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Effects of Climatic Extremes on Ground Water in Western Utah, 1930-2005

Scientific Investigations Report 2007-5045

U.S. Department of the Interior
U.S. Geological Survey

Cover photograph of Twin Springs, located in a ground-water discharge area of Snake Valley, Utah.

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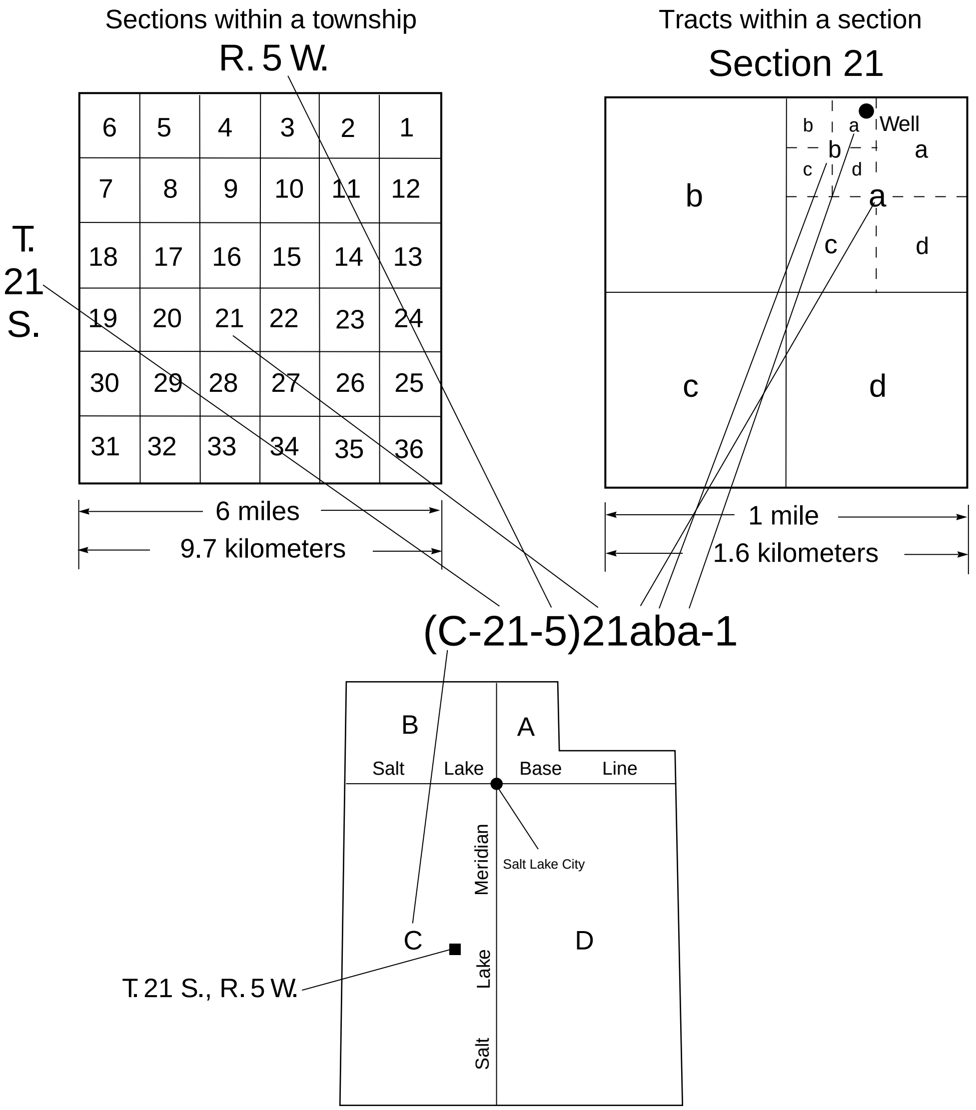
Conversion Factors and Horizontal Datum

Multiply	By	To obtain
acre-foot (acre-ft)	1,233	cubic meter (m^3)
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year (m^3/yr)
foot (ft)	0.3048	meter (m)
inch (in.)	2.54	centimeter (cm)
mile (mi)	1.609	kilometer (km)

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

The system of numbering wells, springs, and other hydrologic-data sites in Utah is based on the cadastral land-survey system of the U.S. Government. The number, in addition to designating the site, describes its position in the land net. By the land-survey system, the State is divided into four quadrants by the Salt Lake Base Line and the Salt Lake Meridian. These quadrants are designated by the uppercase letters A, B, C, and D, indicating the northeast, northwest, southwest, and southeast quadrants, respectively. Numbers designating the township and range, in that order, follow the quadrant letter, and all three are enclosed in parentheses. The number after the parentheses indicates the section and is followed by three letters indicating the quarter section, the quarter-quarter section, and the quarter-quarter-quarter section — generally 10 acres for regular sections[1]. The lowercase letters a, b, c, and d indicate, respectively, the northeast, northwest, southwest, and southeast quarters of each subdivision. The number after the letters is the serial number of the site within the 10-acre tract. The letter S preceding the serial number designates a spring. Thus, (C-21-5)21aba-1 designates the first well constructed or visited in the northeast 1/4 of the northwest 1/4 of the northeast 1/4 of section 21, T. 21 S., R. 5 W. The numbering system is illustrated below.



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

Well-numbering system used in Utah.

Effects of climatic extremes on ground water in western Utah, 1930-2005

By Joseph S. Gates

Abstract

Climatic extremes affect ground-water levels and quality in the basins of western Utah. The five droughts since 1930: 1930-36, 1953-65, 1974-78, 1988-93, and 1999-2004—resulted in much-less-than-average recharge, and the pronounced wet period of 1982-86 resulted in much-greater-than-average recharge. Decreased recharge lowered the ground-water level, and increased recharge raised it. These changes were largest in recharge areas—in discharge areas the water level is relatively constant and the primary effect is a change in the discharge area—smaller during a drought and larger during a pronounced wet period.

The largest part of water-level change during climatic extremes, however, is not a result of changes in recharge but is related to changes in ground-water withdrawal. During a drought withdrawals increase to satisfy increased demand for ground water, especially in irrigated areas, and water levels decline. During a pronounced wet period, withdrawals decrease because of less demand and water levels rise. The amount of water-level change in representative observation wells in a basin is generally proportional to the basin's withdrawal. In undeveloped Tule Valley, water-level changes related to climatic extremes during 1981-2005 are less than 2 feet. In Snake Valley (small withdrawal), Tooele Valley (moderate withdrawal), and Pahvant Valley (large withdrawal), water-level declines in representative wells from 1985-86 to 2005 were 13.4, 23.8, and 63.8 feet, respectively.

Ground-water quality is also affected by climatic extremes. In six irrigated areas in western Utah, water-level decline during drought has induced flow of water with large dissolved-solids concentrations toward areas of pumping, increasing the dissolved-solids concentrations in water sampled from observation wells. During the 1982-86 wet period, increased recharge resulted in a later decrease in dissolved-solids concentrations in three basins.

Introduction

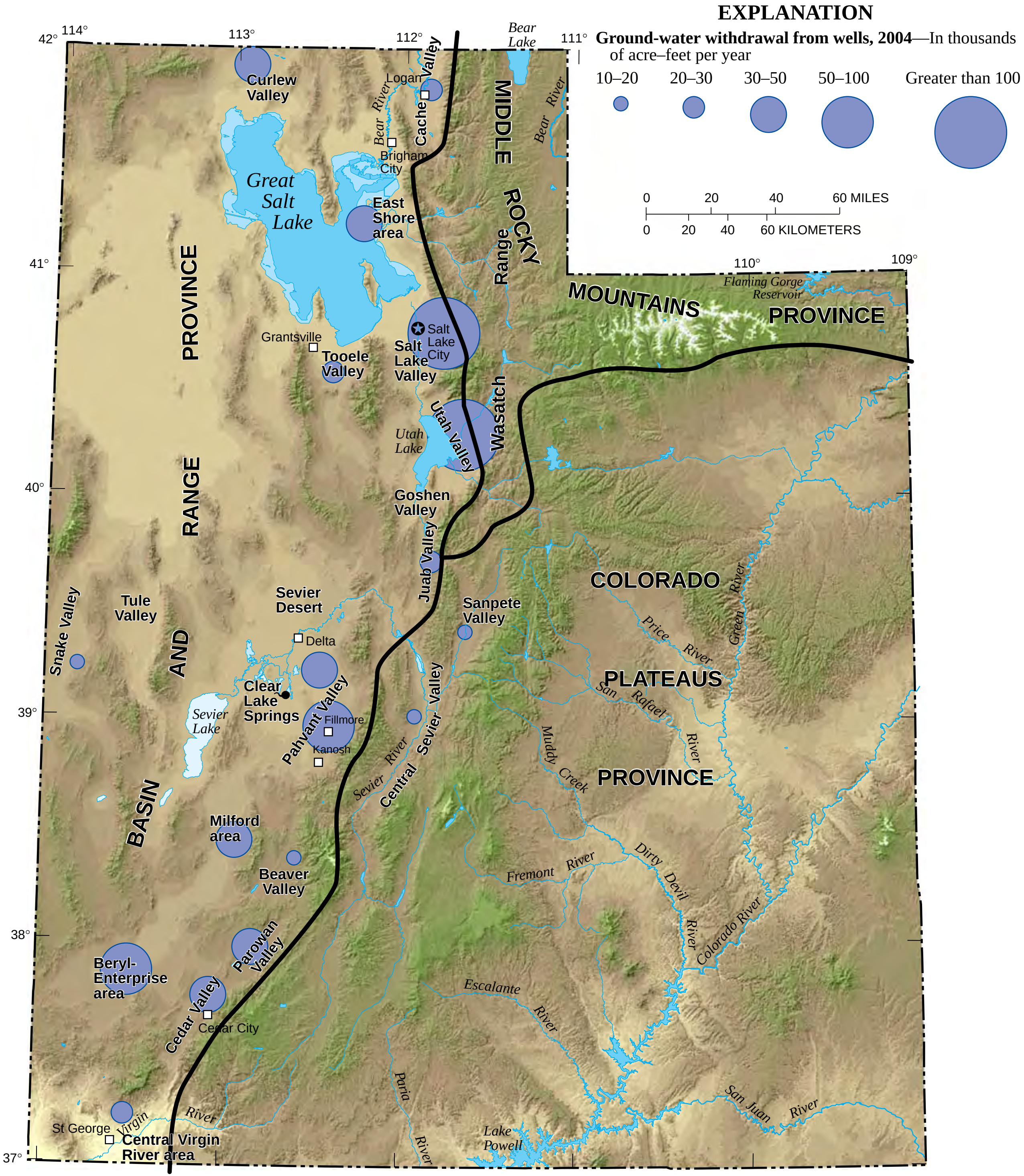
The effects of climate on water resources is a topic of current interest to scientists and water suppliers and users. This report discusses the effects of climatic extremes on ground water in Utah and illustrates how ground-water systems in Utah respond to these extremes. The responses in developed ground-water basins are the result of the combined effects of climate and ground-water withdrawal. Responses in an undeveloped basin and in basins with varying amounts of withdrawal illustrate the feedback between climatic effects and withdrawal and the resulting response of ground-water systems.

Wilkowske and others (2003) identified five statewide periods of drought in Utah since 1930: 1930-36, 1953-65, 1974-78, 1988-93, and 1999-2002 (since extended through 2004). Piechota and others (2004) stated that the 1999-2004 drought in the southwestern United States is the worst in the last 80 years and the seventh worst in the last 500 years. Wilkowske and others (2003) discussed the effects of the droughts since 1930 on surface-water flow, noted intervening periods of flooding, and briefly summarized effects on ground water. This report discusses the effects of the five droughts on ground water in more detail and discusses the effects of the most prominent period of much-greater-than-average precipitation and flooding since 1930—that of 1982-86.

Water beneath the land surface is contained in the unsaturated zone—from the land surface down to the water table—and below the water table is contained in the zone of saturation. Water in the zone of saturation is defined as ground water. The U.S. Geological Survey (USGS) does not monitor water in the unsaturated zone except on projects for which such data are necessary. In cooperation with the Utah Department of Natural Resources, the USGS monitors ground water throughout the State of Utah by measuring water levels annually in about 1,000 observation wells, by estimating the amount of water withdrawn from wells, and by collecting samples of water for chemical analysis from about 270 wells (90 per year).

Selected geographic and geomorphic features of Utah, the 18 areas of major ground-water withdrawal, and the amounts of water withdrawn from the 18 areas in 2004 are shown in *figure 1*. Most of these large-withdrawal areas are topographic basins in western Utah. The aquifers in most of these basins consist of relatively coarse-grained intervals within basin-fill deposits—unconsolidated deposits of clay, silt, sand, and gravel. Most of the water wells in the state are in these 18 areas of major development of ground water, and these areas are the focus of this report.

In the basins of western Utah, ground-water recharge occurs along the mountain fronts. Recharge occurs by infiltration of water from precipitation, by seepage from perennial, intermittent, and ephemeral streams emerging from the



Fenneman, 1946; Burden and others, 2005

Figure 1. Selected geographic and geomorphic features of Utah, areas of major ground-water withdrawal, and amounts of water withdrawn from these areas in 2004.

mountains, and from water moving in the subsurface from the consolidated rock of the mountains into the basin-fill deposits. Ground water then moves toward the lowest parts of the basins, where it discharges by seepage into streams and lakes, from springs, by evapotranspiration from playa areas, areas of phreatophytes, or wetlands, or by flow into a lower basin.

The greatest direct effects and the first effects of drought or a wet period on both the unsaturated and saturated zones are in recharge areas. Most of the precipitation above the recharge areas, with the exception of that which becomes snowmelt and flow of major streams, is consumed by evapotranspiration from vegetation—the remainder becomes surface-water flow and ground-water recharge. In a drought, vegetation likely tries to maintain its rate of evapotranspiration, and in a wet period, more water is available than is needed by vegetation. Thus, ground-water recharge is less during droughts or more during wet periods than would be estimated from the ratio of precipitation to the long-term average precipitation. In areas of discharge, the effects are delayed, and because the water table is at or near the land surface and the unsaturated zone is thin or nonexistent, effects on ground-water levels are minor.

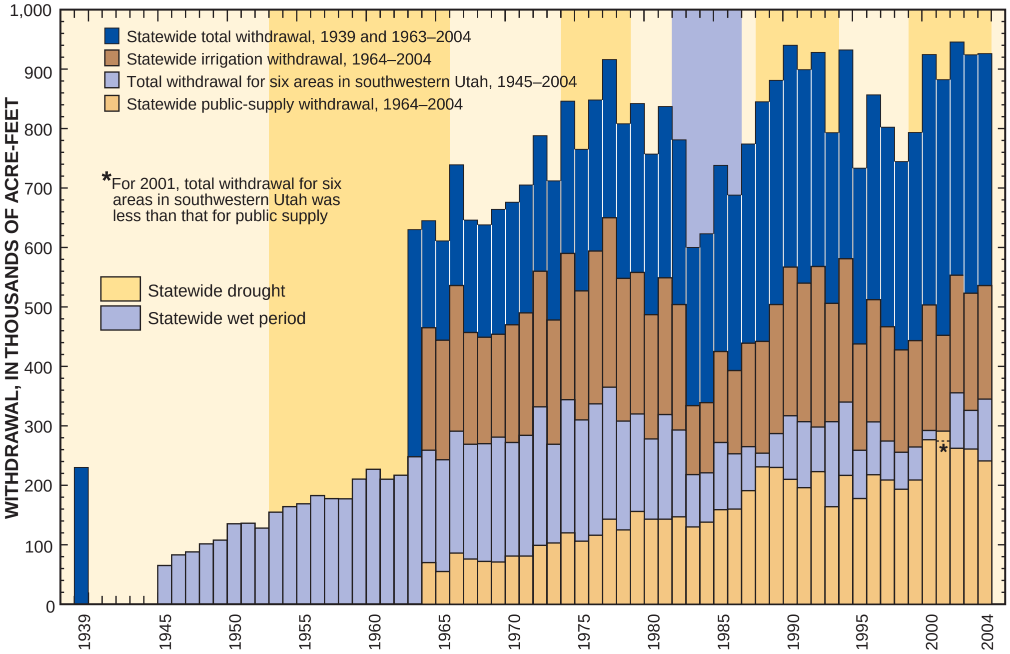
Effects of Climatic Extremes on the Unsaturated Zone

Although the focus of this report is on ground water, a drought or wet period also affects the unsaturated zone, where some water is held by capillary and molecular forces. During a drought, this water, mostly that part held by capillary forces, is depleted as water vapor moves to the land surface and evaporates. Effects on the unsaturated zone in turn affect the saturated zone. When wetter conditions return, the water required by capillary forces must be replaced before water can move downward to recharge the saturated zone. This is most significant in areas where the unsaturated zone is thick, such as along a mountain front where the water table is deep, and in mountain areas where there is a thick soil zone or layer of unconsolidated sediment on top of consolidated rock and the water table also commonly is deep. In contrast, only a small amount of water needs to be replaced where the unsaturated zone is thin or nonexistent, such as along a reach of a stream that is in direct contact with the water table or just above it, or in ground-water discharge areas in the lower parts of basins where the water table is at or near land surface. Another area where relatively less water needs to be replaced in the unsaturated zone after a drought is where consolidated rocks crop out, because these rocks generally have low porosity. In addition, where porosity in consolidated rock is provided by open fractures or joints, the volume of water held by capillary forces is relatively small because the open spaces commonly are relatively large and the forces don't extend out very far from solid material. During a wet period, water can move to the saturated zone after the need for water held by capillary and molecular forces in the unsaturated zone is satisfied, and ground-water levels will rise.

Effects of Climatic Extremes on Statewide Ground-Water Withdrawal

Records of Statewide withdrawal of ground water from wells in Utah (*fig. 2*, updated from Gates, 2004, fig. 5) can be used to assess the influence of droughts and the 1982-86 wet period on withdrawal, which in turn affected ground-water levels. Most of the Statewide withdrawal is from the basins of western Utah. Data on ground-water withdrawal by basin are included in the series of annual reports "Ground-Water Conditions in Utah" prepared by the U.S. Geological Survey in cooperation with the Utah Department of Natural Resources, such as the report by Burden and others (2005). Average withdrawal for specific basins cited later in this report also is obtained from this series of reports.

Total Statewide withdrawal for all uses increased steadily from 1939 to 1977 (*fig. 2*), even though the State has restricted drilling new wells for irrigation in intensively developed parts of or in entire basins, especially in southwestern Utah, beginning in 1935. Large total withdrawal during 1974-77, 1988-94, and 2000-04 generally corresponds to the droughts of 1974-78, 1988-93, and 1999-2004. A substantial drop in withdrawal during 1983-86 corresponds to the 1982-86 wet period, and a smaller decrease in withdrawal during 1995-99 corresponds to a generally wetter period between the droughts of 1988-93 and 1999-2004. Total Statewide withdrawal for irrigation during 1964-2004 (*fig. 2*) shows little overall increase, although it shows a pattern, similar to that of total withdrawal for all uses, of large withdrawal during 1974-77, 1989-94, and 2002-04, and smaller withdrawal during 1983-86 and 1995-99. Total withdrawal for six irrigated areas in southwestern Utah (*fig. 2*, includes Sevier Desert, Pahvant and Parowan Valleys, Cedar Valley in Iron County, and the Milford and Beryl-Enterprise areas, *fig. 1*) increased steadily from 1945 through 1977. This steady increase was caused by an increase in irrigated acreage, an increase in the number of wells used to withdraw water for irrigation, and by the 1953-65 drought, which resulted in increased demand for ground water for irrigation. Since 1977, withdrawal from the six irrigated areas has stabilized, with somewhat larger withdrawal in 1974-77, 1989-94, and 2002-04. A sharp drop in withdrawal during 1983-84 and smaller withdrawal during 1985-88 generally correspond to the 1982-86 wet period. Withdrawal for public supply (*fig. 2*) increased steadily during 1964-2004, due to population growth and urbanization, with a lesser response to droughts and the 1982-86 wet period because urban water demand is more constant.



Data from the series of annual reports "Ground-Water Conditions in Utah," such as Burden, 2005, and from Gates, 2004

Figure 2. Ground-water withdrawal from wells in Utah, 1939 and 1945-2004.

Effects of Climatic Extremes on Ground Water in Western Utah

Hypothetical Effects on Undeveloped Basins

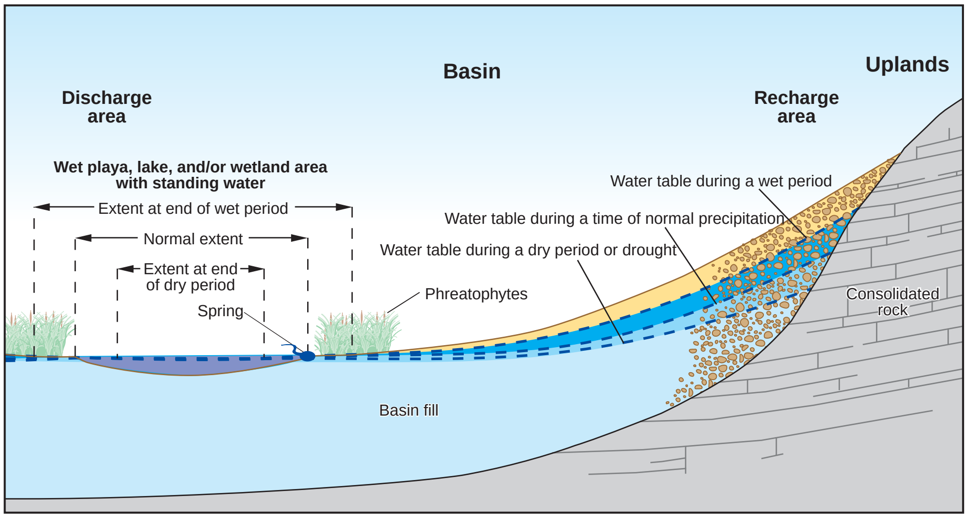
Ground-water systems are in equilibrium when discharge equals recharge and water levels are relatively stable. During a drought when recharge decreases, or during a wet period when recharge increases, the hydraulic gradient (slope of the water table) from recharge to discharge areas adjusts so that the amount of flow balances discharge with the new amount of recharge. The main effect in the discharge area is not a change in water level, which stays relatively constant—the main effect is a change in the size of the area of discharge. During a drought when recharge is smaller, water levels fall in the recharge area, and the hydraulic gradient between recharge and discharge areas becomes flatter. Eventually, less water reaches the discharge area and the area shrinks, the amount of water discharging from the basin drops to balance the smaller recharge, and a new equilibrium is reached. The amount of seepage to streams and lakes, spring discharge, evapotranspiration from playa, phreatophyte, and wetland areas, and any subsurface outflow all decline. During a wet period, the reverse occurs—the hydraulic gradient steepens, more water flows to the discharge area, the size of the discharge area increases, and discharge increases to match the larger rate of recharge. However, many droughts or wet periods may not be long enough for a change in area of discharge to become significant and obvious.

The effects of a climatic extreme on the ground-water system, specifically changes in the hydraulic gradient and the size of the discharge area, are illustrated in *figure 3*. In an undeveloped basin, human activities have not altered the response of the ground-water system to climatic extremes.

Hypothetical Effects on Developed Basins

In a developed basin, the effects of climatic extremes on the ground-water system include both the direct effects resulting from changes in recharge and indirect effects resulting from human activities, as represented by withdrawal of ground water from wells. Changes in ground-water levels in developed basins resulting from climatic extremes are related more to changes in withdrawal associated with a drought or wet period than they are to changes in recharge caused by the drought or wet period.

During a drought, withdrawal of ground water increases in response to increased demand, and water levels decline. Increases in withdrawal are most pronounced in areas where irrigation water is drawn from both ground-water and surface-water sources. During a drought, less surface water is available and more ground water is withdrawn to replace reduced precipitation on cropland and the reduction in surface water available for irrigation. In areas where ground water is the sole source of water for irrigation, withdrawal also increases



Not to scale

Figure 3. Conceptual diagram of the effects of climatic extremes on ground water in an undeveloped basin in western Utah.

during droughts, with resulting water-level declines. However, the effect is less because withdrawals don't need to replace a reduction in surface water. In urban areas where ground water is a source of supply, increases in withdrawal and water-level declines may also occur during a drought because use of water on lawns and landscaped areas increases when precipitation is less.

During wet periods, the reverse occurs—croplands and urban lawns and landscaped areas need less water, more surface water is available, and demand for ground water decreases (especially since the cost to pump ground water commonly is greater than the cost of a surface-water supply). Water levels will rise or at least the rate of decline will decrease.

The largest basin-wide water-level changes during a drought or a wet period (excluding changes in observation wells close to pumping wells) are in basins where ground-water withdrawal is largest. This indicates that the largest part of water-level change is caused by changes in withdrawal associated with a drought or wet period, rather than by changes in recharge during these periods.

Effects of Five Droughts since 1930 and the 1982-86 Wet Period on Ground Water in Selected Basins of Western Utah

The effects of the five droughts since 1930 and the 1982-86 wet period on four basins are discussed in the following sections. These basins include undeveloped Tule Valley, Snake Valley with relatively small withdrawal, Tooele Valley with moderate withdrawal, and Pavant Valley with large withdrawal.

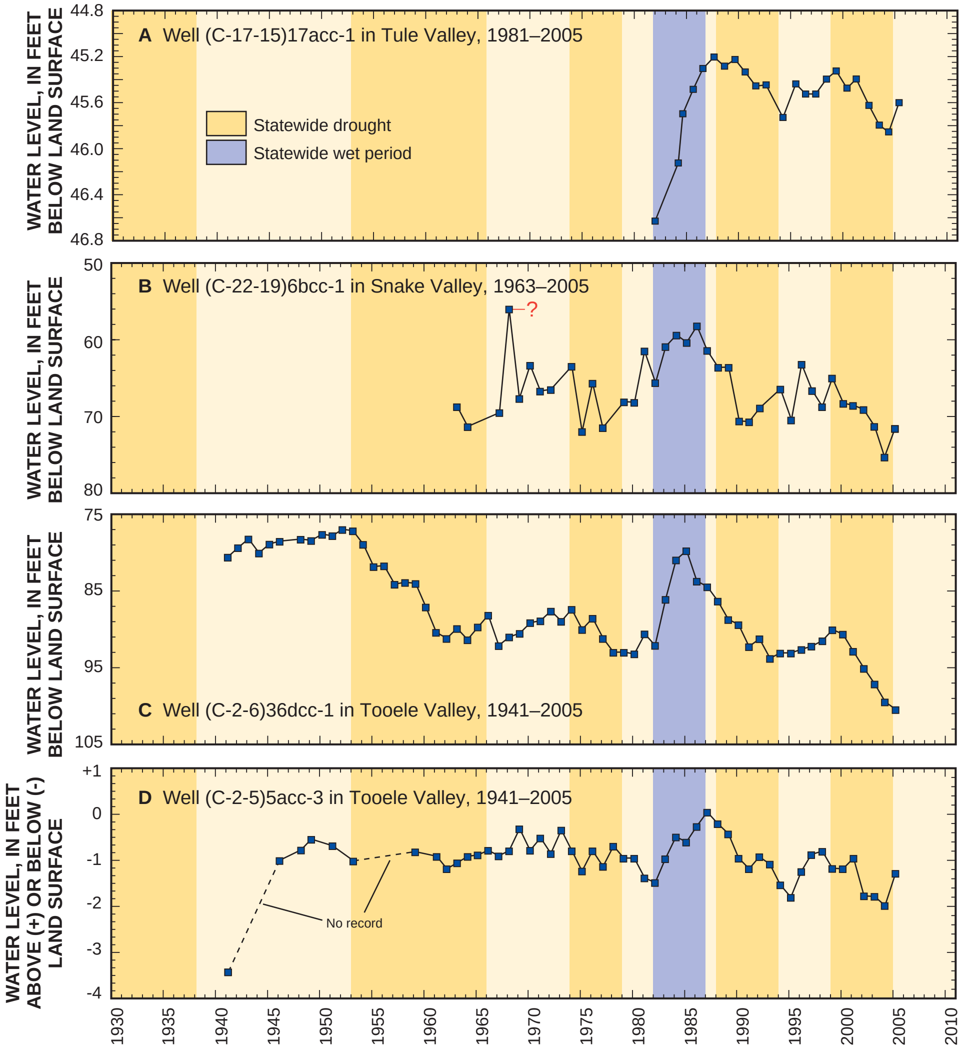
Effects on an Undeveloped Basin—Tule Valley

Tule Valley in west-central Utah (*fig. 1*) is uninhabited and used only for seasonal grazing of livestock. Stephens (1977) conducted a hydrologic reconnaissance of Tule Valley and located eight wells, only five of which were in use for livestock supply. He estimated a total annual withdrawal from wells of 35 acre-feet, which he considered insignificant compared to an estimate of about 40,000 acre-feet per year of discharge by evapotranspiration.

An observation well in Tule Valley is located between a recharge area on the western side of the basin and the basin's major discharge area. The water level in the well (*fig. 4*, graph A) rose 1.4 feet from December 1981 (initial reading) to September 1987, likely in response to the 1982-86 wet period. From 1987 to 2005, the water level declined 0.4 feet. The low level in 1994 may be a response to the 1988-93 period of drought. Overall, the response of the water levels to the 1982-86 wet period and the following two periods of drought during 1988-93 and 1999-2004 has been small, illustrating that a ground-water system in equilibrium does not have a large response to climatic extremes. The water-level change during the wet period was about three times larger than the changes during the droughts, suggesting that the 1982-86 wet period was a major climatic extreme.

Effects on Developed Basins

Ground-water levels in the developed basins of western Utah are affected by both droughts and wet periods—directly by changes in recharge and indirectly by changes in withdrawal of water from wells. The water-level changes in response to changes in withdrawal caused by climatic extremes are larger than the water-level changes caused by changes in recharge caused by climatic extremes.



Data from USGS files and Burden and others, 2005

Figure 4. Water levels in observation wells in Tule, Snake, and Tooele Valleys, Utah, 1941-2005.

A Basin with Relatively Small Withdrawal—Snake Valley

Snake Valley is a long, narrow valley at the Utah-Nevada border (*fig. 1*) and includes parts of Nevada. During 1995-2004, annual withdrawal from the Utah part of Snake Valley (the largest part of the withdrawal in Snake Valley) averaged about 10,600 acre-feet. A hydrograph of water levels in a well in an area of withdrawal at about the midpoint of the valley is shown in graph B of *figure 4*. The highest water level during the period of record (1963-2005) occurred during 1968 (which may be erroneous data), after which it generally declined until 1975. The water level then peaked in 1986 in response to the 1982-86 wet period (1981-87 in Snake Valley) and declined 13.4 feet from 1986 to 2005, with a minor peak in 1996 between the drought periods of 1988-93 and 1999-2004. The water level in another well in an area of flowing wells in a natural discharge area at the northern end of Snake Valley reached its record high in 1985 and declined 4.6 feet from 1985 through 2005 (Burden and others, 2005, fig. 56, p. 134). Because of ground-water pumping, water-level changes in Snake Valley are much larger than those in undeveloped Tule Valley.

A Basin with Moderate Withdrawal—Tooele Valley

Tooele Valley is a basin south of Great Salt Lake (*fig. 1*) where annual ground-water withdrawal averaged more than 22,000 acre-feet during 1995-2004. Hydrographs of water levels in two wells are shown in *figure 4*—one (graph C) in an area of withdrawal in the west-center of the valley, and one (graph D) in the main area of natural ground-water discharge in the northern end of the valley where a few flowing wells are located. The water level in the well shown in graph 4C (*fig. 4*) was at its record high in the early 1950s, typical of many wells in Utah (Gates, 2004, p. 136). The water level declined to a low in 1980, at least partly related to droughts during 1953-65 and 1974-78. The level rose rapidly during the 1982-86 wet period, peaked in 1985, and generally declined through 2005, although it reached a minor peak in 1999 between the droughts of 1988-93 and 1999-2004. The water level in 2005 was 27.6 feet below its record high in 1952 and 23.8 feet below its peak in 1985.

The water level in the well shown in graph D (*fig. 4*) has a similar pattern but a much smaller amount of change. The water level peaked in 1949, reached its record high in 1987 in response to the 1982-86 wet period, and generally declined from 1987 through 2005, with a minor peak in 1998 between the droughts of 1988-93 and 1999-2004. The level in 2005 was 1.3 feet below the record high in 1987. The water level is affected by droughts, the 1982-86 wet period, and withdrawal to the south. However, because the well is more than 5 miles north of a main withdrawal area, its response is muted. Although the observation well is in an area of natural discharge where water levels at the water table are relatively constant, its water level has changed during droughts and the 1982-86 wet period because the depth interval where water enters the well (the water level represents this depth) is hydraulically upgradient from the land surface. In an area of natural discharge, much of the water discharged has moved upward from deeper zones. Because ground-water withdrawal from Tooele Valley is larger than that from Snake Valley, water-level changes during droughts and the 1982-86 wet period are larger in a representative well near the area of pumping in Tooele Valley than those in a similar well in Snake Valley.

A Basin with Large Withdrawal—Pahvant Valley

Pahvant Valley in southwestern Utah (*fig. 1*) is an area of large withdrawal of ground water. During 1995-2004, annual withdrawal, of which more than 95 percent is for irrigation, averaged 78,000 acre-feet. Pahvant Valley was used as the example for basins with large withdrawal because (1) it has observation wells with records of water levels going back as far as 1929, (2) data on withdrawal goes back to 1946, and (3) because both ground and surface water are used for irrigation, the effects of climatic extremes on water levels are relatively large. Water levels in Pahvant Valley have declined in response to large withdrawal—maximum declines for observation wells are more than 60 feet since 1949 and more than 80 feet since 1986 (Burden and others, 2005, p. 78-80). Other areas in Utah have substantially larger withdrawal (Salt Lake and Utah-Goshen Valleys (*fig. 1*)) and larger maximum observed water-level declines (Salt Lake Valley and the Beryl-Enterprise and East Shore areas (*fig. 1*)) (Gates, 2004, p. 136 and 137).

The relation between (A) precipitation at Fillmore, (B) withdrawal of ground water, and (C) annual measurements of water level in a long-term observation well 5 miles west of Fillmore is shown in *figure 5*. The graphs of withdrawal and water levels correlate with long-term changes in precipitation, including the five periods of drought since 1930 and the wet period of 1982-86 (which in Pahvant Valley was 1980-86).

Precipitation

Annual cumulative departure from average precipitation at Fillmore is shown in *figure 5A*—a down-trending line segment indicates less-than-average and an up-trending segment greater-than-average precipitation. Precipitation was less than average during 1931-35, 1948-63, 1974-77, 1989-92, and 2001-2002, generally corresponding to the five Statewide droughts. Precipitation was much greater than average during 1980-86, corresponding to the pronounced Statewide wet period of 1982-86.

Withdrawal

Withdrawal in Pahvant Valley *(fig. 5B*) correlates fairly well with precipitation (*fig. 5A*). Withdrawal more than quadrupled during 1945-66, reflecting the construction of new irrigation wells to supply water to expanded irrigated acreage and to provide increased withdrawal in response to the drought of 1948-66 in Pahvant Valley. In 1946, 343 wells were used to withdraw 17,700 acre-feet of water in Pahvant Valley (Mower, 1965, table 14). Three of the wells were pumped, and the other 340 flowed. By 1962, 540 wells were used to withdraw 61,800 acre-feet of water. Of the 540 wells, 117 were pumped and 423 flowed (Mower, 1965, table 14). By 1966, discharge of flowing wells in Pahvant Valley was less than 1,000 acre-feet per year because of water-level decline, while total withdrawal was about 84,000 acre feet (Holmes and Thiros, 1990, fig. 5). Withdrawal increased slightly during 1974-77, corresponding to the drought of 1974-77 in Pahvant Valley. Withdrawal was lower during 1982-87 and much lower during 1983-84 (about half of that in 1981), corresponding to the pronounced wet period of 1980-86 in Pahvant Valley. Withdrawal returned to its pre-1982 level during 1989-94, mostly in response to a drought during 1989-92 in Pahvant Valley. Withdrawal has increased since 1998, mostly in response to a drought in Pahvant Valley during 2001-2002.

Ground-water levels

Water-level changes since 1930 in a long-term observation well in Pahvant Valley (*fig. 5C*) correspond with changes in precipitation and ground-water withdrawal. Selected periods of substantial water-level change in well (C-21-5)21aba-1 west of Fillmore, corresponding climatic events or changes in precipitation at Fillmore, and changes in ground-water withdrawal from Pahvant Valley are shown in *table 1.*

Before the 1950s, changes in water levels reflecting drought and wet periods were not large because of two factors: (1) withdrawal was small, less than 20,000 acre-feet per year; and (2) more than 95 percent of the withdrawal was from flowing wells (Mower, 1965, table 14), the discharge of which is moderated in response to changes in water levels. For example, during a drought water levels will decline, which will cause a decline in flowing-well discharge which in turn will cause a lessening of the rate of water-level decline. The relation between water levels and flowing-well discharge prevents

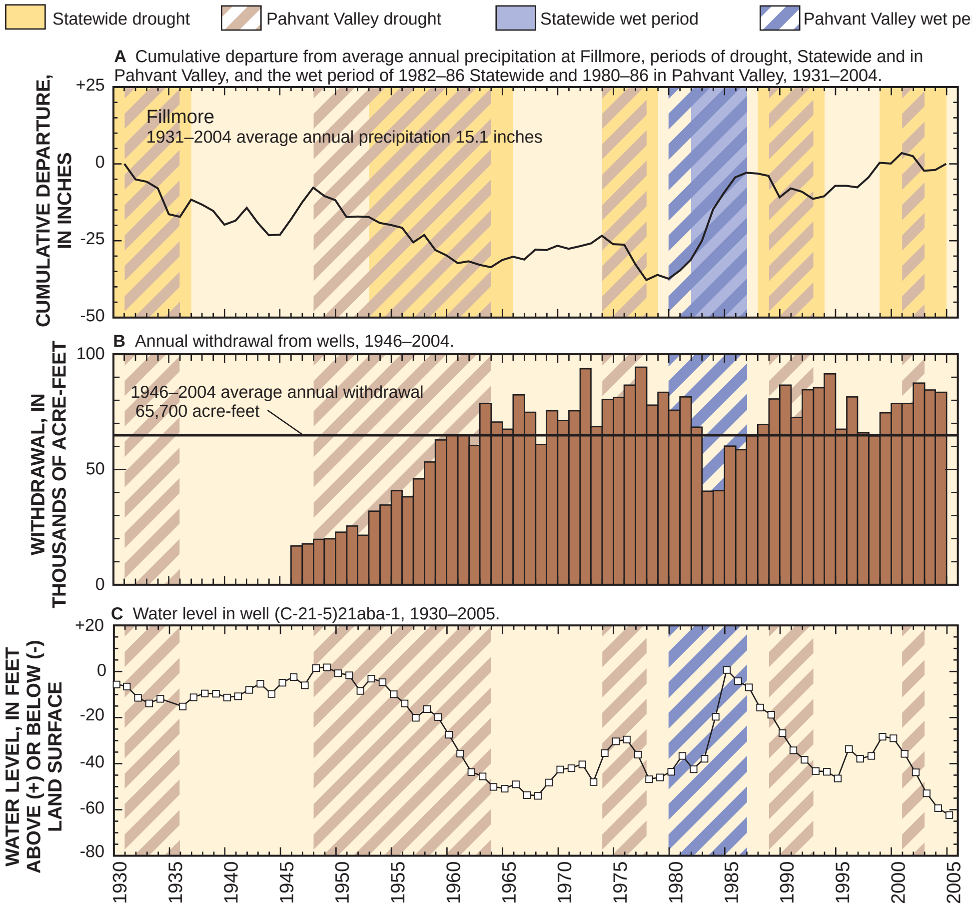


Figure 5. Relation between (A) precipitation at Fillmore, (B) withdrawal of ground water, and (C) water level in an observation well west of Fillmore, Pahvant Valley, Utah, 1930-2005.

Table 1. Changes in water level in well (C-21-5)21aba-1 in relation to climatic events or changes in precipitation and changes in ground-water withdrawal, Pahvant Valley, 1930-2005

Period	Water-level change, in feet	Climatic event, change in precipitation, or change in withdrawal
1930-36	-11.5	Drought, 1931-35
1936-49	+16.4	Overall greater-than-average precipitation, 1936-47
1949-68	-54.6	Drought, 1948-63; increasing withdrawal, 1946 (or before)-1966
1968-76	+23.9	Greater-than-average precipitation, 1964-73; relatively stable withdrawal, 1967-71
1976-78	-16.9	Drought, 1974-77; record high withdrawal, 1977
1978-82	+4.6	Overall greater-than-average precipitation, 1978-81; slight decline in withdrawal, 1978-82
1982-85	+42.6	Pronounced wet period, 1980-86; with much-greater-than-average precipitation, 1982-85 and large decline in withdrawal, 1983-84
1985-95	-47.1	Drought, 1989-92; with overall slightly less-than-average precipitation, 1986-94; and return to large withdrawal, 1988-94.
1995-99	+17.8	Overall greater-than-average precipitation, 1995-98; decline in withdrawal, 1995-98.
1999-2005	-34.5	Drought, 2001-2002; with overall slightly less-than-average precipitation, 1999-2004; and return to large withdrawal, 1999-2004.

large changes in water levels. After 1949, changes in water levels were much larger. The hydrograph for the observation well in *figure 5C* shows that the largest water-level change before 1949 was the 16.4-foot rise from 1936 to 1949; since 1949 declines of more than 60 feet and rises of more than 45 feet have occurred. Significant water-level changes include the 54.6-foot decline from 1949-68, the 42.6-foot rise from 1982-85, the 47.1-foot decline of 1985-95, and the 34.5-foot decline of 1999-005. The 54.6-foot decline of 1949-68 was caused by (1) a drought and decreased recharge during 1948-63 in Pahvant Valley, and (2) an increase in withdrawal during 1946-66 caused by (a) the drought, and (b) an expansion of irrigated land and related drilling of many new wells, most of which are pumped rather than flowing wells.

The sharp rise of 42.6 feet from 1982 to 1985 along with an 11.7-foot rise during 1968-82 essentially reversed the 54.6-foot decline from 1949 to 1968. The 42.6-foot rise corresponds to the very wet period of 1980-86 in Pahvant Valley. In addition, because of the much-greater-than-average precipitation, withdrawal of water from wells declined drastically during 1982-87—during 1983-84 withdrawal was as low as 42,000 acre-feet per year. Discharge from flowing wells, essentially eliminated after 1966 by the large water-level declines, resumed because of the large rise in water levels and averaged about 22,000 acre-feet per year during 1985-86 (Holmes and Thiros, 1990, fig. 2). This wet period probably was on the order of a 100-year event (R.C. Christensen and E.B. Johnson, U.S. Geological Survey, written commun., 1989), thus the recharge during 1980-86 was much greater than normal. Using digital-model results, Holmes and Thiros (1990, table 2) estimated that during 1985, recharge to Pahvant Valley was three times the long-term average amount.

From 1985 to 2005, the water level in the observation well declined 63.8 feet, including 47.1- and 34.5-foot declines during 1985-95 and 1999-2005 and the 17.8-foot rise during 1995-99. The overall decline is a result of less precipitation and recharge and increased withdrawal of ground water after 1986. Withdrawal increased from an average of 61,000 acre-feet per year during 1985-86 to an average of 85,000 acre-feet per year during 1989-95. The water level reached a record low in 2005, 64.1 feet below its 1949 record high.

Because ground-water withdrawal from Pahvant Valley is large, the water-level changes during climatic extremes are much larger than water-level changes in response to the same climatic events in Tule, Snake, and Tooele Valleys, where withdrawal is smaller. This illustrates that the amount of ground-water-level change is related more to changes in withdrawal that result from droughts or wet periods than they are to the changes in recharge related to these climatic events.

Water Quality

Ground-water quality also is affected by droughts and wet periods, with droughts associated with increases in dissolved-solids concentration and the 1982-86 Statewide wet period associated with decreases. Increases in withdrawal of ground water for irrigation related to droughts and increases in irrigated acreage apparently have caused increases in dissolved-solids concentrations in ground water since the 1950s in at least six irrigated areas in western Utah, including, from north to south, Curlew Valley, the Bothwell area northwest of Brigham City in the valley of the lower Bear River, Goshen and Pahvant Valleys, and the Milford and Beryl-Enterprise areas (*fig. 1*). Water-level declines apparently induce flow of ground water containing a large concentration of dissolved solids toward centers of pumping. In contrast, increased recharge during the 1982-86 wet period later resulted in decreases in dissolved-solids concentrations (or decreases in the rate of increase) in several irrigated areas. A more detailed discussion is reported by Gates (2004, p. 137-140).

Summary

Ground-water levels in Utah decline in response to decreased recharge during periods of drought and rise in response to increased recharge during wet periods. In recharge areas, these water-level changes can be large but in other areas, and especially in discharge areas, they generally are small. In the unsaturated zone, water is held mostly by capillary forces, is depleted during a drought, and must be replaced before water can move to and recharge the saturated zone. This is most significant in areas where the unsaturated zone is thick. In an undeveloped basin, a drought or wet period will affect water levels the most in recharge areas. In areas of natural discharge, water-level changes are small, and the area of discharge changes because of the change in the amount of water moving to the discharge area.

In areas of significant ground-water withdrawal, water-level changes are related more to the indirect effects of droughts or wet periods—the changes in withdrawal of water from wells resulting from these periods—than they are related to the direct effects of the changes in precipitation and recharge during droughts or wet periods. This is especially true in irrigated areas where both surface and ground water are used for irrigation. For the major areas of ground-water development, the amount of water-level change in observation wells that represent overall basin conditions is generally proportional to the amount of ground-water withdrawal.

Ground-water quality can also be affected by droughts, which in some basins have been followed by increases in dissolved solids; and by very wet periods, which cause an influx of good-quality recharge water, and in time, a decrease in dissolved solids. However, in the affected basins in Utah, the overall trend is toward poorer quality with the wet period of 1982-86 providing only temporary improvement.

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