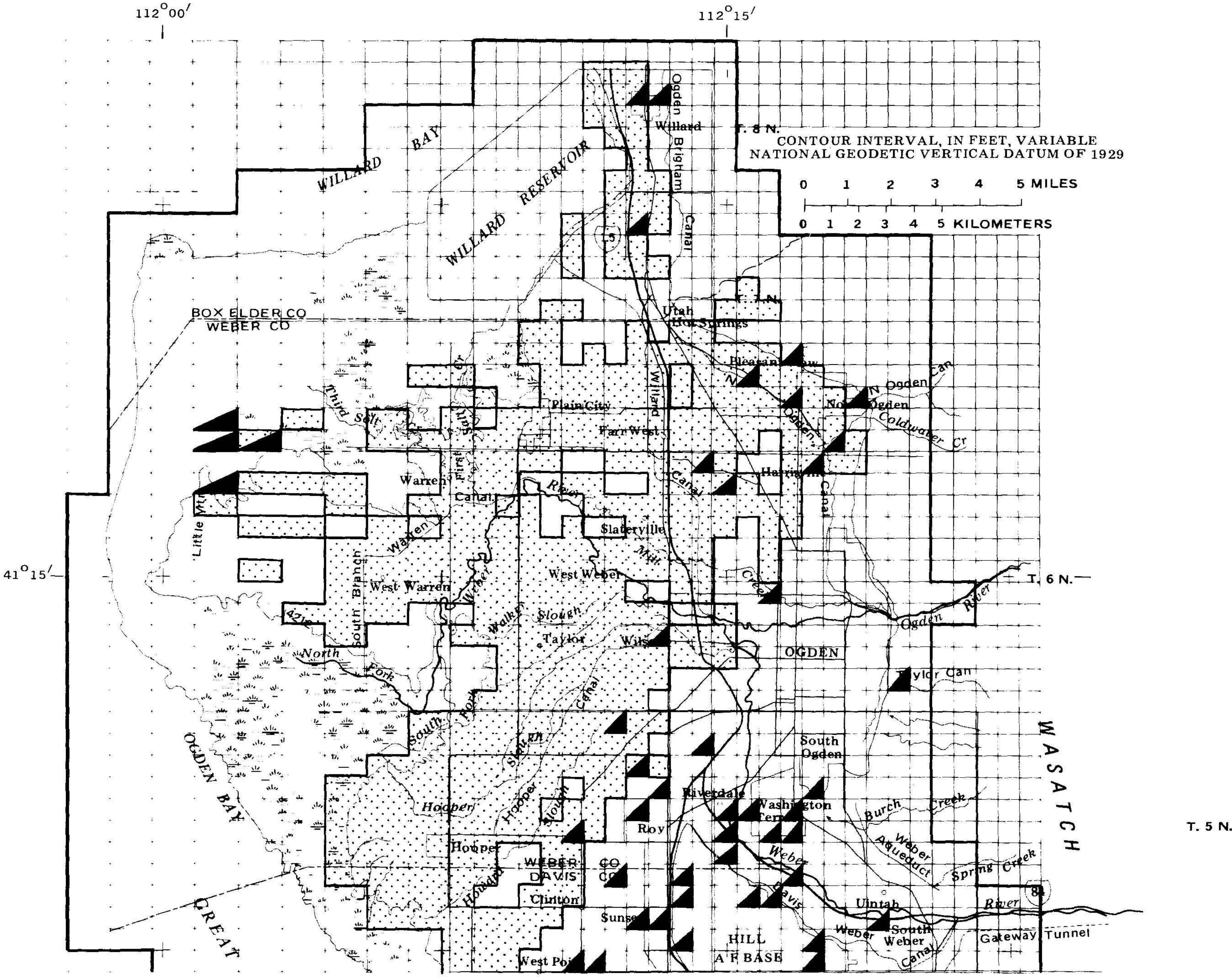
The cells where discharge by flowing, irrigation, municipal, and industrial wells was simulated during transient-state calibration are shown in figure 52. All wells were simulated in at least one pumping period, but not in all pumping periods. The flowing-well area is essentially the same as was simulated during steady-state calibration, with the addition of areas in which new wells were drilled since 1955. The flowing-well area shown in figure 52 includes those areas where flowing wells ceased to flow during the transient simulation period due to water-level declines.

As part of the calibration, total recharge to the aquifer system was assumed to vary from periods of less-than-normal precipitation to periods of greater-than-normal precipitation. During the late 1950's and early 1960's, precipitation was much less than normal (fig. 27), and water levels in many areas declined due to a decrease in recharge and an increase in withdrawals. When normal or greater-than-normal precipitation returned during the late 1960's through 1984, water levels continued to decline, primarily due to additional increases in withdrawals. These declines, however, appear to have been at a slower rate than they would have been otherwise, in most areas, due to the relative increase in recharge. When a constant recharge rate was used during transient calibration, it resulted in water-level changes that compared poorly with measured changes in the area of large water-level declines. Therefore, it was necessary to simulate yearly changes in the total amount of recharge.

The changes in yearly recharge rates were derived from changes in the annual flow in the Weber River, by assuming that when annual surface-water flow was below average, ground-water recharge was also below average. Initially changes in recharge for a particular year were assumed equal to one-half of the departure of surface-water flow for that year from average annual flow. For example, if flow of the Weber River for a particular year was 10 percent greater than the average flow, then recharge was increased 5 percent over the recharge rate used during the steady-state calibration. This assumption was reasonable for years in which flow was near the annual average, but was not valid during years of extremely low or high flow such as 1961 and 1984. The recharge rates were adjusted during calibration to determine the best ratio. The result was that recharge was decreased by about one-fourth of the departure when the flow was less than average, and increased about one-eighth of the flow departure when the flow was greater than average. Changes in total recharge seem to be affected more by a less-than-normal flow year than by a greater-than-normal flow year. Additionally, there seems to be a maximum amount of recharge that can be accepted by the aquifer system. Therefore, during the high-flow years of 1983-84, less than one-eighth of the departure above normal was used. The simulated total annual recharge rates varied from 94,400 acre-feet in 1961 to 114,000 acre-feet in 1984.

Storage-coefficient and specific-yield values were required for the transient-state calibration. Actual values of storage coefficient from aquifer tests of the confined aquifers ranged from about 1×10^{-4} to 3×10^{-6} (table 5). This range of values was initially used in the storage-coefficient array for layer 3. During transient-state calibration, however, changes to this array had little or no effect on the model. Therefore, an average storage coefficient of 5×10^{-4} was used for the confined parts of the Weber Delta aquifer system in layer 2 and most of layer 3. Where parts of the system represented by layer 3 are confined near the mountain front, a larger value of 5×10^{-3} was used; also, a value of 1×10^{-2} was used where the layer represents the unconfined part of the aquifer system near the mouth of Weber Canyon. At the end of transient-state calibration, the change in the total amount of water in storage was computed for the years 1955-85. The simulated decrease in storage was due to greater amounts of discharge than recharge, and was 74,000 acre-feet or about 2 percent of the total discharge during 1955-85.

The components of the total ground-water budget, resulting from the steady-state and transient-state calibrations, are shown in figure 53, which also shows the changes in total recharge and the various types of discharge for 1954-84. Discharge to drains and to the general-head boundary cells, representing leakage to Great Salt Lake, gradually decreased while pumped discharge from wells increased.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112°15′
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T. 8 N.
T. 7 N.
T. 6 N.
T. 5 N.
CONTOUR INTERVAL, IN FEET, VARIABLE
NATIONAL GEODETIC VERTICAL DATUM OF 1929
0 1 2 3 4 5 MILES
0 1 2 3 4 5 KILOMETERS
WILLARD BAY
WILLARD RESERVOIR
Willard
Ogden Brigham Canal
BOX ELDER CO
WEBER CO
Utah Hot Springs
Willard Canal
Plain City
Farr West
Warren
Warren Canal
Third Salt Cr
First Salt Cr
Little Mt
South Branch
West Warren
West Weber
Slaterville
Mill Creek
Weber River
Walker Slough
Taylor
North Fork
South Fork
Hooper Slough
Hooper
Howard Slough
OGDEN BAY
GREAT
WEBER CO
DAVIS CO
Clinton
Sunset
West Point
Roy
Riverdale
Washington Terrace
South Ogden
OGDEN
N Ogden Can
North Ogden
Coldwater Cr
Ogden Canal
Harrisville
Ogden River
Taylor Can
Burch Creek
Weber Aqueduct
Spring Creek
Davis Weber Canal
Uintah
South Weber
Weber River
HILL A F BASE
Gateway Tunnel
WASATCH
84

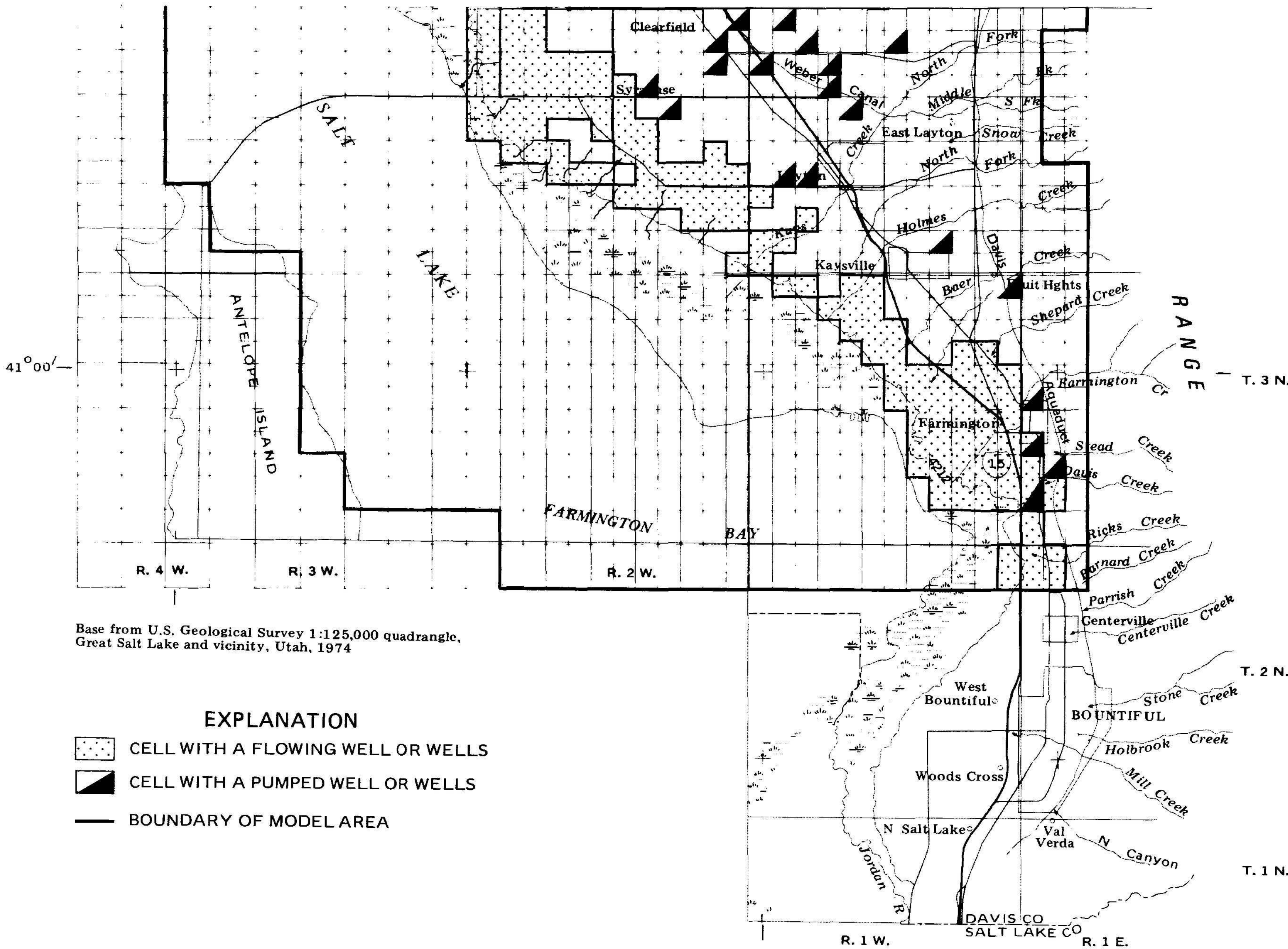


Figure 52.--Location of cells containing flowing and pumped wells.

As part of the transient-state calibration process, measured and computed water-level changes from 1955 to 1985 were compared for the entire model area (fig. 54). Measured changes in water levels were compared to contours of water-level change from steady state to the end of the transient-state calibration period. In most areas, the computed water-level-change contours are a reasonable approximation of the measured water-level changes. In the recharge areas, however, the computed changes generally did not match the measured water-level rises. In areas of large water-level declines caused primarily by increased withdrawals from wells, computed and measured water-level changes are similar.

The measured and computed water levels in the three model layers for 21 observation wells with data for all or some of the 30-year simulation period are shown in figures 55 to 63. Most of the hydrographs show that the computed water levels are close approximations of the measured levels, especially in the areas of large water-level declines caused by increased ground-water withdrawals. It was not possible to match measured and computed water levels in some wells near the recharge areas because actual water levels in these areas change rapidly with changes in recharge, and it was not feasible to simulate those water levels without major changes in the model design and entered data.

At the completion of the transient-state calibration, contour maps of potentiometric surfaces for layers 2 and 3 were constructed and compared to the potentiometric surfaces constructed from measured water levels for 1985 (fig. 7 and pl. 1), (see figures 64 and 65). In most places the measured and computed contours are reasonably similar, except that the configuration of the measured contours are more irregular than the computed contours, which are generally smooth. In figure 65 the computed heads are generally higher than the measured heads in the area near Hill Air Force Base, perhaps because the computed heads at the end of the steady-state calibration are too high due to a lack of water-level data in this area for steady-state calibration.

At the completion of transient-state calibration, the 1955-85 period was simulated again, using a change in the level of Great Salt Lake to test the effect of changing lake levels on water levels and budget components. The actual level of the lake fluctuated about one and one-half feet annually during 1955-82 and then rose about 8 feet during 1983-84. During the simulation, the water-level altitude in the general-head boundary cells that represented Great Salt Lake was raised from 4,200 feet in 1982 to 4,208 feet during 1984. This simulated change in the lake level resulted in water-level rises of five feet or less in layers 2 and 3 near the lake. In the rest of the study area, water-level changes were negligible. Simulated annual discharge to the lake in 1985, through the general-head boundary nodes, decreased from about 15,000 acre-feet to about 6,000 acre-feet with the higher lake level. The remaining 9,000 acre-feet of ground water went into storage. Although it was not simulated, the lake level receded to an altitude of 4,191 feet in 1963, which probably resulted in a larger percentage of the total ground-water discharge moving by upward leakage into the lake.

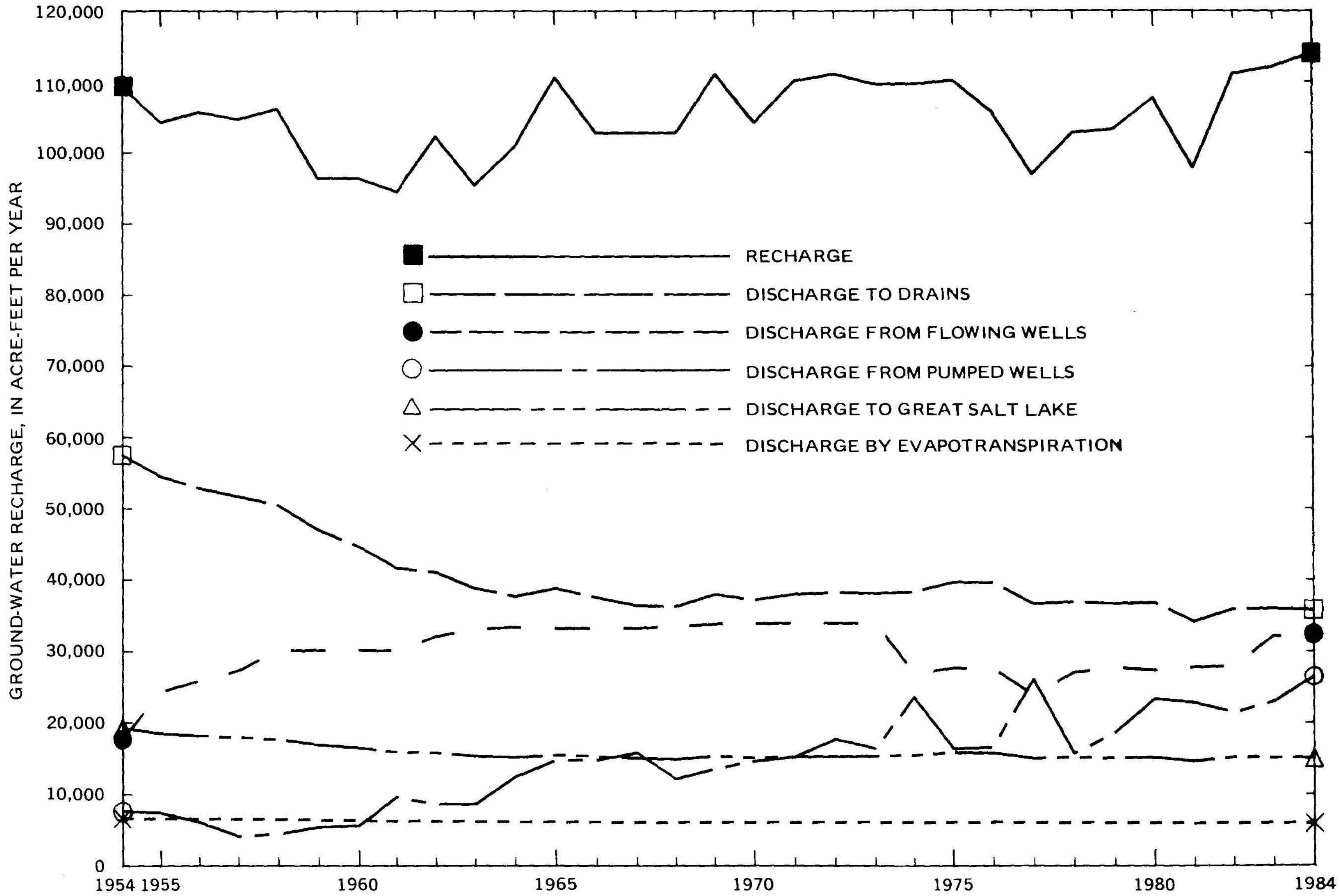
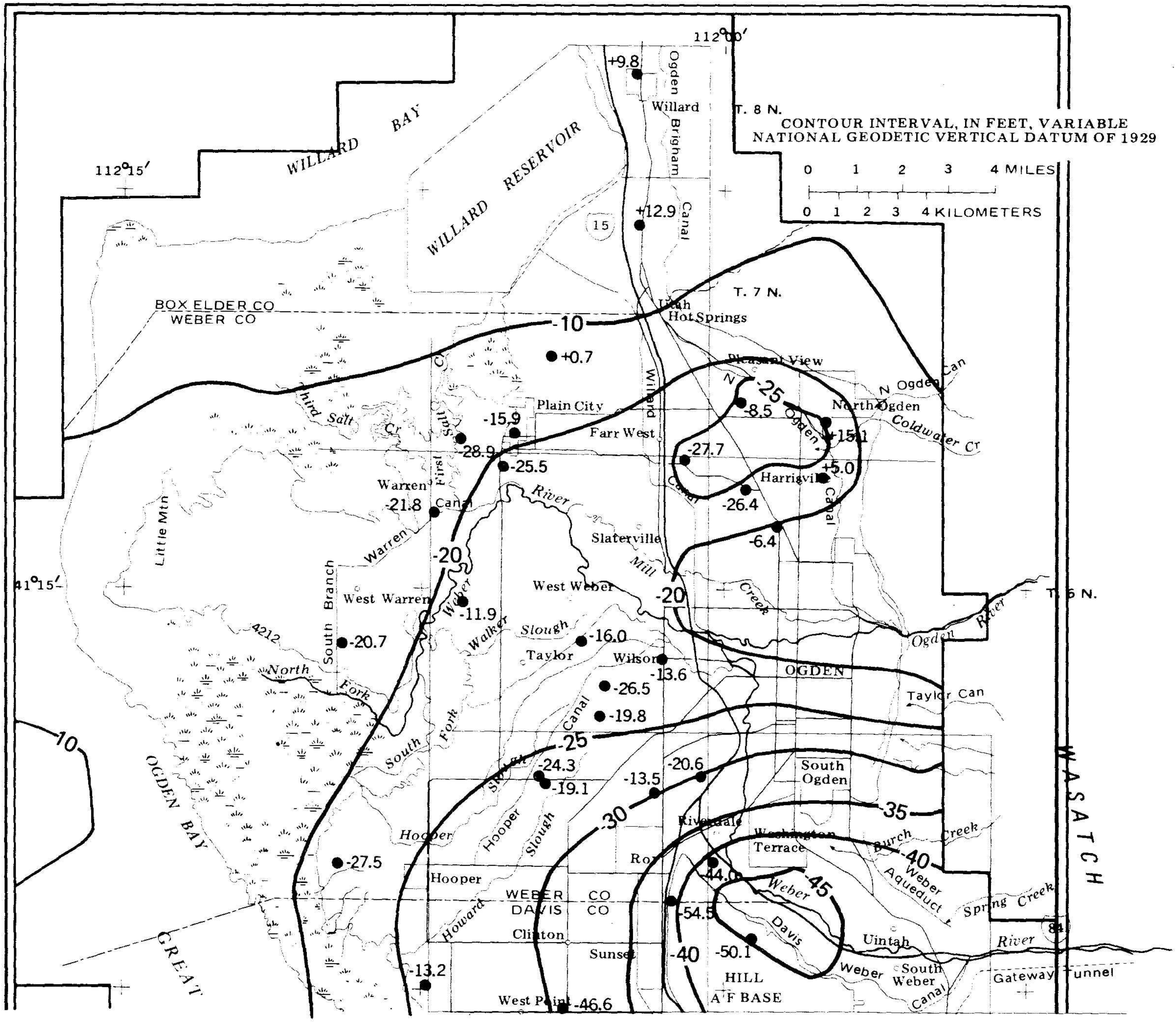


Figure 53.--Ground-water budget resulting from steady-state and transient-state calibrations.
Values for 1954 are steady-state.


CONTOUR INTERVAL, IN FEET, VARIABLE
NATIONAL GEODETIC VERTICAL DATUM OF 1929
0 1 2 3 4 MILES
0 1 2 3 4 KILOMETERS
112°00′
112°15′
41°15′
T. 8 N.
T. 7 N.
T. 6 N.
T. 5 N.
WILLARD BAY
WILLARD RESERVOIR
BOX ELDER CO
WEBER CO
WEBER CO
DAVIS CO
Willard
Ogden Brigham Canal
Utah Hot Springs
Pleasant View
N Ogden Can
North Ogden
Coldwater Cr
Plain City
Farr West
Harrisville
Warren
Warren Canal
Slaterville
Mill Creek
West Weber
West Warren
South Branch
Little Mtn
Third Salt Cr
First Salt
Weber River
Walker Slough
Taylor
Wilson
OGDEN
Ogden River
Taylor Can
North Fork
South Fork
South Ogden
Riverdale
Washington Terrace
Burch Creek
Weber Aqueduct
Spring Creek
Uintah
Hooper
Hooper Slough
Howard
Clinton
Sunset
West Point
HILL AF BASE
Davis Weber Canal
South Weber
Gateway Tunnel
OGDEN BAY
GREAT
WASATCH
4212
15
84
-10
-20
-25
-30
-35
-40
-45
+9.8
+12.9
+0.7
-8.5
+15.1
+5.0
-27.7
-26.4
-6.4
-15.9
-28.9
-25.5
-21.8
-11.9
-20.7
-16.0
-13.6
-26.5
-19.8
-24.3
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-20.6
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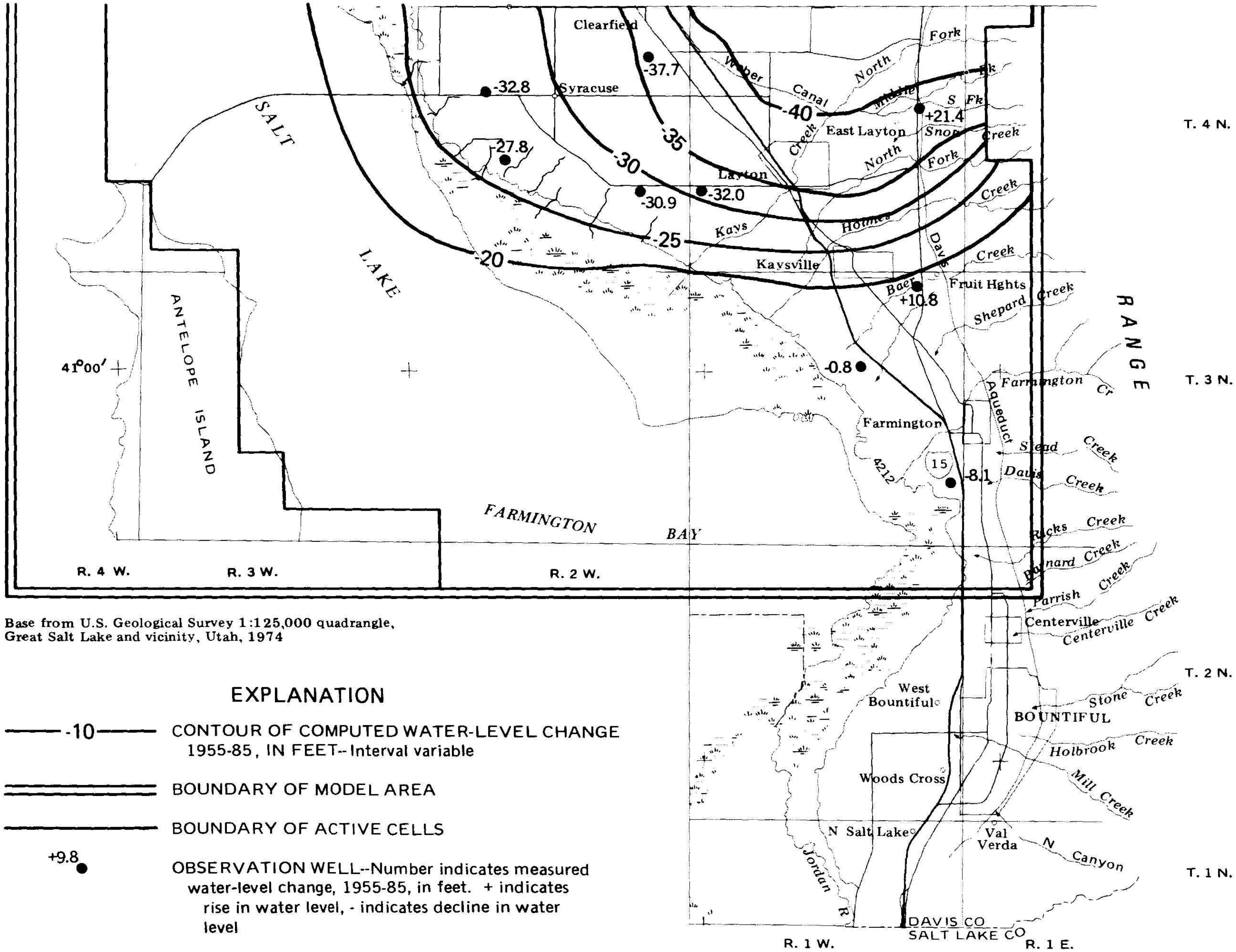
-54.5
-50.1
-27.5
-13.2
-46.6

T. 5 N.



Base from U.S. Geological Survey 1:125,000 quadrangle, Great Salt Lake and vicinity, Utah, 1974

EXPLANATION

-10 CONTOUR OF COMPUTED WATER-LEVEL CHANGE 1955-85, IN FEET--Interval variable

BOUNDARY OF MODEL AREA

BOUNDARY OF ACTIVE CELLS

+9.8 OBSERVATION WELL--Number indicates measured water-level change, 1955-85, in feet. + indicates rise in water level, - indicates decline in water level

Figure 54.--Comparison of measured and computed changes in water levels in layer 3, 1955-85.

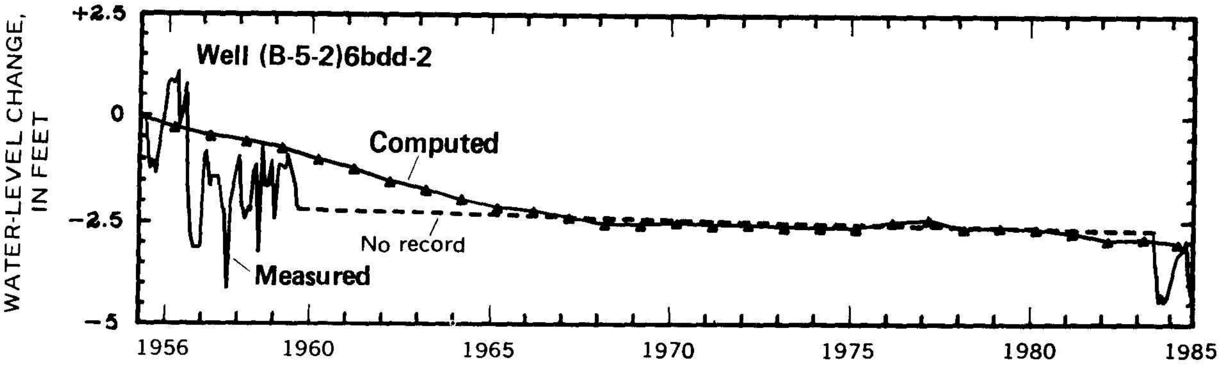


Figure 55.--Measured and computed water levels during 1956-85 for an observation well in layer 1.

The computed water levels and total budget were assumed to be reasonable approximations of the East Shore aquifer system in the Weber Delta area at the end of the steady-state calibration. During the transient-state calibration, computed water-level changes approximated the measured changes in most observation wells. Therefore, the model was used with discretion to simulate changes that could occur with potential increases in pumpage or changes in recharge. Although actual altitudes of the ground-water levels may not be simulated accurately, the water-level changes from the final transient-state levels should be reasonable.

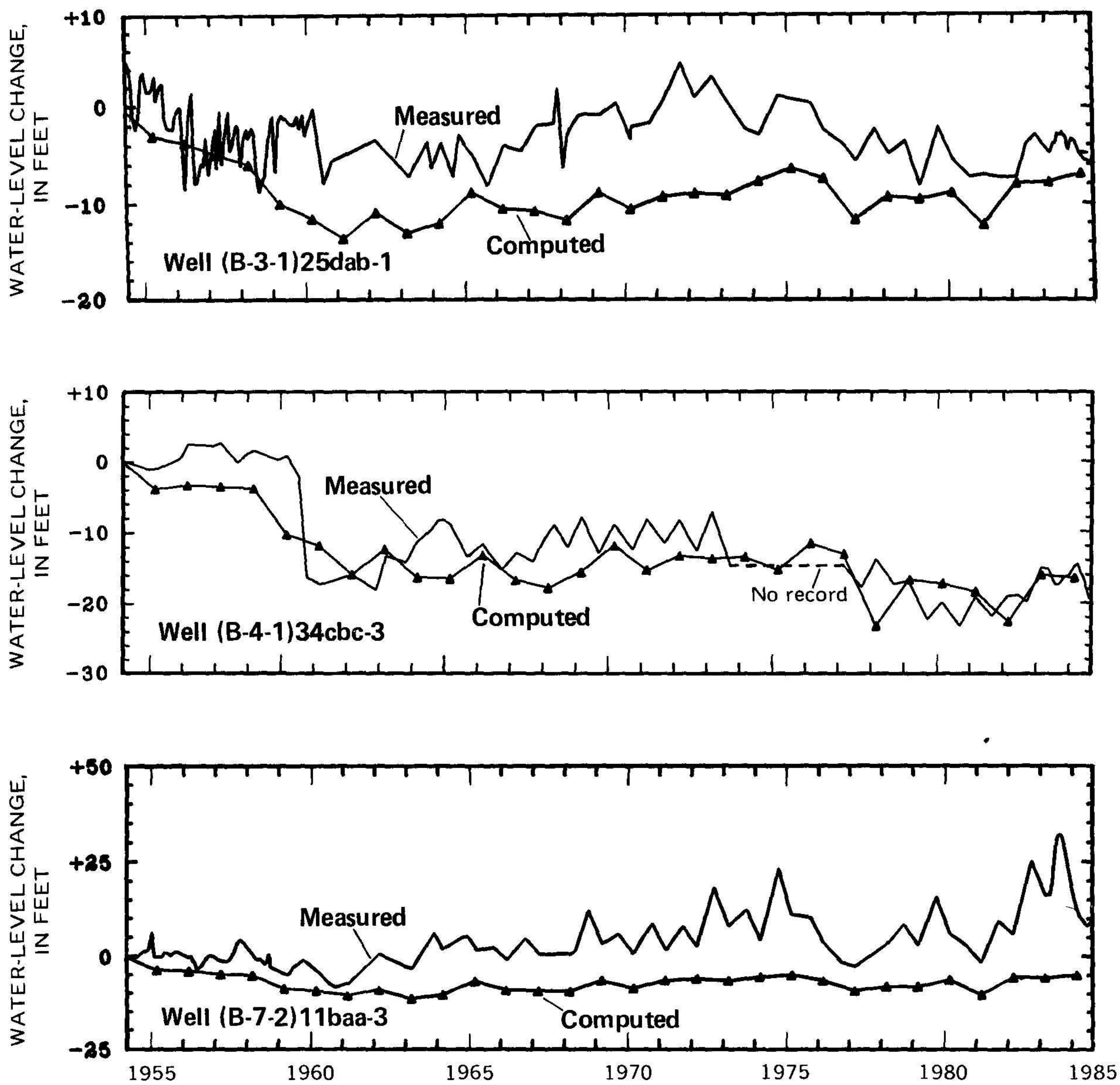


Figure 56.--Measured and computed water levels during 1956-85 for observation wells in layer 2.

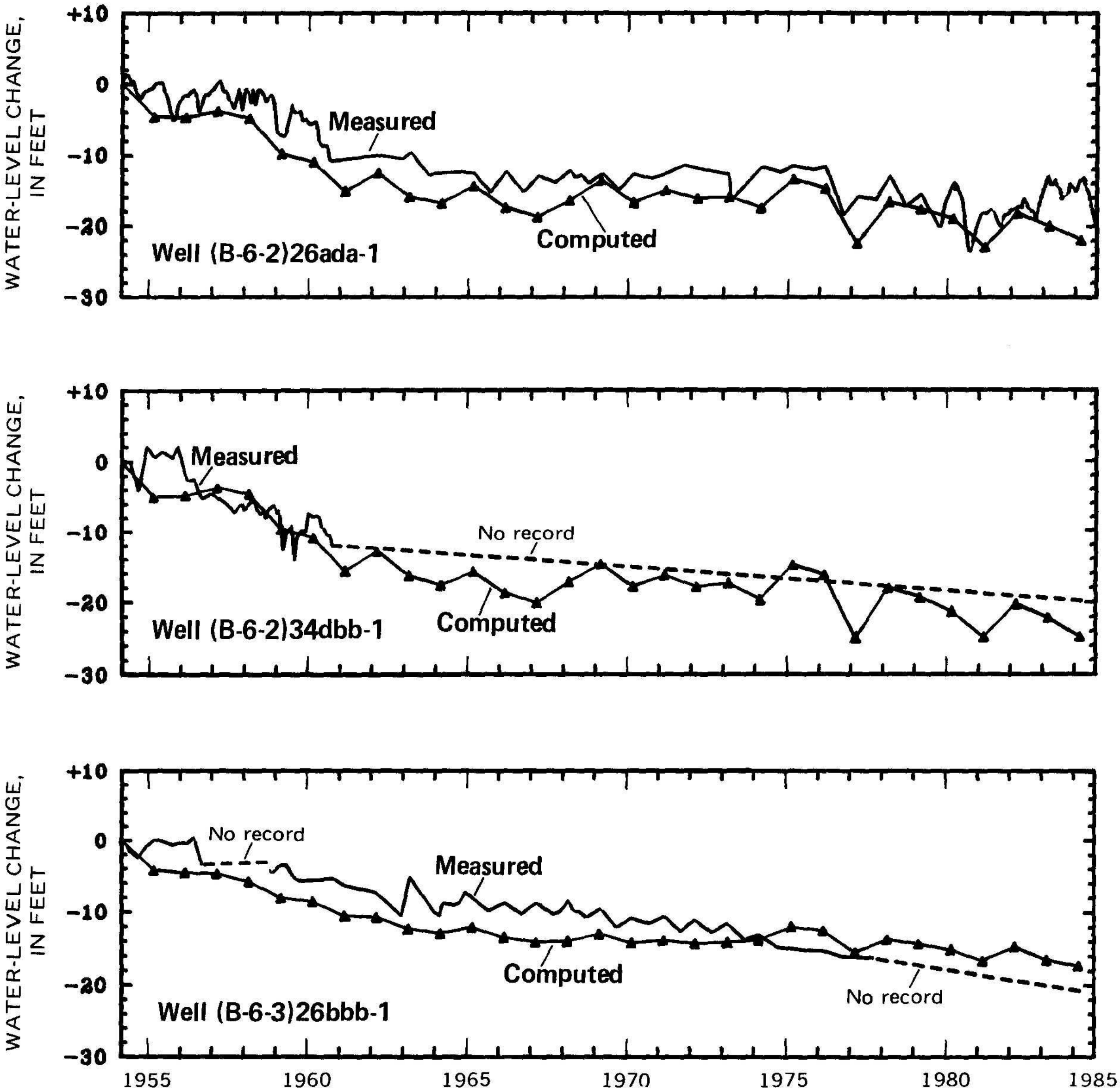


Figure 57.--Measured and computed water levels during 1955-85 for observation wells in layer 3.

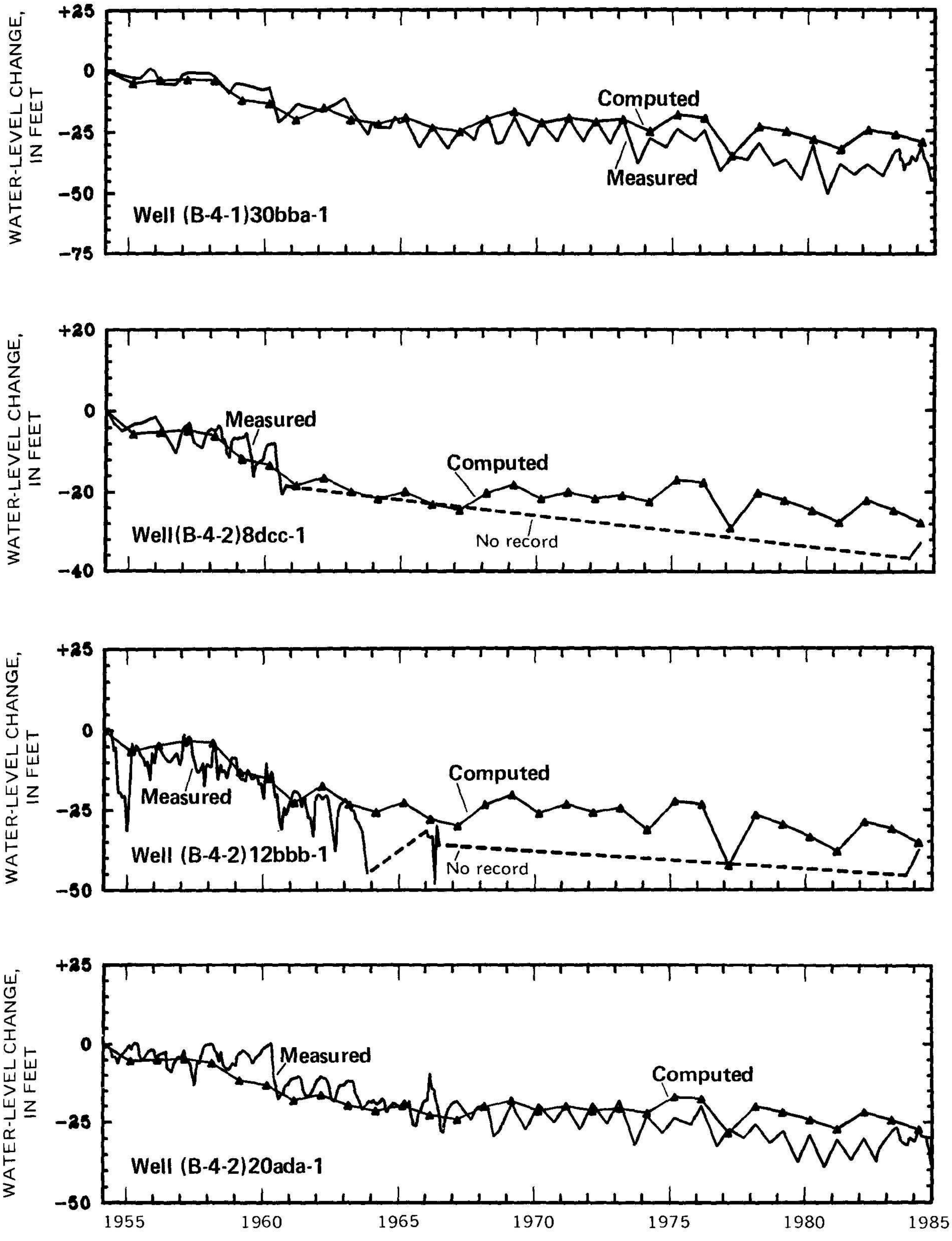


Figure 57.--Measured and computed water levels during 1955-85 for observation wells in layer 3--Continued.

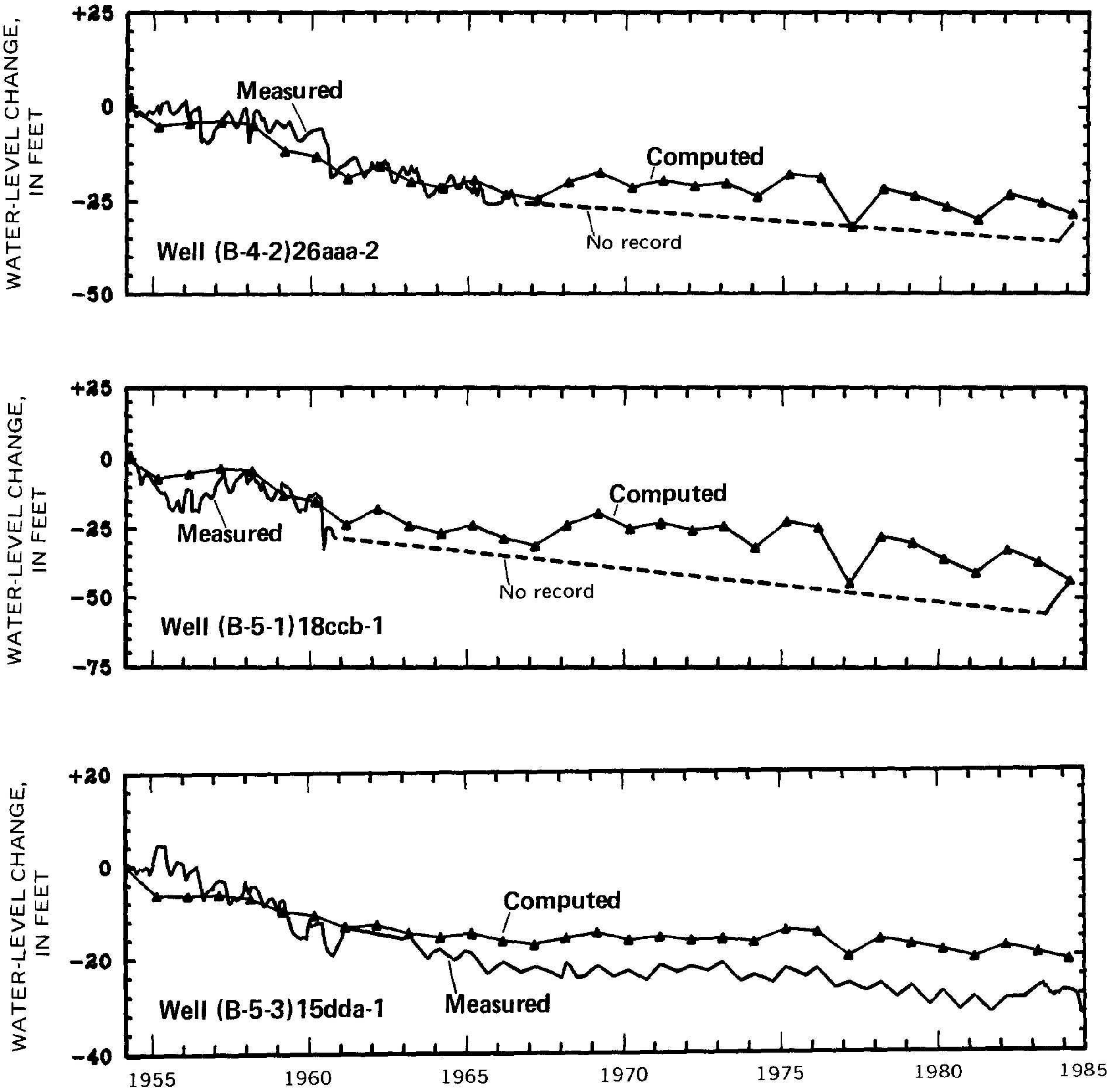


Figure 57.--Measured and computed water levels during 1955-85 for observation wells in layer 3--Continued.

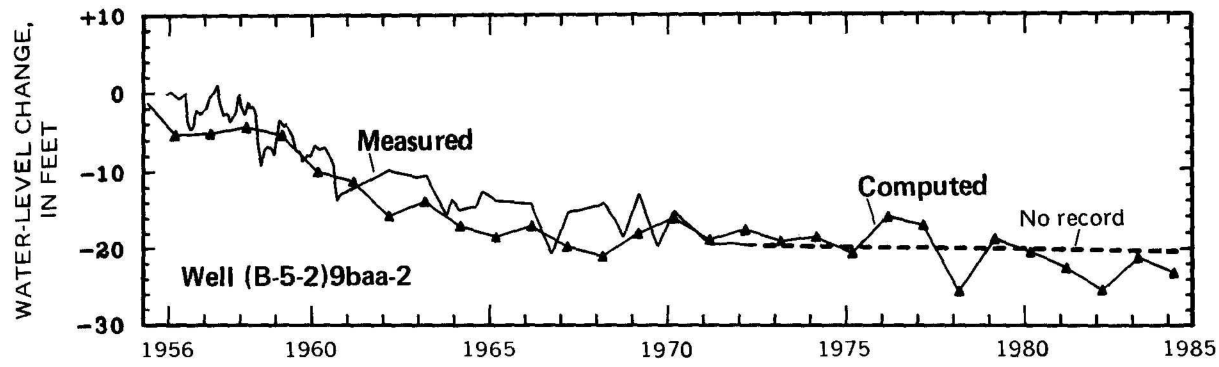


Figure 58.--Measured and computed water levels during 1956-85 for an observation well in layer 3.

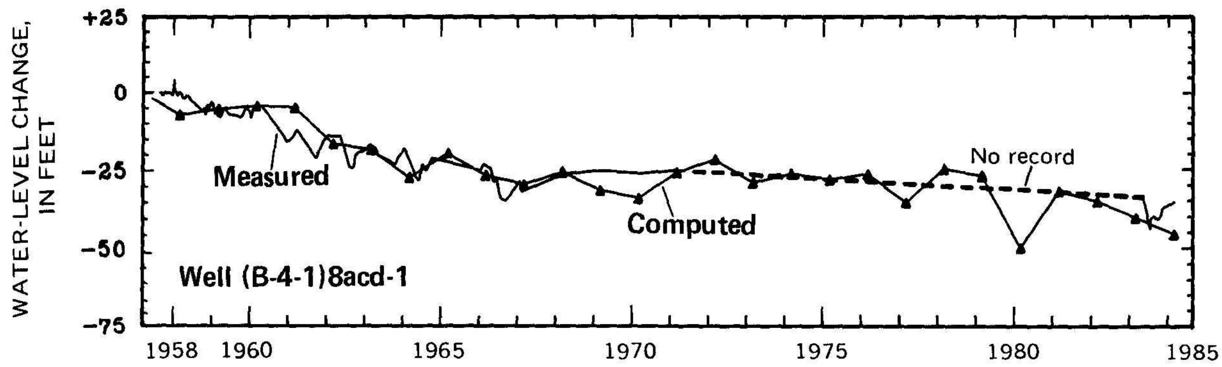


Figure 59.--Measured and computed water levels during 1958-85 for an observation well in layer 3.

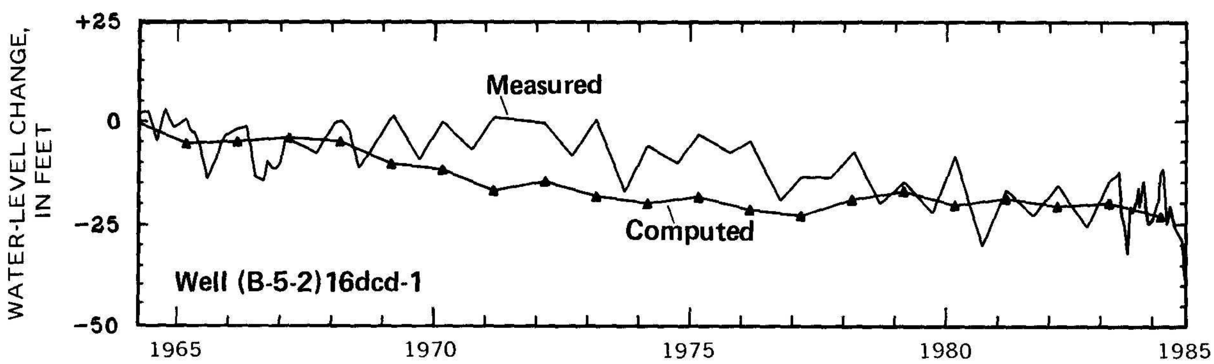


Figure 60.--Measured and computed water levels during 1965-85 for an observation well in layer 3.

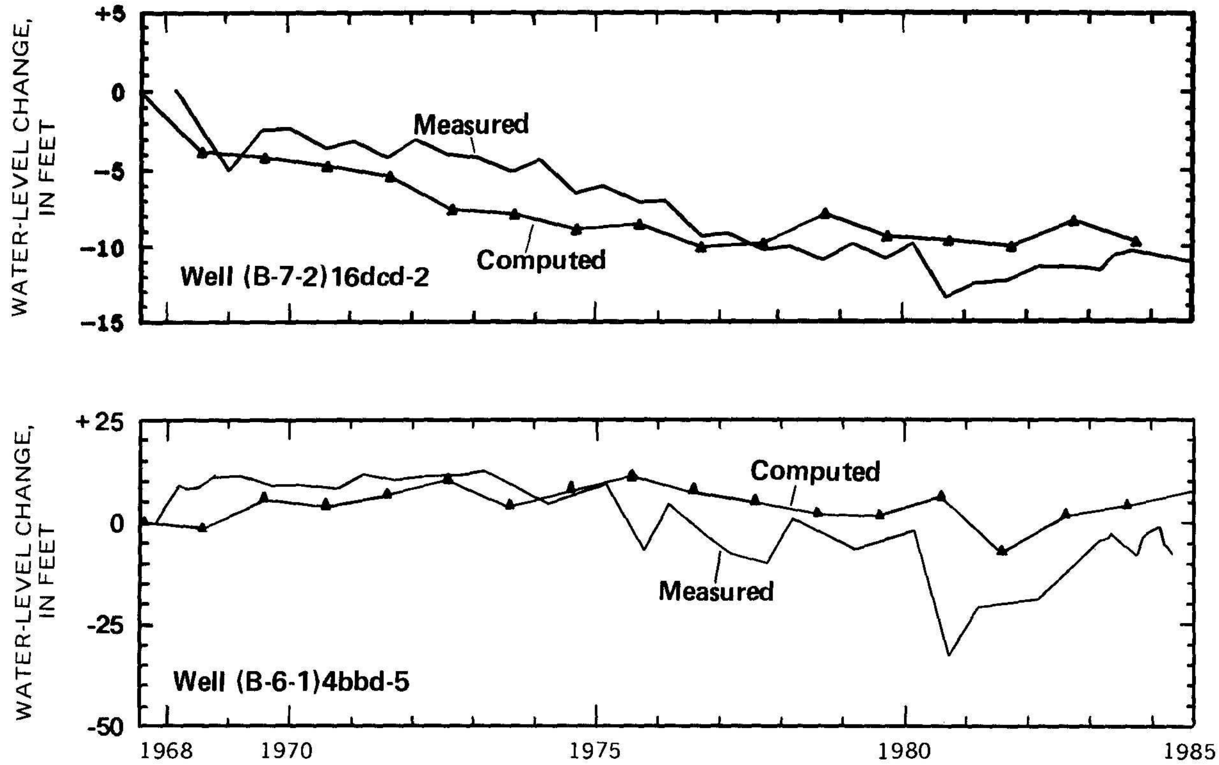


Figure 61.--Measured and computed water levels during 1968-85 for observation wells in layer 3.

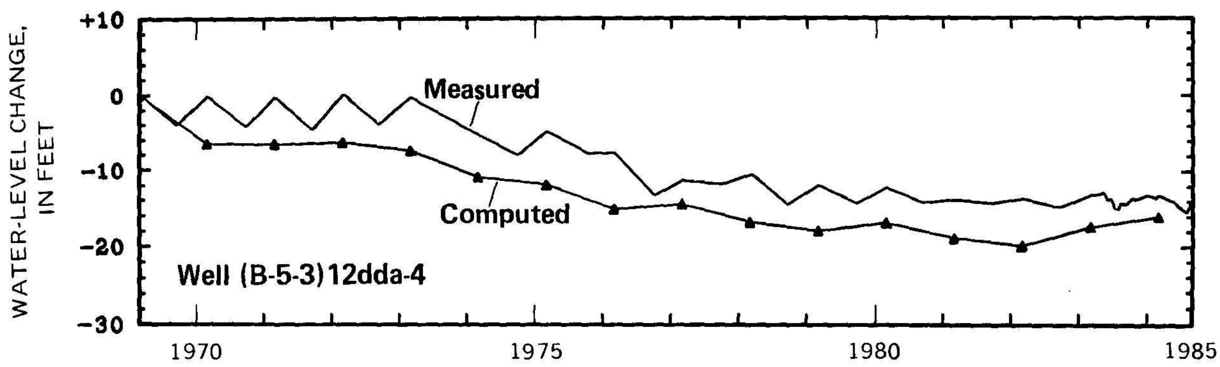


Figure 62.--Measured and computed water levels during 1970-85 for an observation well in layer 3.

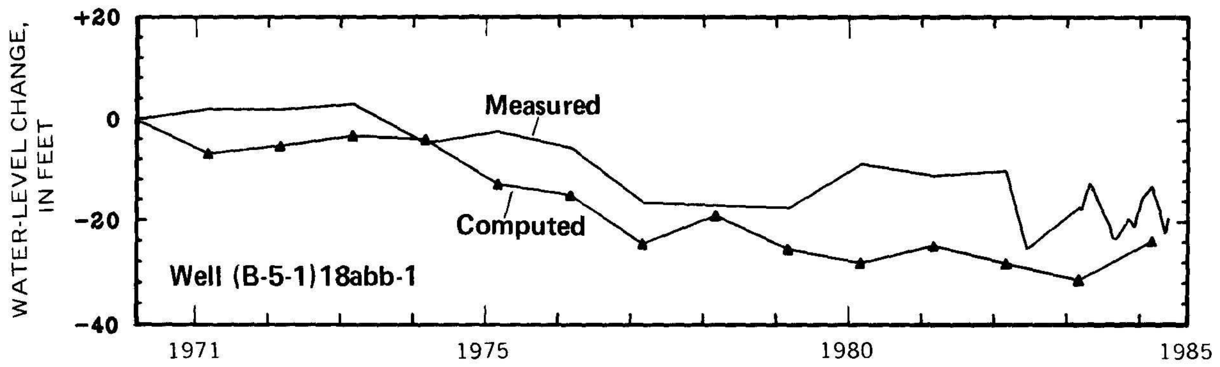
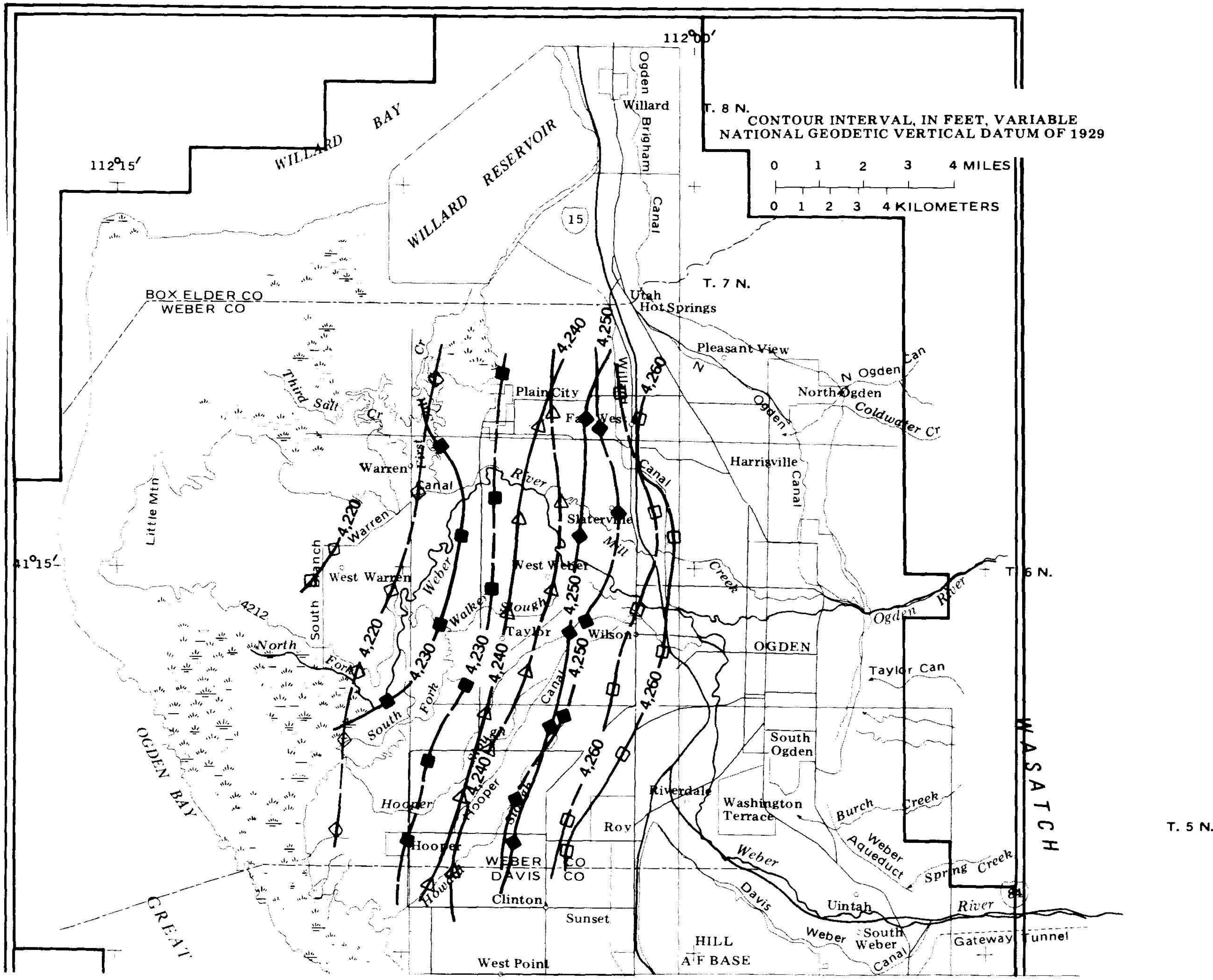


Figure 63.--Measured and computed water levels during 1971-85 for an observation well in layer 3.



CONTOUR INTERVAL, IN FEET, VARIABLE
NATIONAL GEODETIC VERTICAL DATUM OF 1929
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WEBER CO
Utah Hot Springs
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West Weber
West Warren
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South Ogden
Riverdale
Washington Terrace
Burch Creek
Weber Aqueduct
Spring Creek
Roy
Hooper
Hooper
WEBER CO
DAVIS CO
Clinton
Sunset
West Point
HILL AF BASE
Weber River
Davis
Uintah
Weber
South Weber
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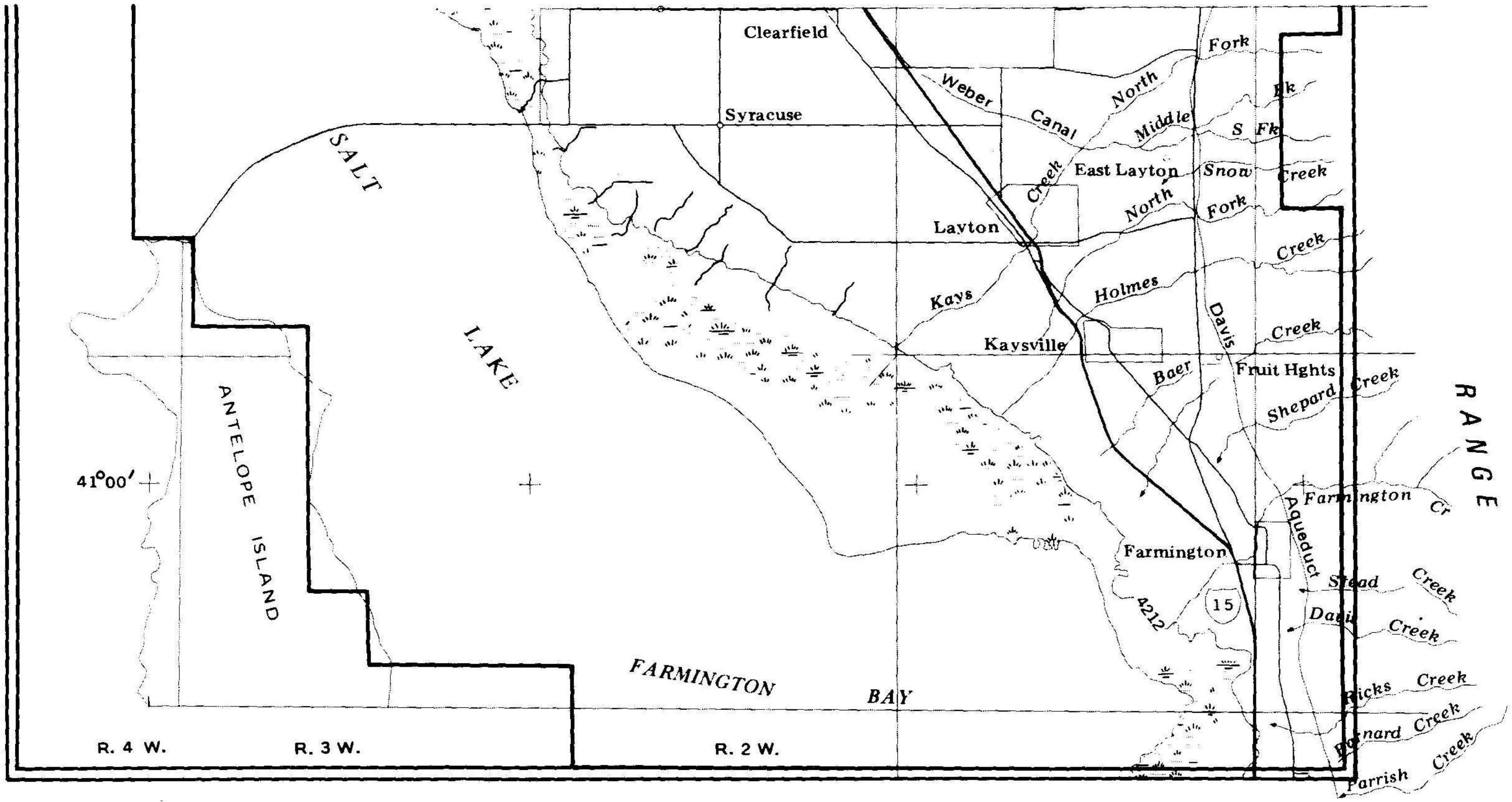


Base from U.S. Geological Survey 1:125,000 quadrangle, Great Salt Lake and vicinity, Utah, 1974

EXPLANATION

POTENTIOMETRIC CONTOUR--Shows approximate altitude, in feet. National Geodetic Vertical Datum of 1929

—— 4,230 —— CONTOUR FROM MEASURED DATA, 1985--Data from figure 16

— — 4,220 — — COMPUTER-GENERATED CONTOUR

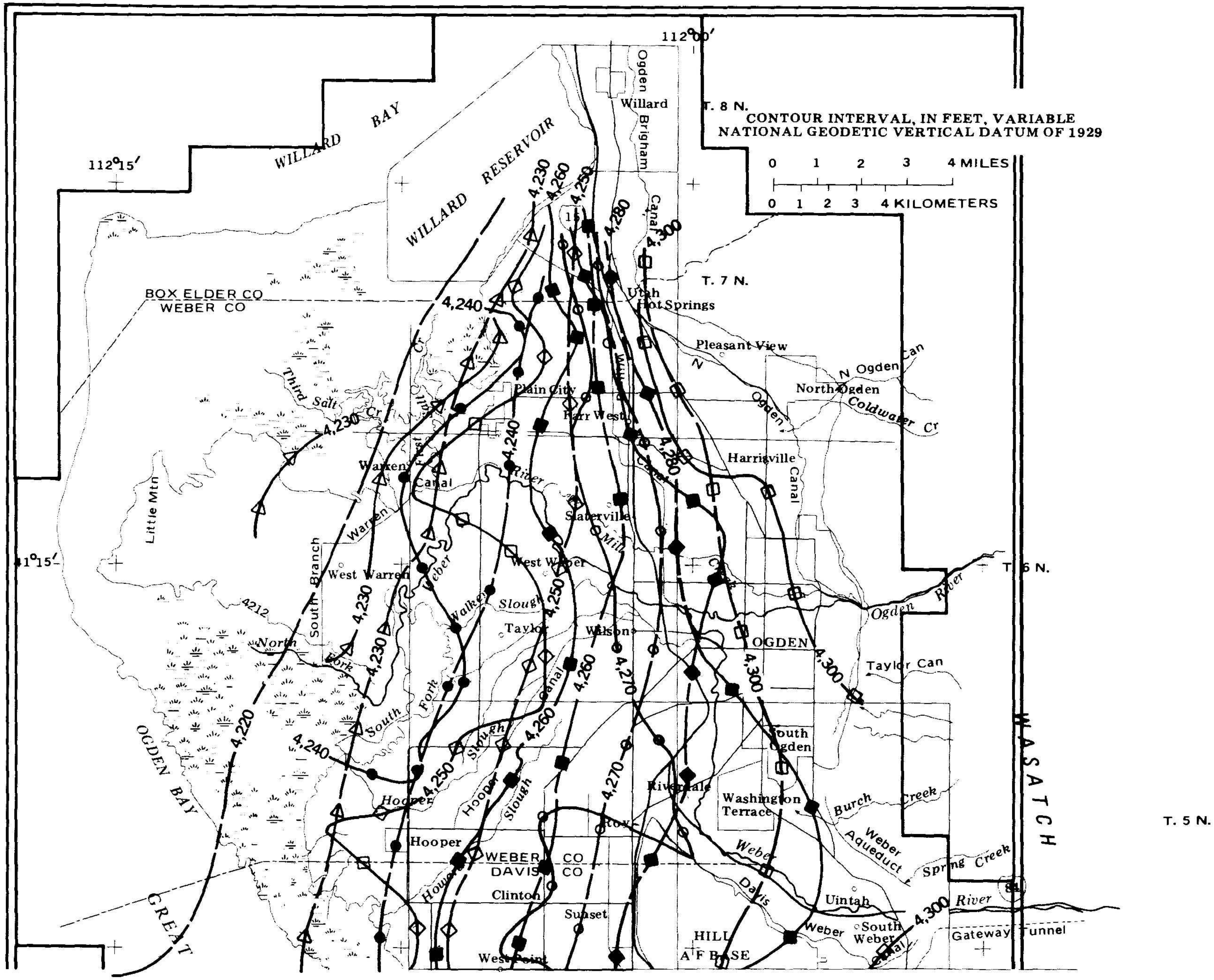
BOUNDARY OF MODEL AREA

BOUNDARY OF ACTIVE CELLS

LIKE SYMBOLS INDICATE EQUAL VALUES

4,220
4,230
4,240
4,250
4,260

Figure 64.--Comparison of potentiometric contours based on measured water levels for 1985 and contours of computed water levels, model layer 2.



CONTOUR INTERVAL, IN FEET, VARIABLE
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WEBER CO
DAVIS CO
Willard
Ogden Brigham Canal
Utah Hot Springs
Pleasant View
North Ogden
N Ogden Can
Coldwater Cr
Third Salt Cr
Plain City
Farr West
Harrisville
Canal
Walker Canal
Slaterville
Mill Cr
West Warren
West Weber
Warren
Little Mtn
South Branch
North Fork
South Fork
Weber River
Slough
Taylor
Wilson
OGDEN
Ogden River
Taylor Can
South Ogden
Riverdale
Washington Terrace
Burch Creek
Weber Aqueduct
Spring Creek
Hooper
Hooper Slough
Howard Slough
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Sunset
West Point
HILL A F BASE
Uintah
South Weber
Davis Weber Canal
Gateway Tunnel
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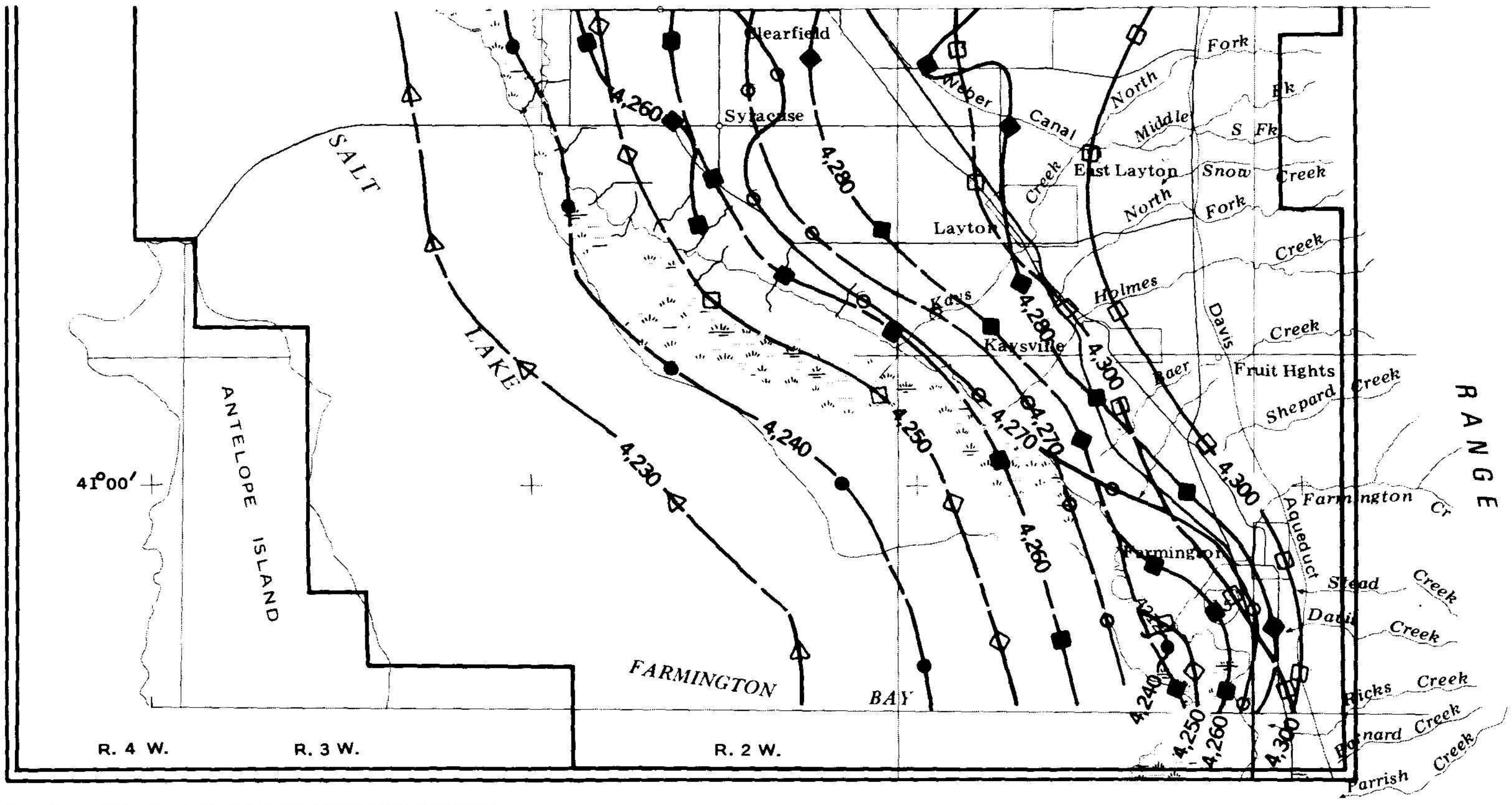


Base from U.S. Geological Survey 1:125,000 quadrangle,
Great Salt Lake and vicinity, Utah, 1974

EXPLANATION

POTENTIOMETRIC CONTOUR--Shows approximate altitude, in feet. National Geodetic Vertical Datum of 1929

——4,230—— CONTOUR FROM MEASURED DATA, 1985--Data from plate 1

– –4,240– – COMPUTER-GENERATED CONTOUR

BOUNDARY OF MODEL AREA

BOUNDARY OF ACTIVE CELLS

LIKE SYMBOLS INDICATE EQUAL VALUES

No symbol 4,220

4,230

4,240

4,250

4,260

4,270

4,280

4,300

Figure 65.--Comparison of potentiometric contours based on measured water levels for 1985 and contours of computed water levels, model layer 3.

Sensitivity Analysis

A detailed sensitivity analysis was not done as part of the calibration process. Sensitivity analysis was an ongoing part of the simulation technique, and it was not conducted separately. A large amount of data was available for the simulation of the system, and therefore, the ranges of estimates for most parameters were not large. For the hydraulic parameters for which ranges were large, primarily vertical hydraulic conductivity and storage coefficient, sensitivity analyses were done as part of the simulation process.

The values for storage coefficient for layer 3 were varied considerably in the transient-state calibration process. The array for storage coefficient was decreased and increased by at least an order of magnitude from the calibrated array, and there was virtually no change in water levels or in the budget terms. The simulations are probably not sensitive to changes in storage coefficients because most of the modeled area is simulated as being under confined conditions, and water-level and storage changes are relatively small.

Predictive Simulations

Predictive simulations were made for a 20-year period beginning in 1985 to estimate the additional water-level declines due to continued or increased ground-water withdrawals from wells. The simulations were made to estimate possible changes in water levels, ground water in storage, and distribution of discharge, using changes from transient-state rates for both ground-water recharge and discharge from wells. Simulations of the effects of current withdrawals were made using an average annual rate of pumpage, about 23,400 acre-feet, from municipal and industrial wells for 1980-84, the last five years of the transient calibration. The first predictive simulation used the average annual recharge rate for 1970-84, about 107,000 acre-feet, to simulate normal recharge, and the second simulation used the average annual recharge rate for 1959-68 of about 100,000 acre-feet to simulate less-than-normal recharge. The simulation using the normal recharge rate and the 1980-84 annual pumpage rate of 23,400 acre-feet resulted in small water-level rises in the principal pumping center and some declines in the recharge area. Using less-than-normal recharge and an annual pumpage rate of 23,000 acre-feet resulted in simulated water-level declines of 5 to 10 feet in the pumping center and larger declines in the recharge areas.

Further predictive simulations were conducted by increasing the pumpage from the municipal and industrial wells over a period of 20 years. The actual annual pumpage from these wells has gradually doubled in the last 20 years from about 10,000 acre-feet in the early 1960's to more than 20,000 acre-feet in the early 1980's (fig. 32). It was assumed that a large increase in the pumpage rate would cause further water-level declines, in turn gradually causing some flowing wells to cease flowing, which would result in a decrease in the total discharge from flowing wells. The well discharge rates used in the predictive simulations are given in the following table:

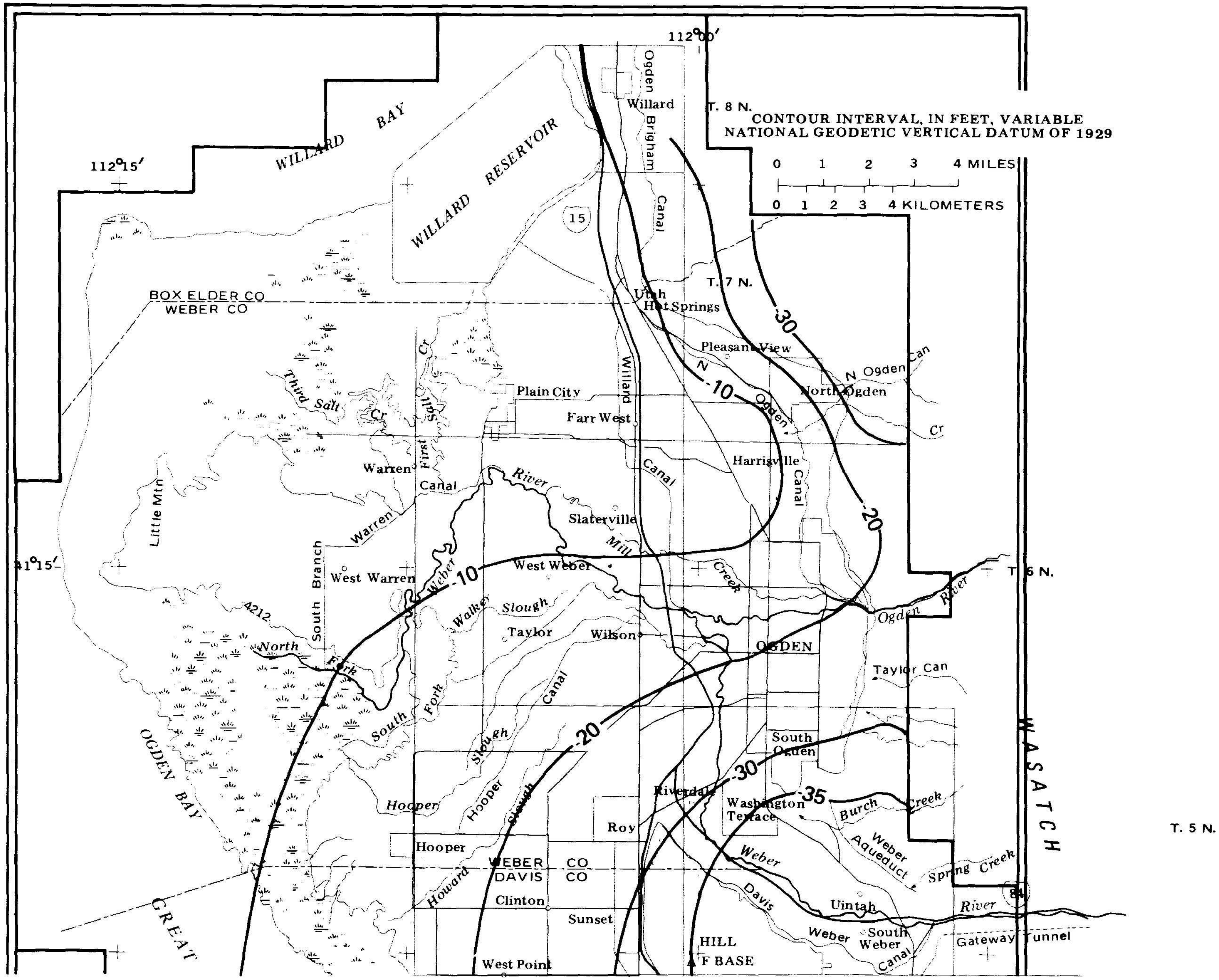
Projected discharge from wells (acre-feet per year)

Period	Discharge		
	Flowing wells	Municipal and industrial wells	Total
1980-84 average (base period)	30,000	23,400	53,400
1985-89	29,900	29,400	59,300
1990-94	27,600	34,600	62,200
1995-99	24,700	40,800	65,500
2000-04	19,300	48,100	67,740

The decrease in flowing-well discharge was estimated from simulations made for five-year periods with normal recharge, and the increasing rate of discharge from pumping wells. At the end of each five-year simulation period, water-level altitudes were compared to land-surface altitudes. In areas where simulated water levels declined below land surface, the discharge from flowing wells was deleted. Simulations were then rerun for 10, 15, and 20 years with the same process being repeated. This method resulted in about a one-third decline in withdrawals from flowing wells during the 20-year simulation.

A 20-year simulation was made using the average long-term recharge rate of 107,000 acre-feet per year and the increased rates of discharge from wells indicated earlier. Predicted water levels in layer 3 declined throughout the area, and declines exceeded 30 feet in the principal pumping center (fig. 66). Declines of greater than 30 feet were simulated in the recharge area near North Ogden, probably because the rate of recharge specified was slightly less than the recharge rate used in the final transient-state stress period. Computed water-level declines in layer 2 indicated a pattern similar to that shown in figure 66; however, simulated declines in layer 2 were about 3 to 5 feet less than in layer 3. A total simulated decrease in storage from 1985-2005 associated with these water-level declines was calculated to be 80,000 acre-feet, or about 4 percent of the total discharge during that period. At the end of the 20-year predictive simulation, the increase in pumpage had caused a decrease of about 10,000 acre-feet per year in discharge to drains and a decrease of about 2,000 acre-feet per year in discharge to the general-head boundary cells representing Great Salt Lake.

An additional 20-year simulation was made using the less-than-normal recharge rate of 100,000 acre-feet per year, while rates of discharge from wells remained the same as in the previous simulation. Simulated water-level declines at the end of the 20-year period are shown in figure 67. The water levels declined throughout model layer 3, and declines exceeded 50 feet in the principal pumping center near Hill Air Force Base. Declines in the recharge



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WEBER CO
Utah Hot Springs
Pleasant View
N Ogden Can
North Ogden
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Plain City
Farr West
Willard Canal
Third Salt Cr
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Harrisville
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Mill Creek
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Burch Creek
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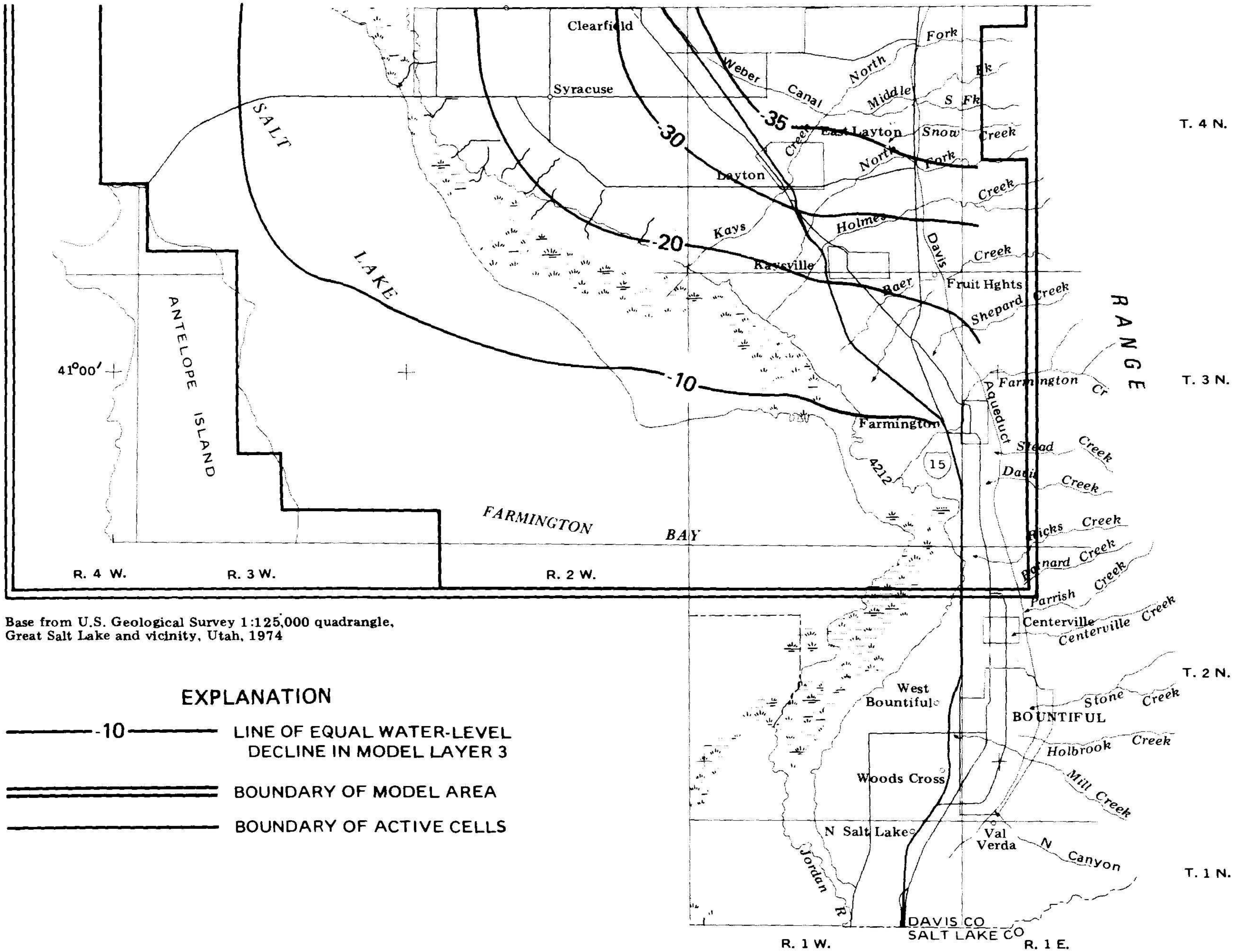


Base from U.S. Geological Survey 1:125,000 quadrangle, Great Salt Lake and vicinity, Utah, 1974

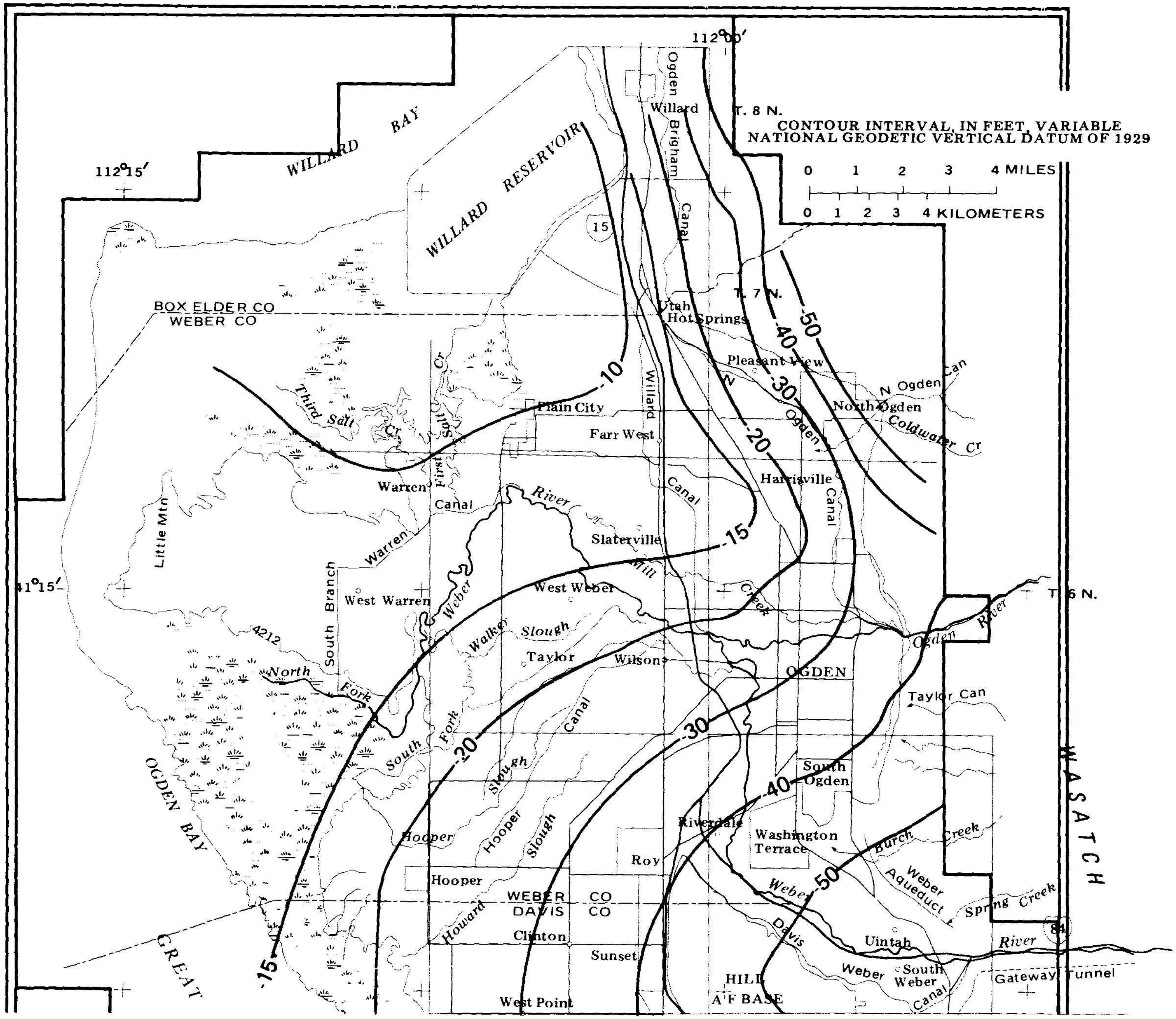
EXPLANATION

-10 — LINE OF EQUAL WATER-LEVEL DECLINE IN MODEL LAYER 3

BOUNDARY OF MODEL AREA

BOUNDARY OF ACTIVE CELLS

Figure 66.--Simulated changes in water levels during 1985-2005, in model layer 3, using a recharge rate of 107,000 acre-feet per year.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Utah Hot Springs
Pleasant View
N Ogden Can
North Ogden
Coldwater Cr
Plain City
Farr West
Willard Canal
Ogden Canal
Harrisville
Slaterville
Third Salt Cr
First Salt Cr
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Little Mtn
South Branch
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West Weber
Mill Creek
Weber River
Ogden River
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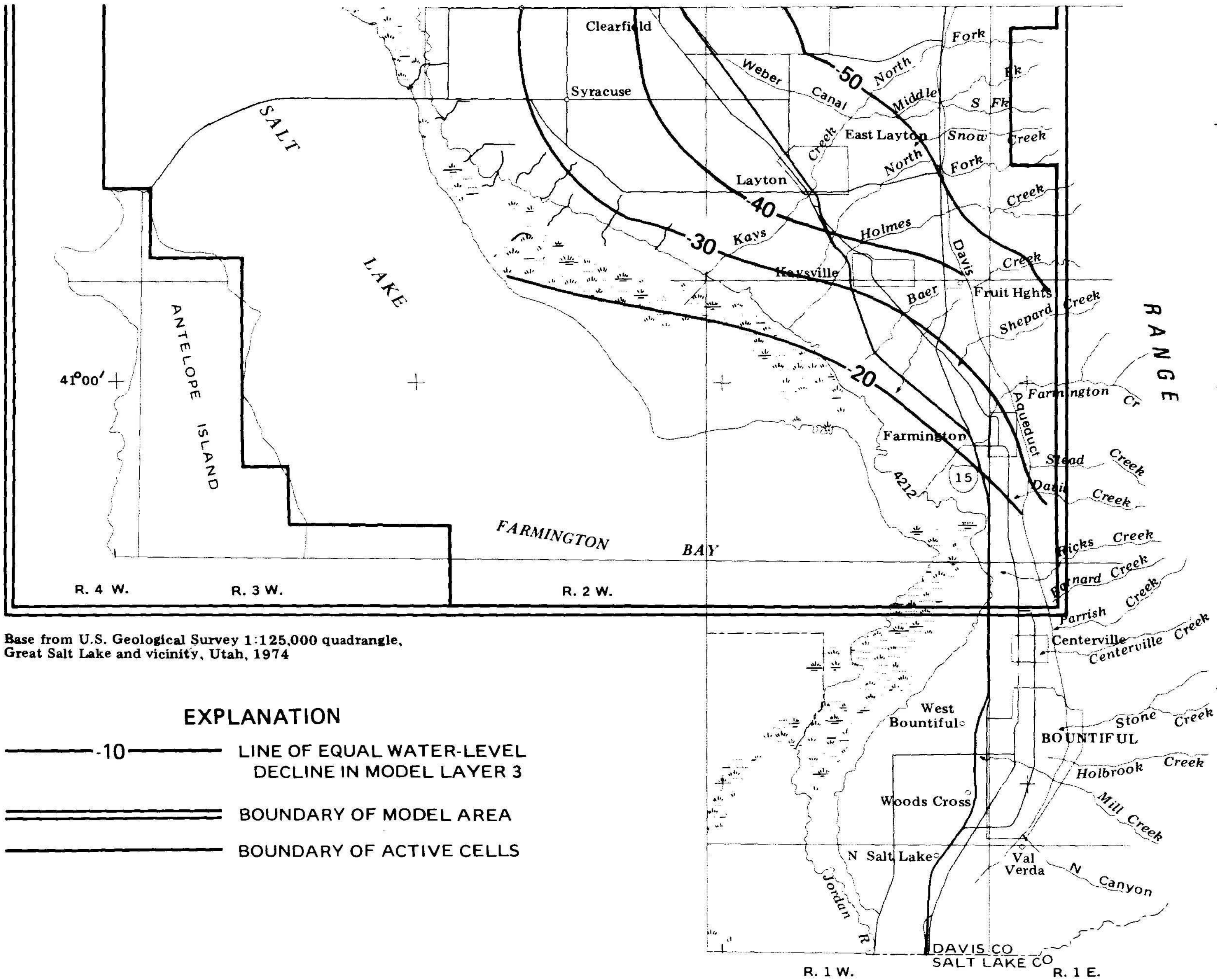

Figure 67.--Simulated changes in water levels during 1985-2005, in model layer 3, using a recharge rate of 100,000 acre-feet per year.

areas near North Ogden also exceeded 50 feet, but were caused primarily by decreases in recharge. The computed water-level decline pattern in layer 2 is similar to the pattern in figure 67 for layer 3; however, the declines in layer 2 were about 10 feet less in the flowing-well area, and 2 to 5 feet less in the principal pumping center. The total simulated decrease in storage for the 20-year period was 115,000 acre-feet, or about 5 percent of the total discharge during that period. At the end of the 20-year period, simulated discharge to drains had decreased about 15,000 acre-feet per year, and discharge to Great Salt Lake, through general-head boundary cells, decreased about 4,000 acre-feet per year.

During the predictive simulations, when water levels in the confined areas west of the mouth of Weber Canyon declined to the extent that they dropped below the bottom of the overlying confining layer, the model simulated these areas as unconfined, using specific-yield values instead of storage coefficients typical of confined conditions. The changes in storage indicated during the predictive simulations include the effects of this conversion.

The results of the predictive simulations indicate that continued increases in withdrawals for municipal and industrial use will cause further declines in water levels in areas of large withdrawals. These declines would be larger if recharge decreased to less-than-normal rates, such as occurred during 1959-68, when precipitation and streamflow were less than normal. Water-level declines of this magnitude would cause the static water levels to fall below land surface in a wide area, causing additional flowing wells to cease flowing, and also causing water levels in some wells to decline below present pump settings. The declines also would cause a decrease in the rates of natural ground-water discharge to drains, by evapotranspiration, and to Great Salt Lake, thereby salvaging or intercepting water.

Results of predictive simulations based on changes in withdrawals or recharge are probably valid over a large area; however, they may not be valid at a specific location because of generalizations made in hydraulic parameters such as the vertical hydraulic conductivity. Simulated water levels in recharge areas may not be accurate because changes in recharge from the transient-state rates apparently have more effect than increases in withdrawals.

SUMMARY AND CONCLUSIONS

The East Shore aquifer system in the basin-fill deposits of an elongate trough (graben) between the Wasatch Range and Great Salt Lake is primarily a confined system with unconfined parts along the mountain front. The aquifer system contains about 100 cubic miles of saturated sediments and has approximately 135 million acre-feet of water in storage, of which an estimated maximum of 37 million acre-feet is theoretically recoverable. It is not known, however, how much dewatering of the system could occur without undesirable side effects on the ground-water system, such as water levels declining to depths from which it is uneconomical to pump, movement of saline water to wells, and land subsidence. An estimated 13,000 acre-feet of water has been removed from storage from the unconfined part of the aquifer system near the mouth of Weber Canyon due to water-level declines since 1953.

Annual recharge to the East Shore aquifer system averaged about 153,000 acre-feet during 1969-84. The primary sources of recharge are seepage from natural channels and irrigation canals, about 60,000 acre-feet, and subsurface inflow from consolidated rock, about 75,000 acre-feet. Total recharge may vary considerably from one year to the next with changes in annual surface-water inflow and precipitation. Total annual surface-water inflow to the study area was estimated to average about 860,000 acre-feet for 1969-84, but averaged almost 1,500,000 acre-feet for 1983-84 when precipitation was much greater than normal.

Estimates of the hydraulic properties of the aquifers were made from aquifer tests, lithologic and specific-capacity data, and with the use of a numerical model. Values of transmissivity determined using these methods range from less than 1,000 feet squared per day in consolidated rock and in basin fill near Great Salt Lake to greater than 100,000 feet squared per day in basin fill near the mouth of Weber Canyon.

Ground water generally moves from recharge areas near the mountain front, where there is a downward vertical gradient, to discharge areas near Great Salt Lake, where artesian pressures create an upward gradient. Locally, the hydraulic gradient may be reversed seasonally or over the long term by large-scale withdrawals of water from wells.

Long-term trends of water levels indicate a steady decline at most observation wells since the early 1950's. The declines generally follow the trend of less-than-normal precipitation until the late 1960's, when water levels continued to decline, despite normal or greater than normal precipitation. The continuing declines are due to large-scale increases in ground-water withdrawals. Water levels have declined as much as 50 feet in the principal pumping center (centered near Hill Air Force Base) and as much as 35 feet in areas farther from the pumping center. The increase in withdrawals and the subsequent water-level declines have caused approximately 700 wells within about 30 square miles to cease flowing since 1954.

The average annual discharge from the East Shore aquifer system during 1969-84 was estimated to be 182,000 acre-feet, including 54,000 acre-feet by wells, 70,000 acre-feet to drainageways and springs, and 50,000 acre-feet as diffuse seepage to Great Salt Lake. The annual withdrawal of ground water for municipal and industrial use increased from about 10,000 acre-feet in 1960 to more than 30,000 acre-feet in 1980 to supply the 66 percent increase in population, which grew from 175,000 people in 1960 to 290,000 in 1980.

Water in the East Shore aquifer system is generally potable and suitable for most uses; however, local areas may contain water with chloride concentrations in excess of 250 milligrams per liter. In addition, local areas contain warm water, with temperatures of 20 to 40 degrees Celsius, associated with a series of fault zones. Little or no evidence exists of changes in the chemical quality of water from most wells sampled prior to 1970 and again after 1980. The changes that have occurred are assumed to be a result of local conditions, such as different proportions of water of different chemical characteristics entering a well, related to vertical variations of water quality and effects of local withdrawals, and not a widespread change in water quality.

A three-dimensional finite-difference numerical model was used in the study of the East Shore aquifer system. The model was used to refine concepts of the aquifer system in the Weber Delta area and to project effects of increases in ground-water withdrawals. It was constructed as a three-layer system, with two layers representing the aquifer system including its confined and unconfined parts, and the uppermost layer used mostly to simulate discharge to the shallow water-table zone from the underlying aquifer system. The area simulated was the part of the East Shore aquifer system extending from north of Willard southward to about one mile north of Centerville, and was defined as the Weber Delta aquifer system. The model was calibrated to steady-state conditions using data for the period 1953-55, and to transient-state conditions using data for the period 1955-85.

Various hydrologic properties and processes were evaluated as part of the calibration process, including (1) construction of transmissivity maps; (2) developing ranges of vertical hydraulic-conductivity values; and (3) determining subsurface recharge from consolidated rock, variation of total recharge with time, and changes in discharge to drains, flowing wells, and Great Salt Lake with changes in ground-water withdrawals and recharge. Changes in recharge during transient-state calibration were estimated using annual changes in streamflow in the Weber River. Large rises in the level of Great Salt Lake in 1983-84 were simulated, with the results indicating only small rises in water levels near the lake and decreased discharge by diffuse seepage to the lake.

A principal test of the simulations and the method of model calibration was to reproduce a measured 50-foot water-level decline during 1955-85, which was primarily a result of increased ground-water withdrawals for municipal and industrial use. The calibrated model was used to project the effects of increased withdrawals in the future. Predictive simulations were made based on doubling withdrawals for municipal and industrial use over a 20-year period while using (1) the average recharge rate of 107,000 acre-feet per year, and (2) a less-than-average rate of 100,000 acre-feet per year. The results were additional water-level declines of 35 to 50 feet in the principal pumping center, and simulated decreases in ground-water storage of 80,000 to 115,000 acre-feet after 20 years. Increased ground-water withdrawals and water-level declines of this magnitude would likely cause flowing wells in a large area to cease flowing, and would decrease the amount of natural discharge as seepage to drains, evapotranspiration, and diffuse seepage to Great Salt Lake.

The predictive simulations are based on a calibrated model. They are assumed to be a reasonable representation of possible changes to the East Shore aquifer system in the Weber Delta area given assumed increases in withdrawals and possible changes in recharge; however, the model results are general and should not be used to evaluate site-specific problems.

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