

Hydrologic Assessment of a Riparian Section Along Boulder Creek Near Boulder, Colorado, September 1989-September 1991

by Robert Kimbrough

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
acre	0.4047	hectare
cubic foot per second (ft ³ /s)	0.028317	cubic meter per second
foot (ft)	0.3048	meter
foot per year (ft/yr)	0.3048	meter per annum
inch (in.)	25.4	millimeter
mile (mi)	1.609	kilometer
square mile (mi ²)	2.590	square kilometer

Temperature in degree Fahrenheit (°F) may be converted to degree Celsius (°C) by using the following equation:
 $^{\circ}\text{C} = 5/9 (^{\circ}\text{F} - 32)$.

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

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Abstract

Native woody riparian species, primarily plains cottonwood (*Populus fremontii*), and various species of willow are regenerating at less than historical rates along Boulder Creek, a regulated stream near Boulder. Loss of native riparian habitats can have an adverse effect on some wildlife species. For example, certain native birds rely on cottonwood stands for food and nesting sites. Previous studies have indicated that streamflow regulation can adversely affect native riparian vegetation reproduction; therefore, understanding hydrologic processes in riparian areas along Boulder Creek will assist ecologists in assessing native woody plant recruitment characteristics. This report describes the surface- and ground-water hydrology of a riparian section of Boulder Creek, called Cottonwood Grove, for September 1989–September 1991.

Annual mean streamflows in Boulder Creek at Cottonwood Grove of 34.5 cubic feet per second for water year 1990 (October 1, 1989–September 30, 1990) and 34.1 cubic feet per second for water year 1991 (October 1, 1990–September 30, 1991) were 53 percent less than the combined streamflows at a station on Boulder Creek about 7 miles upstream from the study area and a tributary station about 5 miles upstream from the study area. Several water diversions dating from 1882 caused most of the decrease.

The alluvial aquifer in the study area averaged 5 feet in thickness and consisted of gravel- to cobble-size particles derived from crystalline rock of Precambrian age. The direction of ground-water movement was similar to the direction of streamflow. Ground-water movement in the northeastern part of the grove was affected by a pond constructed at a lower elevation than the stream channel. Water levels in the alluvial aquifer adjacent to the stream predominantly were affected by stream stage, whereas farther from the channel, ground-water levels were affected by other processes such as evapotranspiration, infiltration, and recharge from urban runoff.

INTRODUCTION

Native woody riparian vegetation, primarily plains cottonwood (*Populus fremontii*), and various species of willow are regenerating at less than historical rates along Boulder Creek, near the city of Boulder, Colo. Formerly abundant, these trees currently are being succeeded by alternate species, such as green ash (*Fraxinus pennsylvanica*), boxelder (*Acer negundo*), and Russian olive (*Elaeagnus angustifolia*). The loss of native riparian habitats could adversely affect certain wildlife species. Many native bird species rely on cottonwoods for nest sites. Furthermore, alternate tree species such as Russian olive do not support the insects that some native birds rely on as a food source. The evolving composition of riparian stands along Boulder Creek may be linked to about 110 years of streamflow regulation. Streamflow regulation alters the timing, magnitude, and duration of snowmelt-flood flows and previous studies have concluded that flood flows are an integral component of cottonwood establishment (Everitt, 1968). Suitable germination sites for cottonwood are sparsely vegetated, moist alluvial soils (Read, 1958), most effectively prepared by floods. Along the Hassayampa River in Arizona, cottonwood and willow seedlings flourished during years that had sustained high spring streamflows (Stromberg and others, 1991). On other rivers, declines in cottonwood recruitment have been directly related to streamflow regulation (Fenner and others, 1985; Bradley and Smith, 1986). Ecologists are specifically concerned with areas adjacent to the stream channel of Boulder Creek because plains cottonwood and sandbar willow (*Salix exigua*) have the best potential to reproduce in these locations (Michael Scott, Gregor Auble, and Larry Martin, U.S. Fish and Wildlife Service, written commun., 1991).

The city of Boulder, in an effort to preserve the remaining native riparian habitats within its boundaries, is studying the relation between riparian vegetation and its environment. An integral component of this assessment is an understanding of the hydrologic processes in riparian ecosystems. In 1989, the U.S. Geological Survey, in cooperation with the city of Boulder, began a 2-year study to investigate the hydrology and surface- and ground-water interactions of a small riparian woodland along Boulder Creek.

Purpose and Scope

This report describes surface water, ground water, and their interaction in a riparian section of Boulder Creek, near Boulder. Surface- and ground-water data were obtained throughout water years 1990 and 1991. However, some ground-water-level measurements were made in September 1989. A continuous record of streamflow was computed for Boulder Creek through the study area to assess surface-water characteristics. Observation wells were installed to monitor ground-water levels near the stream channel and on the established flood plain where mature, woody vegetation exists. Stream-stage data and ground-water levels were compared to study the interaction between Boulder Creek and the adjacent alluvial aquifer.

Description of the Study Area

Boulder Creek originates in the Rocky Mountains near the Continental Divide at an altitude of 13,500 ft, about 23 mi west of Boulder (fig. 1). The stream flows east through igneous and metamorphic rock of Precambrian age before exiting the mountainous region at Boulder (5,300 ft). In Boulder, the stream enters the dissected uplands of the Colorado Piedmont. This section is characterized by sedimentary rock that has been stripped of its Tertiary cover; as a result, Quaternary deposits directly overlie rocks of Cretaceous age (Romero, 1973). Leaving Boulder, the stream flows east northeast for about 17 mi to its confluence with St. Vrain Creek. St. Vrain Creek continues to the northeast another 12 mi to its confluence with the South Platte River.

The study area, known as Cottonwood Grove, is about 28 acres in size. Owned by the city of Boulder, this wooded area is located on Boulder Creek, just downstream from the Boulder city limits (fig. 1). Because of controlled public access, Cottonwood Grove has remained undisturbed for several years. Livestock grazing has been absent for at least a decade, and the stream channel is still susceptible to lateral migration because of the absence of artificial bank stabilization.

Cottonwood Grove sustains a diverse ecosystem; more than 100 bird species have been sighted, as well as 14 mammal species and 6 fish species (Alexander Cruz and Jane Bock, University of Colorado, written commun., 1975). A list of plants recently identified in the grove includes 119 herbaceous species and 11 tree species; crack willow (*Salix fragilis*) is the predominant species in the stand. In addition to a few mature plains cottonwoods and the alternate species listed in

the "Introduction" section of this report, exotic species, such as black locust (*Robinia pseudoacacia*) and Chinese elm (*Ulmus pumila*) are present because of the close proximity of the grove to urban areas (Michael Scott, Gregor Auble, and Larry Martin, U.S. Fish and Wildlife Service, written commun., 1991).

The alluvial aquifer underlying Boulder Creek consists of Piney Creek Alluvium of Holocene age (Trimble, 1975). The Piney Creek Alluvium consists of gravel to cobble-size particles derived from crystalline rock of Precambrian age. Average thickness of the alluvial aquifer in the study area is about 5 ft. The aquifer is topped with 2 to 4 ft of soil and is underlain by a confining layer of Pierre Shale of Upper Cretaceous age. The streambed is composed of coarse gravel to medium cobbles and has a pool and riffle sequence. Banks are vertical and are 2 to 4 ft deep. The drainage area for Boulder Creek Basin upstream from Cottonwood Grove is about 145 mi².

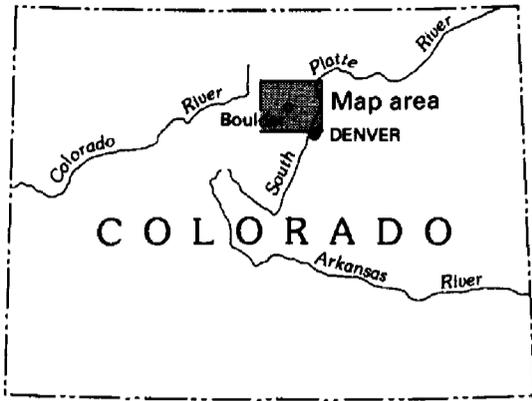
Data-Collection Locations and Methods

Streamflow-gaging station 400118105134600, Boulder Creek at Cottonwood Grove, was installed at the downstream end of the study area (fig. 2). Stream-stage data were collected using a digital punch-tape recorder with a 15-minute punch interval. The recorder was housed in a metal box shelter situated over a 4-in. steel stilling well. Streamflow measurements were made at this site to develop a stage-discharge relation for Boulder Creek. Streamflow measurements obtained at the upstream end of the study area at a non-recording station (fig. 2) were compared with measurements at the downstream site and were not used for rating development. Stream stage at both locations was determined by a drop tape held from a reference point.

Twenty-two observation wells, ranging in depth from 4 to 11 ft below land surface were installed in the study area (fig. 2). Wells were drilled with a portable power auger and cased with 1.75-in.-diameter steel pipe. All wells were completed in the alluvial aquifer with the bottom 30 in. screened. In an effort to describe ground-water-level fluctuations near the stream channel, four wells (well numbers 5, 6, 16, and 17) were equipped with continuous digital recorders that had a 1-hour punch interval (fig. 2). Water levels in the wells were measured manually using a drop tape held from a reference point.

Acknowledgments

The author would like to thank the U.S. Fish and Wildlife Service for sharing well-level measurements.



EXPLANATION

- ▲¹ STREAMFLOW-GAGING STATION 06727000, BOULDER CREEK NEAR ORODELL, COLORADO
- ▲² STREAMFLOW-GAGING STATION 06727500, FOURMILE CREEK AT ORODELL, COLORADO

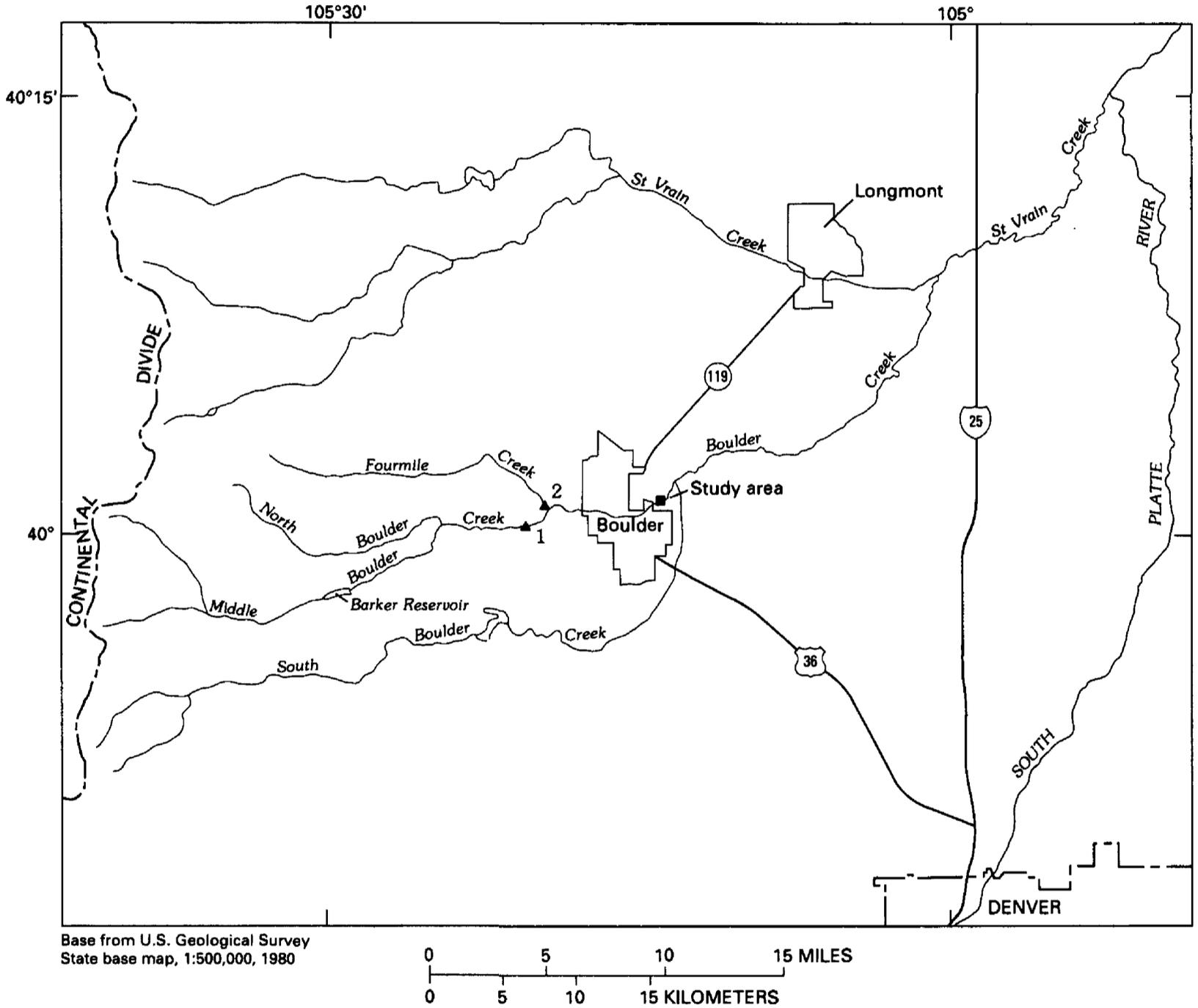


Figure 1. Location of study area and selected streamflow-gaging stations.

EXPLANATION

- | | | | |
|------------------|--|---------------|---------------------------|
| Q^B | OBSERVATION WELL AND NUMBER | — — — | COTTONWOOD GROVE BOUNDARY |
| 16Q^R | OBSERVATION WELL WITH A CONTINUOUS DIGITAL RECORDER | - - - - - | EPHEMERAL CHANNEL |
| \blacktriangle | STREAMFLOW-GAGING STATION 400118105134600
BOULDER CREEK AT COTTONWOOD GROVE
WITH A CONTINUOUS DIGITAL RECORDER | \rightarrow | DIRECTION OF STREAMFLOW |
| \triangle | STREAMFLOW-GAGING STATION WITHOUT A
CONTINUOUS DIGITAL RECORDER | | |

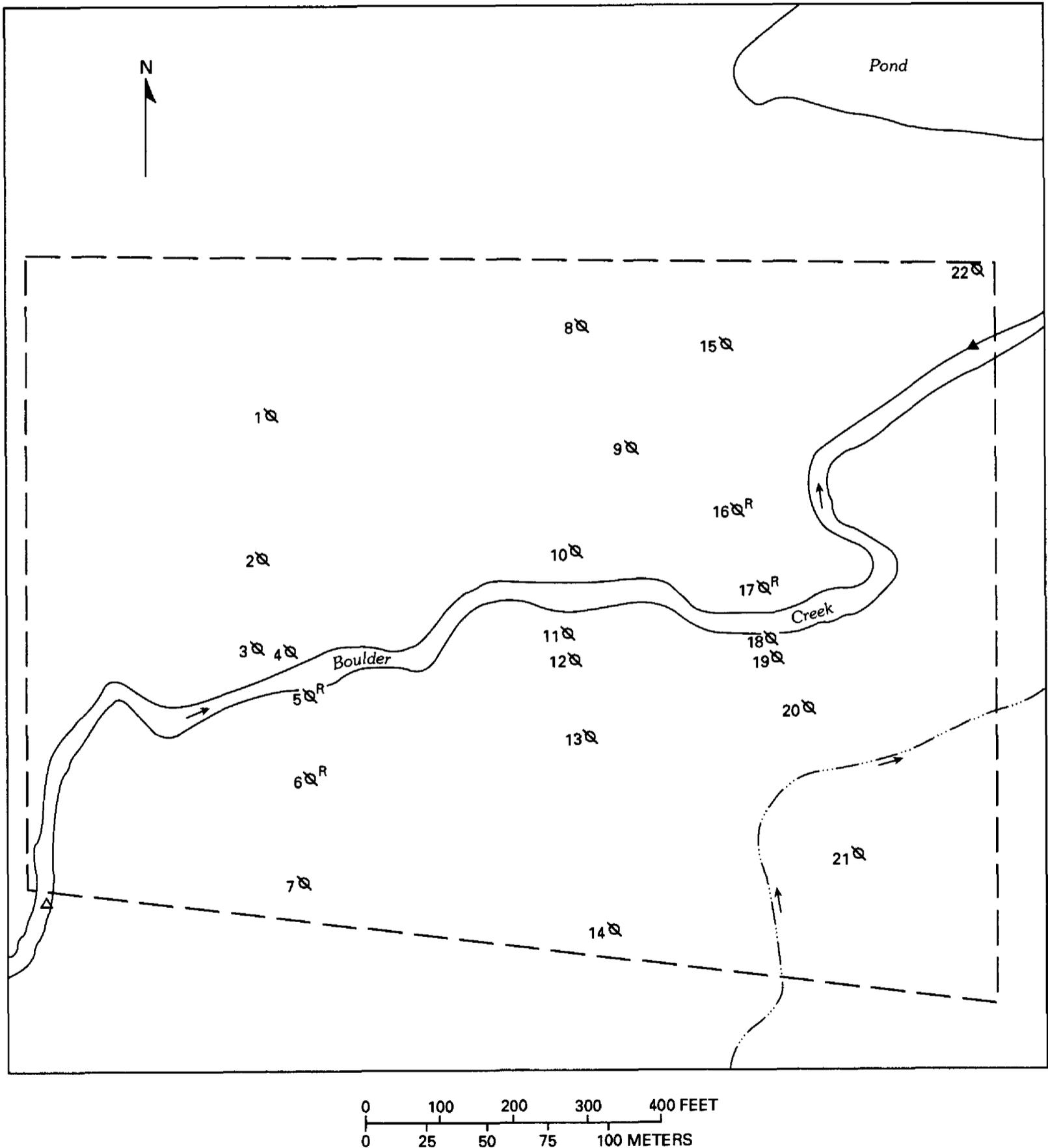


Figure 2. Cottonwood Grove study area and locations of selected measurement sites.

HYDROLOGY OF THE STUDY AREA

Surface Water

Twenty-three streamflow measurements, ranging from 1.57 to 324 ft³/s, were made at the Boulder Creek at Cottonwood Grove station to develop a stage-discharge relation for Boulder Creek through the study area. Three different stage-discharge ratings were used during the 2-year study indicating that Boulder Creek through Cottonwood Grove is a dynamic system with fill and scour of bed material occurring. Peak flows in Boulder Creek normally occur in the spring each year in response to snowmelt within its headwaters. Peak flows for water years 1990 and 1991 occurred in June and were 422 ft³/s and 1,020 ft³/s, respectively. More than 2 in. of precipitation on June 1, 1991, in conjunction with peak snowmelt runoff, resulted in a substantially higher peak for that water year when compared to water year 1990. The high June 1 flow also caused major channel scouring in the vicinity of the Cottonwood Grove station, requiring implementation of a new stage-discharge rating.

Flow in the Boulder Creek Basin during the 2-year study can be compared to the long-term average using streamflow records for station 06727000, Boulder Creek near Orodell (fig. 1). Mean annual streamflow at this station for 83 years (1907–14, 1917–91) was 86.6 ft³/s. Annual mean streamflows of 68.0 ft³/s

for water year 1990 and 66.0 ft³/s for water year 1991 indicate streamflow in the Boulder Creek Basin during the study was about 22 percent less than average. The Boulder Creek near Orodell station is located about 7-mi upstream from Cottonwood Grove and streamflows at the Orodell station have been affected for the entire period of record by diversions and seasonal filling of upstream reservoirs.

Annual mean streamflows in Boulder Creek about 5 mi upstream from Cottonwood Grove (just downstream from the Fourmile Creek inflow) were 73.9 ft³/s for water year 1990 and 71.9 ft³/s for water year 1991. The streamflows were computed by adding annual mean streamflows at tributary station 07627500, Fourmile Creek at Orodell (fig. 1) to annual mean streamflows at the Boulder Creek near Orodell station. Annual mean streamflows at Boulder Creek at Cottonwood Grove (34.5 ft³/s for water year 1990 and 34.1 ft³/s for water year 1991) were 53 percent less than the combined flow at the Orodell stations. Several water diversions located between the Fourmile Creek inflow and Cottonwood Grove dating to 1882 caused most of the decrease. To illustrate the magnitude of the diversions, the sum of mean monthly streamflows at the two Orodell stations are plotted with the sum of mean monthly streamflows at the Boulder Creek at Cottonwood Grove station and the diversions between Fourmile Creek and Cottonwood Grove for water years 1990–91 (fig. 3). Water diverted from Boulder Creek between Fourmile Creek and Cottonwood Grove is

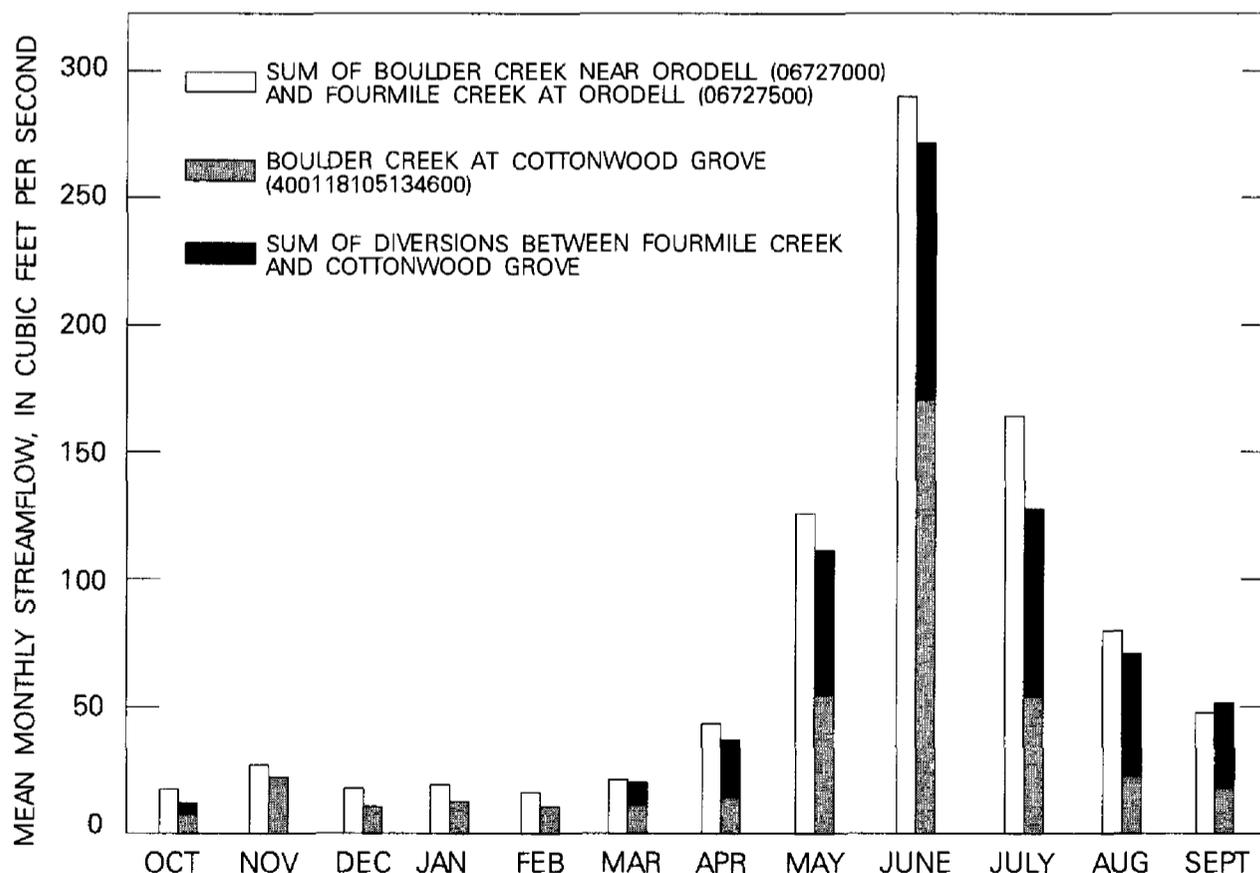


Figure 3. Sum of mean monthly streamflows at stations 06727000, Boulder Creek near Orodell and 06727500, Fourmile Creek at Orodell, compared to the sum of mean monthly streamflows at the Boulder Creek at Cottonwood Grove station (400118105134600), and the diversions between Fourmile Creek and Cottonwood Grove, water years 1990–91.

mainly used for irrigation. During the study, diversions began in March of each year and continued through October. When diversions were active, the amount of water diverted ranged from 24 percent of the total upstream flow (the sum of flow at the two Orodell stations) in October to 72 percent of the total upstream flow in September. During snowmelt runoff season (May, June, July), an average of 42 percent of the total upstream flow was diverted for irrigation.

Ground Water

Water-table maps constructed from discrete well measurements indicate ground-water flow in the study area is to the northeast (figs. 4 and 5). Direction of flow seems to be consistent when observed during periods of high and low streamflow. The direction of ground-water movement in Cottonwood Grove tends to parallel streamflow, which is consistent with ground-water flow in alluvial aquifers along the South Platte River near Denver (Robson, 1989). An artificial pond located just outside the northeast corner of Cottonwood Grove has a water level at a lower elevation than the adjacent stream channel. A survey of pond-water-surface elevation in September 1991 indicated that ground water flows toward and discharges into the pond (fig. 5).

Surface- and Ground-Water Interactions

Water levels in the alluvial aquifer directly adjacent to Boulder Creek predominantly were affected by stream stage. This is evident by noting the similarities between hydrographs for wells near the stream (recording and nonrecording) and the hydrograph for stream stage at the Boulder Creek at Cottonwood Grove station. Continuous recording wells near Boulder Creek had daily mean hydrographs virtually identical in shape to daily mean stream stage for equivalent time periods (fig. 6). Vertical dashed lines are drawn through stream-stage peaks (fig. 6) to illustrate the lag of the ground-water peaks. The lag indicates that surface water was flowing into the alluvial aquifer and affecting adjoining ground-water levels.

The hydrograph for well 2, a nonrecording well about 150 ft from the stream, is similar to the stream-stage hydrograph for the Boulder Creek at Cottonwood Grove station as defined by discrete stream-stage measurements (fig. 7). The similarity also indicates that stream stage was the primary factor controlling ground-water levels in the near vicinity of Boulder Creek. Other wells that have hydrographs indicative of

stream-stage effects are shown in the Appendix at the back of this report.

The hydraulic connection between the stream and the adjacent alluvial aquifer also is indicated by comparing streamflow at Boulder Creek at Cottonwood Grove to water levels in well 17 for the duration of the study (fig. 8). As expected, ground-water levels increased in June of each water year in response to high spring streamflows and decreased during periods of low flow. An exception is the anomalous ground-water peak in December–January of each water year. These peaks were not caused by sustained high daily mean streamflows but rather by elevated stream stage caused by ice dams. During winter, water was released upstream from Barker Reservoir for hydro-power generation. Instantaneous streamflow releases of more than 100 ft³/s and stream-stage changes of more than 1 ft were recorded nightly, November through March, and caused layers of ice to form on the streambanks during cold winter nights in December and January. Ice layers as much as 4 ft thick were observed on January 2, 1991. As ice blocks broke away from the bank, ice dams were formed that caused streamflow to pool and stream stage to rise. The elevated stage provided a gradient for water to flow from the stream into the adjacent alluvial aquifer. Although ice dams caused ground-water levels to increase, water levels in well 17 rapidly returned to pre-ice-dam levels following ice-dam failure (fig. 8).

The magnitude in which stream stage affected ground-water levels diminished with increased distance from the stream and explains, in part, why hydrographs show a different pattern for wells farther from Boulder Creek. Comparing hydrographs for wells of varying distance from the stream illustrates the different ground-water-level patterns. The comparison also indicates that there may be other processes affecting ground-water levels in Cottonwood Grove besides stream stage and distance from the stream. Well 10, located about 40 ft from the streambank, had a hydrograph similar in shape to well 2, illustrating the predominant effect of stream stage on ground-water levels adjacent to Boulder Creek (fig. 9). Well 9, located about 180 ft from the streambank, had some water-level fluctuations similar to well 10, particularly during periods of high stream stage associated with spring runoff and ice damming in January 1991 (fig. 9). Unlike well 10, however, water levels in well 9 increased with greater magnitude during the fall and winter of each year when streamflows were consistently low. Water levels in well 8 (about 340 ft from the streambank) also increased throughout the fall and winter each year, although abrupt changes in water level in response to increased stream stage were not apparent except during

EXPLANATION

- EPIHEMERAL CHANNEL
- DIRECTION OF STREAMFLOW
- 5,202.8 \emptyset OBSERVATION WELL—Number indicates water level in feet above National Geodetic Vertical Datum of 1929
- 5,205.3 \blacktriangle STREAMFLOW-GAGING STATION—Number indicates stream stage in feet above National Geodetic Vertical Datum of 1929
- 5,202 — GROUND-WATER LEVEL CONTOUR—Number indicates ground-water level in feet above National Geodetic Vertical Datum of 1929. Dashed where inferred. Contour interval 1 foot

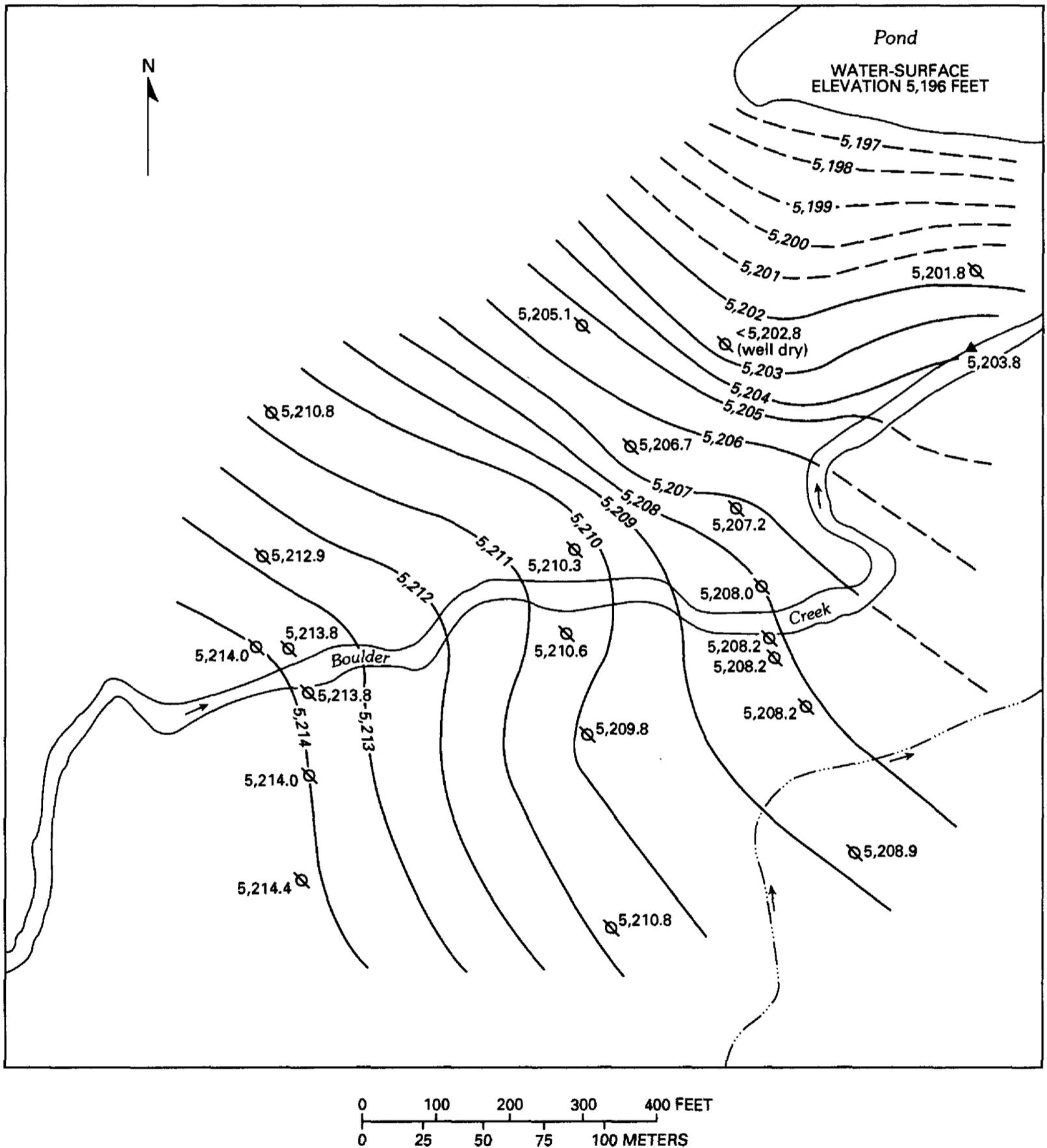


Figure 5. Ground-water-level contours and pond-water-surface elevation in Cottonwood Grove area, September 12, 1991. Streamflow at the Boulder Creek at Cottonwood Grove station (400118105134600) equal to 18.1 cubic feet per second.

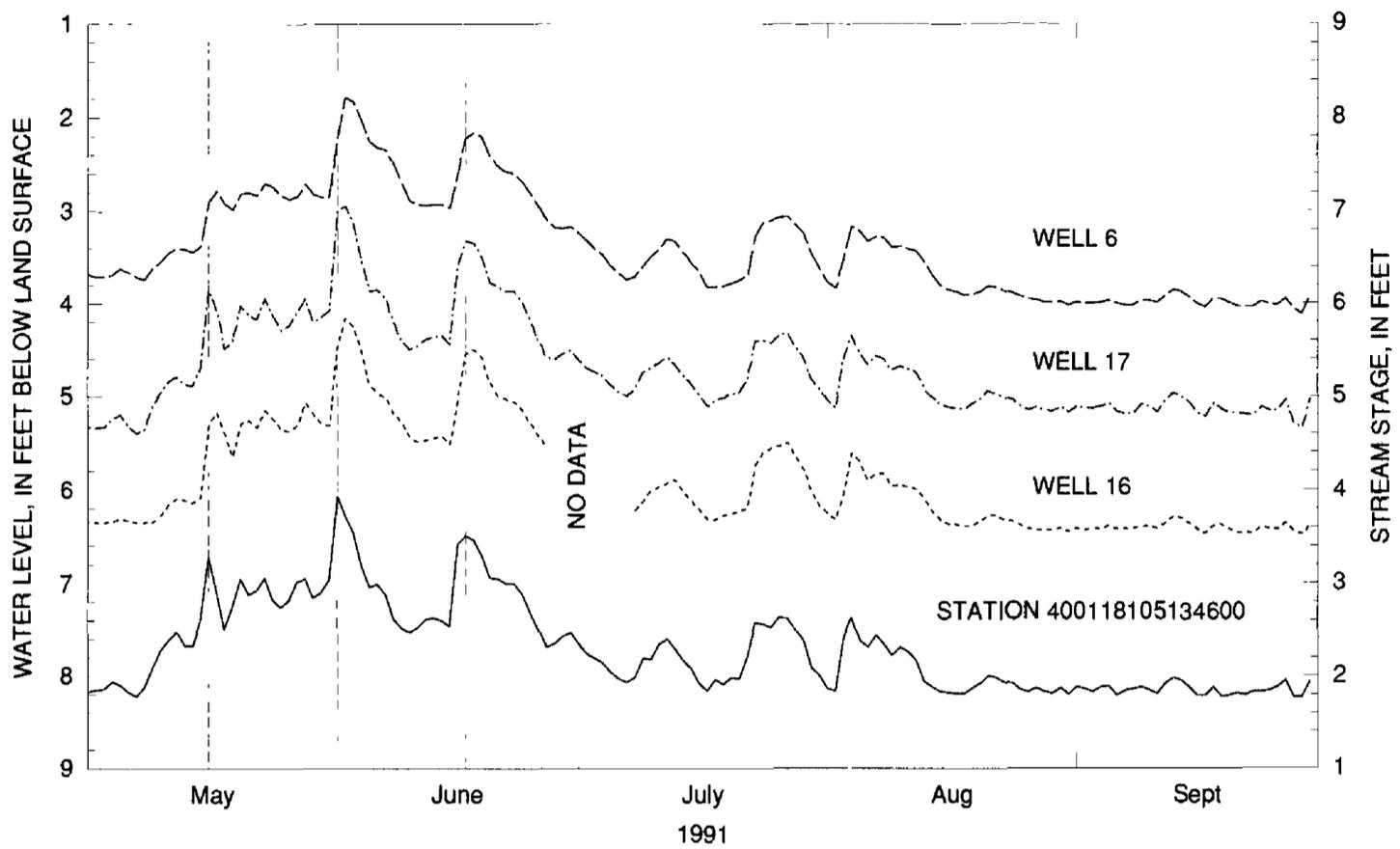


Figure 6. Water levels in wells 6, 16, and 17 and stream stage at the Boulder Creek at Cottonwood Grove station (400118105134600), May–September 1991 (the vertical dashed lines intersect stream-stage peaks.)

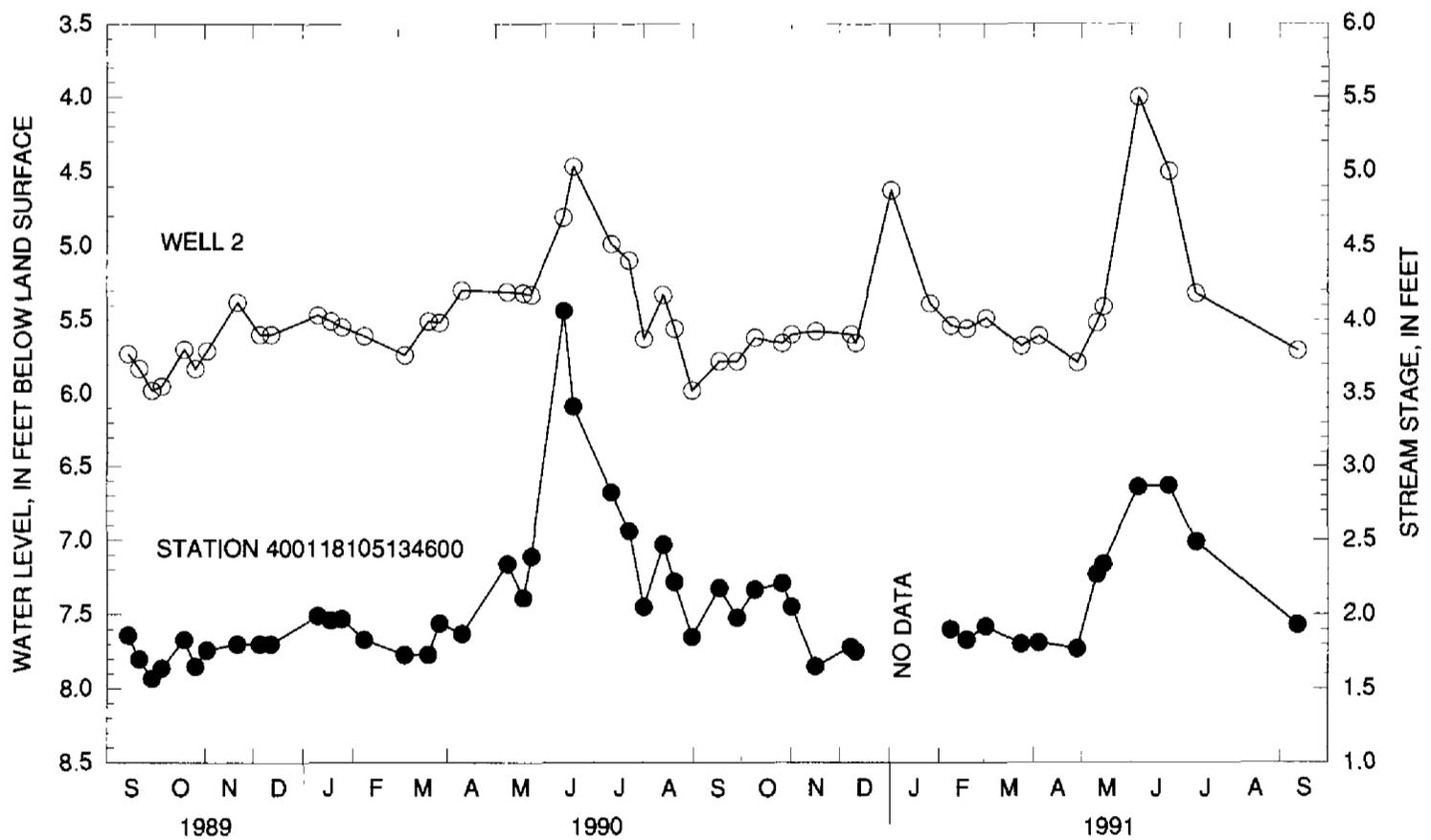


Figure 7. Water levels in well 2 and stream stage at the Boulder Creek at Cottonwood Grove station (400118105134600), defined by discrete measurements, September 1989–September 1991.

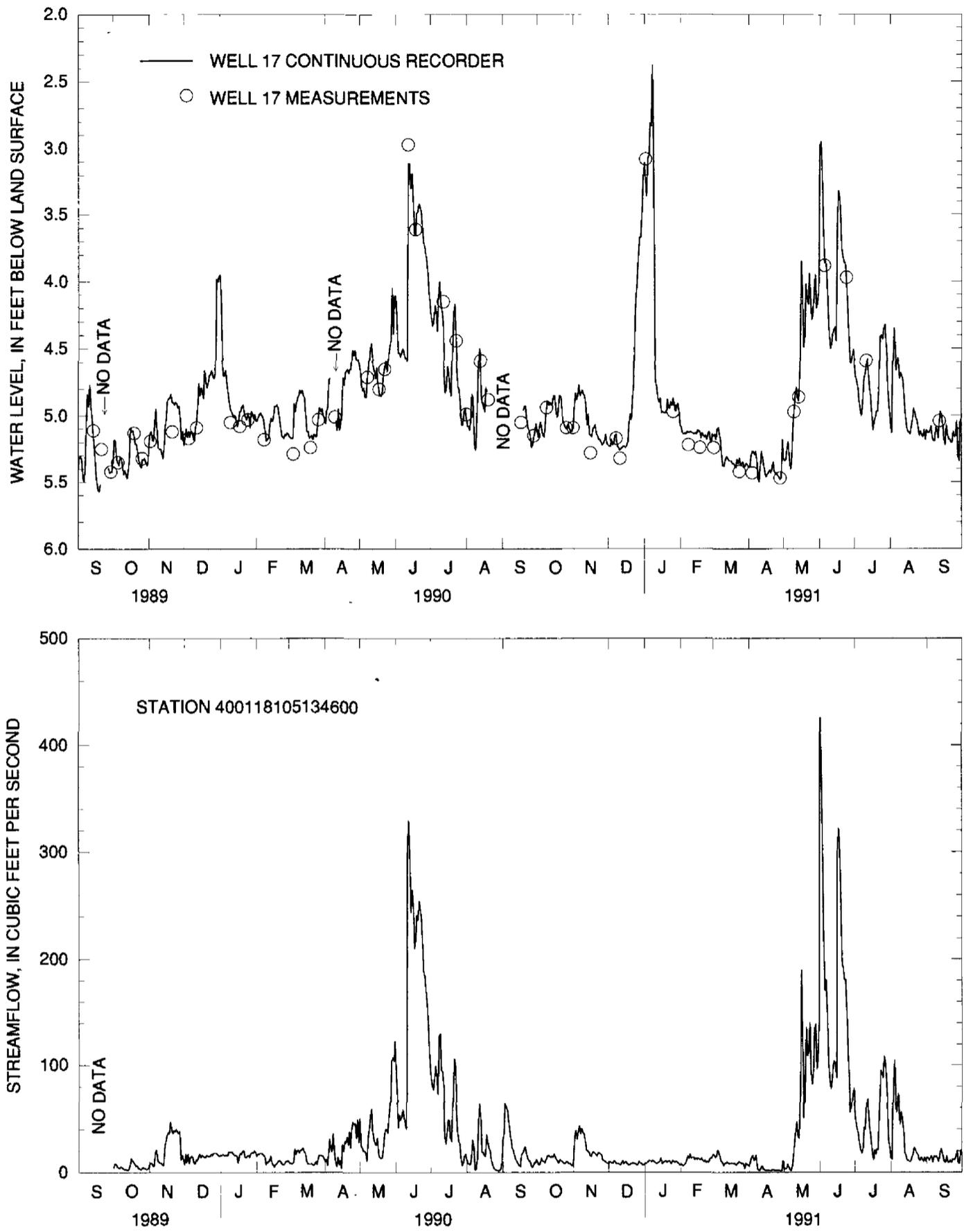


Figure 8. Water levels in well 17 and streamflow at the Boulder Creek at Cottonwood Grove station (400118105134600), September 1989–September 1991.

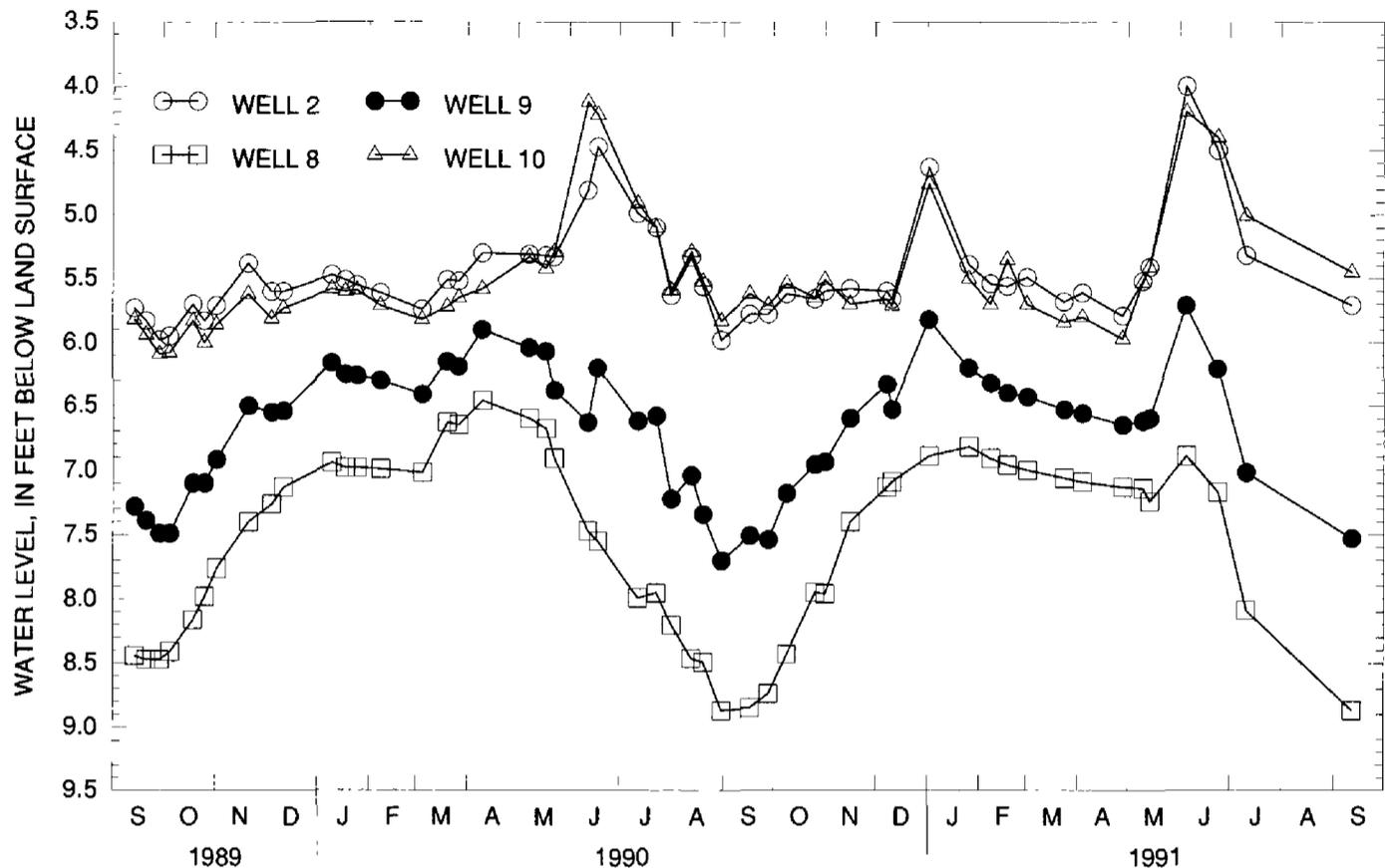


Figure 9. Water levels in wells 2, 8, 9, and 10, defined by discrete measurements, September 1989–September 1991.

high streamflow in June 1991. The timing of annual water-level peaks also varied between wells 2, 8, 9, and 10. The annual water-level peak in wells 2 and 10 coincided with snowmelt runoff, whereas in well 8, the annual peaks occurred in April and January. Well 9 had one annual peak in April 1990 and another during snowmelt runoff in June 1991. Clearly, processes other than stream stage and distance from the stream were affecting water levels in wells 8 and 9 when compared to wells 2 and 10.

Well 8 is located on the established flood plain within Cottonwood Grove where mature plains cottonwood trees are present. Ground water is a primary source of moisture for these riparian trees, thus evapotranspiration may cause ground-water-level declines in these areas. Previous studies have concluded that the quantity of ground water removed by evapotranspiration is substantial. Gatewood and others (1950) documented evapotranspiration rates of 6 ft/yr for cottonwoods along the Gila River in Arizona. Whitcomb (1965) reported that an evapotranspiration rate of 3 ft/yr was reasonable for cottonwood trees in Niobrara County, Wyoming. Eschner and others (1983) assumed a conservative annual evapotranspiration rate of 3.2 ft/yr for vegetation along the Platte River in central Nebraska.

Air temperature greatly affects evapotranspiration (Rosenberg and others, 1983). In general, evapotranspiration increases with increasing air temperature.

Plotting the hydrograph for well 8 with monthly mean air temperature indicated a correlation between low water levels and high temperatures (fig. 10). The declining water levels in well 8 coincided with periods of high monthly mean temperature when evapotranspiration demand was high. The lowest water levels in well 8 occurred around September each water year after monthly mean temperatures had remained above 60°F for at least 3 months (National Oceanic and Atmospheric Administration, 1989, 1990b, 1991). The highest water levels in well 8 followed periods when monthly mean temperatures were consistently less than 40°F, the threshold temperature below which evapotranspiration essentially ceases (Linsley and others, 1982). The effect of evapotranspiration on ground-water levels in other parts of the grove is evident in hydrographs for wells 1, 7, 9, 14, and 15 (fig. 9 and the Appendix).

Evapotranspiration also caused ground-water levels to change on a diel basis. During summer, fluctuating water levels were recorded in well 6 during periods of constant or declining stream stage (fig. 11). Between August 21–24, 1991, water levels in well 6 declined between late morning and about 1800 hours in response to consumptive ground-water use by riparian vegetation. Water levels recovered between 2400 hours and 0600 hours when plant stomata were closed and evapotranspiration demand had decreased. Figure 11 also shows the dual effect of stream stage and

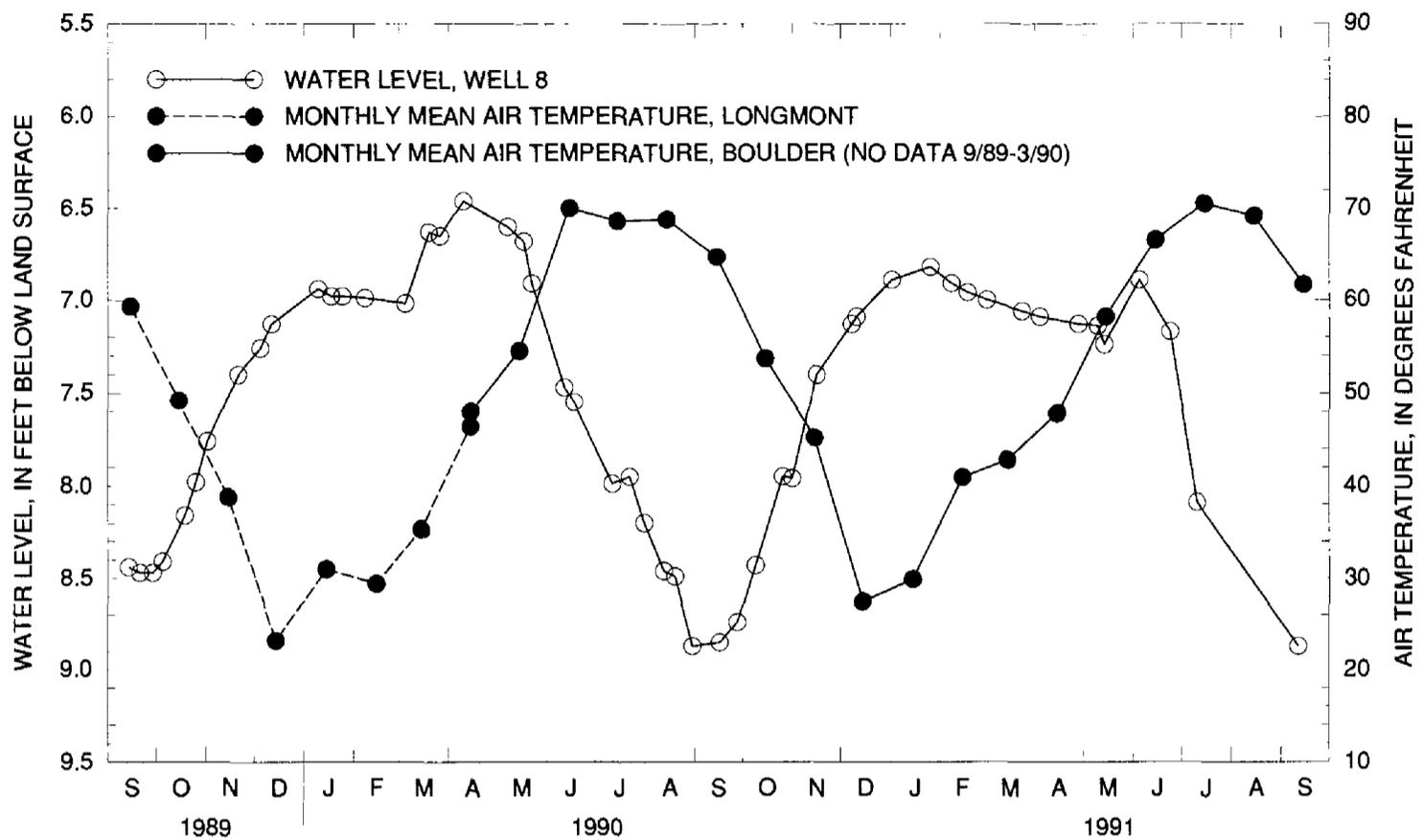


Figure 10. Water levels in well 8, defined by discrete measurements, and monthly mean air temperature in the vicinity of Cottonwood Grove, September 1989–September 1991. Air temperature data from National Oceanic and Atmospheric Administration (1989, 1990b, 1991).

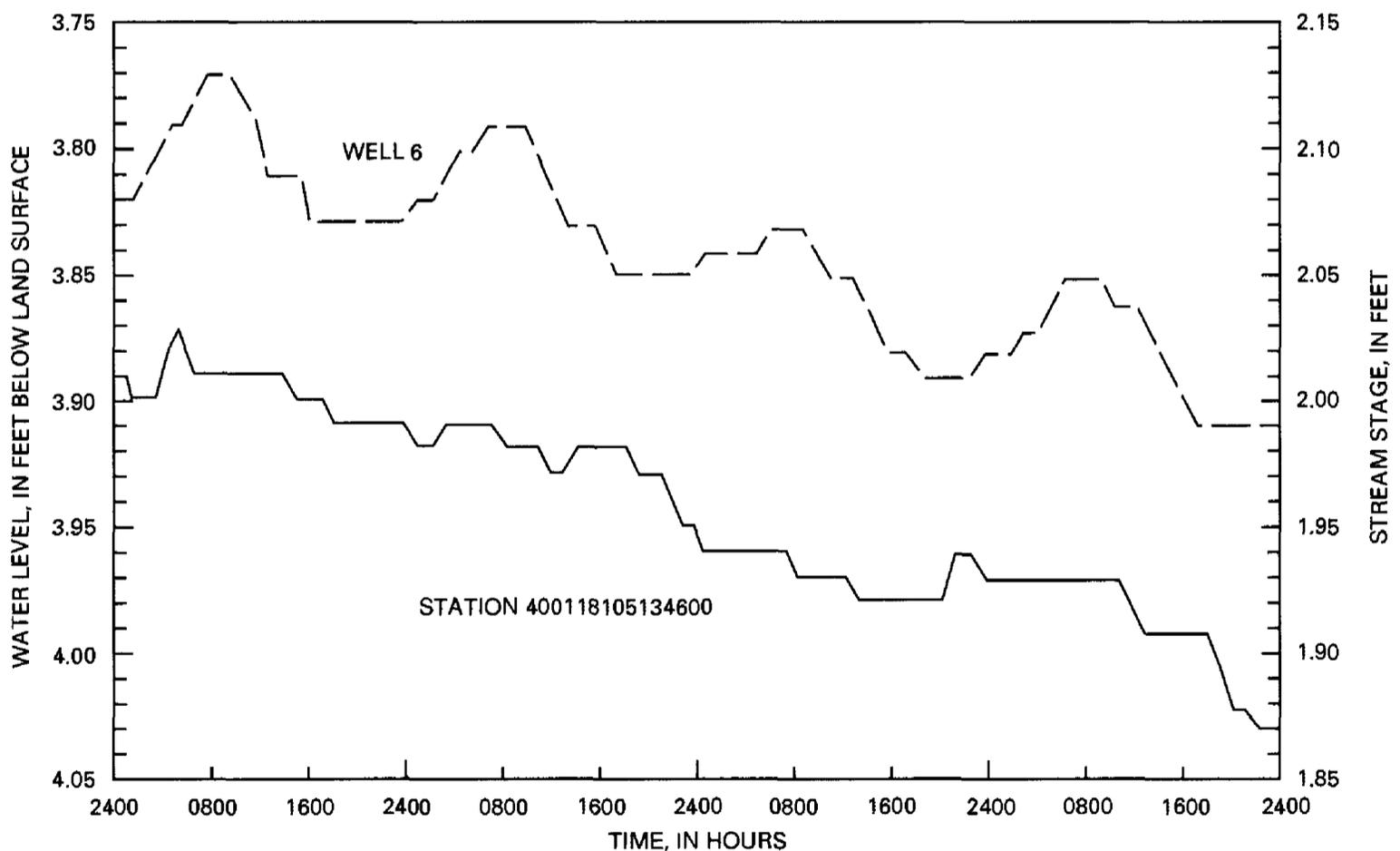


Figure 11. Water levels in well 6 and stream stage at the Boulder Creek at Cottonwood Grove station (400118105134600), August 21–24, 1991.

evapotranspiration on the alluvial aquifer. While the diel effect of evapotranspiration is well pronounced, the overall decline in ground-water level in response to declining stream stage also is evident.

Infiltrating precipitation can recharge the alluvial aquifer in Cottonwood Grove during fall, winter, and early spring. Dugan and Peckenpaugh (1985) reported ground-water recharge by infiltration to be more effective during cool months when evapotranspiration demand was low. Between March 5 and April 10, 1990, when the mean daily temperature was less than 40°F (National Oceanic and Atmospheric Administration, 1990a), water levels in well 7 increased even though streamflow remained relatively constant (fig. 12). Partial infiltration from the more than 4 in. of total precipitation during this time period may have contributed to the increase. In contrast, 2.65 in. of

precipitation between July 12–23, 1990, did not cause water levels in well 7 to increase. The mean daily temperature during this period was almost 70°F, and evapotranspiration demand was much higher.

Hydrographs for wells 20 and 21 seem more erratic when compared to stream stage (fig. 13) and to hydrographs for other wells in Cottonwood Grove (fig. 9 and the Appendix). An additional effect on ground-water levels in this area might be urban storm-water runoff entering Cottonwood Grove through an ephemeral channel between the two wells (fig. 2). The channel contained evidence of recent flow during visits to Cottonwood Grove following precipitation events. Surface-water return flows related to urban practices, such as private and commercial lawn watering, also could be recharging the alluvial aquifer in this area.

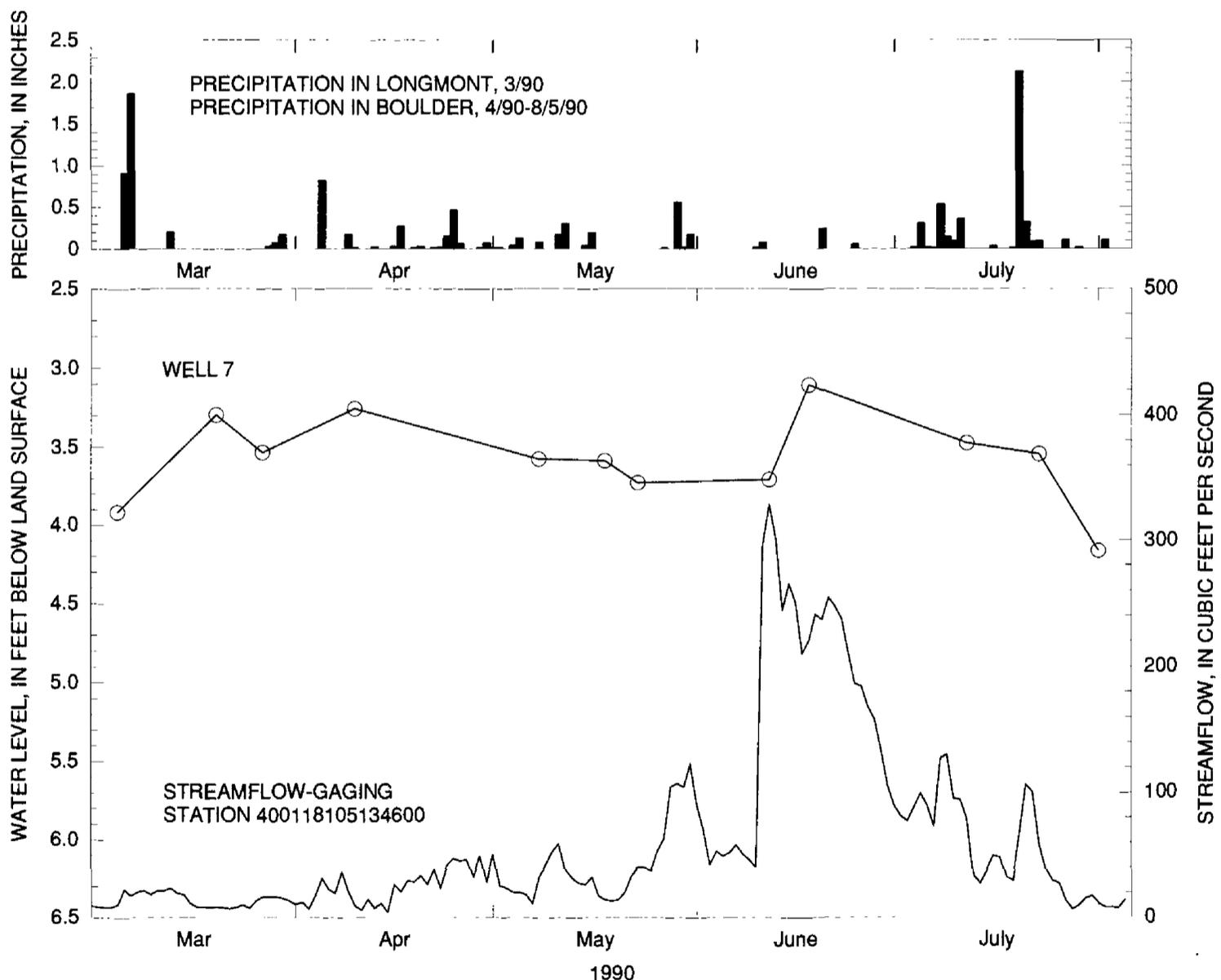


Figure 12. Daily precipitation in the vicinity of Cottonwood Grove; water levels in well 7, defined by discrete measurements; and streamflow at the Boulder Creek at Cottonwood Grove station(400118105134600), March–August 5, 1990. Precipitation data from National Oceanic and Atmospheric Administration (1990a).

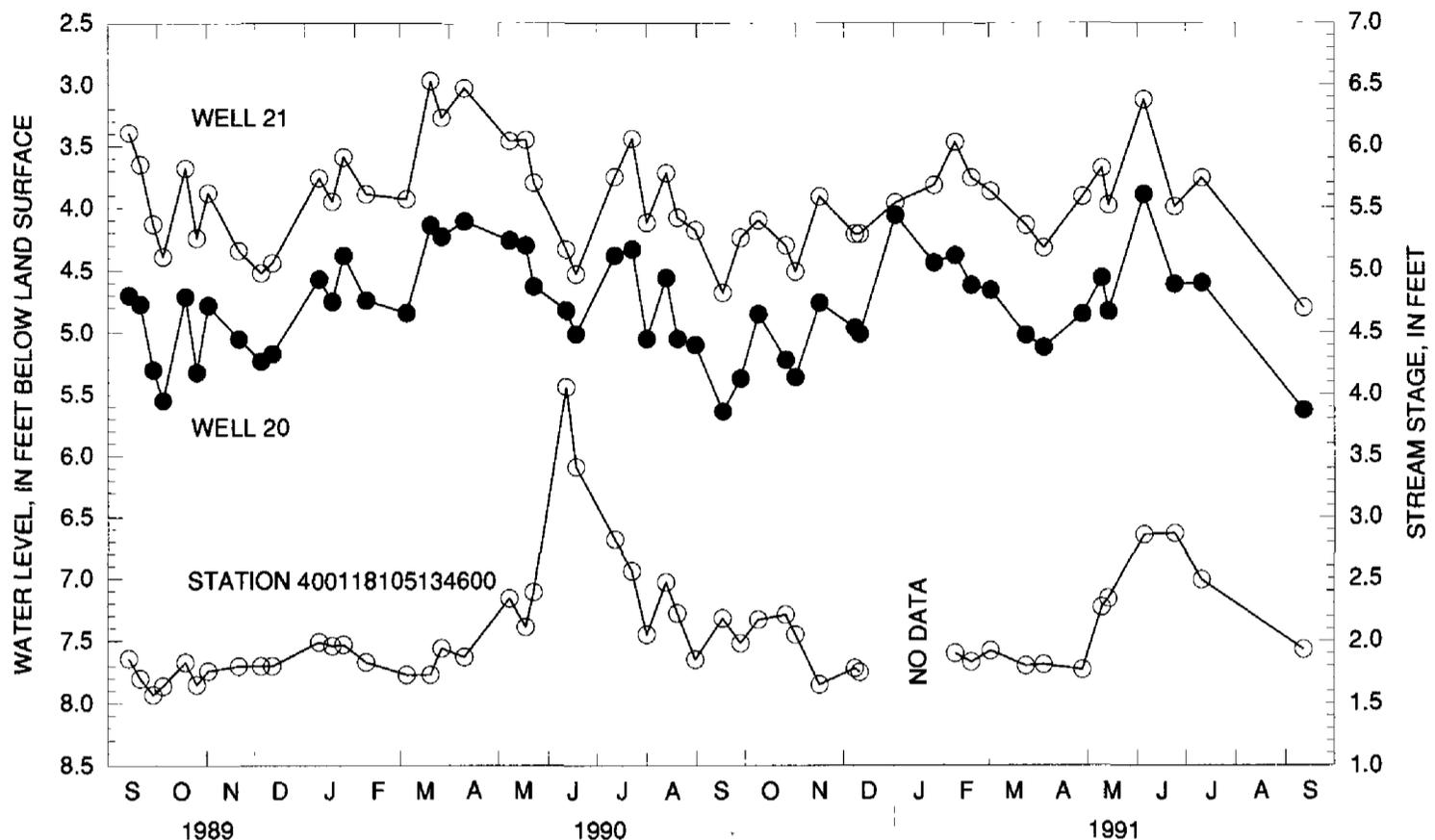


Figure 13. Water levels in wells 20 and 21 and stream stage at the Boulder Creek at Cottonwood Grove station (400118105134600), defined by discrete measurements, September 1989–September 1991.

SUMMARY

A decline in the regeneration of plains cottonwood and other native woody riparian species along Boulder Creek could have an adverse effect on certain native wildlife species. The evolving composition of riparian stands along Boulder Creek might be related to streamflow regulation, which has occurred for more than 100 years. The U.S. Geological Survey and the city of Boulder cooperated in a 2-year study to describe surface- and ground-water hydrology and their interaction in a small riparian woodland along Boulder Creek to assist ecologists in assessing woody plant-recruitment characteristics.

Boulder Creek, situated in the headwaters of the South Platte River Basin, originates near the Continental Divide, about 23 mi west of Boulder. The study area, known as Cottonwood Grove, is about 28 acres in size and is located along Boulder Creek, just downstream from the Boulder city limits. The alluvial aquifer underlying Boulder Creek in Cottonwood Grove consists of Piney Creek Alluvium of Holocene age. Average thickness of the alluvial aquifer in Cottonwood Grove is about 5 ft. The aquifer is covered with 2 to 4 ft of soil and is underlain by Pierre Shale of Upper Cretaceous age.

Streamflow through the study area was computed from a continuous stream-stage record that was

compiled for streamflow-gaging station, Boulder Creek at Cottonwood Grove. Ground-water levels in Cottonwood Grove were monitored in 22 wells, which ranged in depth from 4 to 11 ft below land surface.

Streamflow in the Boulder Creek Basin during the study was about 22 percent less than the historical average. Annual mean streamflows through Cottonwood Grove of 34.5 ft³/s for water year 1990 and 34.1 ft³/s for water year 1991 indicated that streamflow was decreased by 53 percent in a 5-mi reach immediately upstream from Cottonwood Grove. Water diversions dating from 1882 caused most of the decrease. The need for three stage-discharge ratings during the 2-year study indicated that Boulder Creek through Cottonwood Grove was a dynamic system with scour and fill of bed material occurring.

Ground water generally flowed in the same direction as Boulder Creek within Cottonwood Grove. Ground-water movement in the northeastern corner of the grove was affected by an artificial pond constructed outside the study area at a lower elevation than the elevation of the stream channel.

Water levels in the alluvial aquifer adjacent to the stream predominantly were affected by stream stage. This relation accounted for the abnormally high ground-water levels in December–January of each water year, which were caused by water releases from

an upstream reservoir used for hydro-power generation. The magnitude of stream-stage effects on ground-water levels diminished with increased distance from the stream.

Evapotranspiration affected ground-water levels within Cottonwood Grove on a diel and seasonal basis and was prevalent in areas supporting mature plains cottonwoods. Evapotranspiration increased with high air temperature, causing ground-water levels to decrease. Infiltrating precipitation seemed to recharge the alluvial aquifer more effectively when air temperature and evapotranspiration demand were low.

Urban runoff caused by precipitation and private and commercial lawn watering might discharge into Cottonwood Grove through an ephemeral channel. Water levels in wells near this channel were more erratic when compared to other wells in the grove, indicating that urban runoff was recharging the alluvial aquifer in this area.

REFERENCES CITED

- Bradley, C.E., and Smith, D.G., 1986, Plains cottonwood recruitment and survival on a prairie meandering river flood plain, Milk River, southern Alberta and northern Montana: *Canadian Journal of Botany*, v. 64, no. 7, p. 1433–1442.
- Dugan, J.T., and Peckenpaugh, J.M., 1985, Effects of climate, vegetation, and soils on consumptive water use and ground-water recharge to the Central Midwest regional aquifer system, mid-continent United States: U.S. Geological Survey Water-Resources Investigations Report 85-4236, 78 p.
- Eschner, T.R., Hadley, R.F., and Crowley, K.D., 1983, Hydrologic and morphologic changes in channels of the Platte River basin in Colorado, Wyoming, and Nebraska—A historical perspective, chap. A of *Hydrologic and geomorphic studies of the Platte River basin*: U.S. Geological Survey Professional Paper 1277, p. A1–A39.
- Everitt, B.L., 1968, Use of the cottonwood in an investigation of the recent history of a flood plain: *American Journal of Science*, v. 266, no. 6, p. 417–439.
- Fenner, Pattie, Brady, W.W., and Patton, D.R., 1985, Effects of regulated flows on regeneration of the Fremont cottonwood: *Journal of Range Management*, v. 38, no. 2, p. 135–138.
- Gatewood, J.S., Robinson, T.W., Colby, B.R., Hem, J.D., and Halpenny, L.C., 1950, Use of water by bottom-land vegetation in lower Safford Valley, Arizona: U.S. Geological Survey Water-Supply Paper 1103, 210 p.
- Linsley, R.K., Kohler, M.A., and Paulhus, J.L.H., 1982, *Hydrology for engineers* (3d ed.): New York, McGraw-Hill, 508 p.
- National Oceanic and Atmospheric Administration, 1989, *Climatological data—Annual Summary—Colorado, 1989*: Asheville, N.C., National Climatic Data Center, v. 94, no. 13, 35 p.
- _____, 1990a, *Climatological data—Colorado, March–August 1990*: Asheville, N.C., National Climatic Data Center, v. 95, nos. 3–8
- _____, 1990b, *Climatological data—Annual Summary—Colorado, 1990*: Asheville, N.C., National Climatic Data Center, v. 95, no. 13, 35 p.
- _____, 1991, *Climatological data—Annual Summary—Colorado, 1991*: Asheville, N.C., National Climatic Data Center, v. 96, no. 13, 35 p.
- Read, R.A., 1958, *Silvical characteristics of Plains cottonwood*: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station Paper 33, 18 p.
- Robson, S.G., 1989, *Alluvial and bedrock aquifers of the Denver Basin—Eastern Colorado's dual ground-water resource*: U.S. Geological Survey Water-Supply Paper 2302, 40 p.
- Romero, J.C., 1973, *Hydrogeologic investigation of the Boulder Creek drainage basin, Colorado*: Colorado Department of Natural Resources, Division of Water Resources, 21 p.
- Rosenberg, N.J., Blad, B.L., and Verma, S.B., 1983, *Microclimate—The biological environment*: New York, Wiley, 495 p.
- Stromberg, J.L., Duncan, T.P., and Richter, B.D., 1991, *Flood flows and dynamics of Sonoran riparian forests: Rivers*, v. 2, no. 3, p. 221–235.
- Trimble, D.E., 1975, *Geologic map of the Niwot quadrangle, Boulder County, Colorado*: U.S. Geological Survey Geologic Quadrangle Map GQ-1229, 1 sheet, scale 1:24,000.
- Whitcomb, H.A., 1965, *Ground-water resources and geology of Niobrara County, Wyoming, with a section on Chemical quality of the ground water* by T.R. Cummings: U.S. Geological Survey Water-Supply Paper 1788, 101 p.

APPENDIX

Hydrographs showing water levels in selected wells in Cottonwood Grove,
September 1989–September 1991

