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Analysis of Hydrologic Factors That Affect Ground-Water Levels in the Arkansas River Alluvial Aquifer Near La Junta, Colorado, 1959–99

Water-Resources Investigations Report 00–4047

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

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By Clifford R. Bossong

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Denver, Colorado
2000

U.S. DEPARTMENT OF THE INTERIOR
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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
mile (mi)	1.609	kilometer (km)
	Area	
acre	0.4047	hectare (ha)
acre-foot (acre/ft)	0.001233	cubic hectometer (hm^3)
square mile (mi^2)	259	hectare (ha)
	Volume	
million gallons (Mgal)	3,785	cubic meter (m^3)
cubic foot (ft^3)	0.028317	cubic meter ($m4^3$)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Hydraulic gradient	
foot per mile (ft/mi)	0.1786	meter per kilometer (m/km)

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

Analysis of Hydrologic Factors That Affect Ground-Water Levels in the Arkansas River Alluvial Aquifer Near La Junta, Colorado, 1959–99

By Clifford R. Bossong

Abstract

The water table is sometimes near the land surface in the vicinity of La Junta, Colorado, and may impair the use of agricultural and personal property. A water-table map prepared for the alluvial aquifer in the vicinity of La Junta, indicated that, in March 1999, the Fort Lyon Canal and the Arkansas River provided recharge to the aquifer. A depth-to-water map prepared for the same area and period indicated that the water table was relatively shallow (less than 10 feet) in about 50 percent of the area studied. Available historical water-level records visually indicated that water levels tended to increase throughout the study area during the past nearly 4 decades, and regression analysis quantifies this relation. The available records do not address short-term changes.

Several hydrologic factors that affect water levels in the study area were identified, and some simple relations between these factors and changes in water levels also were identified on the basis of coincidence of changes in the time series for the various records. Indications are that flow in the Fort Lyon Canal, surface-water applications for irrigation, and ground-water withdrawals have acted in concert to affect both increases and decreases in ground-water levels. Relatively low levels of ground-water withdrawals in the 1990's may be associated with increases in ground-water levels as well. The elevation for the base of the Arkansas River at the gaging station in La Junta has steadily increased from about 1960 to 1997 and has probably influenced water levels in lowland wells.

INTRODUCTION

La Junta is located in southeastern Colorado on the Arkansas River (fig. 1). Much of the land near the Arkansas River in the vicinity of La Junta is irrigated for agricultural purposes. Water used for irrigation either is taken from the Fort Lyon Canal, which diverts water from the Arkansas River a few miles west of La Junta, or is withdrawn from the local alluvial aquifer in the flood plain of the Arkansas River, which is highly transmissive and capable of yielding relatively large amounts of water to wells. The Fort Lyon Canal provides irrigation water for about 90,000 acres of agricultural land between La Junta and Lamar, about 60 miles downstream. The Fort Lyon Canal is the principal source of water used for irrigation in the study area; however, withdrawals from the local alluvial aquifer can represent as much as 40 to 60 percent of total irrigation when surface-water availability is low (Goff and others, 1998).

Tracts of agricultural land and many residences in the vicinity of La Junta may be affected by the water table which, in places, is near the land surface. Effects include flooded basements and soggy, or water-logged, conditions in agricultural fields that impair their suitability for agriculture. Conveyance losses from the Fort Lyon Canal, recharge from the Arkansas River, and ground-water withdrawals are potential sources of recharge and discharge to the local aquifer that affecting water-table conditions.

In order to better understand hydrologic factors that affect the water table near La Junta, the U.S. Geological Survey (USGS), in cooperation with

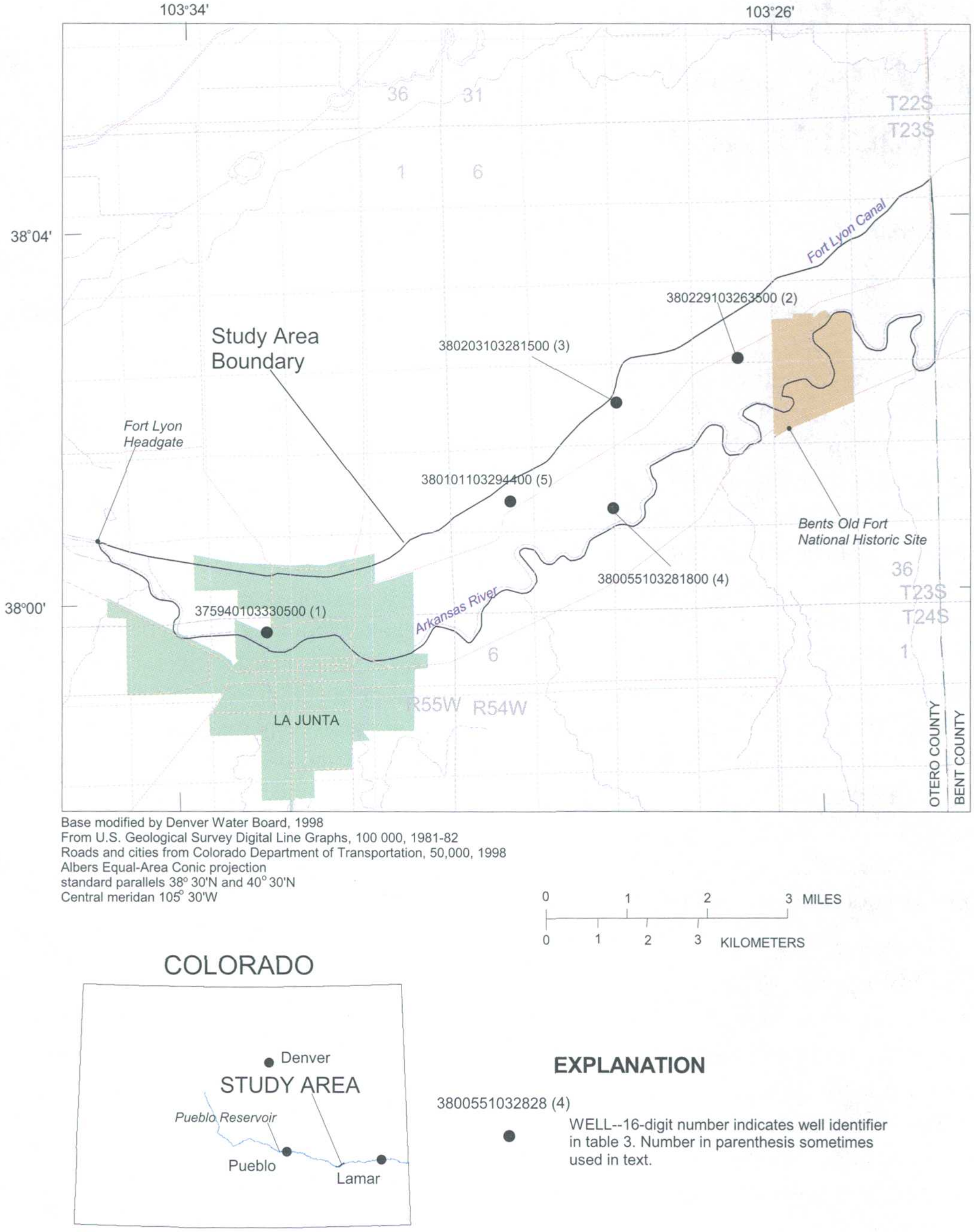


Figure 1. Location of study area and selected wells.

the Colorado Water Conservation Board, conducted a study in 1999 to analyze hydrologic factors that affect ground-water levels in the Arkansas River alluvial aquifer. This report presents the results of that study. More specifically, the report describes water-table conditions in March 1999, historical water levels, and hydrologic factors that affect water levels.

The study was limited to the area between the Fort Lyon Canal and the Arkansas River from the Fort Lyon Canal headgate east to the Otero County line (fig. 1). The description of March 1999 conditions is based on water level measurements made in 49 wells. The description of earlier conditions (generally 1959 through 1998) is based on time-series records for ground-water levels, ground-water withdrawals, applications of ground water and surface water for irrigation, discharge in the Arkansas River, diversions to the Fort Lyon Canal, and channel conditions in the Arkansas River. The study was limited to data that are maintained in a computer system, or archived as digital records.

Previous Investigations

Several hydrologic investigations have been completed in the study area. The results of these investigations are valuable sources of background information to interested readers. Konikow and Bredehoeft (1974) characterized the study area as part of a ground-water modeling investigation of ground-water flow and chemistry. Watts and Lunsford (1992) modeled several different water-management alternatives designed to affect changes in water-table conditions in the study area. Using a digital model that characterized ground-water levels in the area as sensitive to leakage from the Arkansas River, leakage from the Fort Lyon Canal, and ground-water withdrawals, they found that most alternatives would have relatively local effects although modifications to the Arkansas River channel could change ground-water levels throughout the area. Goff and others (1998), provided a modeling analysis of the effects of irrigation in the study area and found that salinity of ground water and surface water was related to irrigation activities. The report by Goff and others (1998) is the source of many data used in this study. Dash (1995) reported on the irrigation water use for the Fort Lyon Canal and documented losses from the canal.

Acknowledgments

The assistance of certain agencies and individuals were critical to the completion of this study. In particular, Lloyd Wadleigh and Don Taylor, from Division II office of the Colorado Division of Water Resources located in La Junta, were extremely helpful with records available from their office that were used for identifying and locating wells for the March 1999 water-level measurements. In addition, many landowners provided access to wells that were measured; without this access, it would not have been possible to characterize water-table conditions in March 1999.

WATER-TABLE CONDITIONS IN MARCH 1999

To document current water-table conditions, the water table was mapped in the spring of 1999 on the basis of measurements from 49 wells. Wells were identified and depths to water from a point where the land surface elevation could be estimated were measured between March 9 and March 19, 1999; the results of those measurements are listed in table 1. During the measurement period, flow in the Fort Lyon Canal was steady but relatively low, about 100 to 200 cubic feet per second, and flow in the Arkansas River at La Junta varied from about 50 to 150 cubic feet per second.

The depth-to-water measurements were converted to elevations of the water-table surface, and the resultant elevations were contoured by hand to produce a generalized water-table map for the study area that is shown in figure 2. Estimates of land-surface elevations were made using 1:24,000-scale topographic maps, and map accuracy and estimation techniques dictated the estimates may depart from actual elevations by as much as 2.5 feet.

In places where water-table surfaces are near the land surface, there is often interest in knowing how close the water-table surface is to the land surface. To show this information, digital elevation models of the generalized water-table map (fig. 2) and the land surface were used to create a depth-to-water map. The digital elevation models provide estimates of either ground-water elevation or land surface elevation for individual grid cells in a gridded network of the study area. Ground-water elevations for individual grid cells were estimated using measurements of ground-water

Table 1. Description of wells used to measure water table, March 9 through March 19, 1999

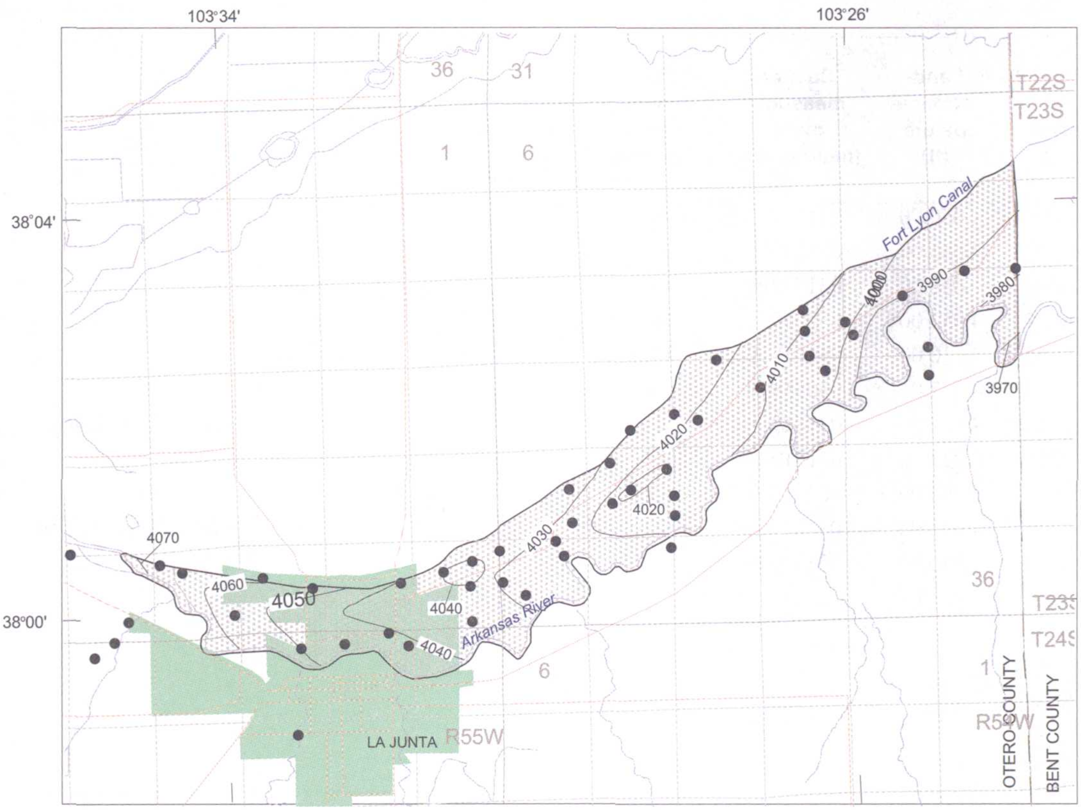
[State permit number, identifier used by Colorado Division of Water Resources; depth to water, measured depth to water adjusted to land-surface datum; land-surface datum, land-surface elevation estimated from 1:24,000 U.S. Geological Survey topographic map; mmddyyyy, date of measurement in month day year format; hhmm, time of measurement in military hours and minutes format; ft, feet; GWSI ID, refers to 15 digit latitude and longitude based identifier used in U.S. Geological Survey Ground-Water Site Inventory data base; --, not available]

State permit number	Depth to water (ft)	Land-surface datum (ft)	Date of measurement (mmddyyyy)	Time of measurement (hhmm)	Distance from measuring point to land surface (ft)	Description of measuring point	Remarks
309	13.10	4,055.00	03151999	1555	0.50	Base of pump	
312	6.43	4,035.00	03191999	1415	1.00	Top of casing	
316	22.40	4,048.00	03151999	1220	0.90	Pipe	
482	11.28	4,075.00	03091999	1109	2.00	Top of casing	
483	6.15	4,078.00	03091999	1645	3.00	Top of shelter	
653	16.49	4,041.00	03191999	1500	0.50	Hole in casing	
1023	19.09	4,011.00	03151999	1120	0.70	Hole in casing	
1791R	1.72	4,019.00	03151999	1740	0.60	Top of casing	
1792	18.40	4,039.00	03151999	1021	2.00	Plug in casing	
1793	19.15	4,041.00	03191999	1530	1.00	Hole in casing	
1794	13.39	4,059.00	03161999	1635	0.40	Hole in casing	
2540	13.75	4,080.00	03091999	1122	1.30	--	
2978	10.56	3,991.00	03161999	1030	2.00	Top of casing	
4467	9.45	4,038.00	03191999	1430	1.75	Top of casing	
4523	9.25	4,085.00	03091999	1805	1.00	Top of casing	
6778	20.52	4,030.00	03151999	1041	1.00	Base of pump	
6780	18.94	4,048.00	03101999	1605	1.50	Top of casing	
6902	14.19	4,068.00	03161999	1301	1.50	Top of casing	
10016	8.30	4,062.00	03161999	1440	0.00	Land surface	
10118	9.53	4,065.00	03011999	1710	0.20	Base of well	
10122	16.01	4,033.00	03101999	1710	0.60	Top of casing	
11878	7.80	3,994.00	03161999	1110	1.80	Top of casing	
12062	8.15	3,998.00	03101999	1215	0.40	Top of casing	
12216	32.52	4,058.00	03151999	1430	1.40	Base of pump	
15093	20.27	4,085.00	03161999	1346	0.00	Land surface	
13215	6.42	4,038.00	03161999	1605	1.60	Top of casing	
13318	12.42	4,095.00	03161999	1225	1.80	Top of casing	
13709	15.98	4,055.00	03151999	1530	0.30	Top of casing	
14180	11.35	4,045.00	03191999	1400	0.00	Land surface	
14375	3.88	4,042.00	03151999	1651	2.00	Top of casing	
14381	15.02	4,046.00	03151999	0941	2.00	Top of casing	
14776	15.96	4,018.00	03101999	1526	1.20	Top of casing	
14778	16.48	4,031.00	03101999	1010	0.80	Top of casing	
14809	16.88	4,024.00	03101999	1040	0.60	Hole in base of pump	
15103	4.72	4,031.00	03151999	1716	1.60	Top of casing	
15344	13.33	4,093.00	03091999	1310	1.50	Top of casing	
15501	7.90	4,065.00	03091999	1620	1.50	Floor of shelter	
15934	5.17	4,030.00	03101999	1751	1.20	Top of casing	

Table 1. Description of wells used to measure water table, March 9 through March 19, 1999—Continued

[State permit number, identifier used by Colorado Division of Water Resources; depth to water, measured depth to water adjusted to land-surface datum; land-surface datum, land-surface elevation estimated from 1:24,000 U.S. Geological Survey topographic map; mmddyyyy, date of measurement in month day year format; hhmm, time of measurement in military hours and minutes format; ft, feet; GWSI ID, refers to 15 digit latitude and longitude based identifier used in U.S. Geological Survey Ground-Water Site Inventory data base; --, not available]

State permit number	Depth to water (ft)	Land-surface datum (ft)	Date of measurement (mmddyyyy)	Time of measurement (hhmm)	Distance from measuring point to land surface (ft)	Description of measuring point	Remarks
21377	11.05	4,050.00	03161999	1511	1.40	Top of casing	
21780	19.63	4,025.00	03151999	1055	0.90	Top of casing	
175747	34.87	4,058.00	03151999	1555	1.50	Top of casing	
195453	8.77	4,052.00	03091999	1440	0.00	Land surface	
201493	15.65	4,010.00	03101999	1441	1.00	Hole in pump	
--	2.35	4,052.00	03091999	--	0.60	Top of casing	
--	1.40	4,057.00	03181999	--	--	--	GWSI ID 375940103330500
--	6.57	4,023.00	03171999	--	--	--	GWSI ID 380036103282100
--	4.17	4,033.00	03221999	--	--	--	GWSI ID 380041103294900
--	–.44	4,013.00	03181999	--	--	--	GWSI ID 380055103281800
--	6.76	3,980.00	03181999	--	--	--	GWSI ID 380229103263300
Mean	12.30						
Minimum	-0.44						
Median	11.35						
Maximum	35.31						
Skewness	0.79						



Base modified by Denver Water, 1998
From U.S. Geological Survey Digital Line Graphs, 100 000, 1981-82
Roads and cities from Col. Department of Transportation, 24 000, 1998
Albers Equal-Area Conic projection
standard parallels 38°30'N and 40°30'N
Central meridan 105°30'W

0 1 2 3 MILES

0 1 2 3 KILOMETERS

EXPLANATION

STUDY AREA

—4050— WATER-TABLE CONTOUR--shows generalized altitude of water table. Contour interval 10 feet. National Geodedic Vertical Datum 1929

● WELL-- shows location of well with measured water level

Figure 2. Generalized water-table contours derived from measurements made March 9 through March 19, 1999.

from March 1999 and an algorithm based on iterative finite-difference methods (Hutchinson, 1989) that is implemented in the Environmental Sciences Resource Institute geographic information system software known as ArcInfo. Land-surface elevations were available in digital elevation models prepared by USGS (REF). The depth-to-water map shown in figure 3 was prepared by subtracting the ground-water elevation model from the land-surface elevation model.

Water-Table Map

The generalized water-table map (fig. 2) indicates the direction of ground-water movement, which is perpendicular to the water-table contours. The map indicates that the general direction of ground-water movement in the study area was from west to east. The gradient of the water table, indicated by the spacing of the contours was comparable to that of the river—about 6 feet per mile.

The map also indicates that in much of the study area, ground water was moving from the area of the Fort Lyon Canal and the Arkansas River toward the center of the study area; a condition indicating that the aquifer was receiving recharge from both the canal and the river. The gradient from the area of the Fort Lyon Canal to the center of the study area is sometimes steeper than the gradient from the river to the center of the study area, especially in the eastern part of the study area.

Estimate of Ground-Water Storage

The generalized water-table map (fig. 2) was used with information describing the elevation for the base of the local alluvial aquifer (Nelson and others, 1989), and with an estimate of the specific-yield of the aquifer (Watts and Lunsford, 1992), to estimate the amount of water stored in the aquifer. The difference between the water-table surface and the base of the aquifer represents the volume of the aquifer. The specific yield, estimated as 0.20 in the study area, is the ratio of the content of water that will drain, due to gravitational forces, to the water content of the aquifer from which it is drained. To obtain the estimate of water contained in the aquifer, the aquifer volume was multiplied by the estimated specific yield. These methods indicated an estimated water content of about 40,000 acre-feet; however, the entire estimated water content of the aquifer would be available to wells only under ideal conditions. Further, under similar ideal conditions, only the water contained in the aquifer that is above the elevation of the Arkansas River would be able to provide ground-water contributions to the river.

Depth to Water

The generalized depth-to-water map (fig. 3) indicates that water levels ranged from less than 5 feet below the land surface to about 50 feet below the land surface. In general, the range of depths to water was greatest in the eastern one-half of the study area.

The digital elevation model for depth to water indicates that water levels were within 5 feet of the land surface in about 31 percent of the study area (table 2), mostly in a zone that parallels the river (fig. 3). Water levels were relatively shallow, from 5 to 10 feet below the land surface, in about 20 percent of the study area. The area of relatively shallow water levels is prominent in the western one-half of the study area where the area is relatively wide compared to the eastern one-half of the study area where it generally is a thin strip; however, there is an area in the eastern part of the study area, mostly in section 21 of township 23 south, range 54 west, where relatively shallow depths to water are more extensive.

Maps made at different times have different locations for the Arkansas River. These differing locations indicate the shifting nature of the river and also indicate that the river channel location, on a decadal scale, is variable.

HISTORICAL WATER LEVELS

The USGS has monitored ground-water levels in the study area for several decades. Water-level records are maintained in a system known as the Ground-Water Site Inventory (GWSI) data base. As part of the study, the GWSI data base was accessed to obtain water-level records from wells in and around the study area; information from 224 wells was obtained. A subset of these wells consisting of 141 wells that wells that have been measured more than one time, is listed in table 3. A brief summary of the information available for each well also is included in table 3.

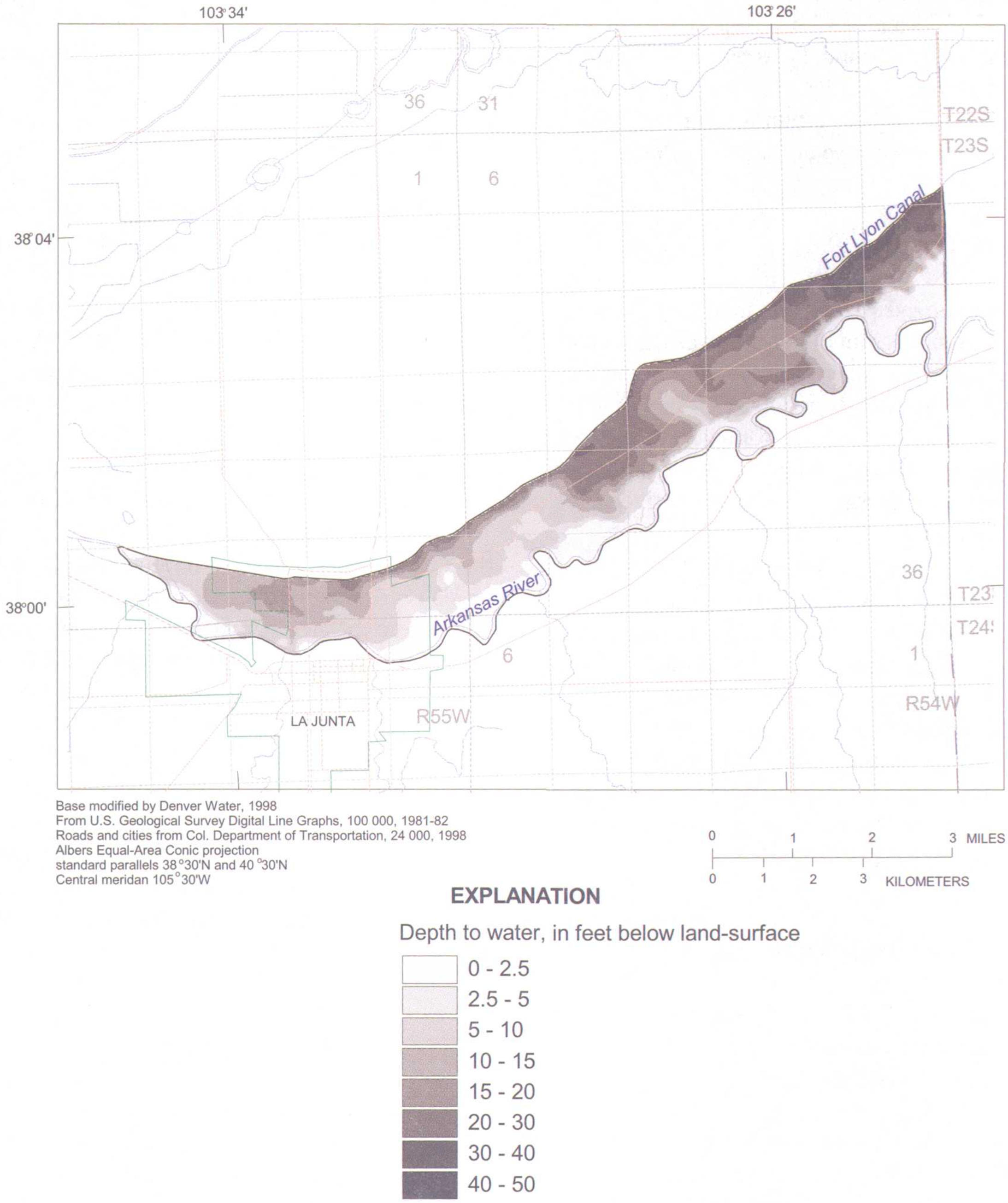


Figure 3. Generalized depth-to-water calculated from measured water table and digital representation of land-surface elevations.

Table 2. Frequency analysis for calculated depths to water

[Depth to water was calculated for a grid of 98 X 98-foot cells; values for individual cells were assigned using an distribution method similar to inverse distance squared weighting]

Interval (feet)	Frequency		
	Absolute	Relative (percent)	Cumulative (percent)
0–5	11,432	31.13	31.13
5–10	7,432	20.24	51.37
10–15	4,730	12.88	64.25
15–20	5,149	14.02	78.27
20–25	3,103	8.45	86.72
25–30	2,387	6.50	93.22
30–35	1,009	2.75	95.97
35–40	683	1.86	97.83
40–45	511	1.39	99.22
45–50	287	0.78	100.00
Total	36,723	100.00	

General Changes in Water Levels

Some of the most useful information available from the historical records concerns how water levels have generally changed through time. For instance, have water levels remained about the same or have they changed substantially, and if they have changed, have the changes been steady or abrupt? A visual inspection of the records indicated that, in most representative cases, ground-water levels have generally had a net increase during the study period. Examples of these increases for the five wells in figure 1 are shown in hydrographs (fig. 4)

For the purposes of this discussion, the wells shown in figure 4 are referred to as "well 1" (SC02405503AAC), "well 2" (SC02305415DCC), "well 3" (SC02305421BCC), "well 4" (SC02305428CCB1), and "well 5" (SC02305430DBD). Information concerning the period of record and the number of measurements for each of these five wells is listed in table 3. Water levels in all five wells have been measured for much of the study period, and water levels in all wells except well 5 have been measured more than 100 times; well 5 has only been measured 36 times.

Wells 1 and 4 are located near the Arkansas River and the other three wells are either close to the Fort Lyon Canal or nearly centrally located between the canal and river (fig. 1); wells 1 and 4 are referred to as "lowland," and wells 2, 3, and 5, are referred to as "upland" wells in this report. This simple geographic classification also fits the differences between the hydrographs for the lowland wells and the upland wells. The lowland wells have water levels that are relatively close to the land surface. Also, although both lowland wells have water-level records that are relatively flat, their water levels still indicate a general tendency to increase through time. In this report, water levels are referred to as "high" or "low", and high water levels correspond to shallow depths to water. In general, the difference between the shallowest and the deepest depth to water, or the difference between the highest and lowest water levels, measured at a given well and referred to as range in this report, is relatively small (table 3) for the lowland wells. However, each lowland well does have at least a few measurements that seem to represent short-term changes in water levels, for instance 1965 for well 4 (SC02305428CCB1) and 1987 for well 1 (SC02405503AAC).

The three upland wells, wells 2, 3, and 5, have hydrographs with shapes that are very different from the hydrographs for the wells near the river (fig. 4). All three wells have much greater ranges than the ranges from the wells near the river. In addition, the hydrographs for these upland wells each have much higher water levels at the end of the period of record than at the early part of the period, indicating a general tendency for increases in water levels that is much more apparent than in the hydrographs for the lowland wells.

Although water levels the in upland wells exhibit long-term general increases in water levels, all three also have a period, from about 1967 through about 1979, during which they had a fairly steady decrease. The decrease is most apparent in wells 2 and 3 and least apparent in well 5. During the 1980s water levels were generally high, increasing in the early part of the decade and decreasing in the later part. Two of the three upland wells experienced the highest water levels measured in the mid-1980's. From about 1990, water levels in the wells began to increase slowly in a trend that continued for the remainder of the period of record.

Table 3. Summary for Ground Water Site Inventory wells with multiple measurements in and near the study area

[GWSI ID, 15-digit latitude- and longitude-based identifier used in GWSI; GWSI local, local township range and section identifier stored in GWSI; state permit number, identifier used by Colorado Division of Water Resources; Rolodex number, local identifier used by La Junta Colorado Division of Water Resources office; n, number of measurements; begin date, beginning date of records; end date, ending date of measurements; regression slope, negative value indicates an increasing slope - wells with 10 or fewer measurements were excepted from regressions; range, the difference between the maximum and minimum water levels measured; --, not available; Text indentifier indicates simple indentifier for well used in text]

GWSI ID	GWSI local	State permit number	Rolodex number	n	Begin date	End Date	Regression slope, in feet per year	Range	Text identifier
			Wells with significant increases in water levels						
380055103281800	SC02305428CCB1	1791	3409	151	04-01-1965	11-19-1998	–0.1689011	6.42	well 4
380041103294900	SC02305431ABB1	--	--	415	02-01-1971	10-22-1998	–0.4368751	11.24	--
380007103311200	SC02305536CAD	27156	--	223	08-01-1961	03-07-1996	–0.1945448	10.26	--
380036103282100	SC02305432AAD	--	--	40	02-01-1971	10-20-1998	–0.2367512	7.21	--
375940103330500	SC02405503AAC	--	--	164	05-01-1966	10-22-1998	–0.1114008	5.19	well 1
375940103323000	SC02405502BBD	--	--	41	03-01-1966	01-17-1987	–0.1376830	4.07	--
380019103335400	SC02305533ADD	10119	2943	178	04-01-1960	10-26-1995	–0.2824091	15.31	--
380229103263300	SC02305415DCC	21780	2784	222	08-01-1961	11-19-1998	–0.3186632	26.04	well 2
380203103281500	SC02305421BCC	317	2314	107	04-01-1960	03-09-1993	–0.3893873	22.04	well 3
380253103253400	SC02305414CAA	--	--	24	02-01-1971	03-09-1993	–0.1768588	5.86	--
380117103271600	SC02305428ADA	--	--	26	07-01-1959	03-10-1993	–0.1492389	6.43	--
380111103285100	SC02305429ACC	14831	2396	40	04-01-1960	03-09-1993	–0.3125154	14.13	--
380025103311500	SC02305536BDA	--	--	34	07-01-1959	03-09-1993	–0.1828608	10.65	--
375933103313000	SC02405501BCB	13919	--	59	11-14-1964	03-08-1988	–0.1612941	6.93	--
380101103294400	SC02305430DBD	--	--	36	03-24-1965	03-09-1993	–0.2226240	9.15	well 5
380004103303200	SC02305431CBC	--	--	19	07-01-1959	03-10-1981	–0.2051883	5.82	--
380029103312101	SC02305536BAC	--	--	51	04-06-1984	11-14-1986	–0.5668344	5.55	--
380052103281700	SC02305428CCB2	--	--	53	02-01-1971	05-23-1983	–0.1241117	3.75	--
380037103350501	SC02305532AAB	--	--	35	04-01-1960	03-09-1993	–0.0824205	7.61	--
380017103285300	SC02305432BDD	11451	--	24	03-01-1965	03-09-1981	–0.1135396	3.09	--
380015103331900	SC02305534BDD	10120	2943	25	04-01-1960	03-15-1977	–0.2034496	7.02	--
380107103281800	SC02305428CBB	1791	3409	77	10-09-1961	03-12-1976	–0.1696023	8.36	--
380001103313801	SC02305535DDAA	--	--	49	04-06-1984	05-16-1985	–0.5666288	2.10	--
375956103353600	SC02305532CDA	--	--	36	03-27-1965	03-10-1993	–0.0532789	4.79	--
380103103290500	SC02305429CAB	10122	147	12	10-01-1959	03-25-1969	–0.5160856	6.18	--
375927103312000	SC02405501BDB	14382	2943	17	11-01-1965	03-01-1973	–0.1140037	1.68	--
380008103312701	SC02305536CBDD	--	--	92	04-06-1984	01-11-1987	–0.6429105	12.03	--
380053103300000	SC02305430CDA	--	--	11	08-01-1959	03-26-1969	–0.4483872	5.87	--
375954103305400	SC02305536DCD	13215	2188	11	10-01-1963	10-04-1967	–0.9872103	6.73	--
380112103293300	SC02305430ADC	--	--	14	07-01-1959	03-25-1969	–0.5345963	8.79	--
Total wells with significant increases in water levels = 30									
			Wells with insignificant increases in water levels						
380143103284900	SC02305420DCB	--	--	26	04-01-1960	01-16-1975	–0.2874012	11.13	--
380148103274000	SC02305421DBD3	14210	3552	34	07-01-1959	03-15-1977	–0.1785594	31.60	--
380052103293000	SC02305430DDA	15934	2275	13	04-01-1960	03-25-1969	–0.2641783	4.57	--
380032103294500	SC02305431ABD	15103	2244	21	10-01-1963	03-29-1976	–0.0662243	3.02	--
375959103301300	SC02305431CDB	--	--	13	02-01-1971	02-22-1972	–0.2870563	0.79	--
380247103262200	SC02305415DAB	14777	2770	12	07-01-1959	03-24-1969	–0.3368387	5.52	--
380152103275900	SC02305421CAC	1792	2382	13	04-01-1960	03-25-1969	–0.4615746	8.41	--

Table 3. Summary for Ground Water Site Inventory wells with multiple measurements in and near the study area—Continued

[GWSI ID, 15-digit latitude- and longitude-based identifier used in GWSI; GWSI local, local township range and section identifier stored in GWSI; state permit number, identifier used by Colorado Division of Water Resources; Rolodex number, local identifier used by La Junta Colorado Division of Water Resources office; n, number of measurements; begin date, beginning date of records; end date, ending date of measurements; regression slope, negative value indicates an increasing slope - wells with 10 or fewer measurements were excepted from regressions; range, the difference between the maximum and minimum water levels measured; --, not available; Text indentifier indicates simple indentifier for well used in text]

GWSI ID	GWSI local	State permit number	Rolodex number	n	Begin date	End Date	Regression slope, in feet per year	Range	Text identifier
Wells with insignificant increases in water levels—Continued									
380128103290600	SC02305429BAB	12216	2395	12	07-01-1959	03-25-1969	–0.4647539	9.08	--
380222103260500	SC02305423BBB	--	--	32	08-08-1959	03-24-1969	–0.1186065	6.59	--
380011103310701	SC02305536CADA	--	--	68	04-06-1984	04-14-1986	–0.2186752	4.50	--
380211103271100	SC02305422BCB	14778	3514	15	07-01-1959	12-21-1971	–0.2684900	9.20	--
380218103265300	SC02305422BAC	--	--	13	07-01-1959	03-25-1969	–0.3066510	6.86	--
380243103263800	SC02305415DBC	--	--	14	04-01-1960	03-24-1969	–0.2748295	9.96	--
375927103335600	SC02405504ADA	4792	3138	19	03-01-1965	03-15-1977	–0.0629570	4.90	--
380319103235400	SC02305413AAA3	--	--	128	02-01-1971	11-19-1998	–0.0139926	7.80	--
380017103314400	SC02305535ADC1	--	--	11	04-01-1960	03-26-1969	–0.2874747	10.30	--
380212103243300	SC02305424BDA	11876	4129	22	07-01-1959	03-07-1979	–0.0296657	4.20	--
380001103315900	SC02305535DCA	10938	2988	31	03-26-1965	03-10-1981	–0.0289099	4.66	--
380226103273700	SC02305421ABA	--	--	12	07-01-1959	01-17-1975	–0.0838574	6.12	--
380032103281600	SC02305433BBB	--	--	24	08-03-1964	03-16-1977	–0.0266024	4.25	--
380018103310501	SC02305536ACCC	--	--	92	04-06-1984	01-11-1987	–0.0453751	4.00	--
380001103311001	SC02305536CDAA	--	--	69	04-06-1984	04-14-1986	–0.0442102	2.70	--
380249103260500	SC02305414CBB	14776	2381	11	04-01-1960	03-24-1969	–0.0693489	8.07	--
375944103343900	SC02305533CDC	--	--	21	03-27-1965	03-15-1977	–0.0112203	3.75	--
380010103310000	SC02305536DBC	--	--	13	02-01-1971	02-22-1972	–0.1266400	2.06	--
380223103274400	SC02305421ABB	--	--	25	07-01-1959	03-11-1980	–0.0116218	11.75	--
375929103314301	SC02405502ADD	--	--	94	04-06-1984	01-17-1987	–0.0026296	4.05	--
380148103271300	SC02305422CCB	--	--	40	05-01-1966	03-16-1977	–0.0007356	1.98	--
380024103315001	SC02305535ADCD	--	--	94	04-06-1984	01-11-1987	–0.0045215	12.05	--
Wells with significant decreases in water levels									
380209103235400	SC02305413DDA	--	--	93	10-01-1961	11-03-1970	0.2890213	5.33	--
380008103320101	SC02305535DBDD	--	--	58	04-06-1984	09-13-1986	0.5922046	2.60	--
380158103271300	SC02305421DAA	--	--	43	05-27-1966	03-10-1981	0.3119051	8.93	--
375934103315701	SC02405502ACAA	--	--	102	04-06-1984	01-11-1987	0.3717283	3.51	--
380228103254600	SC02305414CDC	--	--	28	03-25-1965	03-11-1980	0.1949933	4.46	--
380002103314601	SC02305535DDAB	--	--	92	04-06-1984	01-11-1987	0.2621876	2.86	--
380318103235500	SC02305413AAA2	--	--	55	04-01-1965	05-26-1971	0.2675896	5.02	--
380228103243800	SC02305413CDC2	--	--	14	04-24-1964	03-09-1978	0.3300888	10.67	--
380013103320800	SC02305535DBB	--	--	52	04-25-1964	03-01-1973	0.7555794	10.92	--
375932103310401	SC02405501ACBC	--	--	63	04-13-1984	08-15-1986	0.2854597	3.20	--
380304103252100	SC02305414ACA	1023	4004	22	07-01-1960	03-29-1976	0.1269777	4.53	--
380224103245700	SC02305424BBB	--	--	13	04-24-1964	10-04-1968	0.4894681	4.98	--
375937103312101	SC02405501BACC	--	--	106	04-06-1984	01-17-1987	0.1475387	3.60	--
375952103320001	SC02305535DCDA	--	--	76	04-06-1984	09-21-1986	0.2332515	2.91	--
380029103342700	SC02305533BAD	21458	--	11	07-01-1959	03-28-1969	0.3247730	4.59	--
375945103314201	SC02405502AAA	--	--	77	04-06-1984	09-21-1986	0.2021285	3.63	--

Total cases with significant decreases in water levels = 16

Table 3. Summary for Ground Water Site Inventory wells with multiple measurements in and near the study area—Continued

[GWSI ID, 15-digit latitude- and longitude-based identifier used in GWSI; GWSI local, local township range and section identifier stored in GWSI; state permit number, identifier used by Colorado Division of Water Resources; Rolodex number, local identifier used by La Junta Colorado Division of Water Resources office; n, number of measurements; begin date, beginning date of records; end date, ending date of measurements; regression slope, negative value indicates an increasing slope - wells with 10 or fewer measurements were excepted from regressions; range, the difference between the maximum and minimum water levels measured; --, not available; Text indentifier indicates simple indentifier for well used in text]

GWSI ID	GWSI local	State permit number	Rolodex number	n	Begin date	End Date	Regression slope, in feet per year	Range	Text identifier
					Wells with insignificant decreases in water levels				
375950103313901	SC02305535DDD	--	--	43	04-06-1984	09-21-1986	0.1240969	1.60	--
380027103343400	SC02305533BDB	482	2873	11	07-01-1959	03-28-1969	0.2297103	4.28	--
380122103264400	SC02305427BDA	--	--	13	02-01-1971	02-22-1972	0.4381429	1.04	--
375957103351600	SC02305532DCA	--	--	15	04-01-1960	03-28-1969	0.1379271	15.99	--
375953103332400	SC02305534CDD	--	--	13	04-01-1964	03-27-1969	0.1998883	2.61	--
375944103315801	SC02405502ABAD	--	--	99	04-06-1984	01-17-1987	0.1091177	3.30	--
375949103325700	SC02305534DDC	--	--	11	03-26-1965	03-27-1969	0.3564490	3.20	--
380014103313501	SC02305536CBB	--	--	90	04-06-1984	01-11-1987	0.2126850	4.40	--
380218103262200	SC02305422AAC	--	--	22	04-01-1960	03-16-1977	0.1577617	7.39	--
375929103311701	SC02405501BDCA	--	--	91	04-06-1984	01-17-1987	0.0967708	2.60	--
380311103244300	SC02305413BAC	2362	3660	48	08-01-1960	03-06-1979	0.1124897	9.12	--
380026103344300	SC02305533BCA	--	--	11	03-26-1965	03-27-1969	0.3185980	3.79	--
380009103334900	SC02305534CBB	14818	3853	12	04-01-1960	03-27-1969	0.1440952	3.58	--
380029103313501	SC02305536BCBD	--	--	94	04-06-1984	01-11-1987	0.3193643	8.66	--
380023103333300	SC02305533ADA	2540	2873	12	07-01-1960	10-29-1969	0.1934459	4.81	--
380154103281600	SC02305421CBC	315	2314	13	09-01-1959	03-15-1977	0.1901084	7.62	--
375951103310401	SC02305536DCCC	--	--	75	04-06-1984	09-21-1986	0.1340026	4.00	--
380034103355800	SC02305532BBB	--	--	18	05-01-1964	03-10-1981	0.0416717	3.67	--
375929103313101	SC02405501BCCA	--	--	91	04-13-1984	01-17-1987	0.0553622	2.70	--
380013103310101	SC02305536CACC	--	--	92	04-06-1984	01-11-1987	0.0497712	4.57	--
375937103313001	SC02405501BCAB	--	--	108	04-06-1984	01-17-1987	0.0401740	4.26	--
380157103264300	SC02305422CAA	--	--	13	02-01-1971	02-22-1972	0.3436175	3.13	--
380322103250300	SC02305411DDD	--	--	19	04-01-1965	03-16-1977	0.0152895	2.13	--
380033103305900	SC02305536ABC	1794	2961	11	03-01-1965	03-26-1969	0.1731950	5.69	--
380053103274400	SC02305428DCB	--	--	15	02-01-1971	03-16-1977	0.0231947	1.36	--
380010103292000	SC02305432CBB1	--	--	14	04-01-1960	03-28-1969	0.0190229	5.08	--
380004103291900	SC02305432CBC	--	--	13	02-01-1971	02-22-1972	0.0212911	1.17	--
375941103313400	SC02405501BBC	--	--	12	02-01-1971	02-22-1972	0.0083816	1.03	--
380237103270500	SC02305415CCB	--	--	25	04-01-1960	03-10-1981	0.0026804	10.52	--
					Wells with too few measurements to analyze				
375924103314400	SC02405502ADA	15438	2800	10	03-26-1965	10-03-1968	--	--	--
375928103335300	SC02405504ADD	--	--	2	09-01-1963	03-10-1981	--	--	--
375928103342400	SC02405504ACC	--	--	10	10-14-1964	03-28-1969	--	--	--
375937103313100	SC02405501BBD1	--	--	8	06-01-1960	03-31-1976	--	--	--
375937103354200	SC02405505BAC	15344	2591	10	09-01-1959	03-28-1969	--	--	--
375943103332100	SC02405503BAA	--	--	4	03-26-1965	03-27-1969	--	--	--
375943103351400	SC02405505ABA	--	--	5	03-27-1965	03-28-1969	--	--	--
375946103352700	SC02305532DCC	13318	2809	10	03-27-1965	03-28-1969	--	--	--
375947103333200	SC02405503BAB	--	--	7	03-26-1965	03-25-1967	--	--	--

Table 3. Summary for Ground Water Site Inventory wells with multiple measurements in and near the study area—Continued

[GWSI ID, 15-digit latitude- and longitude-based identifier used in GWSI; GWSI local, local township range and section identifier stored in GWSI; state permit number, identifier used by Colorado Division of Water Resources; Rolodex number, local identifier used by La Junta Colorado Division of Water Resources office; n, number of measurements; begin date, beginning date of records; end date, ending date of measurements; regression slope, negative value indicates an increasing slope - wells with 10 or fewer measurements were excepted from regressions; range, the difference between the maximum and minimum water levels measured; --, not available; Text indentifier indicates simple indentifier for well used in text]

GWSI ID	GWSI local	State permit number	Rolodex number	n	Begin date	End Date	Regression slope, in feet per year	Range	Text identifier
			Wells with too few measurements to analyze—Continued						
380012103305400	SC02305536DBA1	15024	--	9	04-01-1960	03-26-1969	--	--	--
380013103303200	SC02305431BCC	310	2262	9	03-01-1965	10-01-1968	--	--	--
380028103305200	SC02305536ABD	--	--	7	07-01-1959	03-26-1969	--	--	--
380032103322300	SC02305535CAB	--	--	10	03-24-1965	03-27-1969	--	--	--
380032103345100	SC02305533BBC2	483	2543	10	03-01-1965	10-04-1968	--	--	--
380038103355200	SC02305529CCC	--	--	6	03-27-1965	10-04-1967	--	--	--
380044103300000	SC02305430CDD2	15327	2738	6	03-24-1965	10-07-1966	--	--	--
380059103282800	SC02305429DAC	--	--	5	07-01-1959	10-01-1968	--	--	--
380113103271400	SC02305428ADD	--	--	7	04-01-1960	03-28-1969	--	--	--
380118103283200	SC02305429ADB	--	--	10	07-01-1959	03-25-1969	--	--	--
380119103272300	SC02305428ADB	--	--	8	02-01-1971	12-21-1971	--	--	--
380122103282300	SC02305429AAD	--	--	5	07-01-1959	03-25-1969	--	--	--
380202103251600	SC02305423ADC	--	--	8	10-01-1963	03-26-1968	--	--	--
380209103271300	SC02305421ADA	--	--	4	06-01-1960	07-30-1965	--	--	--
380214103245100	SC02305424BBD	11877	4129	10	07-01-1959	10-04-1968	--	--	--
380214103280000	SC02305421BAC	--	--	10	04-01-1964	03-25-1969	--	--	--
380238103260200	SC02305414CCB	--	--	6	04-01-1965	03-24-1969	--	--	--
380246103262900	SC02305415DBD	--	--	3	07-01-1959	07-30-1965	--	--	--
Mean				41.8			6.24		
Minimum				2			0.79		
Median				19			4.98		
Maximum				415			30.81		
Skewness				3.4			2.46		

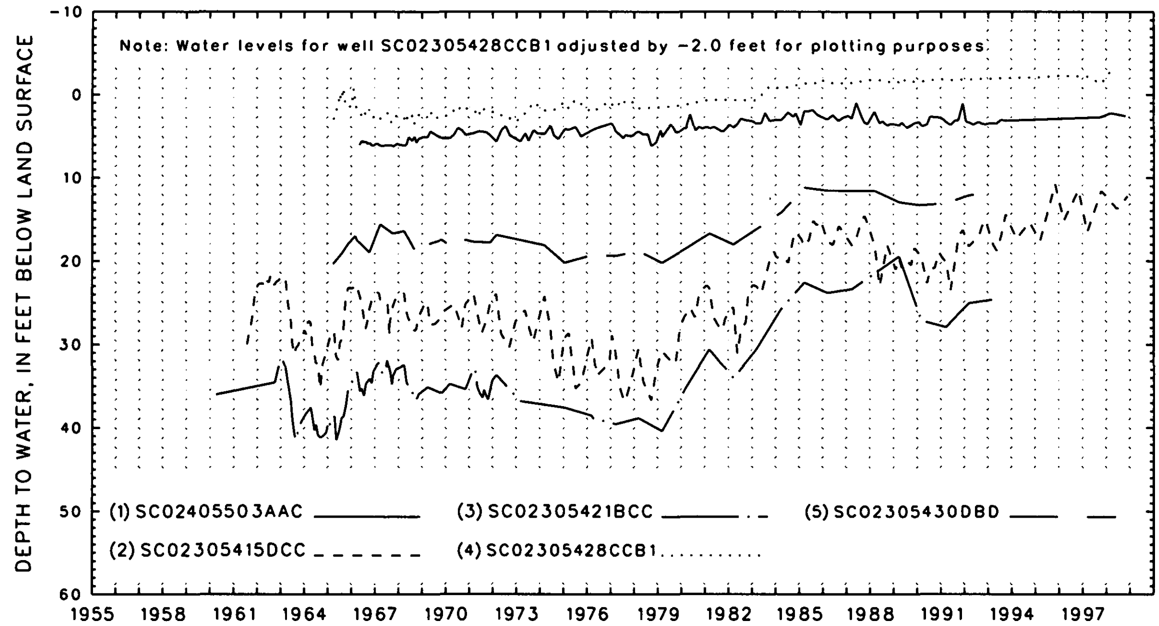


Figure 4. General trends in ground-water levels.

Regression Characterization

General change in water levels through time also can be characterized with simple linear regression. The results of regression analyses can be tabulated and are more convenient to work with than a large number of hydrographs. Linear regression techniques relate a dependent variable (for this study, measured depths to water) to an independent variable (for this study, time). The results of regression analyses can be characterized with an equation, which includes a term describing the slope for a straight line. For regressions of depths to water with time, a negative slope indicates a general decrease in depths to water with time. A decrease in depth to water represents a net increase in water-level elevation.

When using results from linear regression to characterize monotonic changes such as an increasing or decreasing slope, the significance of the slope term in the regression equation can be used to screen slopes that are not considered significant. For the purposes of this report slopes that were not at least 95 percent significant were considered insignificant. Regression slopes for the 141 wells evaluated are listed in table 3 and are characterized as increasing or decreasing and significant or insignificant. The regression slopes indicate that, for wells that have significant slopes, two-thirds of the slopes indicate increasing ground-water levels through time.

Most wells that have increases in water levels also have records that are representative of the period being studied; that is, they span most of the study period. When the regression results are plotted on a map, wells with increasing water levels are distributed uniformly throughout the study area. Although most of the wells have increases in water levels, some have decreases in water levels. Wells that have significant decreases in water levels generally have records that end before the 1980's or have records for only a few years. The hydrographs in figure 4 indicate a prominent period of water-level increase that began about 1980 that is common to wells that have record for this period. Because wells that have decreases in water levels are missing periods of prominent increases or represent only a small part of the period studied, excluding them from a characterization of general trends for water levels in the study area is reasonable. However, they do indicate that the phenomenon of water-level increases in the study area has a temporal element to it and that there can be short-term deviations from the general long-term trend of water-level increases.

Fluctuations in Water Levels

The hydrographs in figure 4 are developed from relatively long records in which the wells were measured systematically, usually in the spring and fall of each year, as a minimum. In general, the deepest depths to water are measured in the fall and the shallowest in the spring. For a period of time such as used in this study, about 40 years, measurements of ground-water levels in the spring and fall probably do a reasonable job of characterizing the extremes of ground-water level fluctuations.

The range in water-level measurements at individual wells is included in table 3. The mean of the ranges is 6.24 feet. The mean range reported here is nearly twice the mean range reported by Konikow and Bredehoeft in 1974. The difference between these two reported ranges reflects the relatively robust nature of the data used for the study described in this report, which covers a period of decades, compared to the Konikow and Bredehoeft (1974) study for which only 1 year of data was available.

To determine if the measured ranges have a distinctive spatial pattern, they were plotted on a map. The mapped ranges seemed to visually indicate a tendency for ranges to be small near the Arkansas River and to increase away from the river. However, closer examination indicated that although fluctuations greater than 10 feet and sometimes as much as 30 feet commonly occur in areas near the Fort Lyon Canal, relatively large fluctuations of about 10 feet also occur near the Arkansas River and there were no statistically significant relations between geographic setting and the range of water level fluctuation. The magnitude of fluctuations near the river are probably due to occasional high flows related to flooding or local effects of ground-water withdrawals, or both.

Short-Term Variation in Water Levels

One question that may arise, especially when a temporal aspect to patterns in water levels has been identified, is "How quickly do water levels change?" Many of the historical water-level records based on spring and fall measurements do not describe potential short-term changes in water levels. The historical records do include some wells that have been measured as frequently as weekly; however, these wells are not located in areas where relatively large fluctuations in water levels have been measured.

Some of the remaining records are in areas where water levels have had relatively large fluctuations and have been measured monthly or bimonthly for at least some part of the record. These records indicate that water levels, in some areas, can change at least as much as 1 foot per month—a rate that would produce the mean fluctuation in 6 months (table 3). However, water levels could change at rates greater than the rates reported for this study.

The historical records also were evaluated for adequacy in their ability to represent changes in cross-sectional gradients between the Fort Lyon Canal and the Arkansas River. Five roughly north-south cross sections of three to seven wells were identified, and the GWSI data base was accessed to obtain historical water levels along the cross sections that were measured within a reasonably narrow window of time (2 weeks). The results of this evaluation principally indicated that the historical records are not ideal for preparation of cross sections. In almost all cases, water levels were not available for all points in a given cross section. In the few cases when data were sufficient, indications are that gradients along some parts of some cross sections became reversed. That is, for a given set of wells, sometimes the gradient might be towards the river and sometimes the gradient might be away from the river; however, it was not possible to determine if such changes occurred routinely or even if they occurred in the short term.

HYDROLOGIC FACTORS THAT AFFECT GROUND-WATER LEVELS

Ground-water levels are controlled by recharge to and discharge from the aquifer. In relatively simple systems, recharge may consist only of precipitation, and discharge may consist only of evapotranspiration and ground-water withdrawals made from wells completed in the aquifer. However, there are additional sources of recharge and discharge in the study area that complicate the system. Some of these additional sources, particularly those related to irrigation, represent major changes from a natural setting. The additional sources of recharge and discharge that can be related to hydrologic processes in the study area are referred to as "hydrologic factors" and are discussed in this section. Precipitation and evapotranspiration are not discussed.

The alluvial aquifer in the study area is hydraulically connected to the Arkansas River. Accordingly, the aquifer and the river can exchange water; if the water-surface elevation in the river is higher than the water-table surface in the surrounding aquifer, then the river provides recharge to the aquifer and vice versa. In addition, the aquifer also can be recharged as a result of modifications to the system made to accommodate irrigation procedures such as application of water derived from surface-water diversions or from ground water, or both. The aquifer also may discharge water to local irrigation and water-supply wells.

Surface-Water Conveyances

There are two principal surface-water conveyances in the study area (fig, 1): the Fort Lyon Canal and the Arkansas River. Records of discharge for the Fort Lyon Canal, that are from the gaging station located downstream from the canal headgate were obtained from the Colorado Division of Water Resources. Records of discharge for the Arkansas River at La Junta, a streamflow-gaging station that is located at La Junta and is downstream from the diversion at the headgate for the Fort Lyon Canal, are stored in a USGS data base known as the Automated Data Processing System (ADAPS).

There are two facts about the Fort Lyon Canal that need to be considered. First, the canal is unlined; that is, the bottom and banks consist of native materials, and, as a consequence there are conveyance losses (in this sense the Fort Lyon Canal provides recharge to the local aquifer). In a 1989 to 1990 study, Dash (1995) estimated that losses could be as high as about 15 acre-feet per day per canal mile.

Second, the Fort Lyon Canal gaging station is located downstream from two structures that are sometimes used to divert water from the canal for maintenance activities related to suspended sediment loads in the canal. As a result, the gaging station does not record water diverted through these structures.

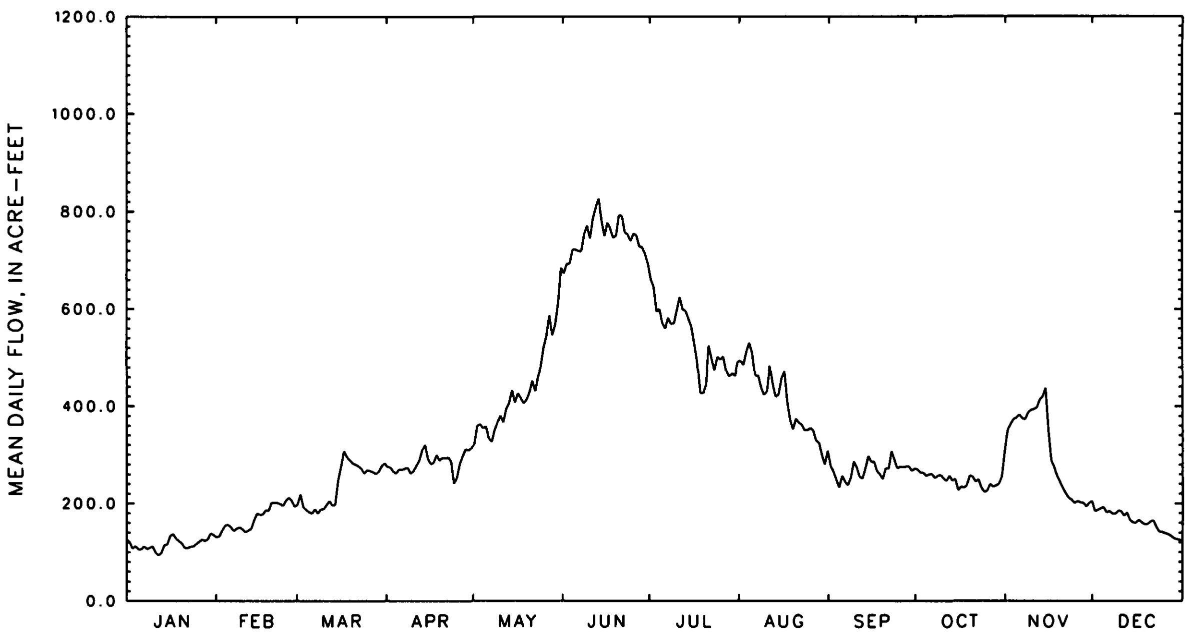
Also, beginning 1975, about the middle of the period being studied, Pueblo Reservoir began to operate (Abbott, 1985). Reservoir operations most pertinent to the study described in this report are the distribution of water stored in the reservoir for use at a later time (winter water) and the distribution of water available from transmountain diversion projects (project water).

The discharge record for the Fort Lyon Canal is shown in figure 5 and table 4. Figure 5 includes the annual total hydrograph, a smoothed curve of the annual total hydrograph, and a line indicating the long-term mean. A smoothed curve indicates general patterns and is prepared using a technique called locally weighted scatterplot smoothing (Cleveland and others, 1979), a computationally intensive technique that is comparable to a moving average. Figure 5 indicates that, generally, flow in the canal was greater than the long-term mean from 1980 through 1989 during the 1980's. This period includes one year of relatively low flow, 1981, and also includes the highest annual total flow for the period of record, 1985 (fig. 5). After 1989, figure 5 indicates that, generally, diversions to the canal were less than the long-term mean, although flow was greater than the long-term mean in 1996 and 1997 and the 1997 flow was almost as high as the 1985 diversion. The mean-daily hydrograph (fig. 5) shows typical seasonal variation of flow for the period studied and indicates that flow is highest in June.

The record for flow in the Fort Lyon Canal, as well as flow in the Arkansas River, indicates a change during the late 1970's. Accordingly, flow-duration analyses were prepared to describe differences in flow characteristics for two periods, 1960 to 1980 and 1981 to 1997. The results for this study (table 5) list a percentage of time, from the period of record being analyzed, that the corresponding rate of flow was exceeded.

The flow-duration statistics in table 5 indicate that there was flow in the Fort Lyon Canal more often during the first period than the second. For instance, there were very low flows (less than 1 cubic foot per second) in the canal for only 1 to 3 percent of the first period, whereas there were very low flows in the canal for 10 to 15 percent of the second period. Perhaps more importantly, the flow-duration statistics indicate that, due to large flows during the 1980's, flow in the canal was greater, usually by a factor of 1.5 to 2, than in the first period. For example, diversions in the canal were greater than about 345 cubic feet per second for 50 percent of the second period; in the first period the 50 percent exceedance flow was about 213 cubic feet per second.

The discharge record for the Arkansas River at La Junta is shown in figure 6. The annual total and particularly the mean-daily hydrographs are generally similar to the hydrographs for the Fort Lyon Canal (fig. 5). The smoothed curve for the annual total flow



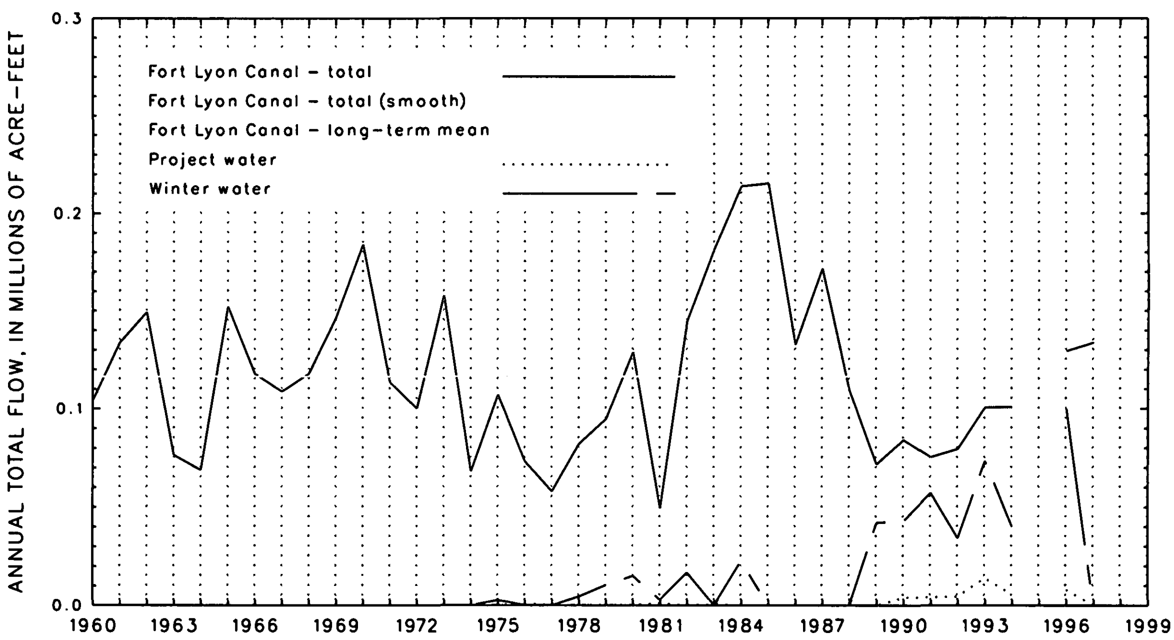


Figure 5. Mean daily and annual total flow in the Fort Lyon Canal.

Table 4. Annual values for hydrologic records in the study area

[Year, calendar year; ground-water withdrawals, based on records of withdrawals for city of La Junta municipal supply wells and electric power consumption records for irrigation wells (Goff and others, 1998); surface water used for irrigation estimated based on Fort Lyon Canal diversions as reported in Goff and others, 1998; --, not available]

Year	Flow volume (millions of acre-feet)				Ground-water withdrawal (feet)	Irrigation (feet)		Gage height in Arkansas River at discharge of 60 cubic feet per second
	Arkansas River	Fort Lyon Canal	Project water	Winter water		Surface water	Ground- and surface-water combined	
1960	0.08	0.10	0.00	0.00	--	--	--	3.22
1961	0.13	0.13	0.00	0.00	--	--	--	3.86
1962	0.12	0.15	0.00	0.00	--	--	--	3.76
1963	0.06	0.08	0.00	0.00	--	--	--	3.99
1964	0.06	0.07	0.00	0.00	--	--	--	4.03
1965	0.45	0.15	0.00	0.00	--	--	--	3.77
1966	0.09	0.12	0.00	0.00	--	--	--	3.58
1967	0.05	0.11	0.00	0.00	--	--	--	3.64
1968	0.10	0.12	0.00	0.00	--	--	--	3.64
1969	0.10	0.15	0.00	0.00	--	--	--	3.90
1970	0.15	0.18	0.00	0.00	--	--	--	4.26
1971	0.10	0.11	0.00	0.00	--	--	--	4.37
1972	0.08	0.10	0.00	0.00	2.05	2.17	4.22	4.16
1973	0.10	0.16	0.00	0.00	1.24	2.17	3.41	4.43
1974	0.07	0.07	0.00	0.00	2.10	1.37	3.47	4.61
1975	0.12	0.11	0.00	0.00	2.37	2.17	4.54	4.76
1976	0.11	0.07	0.00	0.00	3.10	1.58	4.68	4.68
1977	0.06	0.06	0.00	0.00	3.01	1.02	4.03	4.58
1978	0.09	0.08	0.00	0.00	2.71	1.68	4.39	4.51
1979	0.14	0.09	0.00	0.01	1.67	2.79	4.46	4.70
1980	0.31	0.13	0.00	0.01	1.37	2.46	3.83	4.75
1981	0.07	0.05	0.00	0.00	2.48	1.26	3.74	4.73
1982	0.20	0.14	0.00	0.02	1.56	2.92	4.48	4.99
1983	0.25	0.18	0.00	0.00	1.19	3.62	4.81	5.28
1984	0.43	0.21	0.00	0.02	1.18	4.46	5.64	5.19
1985	0.30	0.22	0.00	0.00	1.31	3.92	5.23	5.46
1986	0.17	0.13	0.00	0.00	0.95	2.42	3.37	4.70
1987	0.43	0.17	0.00	0.00	0.53	3.61	4.14	5.01
1988	0.10	0.11	0.00	0.00	0.99	2.09	3.08	5.29
1989	0.11	0.07	0.00	0.04	1.29	1.78	3.07	5.29
1990	0.17	0.08	0.01	0.04	1.27	1.86	3.13	--
1991	0.15	0.08	0.01	0.06	1.42	1.64	3.06	5.49
1992	0.16	0.08	0.01	0.03	1.33	1.81	3.14	5.32
1993	0.19	0.10	0.02	0.07	1.12	2.38	3.50	5.45
1994	0.23	0.10	0.01	0.04	1.40	2.06	3.46	5.50
1995	0.58	--	--	--	--	--	--	4.98
1996	0.14	0.13	0.01	0.10	--	--	--	--
1997	0.37	0.21	0.00	0.00	--	--	--	6.08
Mean	0.17	0.12	0.002	0.01	1.64	2.31	3.95	4.60

Table 5. Flow-duration statistics for the Fort Lyon Canal and the Arkansas River at La Junta

[ft^3/s, cubic feet per second]

Percentage of record flow was exceeded	Flow value, Fort Lyon Canal (in ft3/s)		Flow value, Arkansas River at La Junta (in ft3/s)	
	1960–1980	1981–1997	1960–1980	1981–1997
99	0.50	0.09	4.63	20.38
98	2.59	0.18	5.80	24.99
95	55.95	0.44	8.61	33.52
90	97.60	0.88	12.90	44.12
85	130.74	142.00	16.34	53.60
80	152.38	160.52	19.74	63.30
75	160.85	172.39	23.21	73.54
70	169.31	184.26	26.84	83.97
65	177.77	196.12	30.86	94.51
60	186.23	235.07	35.05	105.10
55	194.69	288.65	40.08	118.09
50	212.62	345.23	47.08	133.17
45	246.48	408.79	55.94	148.26
40	281.42	476.45	66.21	178.33
35	318.84	557.77	81.55	215.44
30	359.42	635.17	103.07	263.11
25	415.64	705.55	140.85	324.50
20	481.53	775.93	203.22	404.29
15	583.61	866.86	310.97	512.36
10	701.39	977.09	451.43	683.10
5	847.30	1087.31	605.25	1283.85
2	1035.61	1387.67	930.43	2807.05
1	1098.38	1642.28	1714.47	3992.77

indicates that flow in the river experienced a high period in the 1980's similar to the canal. However, the high in the river is not as pronounced as the high in the canal, indicating that most of the relatively large amounts of water in the river were diverted to the canal. After 1989, flow in the river, unlike diversions to the canal, remained above the long-term mean and, generally, continued to increase.

The flow-duration statistics for the Arkansas River listed in table 5 also are similar to those for the Fort Lyon Canal. The tendency for flows to be greater in the second period is more pronounced for the Arkansas River; second period flows often exceed first period flows by a factor of 2 and sometimes by a factor of 3. For example, flow in the Arkansas River was greater than about 133 cubic feet per second for 50 percent of the second period; in the first period the 50 percent exceedance flow was about 47 cubic feet per second.

Surface-Water Applications

As indicated in the Introduction, there is a large diversion of water from the Arkansas River into the Fort Lyon Canal a few miles west of La Junta. The Fort Lyon Canal often carries more water than the Arkansas River and is a contributor to the fact that the median flow for the Arkansas River at La Junta, which has a contributing drainage area of about 12,000 square miles, is only about 60 cubic feet per second.

The Fort Lyon Canal conveys water to many areas east of the study area, and only part of the water diverted to the canal is used in the study area. Local

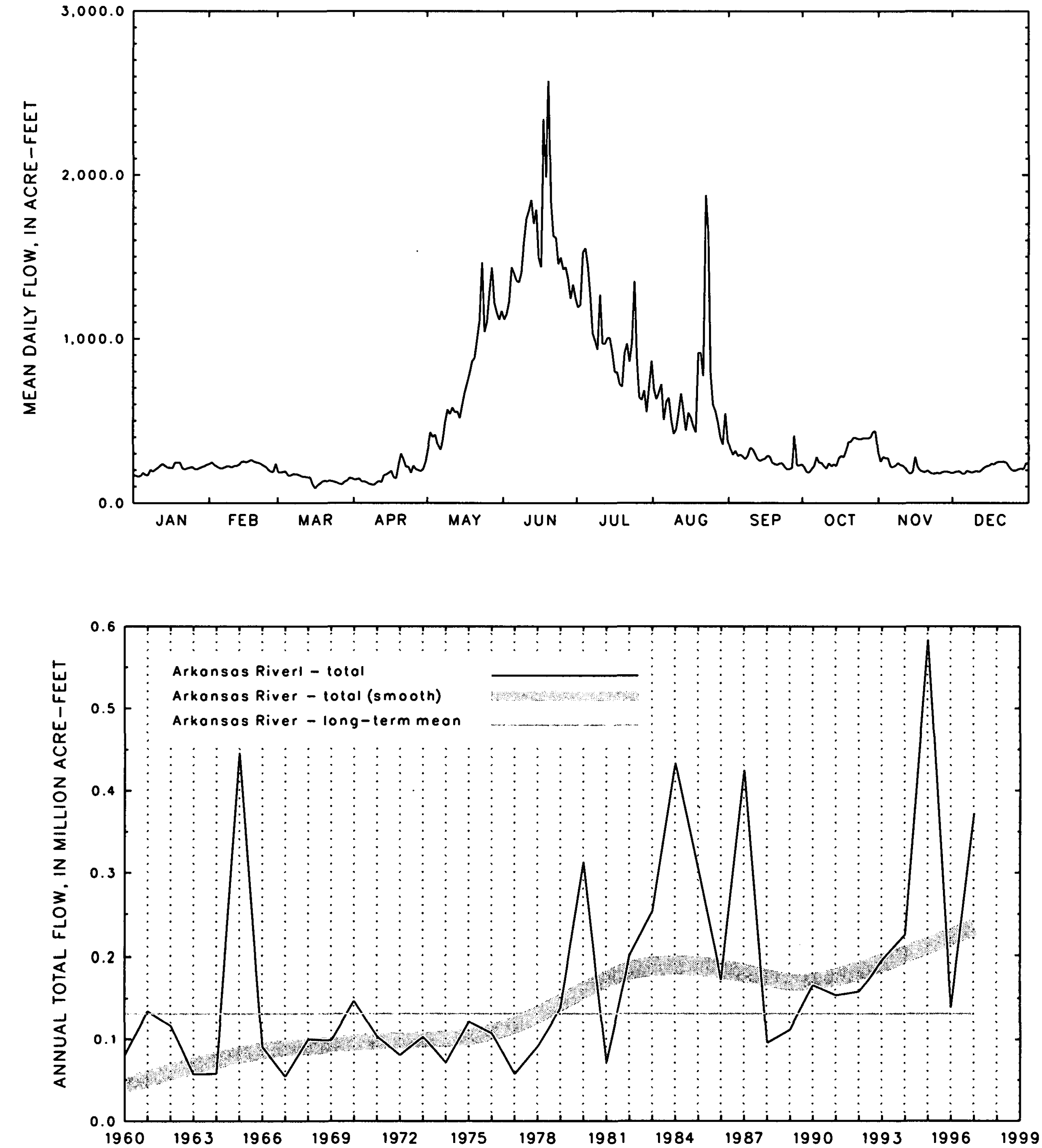


Figure 6. Mean daily and annual total flow in the Arkansas River at La Junta.

surface-water applications for irrigation are made through diversions out of the Fort Lyon Canal into local laterals that deliver water to fields. Usually, the water is used to flood the fields. In this respect, the Fort Lyon Canal represents a source of recharge to the local aquifer.

Goff and others (1998) computed annual surface-water applications using an algorithm that was based on the amount of water in the canal and the ratio of irrigation-program participants in the study area to the total number of participants who are supplied by the canal. The results of their estimates are listed in table 4. Surface-water applications were greater than the long-term mean during most of the 1980's, similar to flow in the Fort Lyon Canal, which generally was high during that decade. After the 1980's, surface-water applications decreased and returned to levels slightly higher than those preceding the 1980's.

Ground-Water Withdrawals

When necessary, generally when water is not available from the Fort Lyon Canal, ground water is routinely withdrawn from the local aquifer for irrigation purposes to supplement irrigation made with surface-water diversions. Ground water also is withdrawn for public water supply. These withdrawals represent discharge from the aquifer. Irrigation wells are distributed throughout the study area in a relatively uniform fashion; however water-supply wells, operated by the city of La Junta are clustered in an area of La Junta on the north side of the Arkansas River. Ground water is withdrawn for irrigation throughout the study area and is usually used to flood fields, although some alternative methods, such as spray and drip irrigation, are used. The records available for analysis in this study are from a previous study (Goff and others, 1998) and are summarized in table 4. They are annual records and are based on reported withdrawals from the city of La Junta and on a power conversion method (Boyle Engineering Corp., 1990) for irrigation wells that estimates the amount of water withdrawn at individual wells based on electric power meter readings.

The Colorado Division of Water Resources has recently begun to maintain records of withdrawals made by irrigation wells. The records are for individual wells and have more detail than is available from the historical records. These contemporary records should be very useful, in the future, for characterizing the amount of ground water withdrawn for irrigation.

The records from Goff and others (1998) indicate that ground-water withdrawals generally have decreased in the study area (table 4). In 1972 and from 1974 through 1978, withdrawals were greater than the long-term mean and increased steadily to a high for the period of record. After a peak in mid 1976, decreases began and continued through about 1987, after which ground-water withdrawals became relatively steady at a level less than the long-term mean. The records indicate that ground-water withdrawals at the end of the period of record were much less than the withdrawals made in the late 1970's and early 1980's. The records also indicate that although ground-water withdrawals in the study area sometimes have a nearly one-to-one inverse relation to surface-water applications, such as in the late 1970's and early 1980's, the relation is not necessarily constant, such as in the period after the mid-1980's when surface-water applications are nearly constant and ground-water withdrawals tend to increase.

Channel Processes

As stated previously, the Arkansas River and the surrounding alluvial aquifer can exchange water. When the river is recharging the aquifer, the amount of recharge increases as the level of the river increases. In the short term, increases in river level, or stage, are related to changes in rates of flow. For instance, flow typically increases when there are widespread rains. In the long term, however, the level of the river may change due to increases in the elevation of the river bed. Long-term changes in the river-bed elevation affect ground-water discharge, or drainage, to the river. In general, ground water at elevations lower than the river bed will not drain from the system and the river bed forms a base level for ground water.

Watts and Lunsford (1992) documented a general increase in the elevation of the river bed for the Arkansas River at La Junta by evaluating the elevation of the point of zero flow, which is determined routinely as a part of maintaining streamflow records. In this study, a similar method was used to evaluate changes in river-bed elevation.

The method used in this study, sometimes referred to as the "specific-stage method"

(Simon, 1994), tracks the river surface elevation, which is a function of the river bed elevation, for a specified discharge. Use of this method can return more frequent values and also provides an analysis based on a cross section of the river rather than a single point in the cross section. Even though the method may be based on a cross section rather than a point, it still describes the river bed only at that cross section and cannot be applied to a river reach without additional supporting information.

The results of this analysis are listed in table 4. The results indicate that the elevation of the river bed has generally increased throughout the study period. The changes in river-bed elevations, unlike the changes in most of the factors previously discussed in this section, are relatively steady. The total increase, from 1960 to 1995, is about 1.76 feet. Between 1996 and 1997 the records indicated an increase of about 1.1 feet, which is a much greater increase than has occurred historically and may be a short-term phenomenon.

The information used as part of this study does not provide definitive findings about why the elevation of the river bed has increased. The changes could be the result of relatively large-scale processes that may affect several miles of the river or they could be the result of local processes related to the maintenance of sediment in the Fort Lyon Canal.

Interrelations of Ground-Water Levels and Affecting Factors

Ground-water levels and factors that affect them can be compared graphically. For this comparison, records were transformed and expressed as a fraction of their range (fig. 7). This transformation facilitates comparisons between factors that are sometimes expressed in different units and generally experience different ranges than ground-water levels that are expressed as depths to water in feet.

A comparison of ground-water levels for two wells (one lowland well and one upland well) with the elevation of the Arkansas River bed, diversions to the Fort Lyon Canal flow from the winter- and project-water programs related to Pueblo Reservoir operation, diversions to the Fort Lyon Canal (annual total flow), flow in the Arkansas River (annual total and daily mean flow), ground-water withdrawals, and surface-water applications is shown in figure 7. There are some qualifications that need to be made concerning such a comparison. First, all factors, except ground-water levels, daily mean discharges, and the river-bed elevations are annual values and are represented as the given annual value for the entire year in figure 7. Second, most factors represent data measured at a specific geographic point. The hydrographs for ground-water withdrawals and surface-water applications are exceptions; they represent the overall study area. The areal nature of the withdrawal and application data means that they may be insensitive to local phenomena.

Even though the curves in figure 7 require some qualifications, the figure still allows for observations of the interrelations being discussed. Some simple relations are readily apparent. One of the most prominent features of the smoothed curves for depths to ground water in figure 7 is that ground-water levels are high in the 1980's. Three of the hydrologic factors, surface-water applications, ground-water withdrawals, and flow in the Fort Lyon Canal, all show clear, either direct or inverse, relations to the high water levels observed in the 1980's. The levels of flow in the Fort Lyon Canal and surface-water applications are both greater than long-term means during this period and represent recharge to the local aquifer. The levels of ground-water withdrawals are less than long-term means and represent a decrease in aquifer discharge. The combination of increased recharge and decreased aquifer discharge result in the high ground-water levels observed in the 1980's.

A prominent feature of the smoothed curve for ground-water levels in well 2 in figure 7 is the relatively steady decrease during the 1970's. Even though the records for ground-water withdrawals and surface-water applications do not include all of the 1970's, their records, along with those for flow in the Fort Lyon Canal, portray the opposite of conditions observed in the 1980's when ground-water levels were high. Recharge to the aquifer from diversions to the canal and surface-water applications is low, and discharge from the aquifer from ground-water withdrawals is high; these conditions combine to affect a decrease in water levels.

The smoothed curves for both wells in figure 7 indicate a tendency for modest increase from about 1990 on. During this time, surface-water applications are relatively constant but are at levels less than, but comparable, to the long-term mean. Ground-water withdrawals are also constant during this period,

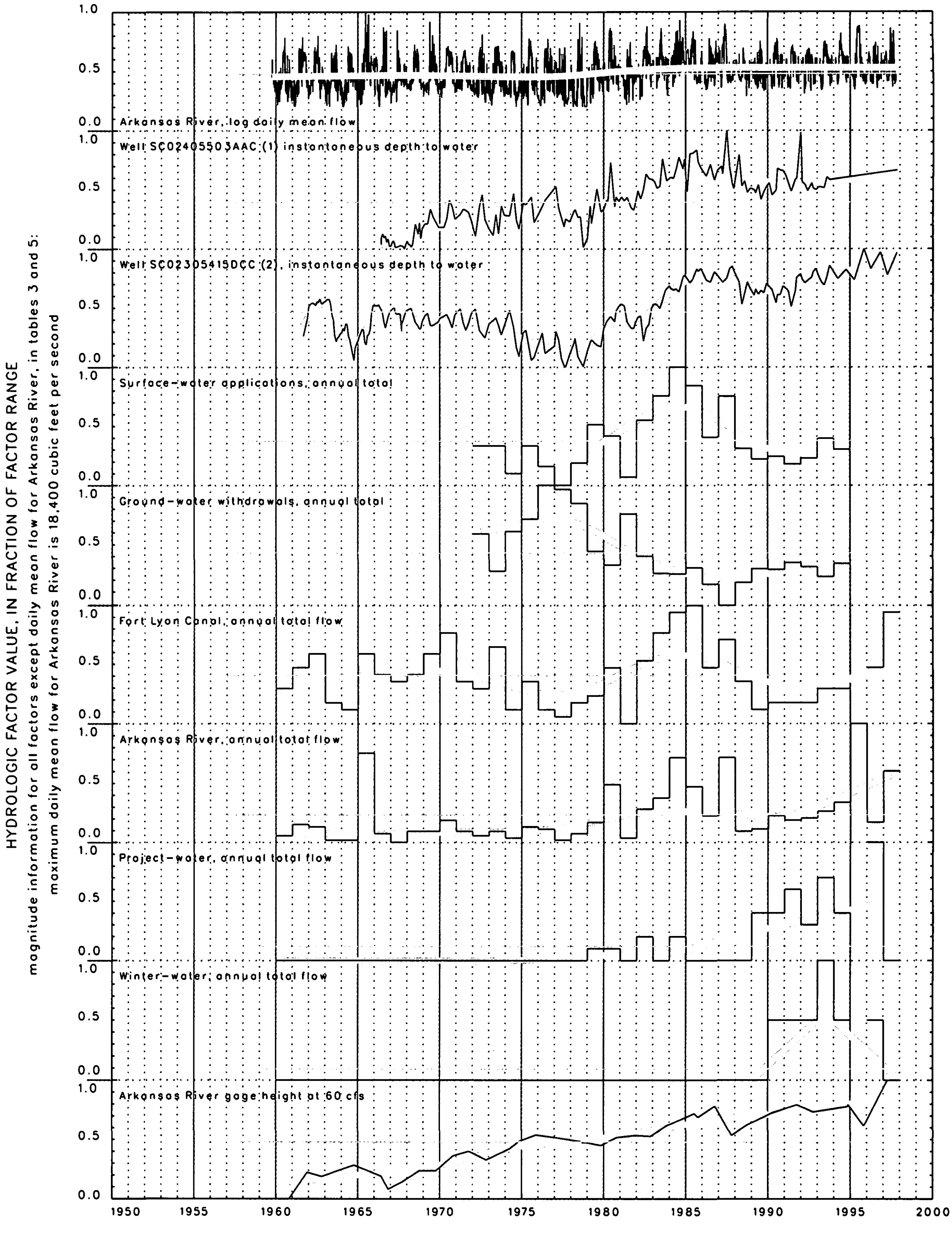


Figure 7. Comparison of annual-total, daily mean, and instantaneous time-series data for hydrologic factors in the study area.

however, they are less than the long-term mean and indicate that there are relatively low levels of discharge due to ground-water withdrawals from the aquifer, a condition that contributes to increases in water levels.

Water levels in well 1, a lowland well, are below the long-term mean before about 1980 and above the long-term mean after 1980. The smoothed curve for the daily-mean flow in the Arkansas River has a similar, nearly step-like pattern indicating the general flow conditions in the river may affect water levels in lowland wells. The step-like increase described here coincides with the appearance of project water in the system.

The elevation for the Arkansas River bed has one of the most consistent patterns of all the hydrologic factors, one of steady increase through the period of record. The pattern is similar to the smoothed curve for water levels in the lowland well indicating that as the river-bed elevation increases local ground-water levels increase too. In addition, the relatively high river-bed elevations of the 1990's combined with relatively low amounts of ground-water withdrawals are likely related to increases in ground-water levels in well 1 observed in the 1990's.

The water level in the lowland well also clearly indicates that it can be affected by short-term condition in the river. The water level in well 1 measured June 1, 1987, is the highest water level measured at the well. The daily mean flow in the Arkansas River peaked at 6,840 cubic feet per second 10 days earlier; on June 1 the flow was 1,680 cubic feet per second. According to the flow-duration statistics in table 5, these are relatively high daily mean flows for the Arkansas River that are exceeded less than 1 and 5 percent of the time during 1981 to 1997. The relation between high flow in the river coinciding with high water levels in well 1 is clear in figure 7 when comparing the daily mean flow in the Arkansas River and the water levels in well 1 during June 1987.

The affects of hydrologic factors, some of which appear to have good visual correlation with changes in ground-water levels, can be quantified with regression techniques. For instance, simple linear regression techniques can be used to explain about 61 percent of the variability measured in upland wells based on ground-water withdrawals and about 70 percent of the variability measured in lowland wells based on river-bed elevation. Other, more advanced regression techniques such as stepwise regression, which automates the procedure of selecting the most effective algorithm for several independent variables (in this case, the independent variables would consist of all hydrologic factors) can be implemented. When stepwise regression was implemented as part of this study, it was not possible to explain more than about 90 percent of the variability observed in either the upland or lowland wells. That is, the results of stepwise regression using all the hydrologic factors to explain changes in water-levels, provided relatively modest improvements over regression models using only ground-water withdrawals for upland wells and river-bed elevation for lowland wells.

One way to improve the current (1999) level of knowledge might be to introduce a data collection effort specifically designed to document losses from the Fort Lyon Canal and the effects of surface-water application in the short term. Such efforts could most likely make use of existing wells to define cross sections of the water table between the canal and the Arkansas River.

SUMMARY

High ground-water levels in the alluvial aquifer between the Fort Lyon Canal and the Arkansas River in the vicinity of La Junta, Colorado, from the Fort Lyon Canal headgate east to the Otero County line, can impair the use of agricultural land and personal property. Water-table and depth-to-water maps made on the basis of water levels measured during March 1999 indicate that the local alluvial aquifer received recharge from the Fort Lyon Canal and the Arkansas River and that the water table was within 5 feet of the land surface in about 31 percent of the study area. In general, water levels are shallowest near the river and become deeper closer to the canal; areas of relatively shallow water levels are fairly widespread in the western part of the study area.

A visual analysis of hydrographs for five wells with water-level measurements from about 1965 to 1995 indicates a general tendency for water levels to have increased. A more detailed examination of the hydrographs indicates:

- Water levels in the two lowland wells near the Arkansas River are relatively close to the land surface.

- Lowland wells near the Arkansas River have relatively flat hydrographs compared to the three upland wells.

- In general, the three upland wells have hydrographs that are similar to each other.

- Water levels in upland wells may be as little as about 10 feet to as much as about 40 feet from the land surface.

- Periods of water-level declines exist in the records for upland wells but are absent or less pronounced in records for wells near the Arkansas River.

Historical water levels for 141 wells also indicated that the average range in ground-water levels at individual wells was about 6 feet and that the largest fluctuations occurred in upland wells. Although there are some wells in which water levels have been measured as frequently as once a 1 week, the historical water-level data, in general, do not describe short-term changes. Also, even though a few places where short-term reversals in water-level gradients between the river and the aquifer can be identified, the historical water-level data generally are not sufficient to determine short-term gradient changes.

Several hydrologic factors that affect water levels are flow in the Fort Lyon Canal, flow in the Arkansas River, surface-water applications for irrigation, ground-water withdrawals, and changes in the river-bed elevation. All of these factors had temporal changes in the study area. The Fort Lyon Canal and the Arkansas River generally conveyed larger amounts of water after about 1980 and during most of the 1980's than before that time. Ground-water withdrawals and surface-water applications have generally decreased although surface-water applications, much like surface-water conveyances, did increase noticeably in the 1980's.

Some simple interrelations, mostly on the basis of coincidence of change, between hydrologic factors can be described:

- The combined effects of flow in the Fort Lyon Canal, surface-water applications, and ground-water withdrawals can be associated with both increases in the 1980's and decreases in the 1970's in ground-water levels.

- Steady, long-term increases in ground-water levels in a well near the Arkansas River are similar to changes in the river-bed elevation.

- Short-term increases for water levels in the Arkansas River are associated with short-term high ground-water levels observed in a well near the river.

- The high river-bed elevation combined with relatively low amounts of ground-water withdrawals are likely related to increases in ground-water levels observed in a well near the river during the 1990's.

- Sustained levels of relatively high flows in the Arkansas River also can be associated with a step-like increase in ground-water levels observed in a well near the river in about 1980.

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Clifford R. Bossong—ANALYSIS OF HYDROLOGIC FACTORS THAT AFFECT GROUND-WATER LEVELS IN THE ARKANSAS RIVER ALLUVIAL AQUIFER NEAR LA JUNTA, COLORADO, 1959-99

USGS/WRIR 00–4047