HYDROLOGIC RELATIONS BETWEEN STREAMFLOW AND SUBALPINE WETLANDS IN GRAND COUNTY, COLORADO

By Barbara C. Ruddy and Robert S. Williams, Jr.

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 90-4129

Prepared in cooperation with the

DENVER WATER DEPARTMENT

Denver, Colorado
1991

U.S. DEPARTMENT OF THE INTERIOR

MANUEL LUJAN, JR., Secretary

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to:

District Chief
U.S. Geological Survey
Box 25046, Mail Stop 415
Federal Center
Denver, CO 80225-0046

Copies of this report can
be purchased from:

U.S. Geological Survey
Books and Open-File Reports Section
Box 25425, Mail Stop 517
Federal Center
Denver, CO 80225-0425

CONTENTS

FIGURES

TABLES

CONVERSION FACTORS

Inch-pound units in this report may be converted to SI (International System) and metric units by using the following conversion factors:

Multiply inch-pound units	*By*	*To obtain SI units*
acre	0.4047	square kilometer
cubic foot per second (ft^3/s)	0.028317	cubic meter per second
foot (ft)	0.3048	meter
gallon (gal)	3.785	liter
inch (in.)	25.40	millimeter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.59	square kilometer

The following terms and abbreviations also are used in this report:

μg/L, micrograms per liter
mg/L, milligrams per liter

National Geodetic Vertical Datum of 1929 (NVGD 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."

HYDROLOGIC RELATIONS BETWEEN STREAMFLOW AND SUBALPINE WETLANDS IN GRAND COUNTY, COLORADO

By Barbara C. Ruddy and Robert S. Williams, Jr.

ABSTRACT

Diversion of streamflow has been proposed from the South Fork Williams Fork (of the Colorado River basin) in Grand County, Colorado, to the South Platte River basin in eastern Colorado. Wetlands are adjacent to the South Fork Williams Fork at numerous locations in this subalpine valley. The study was designed to evaluate the hydrologic relations between the stream and the adjacent wetlands and to evaluate the potential effects that changes in stream stage resulting from diverting streamflow will have on the hydrology of the wetlands.

Four wetlands were studied. Streamflow was expected to be a major source of water supply to two of the wetlands; however, precipitation, snowmelt, valley side-slope flow (including overland and small-channel flow), and ground-water inflow were determined to be the major factors affecting wetland hydrology and the major source of water at all four wetlands. In addition, beaver activity affected water movement in the wetlands.

The hydrologic relations in wetlands 1, 2, and 4 were similar. Streamflow is not a substantial source of water to wetlands 1 and 4. The data indicate that ground water flows from the wetlands to the stream. The water sources for the wetlands are precipitation, snowmelt, valley side-slope flow, and ground-water inflow. Overbank flooding did not occur at wetlands 1 and 4. A similar streamflow and wetlands relation exists at wetland 2, with one exception. Near the downstream end of wetland 2, beavers built a dam in the fall of 1985; the resulting backwater flooded part of the wetland. Ground-water levels rose, and the concentrations of dissolved solids and trace elements increased in the ground water. Water levels in the wells at wetlands 1, 2, and 4 nearly always were higher in elevation than the stream.

The hydrologic relation between streamflow and wetland 3 was more complex than at the other wetlands. Generally, the water flowed from the wetland to the stream except when stream stage was changed by beaver activity and on the east side of cross section 3A. Beaver-dam construction caused increased stream stage, increased ground-water levels, and sometimes adjacent wetland flooding. Beaver-dam destruction relocated streamflow and lowered stream stages and wetland ground-water levels adjacent to the dams. The east side of cross section 3A is physiographically different from the other wetlands. Data that were collected using a hydraulic potentiomanometer indicated water movement from the stream into the wetland ground water at the upstream end of the wetland and from the wetland ground water to the stream at the downstream end of the wetland.

The primary conclusion of the study is that streamflow is not a substantial source of recharge to the ground water in the wetlands. Stream overbank flow and stream recharge to the wetland ground water were uncommon and affected only a limited area near the stream. Consequently, decreases in stream stage due to diversion of main-channel surface-water flows likely will not affect most of the wetland areas studied.

INTRODUCTION

Diversion of streamflow from the South Fork Williams Fork in the upper Williams Fork basin (of the Colorado River basin) in Grand County to the South Platte River basin in eastern Colorado is being considered by the Denver Water Department for use in the Denver metropolitan area. Subalpine wetlands adjacent to the South Fork Williams Fork and the main stem Williams Fork support aquatic and terrestrial plants and provide habitat for wildlife. Wetlands are areas that periodically support predominantly hydrophytic vegetation (Cowardin and others, 1979). Maintenance of the water supply to wetlands is essential to the existence of those wetlands. Possible sources of water for the subalpine wetlands in the Williams Fork basin include direct recharge from precipitation and snowmelt, streamflow in the main channels, valley side-slope flow (including overland flow, which is water that travels over the ground surface to the channel, and small-channel flow), and ground-water inflow from areas upgradient from the wetlands. Interruptions in the water supply to the wetlands may change the vegetation and wildlife habitat of the wetlands. If the stream is the major source of water for the wetlands, then diversion of stream water could disrupt the hydrology of the wetlands. If, however, another source of water (precipitation, snowmelt, valley side-slope flow, ground-water inflow) supplies water for the wetlands, then changes in stream stage due to diversion may not substantially affect the hydrology of the wetlands. Little documented hydrologic information was available about the relation between streamflow and subalpine wetlands; therefore, the U.S. Geological Survey and the Denver Water Department began a cooperative study in October 1984 to investigate the hydrology of the near-stream wetlands in the upper Williams Fork basin.

Purpose and Scope

This report describes the hydrologic relations of streams and selected wetlands in the upper Williams Fork basin and the potential effects of streamflow diversion, as defined by changes in stream stage, on the water supply to the wetlands. Specifically, the hydrologic relations between the streams, ponds, and ground water in the wetlands are discussed with reference to stream stage, precipitation, shallow ground-water levels, and surface- and ground-water chemistry for October 1984 through September 1988. Most of the work for the study was done in the South Fork Williams Fork basin; therefore, the emphasis of this report is on the hydrology of the South Fork Williams Fork. However, water-level data were collected for 1 year in the main stem Williams Fork basin at a site that was considered representative of wetlands on the main stem Williams Fork upstream from the confluence of the South Fork Williams Fork.

Acknowledgments

The authors acknowledge the assistance of Denver Water Department personnel who worked on this project. The authors also appreciate the skill and competence of Ptarmigan Helicopters employees, especially Gordon Beatty, Jr., and James B. Bowman.

DESCRIPTION OF THE STUDY AREA

The Williams Fork of the Colorado River basin is in north-central Colorado, in Grand County, about 50 mi west of Denver (fig. 1). The main stem Williams Fork and the South Fork Williams Fork originate west of the Continental Divide at an elevation of about 11,500 ft. The South Fork Williams Fork flows generally northwest for about 13.5 mi before joining the main stem Williams Fork, which flows west, and then northwest. The South Fork Williams Fork flows through a series of wetlands before it joins the Williams Fork at an elevation of about 8,950 ft. The South Fork Williams Fork drains an area of 27.5 mi^2. At places, the valley constricts to the width of the stream channel (about 20-40 ft).

Most of the Williams Fork and the South Fork Williams Fork basins are underlain by Precambrian hornblende gneiss (Lovering and Goddard, 1950). Part of the Williams Fork basin also is underlain by the Precambrian Silver Plume Granite (Lovering and Goddard, 1950). The South Fork Williams Fork valley (upstream from wetland 2) is U-shaped because it was glaciated during the Pleistocene; glacial deposits, mostly morainal, cover the bedrock (Lovering and Goddard, 1950). Downstream from wetland 2 (fig. 1), the valley bottom is composed of alluvium, rockslide deposits, and pond deposits.

Throughout time, the stream channels have changed location on the valley floor. Past and present beaver activity has affected location of the stream channels and has created ponds where fine-grained material and organic matter have been deposited. Occasionally, pond deposits and stream-channel deposits have become buried as the channel changes location. Stream-channel deposits are characterized by fairly well-washed sand, gravel, and cobbles; pond deposits are characterized by fine-grained organic material, clay, and silt material. In some areas, the deposits can be gradational. Additionally, rockslides from the valley sides have deposited large boulders and cobbles onto the valley floor. The subsurface occurrence and distribution of these various types of deposits generally are unknown, but they may have substantial effects on the movement and quality of shallow ground water.

Wetland vegetation in the study area is comprised of willows, grasses, and forbs. Adjacent to the wetlands are coniferous forests of spruce, fir, and lodgepole pine. Aspens grow in the steep avalanche chutes and hillsides, and stands sometimes extend to the valley bottoms.

Mining occurred in the upper part of the Williams Fork basin during the early 1900's (Lovering and Goddard, 1950). The Bobtail mine, part of the Jones Pass mining district, was on Bobtail Creek, a tributary to the Williams Fork. The mined ore was a complex lead-zinc ore.

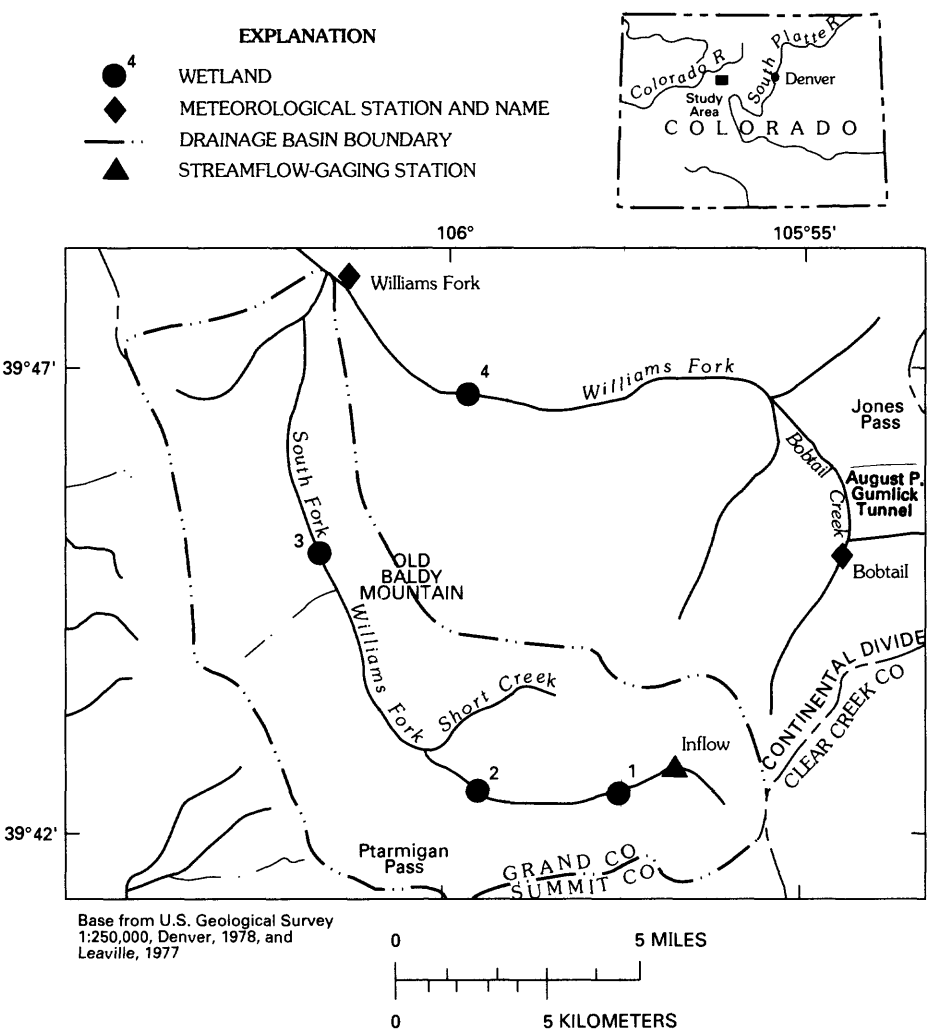

Figure 1.--Location of study area and wetlands (modified from Ruddy, 1989).

The upper Williams Fork and South Fork Williams Fork basins are in the Arapahoe National Forest. The primary land use of the area is recreation--camping, hiking, fishing, and hunting. Access to the area is restricted; use of motor vehicles is limited to the lower part of the basin. The upper Williams Fork basin has been used as a water supply for the Denver metropolitan area since 1940.

DATA-COLLECTION LOCATIONS AND METHODS

Hydrologic data were collected at four wetlands (hereinafter referred to as wetlands 1-4) and at the proposed diversion site (inflow site) (fig. 1). Three wetlands were selected for sampling on the South Fork Williams Fork (fig. 1; wetlands 1, 2, and 3); wetland 4 was selected for sampling on the main stem Williams Fork. The four wetlands were selected for study based on (1) the presence of typical wetland vegetation and (2) differences in streamflow-wetland environment. Data collection at wetland 4 was discontinued after the first year of the study because the maximum measured stream stage in 1985 was 3 ft lower than the ground water in the adjacent wetland and it seemed unlikely that the stream was contributing water to the wetland. Data collection at wetland 3 was expanded and changed during water years 1986 through 1988. Meteorological data were collected near the upstream and downstream parts of the study area in the Williams Fork basin during the 1985 and 1986 water years. The surface- and ground-water data-collection sites that were established within the wetlands in the study area are listed in table 1 and are shown in figures 2-5. The inflow site is included in table 1 and shown in figure 1.

Surface Water

Streamflow data were collected at the inflow site and at each wetland. Seven streamflow-gaging stations were installed consisting of a digital water-stage recorder in a metal box-type shelter on a 4-in.-diameter pipe stilling well and an outside staff gage in the same pool. Stream stage was recorded every 30 minutes. Streamflow measurements were made approximately monthly to develop a stage-streamflow relation. Six crest-stage gages were placed adjacent to the stream at locations to record overbank flooding of the wetlands. These gages were made of 2-in.-diameter pipe, driven 2 ft into the alluvium. Several sets of intake holes were located near the base of the gage. A wooden rod and granulated cork were in the pipe; when the stream stage rose, the cork floated and left a corkline on the rod. The maximum annual stream stage was recorded. A staff gage and 90° V-notch weir were placed in tributaries at wetlands 1 and 2. Staff gages were placed in two beaver ponds at wetland 2. In 1987, staff gages were installed in the South Fork Williams Fork at each well cross section to define empirical relations between stage in the cross sections and streamflow at the most representative gaging station. Measured streamflow at the gaging station was related to stream depth at the cross sections. Regression equations, using streamflow at the gaging station, were developed to estimate stream stage at the cross section for dates when measurements were not made.

Ground Water

Ground-water data were collected to help determine flow direction between the streams and wetlands. Using a portable auger, wells were drilled to a depth at which the auger seized in the hole and further drilling was not possible. At this depth (1.5 to 7 ft), it was assumed that the auger came in contact with large cobbles or bedrock. Most wells were cased with 2-in.-diameter, schedule-40 polyvinylchloride (PVC) pipe. The lower part of the casing was either screen or slotted pipe. Three wells were cased with 4-in.-diameter, schedule-40 PVC pipe and screen. The screen-slot size was 0.020 in., and the length of the screen or slotted PVC was dependent on the total well depth. Streambed sand and gravel were used to gravel pack the wells to within 2 ft of natural land surface. Bentonite was used to cement and seal the well.

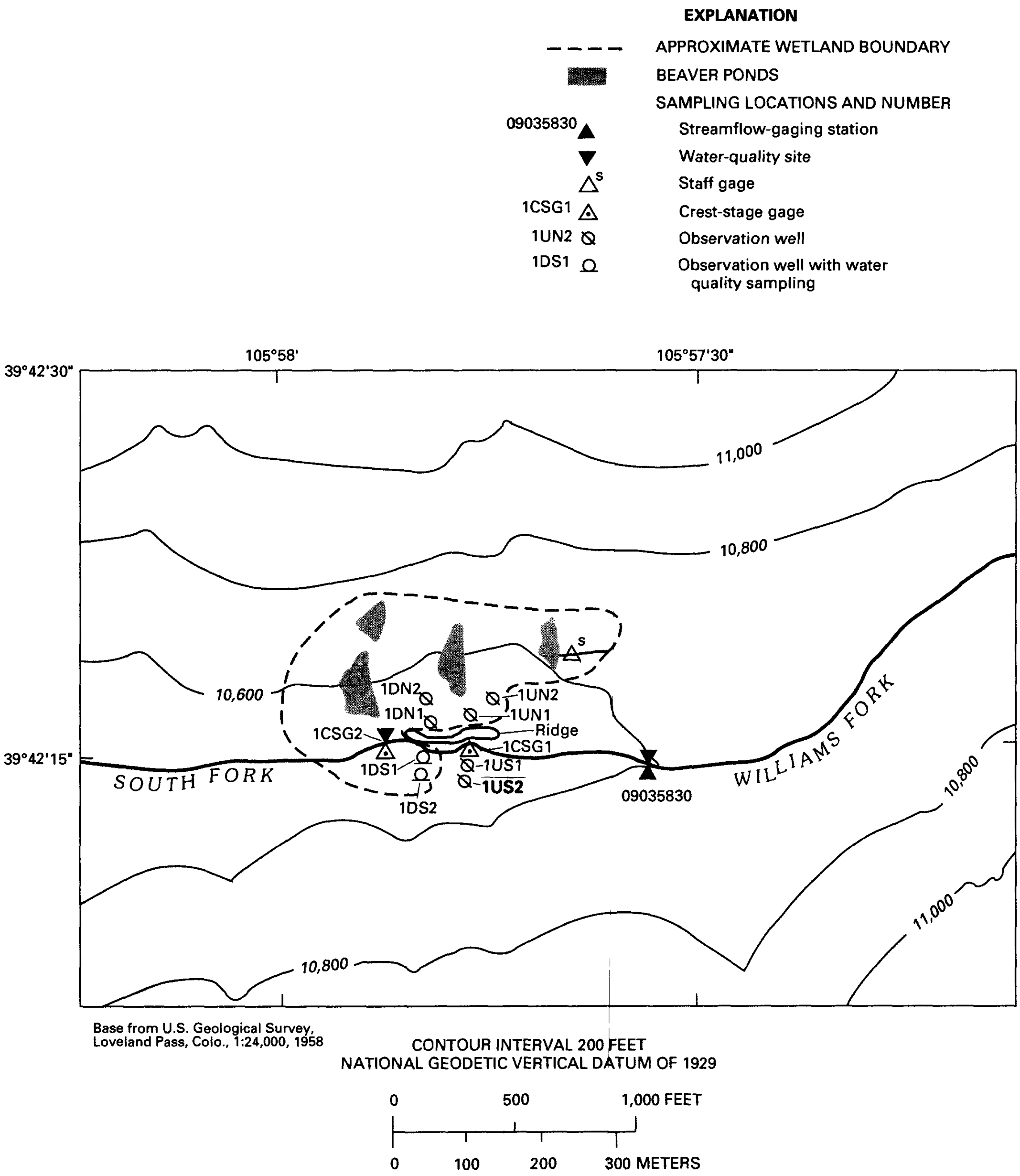

Figure 2.--Sampling sites at wetland 1.

Native soil and surface material were used to cover the bentonite. To develop the well, stream water was pumped into the well for 1 to 5 minutes, and then water was pumped out until the well went dry.

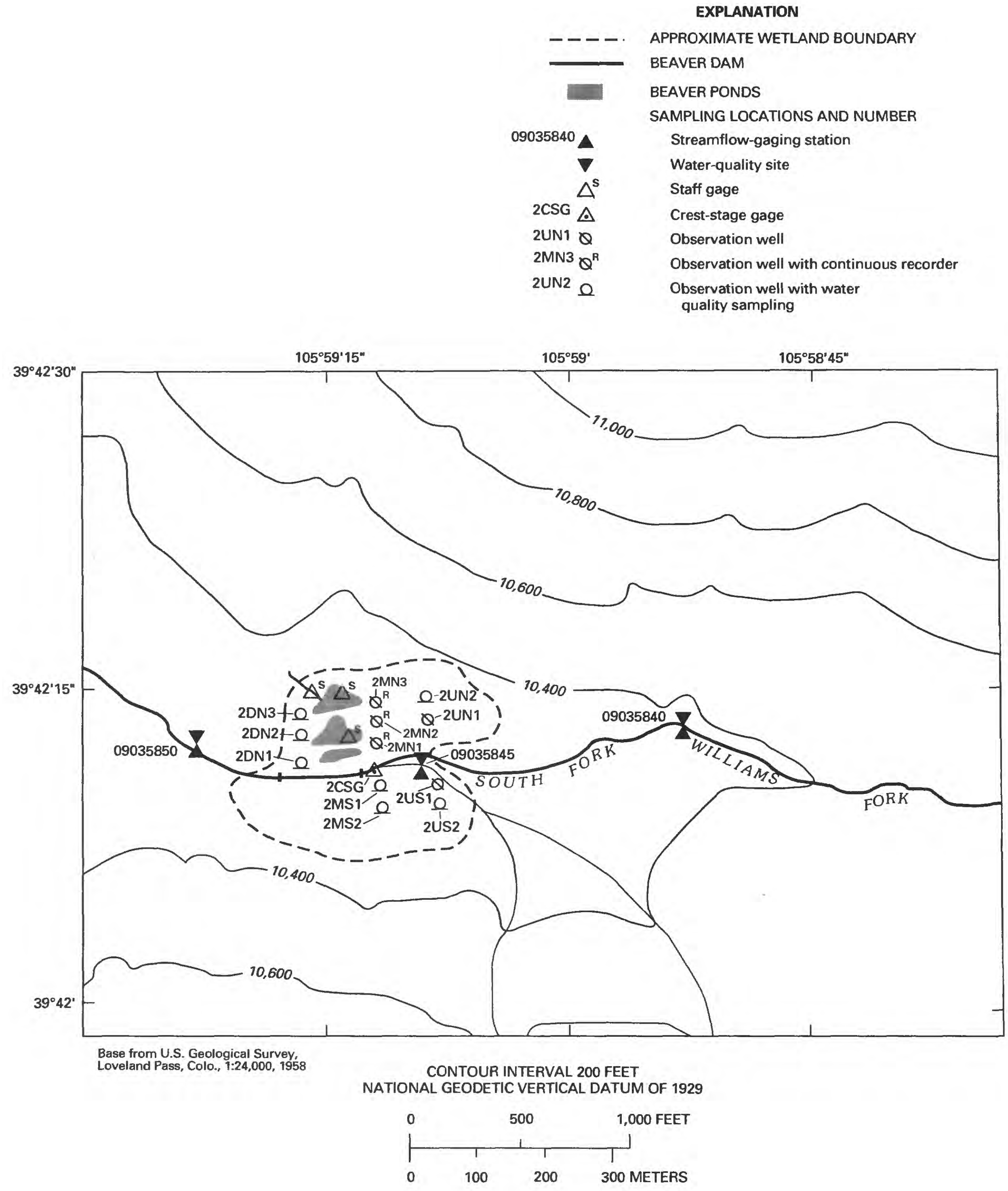

Figure 3.--Sampling sites at wetland 2.

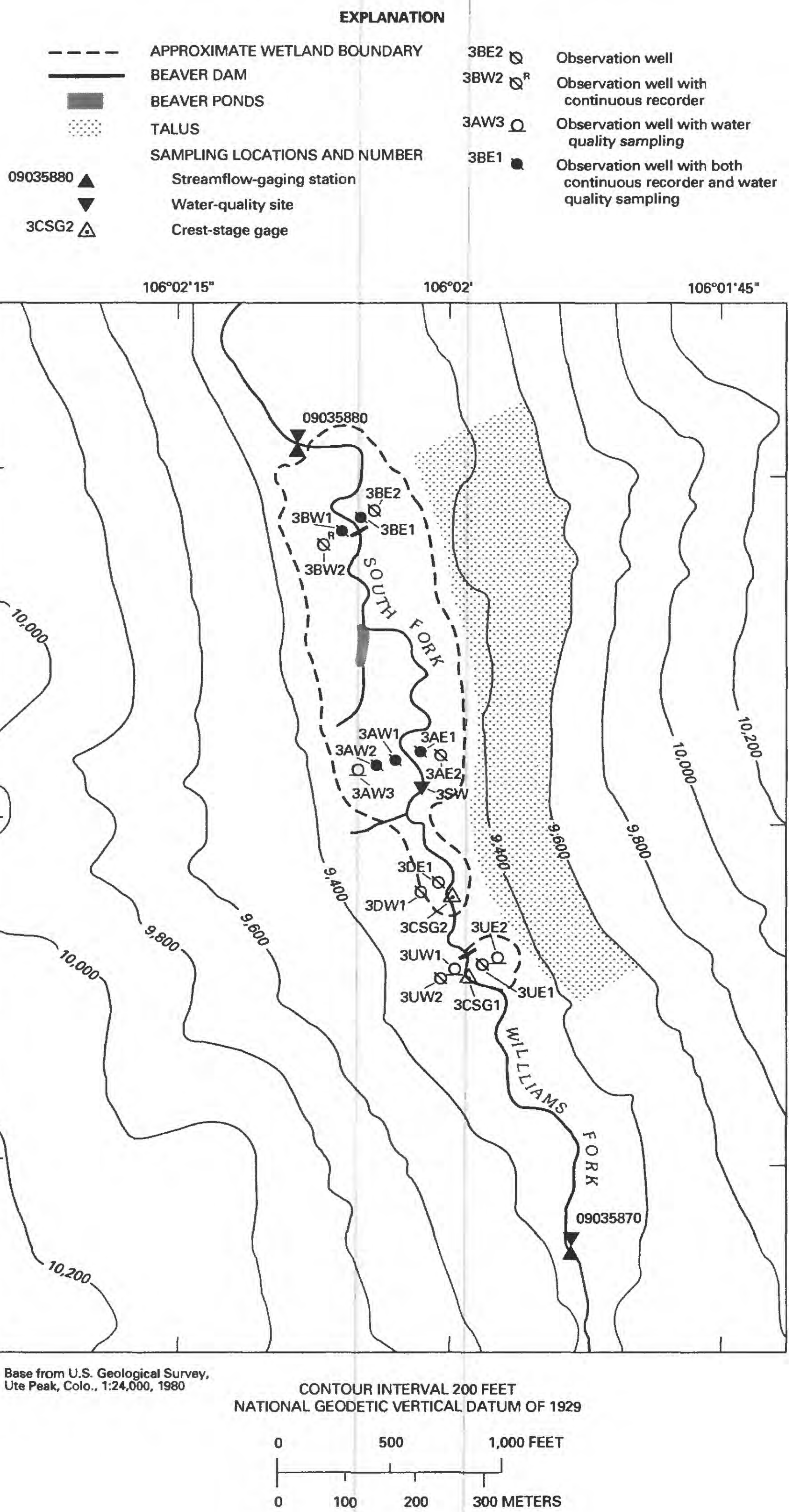

Figure 4.--Sampling sites at wetland 3.

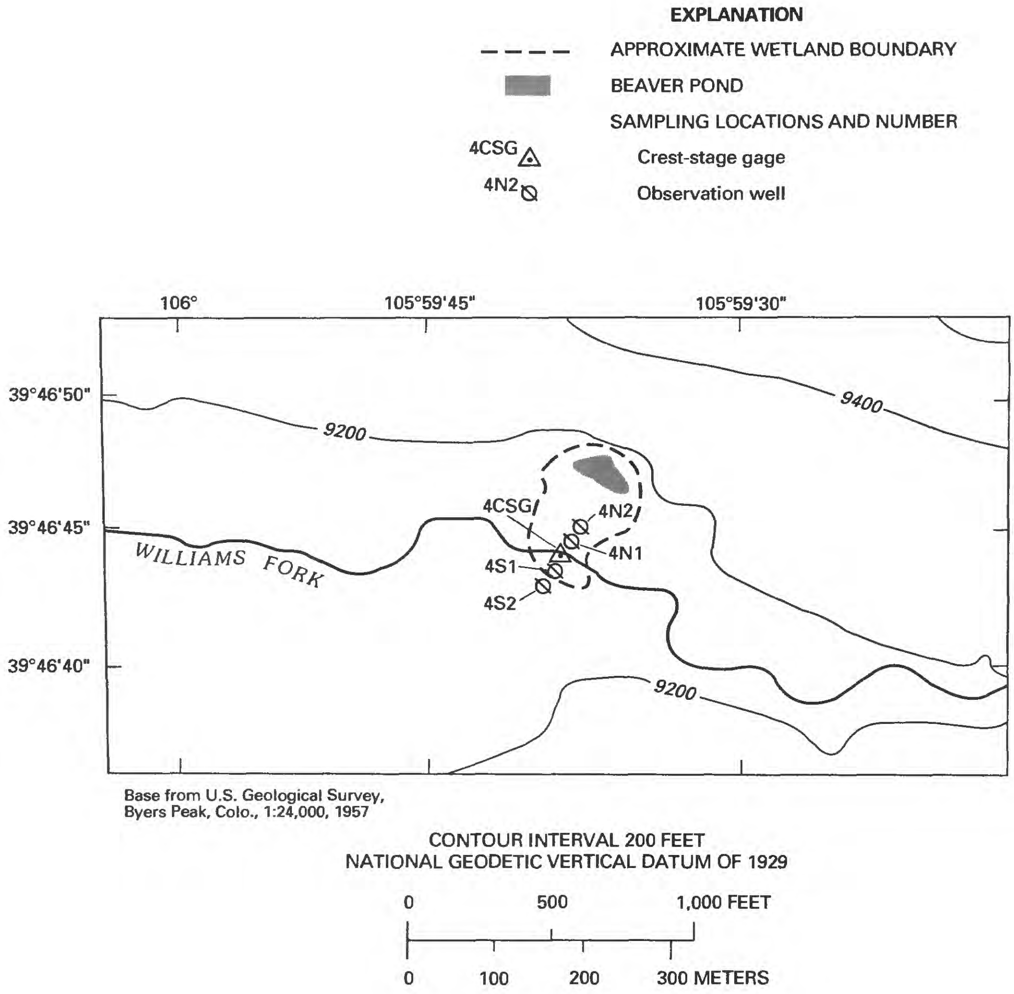

Figure 5.--Sampling sites at wetland 4.

Water levels in wells were measured about eight times per year, more often during the spring and summer than during the winter. Six of the 2-in.-diameter wells and all three 4-in.-diameter wells had continuous recorders that operated from May to October. The wells were located in cross sections that were perpendicular to the stream at each wetland. The wells were identified according to site, cross section, and location relative to the stream. For example, well 1US2 was located at wetland 1, in the upstream (U) cross section, on the south (S) side of the stream, and was the second (2) closest well to the stream. The well network was unique to each wetland and was dependent on conditions at that wetland.

Table 1.--*Surface- and ground-water sampling sites*

[SW, surface water; CR, continuous recorder; QW, water quality; GW, ground water]

Site number[1]	U.S. Geological Survey station number and name[2]	Sampling type and instrumentation
	Inflow	
[3]09035820	09035820, South Fork Williams Fork at upper station near Ptarmigan Pass	SW,CR
	Wetland 1	
09035830	09035830, South Fork Williams Fork near Ptarmigan Pass	SW,QW,CR
1CSG1	394215105574401, upstream crest-stage gage	SW
1UN1	394217105574501	GW
1UN2	394218105574401	GW
1US1	394214105574401	GW
1US2	394213105574401	GW
1DN1	394216105574601	GW
1DN2	394218105574601	GW
1DS1	394214105574601	GW,QW
1DS2	394213105574601	GW,QW
1CSG2	394215105575701, downstream crest-stage gage	SW,QW
	Wetland 2	
09035840	09035840, South Fork Williams Fork above tributary near Ptarmigan Pass	SW,QW,CR
09035845	09035845, South Fork Williams Fork tributary near Ptarmigan Pass	SW,QW,CR
2UN1	394212105590801	GW
2UN2	394213105590901	GW,QW
2US1	394211105590801	GW
2US2	394210105590801	GW,QW
2MN1	394212105591101	GW,CR
2MN2	394213105591101	GW,CR
2MN3	394214105591101	GW,CR
2CSG	394212105591102, crest-stage gage	SW
2MS1	394211105591101	GW,QW
2MS2	394210105591101	GW
2DN1	394211105591701	GW,QW
2DN2	394212105591701	GW,QW
2DN3	394213105591601	GW,QW
09035850	09035850, South Fork Williams Fork above Short Creek near Ptarmigan Pass	SW,QW,CR

Table 1.--*Surface- and ground-water sampling sites*--Continued

Site number[1]	U.S. Geological Survey station number and name[2]	Sampling type and instrumentation
	Wetland 3	
09035870	09035870, South Fork Williams Fork below Fork below Short Creek near Ptarmigan Pass	SW,QW,CR
3UE1	394511106015901	GW
3UE2	394511106015801	GW,QW
3CSG1	394511106020002, upstream crest-stage gage	SW
3UW1	394511106020001	GW,QW
3UW2	394510106020101	GW
3CSG2	394513106015901, downstream crest-stage gage	SW
3DE1	394514106020001	GW
3DW1	394514106020101	GW
3SW	394515106020101, South Fork Williams Fork above Old Baldy Mountain, near Leal	SW,QW
3AW1	394520106020201	GW,QW,CR
3AW2	394520106020301	GW,QW,CR
3AW3	394520106020401	GW,QW
3AE1	394520106020101	GW,QW,CR
3AE2	394520106020001	GW
3BW1	394527106020601	GW,QW,CR
3BW2	394527106020701	GW,CR
3BE1	394528106020501	GW,QW,CR
3BE2	394528106020401	GW
09035880	09035880, South Fork Williams Fork below Old Baldy Mountain, near Leal	SW,QW,CR
	Wetland 4	
4N1	394645105593802	GW
4N2	394645105593801	GW
4S1	394644105593801	GW
4S2	394644105593802	GW
4CSG	394644105593803, crest-stage gage	SW

[1]Wells were located in cross sections that were perpendicular to the stream at each wetland. Wells are identified according to site: Initial numbers (1, 2, 3, 4) refer to wetland; U is upstream cross section; D is downstream cross section; M is middle cross section; N is north side of stream; S is south side of stream; E is east side of stream (except well 3DE1); W is west side of stream; A is the upstream cross section added at site 3 during 1985; B is the downstream cross section added at site 3 during 1985; last numbers (1, 2, 3) refer to whether the well is closest (1), second closest (2), or third closest (3) well to the stream.

[2]Name is listed only for surface-water sites.

[3]Shown as inflow in figure 1.

In 1988 at wetland 3, the east side of cross section A, a hydraulic potentiomanometer (Winter and others, 1988) was used to measure the difference in hydraulic head between the stream and ground water at eight locations in the wetland. Hydraulic gradients were measured to indicate the direction of flow between the stream and shallow ground water in the wetland and to determine the vertical component of ground-water flow.

Water Quality

Water-quality data were collected to characterize the water chemistry in the area and to help identify the source of water in the wetlands. Standard U.S. Geological Survey sampling techniques were used to obtain water-quality samples (Brown and others, 1970). Samples were collected four times a year during water years 1985 and 1986. Point samples were collected at sites because the streams were shallow and well mixed. A hand-held 1-gal jug was submerged in the centroid of the flow with the mouth of the bottle directed toward the current. The water-quality samples collected during July 1986 at wetland 3 were collected by using a depth-integrating sampler at 15 verticals in the cross section (Guy and Norman, 1970). The sample was composited onsite for analyses at the laboratory. Specific conductance, pH, temperature, and dissolved oxygen were measured onsite; these properties can change substantially with time because of physical and chemical reactions.

Wells were sampled on the basis of their location within the wetland, their location within a cross section, and their ability to produce at least 1 gal of water when pumped (1 gal of water was the minimum needed for chemical analyses). In 1985, specific conductance and pH were monitored during the ground-water sample collection. When the specific conductance and pH stabilized, a 1-gal sample was collected. In 1986, the wells were prepumped 2 or 3 days before the sample was collected. At least 1 gal of water was pumped from the well. When the ground-water sample was collected, the container was rinsed with a small volume of sample, which was discarded, and 1 gal was collected for chemical analysis.

Adjustments were made in the water-quality sampling program during the 1986 and 1987 water years. The 1985 water year sampling program included four surface-water sites: The upstream end of wetland 1 (09035820), the upstream and downstream end of wetland 2 (09035840 and 09035850), and the upstream end of wetland 3 (09035870), and four wells: 2MN1 (only one sample was collected in October 1984), 2DN1, 2DN3, and 3UW1. Samples were collected from these surface-water sites and wells for general water-quality analyses. Four surface-water sites and 13 wells were added to the water-quality sampling program during the 1986 water year. The additional surface-water sites included: The downstream end of wetland 1 (1CSG2), the tributary at wetland 2 (09035845), and the middle and downstream end of wetland 3 (3SW and 09035880). These sites were used to monitor changes through the wetlands. The additional wells sampled were: 1DS1, 1DS2 (only one sample was collected because of inability to produce sufficient water when pumped), 2UN2, 2US2, 2MS1, 2DN2, 3UE2, 3AW1, 3AW2, 3AW3, 3AE1, 3BW2, and 3BE1. The wells were added to the sampling program to determine if the ground-water quality varied spatially and to determine water-flow direction. Analyses of trace-element concentrations that were less than U.S. Environmental Protection Agency drinking water standards (U.S. Environmental Protection Agency, 1986) or less than the detection limits of the analyzing equipment of the U.S. Geological Survey central laboratory were discontinued. These dissolved trace elements were: Arsenic, barium, boron, cadmium, chromium, cobalt, copper, lead, lithium, mercury, molybdenum, nickel, selenium, and silver. Analyses for dissolved aluminum, dissolved iron, dissolved manganese, and dissolved zinc were continued during the 1986 water year. Water-quality sampling was discontinued in the 1987 water year because the cost of additional analyses was not justified based on the use of water-quality data in determining water-flow direction between the stream and wetlands. In 1988, specific conductance was measured at sites within wetland 3 where the hydraulic potentiomanometer was used.

Climate

Two meteorological stations were installed in the study area (fig. 1). The Williams Fork station was located about 0.45 mi upstream from the mouth of the South Fork Williams Fork. The Bobtail station was located about 0.5 mi upstream from the west portal of the August P. Gumlick Tunnel. Instrumentation and monitoring was the same at both stations. Wind speed at 15 ft above the surface was measured using a Campbell[1] data logger and a Met-one anemometer. Wind speed was measured every 10 seconds; hourly and daily averages were generated by the data logger. Average air temperature and relative humidity were measured using a Campbell Scientific 201 temperature and humidity probe. Solar radiation was measured using a black-and-white Eppley radiometer. Radiation values were measured every 10 seconds; daily radiation was compiled by the data logger. Precipitation data were collected using a weighing-bucket precipitation gage. The precipitation data were used to interpret water-level fluctuations in the stream and wells. Both meteorological stations were discontinued in the 1987 water year.

The data obtained from the meteorological stations indicate that the climate of the upper Williams Fork basin is typical of mountain areas at high elevation in Colorado. Average daily air temperature usually was less than freezing from October until early May. Monthly precipitation ranged from 0.32 to 3.49 in. at the Williams Fork station (fig. 6) and from 0.76 to 4.32 in. at the Bobtail station (fig. 7). Data were not available for October and November 1985 at the Williams Fork station and for March 1986 at the Bobtail station. Total annual precipitation was similar for water years 1985 and 1986; however, more precipitation fell during early spring in 1986 than in early spring 1985. Snow-survey data collected at the two meteorological stations and at wetlands 1, 2, and 3 indicated that the snowpack and water content of the snow were larger in 1986 than in 1985. As a result of the deeper snowpack, surface-water runoff, peak streamflows, and ground-water levels were higher during 1986 than during 1985.

---

[1]Use of trade names in this report is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey.

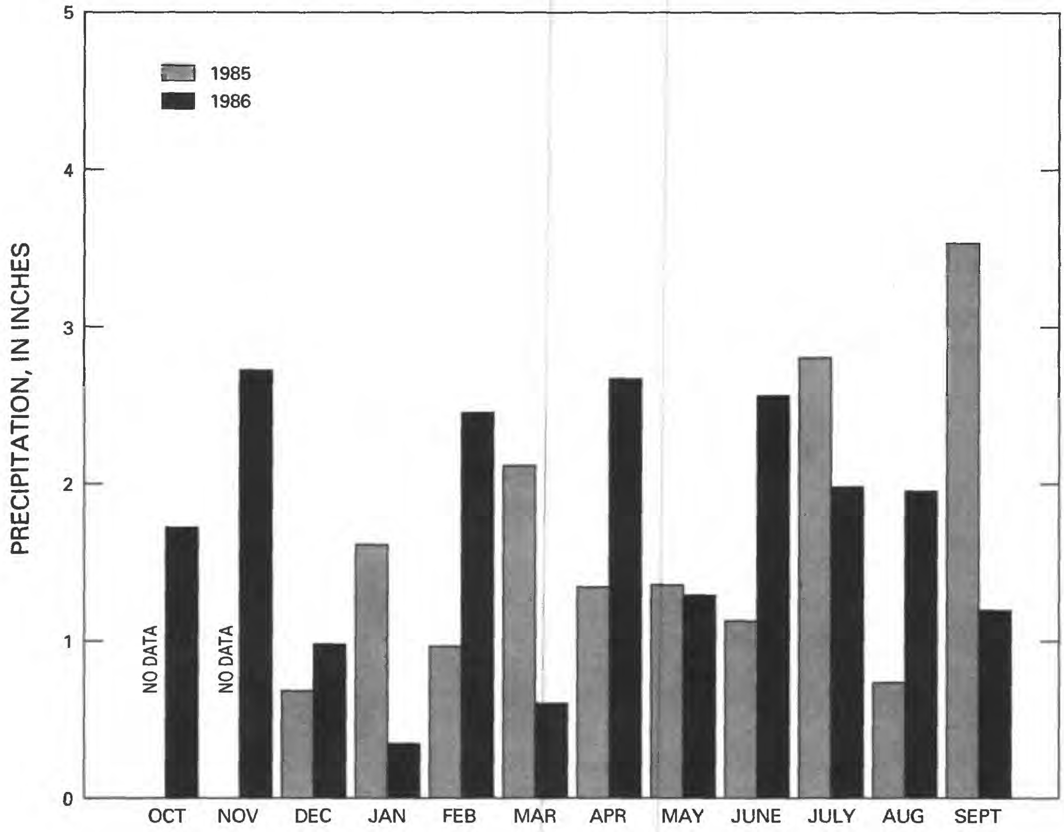

Figure 6.--Total monthly precipitation at the Williams Fork meteorological station, water years 1985-86.

HYDROLOGIC RELATIONS AND CONDITIONS AT WETLAND AREAS

The four wetlands (wetlands 1-4) were selected because visual inspection of the topography and channel conditions indicated that they represent three distinct streamflow-wetland environments. At wetland 1, overbank flooding was considered unlikely to occur, except during extreme hydrologic events. At wetland 2, overbank flooding seemed possible in a limited area of the wetland. Wetland 3 was selected because overbank flooding and consequent streamflow contribution to the ground water in the wetland was likely. Wetland 4 was selected to evaluate an area where overbank flooding of the wetland was unlikely, but the site was representative of wetlands on the main stem Williams Fork upstream from the confluence of the South Fork Williams Fork. The instrumentation network at each wetland was designed to measure surface-water inflows and outflows and to determine the direction of ground-water flow.

Precipitation and snowpack data were collected for 2 water years (1985-86), and streamflow and ground-water level data were collected for 4 water years (1985-88) in the study area. In order to compare streamflow

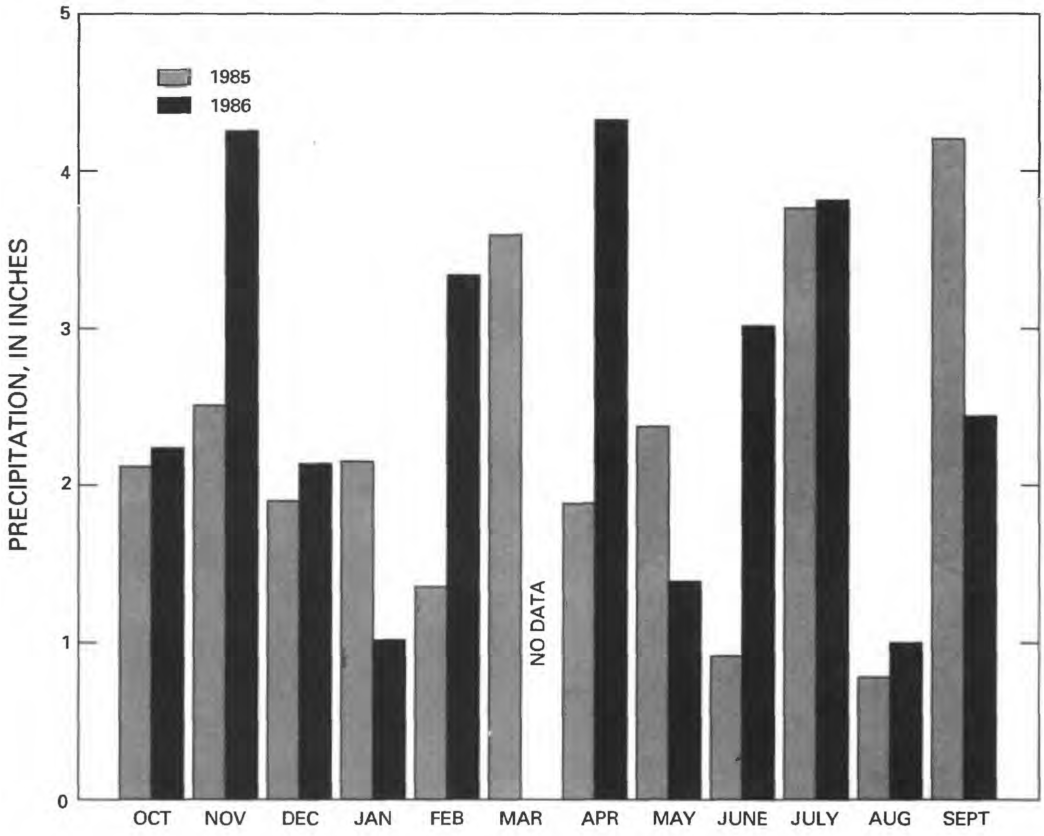

Figure 7.--Total monthly precipitation at the Bobtail meteorological station, water years 1985-86.

with a long-term average, the streamflow at streamflow-gaging station 09035900, South Fork Williams Fork near Leal (outside of study area; 0.6 mi upstream from mouth), was analyzed. The mean daily streamflow for the 23 years of record (1966-88) at this station was 33 ft^3/s; the mean daily streamflows for water years 1985 through 1988 were 34.5 ft^3/s, 40.6 ft^3/s, 25.2 ft^3/s, and 32.8 ft^3/s, respectively. The mean daily streamflows indicate that streamflow during water year 1986 was greater than average for the period of record, streamflow during water years 1985 and 1988 was average, and streamflow during water year 1987 was less than average. The streamflow measured at this station is representative of the streamflow that occurs at higher elevations in the basin in the study area.

A continuous recording streamflow-gaging station, 09035820, South Fork Williams Fork at upper station near Ptarmigan Pass, was installed at the inflow site upstream from the location of the proposed streamflow-diversion structure at the request of the Denver Water Department. This site was established to obtain baseline information and to provide information for future studies. Mean monthly streamflow for water years 1985 and 1986 indicated a typical snowmelt-runoff pattern, with the peak streamflow occurring in June (fig. 8). More than 75 percent of the streamflow occurred during the months of May, June, and July.

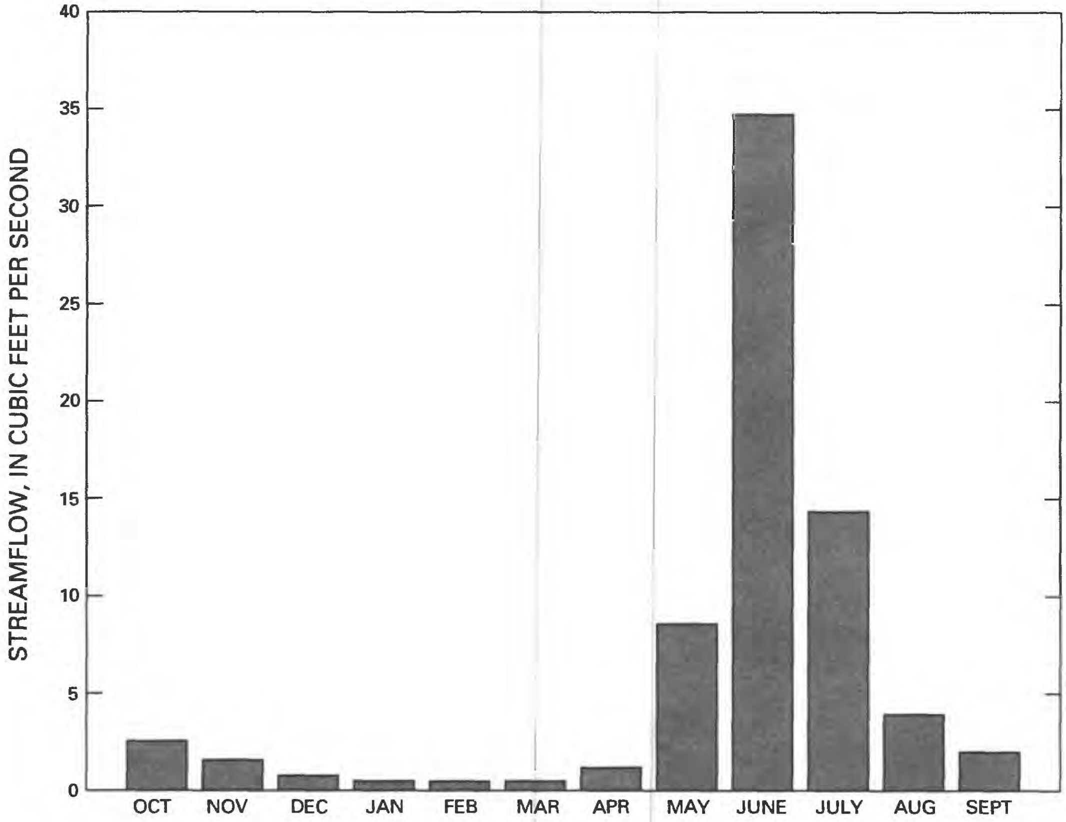

Figure 8.--Mean monthly streamflow at streamflow-gaging station 09035820, South Fork Williams Fork at upper station near Ptarmigan Pass, water years 1985-86.

Wetland 1

Wetland 1 is the uppermost wetland study site in the South Fork Williams Fork valley (fig. 1). The stream is incised, resulting in 2- to 3-ft channel banks. The southern side of the valley slopes steeply to the stream, and a small part of the wetland is on the slope above the stream. Overland flow is toward the stream. The valley bottom is flatter on the northern side of the stream, and the vegetation mostly is willows, grasses, and forbs. The wetland is separated from the stream channel by a low, dry ridge that is comprised of large boulders covered by a thin layer of soil. The beaver ponds on the north side of the stream receive water from side-slope flow.

Instrumentation Network

A continuous recording streamflow-gaging station 09035830, South Fork Williams Fork near Ptarmigan Pass (fig. 2), was installed upstream from wetland 1. Crest-stage gage 1CSG1 was installed midway through the wetland and crest-stage gage 1CSG2 was installed at the downstream end of the wetland. To monitor surface-water inflow, a staff gage and a 90° V-notch weir were installed on a small tributary that flows into the beaver ponds in the wetland.

Eight observation wells were installed in two cross sections in the wetland (fig. 2). Both cross sections consisted of two wells on each side of the stream. In 1987, staff gages were installed in the stream at each cross section. Water samples were collected for chemical analyses at station 09035830, at the downstream crest-stage gage, 1CSG2, and at wells 1DS1 and 1DS2 (fig. 2). Only one ground-water sample was collected from well 1DS2 because quantities of water that were pumped were insufficient for analyses.

Study Results

Streamflow increases through wetland 1, a reach of about 0.25 mi, were minimal. Miscellaneous streamflow measurements that were made at the downstream crest-stage gage, 1CSG2, during 1986 were compared with streamflow measurements at station 09035830; differences in streamflow were insignificant and were within the range of streamflow-measurement error. No overbank flooding into the wetland area was recorded at the two crest-stage gages. For 1985 and 1986, when stream stage was not measured at the cross sections, the maximum possible stream stage, without overbank flooding, was compared to the measured ground-water levels. The maximum possible stream stage and the stream stages measured in 1987 indicated that the stream surface at wetland 1 was always lower than the measured ground-water levels.

Ground-water levels at wetland 1 varied during the year (fig. 9). The depth to water below land surface was largest (more than 2.5 ft) in late winter/early spring, prior to snowmelt, and was smallest (less than 0.5 ft) during snowmelt in late spring. The high water table most likely resulted from direct snowmelt recharge and surface and subsurface flow from upslope melting. Lower ground-water levels in midsummer probably resulted from evapotranspiration loss and decreased direct recharge.

Selected water-quality data for samples collected at wetland 1 are listed in table 2. Data are presented only for the two sites where more than one sample was collected. Dissolved-solids concentrations were similar (about 40 mg/L) for surface water at station 09035830 and for ground water at well 1DS1. The most notable differences were in the concentrations of dissolved aluminum, dissolved iron, and dissolved manganese. The concentrations of these constituents in ground water were as much as 1 to 2 orders of magnitude larger than the concentrations in surface water (table 2).

The South Fork Williams Fork does not seem to be supplying water to wetland 1. The slope of the water table in the downstream cross section was toward the stream throughout the year, and the stream stage was lower than the water levels in all the wells (fig. 10). The water levels between the stream

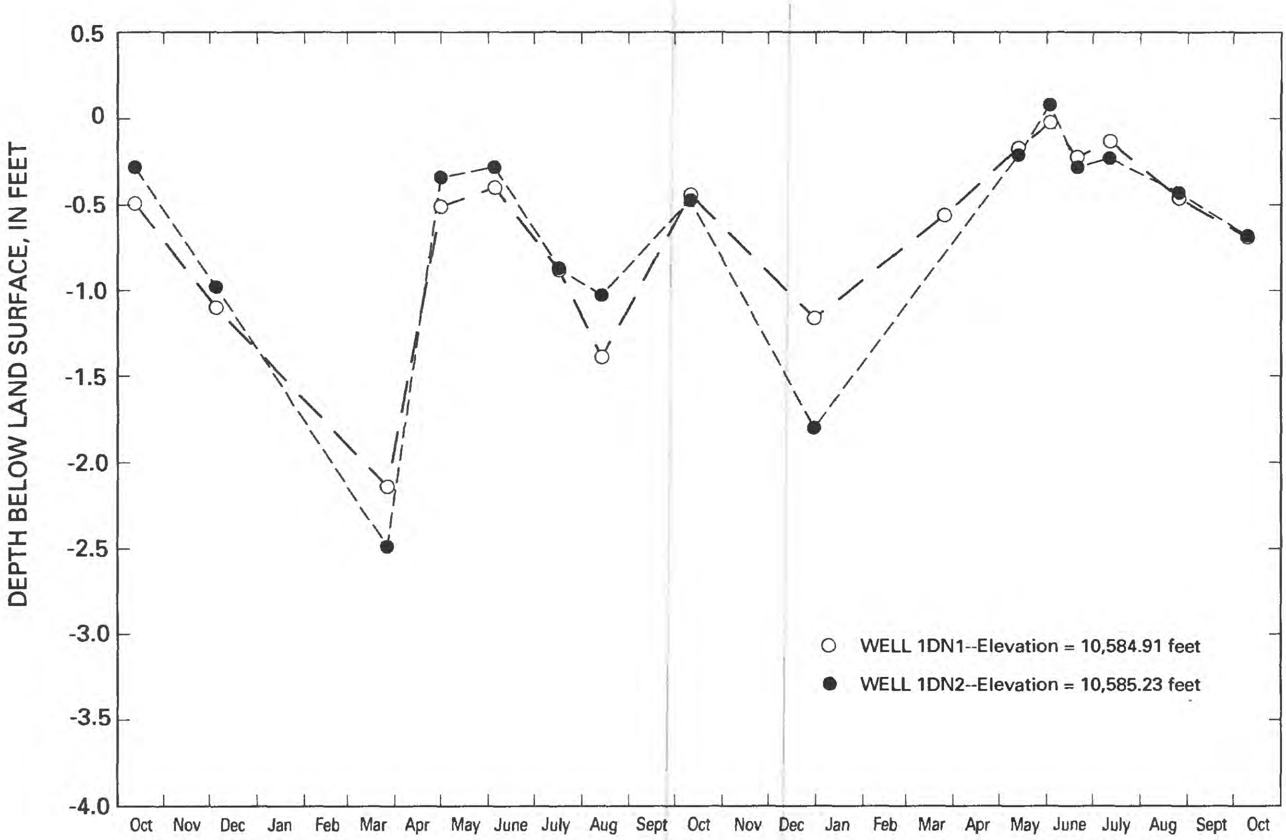

Figure 9.--Water-level measurements for wells 1DN1 and 1DN2 in wetland 1, water years 1985-87.

and nearest well were drawn as straight lines because data were not available to more accurately draw the water levels. The effect of the stream on the ground-water levels between the stream and the nearest well cannot be defined accurately. This hydrology also occurred in the upstream cross section. However, on the north side of the stream, a dry ridge separates the wetland from the stream and may be a barrier to ground-water flow from well 1UN1 perpendicular to the stream. The ground-water gradient between wells 1UN1 and 1DN1 always is toward 1DN1 (fig. 11). This gradient may represent the primary ground-water flow path. The seasonal differences in stream elevation and ground-water levels also are shown in figures 10 and 11. In June, stream elevation and ground-water levels primarily were a function of snowmelt. In September, stream elevation primarily was a function of ground-water discharge and storm events. In contrast, the ground-water levels primarily were a function of accumulated evapotranspiration loss and decreased recharge. The decrease in ground-water levels between June and September was not a direct result of the decrease in stream elevation.

Table 2.--*Selected water-quality data collected at wetland 1, water year 1986*

[mg/L, milligrams per liter; µg/L, micrograms per liter; streamflow-gaging station 09035830, South Fork Williams Fork near Ptarmigan Pass; 1DS1, well; --, no data]

Date	Dissolved solids (mg/L)		Dissolved aluminum (µg/L)		Dissolved iron (µg/L)		Dissolved manganese (µg/L)	
	09035830	1DS1	09035830	1DS1	09035830	1DS1	09035830	1DS1
10-18-85	38	31	20	150	30	2,000	9	120
03-25-86	43	--	20	--	35	--	3	--
06-05-86	--	31	--	330	--	2,000	--	58
08-25-86	40	41	30	300	45	2,500	2	71

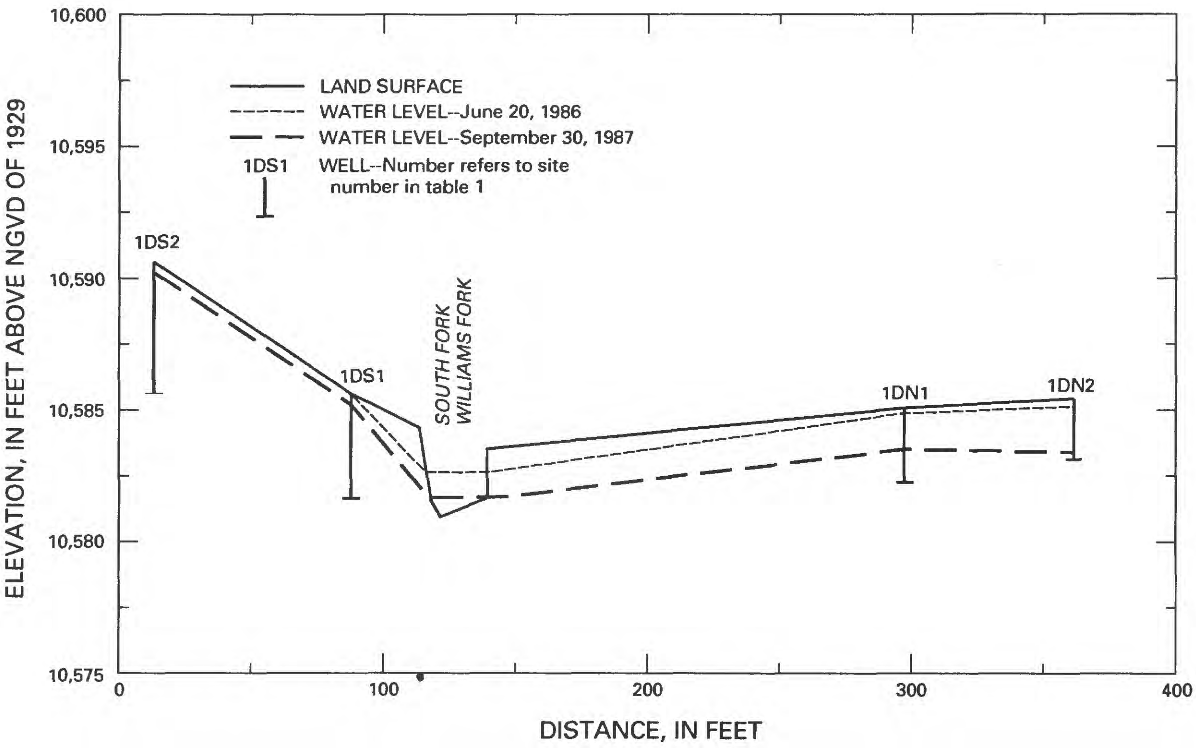

Figure 10.--Water levels for wells in downstream cross section of wetland 1, June 20, 1986, and September 30, 1987.

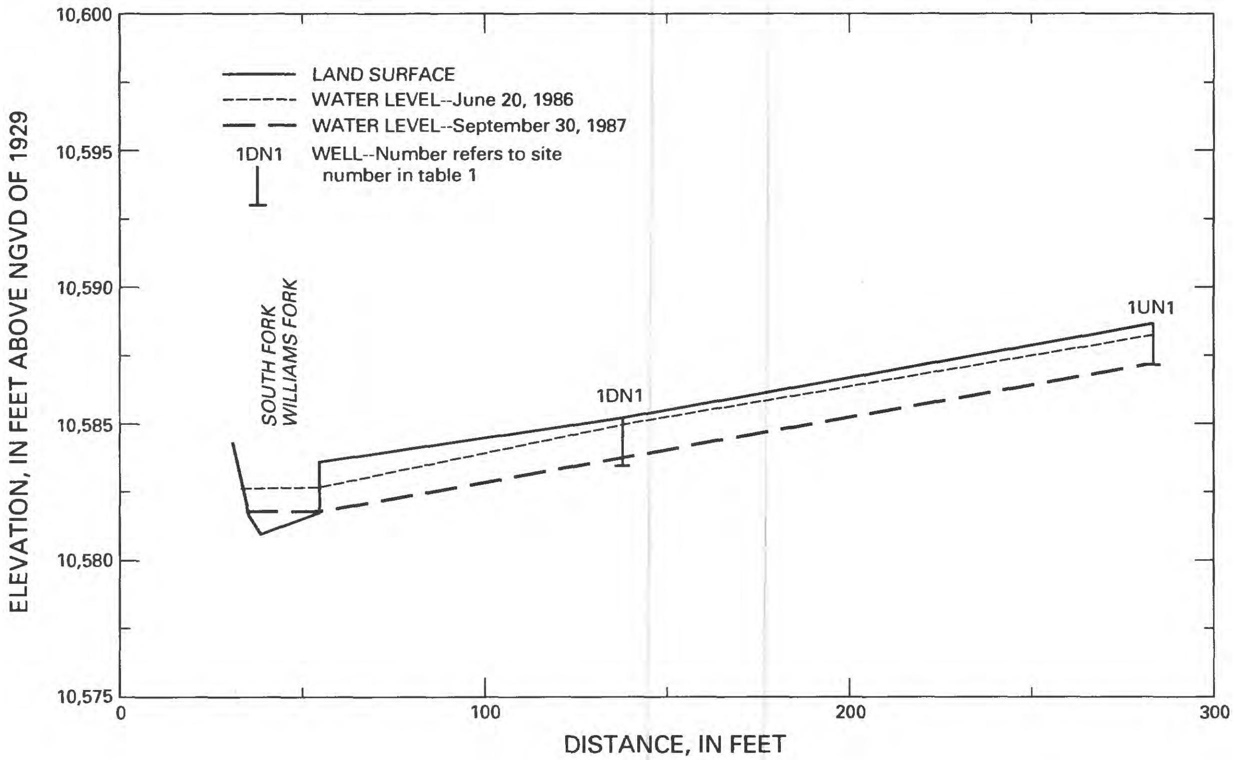

Figure 11.--Water levels in two wells on north side of stream in wetland 1, June 20, 1986, and September 30, 1987.

Recharge to wetland 1 probably is from precipitation, snowmelt, valley side-slope flow, and ground-water inflow. Consequently, decreases in stream stage, resulting from diverting water from the South Fork Williams Fork, probably will have little or no effect on the ground-water levels of wetland 1.

Wetland 2

Wetland 2 is the middle wetland site in the South Fork Williams Fork valley. The stream is incised in the upper half of the wetland and is beaver dammed midway through the wetland. Below the dam, the stream is wider, and the streambanks are less than 1 ft high. During water year 1986, a second beaver dam was built near the downstream end of the wetland. The valley side slopes are fairly steep on both sides of the stream throughout the wetland. The wetland on the north side of the stream contains more than three beaver ponds. The wetland is higher in elevation than the stream, and the ponds receive water from valley side-slope flow. Growth of willows is dense on the north side of the stream. The south side of the stream is drier than the north side, the growth of willows is less dense, and it does not contain any beaver ponds. At the downstream end of the wetland, the vegetation mostly is grasses and forbs.

Instrumentation Network

Three continuous streamflow-gaging stations were established at wetland 2 (fig. 3). Stations 09035840 and 09035850 are on the South Fork Williams Fork, and station 09035845 is on an unnamed intermittent tributary. Another small unnamed intermittent tributary, located on the south side of the main tributary, was measured in conjunction with measurements at the main tributary station 09035845. Crest-stage gage 2CSG was installed adjacent to the stream, midway through wetland 2, to monitor overbank flooding. Staff gages were installed in two beaver ponds. A staff gage and a 90° V-notch weir were installed on the main side-slope channel that flows into the largest beaver pond.

Twelve observation wells were installed in three cross sections in wetland 2 (fig. 3). The upstream cross section contained four wells (2UN1, 2UN2, 2US1, and 2US2), two on either side of the stream. The middle cross section contained five wells, two on the south side of the stream (2MS1 and 2MS2), and three with continuous water-level recorders on the north side of the stream (2MN1, 2MN2, and 2MN3). The continuous water-level recorders were located in a single cross section to monitor the changes in ground-water level to determine the direction of ground-water flow. The downstream cross section contained three wells on the north side of the stream (2DN1, 2DN2, and 2DN3); wells were not located on the south side of the stream because the area was relatively dry. In 1987, staff gages were installed in the stream at the three cross sections. Water samples were collected for chemical analyses at the three streamflow-gaging stations and at six wells.

Study Results

Comparisons of mean monthly streamflow measurements indicate that wetland 2 is a gaining reach (fig. 12). Fourteen sets of streamflow measurements indicate a change in streamflow through wetland 2 (between stations 09035840 and 09035850) that ranged from -2 percent to +71 percent with a mean of about 18 percent (table 3). For the 12 measurements that indicated an increase in downstream streamflow, 40 percent of the increase was due to the measured tributary inflow. The remaining 60 percent increase was due to valley side-slope flow and ground-water inflow.

Overbank flooding was considered possible near the ponds but did not occur at these locations during the study. Although the stream did reach the crest-stage gage, it did not rise enough to flood the wetland.

Ground water flows toward the South Fork Williams Fork and its small tributaries. For 1985 and 1986, when stream stage was not measured at the cross section, the maximum possible stream stage, without overbank flooding, was compared to the measured ground-water levels. The maximum possible stream stage and the stream stages measured in 1987 indicated that the ground-water

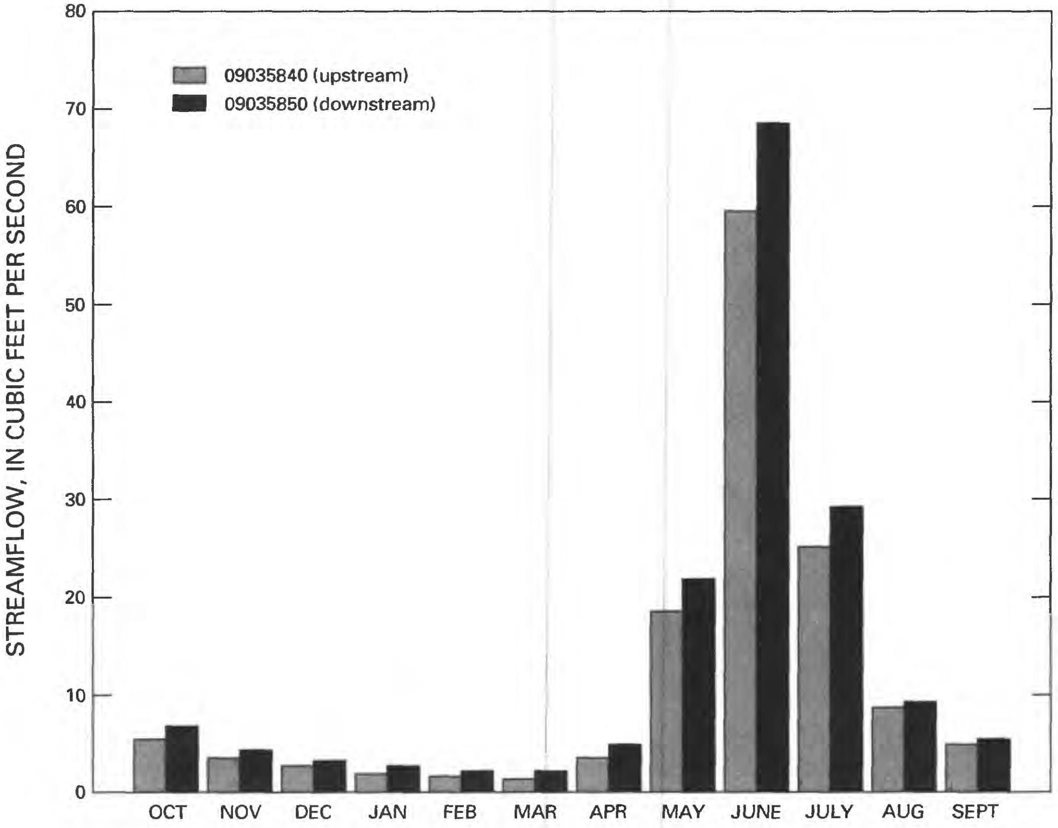

Figure 12.--Mean monthly streamflow at streamflow-gaging stations 09035840, South Fork Williams Fork above tributary near Ptarmigan Pass, and 09035850, South Fork Williams Fork above Short Creek near Ptarmigan Pass, water years 1985-86.

levels were always higher than the stream except in well 2DN1 after it was flooded. The relation between the land surface, the water levels, and the stream is shown in figure 13 for the middle cross section of wells. On the south side of the valley, the ground water flows toward the unnamed tributary or the other two small channels. The unnamed tributary is more incised than the South Fork Williams Fork in this cross section because a beaver dam located 10 ft downstream from the confluence caused slow stream velocities, which resulted in sediment deposition in the main channel. Downstream from the beaver dam, the channel bottom is substantially lower than upstream from the beaver dam. The South Fork Williams Fork is wider and shallower at this cross section than at other parts of the valley. On the north side of the valley, the ground-water levels were always higher than the South Fork Williams Fork, even at bankfull conditions. Ground-water levels on the north side of the valley had little seasonal change (fig. 13). Ground-water-level fluctuations during the year were not large enough to reverse the direction of ground-water flow.

Table 3.--*Summary of streamflow measurements at wetland 2, water years 1985-86*

Date of measurement	Streamflow, in cubic feet per second					Percent change in streamflow between station 09035840 and station 09035850
	Station 09035840 (upstream from wetland 2)	Station 09035845 unnamed tributary)	Small unnamed tributary	Station 09035850 (downstream from wetland 2)	Difference in streamflow not accounted for by measurements	
12-04-84	2.8	0.08	0.10	3.3	0.32	18
04-30-85	3.5	.05	.03	6.0	2.4	71
06-04-85	39	.74	1.9	41	-.64	5
06-10-85	70	3.2	3.1	84	7.7	20
07-16-85	12	.08	.51	14	1.4	17
08-13-85	6.2	.10	.31	6.1	-.51	-2
10-10-85	3.8	.07	.12	4.5	.51	18
12-20-85	2.0	.06	.06	2.4	.28	20
03-25-86	1.3	.04	.04	1.3	-.08	0
06-02-86	53	2.0	2.5	60	2.5	13
06-05-86	55	1.5	2.9	62	2.6	13
06-20-86	71	2.5	3.8	80	2.7	13
07-11-86	34	.25	2.6	43	6.2	26
08-25-86	9.4	.10	.48	11	1.0	17

Ground-water levels changed daily, seasonally, and annually at wetland 2. Daily water-level fluctuations were most evident during the growing season. The August 20-22, 1985, ground-water level rose during the night and reached a daily peak at midmorning (fig. 14). The fluctuations could be partially attributed to the process of evapotranspiration, which consumes water during the day and thereby lowers ground-water levels. These daily fluctuations in ground-water levels are not evident May 16-18, 1985, prior to the growing season (fig. 14). Seasonal ground-water level changes (fig. 15) mostly were due to snowmelt. Recharge to wetland ground water occurred during the snow-melt period. Less fluctuation in water levels was measured after the snowpack began to accumulate in October and November. The water levels on the south side of the valley were closest to the surface in June and decreased during the growing season. A slight increase in water levels occurred after the growing season. The water levels in well 2MS2 had a sharp peak in June. Annual differences in ground-water levels also can be seen in figure 15. In general, ground-water levels were higher during water year 1986 than during water year 1985 because of deeper snowpack and larger water content of the snow.

Water levels in wells 2MN1, 2MN2, and 2MN3 were compared to the stage at the streamflow-gaging station 09035850, which is approximately 600 ft down-stream from the wetland (figs. 16 and 17). Water levels in the three wells exhibited water-level fluctuations similar to changes in stream stage. It seemed that the ground-water levels and the stream responded to snowmelt and precipitation; however, ground-water levels did not respond to changes in stream stage. The water levels in September in wells 2MN2 and 2MN3 were

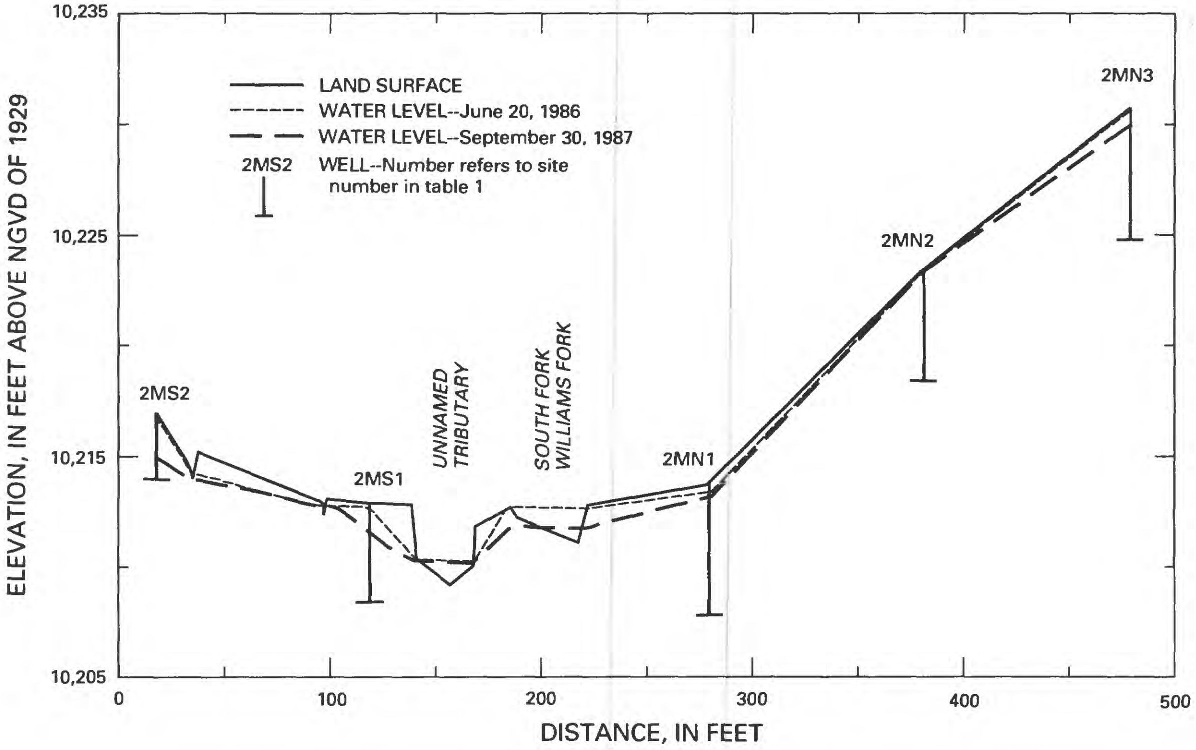

Figure 13.--Water levels in wells in middle cross section of wetland 2, June 20, 1986, and September 30, 1987.

higher in 1986 than in 1985 and did not decrease in 1986 probably because of a deeper snowpack. The water levels in well 2MN1 are more variable than in wells 2MN2 and 2MN3 during both years.

During the fall of 1985, beavers built a dam at the downstream end of wetland 2 on the South Fork Williams Fork. Backwater from the beaver dam flooded well 2DN1, resulting in standing water around the base of the well. The water level in well 2DN1 did not decrease during the winter and rose almost to land surface by the following summer (fig. 18). Water levels in the upslope wells, 2DN2 and 2DN3, followed the normal seasonal fluctuation during this period.

Water was sampled approximately quarterly from six wells for chemical analyses. At times, water-quality samples were not collected because the well was frozen or because sufficient quantities for sampling could not be obtained. The dissolved-solids concentrations generally were larger in the ground water than in the stream except in wells 2MS1 and 2DN2, which had concentrations approximately equal to the stream concentrations (table 4). Dissolved trace-element concentrations were substantially larger in the ground water than in the stream for most of the wells. Dissolved trace-element concentrations were

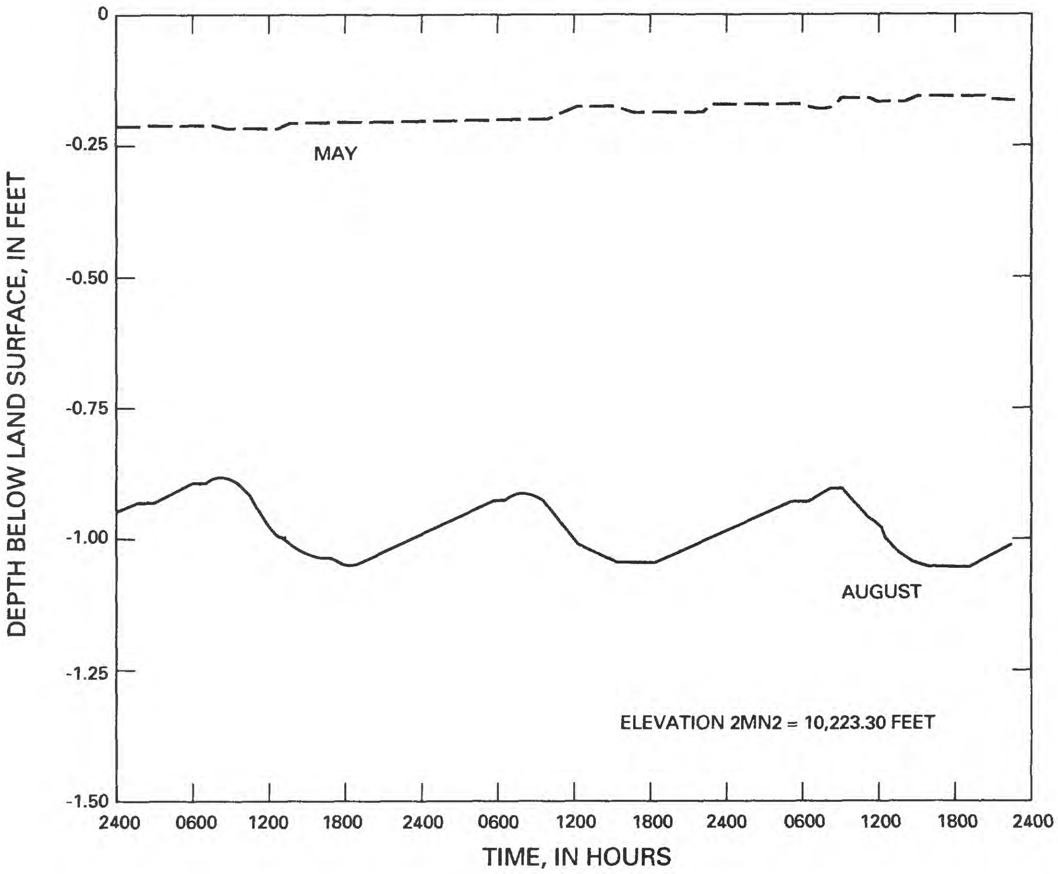

Figure 14.--Daily fluctuation in water level in well 2MN2, May 16-18 and August 20-22, 1985.

1 to 3 orders of magnitude larger in the ground water than in the stream except in well 2MS1, which had concentrations generally less than one order of magnitude larger than the stream (tables 5-7). The difference between the ground water and stream probably was because of reducing conditions in the wetland and oxidizing conditions in the stream. During high-flow conditions in June, a greater percentage of the total streamflow was from snowmelt and overland flow. Consequently, the dissolved-iron concentrations in the stream were as much as 75 percent less than during the rest of the year. During low-flow conditions, ground-water contribution to streamflow was greater; therefore, the dissolved-iron concentration in the stream was proportionately larger.

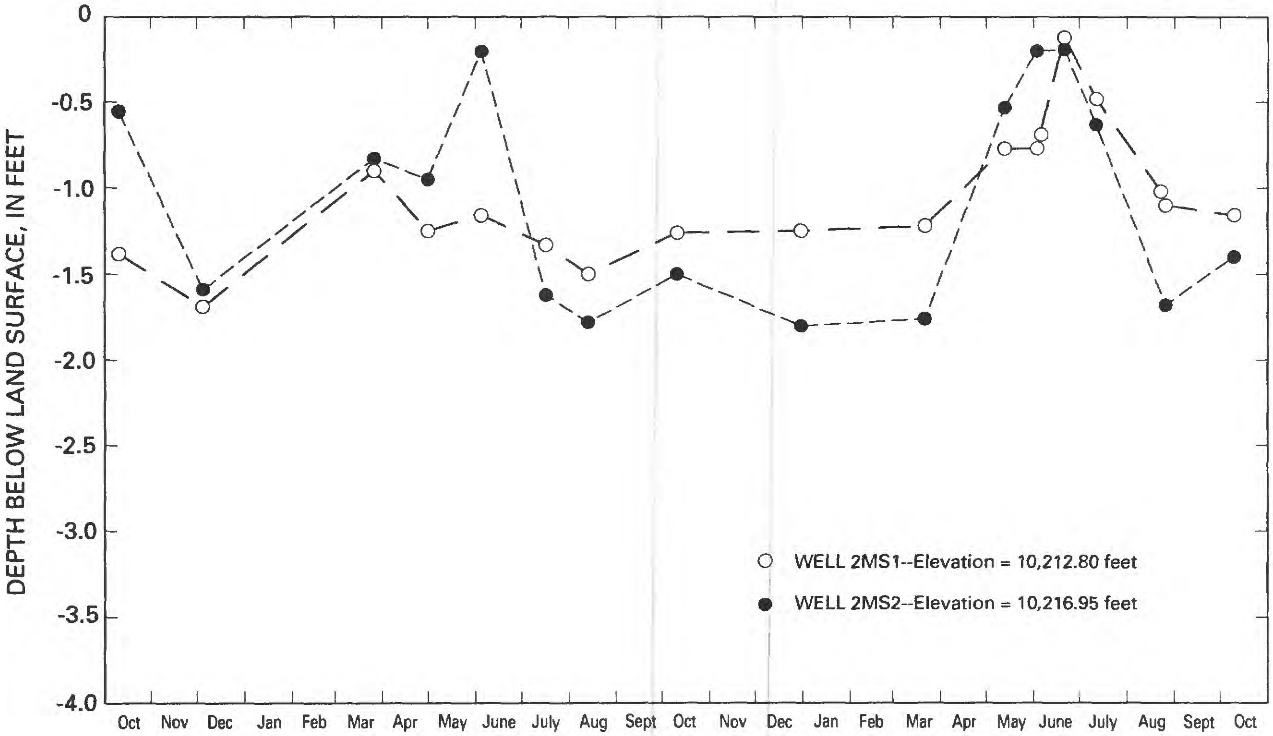

Figure 15.--Water-level measurements for wells 2MS1 and 2MS2 at wetland 2, water years 1985-87.

Water quality of the stream changed very little through wetland 2. The most consistent change was a general increase in the concentrations of dissolved iron downstream. Large concentrations of dissolved iron (table 5) were present in the ground water under the anoxic wetland conditions. The dissolved-iron concentrations in the ground water generally were at least 1 to 2 orders of magnitude greater than in the stream. Changes in dissolved-iron concentrations in a downstream direction ranged from -36 to +76 percent. For all but one analysis, the stream data indicated that the dissolved-iron concentrations increased through wetland 2. These data provide some supporting evidence that the ground water was discharging to the stream. A reddish-orange precipitate coating on the streambed rocks provided evidence that the ground water was flowing into the stream. The precipitate probably was iron oxyhydroxide that precipitated after the anoxic ground water mixed with the oxidized surface water.

The South Fork Williams Fork generally did not contribute water to wetland 2 except at the new beaver dam site, where flooding occurred. Decreases in stream stage, resulting from diverting water from the South Fork Williams Fork, probably will not affect most of wetland 2.

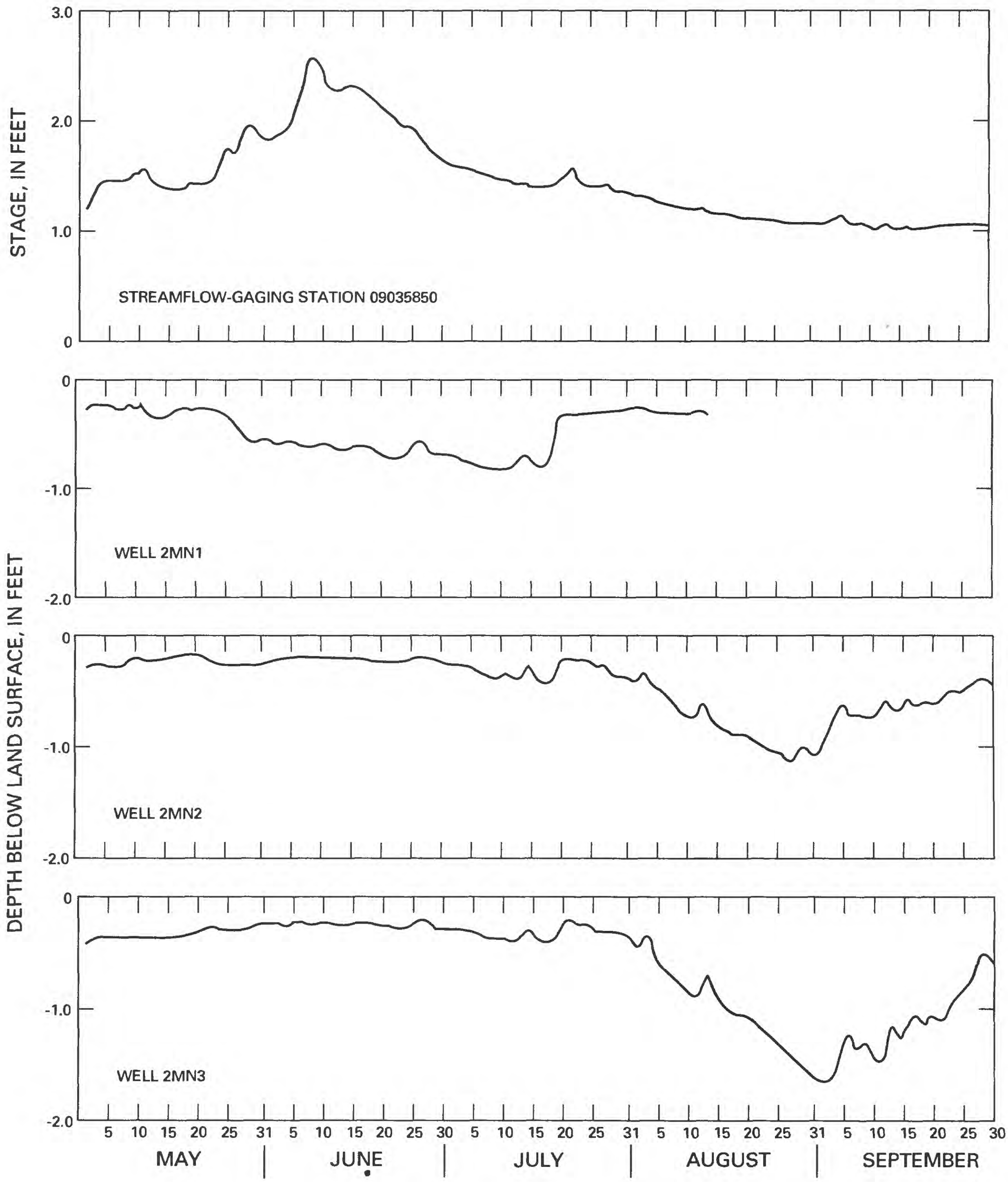

Figure 16.--Stream stage and ground-water levels at wetland 2, May through September 1985.

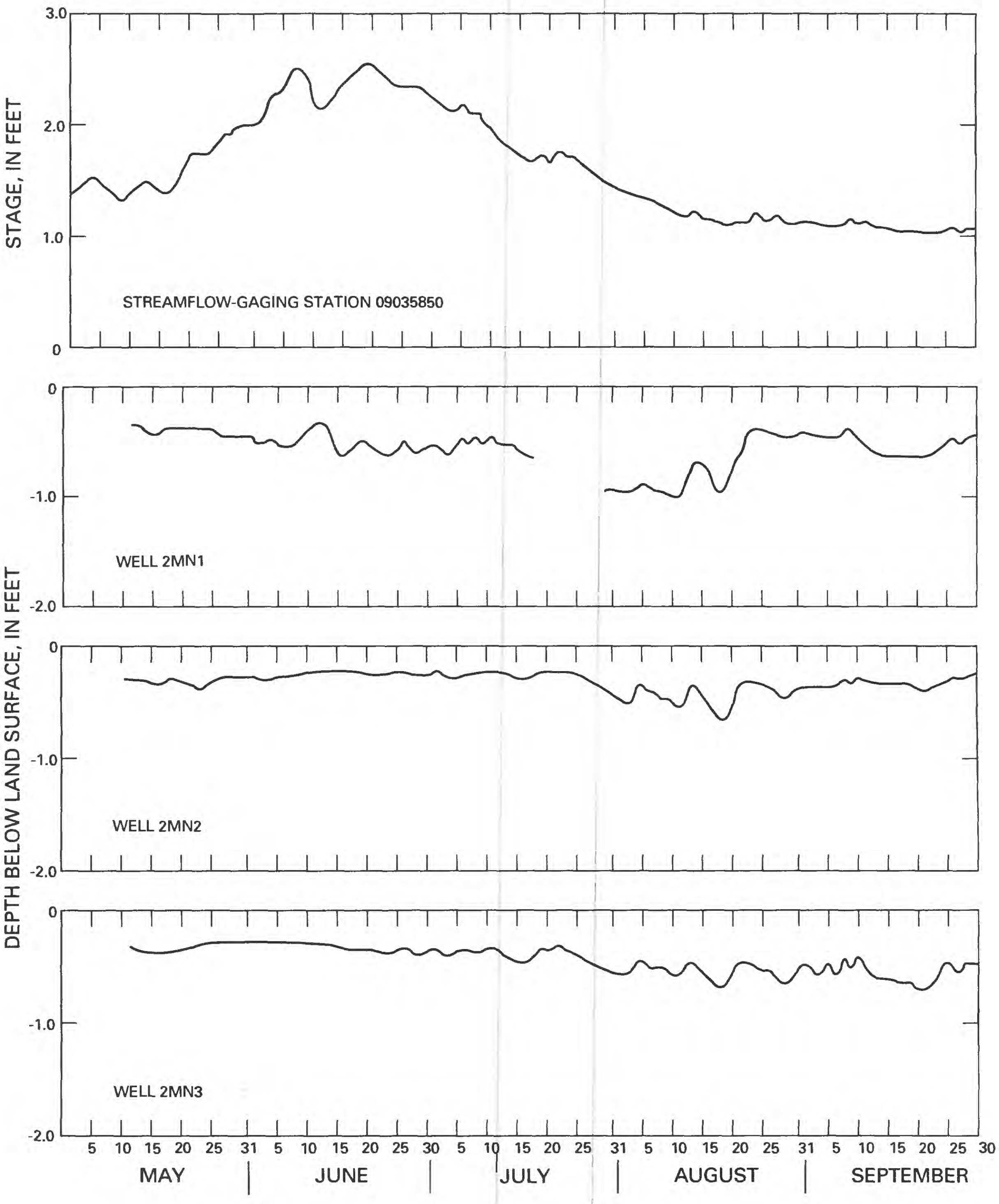

Figure 17.--Stream stage and ground-water levels at wetland 2, May through September 1986.

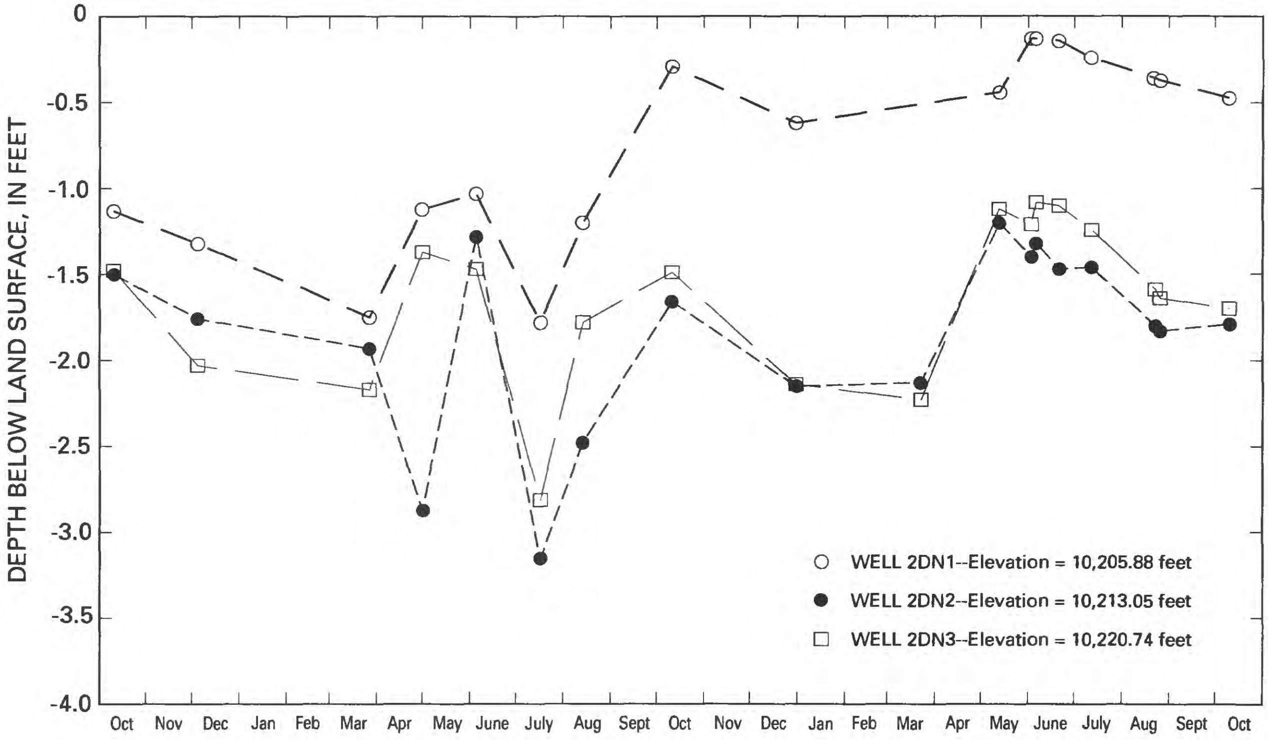

Figure 18.--Water-level measurements for wells 2DN1, 2DN2, and 2DN3 at wetland 2, water years 1985-87.

Table 4.--*Dissolved-solids-concentration data collected at wetland 2, water years 1985-86*

[Values in milligrams per liter; streamflow-gaging station 09035840, South Fork Williams Fork above tributary near Ptarmigan Pass; streamflow-gaging station 09035850, South Fork Williams Fork above Short Creek near Ptarmigan Pass; --, no data; E, estimated]

Date	09035840	Well 2US2	Well 2UN2	Well 2MS1	Well 2DN1	Well 2DN2	Well 2DN3	09035850
10-30-84	43	--	--	--	--	--	--	48
04-30-85	44	--	--	--	91	--	65	44
06-04-85	33	--	--	--	73	--	47	E28
08-13-85	44	--	--	--	150	--	80	44
10-18-85	46	48	110	40	71	65	--	E45
03-25-86	49	65	60	44	--	48	64	--
06-05-86	31	37	58	--	240	38	42	31
08-25-86	44	56	79	48	260	E39	80	45

Table 5.--*Dissolved-iron-concentration data collected at wetland 2, water years 1985-86*

[Values in micrograms per liter; streamflow-gaging station 09035840, South Fork Williams Fork above tributary near Ptarmigan Pass; streamflow-gaging station 09035850, South Fork Williams Fork above Short Creek near Ptarmigan Pass; --, no data; <, less than]

Date	09035840	Well 2US2	Well 2UN2	Well 2MS1	Well 2DN1	Well 2DN2	Well 2DN3	09035850
10-30-84	55	--	--	--	--	--	--	69
04-30-85	54	--	--	--	19,000	--	3,400	95
06-04-85	24	--	--	--	<3	--	1,300	28
08-13-85	100	--	--	--	23,000	--	7,800	64
10-18-85	49	1,400	3,200	370	12	4,300	--	71
03-25-86	78	3,100	1,300	120	--	3,400	4,300	--
06-05-86	34	240	2,300	73	63,000	1,200	440	40
08-25-86	56	1,700	4,000	83	82,000	3,400	6,000	74

Table 6.--*Dissolved-aluminum-concentration data collected at wetland 2, water years 1985-86*

[Values in micrograms per liter; streamflow-gaging station 09035840, South Fork Williams Fork above tributary near Ptarmigan Pass; streamflow-gaging station 09035850, South Fork Williams Fork above Short Creek near Ptarmigan Pass; --, no data; <, less than]

Date	09035840	Well 2US2	Well 2UN2	Well 2MS1	Well 2DN1	Well 2DN2	Well 2DN3	09035850
10-30-84	50	--	--	--	--	--	--	10
04-30-85	30	--	--	--	150	--	320	30
06-04-85	30	--	--	--	130	--	130	70
08-13-85	20	--	--	--	130	--	--	<10
10-18-85	20	140	60	50	230	<10	120	40
03-25-86	20	100	130	80	--	240	70	--
06-05-86	40	40	70	50	210	520	240	40
08-25-86	20	250	100	30	180	480	160	20

Table 7.--*Dissolved-manganese-concentration data collected at wetland 2, water years 1985-86*

[Values in micrograms per liter; streamflow-gaging station 09035840, South Fork Williams Fork above tributary near Ptarmigan Pass; streamflow-gaging station 09035850, South Fork Williams Fork above Short Creek near Ptarmigan Pass; --, no data]

Date	09035840	Well 2US2	Well 2UN2	Well 2MS1	Well 2DN1	Well 2DN2	Well 2DN3	09035850
10-30-84	7	--	--	--	--	--	--	7
04-30-85	5	--	--	--	770	--	44	4
06-04-85	3	--	--	--	720	--	22	3
08-13-85	5	--	--	--	730	--	180	7
10-18-85	5	330	1,400	47	380	99	--	6
03-25-86	9	600	420	11	--	57	97	--
06-05-86	1	34	380	3	1,800	18	7	2
08-25-86	3	270	530	7	1,700	49	90	4

Wetland 3

Wetland 3 is the farthest downstream wetland study site in the South Fork Williams Fork valley. Wetland 3 is substantially different from wetlands 1 and 2. Wetlands 1 and 2 are substantially higher in elevation than the stream. They are maintained, and may have been initially formed, by beaver dams capturing side-slope flow. Beaver activity did not occur in the main channel at wetland 1 and had only a small effect at wetland 2. In contrast, wetland 3 is located in a broad, flat valley with a meandering stream that currently (1988) is dammed and previously was dammed by beavers. Wetland 3 probably was formed as a result of a massive rockslide that blocked the valley. Wetland 3 also has side-slope flows that are dammed by beavers. There are numerous seeps along the base of the western side of the valley bottom. The upstream area of wetland 3 mostly is coniferous forest. Farther downstream the vegetation in the valley bottom consists mainly of willows and grasses. The west valley side is coniferous forest; the east valley side is talus.

Instrumentation Network

Two continuous streamflow-gaging stations are located at wetland 3 (fig. 4). The upstream streamflow-gaging station 09035870, South Fork Williams Fork below Short Creek near Ptarmigan Pass, was installed in October 1984. A second streamflow-gaging station 09035880, South Fork Williams Fork below old Baldy Mountain, near Leal, was installed downstream from the wetland in November 1985. Two crest-stage gages, 3CSG1 and 3CSG2, were installed adjacent to the stream in the upstream half of the wetland to measure overbank flooding.

Six observation wells were installed in October 1984 at cross sections U and D. Nine more wells were installed in November 1985 at cross sections A and B. The wells were aligned in four cross sections perpendicular to the stream (fig. 4). Two continuous recorders at cross section A, 3AW1 and 3AW2, and one continuous recorder at cross section B, 3BW1, were installed in June 1986. One additional continuous recorder at cross section A, 3AE1, and two additional continuous recorders at cross section B, 3BE1 and 3BW2, were installed in May 1987. The continuous recorders on the wells were operated from May or June through September. Staff gages were installed in June 1986 at cross sections A and B and in May 1987 at cross sections U and D. Stream samples were collected for chemical analyses at both streamflow-gaging stations and near cross section A. Ground-water samples were collected from eight wells for chemical analyses.

Additional investigations were made in 1988 at cross section A on the east side of the South Fork Williams Fork. The water levels that had been measured indicated that water was flowing from the stream to the wetland at cross section A, whereas the reverse was true at all the other cross sections. A hydraulic potentiomanometer (Winter and others, 1988) was used to measure the difference in hydraulic head between the stream and ground water and to determine the direction of flow between the stream and ground water. Also, an attempt was made to determine the vertical component of ground-water flow.

Study Results

Streamflow generally increased through wetland 3 during the two water years (1986-87) when data were collected at both gaging stations (figs. 19 and 20). During October through December 1987, there was a slight decrease in streamflow through the wetland. During part of this period, streamflows were estimated because of ice cover at the gaging stations. Streamflow generally increased through the wetland the remainder of the 1987 water year, and there was a gain in streamflow for the entire water year. In July 1986, streamflow measurements were made upstream and downstream from the wetland at the streamflow-gaging stations and at two valley side-slope flows. The measured upstream streamflow, 87 ft^3/s, was combined with the measured side-slope flows, 3.4 and 0.03 ft^3/s, and compared to the measured downstream streamflow, 100 ft^3/s. For the July measurement, a 10-percent increase in streamflow through the wetland could not be accounted for by measured surface-water flows. The increase in streamflow probably was from overland flow and ground-water contribution.

Overbank flooding occurred at the two crest-stage gages. The upstream crest-stage gage, 3CSG1, (fig. 4) is located 25 ft upstream from a beaver dam. During June 1985, backwater from the dam caused overbank flooding. The downstream crest-stage gage, 3CSG2, is located in a section where substantial erosion occurred around the crest-stage gage. Measurements between years cannot be compared. Overbank flooding did occur near crest-stage gage 3CSG1 during peak streamflows in 1986 and lasted from as little as a few hours to as much as 5 days. The exact time and duration that overbank flooding occurred cannot be determined with the available data. The gage height was first exceeded on June 15. The stream was within its banks on June 20, 1986, when measurements were made. The stream had to be at a greater gage height and

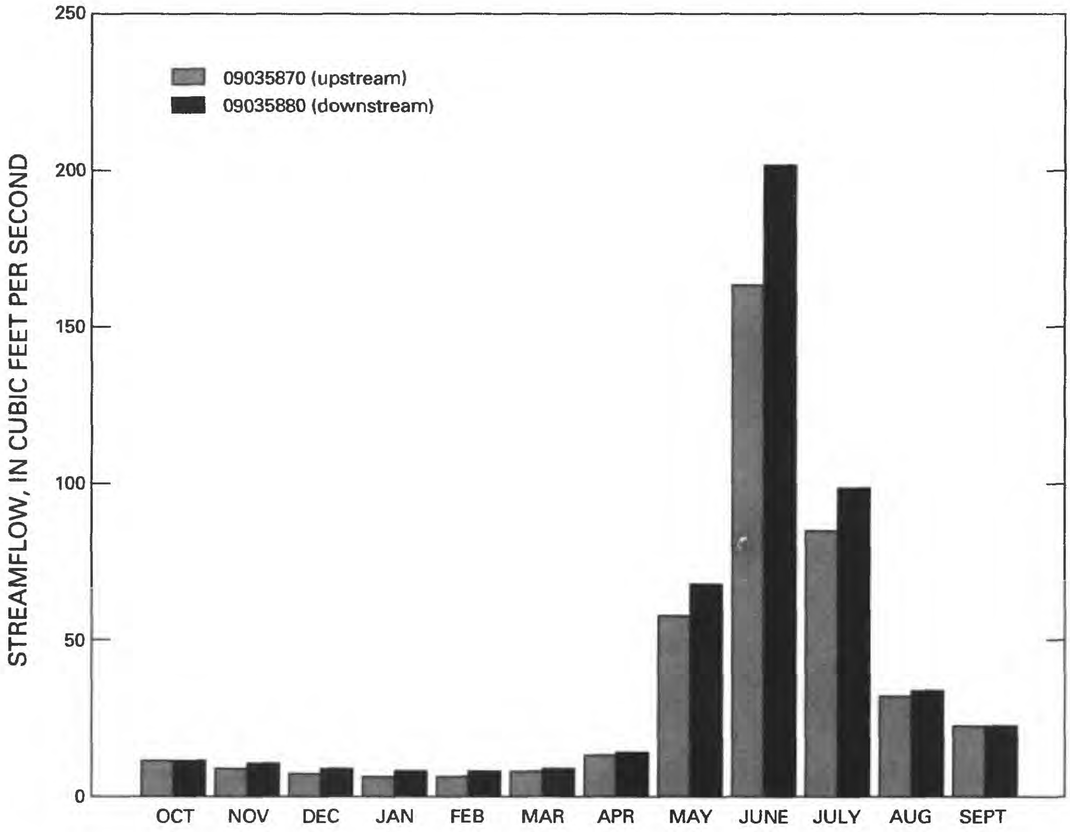

Figure 19.--Mean monthly streamflow at streamflow-gaging stations 09035870, South Fork Williams Fork below Short Creek near Ptarmigan Pass, and 09035880, South Fork Williams Fork below Old Baldy Mountain, near Leal, water year 1986.

streamflow than was measured on June 20 in order to flood the area. Evidence of flooding--standing water, matted grass, and deposited materials--was observed during June 1986. Overbank flooding also occurred at the downstream end of wetland 3, approximately 50 ft upstream from cross section B, where beavers constructed a new dam. There was no crest stage gage at this site to record the maximum gage height. In areas where flooding occurred, the streambanks were less than 2 ft high and gently sloping. The rest of the stream channel is characterized by steep banks, 2 to 3 ft high; overbank flooding is unlikely, and there was no physical evidence of flooding after peak streamflows.

To determine stream stages for times when stream-stage data were not collected, equations were developed that estimated stream stage at cross sections A and B by using streamflow at streamflow-gaging station 09036880. The natural logarithms of stream stage at the two cross sections were related to the natural logarithms of streamflow by using ordinary least-squares

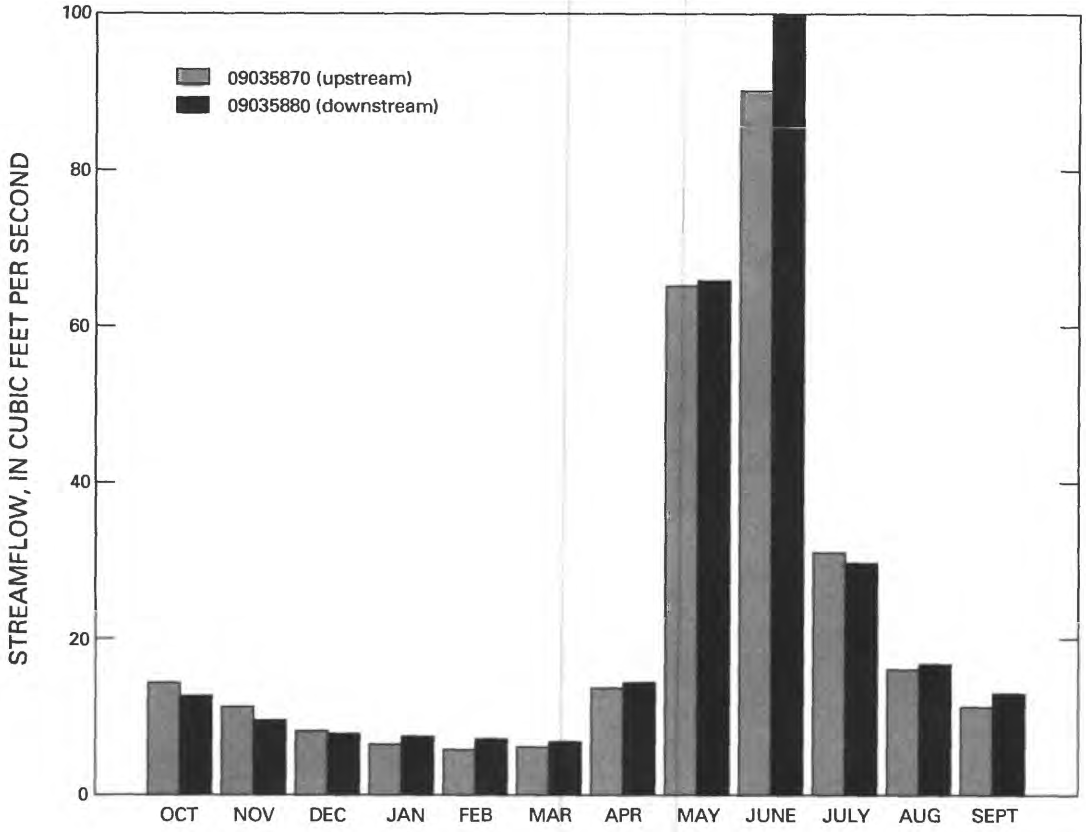

Figure 20.--Mean monthly streamflow at streamflow-gaging stations 09035870, South Fork Williams Fork below Short Creek near Ptarmigan Pass, and 09035880, South Fork Williams Fork below Old Baldy Mountain, near Leal, water year 1987.

regression (SAS Institute, Inc., 1985). A bias correction factor (Miller, 1984) was included in the detransformed equation. The elevation at 0.00 ft on the staff gage also was included in the equation so that the calculated stage was in feet above NGVD of 1929. The equation coefficients and various summary statistics are listed in table 8. The minimum and maximum streamflows used in the analyses also are included in the table to indicate the range of applicability. The water level in well 3AE1 was lower than the stream stage except during low streamflow in early May and late September. The exact duration that the ground-water level in well 3AE1 remained lower than the stream cannot be determined because the continuous recorder operated only from May through September. Well 3AE1 was the only well in the valley with a continuous recorder where water levels were sometimes lower than the stream stage. Miscellaneous ground-water measurements at well 3AE2 also indicated that the water level was sometimes lower than the stream stage.

In 1988, a hydraulic potentiomanometer was used in the vicinity of well 3AE1 to collect additional comprehensive data about ground-water gradients in order to determine flow direction between the stream and the wetland. The hydraulic potentiomanometer measurements were taken in a cross section approximately parallel to the stream across the meander lobe because upon visual inspection of the topography, it was suspected that the water flowed parallel to the stream across the meander lobe.

Table 8.--*Equation coefficients and various summary statistics for regression relations at wetland 3, cross sections A and B*

[Stream stage=(a*Q**b)+elevation correction; a and b, regression coefficients; Q, streamflow at gaging station 09035880]

Cross section	a	b	Elevation correction	Number of measurements	Correlation coefficient	Standard error (percent)	Minimum streamflow	Maximum streamflow
3A	0.0633	0.7066	9,325.16	11	0.97	17.7	9.14	224
3B	.7964	.2370	9,320.19	11	.98	4.3	9.14	224

The east side of the valley at cross section A is physiographically different from the other wetlands. This wetland is located in a meander lobe occupying about 0.22 acre. The wetland is confined on the east side by a steep, dry talus slope and is almost totally encompassed by the stream meander on the remaining sides. The wetland is underlain by the old stream channel, parts of which are still evident along the east side of the wetland. There also are potholes throughout the wetland that occur predominantly adjacent to the talus slope. During the June 1988 site visits, the potholes contained water. Water levels in one pothole, about 5 ft from the streambank, surged in conjunction with the snowmelt surges in the stream, indicating a substantial hydraulic connection. In September 1988, water movement towards the stream was observed in two potholes in the vicinity of potentiomanometer measurement site PE7.

The difference in hydraulic head between the stream and ground water in the wetland was measured four times during 1988. The measurements were made at different stream stages, prior to peak streamflow in early June, during peak streamflow in mid June, during decreasing streamflow in late July, and during low streamflow in late September. The September data were affected by a newly constructed beaver dam, which ponded the stream and raised the stream stage; the stream stage was not representative of a normal low-flow condition. Measurements were made at different stream stages to indicate if flow direction changed with changes in stream stage. Because low-flow conditions were affected by beaver activity, the hydraulic head relation between the stream and ground water in the wetland could not be determined.

The differences in hydraulic head indicated that the water flow was from the stream to the wetland at the upstream end of the meander lobe, through the wetland, and from the wetland to the stream at the downstream end of the meander lobe (figs. 21-24). The generalized flow direction was almost directly across the meander lobe. The largest gradients from the stream toward the wetland occurred in June, during high streamflow, and in September, when the stream stage was increased by a new beaver dam. Because of this beaver dam, the stream and ground-water levels in 1988 were higher than what would normally occur in September. The ground-water flow was across the meander lobe, but it flowed towards the stream farther upstream because of the abrupt change in stream stage caused by the beaver dam (fig. 24). The calculated gradients used in figures 21-24 are listed in table 9. It should be noted that there was as much as ±0.25 ft in the ground-surface definition that could affect the calculated gradients and the direction of ground-water flow. This estimated inaccuracy was due to the variation in land surface near surveyed locations. The potentiomanometer was used in the vicinity of the surveyed locations and was not inserted into the same hole each visit. The inaccuracy possibly could result in recording a change in the flow direction between two specific points but would not affect the generalized direction of flow.

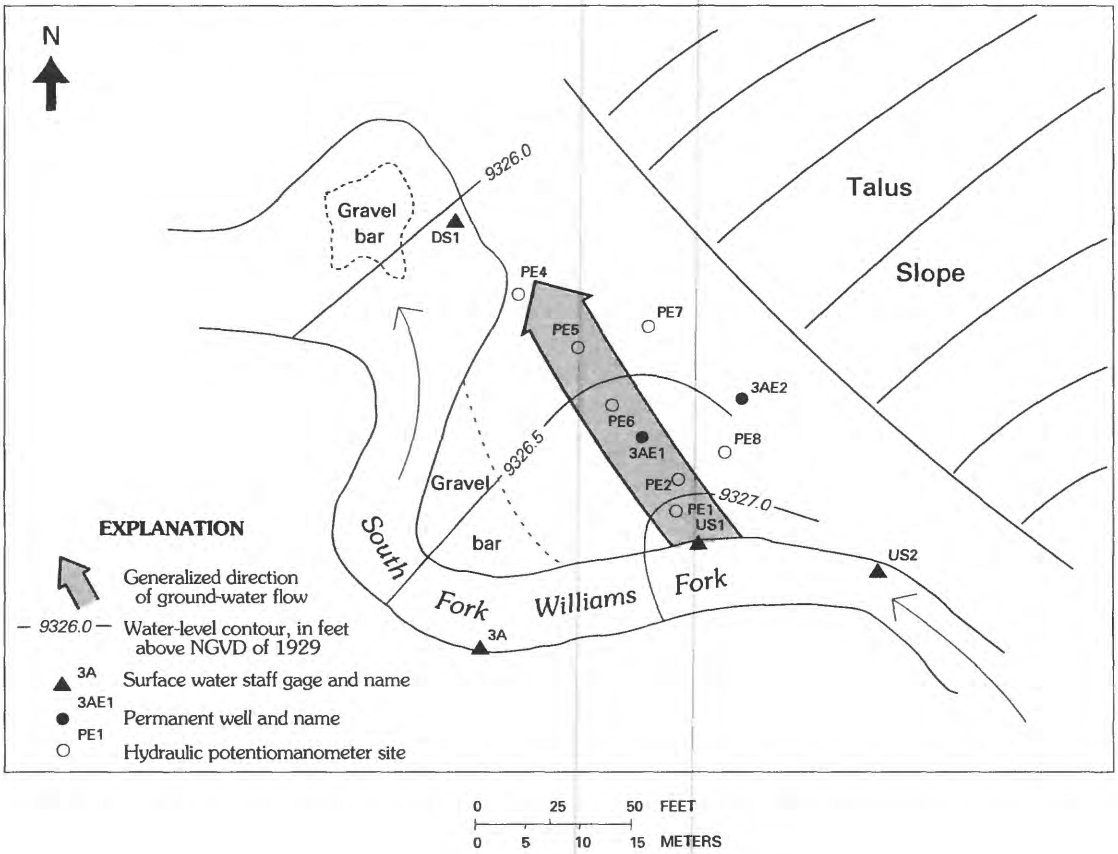

Figure 21.--Potentiometric surface and generalized direction of ground-water flow at wetland 3, cross section A, June 1-2, 1988 (modified from Ruddy, 1989).

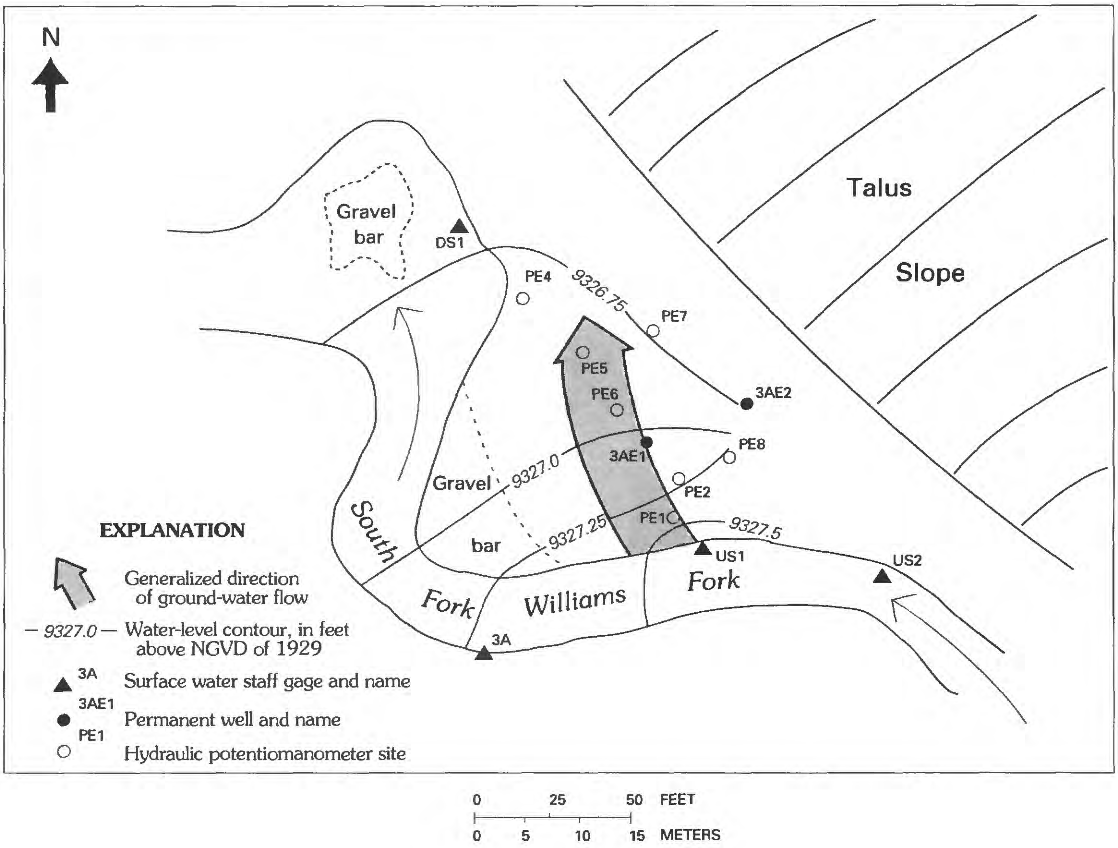

Figure 22.--Potentiometric surface and generalized direction of ground-water flow at wetland 3, cross section A, June 13-14, 1988 (modified from Ruddy, 1989).

Hydraulic potentiomanometer measurements were obtained at multiple depths in one vertical where possible. These measurements were made to determine vertical ground-water movement. Multiple-depth measurements were attempted at all sites, but readings were obtained only at PE2, PE4, PE5, and PE7. Six of the nine measurements indicated that the direction of water movement was downward through the wetland to the underlying ground-water system. At PE4, the June 13-14 measurement did not indicate water movement in either direction. At PE7, the July measurement indicated upward water movement, which may indicate that water is moving from the underlying ground-water system into the wetland. However, the magnitude of the head difference was insignificant. At PE2, the September reading indicated upward vertical movement, but the data from the two depths were taken from two holes. There also are slight discrepancies in the water levels measured at PAE1 and 3AE1 during the June 13-14 and September 27 measurements. The discrepancies probably are due to the difference in elevation between the probe depth and the screened length of the well (3.5-5.5 ft below ground surface).

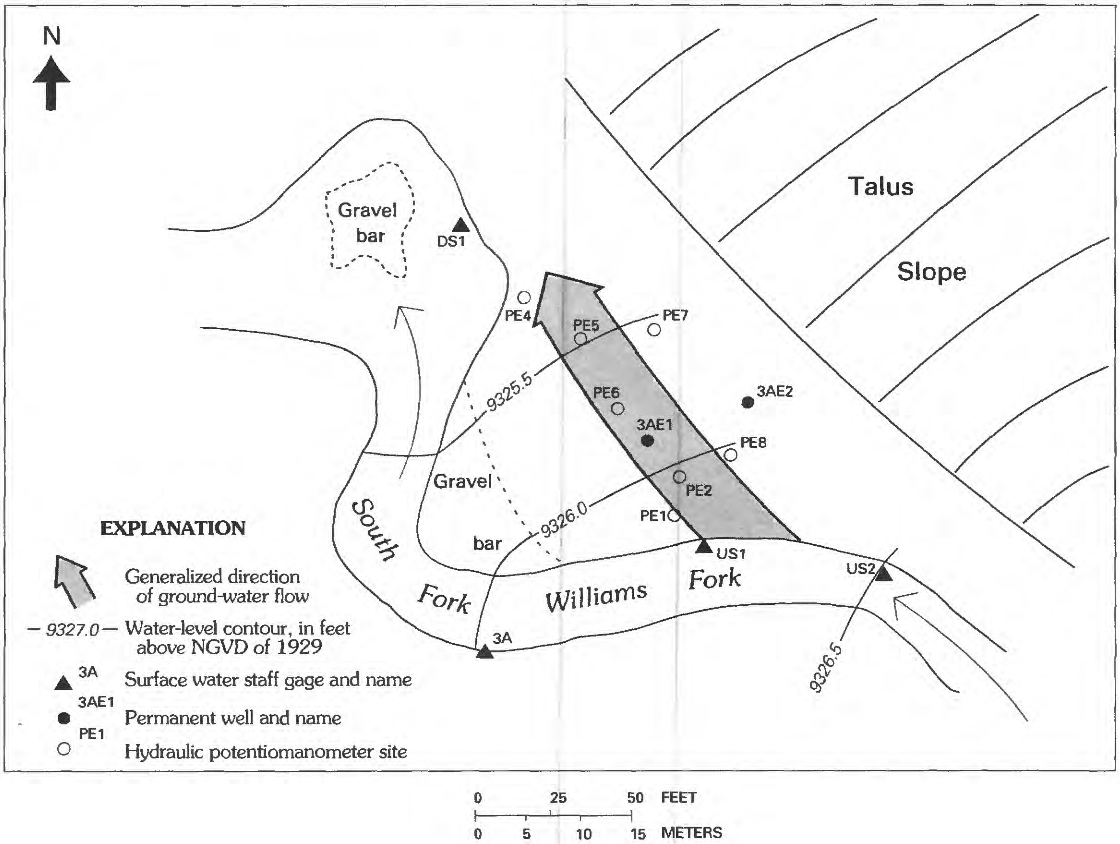

Figure 23.--Potentiometric surface and generalized direction of ground-water flow at wetland 3, cross section A, July 18-19, 1988 (modified from Ruddy, 1989).

The water levels measured at all wells with continuous recorders at wetland 3 were similar to the stage changes measured at streamflow-gaging station 09035880 during 1987-88 (figs. 25 and 26). The small peaks in streamflow related to summer storms (National Climatic Data Center, 1987 and 1988) were more variable in the ground-water levels because the ground-water levels were affected by direct precipitation and soil porosity. At cross section A, there were increases in ground-water levels (3AE1 and 3AW1) and stream stage in September of 1987 and 1988 because beaver dams were constructed downstream from the cross section. The 1987 dam was washed out during 1988 spring flows. Water levels in well 3BE1 were dissimilar to the water levels in the other wells and to the stream stage measured at the streamflow-gaging station. The water levels in well 3BE1 were affected by flooding from an upstream beaver dam during higher streamflows in June. Streamflow was diverted to the east side of the valley floor and bypassed the beaver dam flooding the area around 3BE1. The summer peaks in water levels were most variable in well 3BE1.

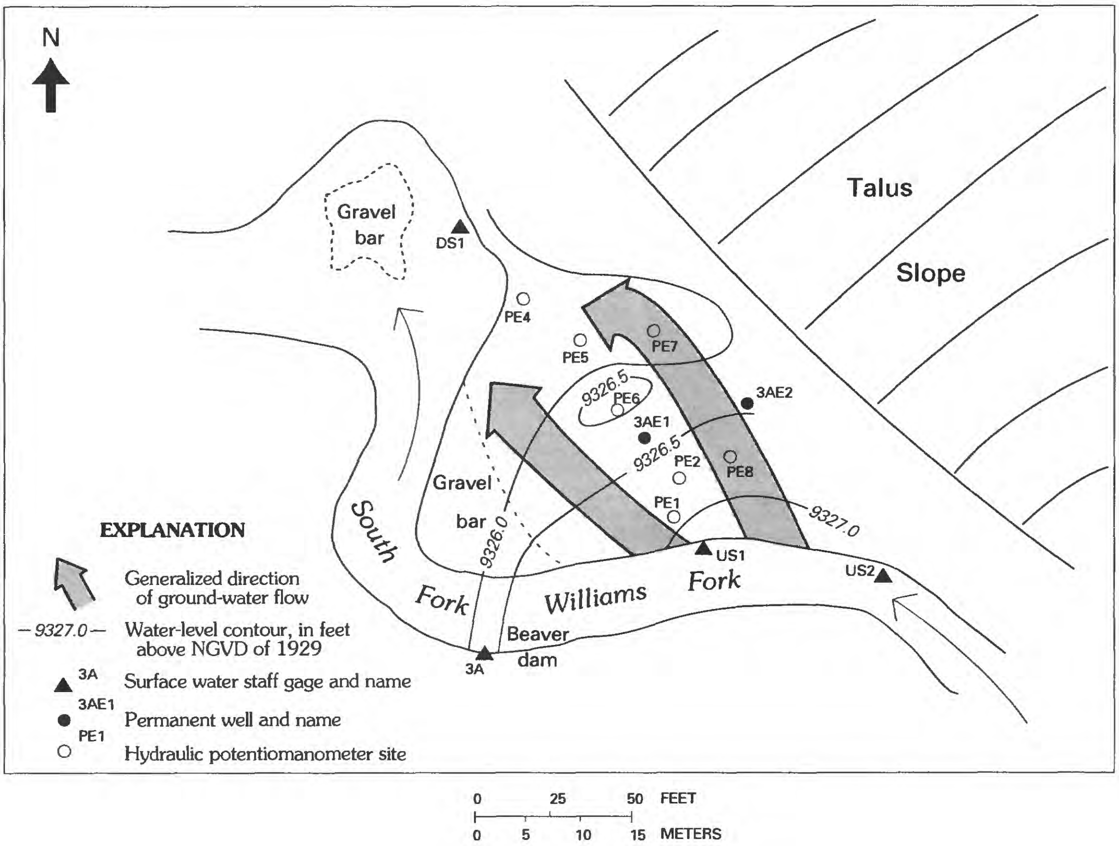

Figure 24.--Potentiometric surface and generalized direction of ground-water flow at wetland 3, cross section A, September 27, 1988 (modified from Ruddy, 1989).

The direction of surface- and ground-water flow can be changed by construction and destruction of beaver dams. Beaver-dam construction can pool streamflow and raise nearby ground-water levels. As stated previously, ground-water levels at cross section 3B on the east side were affected by flooding from an upstream beaver dam. Although the ground-water level changes were similar to the stream stage changes along the east side of cross section B, the flooding from the upstream beaver dam had a greater affect. Beavers constructed dams immediately downstream from cross section A during September 1987 and September 1988, and stream stage and ground-water levels at the cross section had corresponding rises (figs. 25 and 26). Beaver-dam destruction can relocate streamflow, lower stream stage, and lower nearby ground-water levels. At cross section 3U, a beaver dam was breached sometime between the July and August measurements in 1986. The stream stage decreased, and the water levels measured in August and October 1986 at wells 3UE1, 3UE2, 3UW1, and 3UW2 were lower than any previous measurement. The stream had been nearly bankfull until August 1986. After the beaver dam was breached, the stream stage decreased substantially.

Table 9.--*Hydraulic potentiomanometer and water-level data collected at wetland 3, cross section A, 1988*

[Values are elevation in feet above NGVD of 1929; --, no data]

Site name[1]	Ground surface	June 1-2		June 13-14		July 18-19		September 27	
		Probe level	Water level	Probe level	Water level	Probe level	Water level	Probe level	Water level
PE1	9,327.88	9,325.73	9,327.14	9,324.43	9,327.36	9,323.88	9,326.24	9,324.08	9,326.73
PE2	9,328.57	9,324.12	9,326.83	9,225.57	9,327.31	9,325.42	9,326.20	9,326.36	9,326.44
PE2	9,328.57	--	--	9,324.32	9,327.22	9,324.37	9,326.08	9,325.43	9,326.79
PAE1[2]	9,327.71	9,324.06	9,326.82	9,325.56	9,327.11	--	--	9 322.91	9 325.97
PE4	9,327.14	9,325.79	9,326.19	9,325.69	9,326.88	9,324.69	9,325.30	9,323.64	9,325.93
PE4	9,327.14	9,325.09	9,326.06	9,324.99	9,326.88	9,323.49	9,325.02	--	--
PE5	9,328.17	--	9,326.34	9,326.22	9,326.91	--	--	9,324.47	9,325.47
PE5	9,328.17	--	--	9,324.72	9,326.90	--	--	--	--
PE6	9,327.04	9,324.59	9,326.58	9,324.59	9,326.81	9,324.69	9,325.78	9,324.29	9,326.93
PE7	9,326.61	--	--	9,323.36	9,326.72	9,324.26	9,325.53	9,324.18	9,325.54
PE7	9,326.61	--	--	--	--	9,323.16	9,325.60	9,323.25	9,325.51
PE8	9,327.91	--	--	9,325.61	9,327.27	9,325.56	9,326.05	9,325.70	9,326.95
3AE1	9,327.71	--	--	--	9,327.04	--	9,325.54	--	9,326.46
3AE2	9,328.00	--	9,326.30	--	9,326.57	--	9,325.89	--	9,326.17
US1	--	--	9,327.17	--	9,327.61	--	9,326.41	--	9,327.15
US2	--	--	--	--	--	--	9,326.51	--	9,327.18
DS1	--	--	9,326.08	--	9,326.69	--	9,325.15	--	9,325.80
3A	--	--	9,326.84	--	9,327.30	--	9,326.05	--	9,326.04

[1]Location identified in figure 21.
[2]Potentiomanometer site located next to well 3AE1.

Surface-water quality varied minimally through wetland 3. Dissolved-iron concentrations increased slightly in a downstream direction (table 10). This increase in dissolved-iron concentrations may be evidence of ground-water inflow to the stream. However, no significant water-quality trends were observed as indicated by specific-conductance measurements (figs. 27 and 28). The dissolved-iron concentrations in the ground water generally were 1 to 2 orders of magnitude greater than dissolved-iron concentrations in the stream, except at two wells. The dissolved-iron concentrations measured in wells 3UW1 and 3BW1 generally were more similar to concentrations in the stream than concentrations measured at the other wells. Both of these wells were located within 20 ft of the stream channel and may be affected by the stream. However, the ground-water gradient was always toward the stream. In June 1986, the two small concentrations of dissolved iron measured at wells 3AE1 and 3BE2 probably were a result of snowmelt effects. In 1988, specific conductance was measured at the points where the hydraulic potentiomanometer measurements were taken. Specific-conductance values measured in the wetland were similar to the values measured in the stream except at PAE1 and PE7 (table 11). PAE1 and PE7 were located at topographic lows, which probably caused water to drain towards them. The water sampled at PAE1 and PE7 would have been in contact with the soil longer, allowing more mineral dissolution and larger specific-conductance values.

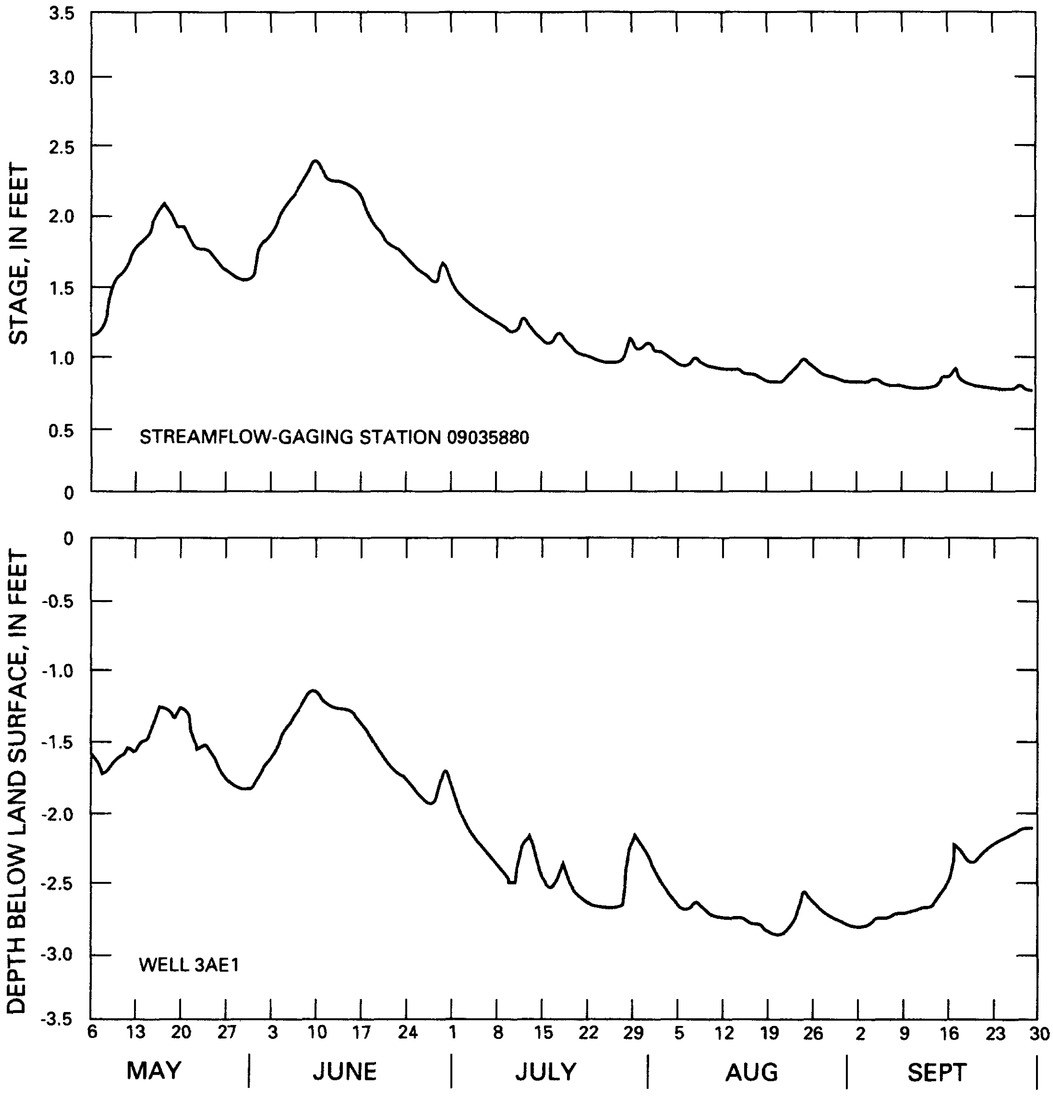

Figure 25.--Stream stage and ground-water levels at wetland 3, May through September 1987.

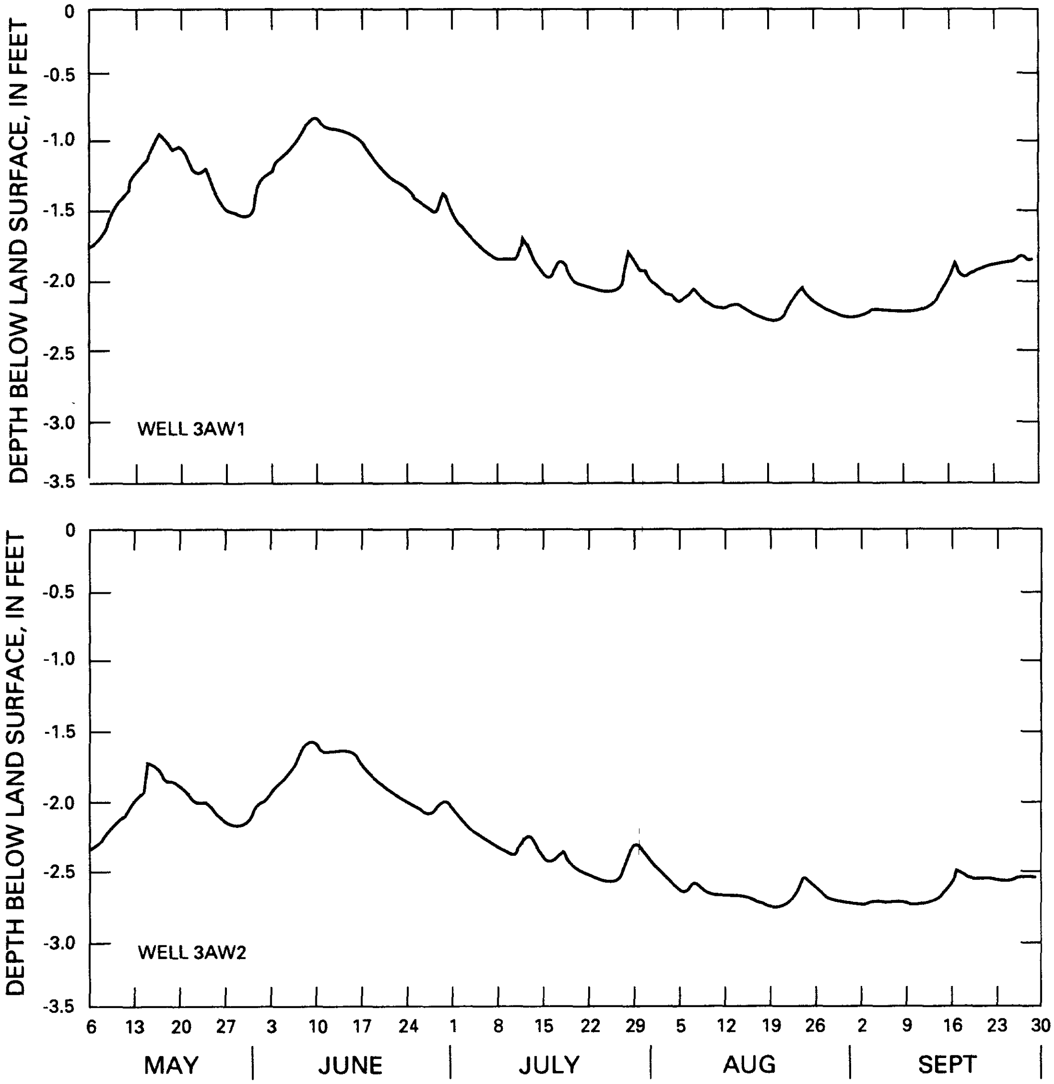

Figure 25.--Stream stage and ground-water levels at wetland 3, May through September 1987--Continued.

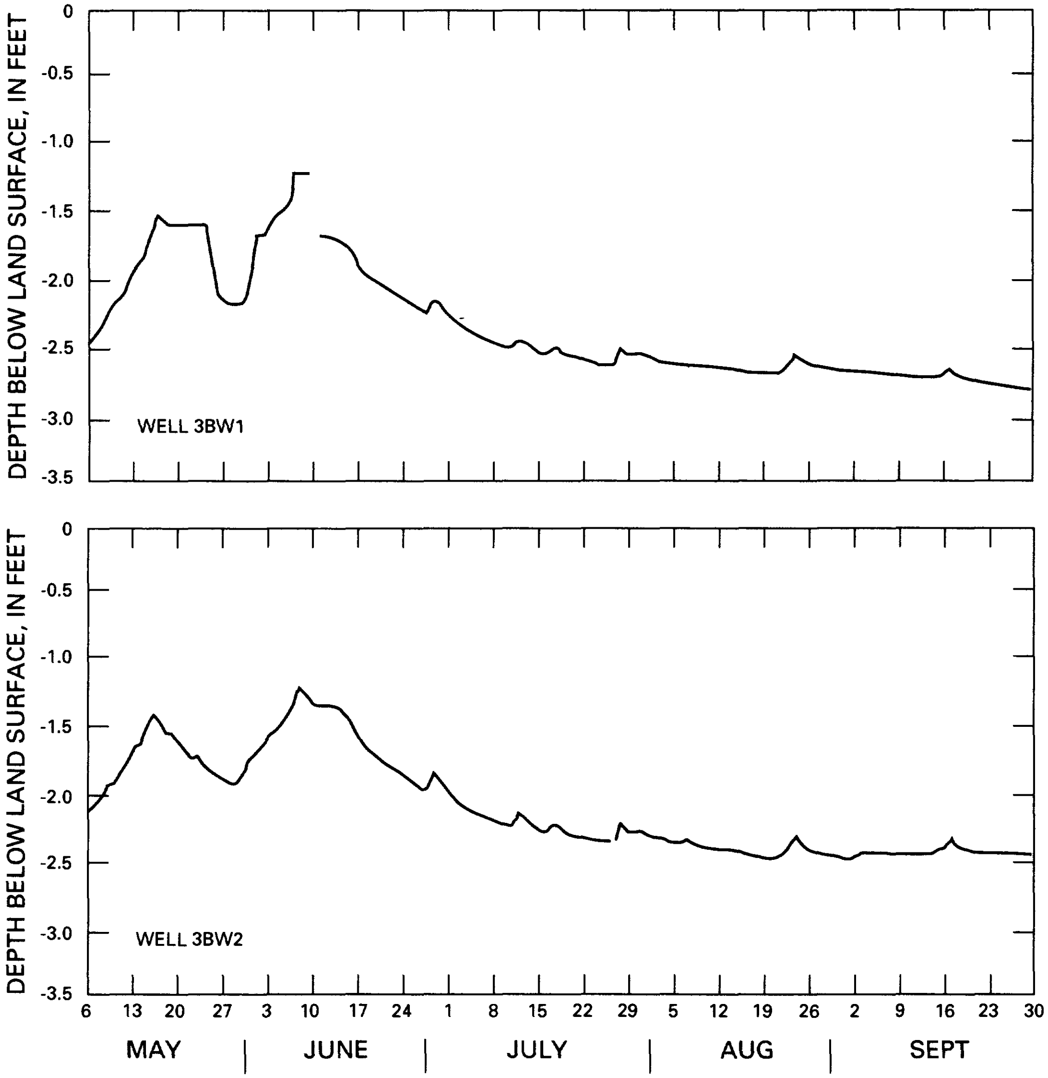

Figure 25.--Stream stage and ground-water levels at wetland 3, May through September 1987--Continued.

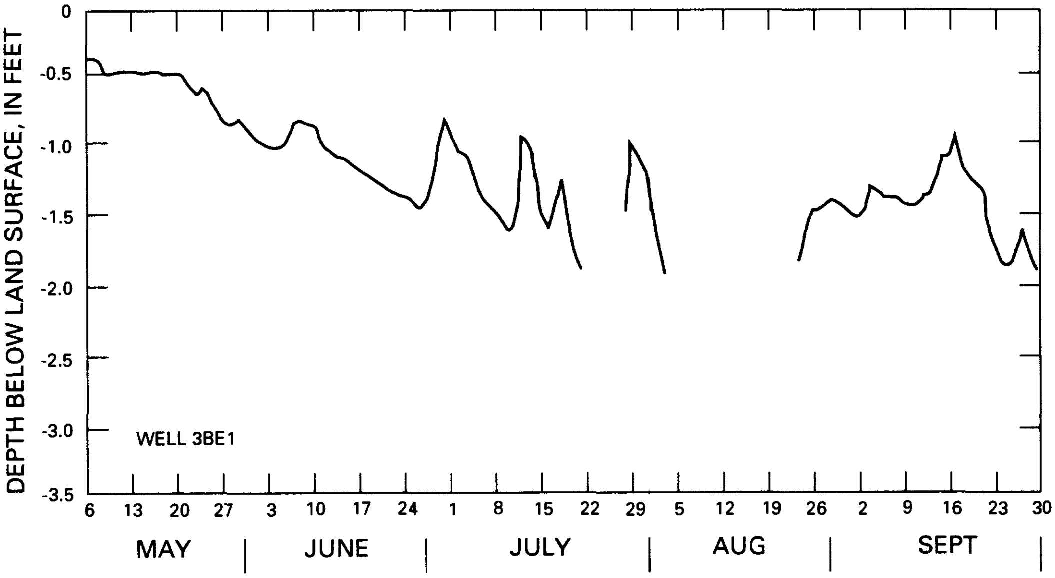

Figure 25.--Stream stage and ground-water levels at wetland 3, May through September 1987--Continued.

Table 10.--*Dissolved-iron-concentration data collected at wetland 3, water years 1985-86*

[Values in micrograms per liter; streamflow-gaging station 09035870, South Fork Williams Fork below Short Creek near Ptarmigan Pass; streamflow-gaging station 09035880, South Fork Williams Fork below Old Baldy Mountain, near Leal; --, no data; <, less than]

Date	09035870	Well 3UW1	Well 3UE2	Well 3AW1	Well 3AW2	Well 3AW3	Well 3AE1	Well 3BW1	Well 3BE2	09035880
11-01-84	25	54	--	--	--	--	--	--	--	--
04-30-85	54	54	--	--	--	--	--	--	--	--
06-04-85	25	81	--	--	--	--	--	--	--	--
08-13-85	24	24	--	--	--	--	--	--	--	--
10-18-85	25	33	210	--	--	--	--	--	--	44
03-25-86	--	95	540	5,500	700	--	7,000	68	5,100	51
06-05-86	54	23	120	2,300	740	3,400	4	90	<3	59
07-11-86	21	40	59	4,700	810	--	6,900	220	3,000	26
08-25-86	23	16	--	6,700	--	--	--	25	680	37

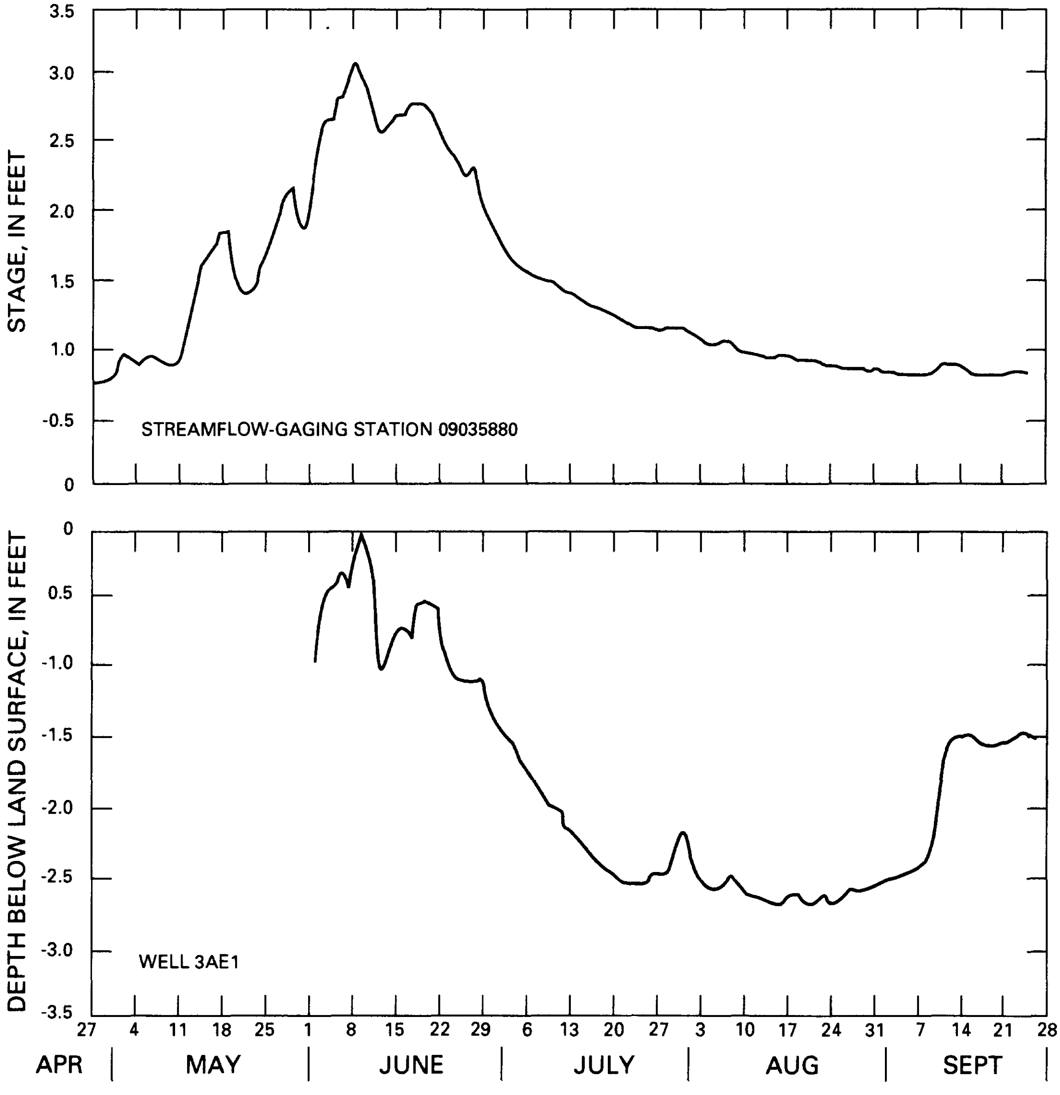

Figure 26.--Stream stage and ground-water levels at wetland 3, May through September 1988.

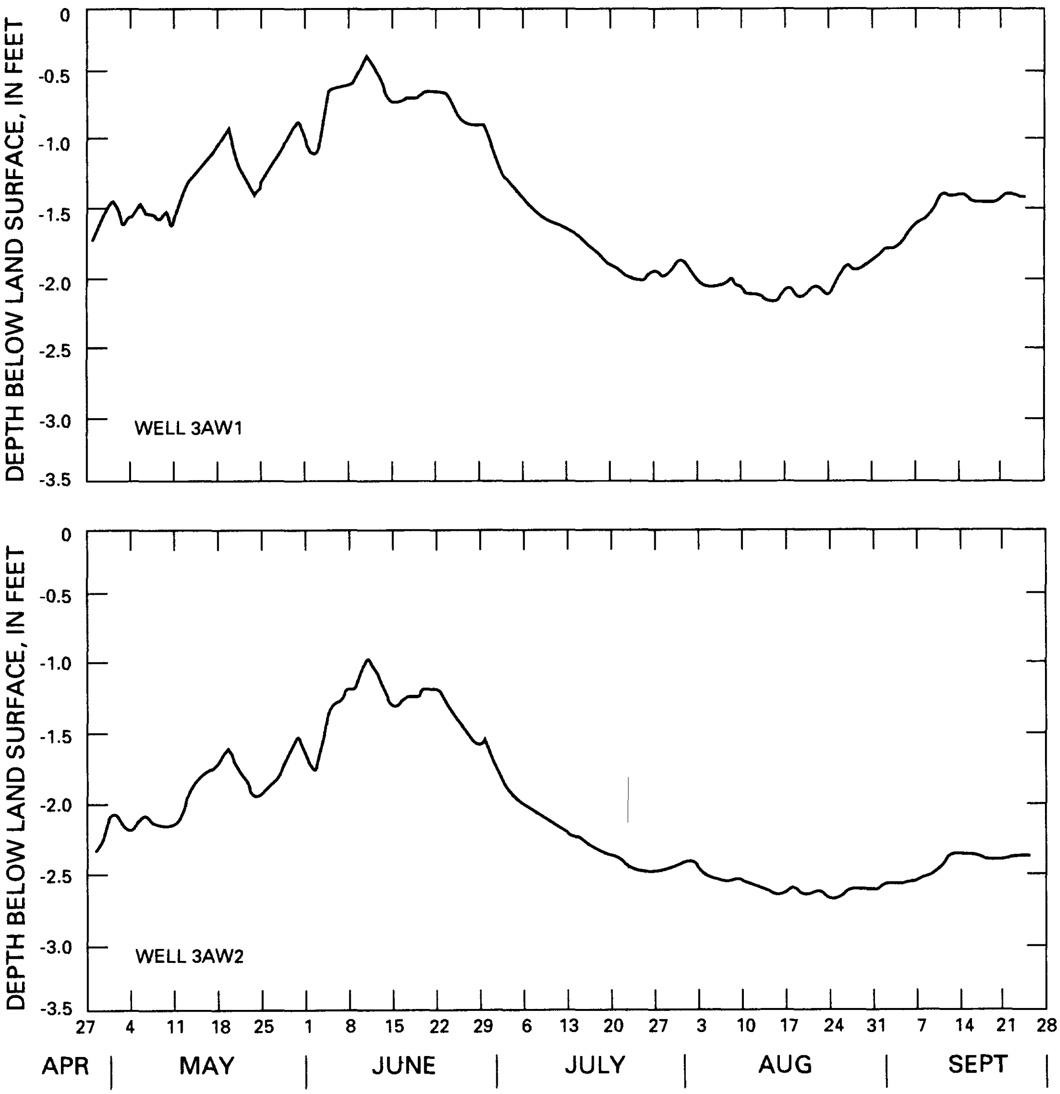

Figure 26.--Stream stage and ground-water levels at wetland 3, May through September 1988--Continued.

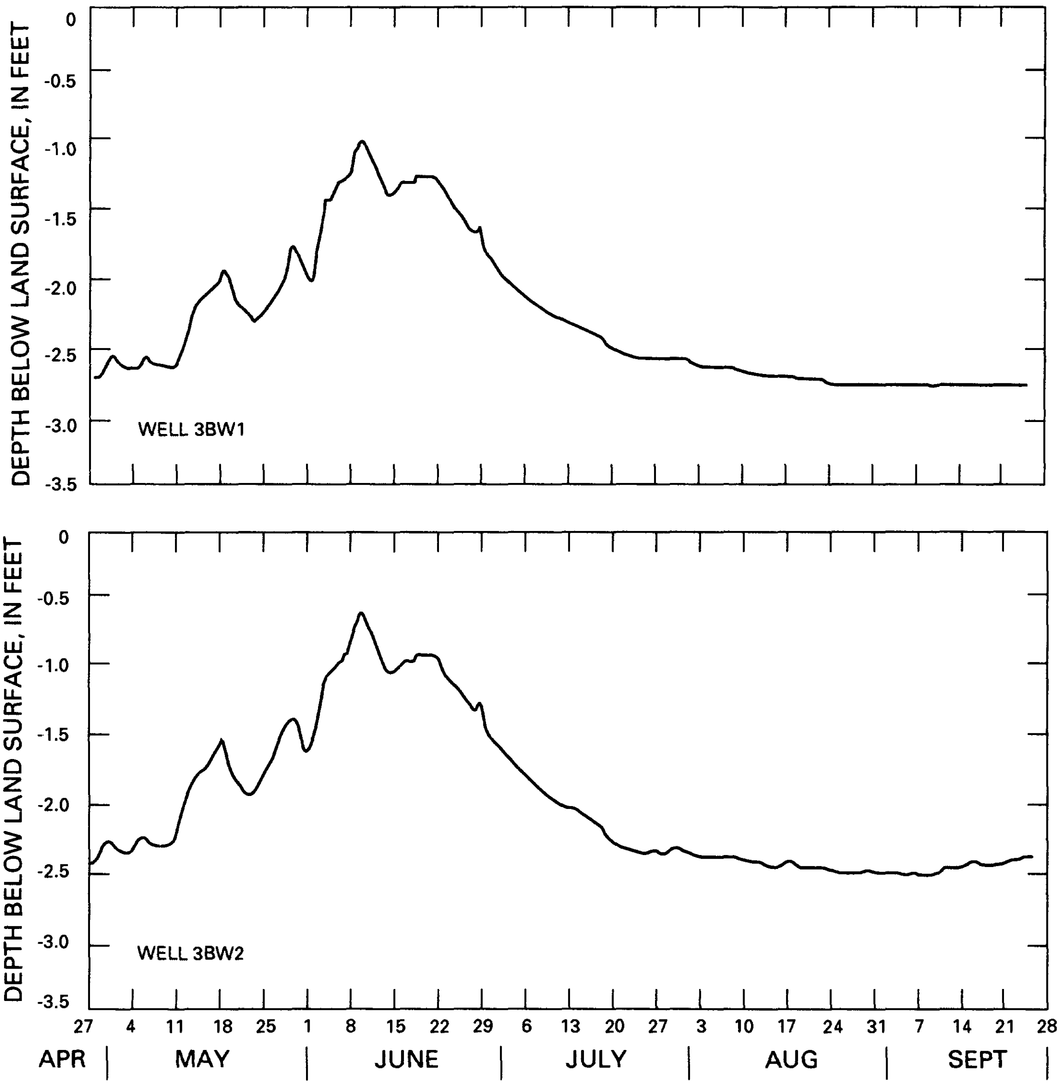

Figure 26.--Stream stage and ground-water levels at wetland 3, May through September 1988--Continued.

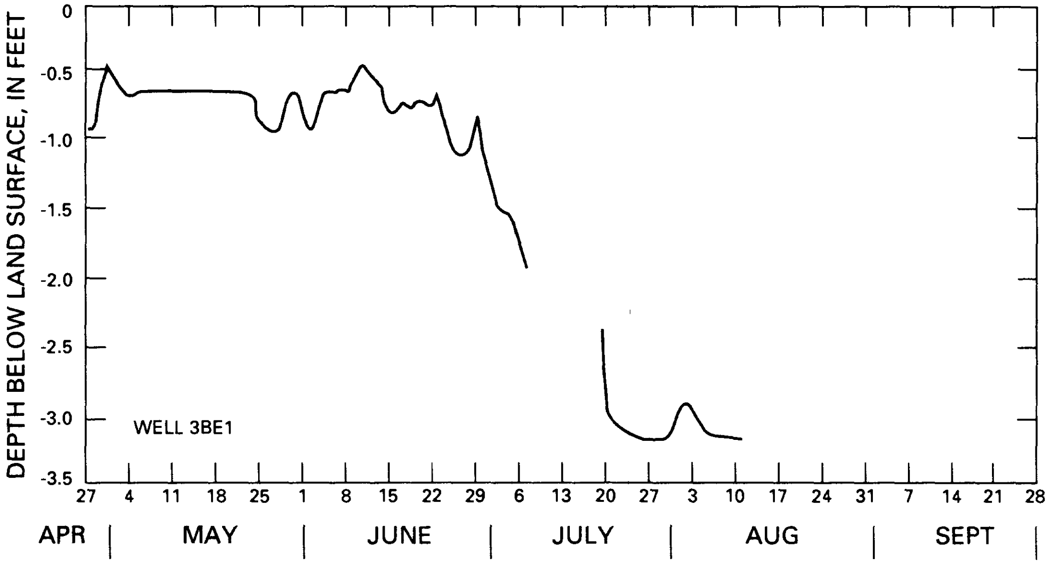

Figure 26.--Stream stage and ground-water levels at wetland 3, May through September 1988--Continued.

Table 11.--*Specific-conductance data collected with the hydraulic potentiomanometer at wetland 3, cross section A, 1988*

[Values in microsiemens per centimeter at 25 degrees Celsius; --, no data]

Site name	Date			
	June 1-2	June 13-14	July 18-19	September 27
PE1	80	79	83	84
PE2	78	69	59	[1]84, 59
PAE1	165	79	--	114
PE4	87	28	61	75
PE5	90	52	--	71
PE6	--	--	54	64
PE7	--	329	--	257
PE8	--	39	--	73
Stream	56	42	59	84

[1]The specific conductance of 84 was from a sample at 2.21 feet; the specific conductance of 59 was from a sample at 3.14 feet.

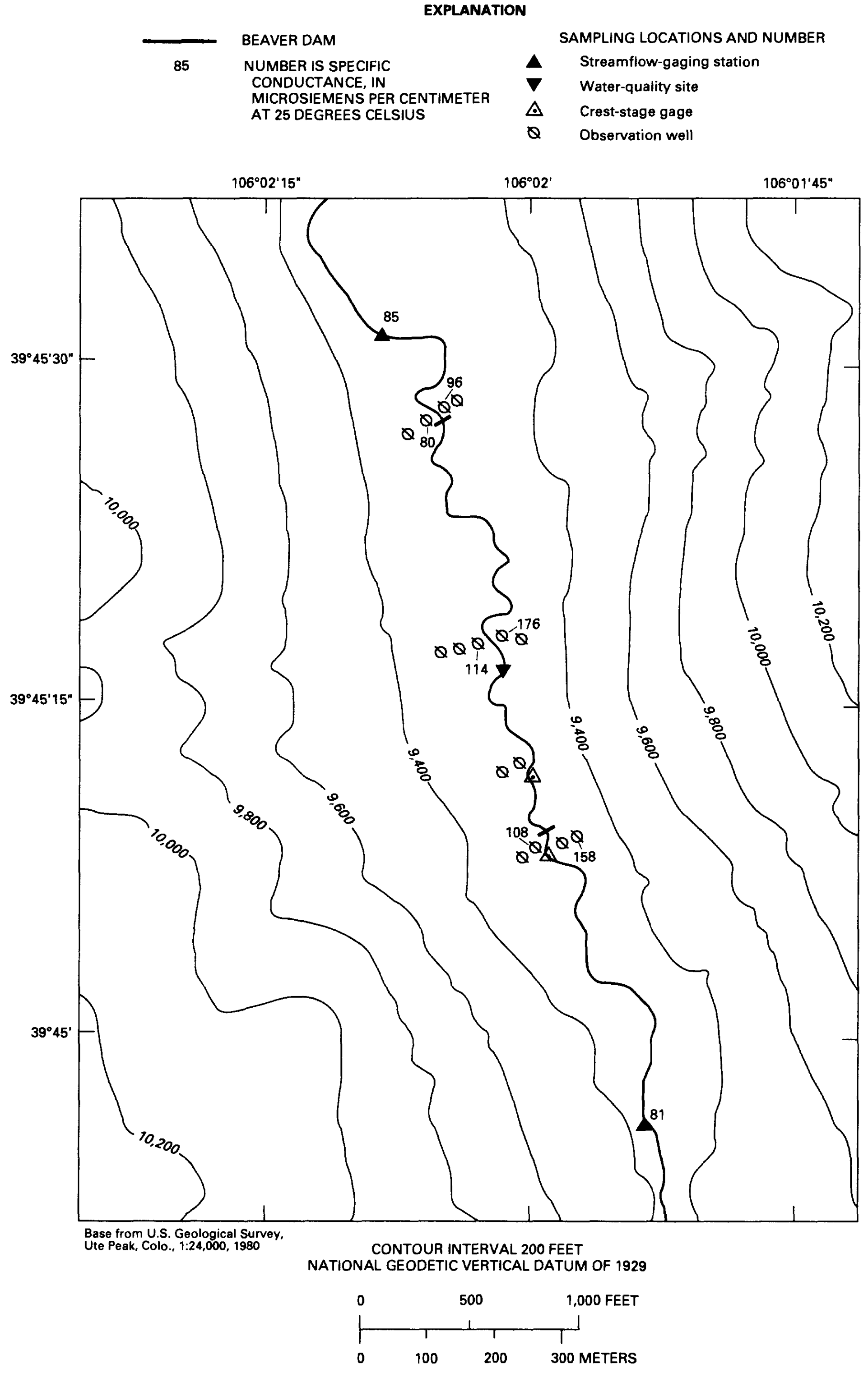

Figure 27.--Onsite specific-conductance data at wetland 3, March 25, 1986.

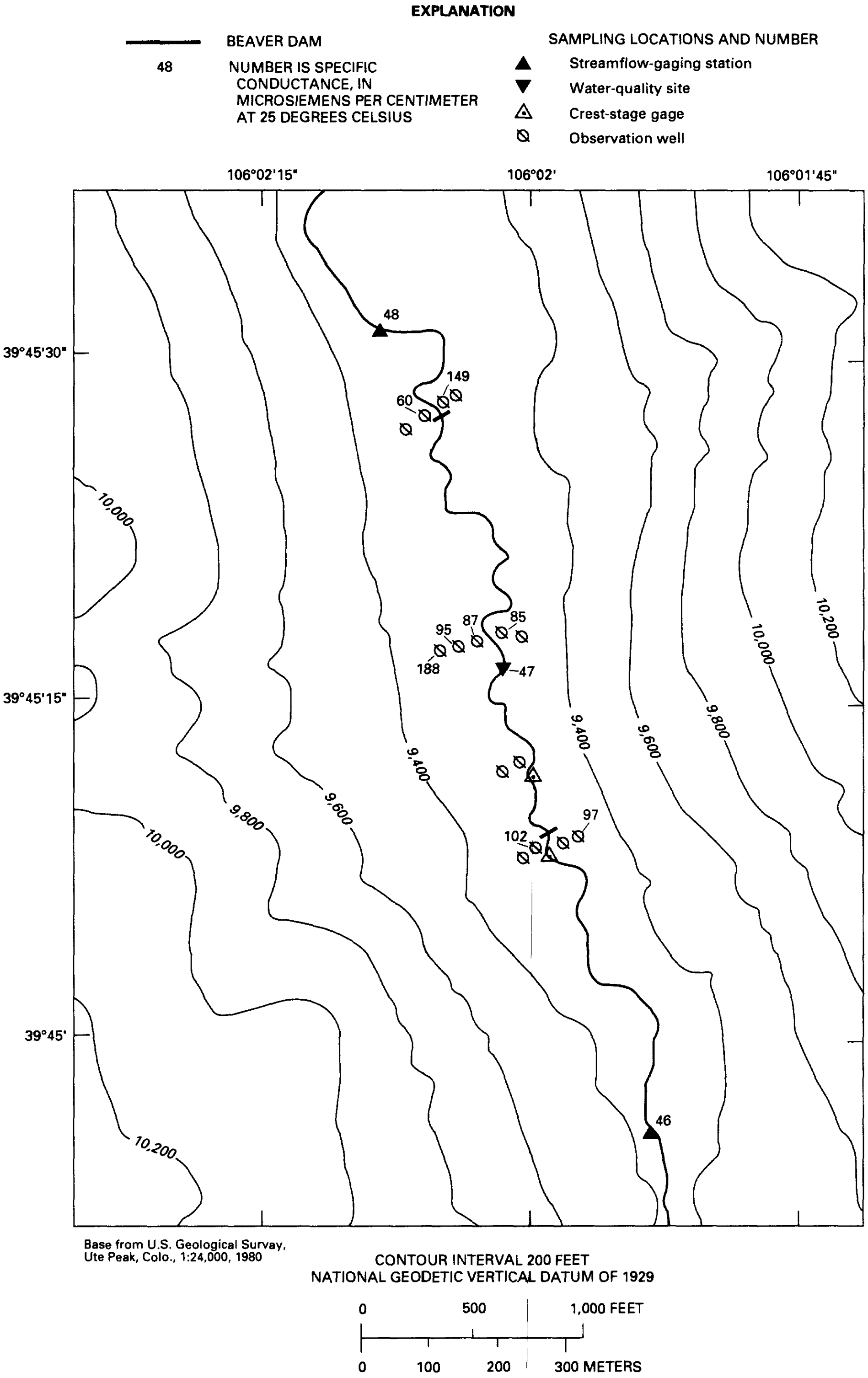

Figure 28.--Onsite specific-conductance data at wetland 3, June 5, 1986.

Throughout wetland 3, water generally flows from the wetland toward the stream. The ground-water levels always sloped toward the stream except at cross section A on the east side. Additional investigation at this site indicated that water moved through the wetland--from the stream to the wetland at the upstream end of the meander lobe and from the wetland to the stream at the downstream end. This situation was unique within the study area but could occur in other wetlands. Although there are some areas within wetland 3 where the stream and ground water are hydrologically connected, the ground-water levels are above the stream stage (except in wells 3AE1 and 3AE2). Most of the recharge to the wetland is from precipitation, snowmelt, valley side-slope flow, and ground-water inflow. Most of wetland 3 should not be affected by decreases in stream stage resulting from diverting water from the South Fork Williams Fork.

Wetland 4

This wetland, which is on the north side of the Williams Fork, is much higher in elevation than the stream and contains a large beaver pond. From the base of the beaver dam, the land surface slopes steeply down to the stream channel. The north slope has a dense growth of willows. On the south side of the stream, the valley side slopes steeply to the stream channel and the vegetation is comprised of coniferous forest. A crest-stage gage and four wells were installed at wetland 4 (fig. 5). The observation wells on the south side of the stream were dry most of the year (table 12). No overbank flooding of the wetland was measured. Monitoring of this wetland was discontinued after 1 year because the Williams Fork probably does not flood the adjacent wetland and because decreases in stream stage would have little or no effect on the wetland. The sources of recharge to wetland 4 probably are the same as at the other wetland sites studied on the South Fork Williams Fork: precipitation, snowmelt, valley side-slope flow, and ground-water inflow.

Table 12.--*Water levels in wells at wetland 4*

Date	Depth below land surface, in feet			
	Well 4N1	Well 4N2	Well 4S1	Well 4S2
10-30-84	0.03	0.04	Dry	Dry
12-04-84	Frozen	Frozen	Frozen	Frozen
04-30-85	.11	.02	Dry	Dry
07-16-85	.57	.28	1.48	Dry
10-10-85	.67	.30	1.08	Dry

SUMMARY AND CONCLUSIONS

The U.S. Geological Survey and the Denver Water Department cooperated in a study to evaluate the hydrologic relations between the South Fork Williams Fork and adjacent subalpine wetlands and to evaluate the potential effects that changes in stream stage resulting from diverting streamflow will have on the hydrology of the wetlands. Four wetlands were studied. Streamflow was expected to be a major source of water to two of the wetlands; however, precipitation, snowmelt, valley side-slope flow (including overland and small-channel flow), and ground-water inflow were determined to be the major factors affecting wetland hydrology and the major source of water at all four wetlands. In addition, beaver activity affected water movement in the wetlands.

The hydrologic relations in wetlands 1, 2, and 4 were similar. Streamflow is not a substantial source of water to wetlands 1 and 4. Streamflow measurements, ground-water-level measurements, and water-chemistry analyses indicate that ground-water flow was from the wetlands to the stream. The sources of water to the wetlands are precipitation, snowmelt, valley side-slope flow, and ground-water inflow. Overbank flooding did not occur at wetlands 1 and 4. A similar streamflow and wetlands relation exists at wetland 2, with one exception. Near the downstream end of wetland 2, beavers built a dam in the fall of 1985; the resulting backwater flooded a small part of the wetland. Ground-water levels rose, and the concentrations of dissolved solids and trace elements in the ground water increased as a result of this flooding. Water levels in the wells at wetlands 1, 2, and 4 nearly always were higher in elevation than the stream. Seasonal differences in stream elevation and ground-water levels do occur. In June, stream elevation and ground-water levels are a function of snowmelt. In September, stream elevation is a function of ground-water discharge and storm events, whereas ground-water levels are a function of accumulated evapotranspiration loss and decreased direct recharge. Seasonal decreases in ground-water levels are not due to decreases in stream elevation; therefore, changes in stream elevation do not substantially affect ground-water levels at wetlands 1, 2, or 4.

The relation between streamflow and wetland 3 was more complex than at the other wetlands. Generally, the water flowed from the wetland to the stream with two major exceptions: (1) When stream stage was changed by beaver activity, and (2) on the east side of cross section 3A. Beaver dams have an unpredictable effect on all of wetland 3. Beaver dam construction caused increased stream stages, increased ground-water levels, and sometimes adjacent wetland flooding. Beaver dam destruction relocated streamflow and lowered stream stages and wetland ground-water levels adjacent to the dams. Because the location of future beaver activity cannot be predicted, neither can the effects of a beaver dam on wetland 3. The east side of cross section 3A is physiographically different from the other wetlands. Data that were collected using a hydraulic potentiomanometer indicated water movement from the stream into the wetland ground water at the upstream end of the wetland and from the wetland ground water to the stream at the downstream end of the wetland.

The primary conclusion of the study is that because streamflow is not a substantial source of recharge to the ground water in the wetlands, decreases in stream stage due to diversion of main-channel surface-water flows likely will not affect most of the wetland areas studied. Wetlands in the South Fork Williams Fork receive water mainly from precipitation, snowmelt, valley side-slope flow (including overland and small-channel flow), and ground-water inflow. Stream-overbank flow and stream recharge to wetland ground water were uncommon and affected only a limited area near the stream.

REFERENCES CITED

Brown, Eugene, Skougstad, M.W., and Fishman, M.J., 1970, Methods for collection and analysis of water samples for dissolved minerals and gases: U.S. Geological Survey Techniques of Water-Resources Investigations, bk. 5, chap. A1, 160 p.

Cowardin, L.M., Carter, Virginia, Golet, F.C., and LaRoe, E.T., 1979, Classification of wetlands and deep water habitats of the United States, U.S. Fish and Wildlife Service Report FWS/OBS-79/31, 103 p.

Guy, H.P., and Norman, V.W., 1970, Field methods for measurement of fluvial sediment: U.S. Geological Survey Techniques of Water-Resources Investigations, bk. 3, chap. C2, 59 p.

Lovering, T.S., and Goddard, E.N., 1950, Geology and ore deposits of the Front Range, Colorado: U.S. Geological Survey Professional Paper 223, 319 p.

Miller, D.M., 1984, Reducing transform bias in curve fitting: The American Statistician, v. 38, no. 2, p. 124-126.

National Climatic Data Center, 1987, Climatological data, Colorado: Asheville, N.C., v. 92, nos. 5 through 9.

_____1988, Climatological data, Colorado: Asheville, N.C., v. 93, nos. 5 through 9.

Ruddy, B.C., 1989, Use of a hydraulic potentiomanometer to determine ground-water gradients in a wetland, Colorado, *in* Woessner, W.W., and Potts, D.F., eds., Proceedings of the Symposium on Headwaters Hydrology: Bethesda, Maryland, American Water Resources Association, p. 675-683.

SAS Institute Inc., 1985, SAS user's guide--Statistics, version 5 edition: Cary, N.C., 956 p.

U.S. Environmental Protection Agency, 1986, Quality criteria for water, Office of Water Regulations and Standards, Washington, D.C.

Winter, T.C., LaBaugh, J.W., and Rosenberry, D.O., 1988, The design and use of a hydraulic potentiomanometer for direct measurement of differences in hydraulic head between ground water and surface water: Limnology and Oceanography, v. 33, n. 5, p. 1209-1214.

U.S. GOVERNMENT PRINTING OFFICE: 1991-573-207/40012