Ground Water in Utah's Densely Populated Wasatch Front Area—the Challenge and the Choices

United States Geological Survey Water-Supply Paper 2232

Ground Water in Utah's Densely Populated Wasatch Front Area—the Challenge and the Choices

By DON PRICE

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PREFACE

TIME WAS

Time was when just the Red Man roamed this lonely land,
Hunted its snowcapped mountains, its sun-baked desert sand;
Time was when the White Man entered upon the scene,
Tilled the fertile soil, turned the valleys green.
Yes, he settled this lonely region, with the precious water he found
In the sparkling mountain streams and hidden in the ground;
He built his homes and cities; and temples toward the sun;
But without the precious water, his work might not be done.

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Ground Water in Utah's Densely Populated Wasatch Front Area—The Challenge and the Choices

By Don Price

Abstract

Utah's Wasatch Front area comprises about 4,000 square miles in the north-central part of the State. In 1980, the area had a population of more than 1.1 million, or about 77 percent of Utah's total population. It contains several large cities, including Salt Lake City, Ogden, and Provo, and is commonly called Utah's urban corridor.

Most of the water supply for the Wasatch Front area comes from streams that originate in the Wasatch Range and nearby Uinta Mountains; however, ground water has played an important role in the economic growth of the area. The principal source of ground water is the unconsolidated fill (sedimentary deposits) in the valleys of the Wasatch Front area—northern Juab, Utah, Goshen, and Salt Lake Valleys; the East Shore area (a valley area east of the Great Salt Lake), and the Bear River Bay area. Maximum saturated thickness of the fill in the principal ground-water reservoirs in these valleys exceeds 6,000 feet, and the estimated volume of water that can be withdrawn from just the upper 100 feet of the saturated fill is about 8 million acre-feet. In most places the water is fresh, containing less than 1,000 milligrams per liter of dissolved solids; in much of the Bear River Bay area and most of Goshen Valley (and locally in the other valleys), the water is slightly to moderately saline, with 1,000 to 10,000 milligrams per liter of dissolved solids.

The principal ground-water reservoirs receive recharge at an annual rate that is estimated to exceed 1 million acre-feet—chiefly as seepage from consolidated rocks in the adjacent mountains from canals, ditches, and irrigated land, directly from precipitation, and from streams. Discharge during 1980 (which was chiefly from springs, seepage to streams, evapotranspiration, and withdrawal by wells) was estimated to be about 1.1 million acre-feet. Withdrawal from wells, which began within a few years after the arrival of the Mormon pioneers in the Salt Lake Valley in 1847, and had increased to about 320,000 acre-feet during 1979. Additional withdrawals from wells may cause water levels to decline, possibly leading to such problems as conflicts among water-right owners, increased pumping costs, land subsidence, and deterioration of ground-water quality. Some of these problems cannot be avoided if the principal ground-water reservoirs are to be fully used; however, management practices such as artificial ground-water recharge in intensively-pumped areas may help to alleviate those problems.

SIGNIFICANCE

Ground Water in Perspective

During 1940-80 the Wasatch Front area of north-central Utah experienced tremendous growth in population and related business and industrial development. The population more than tripled. (See figure 1.) Many of the fields that once produced sugar beets, alfalfa, and other irrigated crops have become sites of new schools, shopping centers, and residential areas. Orchards and groves of native scrub oak on the terraces (benches) overlooking the Wasatch Front valleys have given way to "view property" housing developments. Even at this writing, urbanization of this once predominantly rural agricultural area continues, and it is expected to continue into the 21st century.

Water needed to support the large influx of people to the Wasatch Front area has come chiefly from streams that originate in the Wasatch Range and nearby Uinta Mountains. Ground water, however, has and will continue to play an important role in helping to meet the increasing water needs for public supply, industry, and other uses. The area has a tremendous supply of ground water—more than the contents of Utah Lake and Great Salt Lake combined. Competition for this ground water will increase as the available surface-water supply becomes fully used.

Ground water has certain advantages over surface water for some uses; this is especially true for public supply where dependability and quality of the supply are extremely important. Ground water is a more dependable water source than surface water during droughts—wells generally continue to produce water after streams have ceased flowing. Ground water generally is available where needed, whereas surface water may have to be conveyed long distances from the source to the area of use. Ground water is less subject to contamination and pollution than is surface water—it is much more difficult to introduce contaminants (intentionally or accidentally) into a deep ground-water source than into a stream or surface reservoir.

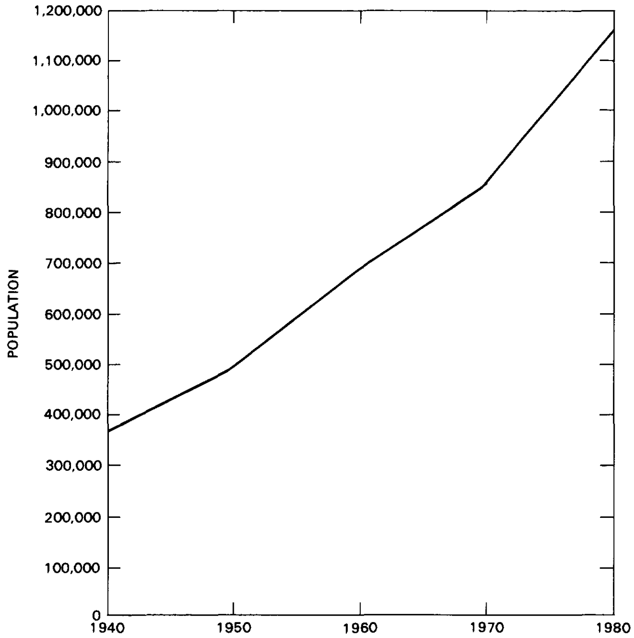


Figure 1. Population growth in the Wasatch Front area, 1940–80.

The population of the area more than tripled between 1940 and 1980; by 1980 it exceeded 1.1 million, or was about 77 percent of Utah's total population.

Ground water also may be a more dependable source of water during periods of natural or man-caused disasters. For example, local wells eliminate the need for long aqueducts than can be ruptured by landslides or movement along geologic faults.

Because of the large volume of available ground water in the Wasatch Front area, and the advantages that this resource may have over surface water, it needs to be given more consideration in future water-supply and management plans for the area. Large-scale ground-water withdrawals in this densely populated area, however, could create problems associated with resulting declining ground-water levels—problems such as conflicts among the many water-right owners, ground-water quality deterioration, and land subsidence. Those problems can be avoided or minimized, however, by effective management based on sound knowledge of ground-water conditions in the area.

The U.S. Geological Survey, under its cooperative programs with the State of Utah, has been studying the groundwater resources of the Wasatch Front area since the early 1900's. Much information has been gained about the resource from those studies, the results of which are published in the reports listed on pages 70-71. This report includes selected information gained during those studies; it is chiefly intended for use by Wasatch Front area water planners, managers, policy makers, and educators in their decision making and education processes. Because some of these people have nontechnical backgrounds in groundwater hydrology, the information is presented in nontechnical language. The illustrations, compiled chiefly for planning purposes, are generalized and need to be viewed with discretion. More detailed site-specific information can be obtained from the referenced reports or the U.S. Geological Survey, Salt Lake City, Utah.

THE WASATCH FRONT AREA

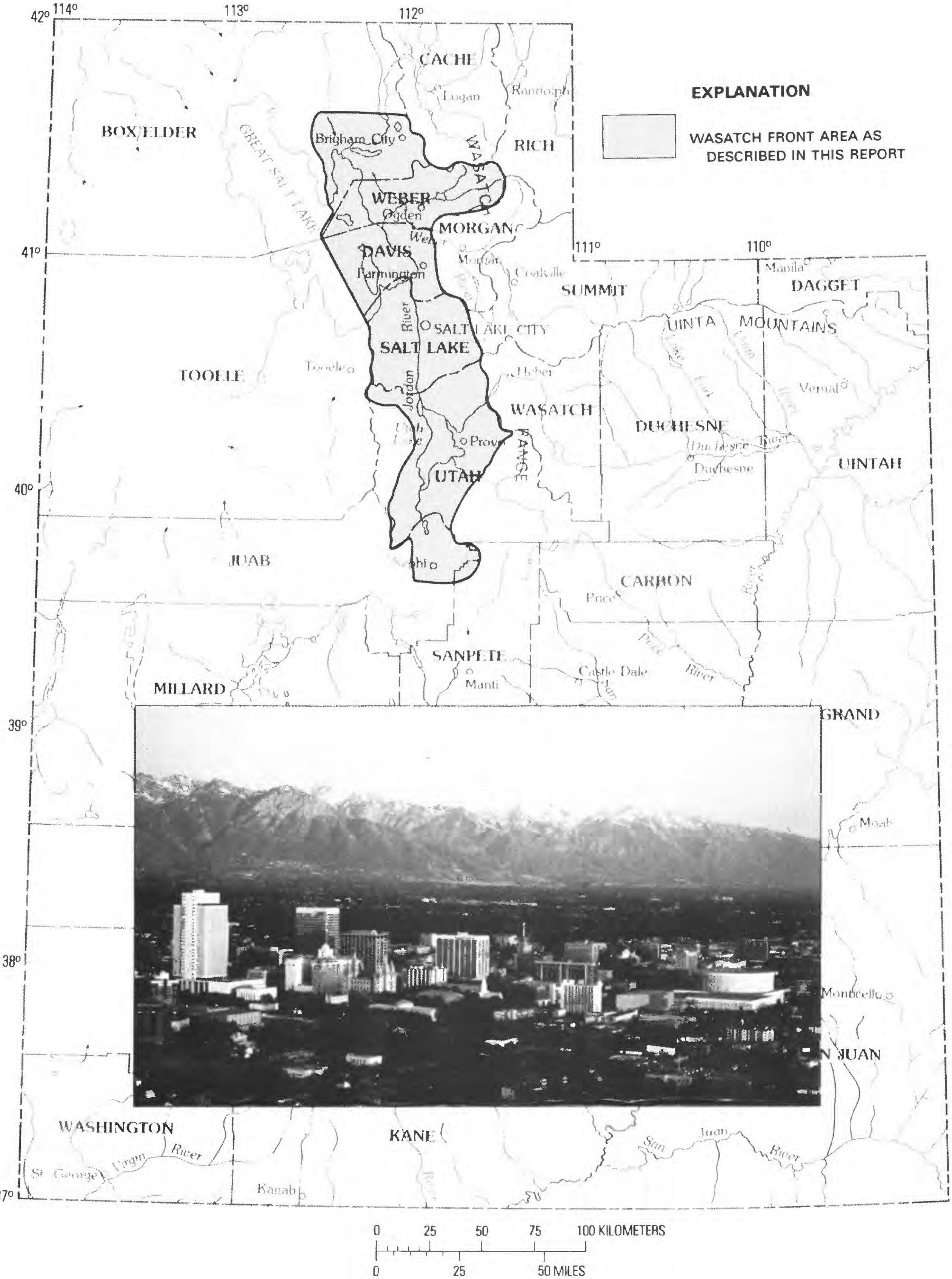
Utah's Urban Corridor

The Wasatch Front of Utah has no distinct formal boundaries. To some people, it is a narrow strip of land along the western foot of the Wasatch Range. To other people, it is a broad strip of land including the entire Wasatch Range and adjacent valleys to the west. To still others, it is a strip of land extending completely across the middle of Utah from Arizona to Idaho.

The Wasatch Front area as described in this report is that part of north-central Utah in and adjacent to the Wasatch Range that extends from the vicinity of Nephi on the south to the vicinity of Brigham City on the north. The eastern boundary of the area is along the crest of the Wasatch Range; the western boundary extends along the crests of the East Tintic and Oquirrh Mountains, across Great Salt Lake, and along the crest of the Promontory Mountains. The location of the Wasatch Front area is shown in figure 2, and some general physical features of the area are shown in figures 5, 6, 11, and 14. The 4,000-square-mile area includes all Davis, Salt Lake, and Weber Counties, most of Utah County, parts of Box Elder and Juab Counties, and a small uninhabited part of Sanpete County. In 1980, the area had a population of about 1.1 million, of which more than 50 percent resided in Salt Lake County (fig. 3). The principal population centers in the area are Salt Lake City, West Valley

Figure 2 (facing page). Location of the Wasatch Front area.

The Wasatch Front area as described in this report includes 4,000 square miles in north-central Utah. It contains about 77 percent of Utah's population. Salt Lake City (photograph) is the principal commercial center in the area. (Photograph courtesy of Salt Lake Valley Convention and Visitors Bureau.)


EXPLANATION
WASATCH FRONT AREA AS DESCRIBED IN THIS REPORT
42°
41°
40°
39°
38°
37°
114°
113°
112°
111°
110°
CACHE
Logan
BOX ELDER
Brigham City
GREAT SALT LAKE
RICH
WASATCH
WEBER
Ogden
MORGAN
Weber
DAVIS
Farmington
Morgan
Coalville
SUMMIT
Manila
DAGGET
UINTA MOUNTAINS
SALT LAKE CITY
SALT LAKE
Jordan River
TOOELE
Tooele
Heber
WASATCH
DUCHESNE
Duchesne River
Duchesne
Vernal
UINTAH
Utah Lake
Provo
RANGE
UTAH
Nephi
JUAB
CARBON
Price
SANPETE
Manti
Castle Dale
MILLARD
GRAND
Moab
Monticello
SAN JUAN
WASHINGTON
Virgin River
St. George
KANE
Kanab
San Juan River
0 25 50 75 100 KILOMETERS
0 25 50 MILES

City, Ogden, Provo, Orem, and Sandy; however, expanding urbanization has transformed a large part of the Wasatch Front into an "urban corridor." The urban character of the central part of the area is shown in figure 4.

The economy of the Wasatch Front area is very diversified. Agriculture, minerals mining and processing, manufacturing, and national defense are the major economic activities. Of major long-standing importance to the economy are the Kennecott Minerals Co. open-pit copper mine in the Oquirrh Mountains and that firm's ore-processing plants west of Salt Lake City, the U.S. Steel Corp. Geneva Steel Mill near Orem, and Hill Air Force Base near Ogden. Recreation and tourism also are important to the economy. The Salt Lake City area, in which Interstate Highways I-15 and I-80 intersect, is commonly referred to as "the crossroads of the west."

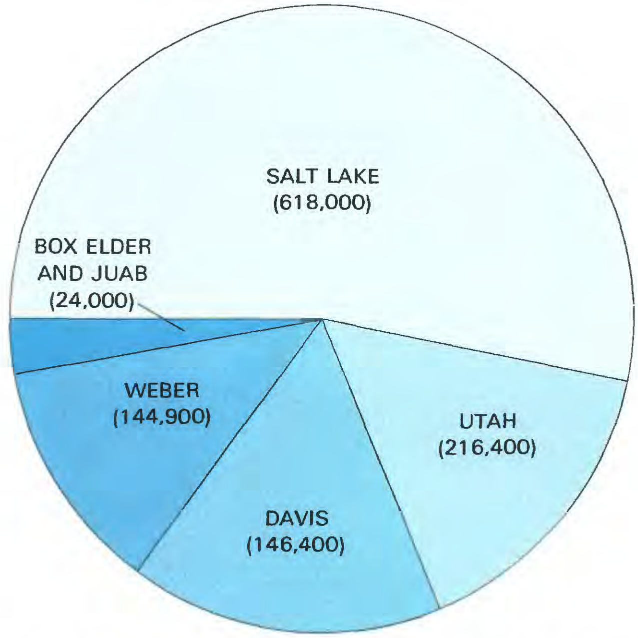


Figure 3. Distribution of 1980 population in the Wasatch Front area by county.

The graph represents the total population of Davis, Salt Lake, and Weber Counties (which are wholly in the Wasatch Front area) and the population of only those parts of Box Elder, Juab, and Utah Counties that are within the area. The numbers in parentheses are the estimated 1980 populations.

PHYSIOGRAPHIC SETTING AND DRAINAGE

Where Clear Mountain Streams Meet Desert Valley Floors

The Wasatch Front area is on the east edge of the Great Basin section of the Basin and Range physiographic province (Fenneman, 1946). The Basin and Range province, as the name implies, is a large region in the western United States that is occupied by a series of valleys or desert basins separated by mountain ranges. The mountain ranges, most of which trend north, were elevated by block faulting; and as they rose during geologic time, rock materials eroded from them were deposited in the adjacent valleys (as clay, silt, sand, gravel, and boulders). Those valleys of the Basin and Range province that lie in the Wasatch Front area include northern Juab, Goshen, Utah, and Salt Lake Valleys; they also include the lower Bear River valley (Bear River Bay area) and the area (East Shore area) between the Salt Lake Valley and the Bear River Bay area. Major mountain ranges of the province that lie wholly or partly in the Wasatch Front area include the Wasatch Range; the East Tintic, Lake, Traverse, Oquirrh, and Promontory Mountains; and Antelope Island (fig. 5). Some of the mountains have altitudes of more than 11,000 feet and rise more than 7,000 feet above the adjacent valley floor.

The Great Basin, as the name implies, is a large basin-like section of the Basin and Range province. It is topographically closed and has no surface drainage to the sea. All surface drainage and most subsurface drainage in this region is toward saline mudflats or lakes that occupy the lowest parts of many of the individual valleys. The largest of the saline lakes is Great Salt Lake, and all surface drainage in the Wasatch Front area directly or indirectly discharges to that lake. Water that reaches Great Salt Lake eventually evaporates. Only then, as water vapor, can it escape the Great Basin by natural means.

Surface drainage in the Wasatch Front area is by several relatively large perennial streams that originate outside the area and by numerous smaller streams that originate within the area. The streams that originate outside the area include the Bear, Weber, and Provo Rivers and Spanish Fork. The Bear and Weber Rivers drain directly to Great Salt Lake; the Provo River and Spanish Fork drain directly to Utah Lake, and ultimately to Great Salt Lake by way of the Jordan River.

Most of the perennial streams that originate in the Wasatch Front area have their sources in the Wasatch Range and are herein referred to as the Wasatch Front streams. The largest of these streams from north to south are: the Ogden River and Farmington,

Figure 4. The central part of the Wasatch Front area as seen from an orbiting satellite.

This ERTS (Earth Resources Technical Satellite) imagery taken in June 1981 shows the urban character of the central part of the Wasatch Front area (Utah's "Urban Corridor"). Before 1950, the large residential and business area between Salt Lake City and Provo was largely agricultural land, as was the densely populated area north of Salt Lake City.

North segment including Salt Lake Valley and the East Shore and Bear River Bay areas

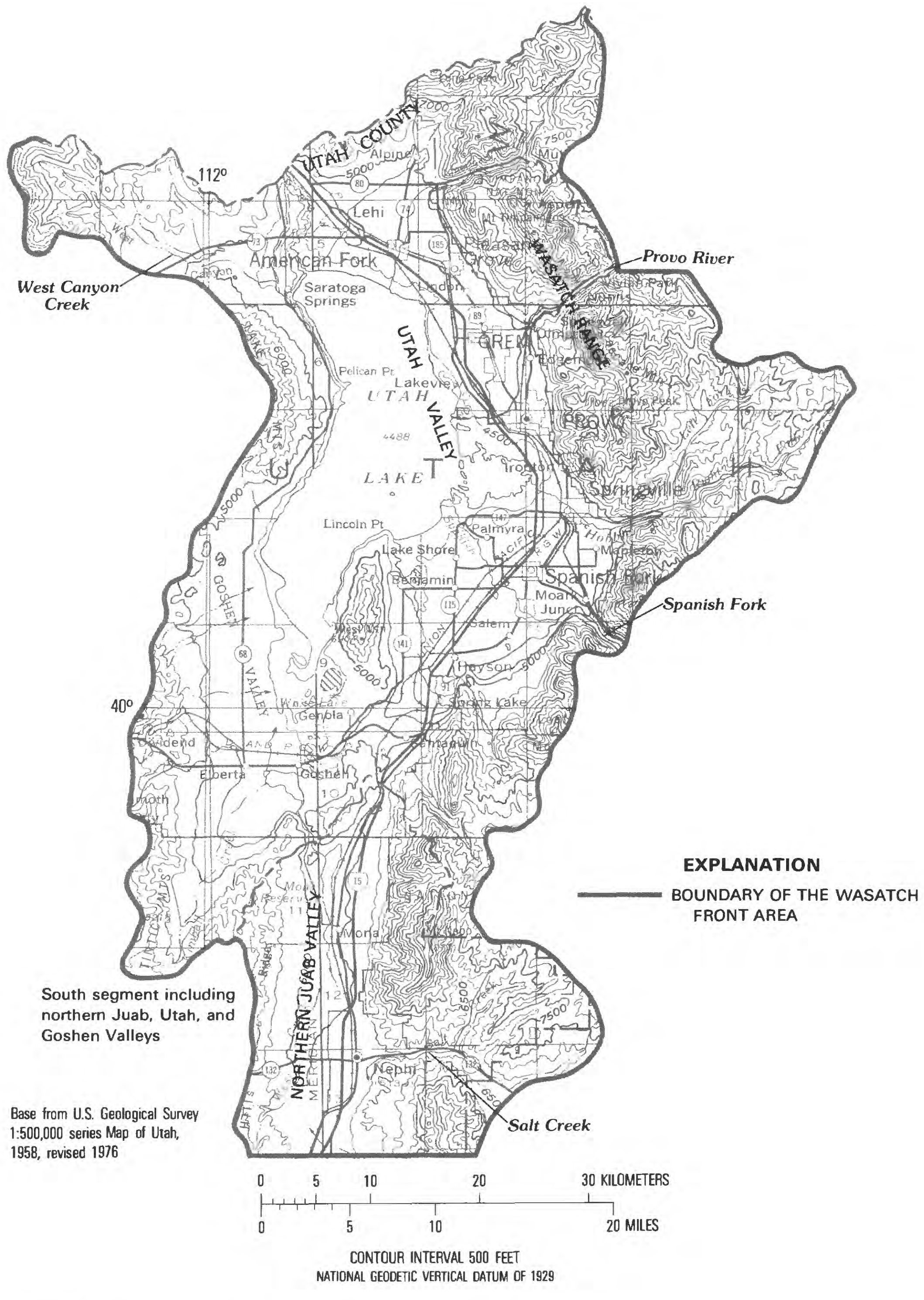
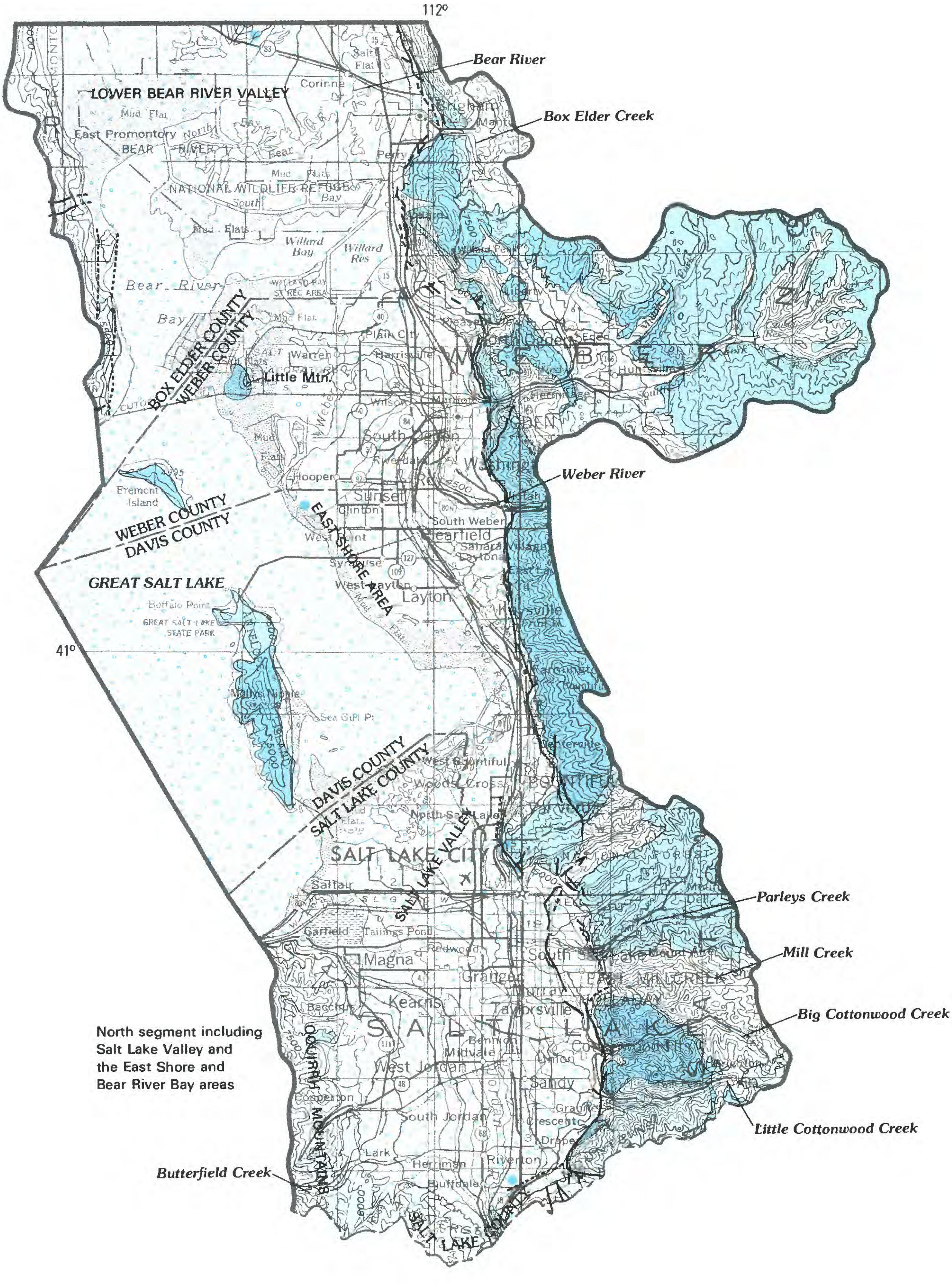


Figure 5 (above and facing page). Physiography and drainage.

Some peaks in the Wasatch Range have altitudes of more than 11,000 feet and rise more than 7,000 feet above the adjacent valley floor. The orographic effects of the mountains determine how precipitation (fig. 11) is distributed. All drainage in the area eventually reaches Great Salt Lake, a briny remnant of Pleistocene Lake Bonneville. (Map from U.S. Geological Survey relief map of Utah, 1958; 1976 revision.)



North segment including Salt Lake Valley and the East Shore and Bear River Bay areas

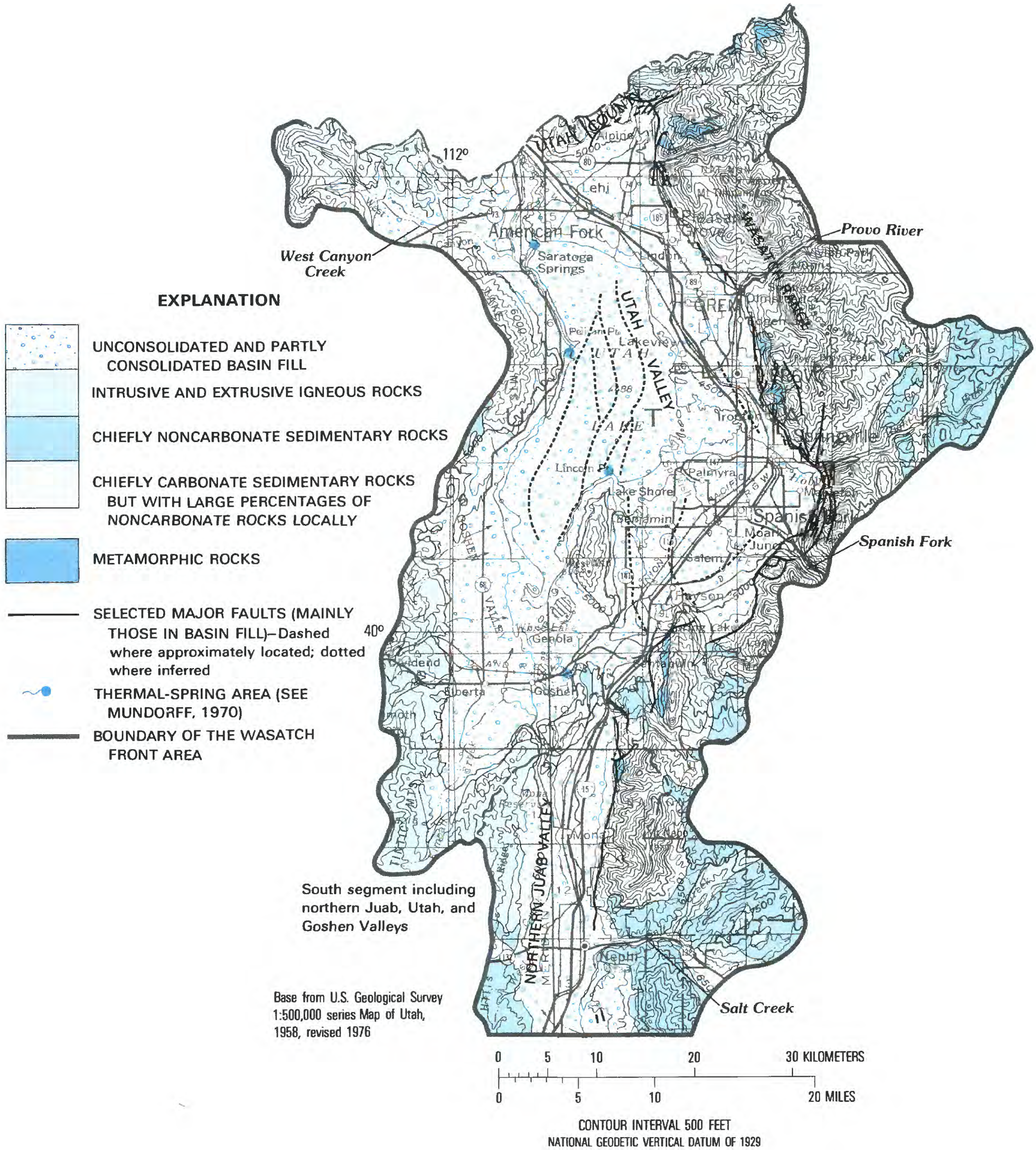


Figure 6 (above and facing page). General geology and thermal-spring areas.

Rocks ranging in age from Precambrian to Holocene underlie the area. Sedimentary, igneous, and metamorphic rocks underlie the mountains. Unconsolidated and partly consolidated deposits (basin fill) of clay, silt, sand, gravel, and boulders derived from the mountains underlie the valley floors. These deposits are the principal source of ground water in the area.

The thermal springs shown on this map probably are associated with faults—some of which have not been mapped. (Map compiled by Dale Wilberg, U.S. Geological Survey, from Hintze, 1980.)

Mill, Big Cottonwood, Little Cottonwood, and Hobble Creeks and American Fork. Several small perennial streams also originate in the mountains that border the Wasatch Front area on the west, including West Canyon and Butterfield Creeks, which originate in the Oquirrh Mountains. All the streams, including the intermittent ones (those that flow only part of the year), play a role in determining both the availability and chemical quality of ground water in the Wasatch Front area.

GEOLOGIC SETTING

The Vanished Inland Sea and the Ever-Present Escarpment

The Wasatch Front area has had a complex geologic history. The rocks that form the bulk of the Wasatch Range between Salt Lake City and Ogden (fig. 6) date all the way back to Precambrian time—more than 600 million years ago. This is also true of many of the rocks that form the walls of Big Cottonwood Canyon, southeast of Salt Lake City. These Precambrian rocks were subjected to tremendous heat and pressure (metamorphism) during geologic time; and they consist largely of schist, gneiss, and quartzite (metamorphic rocks)—the kind of rocks that unless badly fractured, absorb and transmit water very slowly.

In some parts of the Wasatch Range, the Precambrian rocks lie beneath younger sedimentary and igneous rocks. The sedimentary rocks (mostly 5 million to 500 million years old) consist chiefly of shale, sandstone, conglomerate, limestone, and dolomite. The shale, sandstone, and conglomerate (noncarbonate rocks) are most widely exposed in the mountains east of Salt Lake City; the limestones and dolomites (carbonate rocks) are widely exposed in the mountains east of Provo and in all the mountain ranges along the western boundary of the Wasatch Front area (fig. 6). Like the Precambrian metamorphic rocks, the ability of the sedimentary rocks to absorb and transmit water is dependent largely on how much they are fractured; or, in the case of carbonate rocks, how much the fractures have been enlarged by solution.

The geologic history of the Wasatch Front area includes several periods of igneous activity. The granite walls in Little Cottonwood Canyon east of Sandy are evidence of a large intrusion of magma (molten rock) in that area more than 25 million years ago. Lava flows and related igneous rocks, which are widely exposed in the East Tintic and Traverse Mountains, are evidence of volcanic activity that occurred throughout the region several million years ago. Some of the lava flows contain small cavities, formed by escaping gas when the rock was molten, through which water is easily transmitted. For the most part, however, these lava flows and the other igneous rocks depend largely on fractures to absorb and transmit water.

One of the more interesting episodes in the geologic history of the Wasatch Front area was the formation of Lake Bonneville during the most recent ice age of about 25,000 to 12,000 years ago. (See Gwynn, 1980, p. 81.) This large inland sea once spread over more than 19,700 square miles of western Utah and adjacent parts of Idaho and Nevada (fig. 7). The level of the lake rose and fell a number of times during its long history. At one time it rose to an altitude of about 5,200 feet (about 1,000 feet higher than the present level of Great Salt Lake) and spilled out of the Great Basin into the Snake River basin in southern Idaho. It then declined to an altitude of about 4,800 feet and remained there for a long time while the volume of water flowing into the lake was virtually balanced by the volume lost by evaporation. During the last several thousand years, however, the rate of evaporation from the lake exceeded the rate of inflow, the lake level progressively declined, and the once large body of fresh water was eventually reduced to the body of brine we know as Great Salt Lake.

Aside from Great Salt Lake, Lake Bonneville left many reminders of its existence. It left a number of terraces (like those shown in fig. 8) along the lower slopes of the Wasatch Range and other mountain ranges in the eastern Great Basin. It left numerous shoreline features, including sandy and pebbly beaches, spits, and bars. Of greater importance with regard to ground water, it left large quantities of clay, silt, sand, gravel, and boulders, which were transported into the lake by the swollen ice-age streams. The coarser grained deposits are important sources of water in the Wasatch Front area, and the finer grained deposits influence the occurrence and availability of the water.

The history of Lake Bonneville, this now vanished inland sea, has been studied and documented by many workers. One of the earliest and most complete documentations is that of Gilbert (1890)—regarded as a classic in the field of investigative geology.

Faulting and associated earthquake activity has always played a major role in the geologic history of the Wasatch Front area. As noted earlier in this report, block faulting elevated the Wasatch Range and other mountain ranges of the area. The rocks that form those mountain blocks have been complexly faulted and fractured during geologic time.

The Wasatch fault, along which the Wasatch Range was elevated, passes completely through the Wasatch Front area. It is an active fault, which together with a number of associated other active faults is collectively referred to as the Wasatch fault zone.

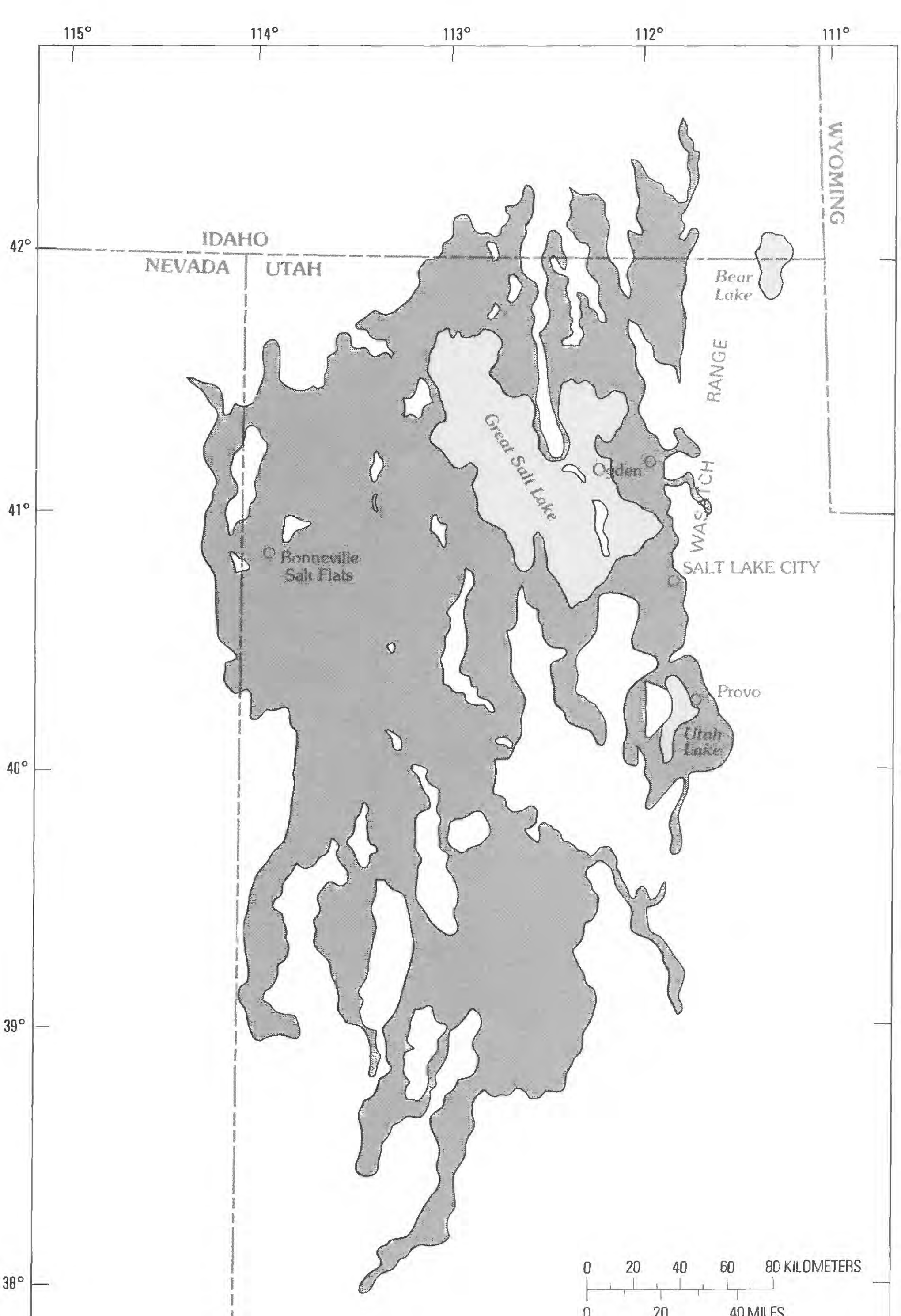


Figure 7. Approximate areal extent of Lake Bonneville.

This former inland sea (shaded area) existed during the latter part of the great ice age (Pleistocene Epoch), between about 25,000 and 12,000 years ago. It covered an area of more than 19,700 square miles, including the area now occupied by Great Salt Lake (one of its briny remnants), and was about 1,000 feet deep. Sand, gravel, and boulders deposited in the lake by swollen ice-age streams have become important sources of ground water in the Wasatch Front area. (Map from Keck and Hassibe, 1979.)

Figure 8. View of Little Mountain near Corinne showing terraces (benches) formed along the shore of Lake Bonneville as the lake surface remained at various levels.

Lakeshore deposits of permeable sand and gravel on terraces formed by Lake Bonneville readily absorb and transmit rainfall, melting snow, and irrigation water to the underlying ground-water bodies. The Wasatch Range is shown in the background. (Photograph by Robert Miller, U.S. Geological Survey.)

Several of the known and inferred faults in the Wasatch fault zone are shown in figure 6. A sobering reminder of the presence of this fault zone is the steep escarpment that forms the western edge of the Wasatch Range—that is, the Wasatch Front. Other reminders are the occasional shaking of the earth due to local movement along the fault zone and associated thermal springs scattered throughout the area. Water discharging at these springs rises from great depths along passageways in the fault zone. Municipal water-supply-treatment plants and reservoirs in the Wasatch Front area are within the Wasatch fault zone, and many of the water-supply pipelines cross the fault zone.

THE HYDROLOGIC SYSTEM

Variability of the Water Supply is Reflected in the Ever-Changing Level of Great Salt Lake

The hydrologic system in the Wasatch Front area is shown diagrammatically in figure 9. Water entering the area comes almost entirely from precipitation and as both natural surface inflows and manmade imports (in the Bear, Weber, Provo, and Spanish Fork river systems). Although some springflow is imported into the Salt Lake Valley from Tooele Valley, inflows and imports of ground water are negligible compared

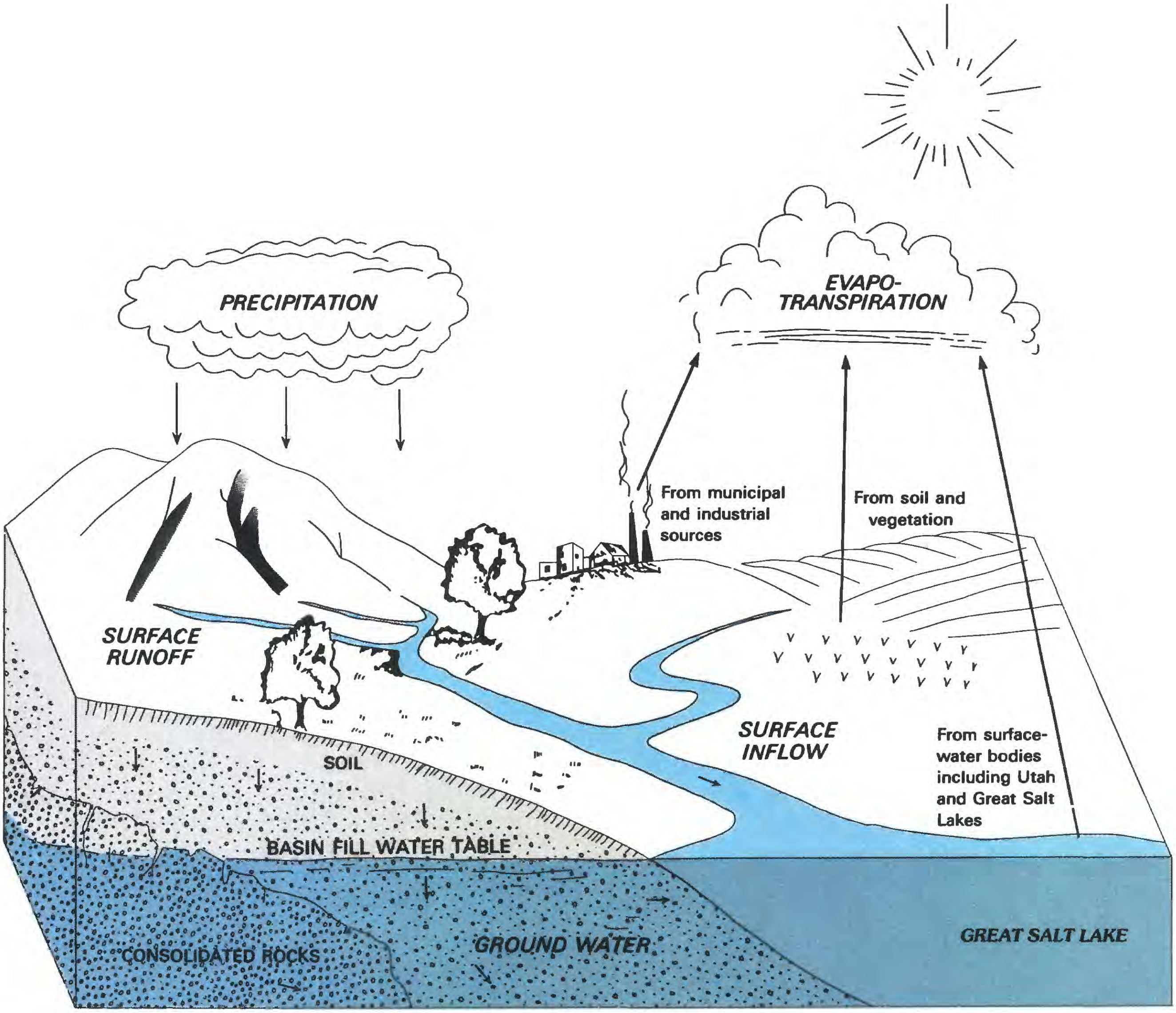


Figure 9. Principal components of the hydrologic system in the Wasatch Front area.

The principal sources of water are precipitation that falls on the area (chiefly as snow in the mountain watersheds) and surface inflows (and imports) from the Bear, Weber, Provo, and Spanish Fork river systems. Average annual precipitation on the area is estimated to be about 4 million acre-feet; average annual inflow is about 1.9 million acre-feet. Because there is no surface outflow, virtually all water leaves the area by evapotranspiration. (Diagram modified from Utah State University and Utah Water and Power Board, 1963, fig. 1.)

to the total supply. Because the Wasatch Front area is in a topographically closed basin, water leaves the area almost entirely by evapotranspiration—that is, the combined effect of direct evaporation and transpiration by vegetation. There are no surface exports and ground-water outflow probably is negligible.

The water supply for the Wasatch Front area varies considerably both annually and over the long term, depending chiefly on the variability of precipitation in the eastern Great Basin. The variation in supply is reflected in fluctuations of the level of Great Salt Lake (fig. 10). The declining levels of the lake indicate that the inflow was insufficient to offset evaporation and that there probably was a smaller than average water supply for the Wasatch Front area. Rising levels of the lake indicate that evaporation was insufficient to

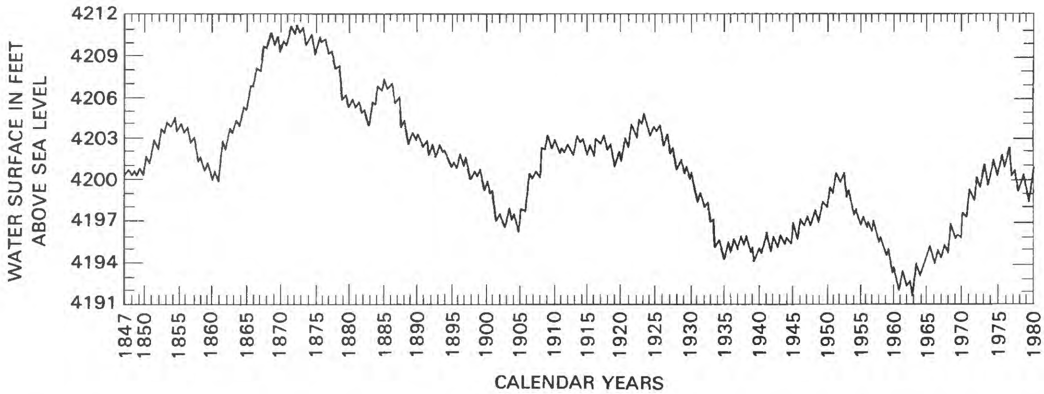


Figure 10. Fluctuations of the level of Great Salt Lake.

Most of the water that flows into Great Salt Lake passes through the Wasatch Front area: therefore, fluctuations of the lake level reflect the volume of water available to the area. The declining levels reflect major dry periods, such as that of the 1930's—which also was a period of accelerated ground-water development in the Wasatch Front area. (Photograph courtesy of Salt Lake Valley Convention and Visitors Bureau.)

offset inflow and that there was a larger than average water supply for the area. The lowest recorded level of the lake in 1963 followed several years of less than average precipitation and runoff in the Wasatch Front area and surrounding region.

PRECIPITATION AND LOCAL RUNOFF

Importance of the Mountain Snowpack

Precipitation varies considerably throughout the Wasatch Front area, generally increasing with altitude. As indicated in figure 11, average annual precipitation varies from less than 10 inches on parts of Utah Lake and Great Salt Lake to more than 40 inches in some high parts of the Wasatch Range. The annual precipitation on the Wasatch Front area is estimated to total about 4 million acre-feet.[1] Precipitation on the area also varies considerably with time. There are wet years and dry years, wet seasons and dry seasons, and long periods when the overall precipitation is greater than or less than the average. During 1875-1980, for example, total annual precipitation at Salt Lake City ranged from about 10 to 23 inches. Total annual precipitation (1931-80) as recorded at the Salt Lake City International Airport and near Brighton is shown in figure 12.

An estimated 70 percent of the annual precipitation in the Wasatch Front area falls from October through April, when the area is chiefly under the influence of frontal-type storms that move across the country from west to east. Most of this October-through-April precipitation is snow, which is the main source of streamflow during the late spring and early summer (figs. 13 and 14). During wet years, the mountain

[1]The acre-foot is a common unit used for measuring volume of water. One acre-foot of water is the volume of water than can cover 1 acre of land 1 foot deep. It is equal to 43,560 cubic feet or 325,900 gallons.

snowpack accumulates to depths of more than 100 inches, skiing is great, and there is average or greater than average streamflow for irrigation, public supply, wildlife, and other uses. During dry years, the mountain snowpack may not accumulate to 100 inches; skiing is not so great, and streamflow available for use may be significantly less than average. During both wet and dry years, however, the ground-water system is replenished by seepage from the snowmelt and the streamflow it sustains.

The Wasatch Front area receives relatively little precipitation during the summer. The precipitation received commonly results from localized convection-type storms (thunderstorms) which move into the area from the south. Those storms, although they produce torrential rains, contribute little to the water supply of the area because they are usually of small areal extent and generally not more than an hour or so in duration. They do, however, tend to decrease the demand for water for irrigation and lawn watering.

SURFACE INFLOWS AND IMPORTS

They Also Affect Ground Water

Total annual inflow and import to the Wasatch Front area is estimated to be about 2 million acre-feet, with more than one-half coming from the Bear River system. The Wasatch Front area could not have reached its present (1982) level of economic growth without this water. The importance of those inflows and imports on the ground-water system are not quite as apparent, but diversion and use of the water doubtless has affected the availability and the chemical quality of the ground water. These effects are due chiefly to diversions of streamflow for irrigation, but also are due locally to other activities, such as fluid-waste disposal, based on use of surface water. The changes are discussed in later sections of this report.

GROUND WATER

Where Geology Becomes An Important Controlling Factor

Water occurs at some depth in virtually all the rocks that underlie the Wasatch Front area. The sources of this ground water, the rocks in which it occurs and moves, and the means by which it is discharged from the rocks are all part of the ground-water system. Rocks that transmit water with relative ease have relatively large permeability and may be referred to as aquifers. Those rocks that restrict the flow of ground water have relatively small permeability and may be referred to as confining beds. They restrict the movement of water from one aquifer to another. The various types of aquifers, their relation to the confining beds, and general features of the ground-water system in the Wasatch Front area are shown diagrammatically in figure 15.

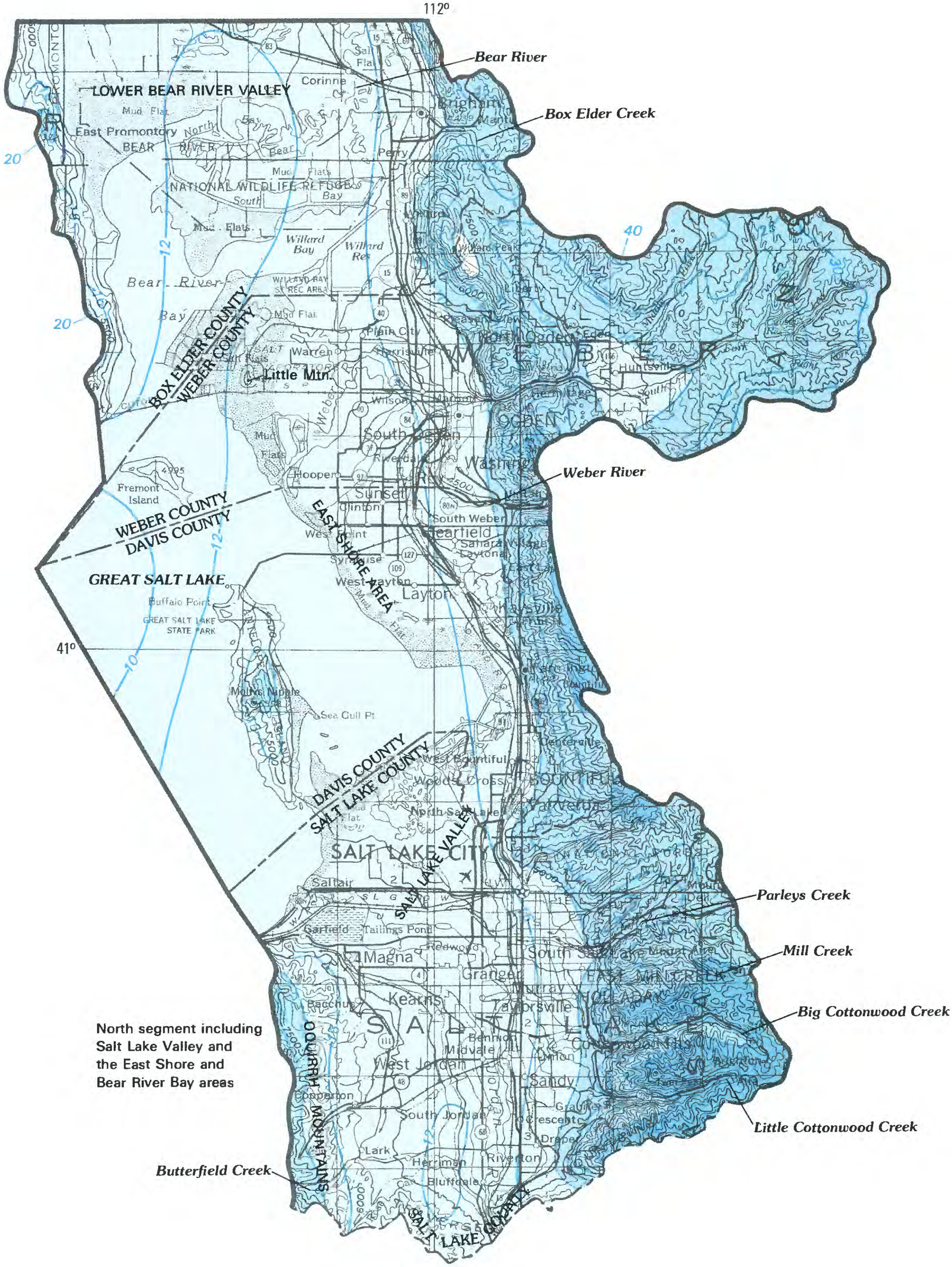
Water in the groundwater system is continuously affected by geologic conditions. The ease with which the water can enter and seep through the rocks depends greatly on the permeability of these rocks; the direction in and depth to which the water seeps are affected by the structural deformation and fracturing of the rocks; and the chemical quality of the water is affected by the mineral composition of the rocks. Geologic conditions vary considerably throughout the Wasatch Front area; consequently, ground-water occurrence, movement, quality, and availability also vary considerably. Major rock units exposed in the area are shown in figure 6 and the general water-bearing properties of those units are summarized in the table on page 22.

WATER IN CONSOLIDATED ROCKS

It Is There, but Not Easy to Find, or Withdraw by Wells

Consolidated rocks of Precambrian to Tertiary age, which form the Wasatch Range and other mountain ranges in the Wasatch Front area, yield water chiefly through complex systems of fractures, joints, solution cavities, fault zones, and vesicles. These water-bearing zones, which are not present at all locations, are difficult to find and delineate. In addition, drilling wells in consolidated rocks commonly is difficult because the rocks are hard and the terrain can be steep. Wells in consolidated rocks also commonly have small yields, and the depth to the saturated zone can be great. Consequently, the consolidated rocks in the Wasatch Front area are not considered to be favorable sources of water for withdrawal from wells. As a unit, however, they do absorb, store, and transmit large volumes of water.

The consolidated rocks receive water (recharge) chiefly by seepage of rain and melting snow and by seepage from some stream reaches (losing reaches) in the mountains. The rocks discharge water naturally through numerous mountain springs, by seepage to some stream reaches (gaining reaches), by seepage to



North segment including Salt Lake Valley and the East Shore and Bear River Bay areas

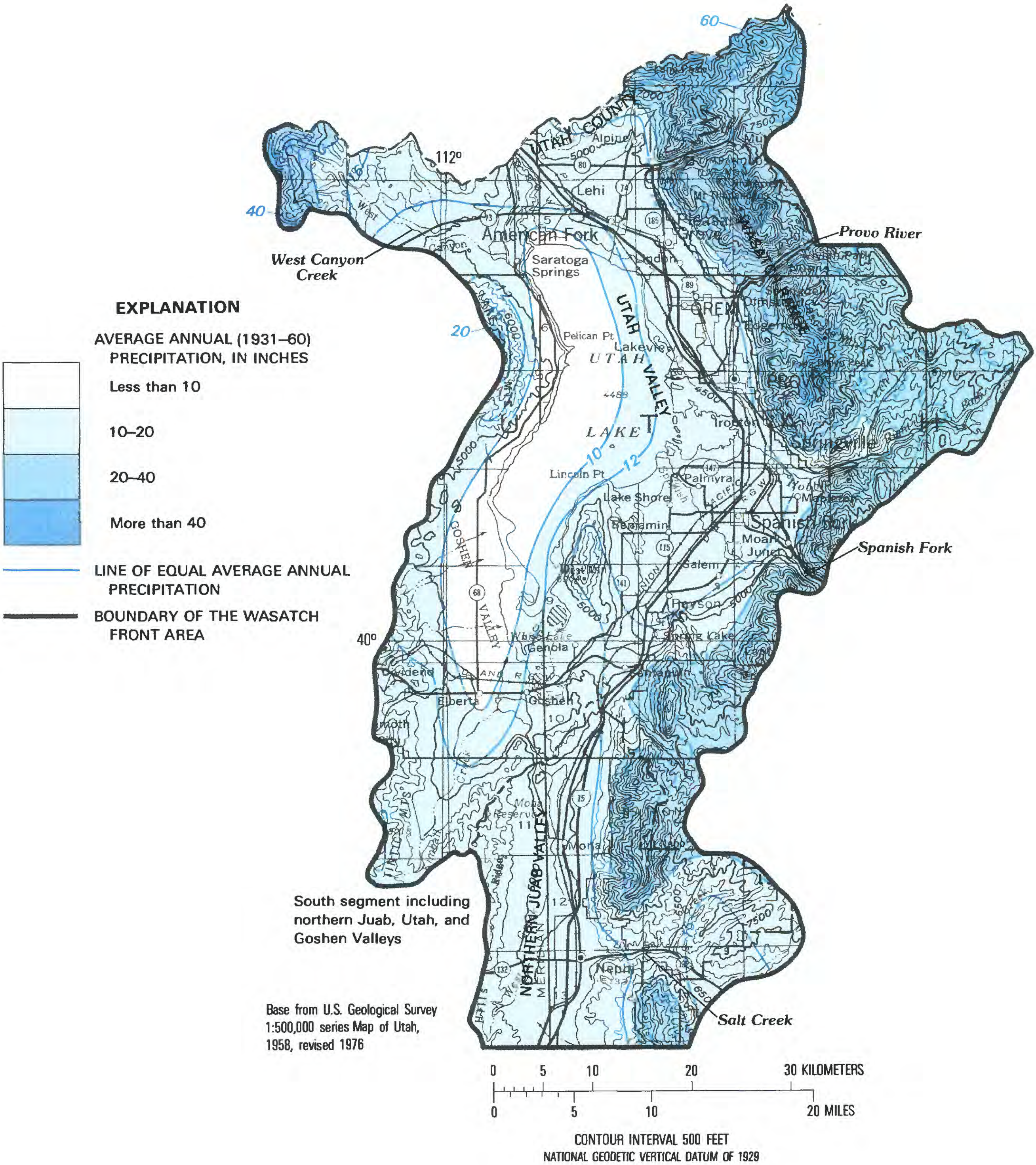


Figure 11 (above and facing page). Average annual precipitation.

Average annual precipitation varies from less than 10 inches on the western part of Great Salt Lake and the Utah Lake area to more than 40 inches in the mountains near Alta; it totals more than 4 million acre-feet. About 70 percent of the annual precipitation falls during October–April, and the resulting mountain snowpack provides valuable runoff during the dry summer months. (Map compiled from U.S. Weather Bureau, 1963.)

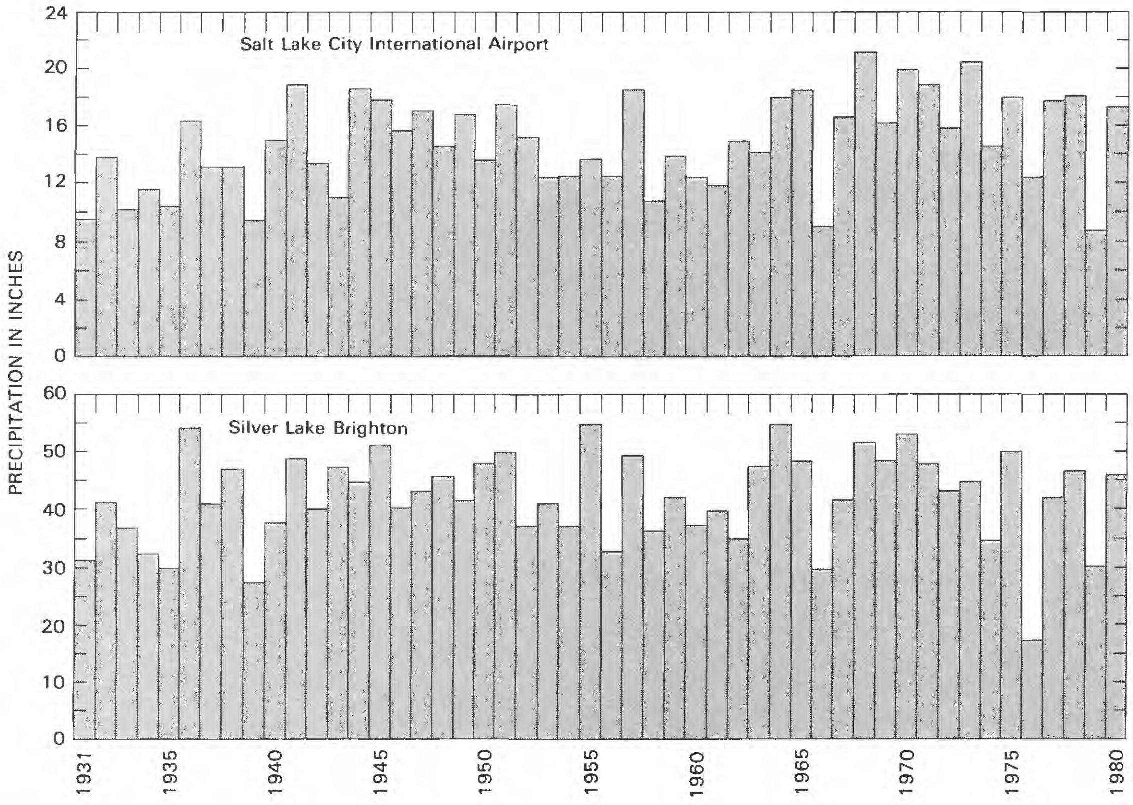


Figure 12. Annual precipitation near Brighton and at the Salt Lake City International Airport.

Most of the precipitation falls as snow during October–April. The snowpack that accumulates in mountainous areas, such as near Brighton, is an important tourist attraction for skiing and other winter recreation. It also provides valuable surface runoff (and ground water) for the Wasatch Front area. (Photograph courtesy of Salt Lake Valley Convention and Visitors Bureau.)

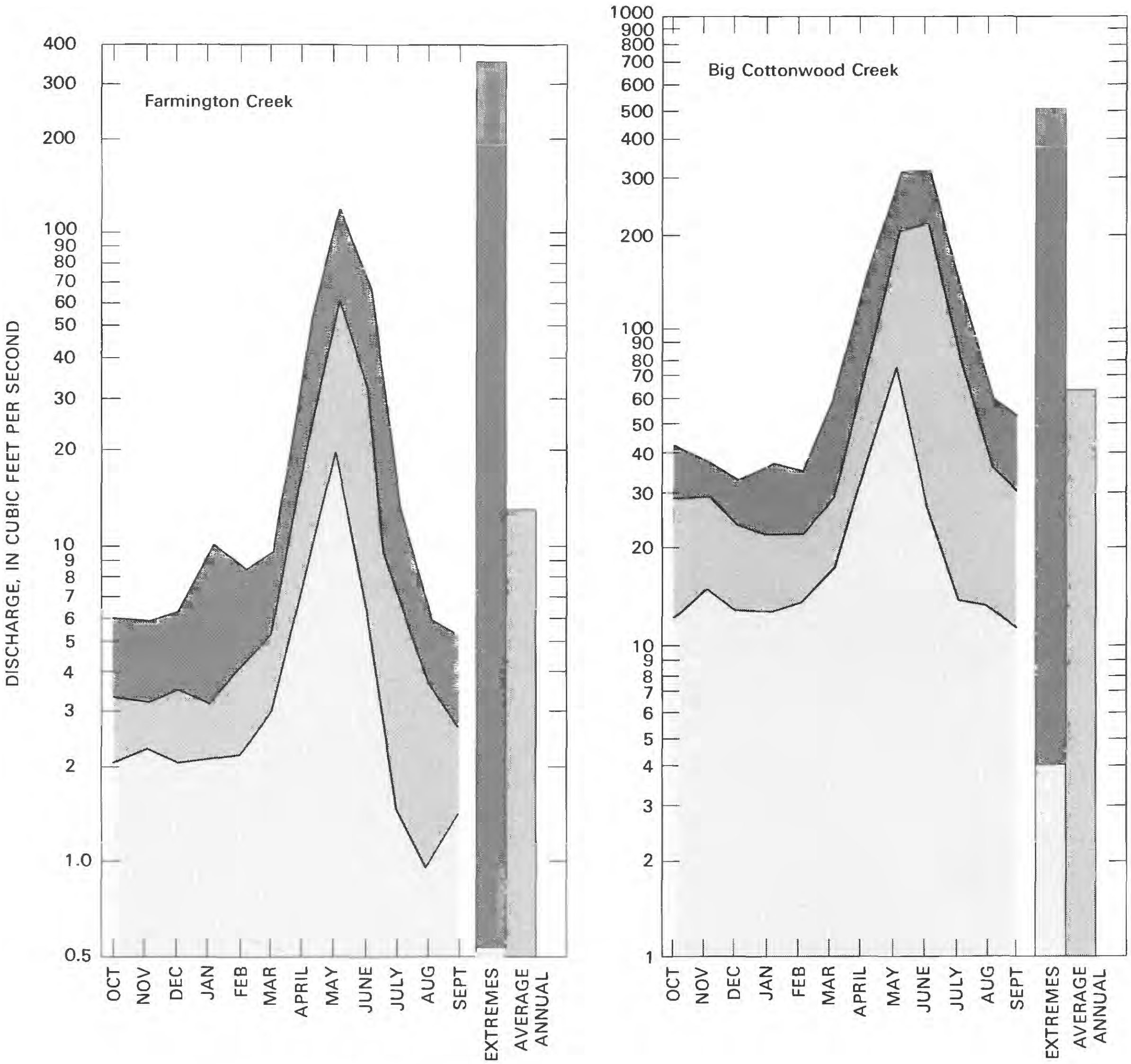
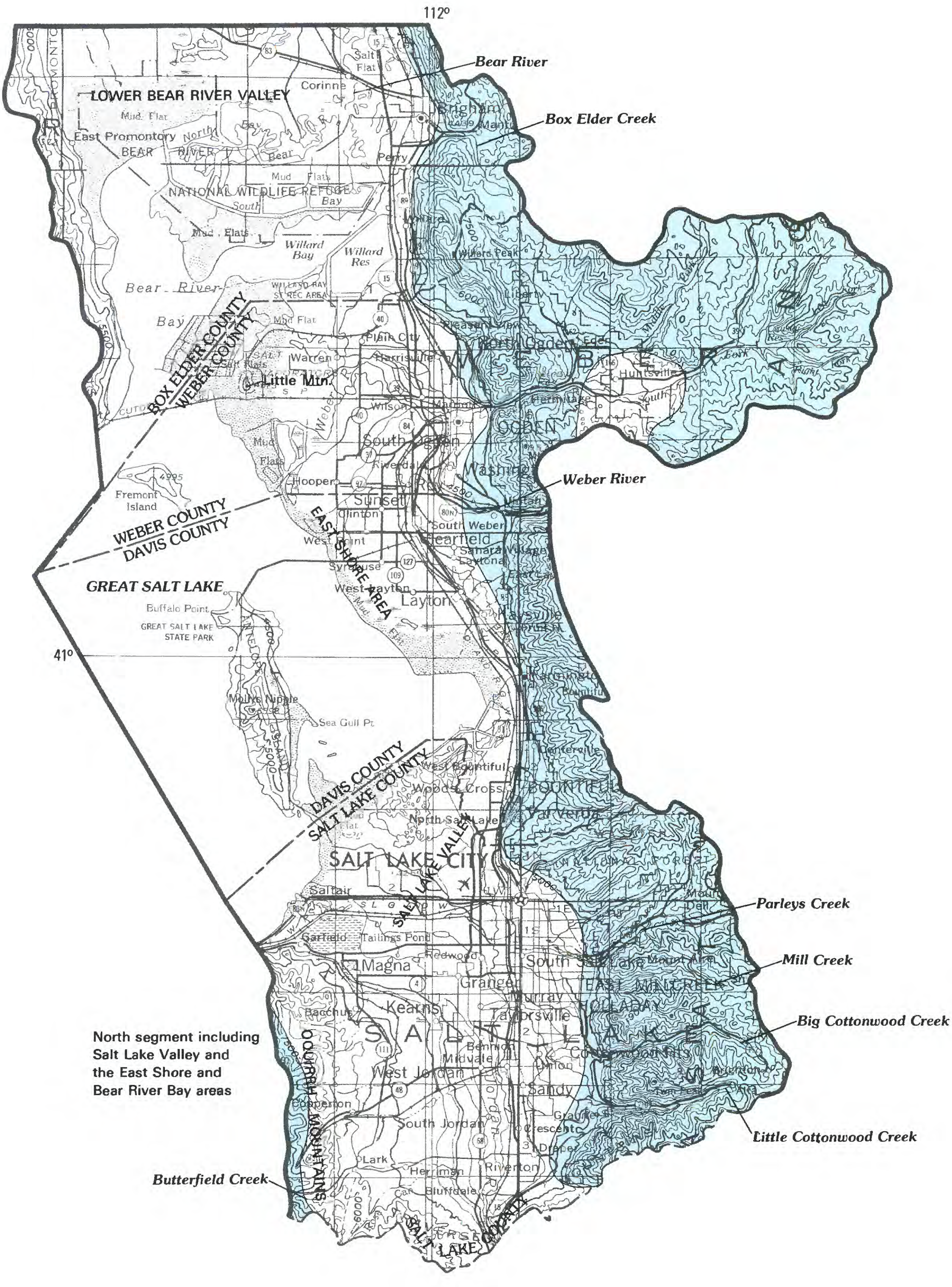


Figure 13. Runoff characteristics of two Wasatch Front streams.

As indicated by the two graphs, the period of peak runoff along the Wasatch Front is May and June. Runoff during these months is chiefly in response to melting of the winter's snowpack. By late summer, daily discharges of many of the streams, such as Farmington Creek, decrease to less than a cubic foot per second; some cease to flow. Photograph (by George Pepper, U.S. Geological Survey) shows a streamflow gaging station near the mouth of Big Cottonwood Creek Canyon.


112°
41°
Bear River
Box Elder Creek
Weber River
Parleys Creek
Mill Creek
Big Cottonwood Creek
Little Cottonwood Creek
Butterfield Creek
LOWER BEAR RIVER VALLEY
BOX ELDER COUNTY
WEBER COUNTY
WEBER COUNTY
DAVIS COUNTY
DAVIS COUNTY
SALT LAKE COUNTY
GREAT SALT LAKE
EAST SHORE AREA
SALT LAKE VALLEY
OQUIRRH MOUNTAINS
North segment including
Salt Lake Valley and
the East Shore and
Bear River Bay areas

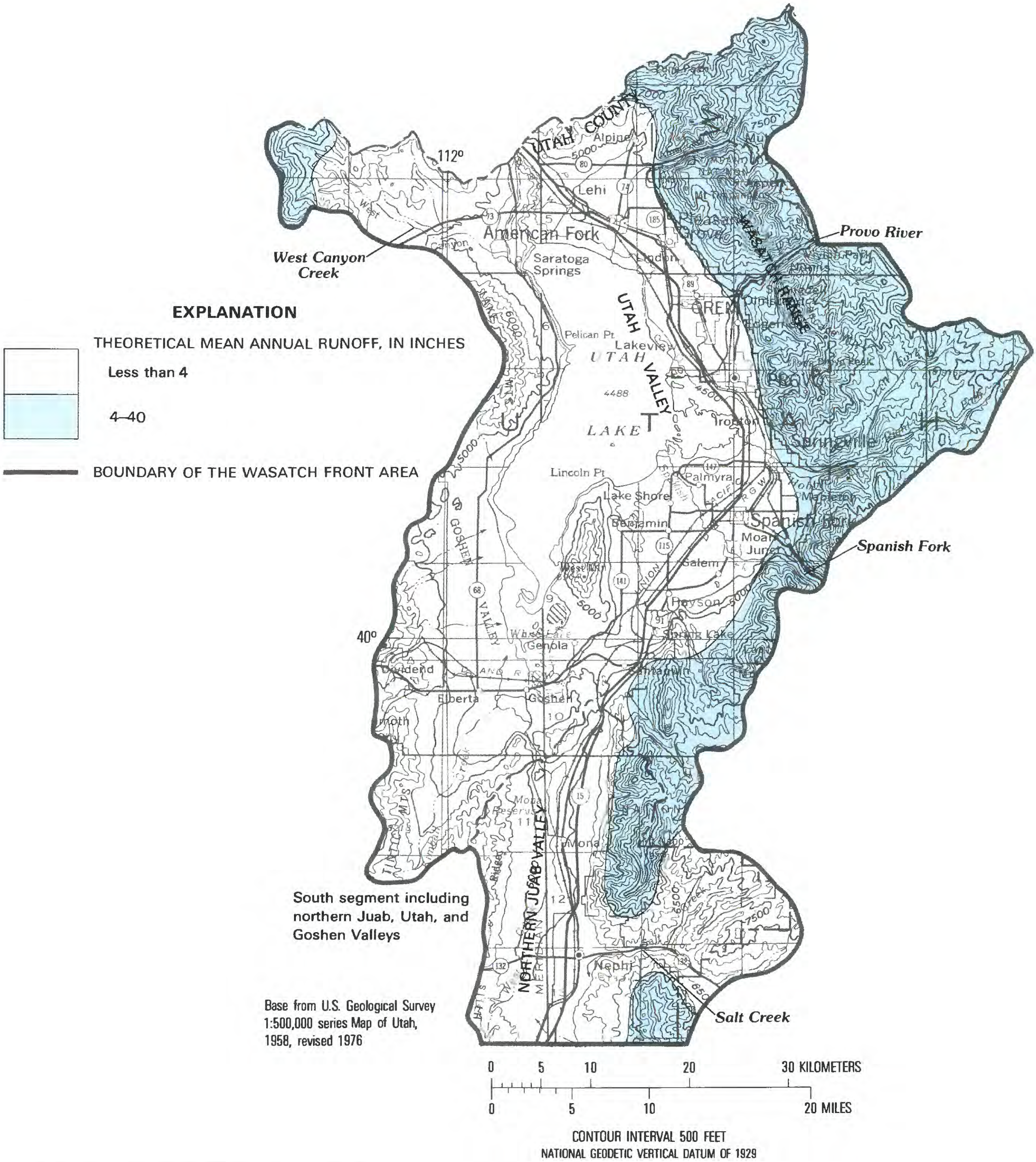


Figure 14 (above and facing page). Principal runoff-producing areas.

The Wasatch Range produces most of the runoff in the area. Theoretical mean annual runoff from most mountain areas ranges from 4 to 40 inches (about 215 to 2,135 acre-feet per square mile). Some of that runoff seeps underground and helps to replenish the ground-water supply. (Map adapted from Bagley and others, 1964, fig. 16.)

Rock unit[1] (Number corresponds to number in fig. 6)	Dominant rock type	General water-bearing properties
1. Unconsolidated and partly consolidated basin fill	Clay, silt, sand, gravel, and boulders; mostly stratified but locally intermixed	Clay, silt, and very fine sand transmit water slowly; coarser-grained fill transmits water readily and is the principal source of ground water for withdrawal from wells in the Wasatch Front area.
2. Intrusive and extrusive igneous rocks	Mostly granitic rocks east of Sandy; mostly lava flows, tuffs, and breccias in other areas.	Granitic rocks absorb and transmit water slowly, as do most tuffs and breccias; some vesicular lava flows transmit water readily—especially where jointed and fractured.
3. Clastic sedimentary rocks	Mostly shale, siltstone, sandstone, and conglomerate (cemented gravel); includes some quartzite.	Shale and siltstone transmit water slowly; sandstone and conglomerate where fractured transmit water readily.
4. Carbonate sedimentary rocks	Mostly limestone and dolomite.	Generally transmit water slowly; but where fractured contain and transmit large amounts of water, especially where the fractures have been enlarged by solution of the rock. The source of most large springs in consolidated rock in the Wasatch Front area.
5. Metamorphic rocks	Mostly schist, gneiss, and quartzite.	Absorb and transmit water slowly, except locally where shattered (especially the quartzite) by fracturing.

[1]The units are groupings of many geologic formations on the basis of their relative water-bearing properties. The reader interested in more detailed geologic mapping of individual formations is referred to Hintze (1980).

basin fill and fractured zones along the mountain fronts, and by evapotranspiration. They also discharge some water to mine workings and to wells in several areas. Most of the wells that obtain water from the consolidated rocks are used for domestic supply and produce only a few gallons of water per minute. Some of the springs that discharge from these rocks (especially carbonate rocks), however, produce several hundred to more than 1,000 gallons per minute.

WATER IN BASIN FILL

The Principal GroundWater Reservoirs

Unconsolidated and partly consolidated basin fill (chiefly alluvial, glacial, and lake deposits) in the Wasatch Front valleys contains most of the water available for withdrawal from wells. This fill, of Tertiary and Quaternary age, consists chiefly of interbedded clay, silt, sand, and gravel and local intermixes of those materials and boulders. Most of the fill was derived from adjacent mountains as those mountains were being elevated by block faulting. The coarser materials are predominant near the mountains (as shown in fig. 15), whereas the finer materials are predominant in the lower valley areas (including the area beneath Great Salt Lake). Maximum thickness of the fill exceeds 6,000 feet; and in parts of the lower valley areas, the fill is saturated to the land surface. Where the fill is saturated, the intergranular spaces are completely filled with water (fig. 15). The water is more uniformly distributed; thus it is easier to find, evaluate, develop, and manage than is the water in the consolidated rocks.

Although the fill consists of both Tertiary and Quaternary deposits, the deposits of Quaternary age, being more loosely packed and less cemented, contain more intergranular space. Therefore, these deposits generally are more permeable and transmit water more readily than do the deposits of Tertiary age. Saturated deposits of Quaternary Age are more than 200 feet

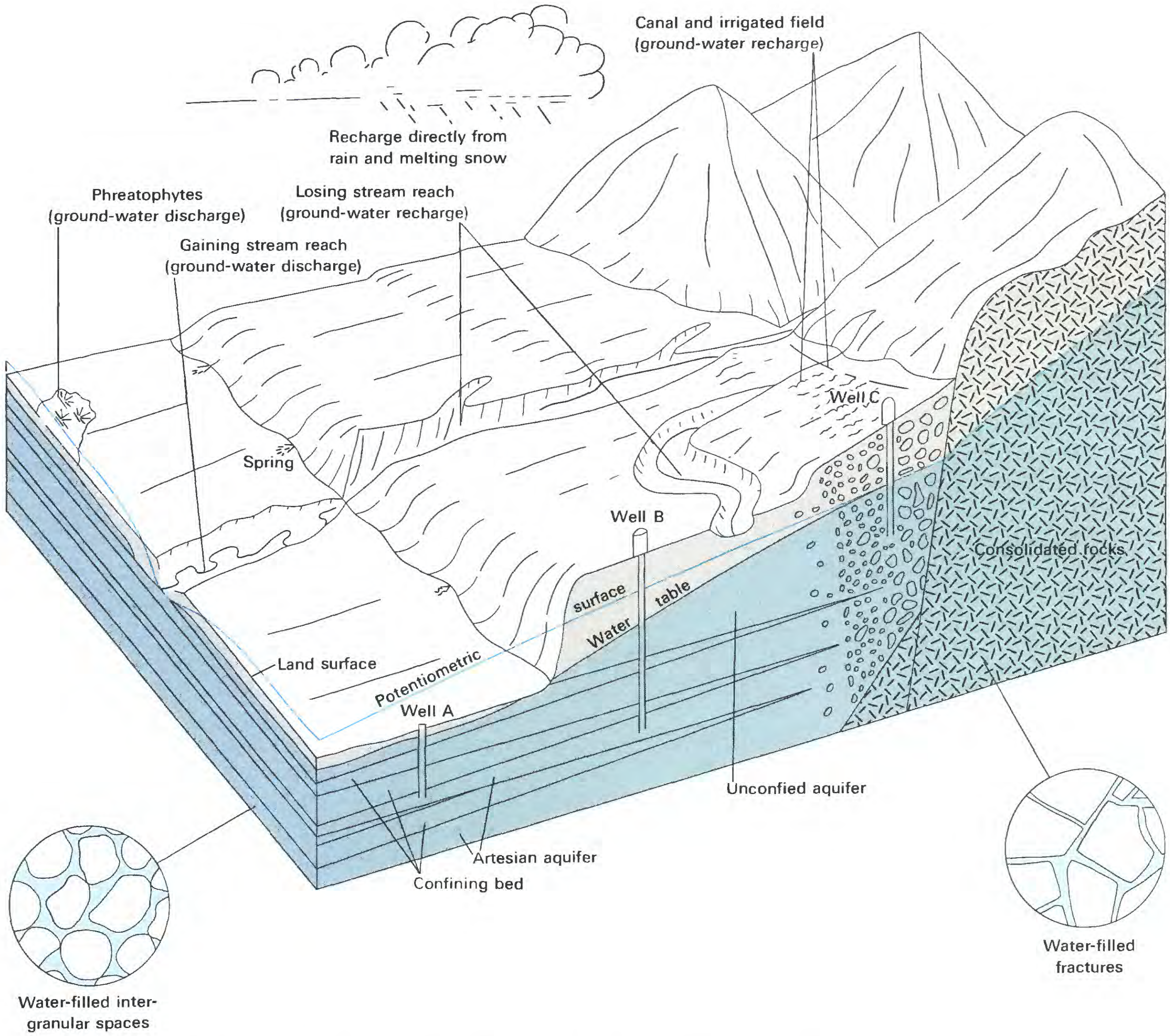


Figure 15. General features of the ground-water system in the Wasatch Front area.

Water occurs in virtually all the rocks that underlie the area. It fills intergranular spaces in the unconsolidated and partly consolidated fill (basin fill) of the valleys, and it moves chiefly in fractures, faults, and solution openings in the consolidated rocks of the mountains. The character of the consolidated rocks and the unconsolidated fill affects the occurrence, movement, availability, and quality of the water. Well A (capped) and well B in the diagram obtain water from artesian aquifers, and well C obtains water from an unconfined aquifer. The water level in those wells is the level of the potentiometric surface; thus well A, if uncapped, would flow under artesian pressure whereas wells B and C need to be pumped. (Diagram modified from Arnow, 1965).

thick throughout most of the Wasatch Front area; according to Hely and others (1971, fig. 64), they exceed 2,200 feet in thickness in the lower part of the Salt Lake Valley.

Water in the basin fill occurs under a variety of conditions. Near the mountains, the water is unconfined under water-table conditions, and the permeable deposits in which it occurs are called unconfined aquifers. The level at which water will stand in a well that is completed in an unconfined aquifer is the water table or the potentiometric surface of the unconfined water. As the water seeps from recharge areas downgradient to discharge areas, much of it becomes confined under artesian pressure in relatively coarse-grained permeable strata (confined aquifers) beneath fine-grained less permeable strata (confining beds). The level to which water will rise in a well that is completed in a confined aquifer is the artesian head or the potentiometric surface of the confined water.

At several places in the Wasatch Front area, especially near the mountains, saturated discontinuous strata of sand and gravel lie above the water table. These strata are referred to as perched aquifers, and the water they contain is referred to as perched ground water. Similarly, shallow unconfined ground water, derived chiefly from deeper artesian aquifers (as upward leakage through confining beds), and irrigation, occurs in the lowermost parts of the valleys. Although these sources of ground water are important to the ground-water system as a whole, they generally are not considered as adequate or favorable (from the standpoint of chemical quality) sources for large-scale withdrawal from wells. Most of the information given here is for the deeper unconfined and confined ground water.

In this report, the saturated fill (excluding the local perched water) in a given valley is referred to as the principal ground-water reservoir. Five such reservoirs are in the Wasatch Front area, and although hydrologically interconnected to some degree, they are considered to be separate units. They are the ground-water reservoirs in northern Juab Valley, Utah and Goshen Valleys, Salt Lake Valley, the Bear River Bay area, and the East Shore area (the valley area east of Great Salt Lake). Approximate boundaries of these reservoirs are shown in figure 16. All but the ground-water reservoir in the Bear River Bay area lie wholly within the Wasatch Front area. The groundwater reservoir in the Bear River Bay area is part of a larger ground-water reservoir (the lower Bear River valley) which extends northward into Idaho. (See Bjorklund and McGreevy, 1974.)

One of the most important properties of the principal ground-water reservoirs is the variation of transmissivity[2] of the basin fill that forms the reservoirs. Yields of wells depend on the transmissivity of the basin fill in which the wells are completed—in general, the greater the transmissivity, the more water the wells can yield. Transmissivity of the principal ground-water reservoirs varies considerably from place to place, but it generally is greatest near the mountains where the valley fill is coarsest. Areas in which the transmissivity of the valley fill of the principal ground-water reservoirs generally exceeds 10,000 feet squared per day (locally 50,000 feet squared per day) are shown in figures 17-21. Within those areas, yields of properly constructed large-diameter wells can exceed 1,000 gallons per minute.

GROUND-WATER STORAGE

The Time-Limited Ground-Water Supply

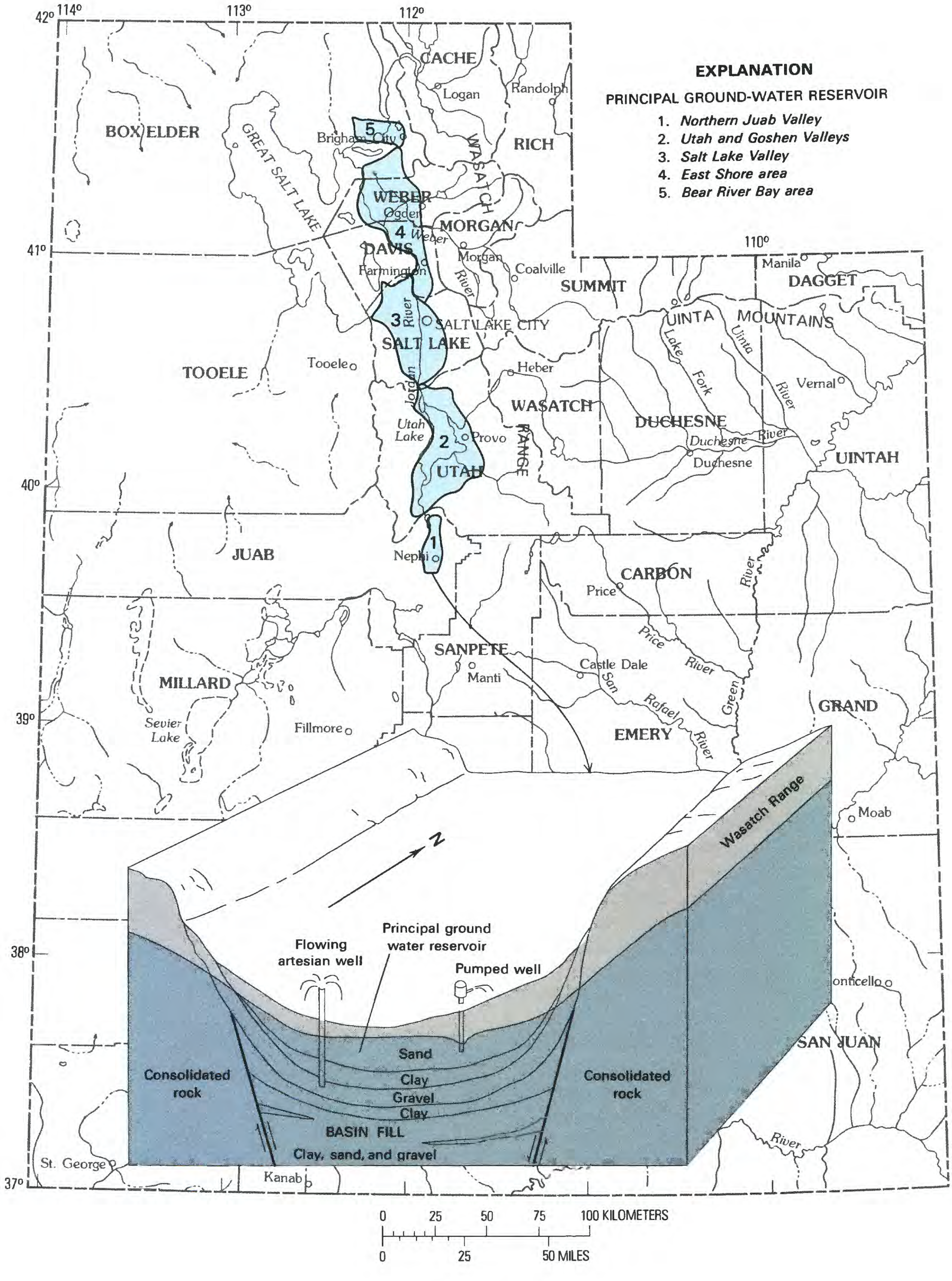
The principal ground-water reservoir in each valley contains large quantities of water in storage. Some of the stored water cannot be withdrawn by wells because it is held in place by forces and processes such as the surface tension of the water and adsorption of the water on the grains that comprise the basin fill. Some of the water is not available because of economic reasons. For example, the water may be too deep to pump or too salty to demineralize under prevailing economic conditions. Nevertheless, the volume of water that can be economically recovered under present (1982) technological and economic conditions is still large. An estimated 8.0 million acre-feet of water is available from just the upper 100 feet of saturated fill[3] of the principal ground-water reservoirs in the Wasatch Front area. This is nine times the content of Utah Lake, but it is only a fraction of the total water content of the principal groundwater reservoirs in the Wasatch Front area. For example, the total water content of the complete saturated section of fill in the Salt Lake Valley alone is 60 million acre-feet (Hely and others, 1971, p. 133). This is nearly four times the combined content of Utah Lake and Great Salt Lake. Estimated

[2]Transmissivity is the rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. It is a measure of the volume of water the fill can transmit, and is a function of the thickness and permeability of the fill. The units for transmissivity are cubic feet per day per foot, which reduces to feet squared per day.

[3]Estimates of recoverable ground water in storage in the valley fill in Utah commonly are made for only the upper 100 feet of saturated fill. Most of the valleys contain at least 100 feet of saturated fill, and in most valleys it is economically feasible to lower water levels at least 100 feet. In addition, data for storage properties of aquifers are best known in relation to water-level declines of 100 feet or less.

Figure 16. (facing page) Locations of the principal ground-water reservoirs in the Wasatch Front area.

These reservoirs consist of mostly saturated, unconsolidated basin fill. They function much the same as surface-water reservoirs in that they have a finite storage capacity and in that the storage changes in response to inflow (ground-water recharge) and outflow (ground-water discharge). (Map from Herbert and others, 1981, fig. 1.)


EXPLANATION
PRINCIPAL GROUND-WATER RESERVOIR
1. Northern Juab Valley
2. Utah and Goshen Valleys
3. Salt Lake Valley
4. East Shore area
5. Bear River Bay area
BOX ELDER
CACHE
RICH
WEBER
MORGAN
DAVIS
SUMMIT
DAGGET
SALT LAKE
TOOELE
WASATCH
DUCHESNE
UINTAH
UTAH
JUAB
CARBON
SANPETE
MILLARD
EMERY
GRAND
SAN JUAN
GREAT SALT LAKE
WASATCH RANGE
UINTA MOUNTAINS
Flowing artesian well
Principal ground water reservoir
Pumped well
Sand
Clay
Gravel
Clay
BASIN FILL
Clay, sand, and gravel
Consolidated rock
Consolidated rock
Wasatch Range
N
0 25 50 75 100 KILOMETERS
0 25 50 MILES

recoverable water in the upper 100 feet of saturated fill in the five principal ground-water reservoirs is shown in the following table:

Principal ground-water reservoir	Estimated recoverable water in upper 100 feet of saturated fill[1] (million acre-feet)
Northern Juab Valley	0.5
Utah and Goshen Valleys	3.0
Salt Lake Valley	1.3
East Shore area	2.9
Bear River Bay area	[2].5
Total (rounded)	8.0

[1]From Price (1979, table 1).
[2]The estimate is about one-fourth of the estimate (for a much larger part of the Bear River Bay area) listed in Price (1979, table 1).

The ground-water reservoirs function much the same as surface-water reservoirs in that they have a relatively (or nearly) fixed storage capacity and varying volumes of inflow and outflow. When the inflow exceeds the outflow, the volume of water in storage increases and ground-water levels (the potentiometric surface) rise just as does the level of a surface reservoir that is being filled. When outflow exceeds inflow, the volume of water in storage decreases and ground-water levels decline just as does the level of a surface reservoir that is being emptied.

The principal ground-water reservoirs in the Wasatch Front area, over the long term, are filled to levels where total inflow is balanced by total outflow (in dynamic equilibrium). Thus, should inflow be increased over the long term, water levels would rise, land would become water logged, and basements might be flooded, but outflow would eventually increase to balance the inflow. Should inflow be decreased over the long term, the volume of ground water in storage would be decreased, water levels in wells would decline, some flowing wells would cease to flow, some might not yield any water, and even the land surface might begin to subside. The same results could be brought about by mining the principal ground-water reservoirs—that is withdrawing considerably more water from water wells over the long term than can be replaced naturally or by artificial means.

GROUND-WATER RECHARGE

The Perennial Ground-Water Supply

Inflow to the principal ground-water reservoirs is referred to as groundwater recharge. This recharge comes from a variety of sources; and it occurs in many places, mostly along the margins of the valleys. It occurs as seepage from fractures, faults, and other openings in the consolidated rocks. It occurs as seepage from losing reaches of streams and underflow in the alluvium of stream channels as they leave the mountains. It occurs as seepage from canals, ditches, and irrigated fields. It also occurs as direct seepage from rain and melting snow. Unfortunately, some even occurs as seepage from garbage dumps and liquid-waste-disposal ponds.

The average annual rate of recharge to a given ground-water reservoir can be referred to as the perennial

A NOTE ABOUT FIGURES 17–21

Most of the transmissivities from which these maps were compiled were estimated from the specific capacities of wells; that is, the ratio of the yield of the well and water-level decline in the discharging well. These estimates are less accurate and more conservative than transmissivities determined by aquifer tests; however, they do provide reasonable approximations of the ranges shown in figures 17–21.

EXPLANATION

AREA IN WHICH TRANSMISSIVITY OF THE BASIN FILL GENERALLY EXCEEDS 10,000 FEET SQUARED PER DAY

AREA IN WHICH TRANSMISSIVITY OF THE BASIN FILL GENERALLY IS LESS THAN 10,000 FEET SQUARED PER DAY OR DATA ARE INSUFFICIENT TO DETERMINE THE VALUE

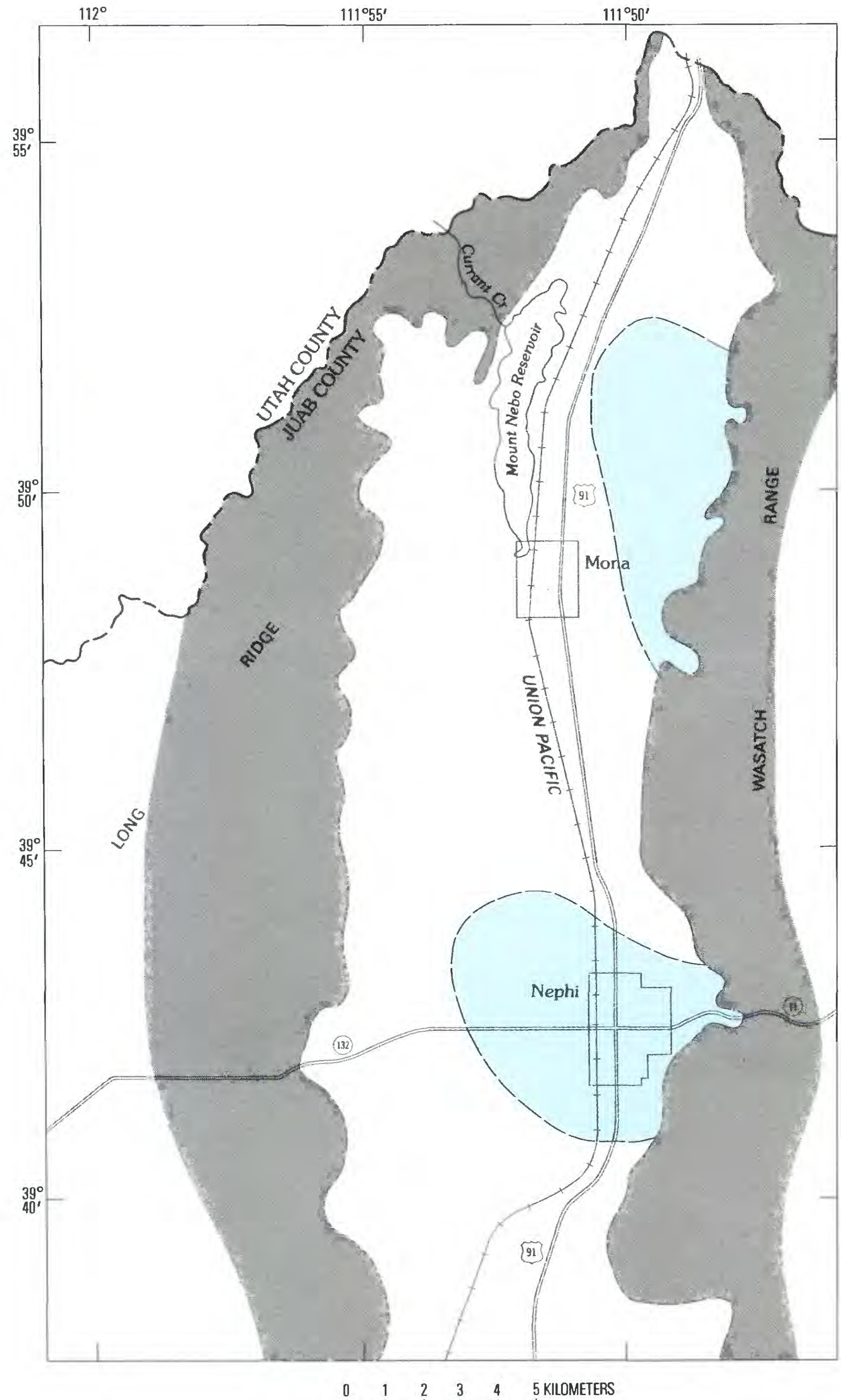
CONSOLIDATED ROCK

APPROXIMATE CONTACT BETWEEN VALLEY FILL AND CONSOLIDATED ROCK

APPROXIMATE BOUNDARY BETWEEN AREAS WITH DIFFERENT TRANSMISSIVITY

Figure 17 (above and facing page). Areas in which transmissivity of the principal ground-water reservoir in northern Juab Valley generally exceeds 10,000 feet squared per day.

The areas in which transmissivity of the fill in northern Juab Valley exceeds 10,000 feet squared per day probably reflect the great permeability of alluvial-fan deposits of Salt Creek and other Wasatch Front streams. Several irrigation and public-supply wells that obtain water from the fill in those areas reportedly yield more than 1,000 gallons per minute (Bjorklund, 1967, table 4).


112°
111°55′
111°50′
39° 55′
39° 50′
39° 45′
39° 40′
UTAH COUNTY
JUAB COUNTY
Currant Cr
Mount Nebo Reservoir
91
Mona
RANGE
WASATCH
RIDGE
LONG
UNION PACIFIC
Nephi
132
91
0 1 2 3 4 5 KILOMETERS
0 1 2 3 MILES

EXPLANATION

AREA IN WHICH TRANSMISSIVITY OF THE BASIN FILL GENERALLY EXCEEDS 10,000 FEET SQUARED PER DAY

AREA IN WHICH TRANSMISSIVITY GENERALLY IS LESS THAN 10,000 FEET SQUARED PER DAY

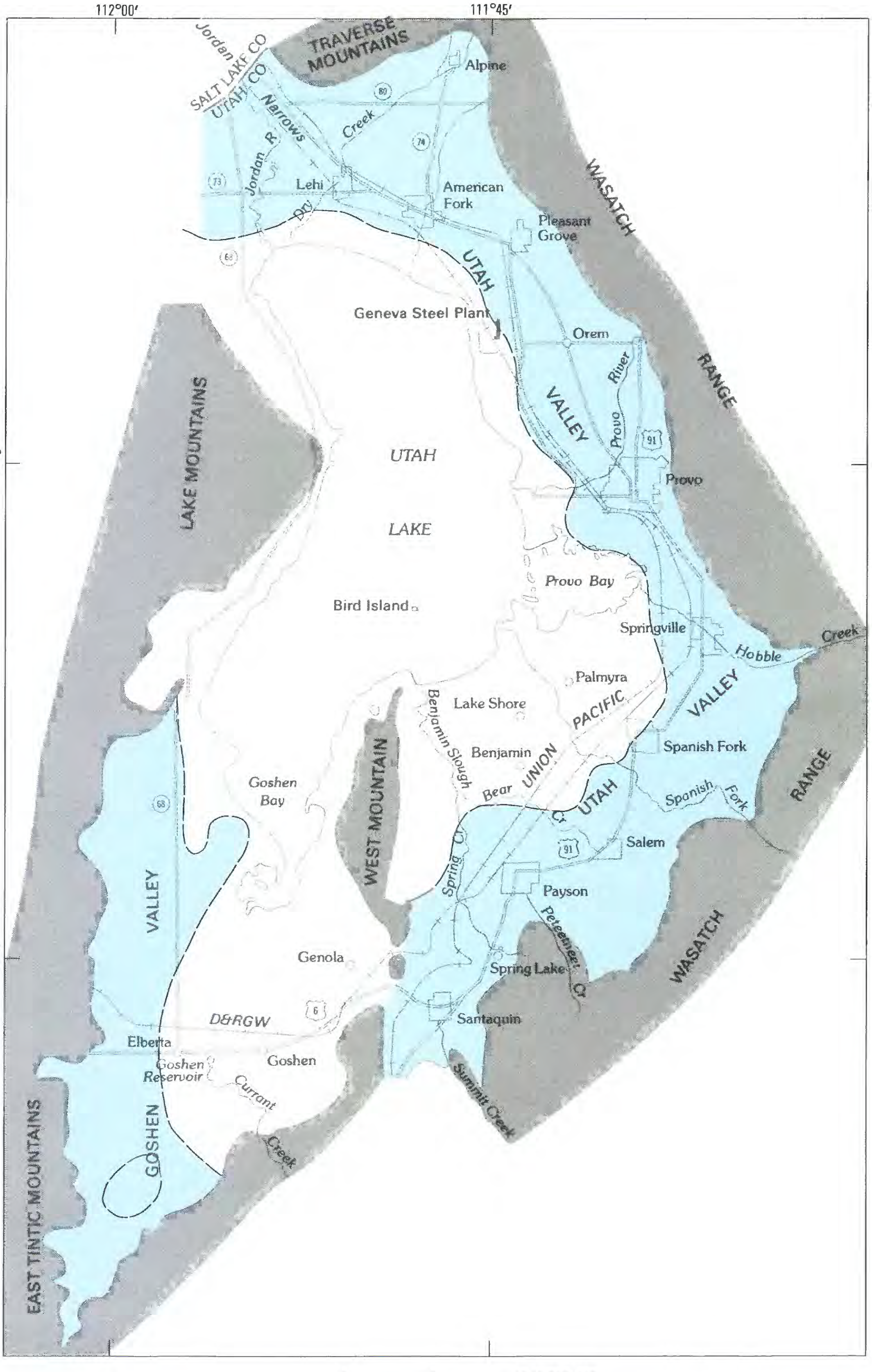
CONSOLIDATED ROCK

APPROXIMATE CONTACT BETWEEN VALLEY FILL AND CONSOLIDATED ROCK

APPROXIMATE BOUNDARY BETWEEN AREAS WITH DIFFERENT TRANSMISSIVITY

Figure 18 (above and facing page). Areas in which transmissivity of the principal ground-water reservoirs in Utah and Goshen Valleys generally exceeds 10,000 feet squared per day.

The fill in Utah Valley contains several aquifers (Hunt and others, 1953; Cordova and Subitzky, 1965; and Cordova, 1970). The information shown on this map represents chiefly two aquifers (the shallow and deep Pleistocene aquifers) in which most wells are completed. These aquifers locally have transmissivities of more than 50,000 feet squared per day and yield several thousand gallons per minute to individual wells. (Information for the area between Springville and the Traverse Mountains is adapted from information supplied by David Clark, U.S. Geological Survey, written commun., 1982.)



112°00′
111°45′
40° 15′
40° 00′
TRAVERSE MOUNTAINS
WASATCH RANGE
LAKE MOUNTAINS
WEST MOUNTAIN
EAST TINTIC MOUNTAINS
UTAH VALLEY
GOSHEN VALLEY
UTAH LAKE
SALT LAKE CO
UTAH CO
Jordan
Jordan R
Narrows
Creek
Dry
Alpine
Lehi
American Fork
Pleasant Grove
Geneva Steel Plant
Orem
Provo River
Provo
Provo Bay
Bird Island
Springville
Hobble Creek
Palmyra
Lake Shore
Benjamin Slough
Benjamin
UNION PACIFIC
Spanish Fork
Bear Cr
Goshen Bay
Spring Cr
Salem
Payson
Peteetneet Cr
Spring Lake
Genola
D&RGW
Santaquin
Summit Creek
Elberta
Goshen Reservoir
Goshen
Currant Creek
0 5 10 KILOMETERS
0 5 MILES

EXPLANATION

AREA IS WHICH TRANSMISSIVITY OF BASIN FILL GENERALLY EXCEEDS 10,000 FEET SQUARED PER DAY

AREA IN WHICH TRANSMISSIVITY GENERALLY IS LESS THAN 10,000 FEET SQUARED PER DAY

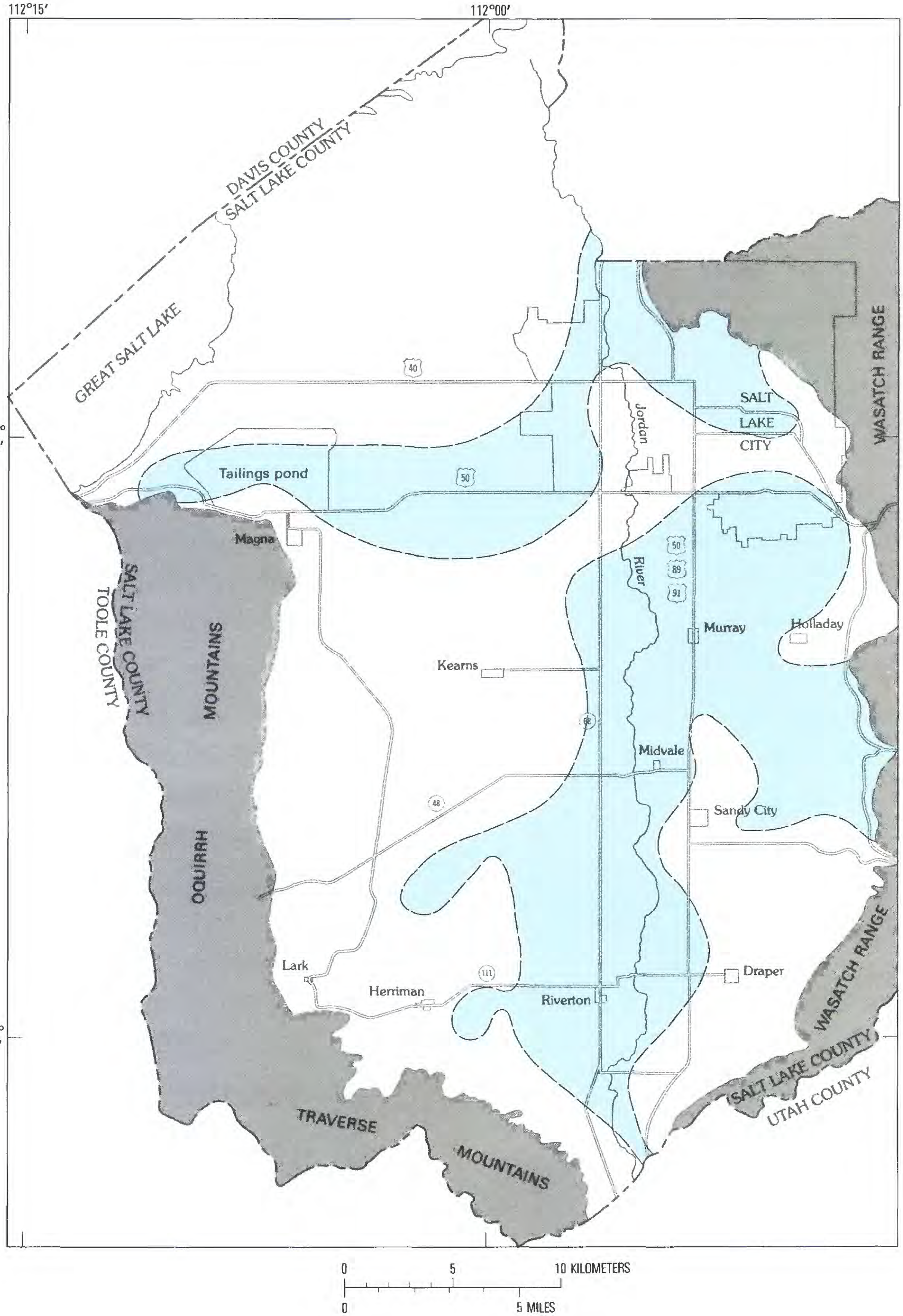
CONSOLIDATED ROCK

APPROXIMATE CONTACT BETWEEN VALLEY FILL AND CONSOLIDATED ROCK

APPROXIMATE BOUNDARY BETWEEN AREAS WITH DIFFERENT TRANSMISSIVITY

Figure 19 (above and facing page). Areas in which transmissivity of the principal ground-water reservoir in the Salt Lake Valley generally exceeds 10,000 feet squared per day.

The fill in the eastern part of the Salt Lake Valley consists chiefly of coarse-grained alluvial-fan deposits of Wasatch Front streams. As shown, the transmissivity of these deposits in most places exceeds 10,000 feet squared per day; in some places they exceed 50,000 feet squared per day. The transmissivity of water-bearing deposits generally increases with the thickness of these deposits; therefore, even though the fill in the northwest part of the valley is fine grained and has relatively little permeability, it is so thick that the transmissivity is almost 10,000 feet squared per day. (Adapted from Hely and others, 1971, fig. 19.)



112°15′
112°00′
40° 45′
40° 30′
DAVIS COUNTY
SALT LAKE COUNTY
GREAT SALT LAKE
WASATCH RANGE
SALT
LAKE
CITY
Jordan
River
Tailings pond
Magna
SALT LAKE COUNTY
TOOLE COUNTY
OQUIRRH
MOUNTAINS
Kearns
Murray
Holladay
Midvale
Sandy City
Lark
Herriman
Riverton
Draper
TRAVERSE
MOUNTAINS
SALT LAKE COUNTY
UTAH COUNTY
0 5 10 KILOMETERS
0 5 MILES

EXPLANATION

AREA IN WHICH TRANSMISSIVITY OF BASIN FILL GENERALLY EXCEEDS 10,000 FEET SQUARED PER DAY

AREA IN WHICH TRANSMISSIVITY GENERALLY IS LESS THAN 10,000 FEET SQUARED PER DAY, OR DATA ARE INSUFFICIENT TO DETERMINE THE VALUE

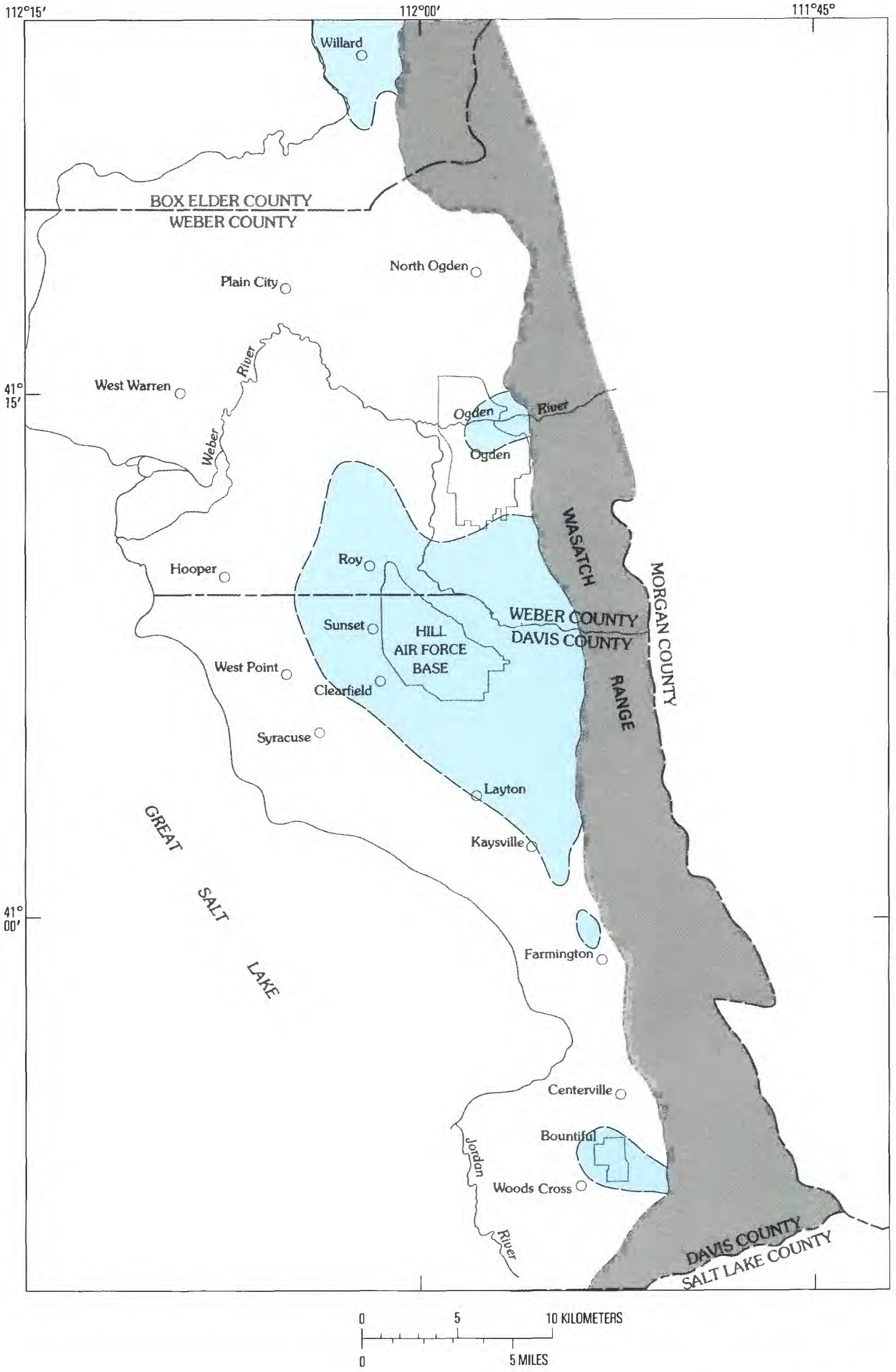
CONSOLIDATED ROCK

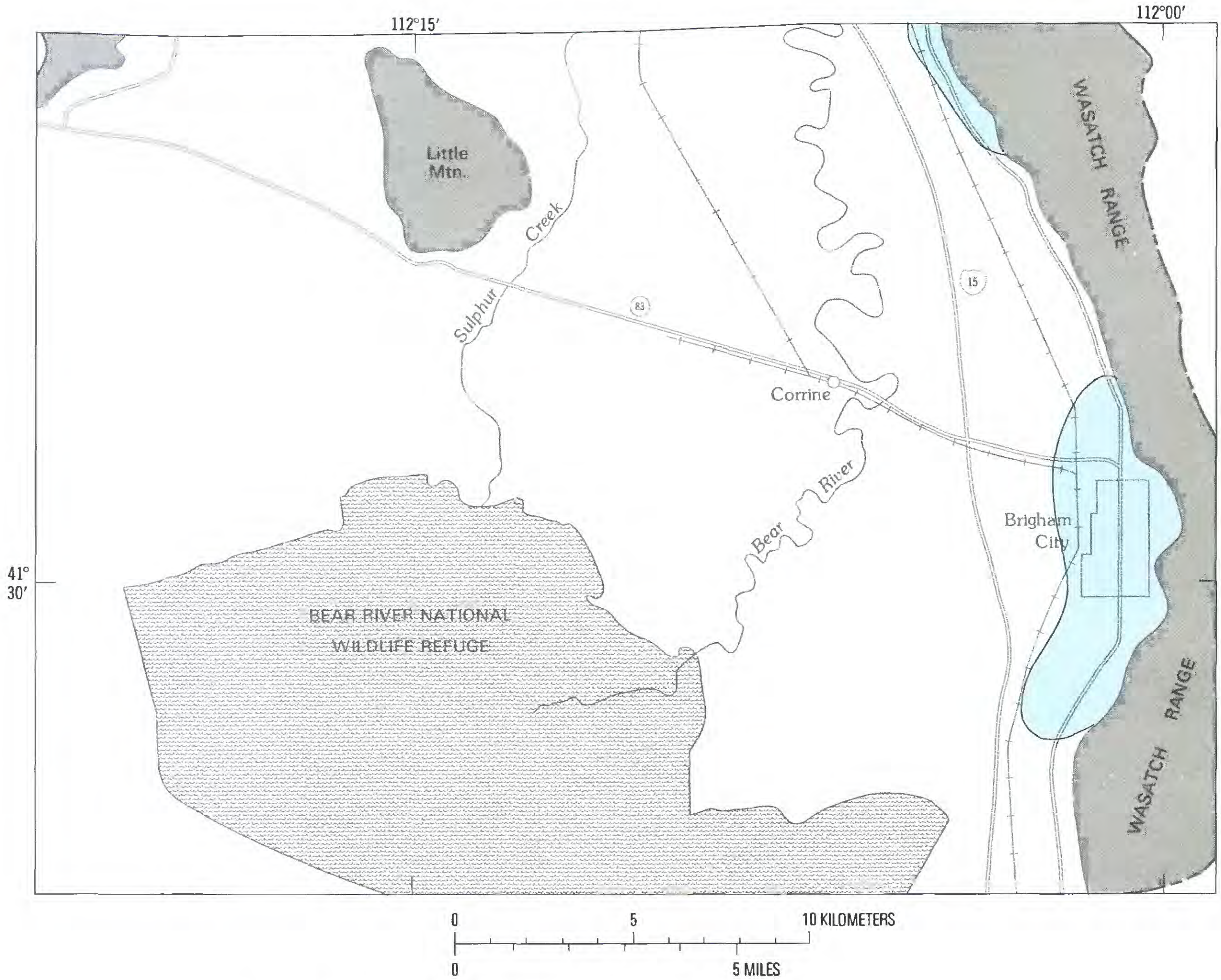
APPROXIMATE CONTACT BETWEEN VALLEY FILL AND CONSOLIDATED ROCK

APPROXIMATE BOUNDARY BETWEEN AREAS WITH DIFFERENT TRANSMISSIVITY

Figure 20 (above and facing page). Areas in which transmissivity of the principal ground-water reservoir in the East Shore area generally exceeds 10,000 feet squared per day.

The Clearfield-Ogden area is part of the Weber Delta District (Feth and others, 1966); it is underlain by permeable coarse-grained deposits of the Weber River. The transmissivity of these deposits generally exceeds 10,000 feet squared per day and locally exceeds 20,000 feet squared per day. Similar deposits have been penetrated by wells in the Bountiful, Farmington, and Willard areas. In most other parts of the East Shore area, however, the fill is finer-grained, with transmissivities of generally less than 10,000 feet squared per day.


112°15′
112°00′
111°45°
41° 15′
41° 00′
Willard
BOX ELDER COUNTY
WEBER COUNTY
North Ogden
Plain City
West Warren
Weber River
Ogden River
Ogden
Ogden
WASATCH RANGE
MORGAN COUNTY
Hooper
Roy
WEBER COUNTY
DAVIS COUNTY
Sunset
HILL AIR FORCE BASE
West Point
Clearfield
Syracuse
Layton
Kaysville
GREAT SALT LAKE
Farmington
Centerville
Bountiful
Jordan River
Woods Cross
DAVIS COUNTY
SALT LAKE COUNTY
0 5 10 KILOMETERS
0 5 MILES



EXPLANATION

AREA IN WHICH TRANSMISSIVITY OF THE VALLEY FILL GENERALLY EXCEEDS 10,000 FEET SQUARED PER DAY

AREA IN WHICH TRANSMISSIVITY OF THE VALLEY FILL GENERALLY IS LESS THAN 10,000 FEET SQUARED PER DAY OR DATA ARE INSUFFICIENT TO DETERMINE THE VALUE

CONSOLIDATED ROCK

APPROXIMATE CONTACT BETWEEN VALLEY FILL AND CONSOLIDATED ROCK

APPROXIMATE BOUNDARY BETWEEN AREAS WITH DIFFERENT TRANSMISSIVITY

Figure 21. Areas in which transmissivity of the principal ground-water reservoir in the Bear River Bay area generally exceeds 10,000 feet squared per day.

Because most of the Bear River Bay area is underlain by fine-grained, lake-bottom deposits with relatively little permeability, the transmissivity in few areas exceeds 10,000 feet squared per day. The largest of these areas, encompassing Brigham City, probably represents alluvial-fan deposits of Box Elder Creek, which enters the valley east of Brigham City.

water supply of that reservoir. It is the volume of water that can be discharged from the reservoir annually over the long term without depleting the storage.

Estimated annual rates of recharge to the principal ground-water reservoirs in the Wasatch Front area are given in the table at the top of page 35.

A comparison of annual recharge to the Salt Lake Valley ground-water reservoir from various sources is shown in figure 22. Similar data are not available for the other principal ground-water reservoirs; however, it is assumed that seepage from consolidated rock and irrigation systems also are major sources of recharge to those reservoirs.

Ground water moves from the principal areas of recharge, which generally are near the valley margins, to principal areas of natural discharge, which are in the lower parts of the valleys. This is shown in figures 23–27.

Ground-water reservoir	Estimated average annual rate of recharge (acre-feet)	Source of estimate
Northern Juab Valley	40,000	Gates (1982, table 2)
Utah and Goshen Valleys	>450,000	J.S. Gates, U.S. Geological Survey, written commun., 1982, adapted from Cordova and Subitsky (1965, p. 13 and 19); Cordova (1970, p. 23 and 30)
Salt Lake Valley	367,000	Hely and others (1971, p. 119)
East Shore area	>86,000	J.S. Gates, U.S. Geological Survey, written commun., 1982, adapted from Thomas and Nelson (1948, p. 195) and Feth and others (1966).
Bear River Bay area	[1]75,000	Bjorklund and McGreevy (1974, p. 15)
Total	>1,000,000	

[1]Estimate is one-fourth of the total given in the cited source for a much larger area than described in this report.

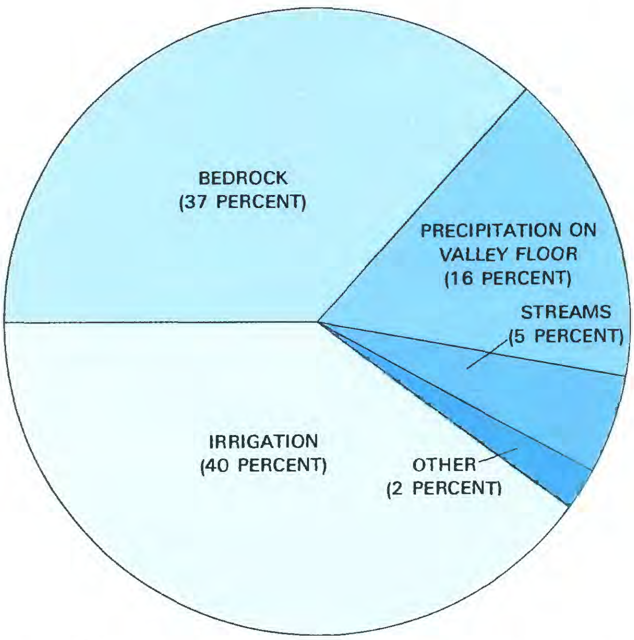


Figure 22. Annual rates of recharge to the principal ground-water reservoir in the Salt Lake Valley from various sources.

About 40 percent of the annual recharge (about 367,000 acre-feet) to the principal ground-water reservoir in the Salt Lake Valley comes from irrigation seepage. This includes seepage chiefly from canals, ditches, and irrigated fields. More than 35 percent of the annual recharge is seepage to the reservoir from consolidated rocks in the adjacent mountains—chiefly the Wasatch Range. This seepage also includes underflow in the channels of streams that enter the valley from the adjacent mountains. About 16 percent of the annual recharge is seepage from precipitation on the valley floor and 5 percent is seepage from streams after they enter the valley. Other sources of recharge include subsurface flow from the Utah Valley ground-water reservoir, which amounts to less than 1 percent of the annual rate. (Diagram based on 1964-68 annual averages from Hely and others, 1971, table 21.)

GROUND-WATER DISCHARGE

Distribution Of The Perennial Supply

Outflow from the principal ground-water reservoirs is referred to as ground-water discharge. It occurs as seeps and springs (including seepage to gaining reaches of streams), as evapotranspiration, and as subsurface flow to Great Salt Lake or other valleys in the Wasatch Front area. Discharge also occurs as withdrawals from wells and manmade drains. As indicated in the captions in figures 23-27, the principal areas of ground-water discharge are the lower valley areas (chiefly the flowing-well areas); however, considerable volumes of water are withdrawn by wells in other parts of the valleys, particularly the eastern sides, where transmissivities and well yields generally are greatest.

Ground-water recharge and discharge in the Wasatch Front area are in dynamic equilibrium. Except for withdrawal by wells (which may be taking water from storage), annual rates of discharge from the principal ground-water reservoirs are approximately equal to the annual rates of recharge to the respective reservoirs. Estimates of average annual discharge are given in the following table:

Principal ground-water reservoir	Estimated average annual rate of discharge (acre-feet)
Northern Juab Valley	40,000
Utah and Goshen Valleys	450,000
Salt Lake Valley	367,000
East Shore area	86,000
Bear River Bay area	75,000
Total (rounded)	1,000,000

The above estimates, derived from the preceding table of estimated ground-water recharge, reflect annual withdrawals by wells at the time the estimates originally were made. By 1980, annual withdrawals by wells in the Wasatch Front area had increased by about 100,000 acre-feet, and thus, total ground-water discharge had increased accordingly. However, this increase in discharge probably was offset by a proportionate increase in ground-water recharge.

The approximate annual rate of ground-water discharge by various means in the Salt Lake Valley is shown in figure 28. The figure is based on annual averages for 1964-68. Withdrawal from wells increased between 1968 and 1982, probably in part at the expense of one or more of the other forms of discharge and in part by local withdrawal of some water from storage. Similar comparisons of the distribution of discharge have not been made for the other principal ground-water reservoirs. Available data indicate, however, that discharge by evapotranspiration is significant for all those reservoirs. Discharge from wells is significant for Utah and Goshen Valleys and the East Shore area. Subsurface flow to Utah Lake and the Jordan River is significant in Utah Valley, and subsurface flow to Great Salt Lake is significant in the East Shore area.

GROUND-WATER QUALITY

Most Is Fresh but Some Is Saline

Many factors affect the chamical quality of ground water. They include the quality of recharge water, the character of the rocks through which the water circulates, the depth and distance of circulation, and the time in contact with soluble minerals. They also include the activities of man.

With the exception of some irrigation sources, the chemical quality of major ground-water recharge sources in the Wasatch Front area is good and is suitable for most uses including public supply. Therefore, the chemical quality of ground water in and near the major recharge areas generally is suitable for most uses. Ground water moves slowly, dissolving mineral constituents from the rocks as it passes from recharge to discharge areas. The time-of-travel generally takes years, and water may dissolve large quantities of mineral constituents during that time. This is especially true where the rocks contain such natural soluble minerals as salt and gypsum.

Ground water in the Wasatch Front area generally ranges from fresh to moderately saline according to the following classification commonly used by the U.S. Geological Survey:

Class	Dissolved-solids concentration (milligrams per liter)
Fresh	Less than 1,000
Slightly saline	1,000 to 3,000
Moderately saline	3,000 to 10,000
Very saline	10,000 to 35,000
Briny	More than 35,000

A NOTE ABOUT FIGURES 23-27

The contours shown in figures 23-27 were compiled from water-level measurements made in about 160 selected observation wells. The maps are intended to show the approximate altitude of the potentiometric surface for aquifers at depths of about 100 to 1,000 feet. The flowing-well areas change with the rise and decline of the potentiometric surface; they may expand or shrink to some degree both seasonally and from year to year depending on the altitude of the potentiometric surface. Consequently, accurate determinations of the altitude of the potentiometric surface and of the boundary of the flowing-well area at a given site can be made only by special investigation.

EXPLANATION

AREA IN WHICH MOST WELLS THAT OBTAIN WATER FROM THE BASIN FILL FLOW UNDER ARTESIAN PRESSURE (1980)

CONSOLIDATED ROCK

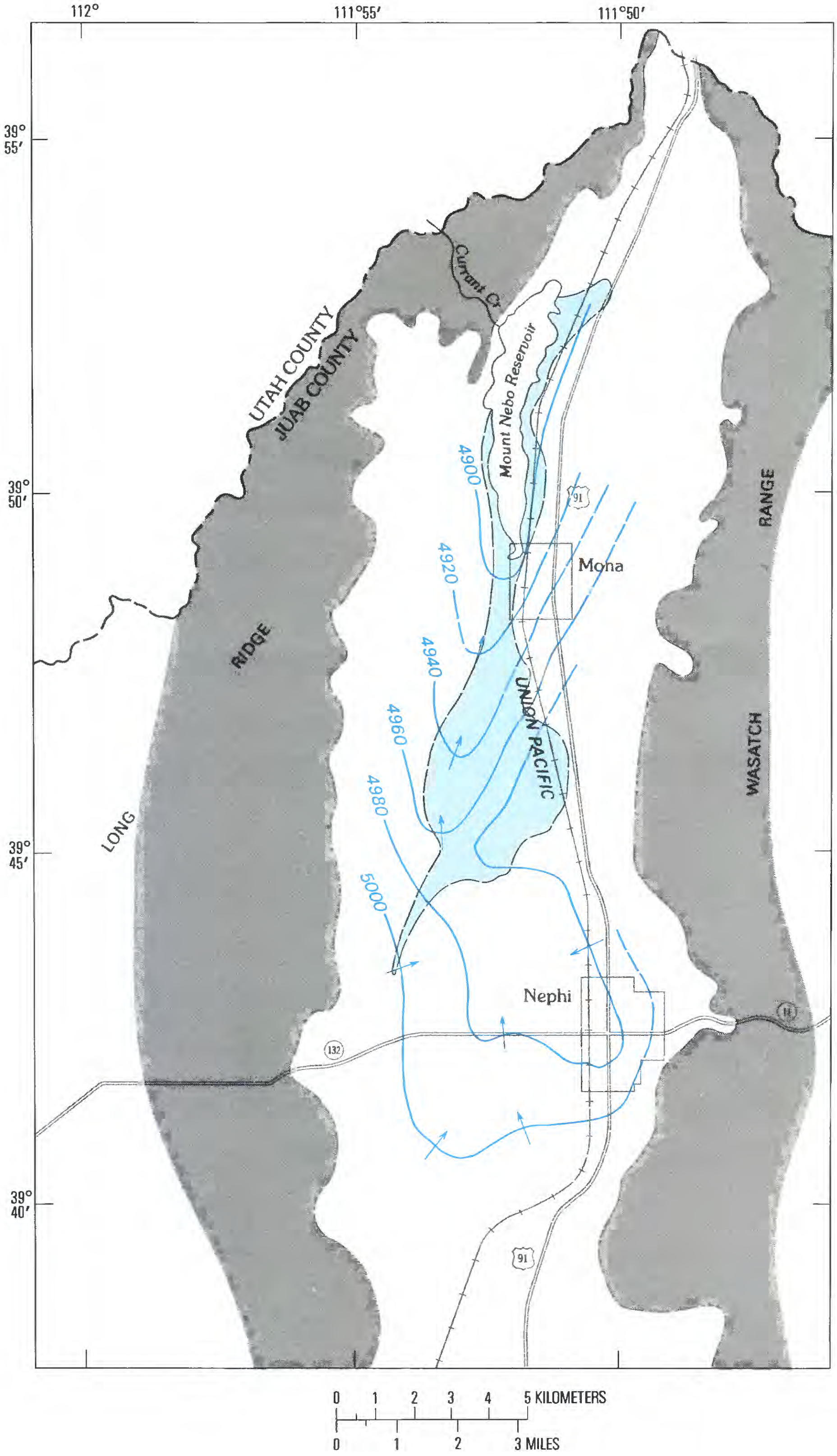
LINE OF EQUAL ALTITUDE OF THE POTENTIOMETRIC SURFACE, MARCH 1980.—Dashed where approximately located. Contour interval 20 feet. Arrows show direction of ground-water flow.

APPROXIMATE CONTACT BETWEEN VALLEY FILL AND CONSOLIDATED ROCK

APPROXIMATE BOUNDARY OF AREA WITH FLOWING WELLS

Figure 23 (above and facing page). Potentiometric surface and approximate flowing-well area in northern Juab Valley.

Ground water generally flows from the margins to the axis of northern Juab Valley, and then northward. Some of the water continues northward into Goshen Valley; but according to Bjorklund (1967, p. 44), the volume is negligible. Most is discharged by seepage to Mona (Mount Nebo) Reservoir and Currant Creek, evapotranspiration, and wells in the flowing-well area.



112°
111°55′
111°50′
39° 55′
39° 50′
39° 45′
39° 40′
UTAH COUNTY
JUAB COUNTY
Currant Cr
Mount Nebo Reservoir
4900
4920
4940
4960
4980
5000
Mona
Nephi
UNION PACIFIC
LONG
RIDGE
WASATCH
RANGE
91
132
0 1 2 3 4 5 KILOMETERS
0 1 2 3 MILES

EXPLANATION

AREA IN WHICH MOST WELLS THAT OBTAIN WATER FROM THE BASIN FILL FLOW UNDER ARTESIAN PRESSURE (1980)

CONSOLIDATED ROCK

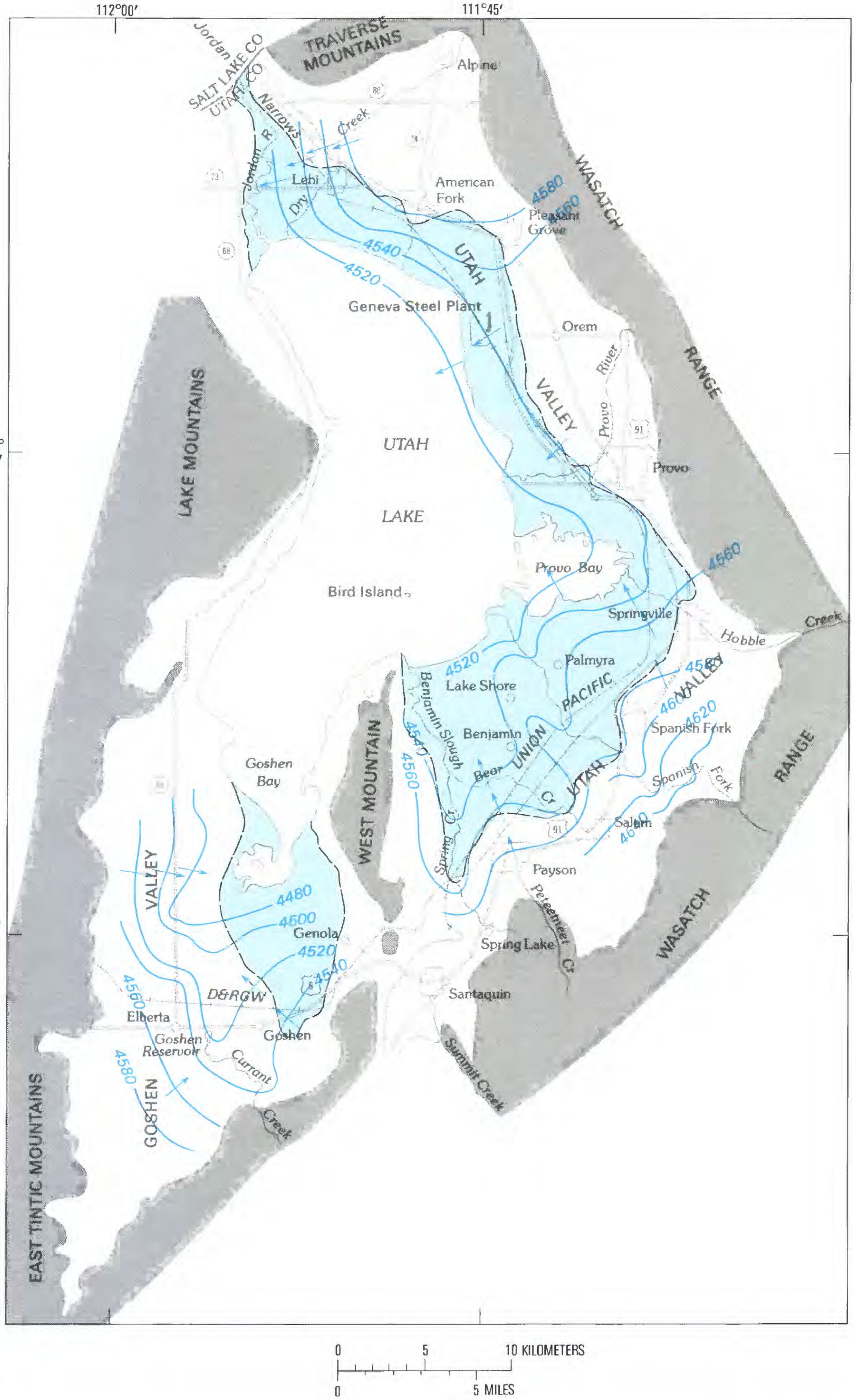
LINE OF EQUAL ALTITUDE OF THE POTENTIOMETRIC SURFACE, MARCH 1980.—Dashed where approximately located. Contour interval 20 feet. Arrows show direction of ground-water flow.

APPROXIMATE CONTACT BETWEEN VALLEY FILL AND CONSOLIDATED ROCK

APPROXIMATE BOUNDARY BETWEEN AREAS WITH DIFFERENT TRANSMISSIVITY

Figure 24 (above and facing page). Potentiometric surface and approximate flowing-well area in Utah and Goshen Valleys.

The potentiometric surface as depicted here is for water in aquifers of both Tertiary and Pleistocene age. As shown, ground water flows from near the mountains toward Utah Lake. Most is discharged by springs, drains, wells, and evapotranspiration in the flowing-well area which contains numerous flowing wells. Very little flows northward into Salt Lake Valley.


112°00′
111°45′
40° 15′
40° 00′
TRAVERSE MOUNTAINS
SALT LAKE CO
UTAH CO
Jordan
Narrows
Jordan R.
Alpine
Creek
Dry
Lehi
American Fork
Pleasant Grove
WASATCH
RANGE
UTAH
VALLEY
Geneva Steel Plant
Orem
Provo
River
Provo
LAKE MOUNTAINS
UTAH
LAKE
Provo Bay
Bird Island
Springville
Hobble
Creek
Palmyra
Lake Shore
Benjamin
Benjamin Slough
Bear
Cr
UNION
PACIFIC
Spanish Fork
Spanish
Fork
Salem
Payson
Spring Lake
Peteetneet
Santaquin
Summit Creek
WASATCH
RANGE
WEST MOUNTAIN
Goshen Bay
GOSHEN
VALLEY
Genola
D&RGW
Elberta
Goshen
Goshen Reservoir
Currant
Creek
EAST TINTIC MOUNTAINS
4480
4500
4520
4540
4560
4580
4600
4620
4640
0 5 10 KILOMETERS
0 5 MILES

EXPLANATION

AREA IN WHICH MOST WELLS THAT OBTAIN WATER FROM THE BASIN FILL FLOW UNDER ARTESIAN PRESSURE (1980)

CONSOLIDATED ROCK

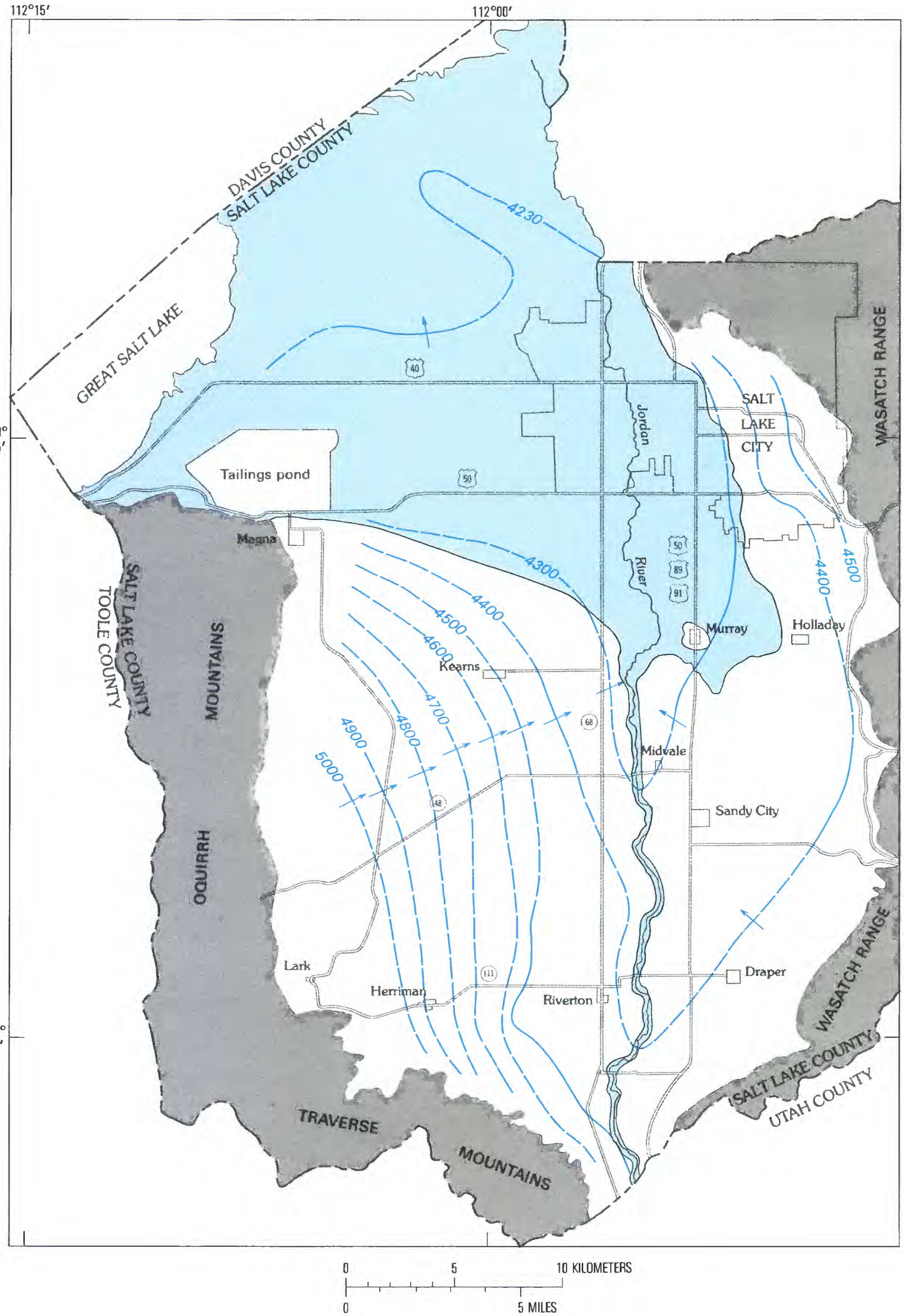
LINE OF EQUAL ALTITUDE OF THE POTENTIOMETRIC SURFACE, FEBRUARY 1981—Dashed where approximately located (from Herbert and others, 1981, fig. 9). Contour interval 70 and 100 feet. Arrow shows direction of ground-water flow. National Geodetic Vertical Datum of 1929 (sea level).

APPROXIMATE CONTACT BETWEEN VALLEY FILL AND CONSOLIDATED ROCK

APPROXIMATE BOUNDARY OF AREA WITH FLOWING WELLS

Figure 25 (above and facing page). Potentiometric surface and approximate flowing-well area in the Salt Lake Valley.

In the Salt Lake Valley, ground water flows from the margins of the valley toward the Jordan River and the low-lying areas adjacent to Great Salt Lake. The Jordan River is a ground-water drain and virtually all its flow during the nonirrigation season is derived from ground water. The flowing-well area contains hundreds of flowing artesian wells.



112°15′
112°00′
40° 45′
40° 30′
DAVIS COUNTY
SALT LAKE COUNTY
GREAT SALT LAKE
Tailings pond
Magna
SALT LAKE COUNTY
TOOLE COUNTY
OQUIRRH MOUNTAINS
TRAVERSE MOUNTAINS
WASATCH RANGE
SALT LAKE CITY
Jordan River
Murray
Holladay
Kearns
Midvale
Sandy City
Lark
Herriman
Riverton
Draper
UTAH COUNTY
4230
4300
4400
4500
4600
4700
4800
4900
5000
0 5 10 KILOMETERS
0 5 MILES

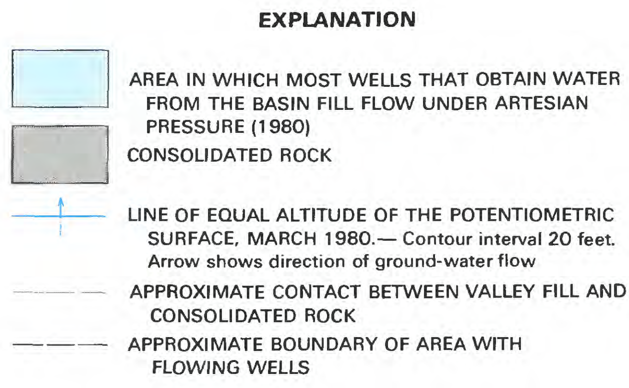
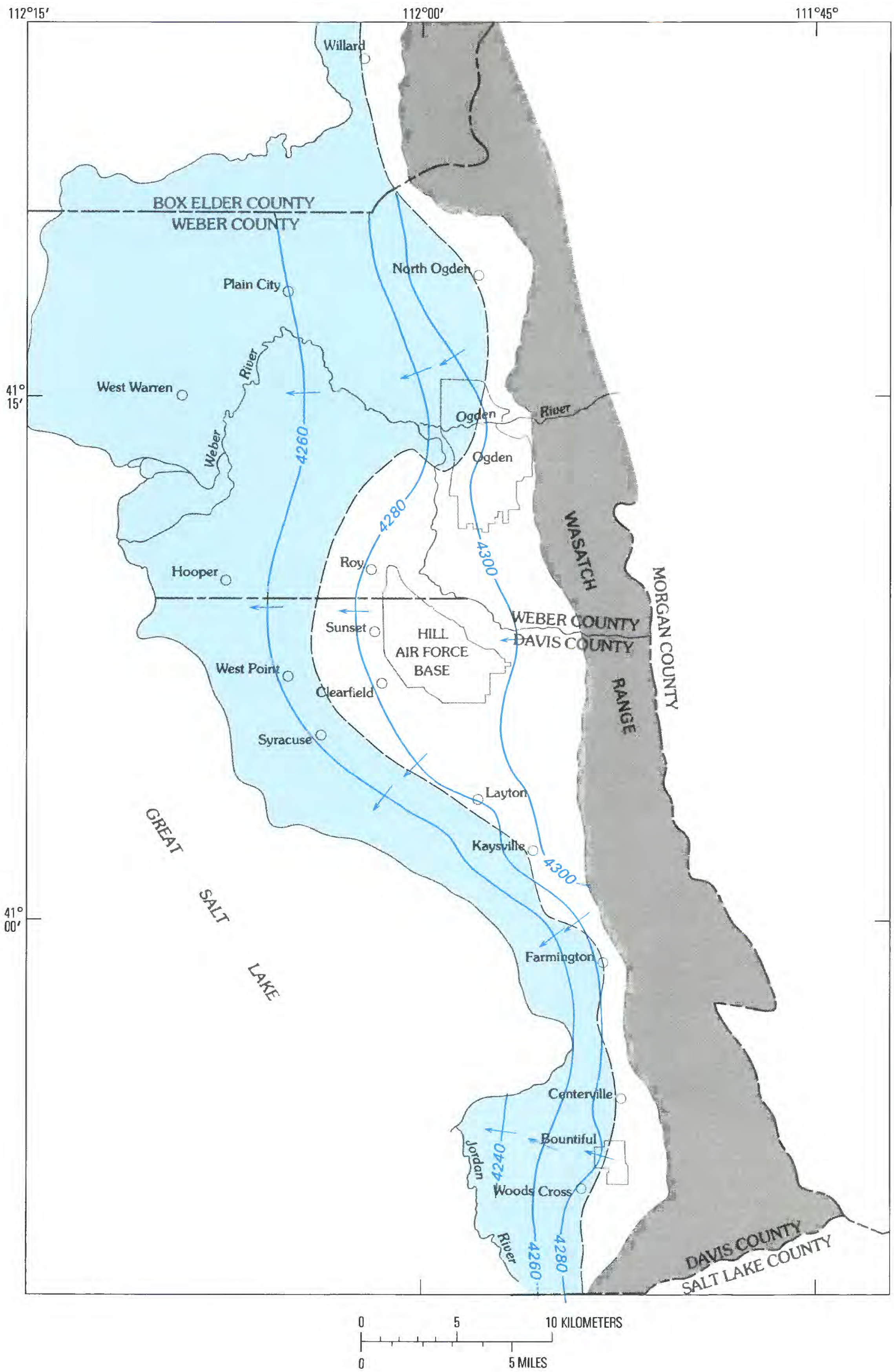
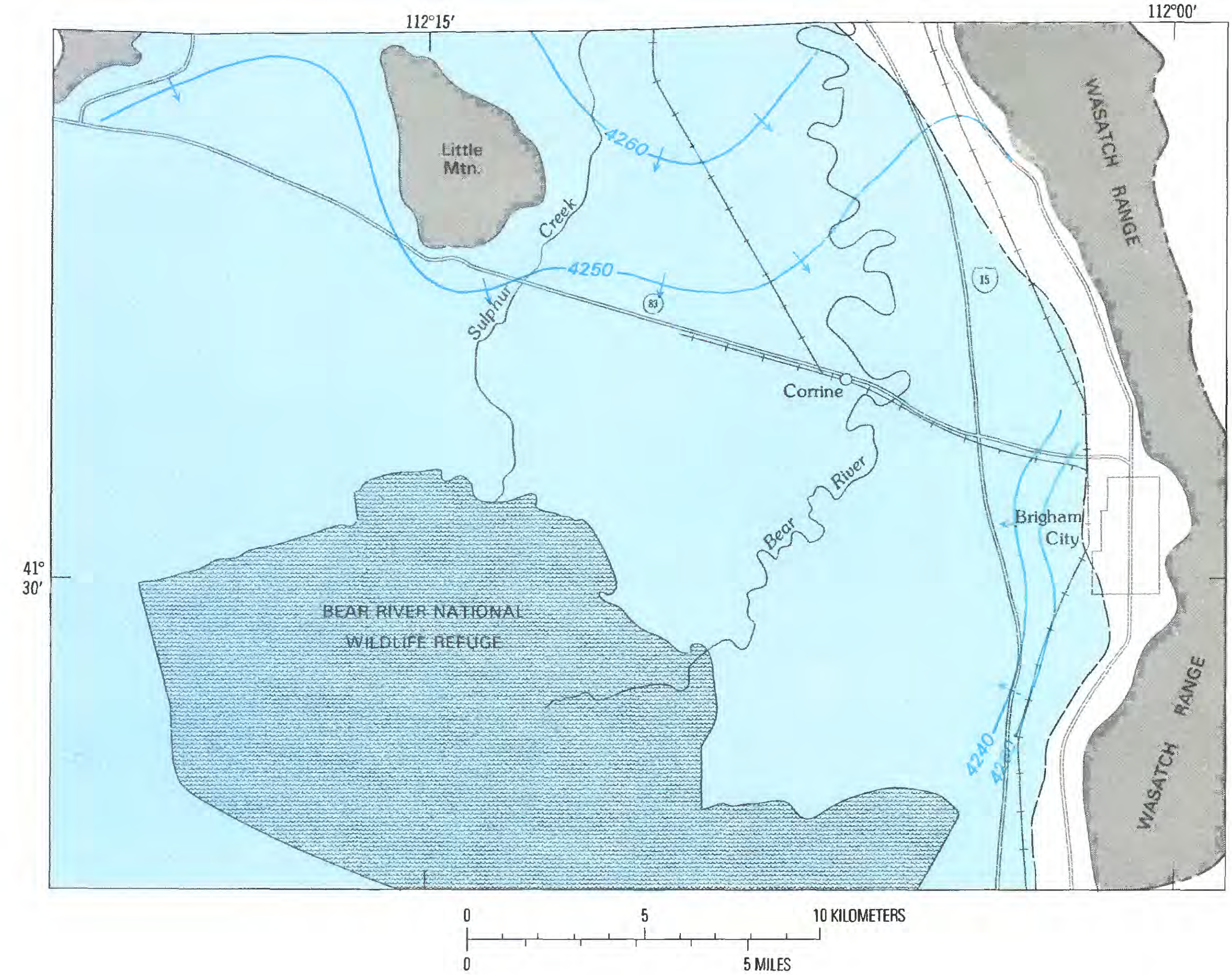


Figure 26 (above and facing page). Potentiometric surface and approximate flowing-well area in the East Shore area.

In the East Shore area, ground water flows from near the Wasatch Range toward Great Salt Lake and the Jordan River. The water discharges naturally to the lake and the river and by evapotranspiration in the adjacent wetlands. According to Arnow (1978, p. 12), nearly 50,000 acre-feet seeps directly into Great Salt Lake each year along its entire perimeter. The flowing-well area contains hundreds of flowing artesian wells.


112°15′
112°00′
111°45°
41°
15′
41°
00′
Willard
BOX ELDER COUNTY
WEBER COUNTY
North Ogden
Plain City
West Warren
Weber River
Ogden River
Ogden
Hooper
Roy
Sunset
HILL
AIR FORCE
BASE
West Point
Clearfield
Syracuse
Layton
Kaysville
Farmington
Centerville
Bountiful
Woods Cross
Jordan River
WASATCH RANGE
MORGAN COUNTY
WEBER COUNTY
DAVIS COUNTY
DAVIS COUNTY
SALT LAKE COUNTY
GREAT SALT LAKE
4240
4260
4280
4300
0 5 10 KILOMETERS
0 5 MILES



EXPLANATION

AREA IN WHICH MOST WELLS THAT OBTAIN WATER FROM THE BASIN FILL FLOW UNDER ARTESIAN PRESSURE (1980)

CONSOLIDATED ROCK

LINE OF EQUAL ALTITUDE OF THE POTENTIOMETRIC SURFACE, MARCH 1971 (after Bjorklund and McGreevy, 1974, pl. 2). Contour interval 10 and 20 feet. Arrow shows direction of ground-water flow. Datum is National Geodetic Vertical Datum of 1929 (sea level).

APPROXIMATE CONTACT BETWEEN VALLEY FILL AND CONSOLIDATED ROCK

APPROXIMATE BOUNDARY OF AREA WITH FLOWING WELLS

Figure 27. Potentiometric surface and approximate flowing-well area in the Bear River Bay area.

The potentiometric surface in much of the Bear River Bay area is within 20 feet of the level of Great Salt Lake. Recharge of ground water in this area is chiefly near the base of the Wasatch Range and in the valley area to the north. Because of the low gradient of the potentiometric surface and the fine-grained nature of the basin fill in this area, ground water moves very slowly. It discharges chiefly by evapotranspiration in and around the Bear River National Wildlife Refuge. Very little, if any, ground water reaches Great Salt Lake, which is adjacent to the Refuge on the south.

Most of the water in the consolidated rocks in mountainous parts of the Wasatch Front area is fresh and generally contains less than 500 milligrams per liter of dissolved solids. Local exceptions are in and near mining districts where the water has been in contact with easily dissolved ore minerals, or its quality has been affected by mining activities. Even in those areas, however, the water generally is only slightly saline.

The chemical quality of water in most of the principal ground-water reservoirs generally is suitable for most uses but quite variable as shown in figures 29–33. In all the reservoirs, with the exception of northern Juab Valley, the freshest water is in and near the principal areas of recharge along the Wasatch Range. The generally more mineralized ground water

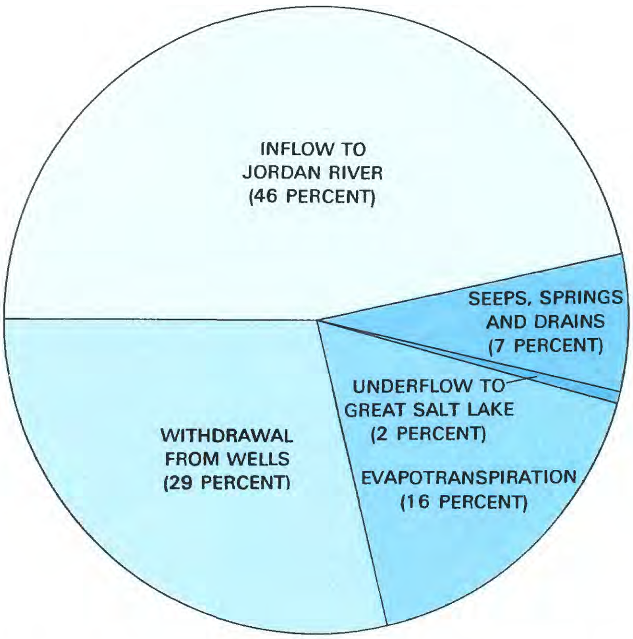


Figure 28. Annual rates of discharge from the ground-water reservoir in the Salt Lake Valley by various means.

More than 45 percent of the 367,000 acre-feet of water discharged each year from the ground-water reservoir in the Salt Lake Valley is inflow to the Jordan River. Withdrawal from wells (about 107,000 acre-feet) accounted for nearly 30 percent of the annual discharge. The diagram is based on average annual estimates for 1964–68 (Hely and others, 1971, table 22).

in the southeastern part of northern Juab Valley (fig. 29) is attributed to a salt-bearing geologic formation that crops out in the Wasatch Range east of Nephi and probably has contributed salt-bearing erosional material to the valley fill in the Nephi area. The saline water in Goshen Valley (fig. 30), the northeastern part of Salt Lake Valley (fig. 31), and locally in the East Shore area (fig. 32) is attributed to thermal saline water rising along faults and apparently seeping into the basin fill. Recharge with saline irrigation water, residual salt in the basin fill, and concentration of salts in ground water by evapotranspiration probably are the principal causes of the widespread occurrence of saline water in the Bear River Bay area ground-water reservoir.

Dissolved-solids concentrations of the ground water generally increases with depth. In many artesian areas, however, the reverse occurs as freshwater from deep artesian aquifers leaks upward through confining beds into progressively shallower aquifers, dissolving minerals along the way. This is, for example, true in the area south of American Fork (fig. 30) where several wells deeper than 250 feet yield water with less than the indicated 500 to 1,000 milligrams per liter of dissolved solids.

Temperature is an important property of ground water, particularly with regard to use for public supply, artificial recharge, certain industries, and possible development of geothermal energy. The degree of success of most artificial-recharge operations (or fluid-waste disposal) depends largely on the thermal compatability of the recharge water and the natural ground water. The efficiency of industrial cooling systems that require water to dissipate heat depends at least in part on the initial temperature of the cooling water. Finally, the areal distribution of thermal water—water whose temperature is at least 5°C (Celsius) warmer than the mean annual air temperature of the area in which the water occurs—is a guide in locating potential sites for development of geothermal energy.

Temperatures of the water in the principal ground-water reservoirs of the Wasatch Front area generally range from about 5° to 25°C—generally 5° to 15°C in principal recharge areas and 15° to 25°C in principal areas of natural discharge. Thermal ground water, with temperatures locally exceeding 40°C, occurs in the areas of the major thermal springs shown in figure 6.

RELATION OF GROUND WATER AND SURFACE WATER

To Alter One Is to Alter the Other

Surface water and ground water in the Wasatch Front area are hydraulically connected, as illustrated in figure 34. Some Wasatch Front streams, such as Big and Little Cottonwood Creeks in the Salt Lake Valley, contribute significantly to ground-water recharge. The downstream reaches of those same streams, however, receive most of their late summer to early spring flow from the ground-water reservoir. During the winter, the Jordan River also receives most of its flow from the ground-water reservoirs in Utah and Salt Lake Valleys. As was shown in figure 28, inflow to the Jordan River accounts for nearly one-half the annual ground-water discharge from the Salt Lake Valley ground-water reservoir.

Because of this hydraulic connection, any change in the surface-water system would doubtless affect the ground-water system. For example, lining the channel of a losing stream reach with impervious concrete would decrease recharge to the ground-water reservoir. Conversely, increasing withdrawals of ground water by wells may eventually decrease the flow in the downstream reaches of streams as illustrated in figure 34.

The relation does not only pertain to the availability of water, it also pertains to the quality of water. Because ground-water recharge comes in part from surface-water sources, its quality reflects the quality of the surface water. Similarly, the quality of the flow in most downstream reaches reflects the quality of the ground water from which that flow is derived. Recharge with slightly saline irrigation water from the Bear and Jordan Rivers locally tends to degrade the quality of the ground water. Conversely, water in streams, the lower Bear River in particular, is degraded by inflow of very saline or briny ground water (chiefly from thermal springs).

GROUND-WATER WITHDRAWALS

Wells in the Principal Ground-Water Reservoirs

Ground-water withdrawal as discussed here is the withdrawal of water from the principal ground-water reservoirs by wells. The diversion of water at springs and the construction of drains are not discussed here because their effects on the ground-water system are relatively small compared to withdrawals by wells at the present (1982) level.

Withdrawal of ground water by wells in the Wasatch Front area began within a few years after the arrival of the Mormon pioneers in the Salt Lake Valley in 1847. As the population increased and new settlements were established through out the Wasatch Front area, more water was withdrawn from an increasing number of wells. The earliest wells were mostly shallow dug wells and small diameter drilled and jetted wells constructed to obtain water for domestic and stock use. By the early 1930's, brought about in part by the growing population and the major drought of the 1930's, an increasing number of large-capacity industrial, public supply, and irrigation wells were being drilled throughout the area.

Few records were kept of ground-water withdrawals prior to 1930. It has been estimated, however, that by 1931, annual withdrawals by wells in the Salt Lake Valley alone were at least 38,000 acre-feet. They increased to about 136,000 acre-feet in 1979 (fig. 35). In 1963, when the U.S. Geological Survey began to determine annual withdrawals from wells in Utah (under a continuing cooperative program with the Utah Division of Water Resources), withdrawals from the principal ground-water reservoirs in the Wasatch Front area were about 260,000 acre-feet. By 1979, a year when there was a relatively large demand for ground water for public supply and irrigation, the withdrawals had increased to about 320,000 acre-feet.

The largest withdrawals are from the ground-water reservoirs in Salt Lake, Utah and Goshen Valleys, and the East Shore area (fig. 36). Principal uses of the water are for public supply and irrigation (fig. 37). Types of ground-water use have shifted significantly since 1965, as illustrated in figure 38. The shift reflects growing population and decreased agriculture in the area and dependence on ground water to help support population increase.

The effects of ground-water development are reflected in declines of water levels in wells (figs. 39

A NOTE ABOUT FIGURES 29–33

The ranges of dissolved-solids concentrations shown in figures 29–33 are those that are most commonly found in well water. They were compiled using chemical analyses of water from several hundred wells, most of which are less than 1,000 feet deep; therefore, the ranges of dissolved solids shown represent only the upper 1,000 feet of saturated fill. In most places ground water tends to become more saline below depths of about 1,000 feet; thus, water in the fill at depths greater than 1,000 feet may contain greater concentrations of dissolved solids than indicated in figures 29–33. Information about other chemical characteristics of the ground water may be obtained from reports listed in "Selected References."

EXPLANATION

DISSOLVED-SOLIDS CONCENTRATION, IN MILLIGRAMS PER LITER

LESS THAN 500

500—1000

1000—3000

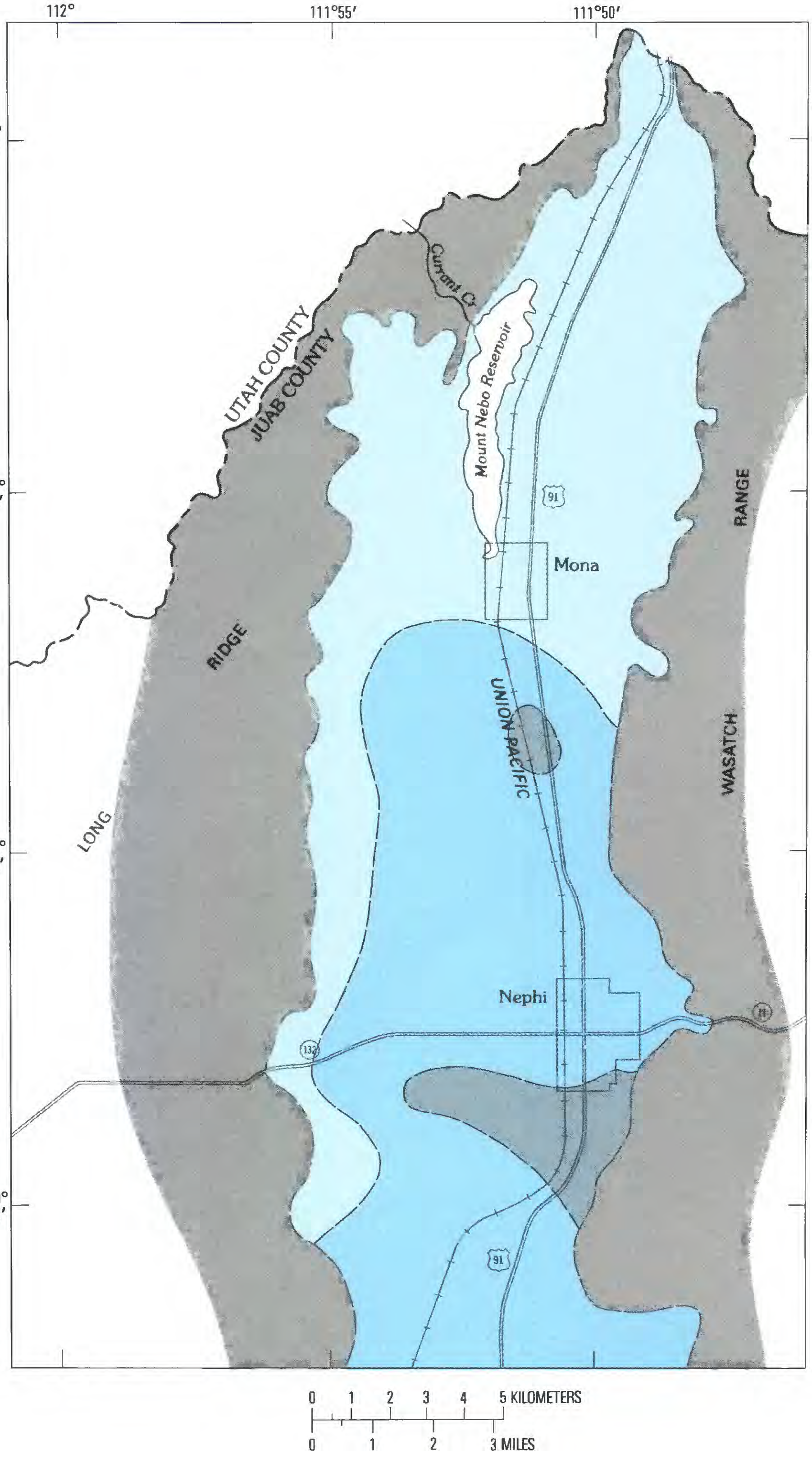
CONSOLIDATED ROCK

APPROXIMATE CONTACT BETWEEN VALLEY FILL AND CONSOLIDATED ROCK

APPROXIMATE BOUNDARY BETWEEN AREAS WITH DIFFERENT DISSOLVED-SOLIDS CONCENTRATIONS

Figure 29 (above and facing page). Dissolved-solids concentrations of water in the principal ground-water reservoir in northern Juab Valley.

The ground water generally is fresh; however, dissolved-solids concentrations generally exceed 500 milligrams per liter and locally exceed 1,000 milligrams per liter south of Mona. These larger concentrations apparently were derived from a salt-bearing geologic formation. This formation is exposed in the watershed east of Nephi and has contributed salt-bearing erosional material to the basin fill in the Nephi area.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39° 40′
UTAH COUNTY
JUAB COUNTY
Currant Cr
Mount Nebo Reservoir
Mona
Nephi
LONG
RIDGE
WASATCH
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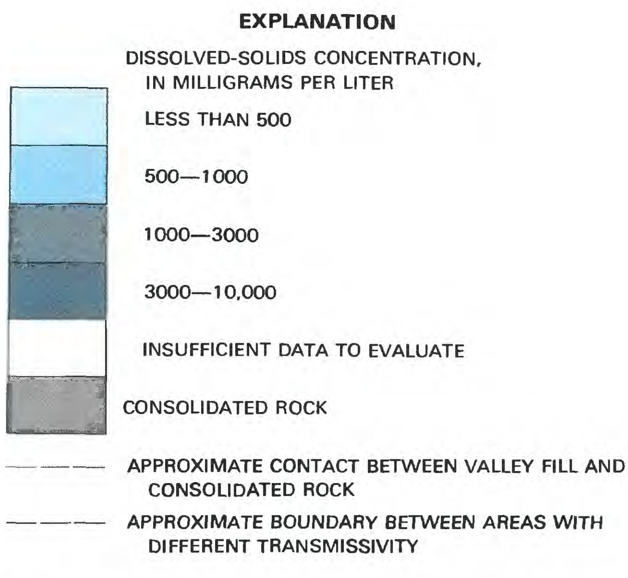
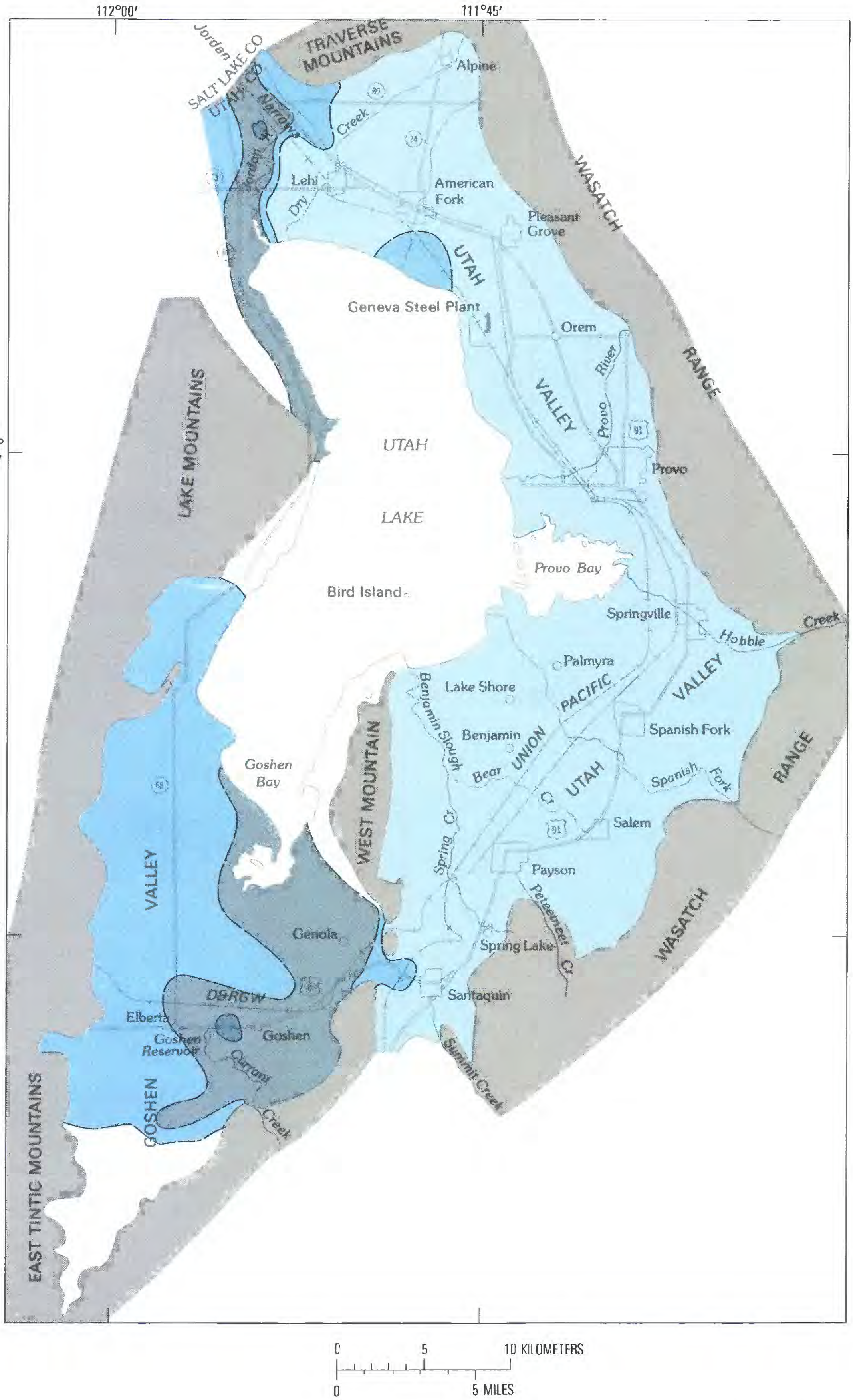


Figure 30 (above and facing page). Dissolved-solids concentrations of water in the principal ground-water reservoir in Utah and Goshen Valleys.

In Utah Valley, most of the ground water is fresh; dissolved-solids concentrations generally are less than 500 milligrams per liter and locally are less than 250 milligrams per liter. In the eastern part of Goshen Valley and in the northwestern part of Utah Valley, the water generally is slightly saline and locally moderately saline with dissolved-solids concentrations ranging from 1,000 to 10,000 milligrams per liter. These large concentrations may be due to movement into the fill of saline water that rises along a major inferred north-trending fault zone between West Mountain and the Lake Mountains (fig. 6). (Data for Pleasant Grove–Jordan Narrows area in part after David Clark, U.S. Geological Survey, written commun., 1982.)


112°00′
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TRAVERSE MOUNTAINS
SALT LAKE CO
UTAH CO
Jordan
Narrows
Alpine
Dry
Creek
Lehi
American Fork
Pleasant Grove
WASATCH
UTAH
Geneva Steel Plant
Orem
Provo River
RANGE
VALLEY
LAKE MOUNTAINS
UTAH
LAKE
Provo
Provo Bay
Bird Island
Springville
Hobble Creek
Palmyra
Lake Shore
PACIFIC
VALLEY
Benjamin Slough
Benjamin
UNION
Spanish Fork
Goshen Bay
WEST MOUNTAIN
Bear Cr
UTAH
Spanish Fork
RANGE
Salem
Spring Cr
Payson
VALLEY
Peteetneet Cr
Genola
Spring Lake
WASATCH
D&RGW
Santaquin
Elberta
Goshen Reservoir
Goshen
Currant Creek
Summit Creek
GOSHEN
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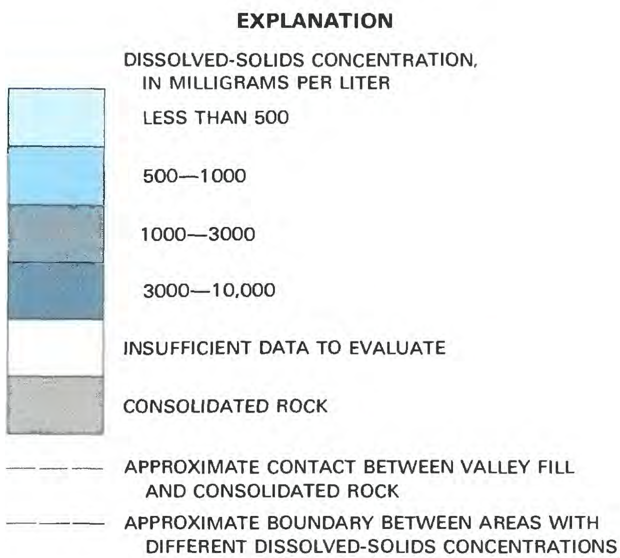
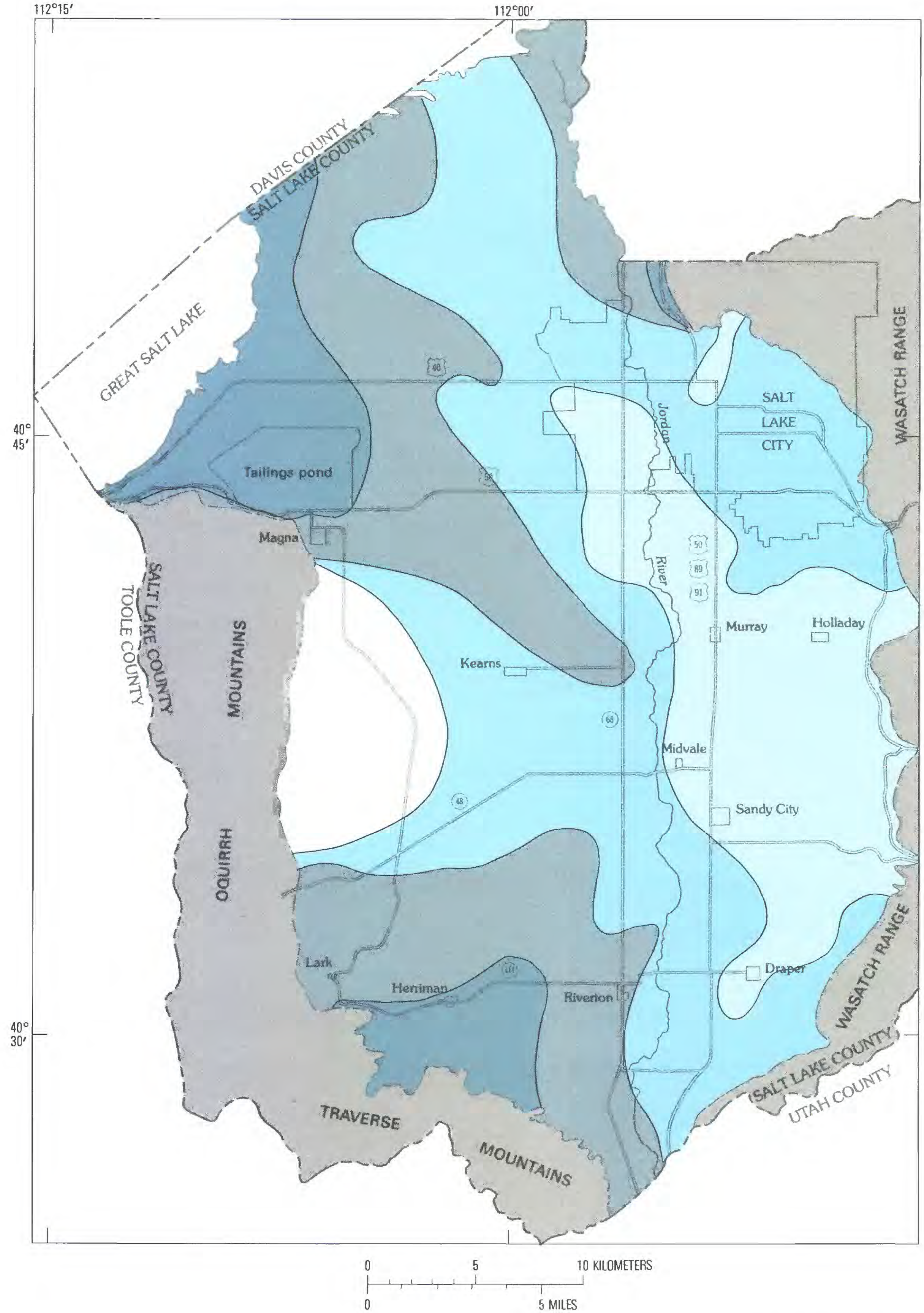


Figure 31 (above and facing page). Dissolved-solids concentrations of water in the principal ground-water reservoir in the Salt Lake Valley.

In the Sandy-Holladay area, dissolved-solids concentrations generally are less than 500 milligrams per liter and commonly are less than 300 milligrams per liter. These relatively small concentrations reflect recharge of fresh water from Big and Little Cottonwood Creeks and consolidated rocks in the adjacent part of the Wasatch Range. The greater concentrations, in the area north of Salt Lake City, may be due to saline water entering the fill along a fault. In the Herriman area, they are attributed to mining activities. (See Hely and others, 1971, p. 164.) In the area northwest of Kearns, they probably are due to a number of reasons including the long distance the water has traveled from recharge areas and the relatively slow rate of movement through the generally fine-grained fill in the lower part of the valley. In most other areas, they may be attributed to recharge from slightly saline irrigation water diverted from the Jordan River.


112°15′
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40° 45′
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DAVIS COUNTY
SALT LAKE COUNTY
GREAT SALT LAKE
Tailings pond
Magna
SALT LAKE COUNTY
TOOLE COUNTY
OQUIRRH
MOUNTAINS
Kearns
Jordan
River
SALT
LAKE
CITY
WASATCH RANGE
Murray
Holladay
Midvale
Sandy City
Draper
Lark
Herriman
Riverton
TRAVERSE
MOUNTAINS
UTAH COUNTY
0
5
10 KILOMETERS
0
5 MILES

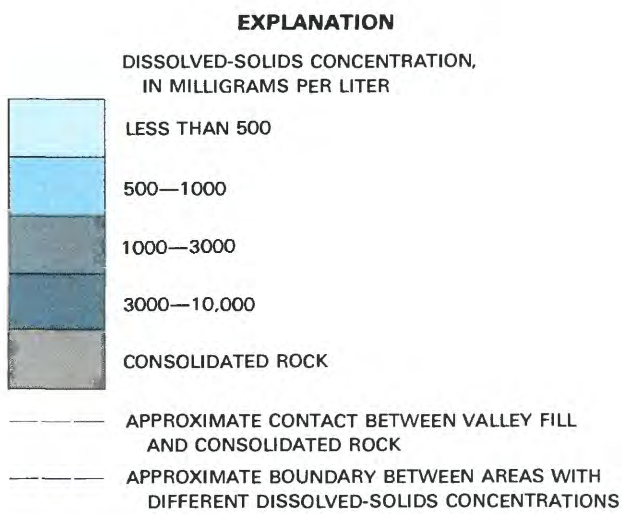
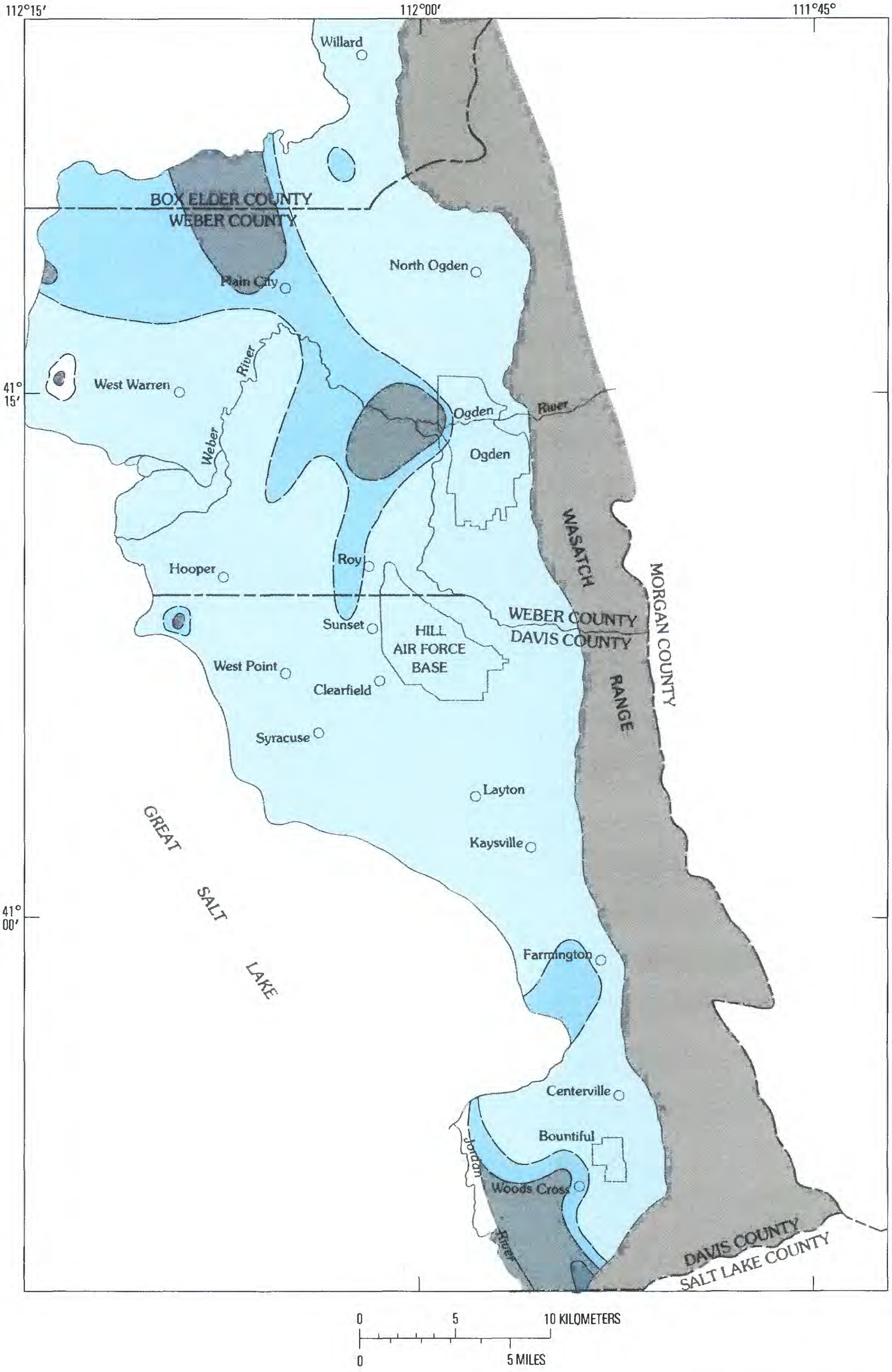


Figure 32 (above and facing page). Dissolved-solids concentrations of water in the principal ground-water reservoir in the East Shore area.

Nearly all the water in the fill of the East Shore area is fresh. Dissolved-solids concentrations in most of the area generally are less than 500 milligrams per liter; and in the Kaysville-Clearfield area, they are commonly less than 250 milligrams per liter. A well that is 6 miles offshore west of Syracuse produced water that contained less than 500 milligrams per liter of dissolved solids, indicating that the freshwater in the fill extends considerably beyond the shore of Great Salt Lake. The locally saline ground water along the west edge of the area may be due to movement into the fill of saline water along a fault. Northwest of Ogden, it probably is due to very slow movement of the water through fine-grained basin fill.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MORGAN COUNTY
Hooper
Roy
Sunset
HILL AIR FORCE BASE
WEBER COUNTY
DAVIS COUNTY
West Point
Clearfield
Syracuse
Layton
Kaysville
GREAT SALT LAKE
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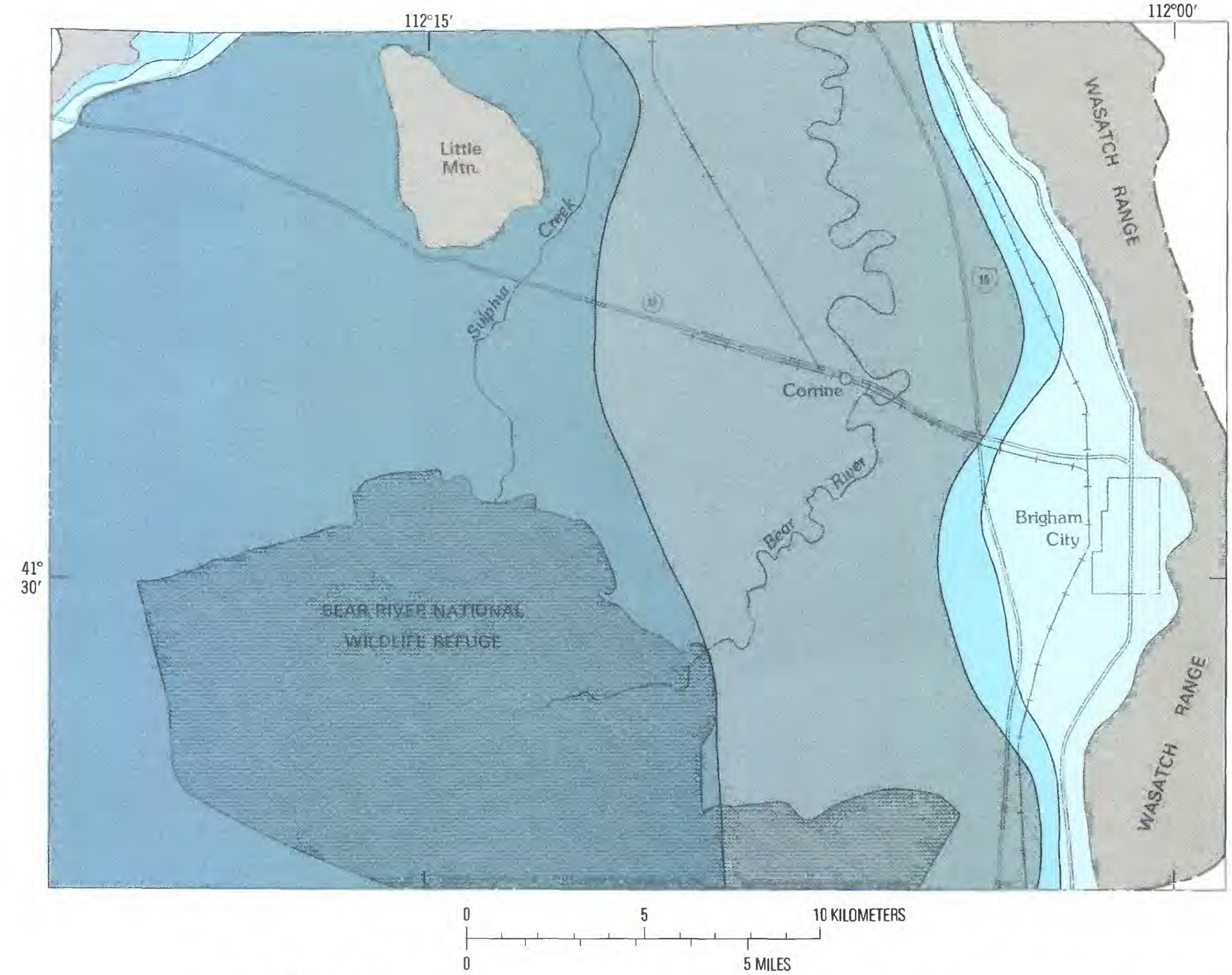


EXPLANATION

DISSOLVED-SOLIDS CONCENTRATION, IN MILLIGRAMS PER LITER

- LESS THAN 500
- 500—1000
- 1000—3000
- 3000—10,000
- CONSOLIDATED ROCK

APPROXIMATE CONTACT BETWEEN VALLEY FILL AND CONSOLIDATED ROCK

APPROXIMATE BOUNDARY BETWEEN AREAS WITH DIFFERENT DISSOLVED-SOLIDS CONCENTRATIONS

Figure 33. Dissolved-solids concentrations of water in the principal ground-water reservoir in the Bear River Bay area.

The eastern part of the reservoir receives recharge from the Wasatch Range and the ground water there generally is fresh; however, water in the rest of the reservoir is saline, generally containing 1,000 to 10,000 milligrams per liter of dissolved solids. The sources of these large concentrations include recharge from saline and nearly saline irrigation water and seepage into the fill of saline water rising along faults. Very slow movement of water through the fine-grained fill of this area and evapotranspiration also contribute to the large dissolved-solids concentrations.

and 40) and general changes in the potentiometric surface (figs. 41-44). The declines of the water levels in the well east of Sandy (fig. 39) and the well west of Ogden (fig. 40) are due chiefly to increased withdrawals of ground water for public supply and industrial use. As shown in figures 43 and 44, the declines are rather widespread; although in other parts of the Salt Lake Valley, water levels rose during the same period in response to increased recharge from lawn watering and irrigation. Water levels also rose throughout much of Utah, Goshen, and northern Juab Valleys (figs. 41

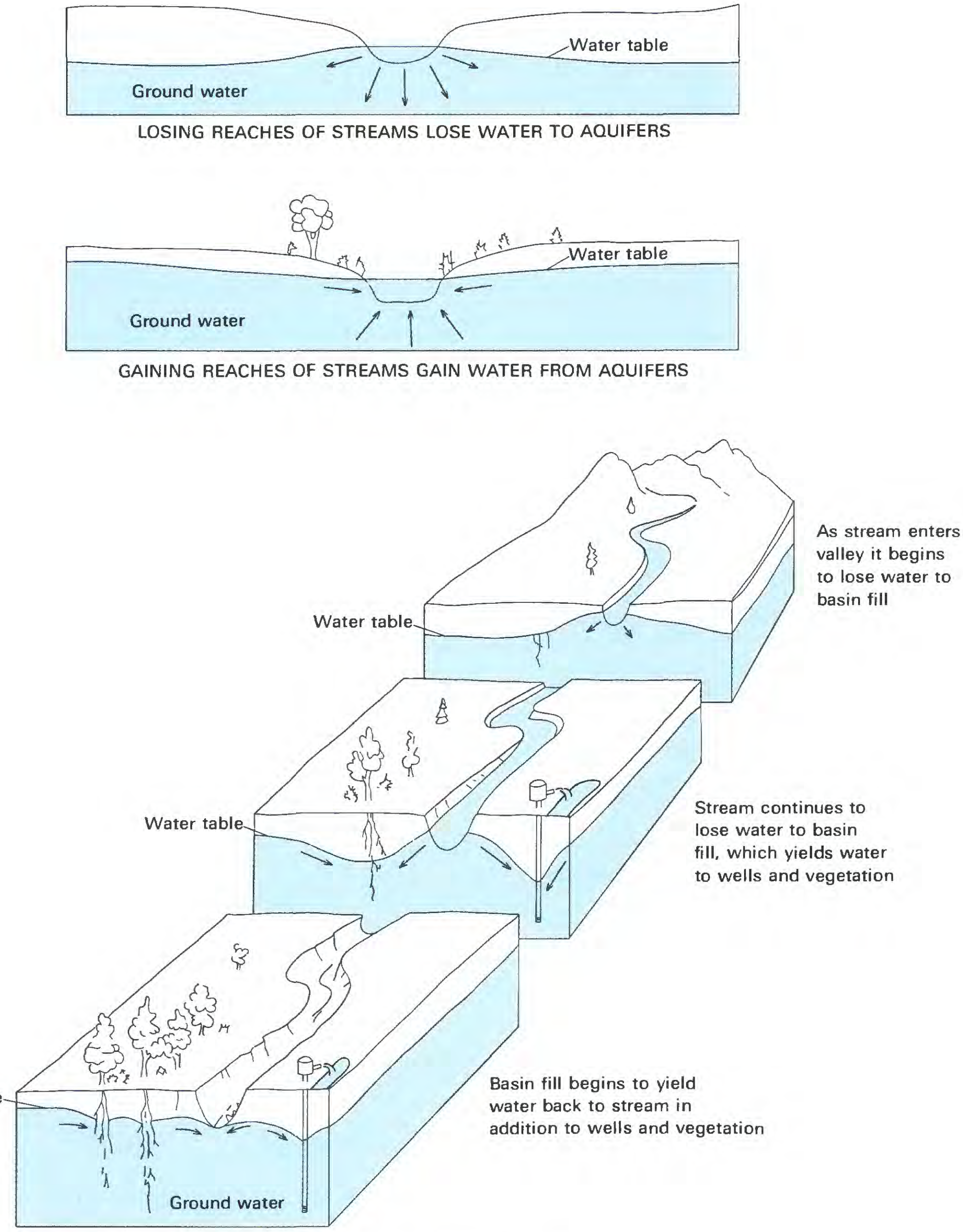


Figure 34. Relation between ground water and surface water.

A continual interchange of water occurs between streams and the valley ground-water reservoirs. Along their losing reaches, generally near the margins of the valleys, streams contribute water to the ground-water reservoirs; along their gaining reaches, generally in the lower valley areas, the streams receive water from the reservoirs. The quality as well as availability of surface and ground water can be affected by this interchange. As shown, vegetation (phreatophytes) and discharging wells can affect streamflow in both the losing and gaining reaches.

and 42). The localized declines in these valleys are due to withdrawals for irrigation and industry as well as public supply. Data from which to determine changes of the potentiometric surface in the Bear River Bay area are insufficient. However, withdrawals from wells there have not increased greatly during the past several decades, and no evidence exists of any significant water-level declines during 1965-80.

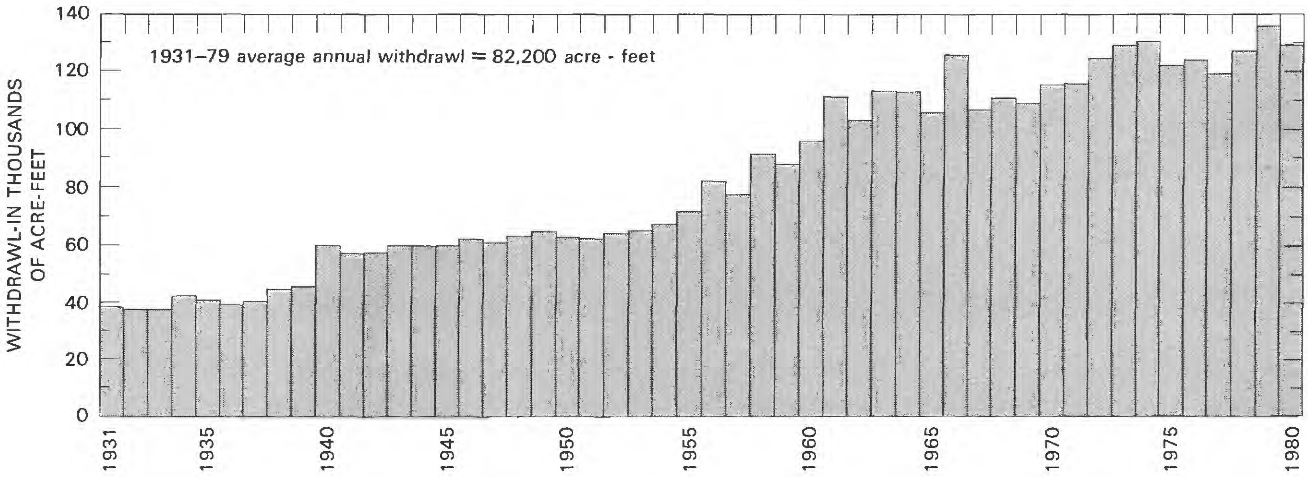


Figure 35. Annual withdrawals from wells in the Salt Lake Valley, 1931–80.

The increase in annual withdrawals from the principal ground-water reservoirs in the Wasatch Front area is reflected in the records for Salt Lake Valley. Withdrawals began within a few years after the arrival of the Mormon pioneers in the valley in 1847. Annual withdrawals in the valley increased to nearly 40,000 acre-feet in 1931 and were as large as 136,000 acre-feet in 1979 (from Herbert and others, 1981, fig. 6).

PROBLEMS ASSOCIATED WITH GROUND-WATER WITHDRAWALS

Some of the Hidden Costs

Theis (1940, p. 280) listed some of the basic principles regarding ground-water withdrawals, and a summary of them follows:

1. All water discharged by a well is balanced by a loss of water somewhere in the system. The loss may be depletion of aquifer storage, decrease in streamflow, decrease of evapotranspiration, or decreased normal ground-water flow from the area.
2. The loss is in many instances largely from aquifer storage. Some ground water is always mined (taken from storage). The ground-water reservoir is in effect bounded by time, by boundaries of rocks with little permeability on its sides and base, and by the water table. The volume of water removed from storage is proportional to the drawdown of the ground-water level, which, in turn, is proportional to the rate of pumping.
3. If drawdown of ground-water levels occurs in an area of recharge, the well discharge may be replaced, at least in part, by an increase in the recharge. If there were no source of additional recharge, or if the increased recharge were by increased seepage from a stream, an economic loss could result owing to resulting decrease in spring or stream discharge.
4. If the drawdown of ground-water level reaches areas of natural discharge, further discharge by wells will be replaced, in part, by a decrease in natural discharge. If this natural discharge flowed into surface streams, prior rights to the surface water may be adversely affected. If it flowed into a wetland area (such as those around Great Salt Lake) a valuable wildlife refuge may be partly or wholly destroyed.
5. In artesian aquifers, decline of artesian pressure spreads with great rapidity, and each well in a short time has its maximum effect on the whole aquifer and obtains most of its water by increase of recharge or decrease of natural discharge.

Water levels (or artesian pressures) in the vicinity of a discharging well or group of wells will decline as long as the rate of well discharge exceeds the rate of recharge to (or natural discharge from) the aquifers supplying the water. Decline of water levels is in the form of an inverted cone (cone of depression), as shown in figure 45. As the cone expands and deepens, the volume of water moving toward the well(s) will increase until it equals the volume discharged by the well(s); then the water level should cease to decline. When the wells cease to discharge, the water levels should rise again. When water levels decline around a discharging well, they also may decline in nearby wells, thus affecting the yield of those wells. Consequently, in areas of closely spaced wells, such as most of the Wasatch Front area, declining water levels caused by discharging wells can result in water-right conflicts. This is especially true in areas of artesian flow (figs. 23-27) where large pumped wells can draw water levels down below the outlet of flowing wells, so that the flow of these wells ceases.

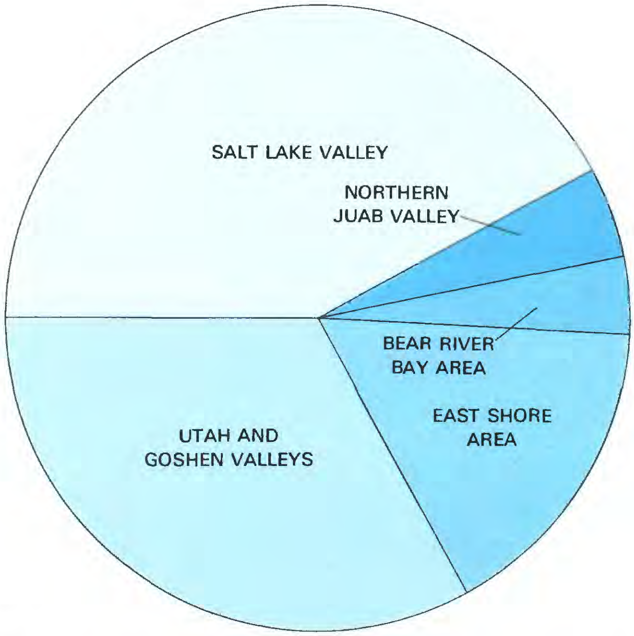


Figure 36. Withdrawal by wells from principal ground-water reservoirs, 1979.

Of the 323,000 acre-feet of water withdrawn from wells in the Wasatch Front area during 1979, 75 percent was withdrawn from Salt Lake, Utah, and Goshen Valleys. The 323,000 acre-feet was about 38 percent of the total ground-water withdrawal in Utah during 1979.

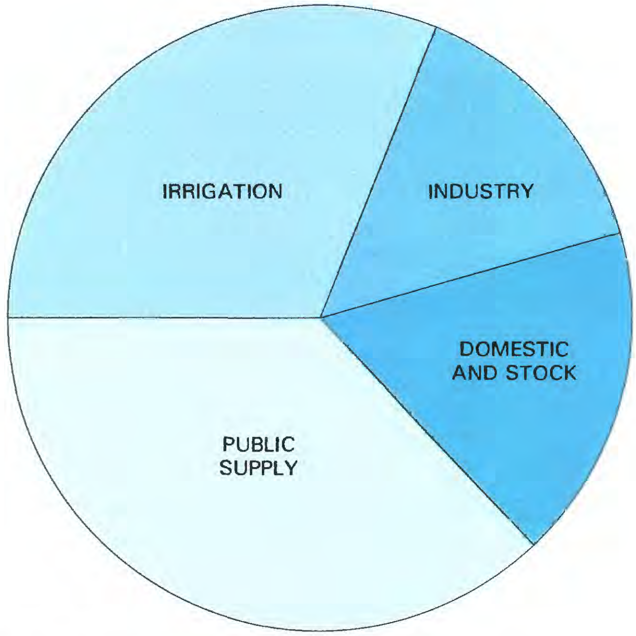


Figure 37. Withdrawal by wells from the principal ground-water reservoirs for various uses, 1979.

Of the 323,000 acre-feet of water withdrawn from wells in the Wasatch Front area during 1979, about 37 percent was used for public supply and 31 percent was used for irrigation.

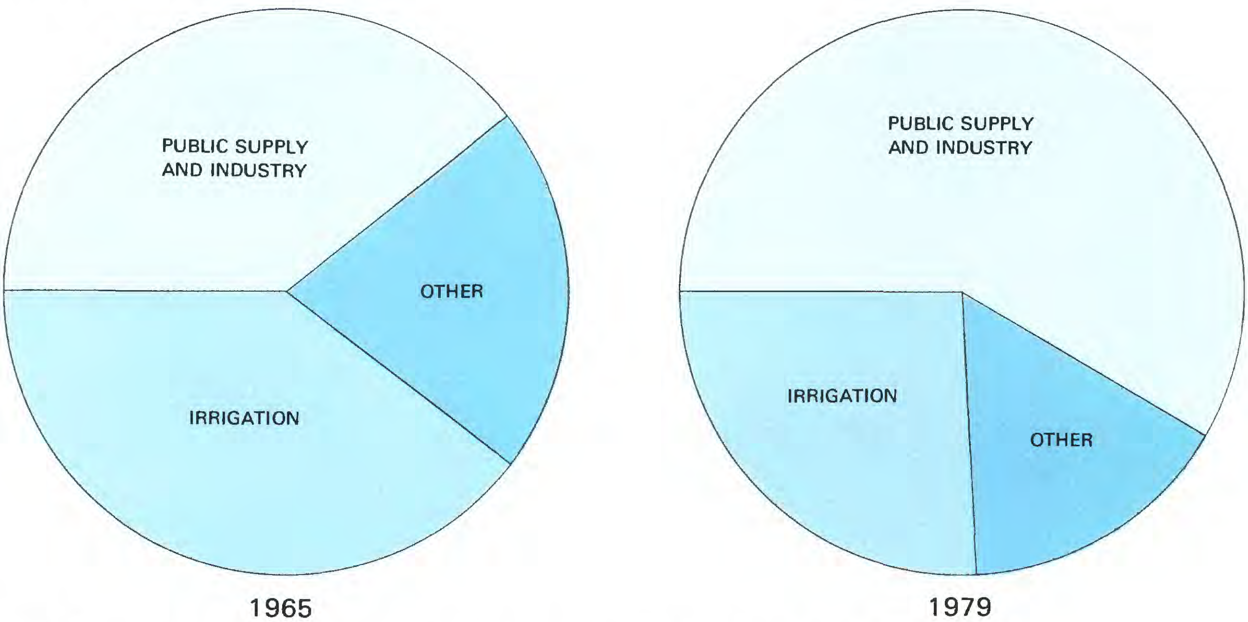


Figure 38. Use of water withdrawn by wells in the central Wasatch Front area, 1965 and 1979.

Of the total ground-water withdrawal in the densely populated central part of the Wasatch Front area (Utah and Goshen Valleys, Salt Lake Valley, and East Shore area), that withdrawn for irrigation decreased from 40 percent in 1965 to 26 percent in 1979; that withdrawn for public supply and industry increased from 40 percent in 1965 to 58 percent in 1979.

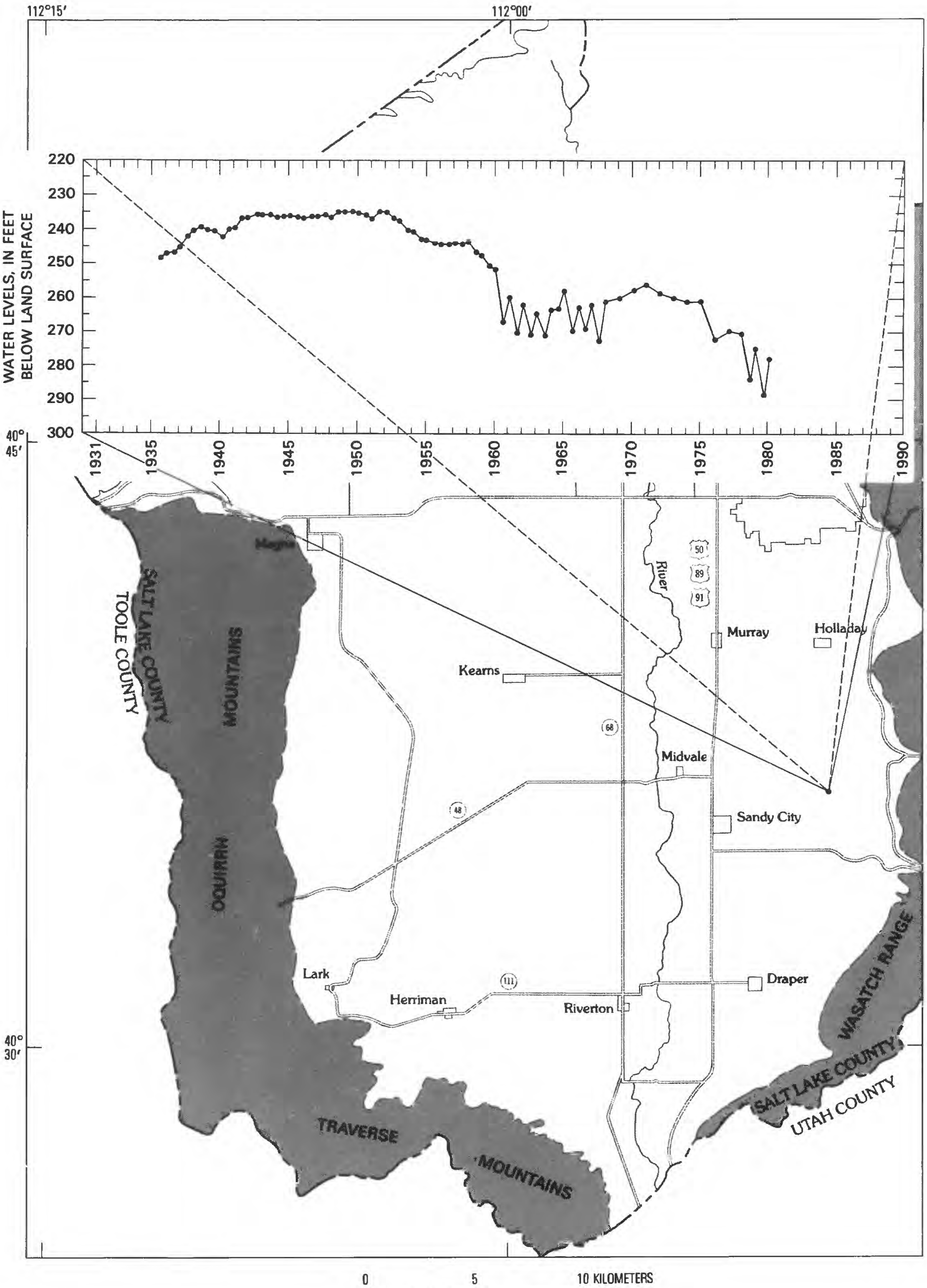


Figure 39 Change in the ground-water level in a well in the Salt Lake Valley.

The graph was compiled from measurements of the water level in a well at the indicated site. The graph shows a progressive decline in ground-water level since about 1952. The decline is attributed primarily to withdrawals of ground water in the Sandy-Holladay area for public supply.

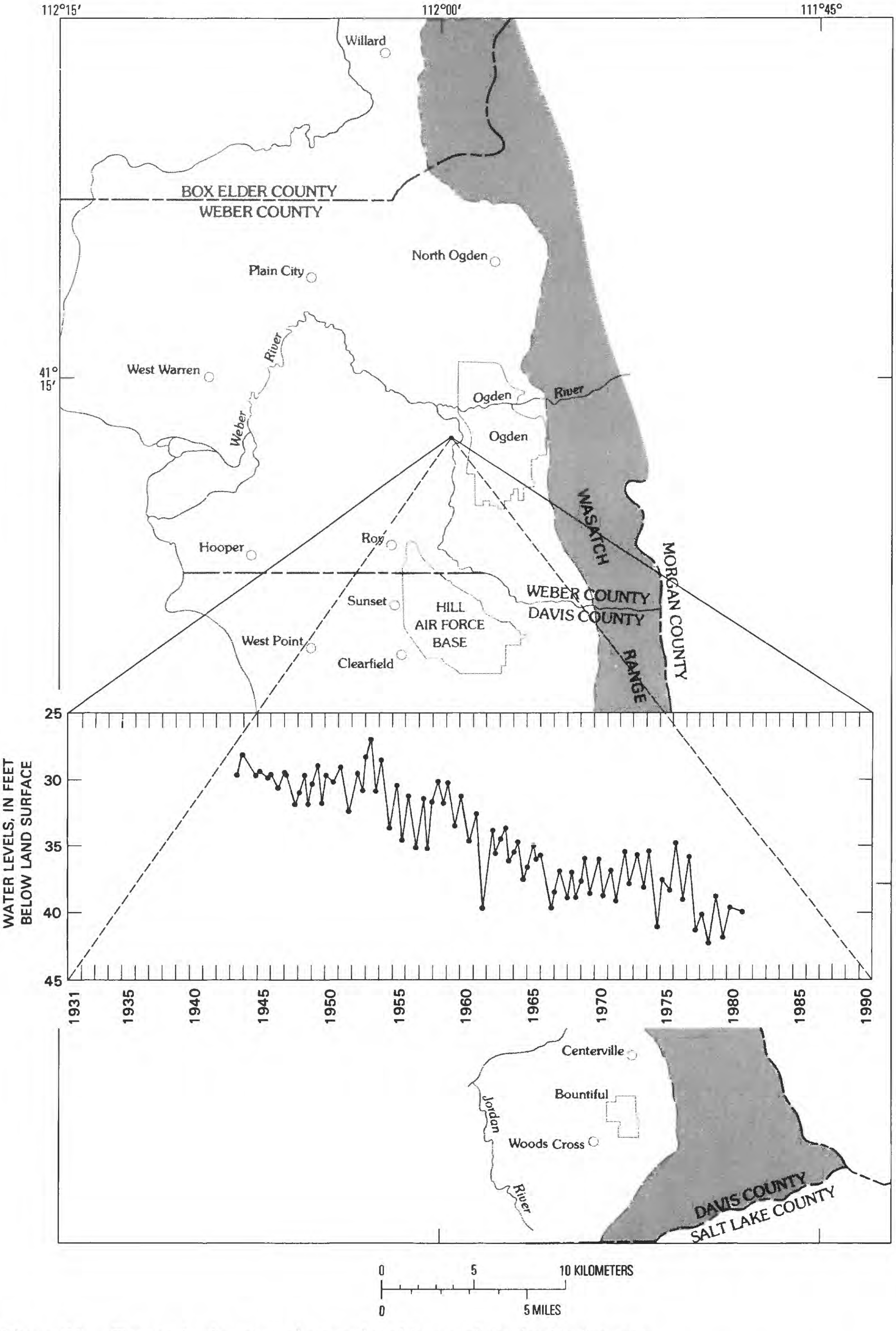


Figure 40. Change in the ground-water level in a well in the Ogden area.

The graph was compiled from measurements of the water level in a well at the indicated site. The water level has been declining in this well since 1953. The declines are attributed chiefly to withdrawals of ground water in the Clearfield-Ogden area for public supply and industry.

If wells continue to discharge at rates greater than the rate of recharge to the aquifers that supply the water, water levels will continue to decline, and the decline may become widespread. This appears to be what has happened in parts of Utah and Goshen Valleys, the Salt Lake Valley, and the East Shore area, as indicated in figures 42–44.

When ground-water levels decline, the cost of the water increases. This is because it becomes more costly to pump the water from the greater depth, wells may need to be drilled deeper, and larger pumps may be required. If wells have to be drilled deeper, there is a possible increased cost due to conflicts among water-right owners because of the effect on other existing wells.

Declining water levels in some aquifers also may lead to deterioration of the quality of water. In many parts of the Wasatch Front area, fresh ground water is underlain by or is adjacent to saline water. The new pressure differential resulting from declining water levels could cause some of the saline water to migrate into the freshwater zone as shown in figure 45. This could eventually seriously deteriorate the quality of water discharged from some wells, including public-supply wells.

Some stream reaches derive all or part of their flow from ground water, as discussed earlier and illustrated in figure 34. Consequently, streamflow will be depleted when ground-water levels decline below the level of the stream. This would not only result in additional conflicts among water-right owners, but it also could have adverse physical impacts on in-stream water uses and wetlands supported by those streams, and the local esthetics in general.

Another serious problem that could be associated with declining water levels is land subsidence. The removal of water from and the decreasing of pressure in fine-grained sediments, which are interbedded with or are above aquifers, could result in compaction of those fine materials. This in turn results in a local lowering of the land surface. In populated areas, such as the Wasatch Front area, land subsidence could result in costly damage to buildings, sidewalks, and other structures—including the water-supply systems to which the subsidence is related. However, it is not known whether the sediments of the Wasatch Front area would react to water-level declines with compaction and land subsidence, or if they did, what magnitude of decline would cause these reactions.

GROUND WATER AND THE FUTURE

The Challenge and the Choices

The population of the Wasatch Front area probably will continue to increase well into the future. Industrial development and changes in land use from agricultural to urban and residential probably also will continue. These changes probably will affect the area's ground-water resources.

Changes in land use from agriculture to urban and residential, for example, will affect ground-water recharge. A large percentage of ground-water recharge in the Salt Lake Valley comes from irrigation (fig. 22), as is probably also true in the other valleys in the area. That percentage could be significantly decreased if large tracts of land in recharge areas are converted from irrigated farmland to urban use and the canals

A NOTE ABOUT FIGURES 41–44

Changes in the potentiometric surfaces shown in figures 41–44 were determined from water levels measured in about 160 observation wells during February and March of each year. Maps showing year-to-year changes in the potentiometric surfaces since 1963 may be found in Arnow and others (1964) and in succeeding members of that report series.

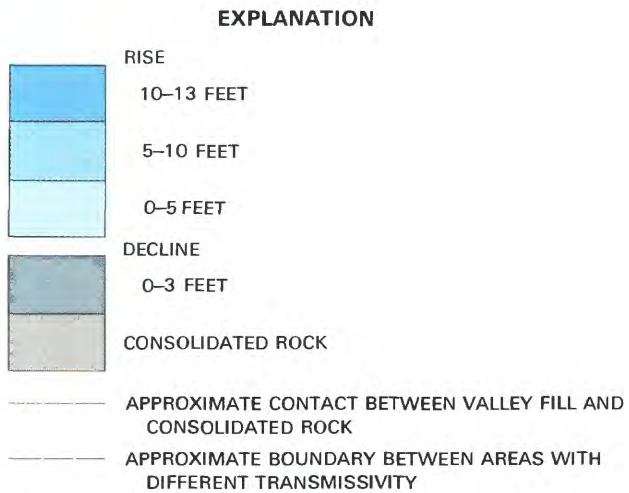
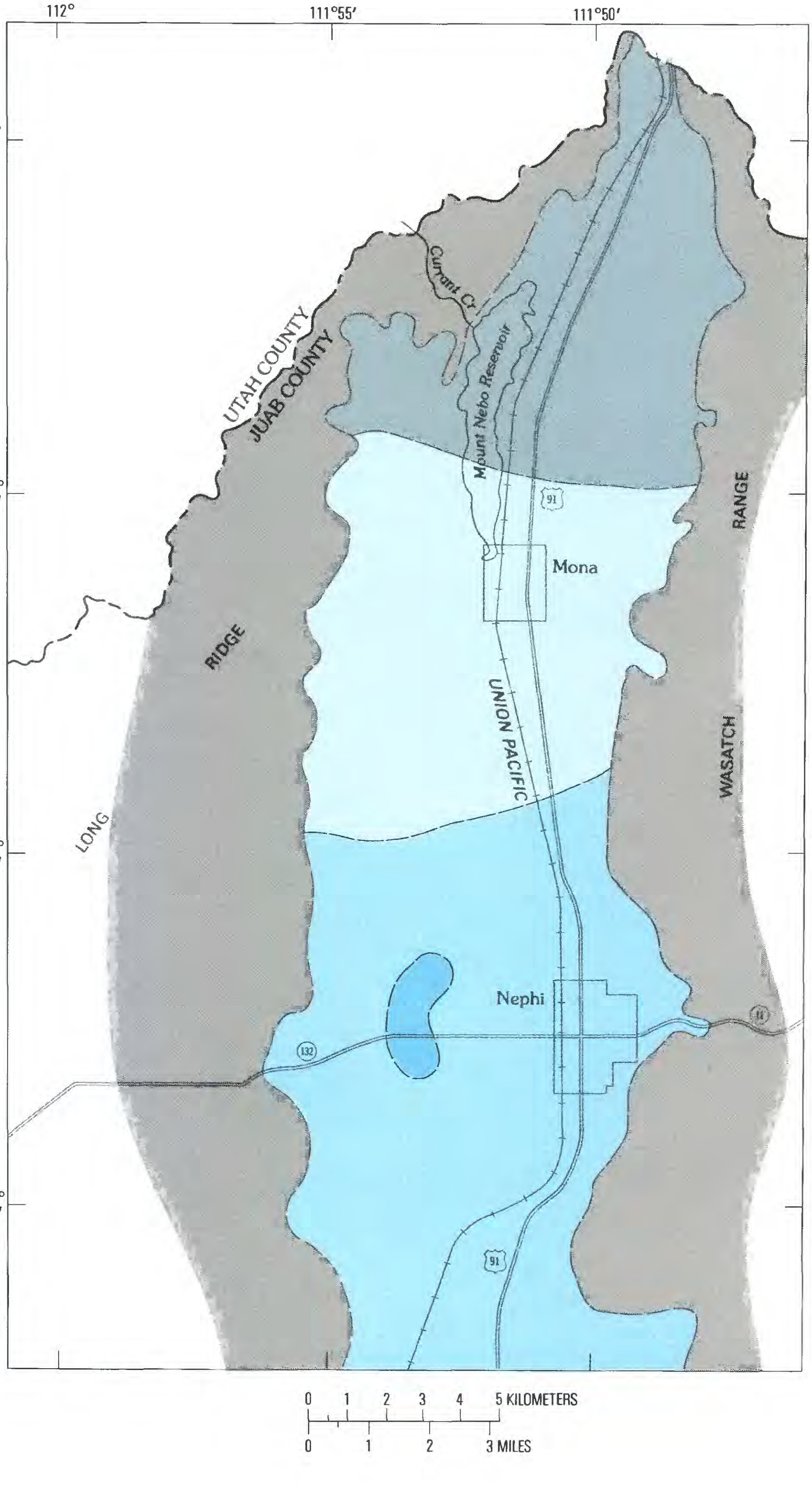


Figure 41 (above and facing page.) Changes in the potentiometric surface in northern Juab Valley, spring 1965–spring 1980.

Withdrawals of ground water from wells have had minor effect on the potentiometric surface in northern Juab Valley. The small declines in the northern end of the valley may be due chiefly to a natural short-term imbalance between recharge and discharge in the area rather than to withdrawal from wells.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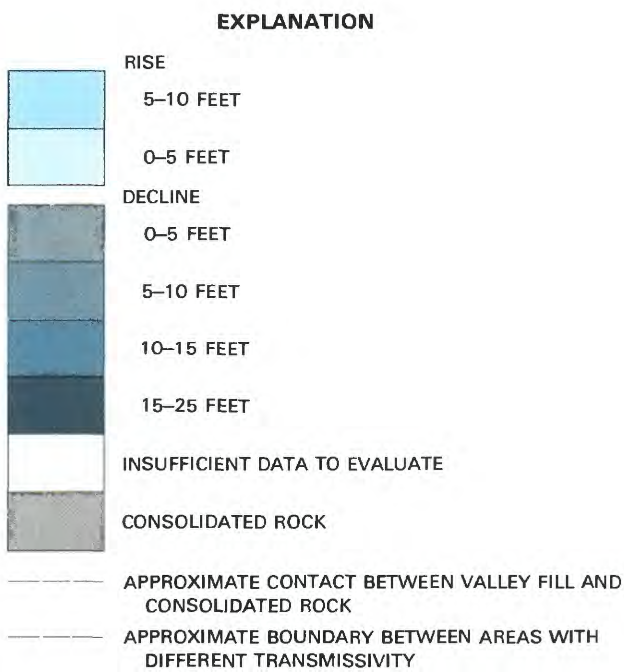
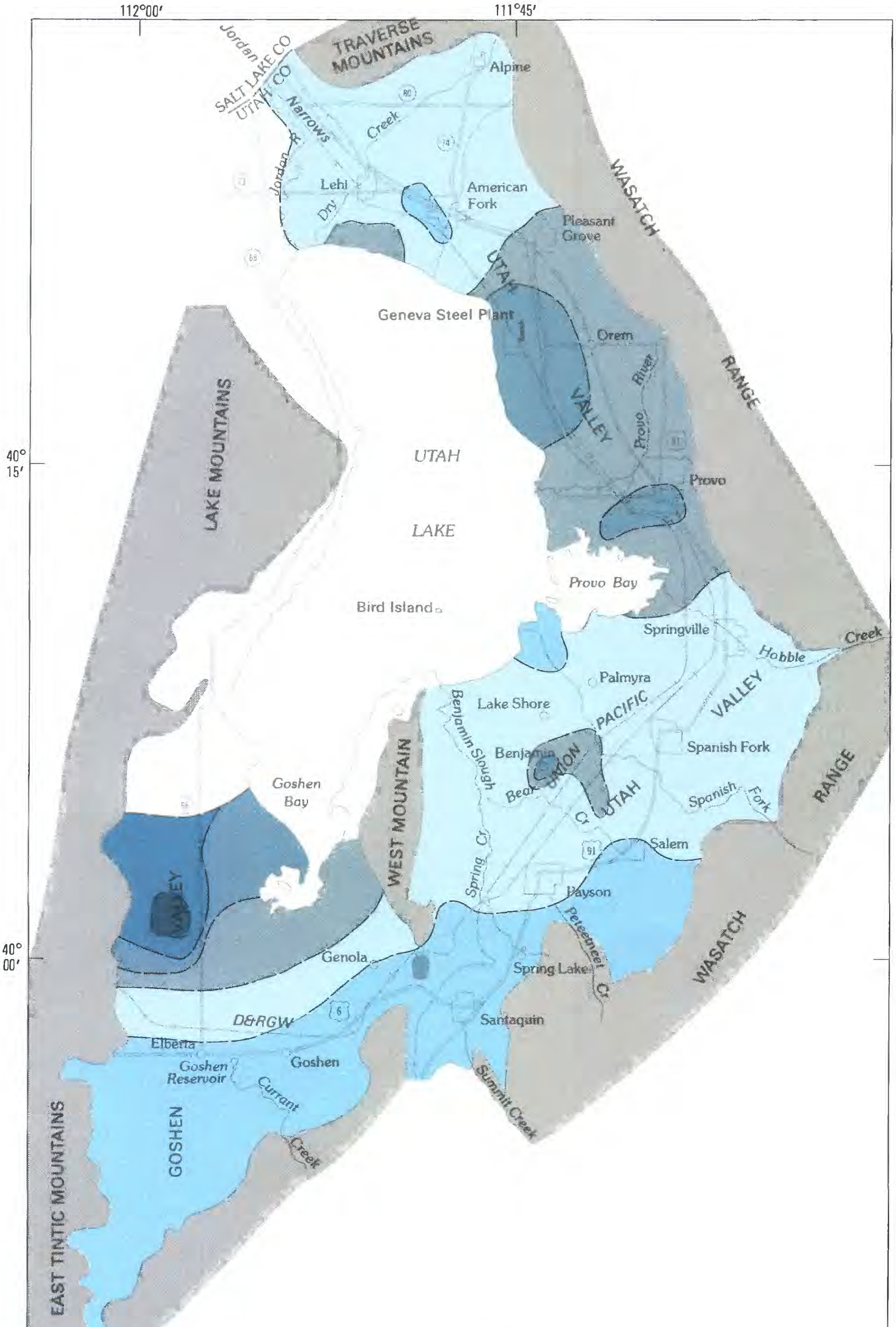


Figure 42 (above and facing page). Changes in the potentiometric surface in Utah and Goshen Valleys, spring 1965–spring 1980.

The potentiometric surface had a net decline of more than 24 feet north of Elberta from the spring of 1965 to the spring of 1980. The decline was due to withdrawals of ground water for irrigation.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Lehi
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Pleasant Grove
WASATCH
RANGE
UTAH
VALLEY
Geneva Steel Plant
Orem
Provo
River
Provo
UTAH
LAKE
LAKE MOUNTAINS
Provo Bay
Bird Island
Springville
Hobble
Creek
Palmyra
Lake Shore
Benjamin Slough
Benjamin
UNION PACIFIC
Bear
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UTAH
VALLEY
Spanish Fork
Spanish
Fork
RANGE
Goshen Bay
WEST MOUNTAIN
Spring Cr
Salem
Payson
Peteetneet Cr
Genola
Spring Lake
WASATCH
D&RGW
Santaquin
Elberta
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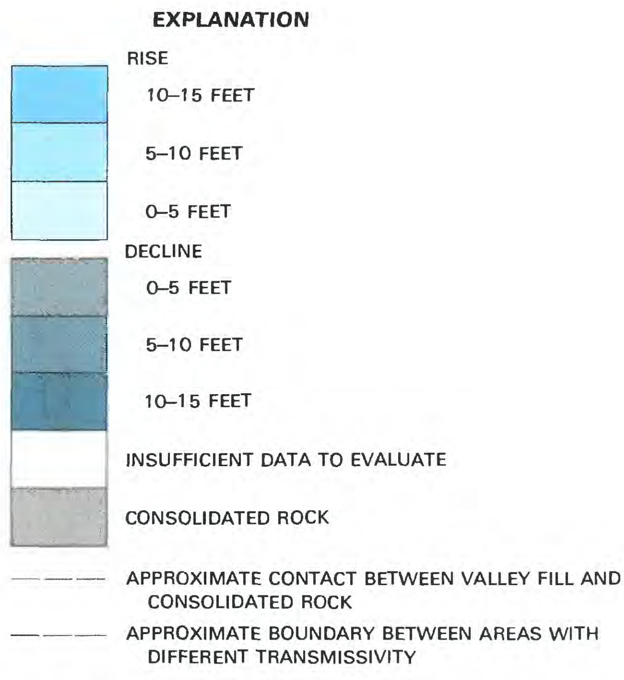
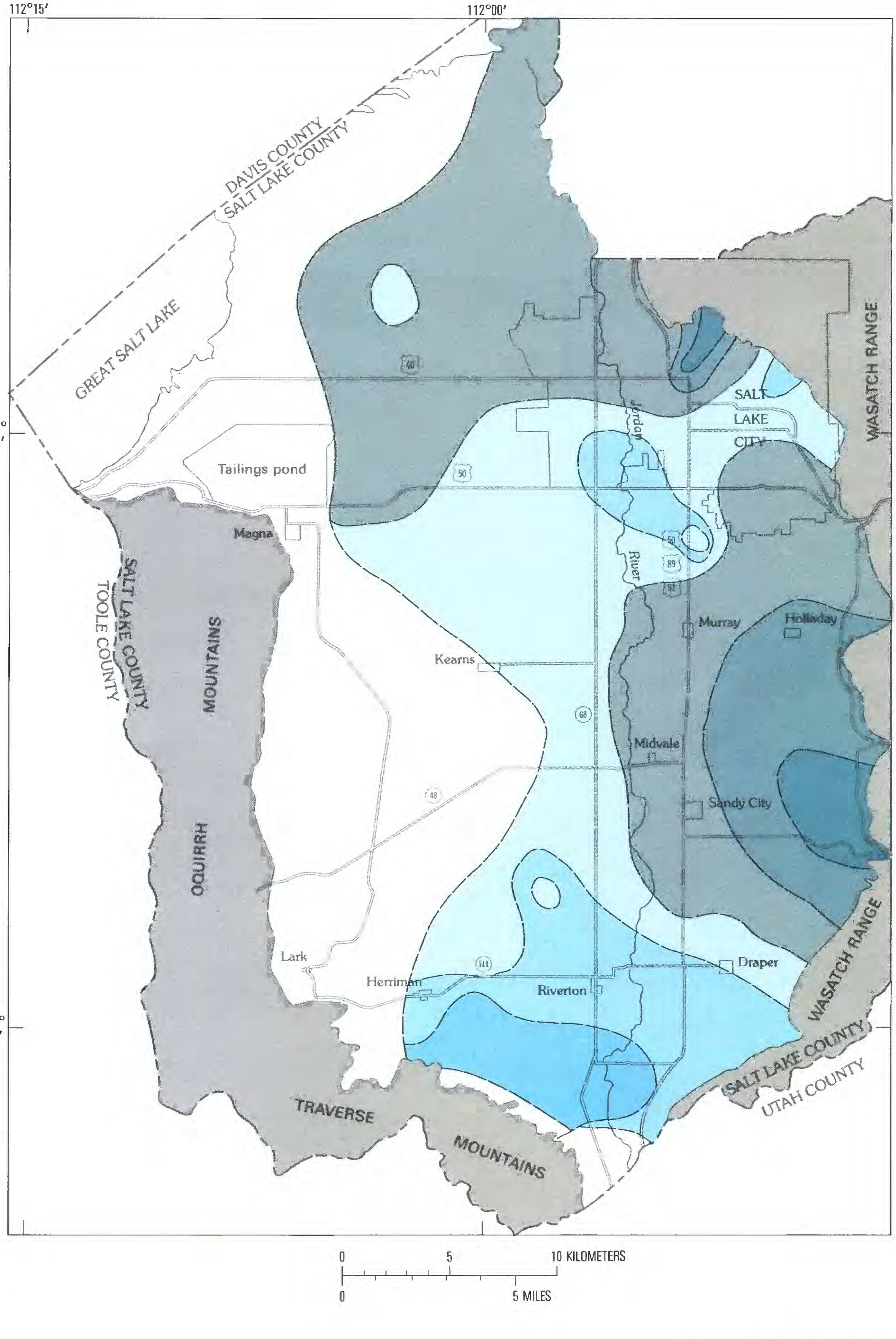


Figure 43 (above and facing page). Changes in the potentiometric surface in the Salt Lake Valley, spring 1965–spring 1980.

Net declines of the potentiometric surface were as much as 15 feet in the Salt Lake City and Sandy-Holladay areas between the spring of 1965 and spring of 1980. These declines reflect the increase in ground-water withdrawals by public-supply wells in those areas. The rise of as much as 15 feet in the Herriman-Riverton area may be related to increased recharge from local irrigation.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TOOLE COUNTY
OQUIRRH MOUNTAINS
SALT LAKE CITY
Jordan River
WASATCH RANGE
Murray
Holladay
Kearns
Midvale
Sandy City
Lark
Herriman
Riverton
Draper
TRAVERSE MOUNTAINS
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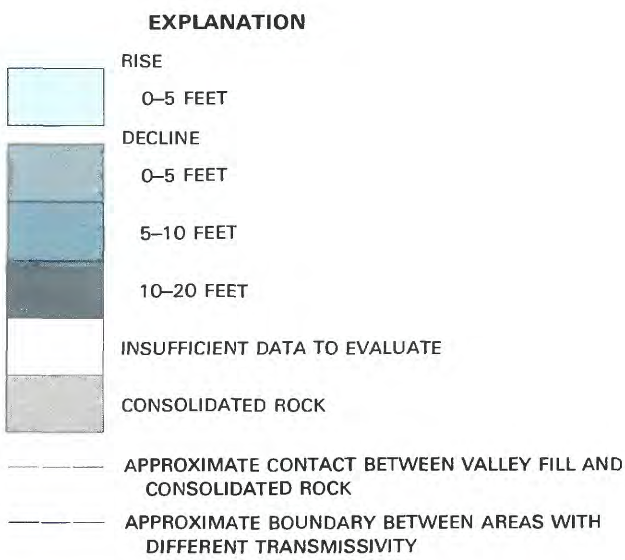
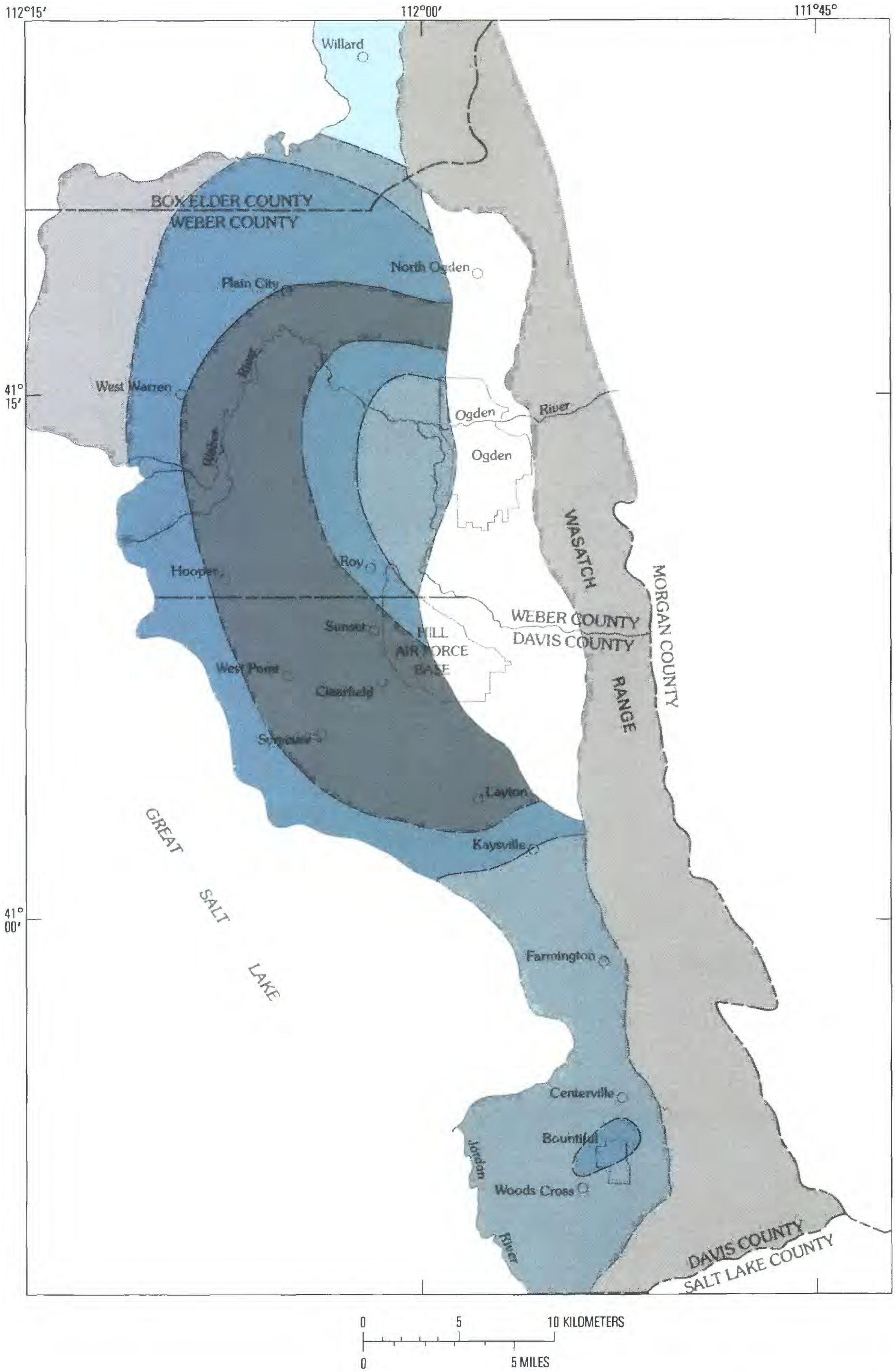


Figure 44 (above and facing page). Changes in the potentiometric surface in the East Shore area, spring 1965–spring 1980.

The potentiometric surface declined (locally more than 15 feet) in most of the East Shore area between the spring of 1965 and the spring of 1980. During the period 1953–81, a decline of as much as 48 feet occurred in the vicinity of West Point. The decline is attributed chiefly to increased ground-water withdrawal for public supply and industrial use. The small rise in the Willard area may be related to storage changes in the Willard Bay Reservoir west of Willard, and generally greater than average precipitation (and ground-water recharge from precipitation) in the area.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Roy
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WASATCH
MORGAN COUNTY
WEBER COUNTY
DAVIS COUNTY
Sunset
HILL AIR FORCE BASE
West Point
Clearfield
RANGE
Layton
Kaysville
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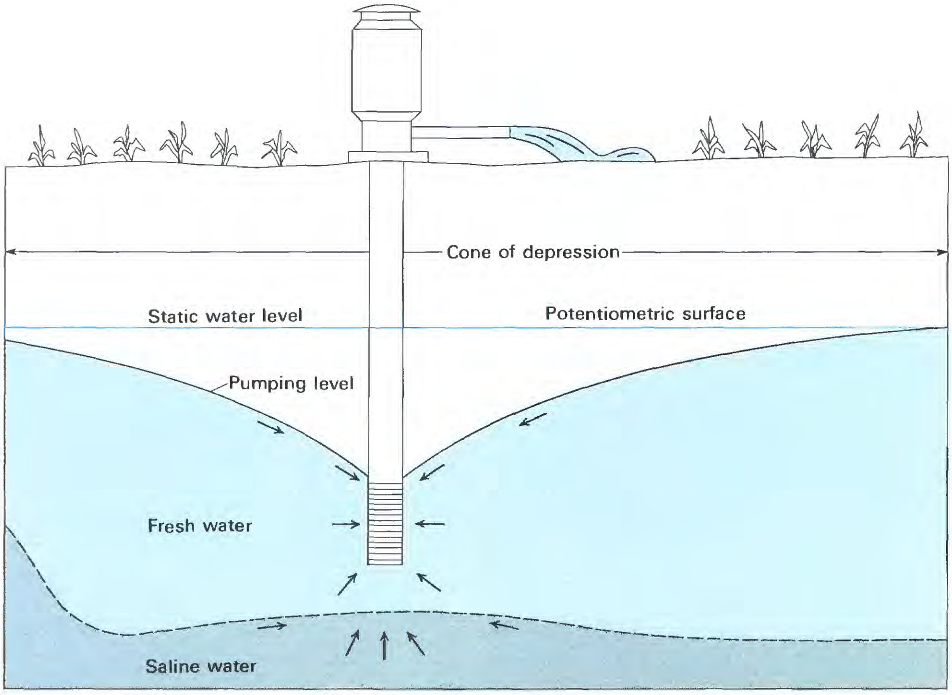


Figure 45. Hydrologic effects of a discharging well.

When one or more wells are discharging, they draw down the ground-water level or potentiometric surface as shown above and in figures 42–44. The resulting hydraulic gradient causes water to move toward the well(s). As withdrawal increases, drawdown increases, and water is drawn in from deeper and more distant sources. This could result in saline-water encroachment from depth (as shown above), from a saline thermal spring area like the one north of Salt Lake City (fig. 6), or from other areas with saline ground water.

and ditches that serve those areas are eliminated. On the other hand, if the irrigated lands are replaced by residential developments, zealous lawn watering might actually result in an increase of recharge. Data are insufficient to determine all the consequences of such changes, but they need to be considered in future water and land-management programs. If, for example, a vital wetland area (supplied by ground water) is dried up because of decreased recharge from irrigation, some type of mitigating program may be needed.

Increased population and industry could result in the production, transport, and disposal of more toxic material, thus increasing the risk of ground-water contamination. As noted by Meyer (1980), there is no "quick fix" for ground-water contamination. Once a contaminant enters the ground-water system, it is extremely difficult and expensive to remove; it could destroy the utility of the water for years. Areas in which contaminants are most likely to enter the ground-water system are the principal recharge areas near the margins of the valleys. Added precaution is needed to protect those areas—especially losing stream and canal reaches—from the increasing quantities of potential toxic contaminants.

The increase in population and industry will be accompanied by a need for larger and wider distribution of public-water supplies. Decisions will be needed to determine the best water sources to meet those increasing needs. In calculating the costs and benefits associated with various water sources, consideration needs to be given to the increased risk of contamination or disruption of water supplies due to possible natural or man-caused disasters. Decisionmakers will also need to consider the increased constraints to certain types of development because of increased legal complexities and the increasing public concern about the environment. The options for water sources are streamflow, the principal ground-water reservoirs, or the conjunctive use of both sources.

There are advantages and disadvantages for the use of either surface or ground water for public supply. Some of those advantages and disadvantages are listed in the following table:

Surface Water

Advantages

1. Can support multiple use, including flood control, recreation, and hydroelectric-power generation.
2. Can generally provide larger withdrawal rates than a single source (well or spring).
3. Can conserve peak stream discharges which might otherwise by wasted.
4. Water generally distributed by gravity, thus conserving energy.
5. Can provide uniform, more dependable flows in downstream reaches.
6. Can provide sediment trap, thus improving quality of flow in downstream reaches.
7. Pollution or contamination relatively easy to detect and remove.

Disadvantages

1. Can result in relatively large undesirable environmental impacts, such as inundation of usable land.
2. Cost per unit volume of water is relatively large.
3. Evaporative water losses are relatively large.
4. Dams and water-distribution systems are subject to damage during natural or man-caused disasters.
5. Water is easily contaminated or polluted, both intentionally or accidentally.
6. Storage capacities are relatively small and in some cases carryover storage is inadequate during drought.
7. May result in complex and costly legal problems associated with water rights and landownership.
8. Surface reservoirs may have a short duration due to siltation.

Ground Water

Advantages

1. The water generally is where needed; cost and environment impact are relatively small.
2. No dams or long distribution systems to be damaged by natural or man-caused disaster
3. No large open bodies of water, thus little evaporation loss and relatively little chance for intentional or accidental contamination or pollution.
4. The storage capacity is relatively large, thus providing carryover during prolonged drought.
5. Multiple well (and spring) systems assure continuous supply even when part of the system is disrupted.
6. Wells can be drilled or replaced relatively fast and at relatively small cost.
7. Wells can be placed so as to intercept some nonbeneficial discharge of ground water, such as evapotranspirtion by phreatophytes or flow to saline lakes.

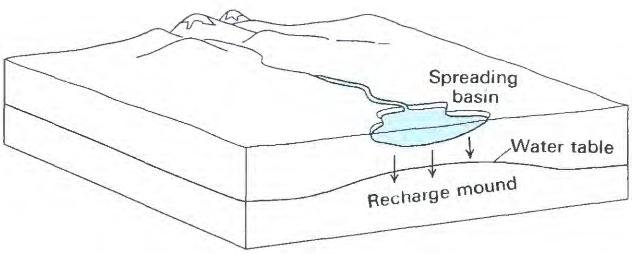
Disadvantages

1. Supply from a single source (well or spring is relatively small).
2. Quality of the water is not everywhere suitable for the intended use.
3. Energy is generally required to lift and distribute the water.
4. Management experience with large-scale well fields is relatively slight and data needed for optimum design and operation may be inadequate.
5. Because of the numerous wells in the Wasatch Front area, the construction of new large-scale well fields may result in costly water-right conflicts.
6. Pollution or contamination of aquifers are difficult or costly to detect and commonly are long lasting and difficult and costly to alleviate.
7. Water-level declines can cause deterioration of ground-water quality, land subsidence, and interference with other water use.

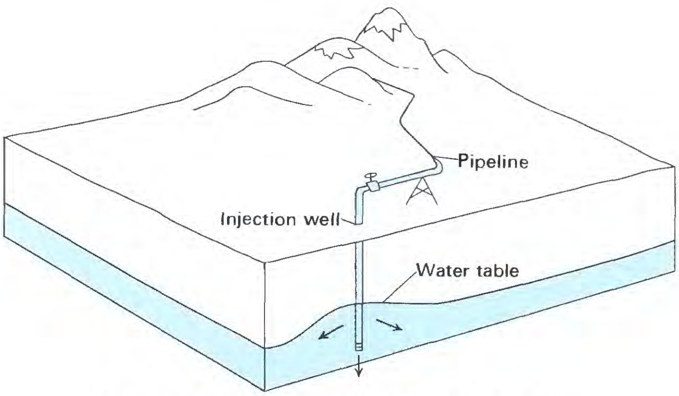
Some of the benefits of both surface- and ground-water use might be realized and the disadvantages overcome or offset if both were used conjunctively. For example, a properly designed ground-water system, consisting of strategically placed wells and storage reservoirs, might be used to supplement surface-water supplies during droughts. The ground-water system also could provide an emergency water source if the surface-water supply were contaminated or disrupted by a natural or man-caused disaster. Some of the wells in the system might include existing public supply, industrial, and irrigation wells; some also might be equipped with standby diesel-powered as well as electric-powered pumps.

Large-scale pumping from wells in any of the principal ground-water reservoirs in the Wasatch Front area would be expected to cause water-level declines. However, some of the problems associated with water-level declines could be alleviated by using streamflow as a source of artificial recharge. The recharge could be accomplished by surface spreading or subsurface injection as shown in figure 46. The peak snowmelt and stream discharges that generally flow into Great Salt Lake unused, or other unused surface flow, could be diverted to artificial recharge basins. This is especially true in the eastern part of the Salt Lake Valley and the East Shore area where ground-water levels have declined and where unused water is available in nearby streams. Recharge basins could be constructed in the permeable, gravelly terraces at the margins of the valleys, and with proper design and landscaping those basins could enhance the environment of the local area. Extensive successful experiments for recharge by water spreading have been made in the Wasatch Front area. These were done in 1936 using water from Parleys and Mill Creeks in the Salt Lake Valley (Lazenby, 1938); in 1938-47 using water from Centerville and Barton Creeks in the East Shore area (Thomas and Nelson, 1948, p. 200-205); and in 1953-55 using water from the Weber River in the East Shore area (Feth and others, 1966, p. 44-47).

If the artificial recharge by subsurface injection were preferred, it might be possible to use as the injection wells the same production wells that cause water levels to decline. This could be done during nonpumping periods (which generally are during peak-runoff periods, when recharge water is most likely to be available). Price and others (1965) describe several examples of both surface spreading and subsurface injection in the Pacific Northwest, some of the problems



ARTIFICIAL RECHARGE BY SURFACE SPREADING



ARTIFICIAL RECHARGE BY SUBSURFACE INJECTION

Figure 46. Basic methods of artificial ground-water recharge.

Ground water may be recharged artificially by diverting runoff into recharge basins (surface spreading) and allowing it to seep underground, or by injecting it directly underground through wells (subsurface injection). The wells used for subsurface injection also may serve as supply wells during periods of small water demand.

encountered, and the methods of alleviating those problems.

SUMMARY AND CONCLUSIONS

The principal source of ground water available to wells in the Wasatch Front area is the unconsolidated and partly consolidated fill in the Wasatch Front valleys—northern Juab, Utah, Goshen, and Salt Lake, the valley area east of Great Salt Lake (the East Shore area), and the Bear River Bay area. The maximum thickness of the saturated fill in the principal ground-water reservoirs in these valleys exceeds 6,000 feet, and the estimated volume of water available from just the upper 100 feet of that fill is about 8 million acre-feet. In most places the water is fresh, containing less than 1,000 milligrams per liter of dissolved solids. In most of the Bear River Bay area and much of Goshen Valley (and locally in the other valleys) the water is slightly to moderately saline, containing 1,000 to 10,000 milligrams per liter of dissolved solids.

Water in the fill near the margins of the valleys is unconfined (under water-table conditions); in the lower valley areas much of it is confined (under artesian conditions). The valley fill receives recharge at an annual rate that is estimated to exceed 1 million acre-feet (mostly as seepage from consolidated rocks of the mountains, from irrigation systems, directly from precipitation, and from streams). Annual discharge (mostly by springs, seepage to streams, evapotranspiration, and withdrawal from wells) during 1980 was estimated to be about 1.1 million acre-feet, indicating that wells may be withdrawing some water from storage. Withdrawal from wells, which began within a few years after the arrival of the Mormon pioneers in the Salt Lake Valley in 1847, had increased to about 320,000 acre-feet during 1979.

The population of the Wasatch Front area probably will continue to increase, and there probably will be a need for additional ground-water withdrawal to help meet the increasing demand for public-water supply. Additional withdrawals from wells may cause water levels to decline, possibly leading to such problems as water-right conflicts, increased pumping costs, land subsidence, and deterioration of ground-water quality. Some of those problems cannot be avoided if the principal ground-water reservoirs are to be fully used; however, management practices such as artificial ground-water recharge in intensely-pumped areas may help to alleviate those problems.

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