SELECTED HYDROLOGIC CHARACTERISTICS OF THE SOUTH PLATTE RIVER IN THE VICINITY OF THE PROPOSED NARROWS RESERVOIR NEAR FORT MORGAN, COLORADO

By Donald R. Minges

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 82-4071

Prepared in cooperation with the

U.S. BUREAU OF RECLAMATION

Lakewood, Colorado
1983

UNITED STATES DEPARTMENT OF THE INTERIOR

JAMES G. WATT, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to:

Colorado District Chief
U.S. Geological Survey MS 415
Box 25046, Denver Federal Center
Lakewood, CO 80225

For sale by:

Open-File Services Section
Western Distribution Branch
U.S. Geological Survey, MS 306
Box 25425, Federal Center
Denver, CO 80225
Telephone: (303) 234-5888

CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS

Inch-pound units used in this report may be converted to SI (International System of Units by the following conversion factors:

Multiply inch-pound unit	*By*	*To obtain SI unit*
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
gallon (gal)	3.785	liter
inch (in.)	2.54	centimeter
mile (mi)	1.609	kilometer
ton	9.072×10^{-1}	megagram

SELECTED HYDROLOGIC CHARACTERISTICS OF THE SOUTH PLATTE RIVER IN THE VICINITY OF THE PROPOSED NARROWS RESERVOIR NEAR FORT MORGAN, COLORADO

By Donald R. Minges

ABSTRACT

A 3-year study was made to document water quality, suspended sediment, and gain-and-loss characteristics of the South Platte River near Fort Morgan, Colo., prior to construction of the proposed Narrows Reservoir. Statistical summaries of water-quality data collected at two streamflow-gaging stations on the South Platte River during water years 1977-79 indicate that the mean concentrations of most constituents increase downstream. Linear-regression summaries of water-quality data at the two stations indicate most major chemical constituents are significantly correlated with specific conductance at the 95-percent confidence level. Suspended-sediment data also were obtained at the station located at the proposed dam site. The monthly suspended-sediment load at this station had a general linear relation to monthly discharge. Water-quality data also were collected at a streamflow-gaging station on Bijou Creek, a major tributary that would be significantly affected by the proposed reservoir.

Twenty-five gain-and-loss investigations conducted along a 25.8-mile study reach of the South Platte River indicated an average discharge gain of 143 cubic feet per second. The gain averaged 138 cubic feet per second in 20 investigations during the irrigation season (April 1 to October 31), and 161 cubic feet per second in 5 investigations during the winter months of December and February. Correlative discharge measurements to relate ungaged flow near selected ditch headgates to flow at the two main-stem streamflow-gaging stations indicated a significant degree of correlation between gaged and ungaged flow. These measurements indicated an average gain of 44.1 cubic feet per second within the 4.1 miles of the most upstream subreach and an average gain of 13.6 cubic feet per second within the 4.5 miles of the two most downstream subreaches. These average gains were determined to be virtually constant and independent of the magnitude of riverflow. In addition, the average gains in the individual subreaches were related to the saturated thickness of the aquifer in the valley-fill alluvium whose saturated thickness ranged from more than 120 feet in the upstream subreach to less than 10 feet in the downstream subreaches cited above.

INTRODUCTION

The proposed Narrows Reservoir on the South Platte River near Fort Morgan, Colo., is the principal feature of the U.S. Bureau of Reclamation's Narrows Unit, South Platte Division, Missouri River Basin Project, which was authorized for development by the Flood Control Acts of 1944, 1946, and 1950. The Narrows Reservoir would be a multipurpose development intended to provide irrigation water, flood control, recreation, and fish and wildlife habitat. Irrigation water to be stored by the reservoir would be conveyed to and used by several existing irrigation systems in Morgan, Logan, Washington, and Sedgwick Counties (fig. 1).

Purpose and Scope

Construction of the Narrows Reservoir will affect the water quality and gain-and-loss characteristics of the South Platte River. A knowledge of existing water quality, including sediment load, and gain-and-loss characteristics is needed so that the effects of the reservoir on these characteristics can be determined both during and after construction.

In December 1976, the U.S. Geological Survey, in cooperation with the U.S. Bureau of Reclamation, began a data-collection program with the installation of two continuous-record streamflow-gaging stations: one on the South Platte River at Masters (U.S. Geological Survey station 06756995), upstream from the proposed Narrows Reservoir; and the other near the mouth of Bijou Creek near Fort Morgan (U.S. Geological Survey station 06759100), a major tributary which joins the South Platte River 4.5 mi downstream from the proposed reservoir (fig. 2). Records from these new stations supplement the records from an existing station, 06758500 South Platte River near Weldona, located at the Narrows, a natural constriction in the river valley, which is the proposed dam site. Staff gages were installed at additional main-stem measurement sites and at selected inflow measurement sites (fig. 3). The program included collection of streamflow, water-quality, and suspended-sediment-load data at the station near Weldona and collection of streamflow and water-quality data at the stations at Masters and Bijou Creek. In addition, investigations were conducted to document gains and losses in discharge in the South Platte River in the vicinity of the proposed reservoir and to document river discharges near the headgates of three ditch systems that would be affected by the reservoir. The program was decreased in scope during the 1979 irrigation year (November 1 to October 31) and was discontinued in October 1979 due to the temporary suspension of planned reservoir construction.

Acknowledgments

Installation of streamflow-gaging stations and collection of data were facilitated by the cooperation of several private individuals as well as several ditch companies. The author wishes to thank in particular Mr. Robert Samples, Water Commissioner for District 1, Division 1, Colorado Division of Water Resources, for his cooperation and assistance in conducting the gain-and-loss investigations.

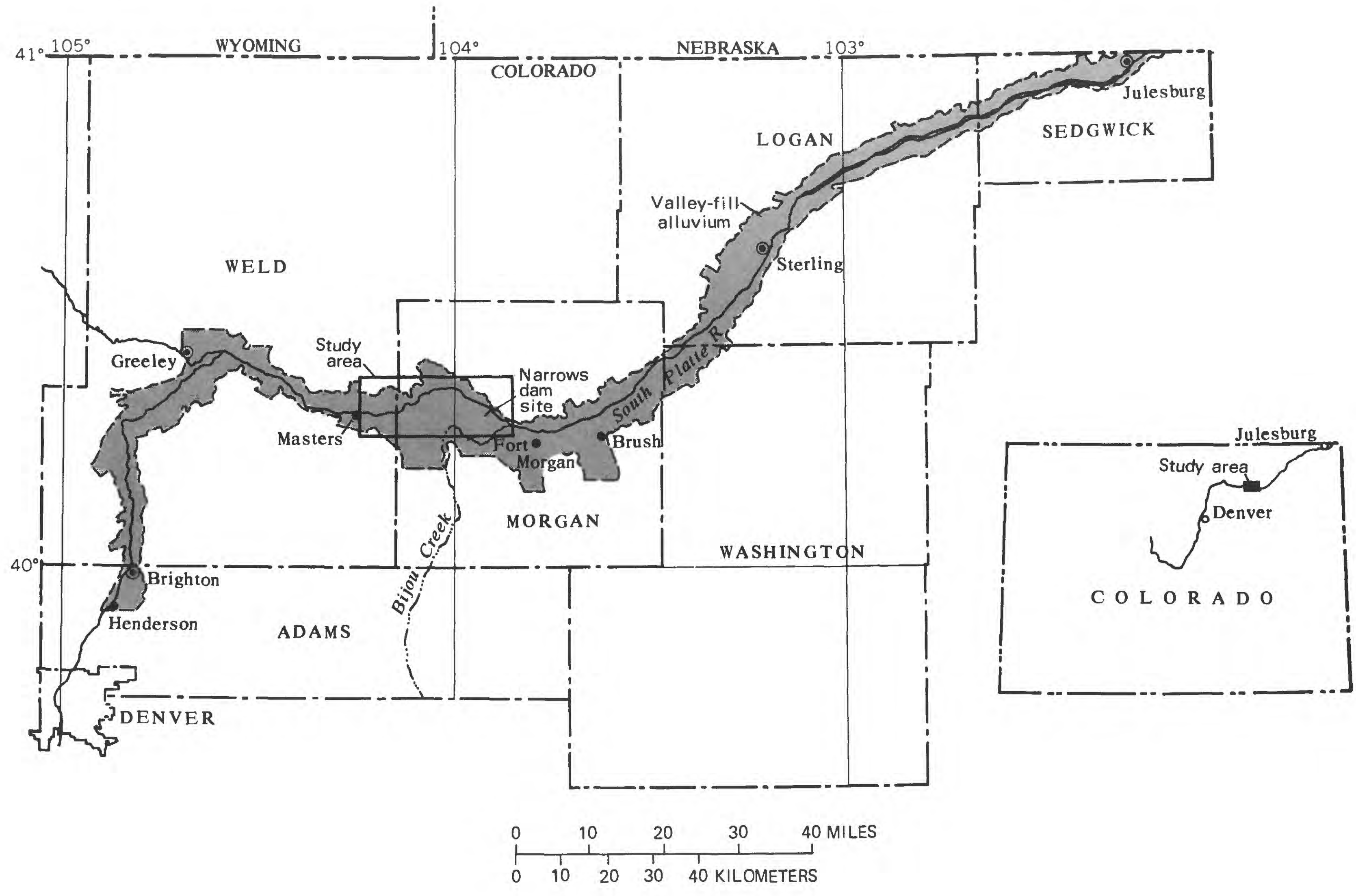

Figure 1. – Location of study area.

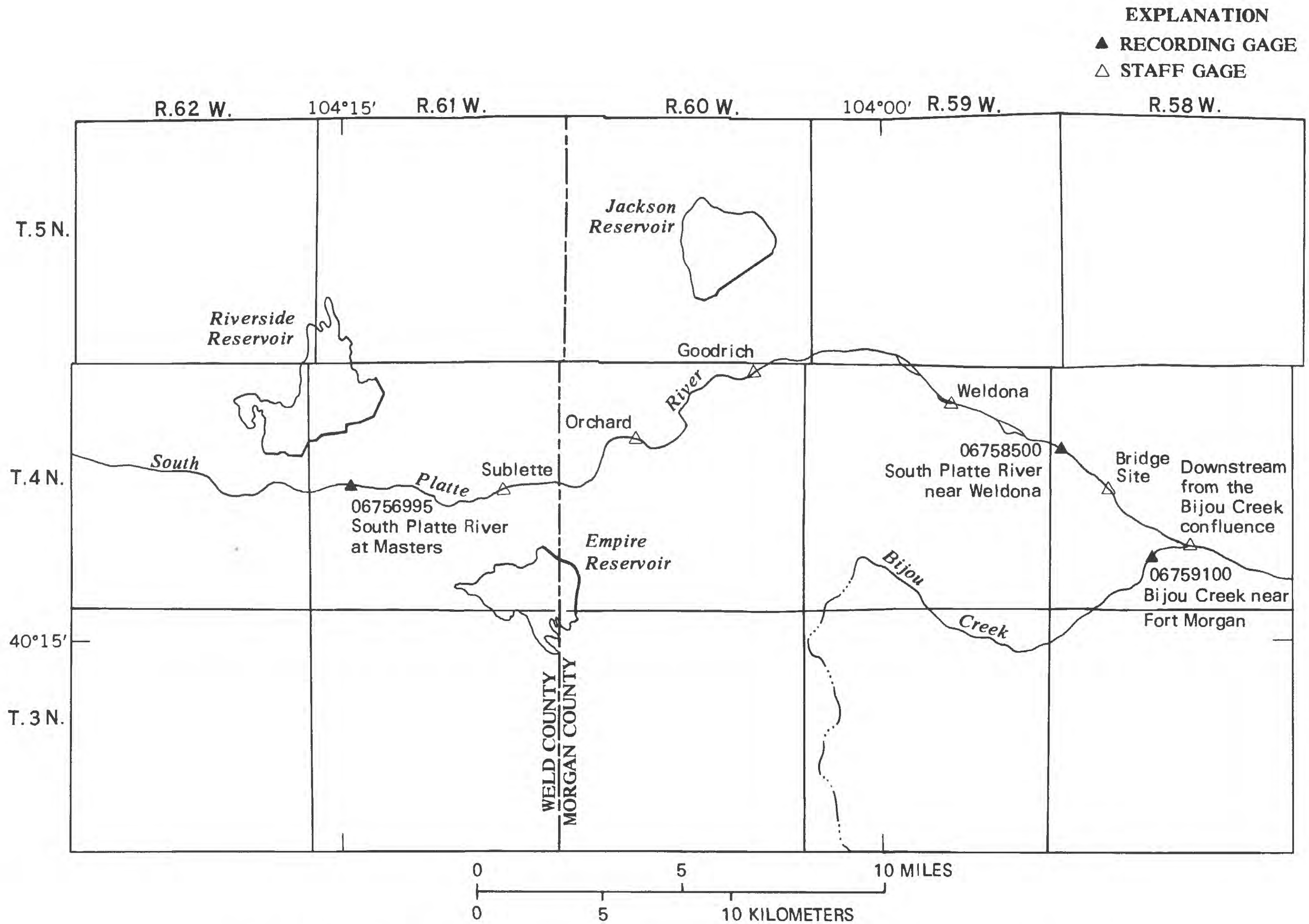

Figure 2.--Location of streamflow-gaging stations and main-stem measurement sites.

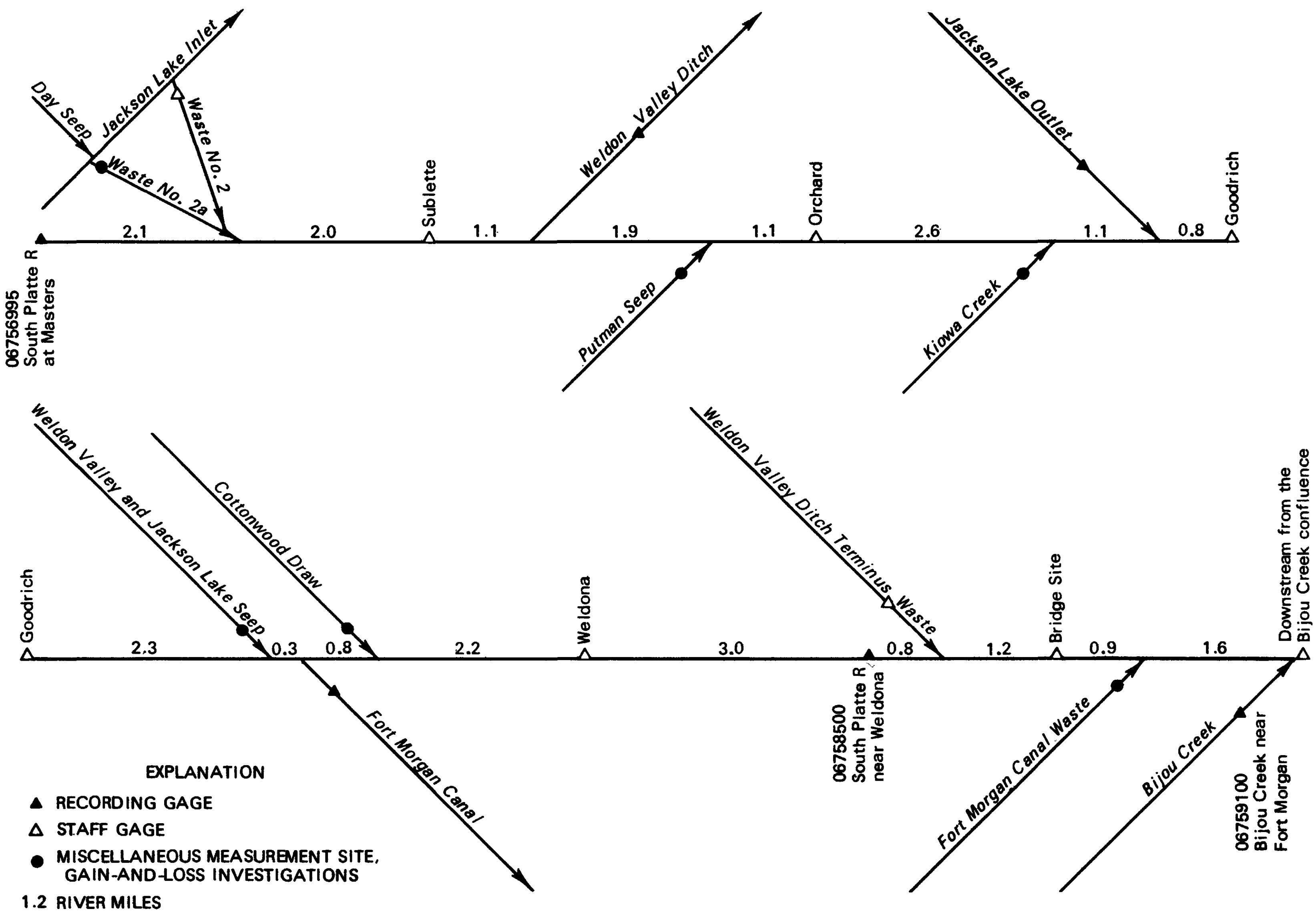

Figure 3.--Schematic diagram of South Platte River system from station 06756995 at Masters to a site downstream from the Bijou Creek confluence.

WATER QUALITY

Water-quality data were collected to document existing conditions so that any changes in water quality resulting from construction of the Narrows Reservoir could be quantified. Water-quality data and samples for laboratory analysis were collected at the three streamflow-gaging stations, 06756995 South Platte River at Masters, 06758500 South Platte River near Weldona, and 06759100 Bijou Creek near Fort Morgan twice a month from April to September and monthly from October to March. Water-quality characteristics determined at the stations were temperature, specific conductance, pH, and dissolved-oxygen concentration. Laboratory determinations were made for concentrations of dissolved silica, calcium, magnesium, sodium, potassium, carbonate, bicarbonate, sulfate, chloride, fluoride, nitrite plus nitrate nitrogen, orthophosphate, iron, and manganese. Dissolved-solids concentration was determined from the sum of dissolved constituents. These data were published annually by the U.S. Geological Survey (1978, 1979, and 1980). In September 1979 collection of water-quality data was discontinued at stations 06756995 South Platte River at Masters and 06759100 Bijou Creek near Fort Morgan and was decreased in scope at 06758500 South Platte River near Weldona owing to the temporary suspension of planned reservoir construction. Station 06758500 South Platte River near Weldona was a water-quality data-collection station prior to the present study, and the station continues to be operated for the collection of monthly samples for determination of major ions and cations. From April to September, monthly samples are collected to determine algae-growth potential.

Suspended Sediment

Suspended-sediment data were collected to document existing sediment-load characteristics at the dam site where releases to downstream water users would occur. Impoundment of water significantly decreases its suspended-sediment load as streamflow velocities are decreased virtually to zero and the entrained sediment settles out. The subsequent release of this "clean" water could have an effect on the downstream river channel or irrigation ditches. Starting in April 1977, sediment data were collected at 06758500 South Platte River near Weldona for computation of a continuous record of suspended-sediment load. Suspended-sediment samples collected by personnel of the U.S. Geological Survey and by a hired observer were provided to the U.S. Bureau of Reclamation for analysis in their laboratory. The analyses results, in turn, were given to the U.S. Geological Survey for computation of the suspended-sediment load records. Collection of suspended-sediment data at the station was discontinued in March 1979.

Discussion of Analyses Results

Statistical summaries of water-quality data collected at the three stations for the 1977, 1978, and 1979 water years are presented in tables 1, 2, and 3. The summaries include: (1) The number of measurements or determinations of each constituent or property; (2) the maximum, minimum, and mean values; and (3) the standard deviation from the mean. In addition, linear-regression summaries relating major chemical constituents to specific conductance are included for those constituents which are significantly correlated with specific conductance at the 95-percent confidence level. The regression coefficient (R), the intercept or constant (B), the correlation coefficient, and the standard error of estimate are shown. The linear-regression equation relating specific conductance to constituent concentration generally is expressed as:

$$\text{Constituent concentration (milligrams per liter)} = \text{specific conductance (microsiemens per centimeter at 25°Celsius)} \times R + B.$$

A comparison of data in tables 1 and 2 shows that mean concentrations of most constituents increase from the upstream station at Masters to the station near Weldona, 21.3 river miles downstream. Exceptions to this are concentrations of orthophosphate, iron, and manganese, which are less at the Weldona station than at the Masters station. Significant correlations between specific conductance and the concentrations of bicarbonate, hardness, calcium, magnesium, sodium, potassium, chloride, sulfate, and dissolved solids at the two stations are indicated by correlation coefficients that range from 0.76 to 0.97 (tables 1 and 2). Specific conductance is an easily measured property and can provide a reliable estimate of the concentrations of these constituents at the two stations for discharges of as much as 7,500 ft^3/s.

In contrast, the relations between specific conductance and dissolved-solids concentration values are less reliable for the Bijou Creek station (table 3). Fewer constituents are significantly correlated with specific conductance at the 95-percent confidence level, and correlation coefficients for those relations range from only 0.32 to 0.61. These correlations probably are partly the result of the much more limited range of discharges (4.40 to 55.5 ft^3/s) sampled at the Bijou Creek station than at the South Platte River stations. Dissolved-solids concentrations generally vary inversely with discharge. Higher discharges, which usually result from snowmelt or rainfall runoff, generally have lesser dissolved-solids concentrations than low to moderate flows which consist largely of ground water having greater dissolved-solids concentrations.

A graph of total monthly suspended-sediment load versus total monthly discharge for station 06758500 South Platte River near Weldona for the period of record, April 1977 to March 1979, is presented in figure 4. The upper leftmost data point represents a large suspended-sediment load peak accompanying a discharge peak on May 2, 1977. Discharge for the remainder of May 1977 was only moderate, resulting in a relatively large monthly sediment load in conjunction with only moderate monthly discharge. In general, however, the monthly suspended-sediment load at the station is linearly related to the monthly discharge.

Table 1.--*Statistical summary of concentrations of selected dissolved chemical constituents, measurements of water properties, and regression relations of constituent concentrations to specific conductance, station 06756995 South Platte River at Masters, water years 1977-79*

[°C=degree Celsius; ft^3/s=cubic foot per second; μmho=microsiemens per centimeter at 25°C; mg/L=milligram per liter; μg/L=microgram per liter]

Constituent or property	Sample size	Concentration or property value			Regression summary			
		Mean	Standard deviation	Range	Regression coefficient, *R*	Constant, *B*	Correlation coefficient	Standard error of estimate
Temperature (°C)	72	14.0	7.34	0.0-27.5	-----	-----	----	-----
Discharge (ft^3/s)	44	484	1,130	4.94-7,480	-----	-----	----	-----
Specific conductance (μmho)	72	1,480	257	555-1,750	-----	-----	----	-----
Oxygen, dissolved (mg/L)	43	8.8	1.41	6.7-13	-----	-----	----	-----
pH	46	--------	--------	7.7-8.5	-----	-----	----	-----
Bicarbonate (mg/L as HCO_3)	37	298	35.9	160-340	0.169	37.9	0.90	16.0
Carbonate (mg/L as CO_3)	37	.22	.95	.0-5.0	-----	-----	----	-----
Nitrogen, NO_2+NO_3, dissolved (mg/L as N)	45	3.6	1.23	1.2-7.1	-----	-----	----	-----
Orthophosphate, dissolved (mg/L as P)	35	.31	.26	.02-1.2	-----	-----	----	-----
Hardness (mg/L as $CaCO_3$)	46	572	102	190-730	.361	33.8	.93	38.8
Calcium, dissolved (mg/L as Ca)	46	131	23.4	47-180	.082	9.26	.91	9.80
Magnesium, dissolved (mg/L as Mg)	46	59	11.4	17-75	.039	1.50	.88	5.54
Sodium, dissolved (mg/L as Na)	46	133	25.6	43-160	.088	2.12	.89	11.7
Potassium, dissolved (mg/L as K)	46	7.0	.95	3.9-8.9	.003	2.83	.76	.62
Chloride, dissolved (mg/L as Cl)	46	58	13.7	18-80	.041	-2.68	.77	8.88
Sulfate, dissolved (mg/L as SO_4)	46	512	96.6	150-650	.334	13.5	.90	42.6
Fluoride, dissolved (mg/L as F)	45	1.0	.13	.6-1.2	-----	-----	----	-----
Silica, dissolved (mg/L as SiO_2)	45	12	1.86	7.9-16	-----	-----	----	-----
Dissolved solids (mg/L calculated)	45	1,070	187	352-1,250	.677	60.3	.94	62.7
Minor elements:								
Iron, dissolved (μg/L as Fe)	46	32.6	46.3	.0-290	-----	-----	----	-----
Manganese, dissolved (μg/L as Mn)	46	80.0	47.5	10-200	-----	-----	----	-----

Table 2.--*Statistical summary of concentrations of selected dissolved chemical constituents, measurements of water properties, and regression relations of constituent concentrations to specific conductance, station 06758500 South Platte River at Masters, water years 1977-79*

[°C=degree Celsius; ft^3/s=cubic foot per second; μmho=microsiemens per centimeter at 25°C; mg/L=milligram per liter; μg/L=microgram per liter]

Constituent or property	Sample size	Concentration or property value			Regression summary			
		Mean	Standard deviation	Range	Regression coefficient, *R*	Constant, *B*	Correlation coefficient	Standard error of estimate
Temperature (°C)	158	18.2	6.59	0.0-29.5	-----	-------	----	-----
Discharge (ft^3/s)	163	382	668	31.0-7,650	-----	-------	----	-----
Specific conductance (μmho/cm)	49	1,750	400	640-2,800	-----	-------	----	-----
Oxygen, dissolved (mg/L)	42	9.8	2.19	6.5-18	-----	-------	----	-----
pH	49	--------	------	7.6-8.7	-----	-------	----	-----
Bicarbonate (mg/L as HCO_3)	38	310	52.2	200-440	0.124	79.4	0.80	32.0
Carbonate (mg/L as CO_3)	38	.26	.89	.0-5.0	-----	-------	----	-----
Nitrogen, NO_2+NO_3, dissolved (mg/L as N)	45	4.0	1.81	1.0-8.8	-----	-------	----	-----
Orthophosphate, dissolved (mg/L as P)	34	.20	.24	.01-1.3	-----	-------	----	-----
Hardness (mg/L as $CaCO_3$)	47	680	174	220-1,200	.426	-71.4	.96	51.9
Calcium, dissolved (mg/L as Ca)	47	160	41.8	55-260	.097	-12.1	.91	17.6
Magnesium, dissolved (mg/L as Mg)	47	68	20.5	20-150	.044	-10.0	.84	11.1
Sodium, dissolved (mg/L as Na)	47	162	36.7	50-260	.087	8.48	.93	13.9
Potassium, dissolved (mg/L as K)	46	8.3	1.33	4.9-11	.003	3.68	.77	.86
Chloride, dissolved (mg/L as Cl)	47	69	13.5	20-92	.029	17.6	.84	7.42
Sulfate, dissolved (mg/L as SO_4)	47	652	184	200-1,200	.445	-133	.94	61.3
Fluoride, dissolved (mg/L as F)	47	1.1	.13	.6-1.4	-----	-------	----	-----
Silica, dissolved (mg/L as SiO_2)	47	15.5	5.49	7.7-30	.010	-2.98	.75	3.68
Dissolved solids (mg/L calculated)	46	1,295	324	427-2,240	.805	-117	.97	83.2
Minor elements:								
Iron, dissolved (μg/L as Fe)	47	30.2	28.8	.0-140	-----	-------	----	-----
Manganese, dissolved (μg/L as Mn)	46	38.8	32.6	6-200	-----	-------	----	-----

Table 3.--*Statistical summary of concentrations of selected dissolved chemical constituents, measurements of water properties, and regression relations of constituent concentrations to specific conductance, station 06759100 South Platte River at Masters, water years 1977-79*

[°C=degree Celsius; ft^3/s=cubic foot per second; µmho=microsiemens per centimeter at 25°C; mg/L=milligram per liter; µg/L=microgram per liter]

Constituent or property	Sample size	Concentration or property value			Regression summary			
		Mean	Standard deviation	Range	Regression coefficient, *R*	Constant, *B*	Correlation coefficient	Standard error of estimate
Temperature (°C)	71	15.0	3.87	5.0-21.5	-----	-----	----	-----
Discharge (ft^3/s)	46	11.3	9.77	4.40-55.5	-----	-----	----	-----
Specific conductance (µmho/cm)	71	1,660	127	1,250-2,150	-----	-----	----	-----
Oxygen, dissolved (mg/L)	44	6.8	1.36	3.5-10	-----	-----	----	-----
pH	46	--------	------	7.2-8.6	-----	-----	----	-----
Bicarbonate (mg/L as HCO_3)	37	315	8.89	300-340	0.039	249	0.51	7.75
Carbonate (mg/L as CO_3)	37	.03	.16	.0-1.0	-----	-----	----	-----
Nitrogen, NO_2+NO_3, dissolved (mg/L as N)	45	7.56	1.38	4.0-11	-----	-----	----	-----
Orthophosphate, dissolved (mg/L as P)	34	.05	.06	.01-.38	-----	-----	----	-----
Hardness (mg/L as $CaCO_3$)	46	672	44.4	570-890	.217	306	.56	37.1
Calcium, dissolved (mg/L as Ca)	46	201	15.1	130-220	-----	-----	----	-----
Magnesium, dissolved (mg/L as Mg)	46	41.3	8.64	28-88	.038	-22.1	.50	7.56
Sodium, dissolved (mg/L as Na)	46	143	12.3	120-210	.040	75.4	.38	11.5
Potassium, dissolved (mg/L as K)	46	9.5	.61	6.9-11	-----	-----	----	-----
Chloride, dissolved (mg/L as Cl)	46	55.7	6.88	23-78	.019	23.5	.32	6.59
Sulfate, dissolved (mg/L as SO_4)	46	600	45.5	530-860	.237	201	.60	36.7
Fluoride, dissolved (mg/L as F)	45	1.0	.09	.80-1.3	-----	-----	----	-----
Silica, dissolved (mg/L as SiO_2)	45	21.0	2.32	11-23	-----	-----	----	-----
Dissolved solids (mg/L calculated)	45	1,260	73.0	1,110-1,660	.380	620	.61	58.8
Minor elements:								
Iron, dissolved (µg/L as Fe)	46	23.5	18.8	.0-80	-----	-----	----	-----
Manganese, dissolved (µg/L as Mn)	46	239	113	50-450	-----	-----	----	-----

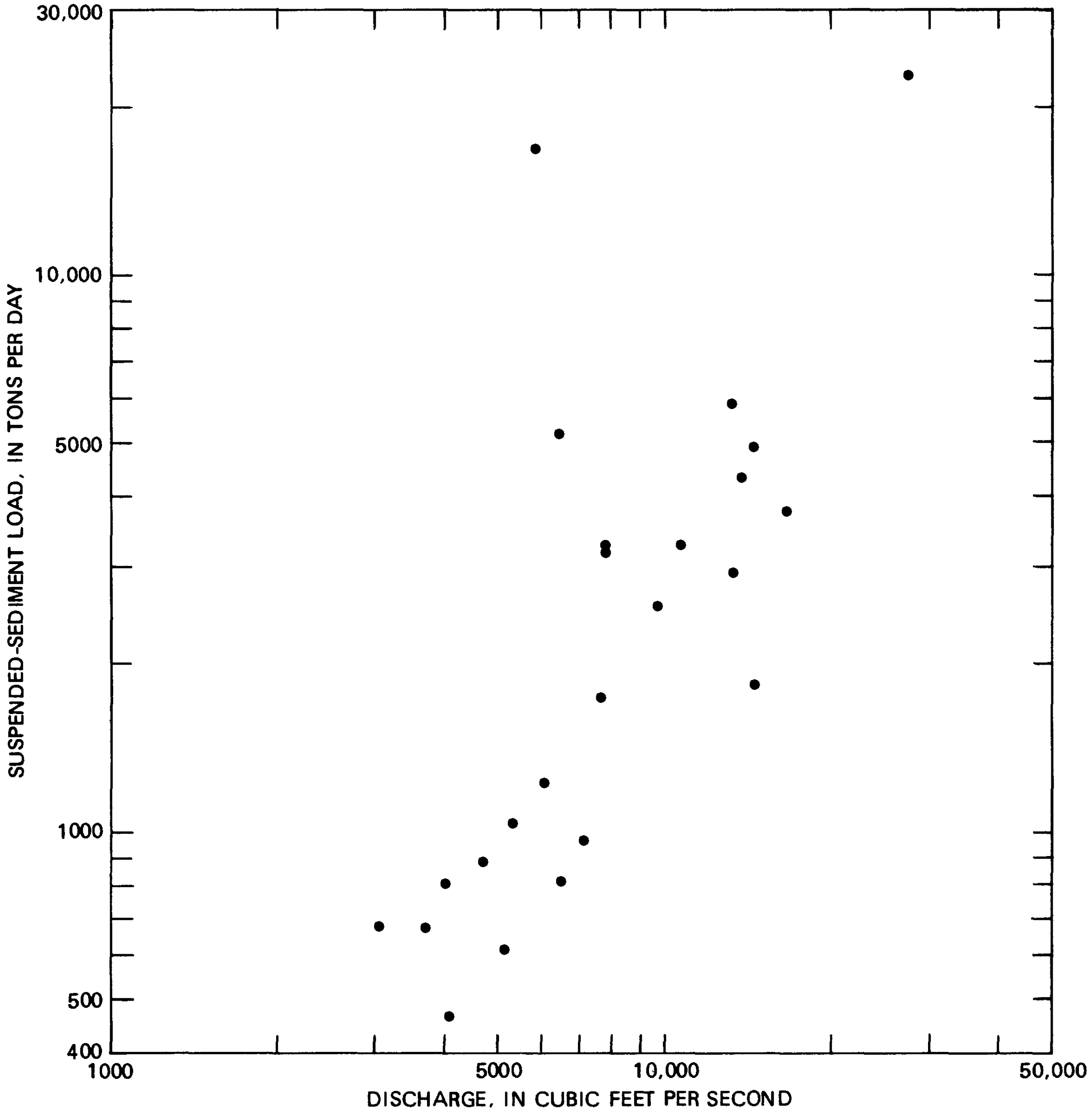

Figure 4.--Monthly relation between total suspended-sediment load and total discharge, April 1977 to March 1979, at station 06758500 South Platte River near Weldona.

STREAMFLOW GAIN-AND-LOSS INVESTIGATIONS

Historically, upstream irrigation return flows have been a significant part of the surface water diverted by users of the South Platte River water. Since the magnitude and distribution of such return flows would be altered by construction of the reservoir, releases from the reservoir should provide downstream water users with the same amount of water they have been receiving.

To document existing conditions, streamflow gain-and-loss investigations were conducted on the 25.8-mi reach of the South Platte River from the gaging station at Masters to immediately downstream from the confluence with Bijou Creek. The gain-and-loss investigations were conducted approximately monthly from April 1 to October 31 to document irrigation season conditions and during December and February to document winter conditions. No data were collected in December 1978 owing to severe ice conditions. When it was determined that conditions were favorable to conduct a gain-and-loss investigation, the investigation was completed in 1 day using four hydrographers. The work within a hydrographer's assigned reach was done in a downstream direction so that, in the event of a change in stage traversing the study reach, the discharge measurements would tend either to lead or follow the change.

During each investigation, flow was either measured or a determination of no flow was made at about 20 sites (fig. 3). Gains (positive values) or losses (negative values) for a subreach were computed as the difference between the sum of all outflows or diversions minus the sum of all inflows within the subreach, the upstream main-stem measurement being considered an inflow and the downstream main-stem measurement being considered an outflow. If all surface inflows and outflows are accounted for, the computed difference in main-stem flow can be attributed to accretion to surface flow from ground water (gain) or, conversely, accretion to the ground-water aquifer from surface flow (loss). The number of gain-and-loss investigations was decreased during the 1979 irrigation year, and the investigations were discontinued in October 1979 owing to the temporary suspension of planned reservoir construction.

With steady-state conditions prevailing for the South Platte River and Bijou Creek and with no changes in diversions or inflows, the discharges measured during a gain-and-loss investigation were tabulated directly. Although coordination was maintained with the water commissioner for District 1 (which includes the study area) in an effort to minimize changes in ditch diversions or in the Jackson Lake outlet during the investigations, some changes were inevitable. Corrections to measured main-stem discharges to compensate for changes in stage were calculated by first determining traveltime between the two South Platte River streamflow-gaging stations. This was done by matching a number of peaks and troughs on the two hydrograph chart records at about the same stage at which the discharge measurements were made. By assuming this rate to be constant for the entire study reach, points on the hydrograph chart of the nearest station corresponding to the times of the intermediate measurements were determined. If the gage heights thus determined for adjacent main-stem measurements differed by more than 0.01 ft, a correction to the measured discharge was applied. Corrections in discharge were determined by using the rating table for the station in conjunction with the shift determined from the measurement made at the station during the investigation. A similar procedure using mean measurement velocity was used in routing changes in stage to the main stem of the South Platte River when they occurred at the Bijou Creek station or at the stations on Weldon Valley ditch, Fort Morgan canal, or Jackson Lake outlet (fig. 3).

The results of all investigations are presented by subreach and total reach in table 4. A footnote indicates measurements adjusted for nonsteady-state conditions. Averages for the winter (December and February), for the irrigation season (April 1 to October 31), and for all investigations also are included. The totals of these averages do not agree with comparable averages computed from the totals column on the right side of the table because average subreach values exclude combined subreach values (see footnotes 3 and 4). Data from subreaches were combined when calculations indicated a possible error in the intermediate main-stem measurement, such as when a large gain was accompanied by a loss in an adjoining subreach and vice-versa, or when a main-stem measurement was known to have been made during a rising or a declining stage.

Measured Ground-Water Discharge

Several water courses in the study area transport predominantly ground-water effluent to the river. The water courses are either natural sloughs or dug drainage ditches that intercept ground-water flow that eventually would have reached the river. However, because the river valley is extensively irrigated during the growing season, these water courses intermittently may carry irrigation waste flows that must be included as inflows in computing gains or losses in the affected subreach. As a means of estimating the magnitude of such waste flows, the principal water courses with opportunity to intercept direct irrigation waste--Putman Seep, and Weldon Valley and Jackson Lake Seep--were measured during each gain-and-loss investigation (fig. 3). Comparison of the irrigation season and winter discharges for these sloughs was used as an indication of the quantities of direct irrigation waste flows they transport, and only the direct irrigation waste component of the flow, if any, was entered in the tabulation.

Putman Seep can intercept direct irrigation waste flows from irrigated land upslope and generally south of the slough. However, flow in the slough was found to be very uniform for all investigations, varying only from 4.44 to 6.84 ft^3/s. Moreover, the average winter flow was 0.16 ft^3/s greater than the average irrigation season flow, indicating no direct irrigation waste-flow component.

Weldon Valley and Jackson Lake Seep is a dug drainage-canal network intended to be a ground-water drain. Measured discharges in this slough, which ranged from 2.81 to 20.3 ft^3/s, had a significant seasonal variation. The lowest flows occurred in the winter and the highest flows occurred in July and August, indicating a large direct irrigation waste-flow component. Opportunity for interception of direct irrigation waste flows is common because the drainage network dissects extensively irrigated cropland. Because measured winter flows were fairly uniform

Table 4.--*Summary of gain-and-loss investigations of the South Platte River from station 06756995 at Masters to a site downstream from the Bijou Creek confluence, irrigation years 1977-79*

[Values are subreach gains or losses, in cubic feet per second. Values in parentheses are gains or losses per river mile, in cubic feet per second]

Date of investigation	Subreaches and lengths in river miles[1]: 06756995 to Sublette 4.1	Sublette to Orchard 4.1	Orchard to Goodrich 4.5	Goodrich to Weldona 5.6	Weldona to 06758500 3.0	06758500 to Bridge site 2.0	Bridge site to downstream from Bijou Creek confluence 2.5	Total reach: 06756995 to downstream from Bijou Creek confluence 25.8
Dec. 16, 1976	59(14)	24(6)	-------44(4)-------		7(2)	7(4)	1(0)	142(6)
Feb. 1, 1977	16(4)	23(6)	23(5)	[2]67(12)	37(12)	-29(-14)	-2(-1)	135(5)
Apr. 14	27(7)	------[2]30(3)-----		------[2]46(5)------		------- -21(-8)-------		82(3)
May 17	44(11)	31(8)	24(5)	7(1)	19(6)	0(0)	-1(0)	124(5)
June 16	39(10)	25(6)	15(3)	48(9)	15(5)	-3(-2)	[2]5(2)	144(6)
Aug. 4	64(16)	9(2)	-------42(4)-------		21(7)	--------2(0)----------		138(5)
Aug. 29	38(9)	11(3)	28(6)	31(6)	15(5)	16(8)	3(1)	142(6)
Sep. 27	65(16)	12(3)	17(4)	11(2)	3(1)	8(4)	4(2)	120(5)
Oct. 17	45(11)	41(10)	8(2)	46(8)	13(4)	2(1)	2(1)	157(6)
Dec. 12	40(10)	30(7)	41(9)	5(1)	[2]0(0)	8(4)	22(9)	146(6)
Feb. 7, 1978	29(7)	54(13)	-------33(3)-------		[2]15(5)	4(2)	27(11)	162(6)
Apr. 4	24(6)	24(6)	16(4)	-------16(2)------		16(8)	7(3)	103(4)
May 17	39(10)	36(9)	29(6)	1(0)	[2]6(2)	3(2)	21(8)	135(5)
June 29	54(13)	34(8)	[2]32(7)	[2]11(2)	[2]1(0)	-------[2]23(9)---------		155(6)
July 25	46(11)	29(7)	----------[2]96(7)------------			4(2)	[2]1(0)	176(7)
Aug. 15	55(13)	[2]33(8)	41(9)	------[2]55(6)------		-2(-1)	-42(-17)	140(5)
Sep. 12	31(8)	[2]35(9)	16(4)	-15(-3)	-11(-4)	17(8)	9(4)	82(3)
Oct. 10	-----76(9)-------		6(1)	--------8(1)------		33(16)	7(3)	130(5)
Feb. 27, 1979	46(11)	41(10)	26(6)	------[2]48(6)------		5(2)	18(7)	184(7)
Apr. 10	38(9)	29(7)	5(1)	6(1)	13(4)	11(6)	16(6)	118(5)
July 19	18(4)	-------39(5)-----		29(5)	[2]20(7)	-1(0)	8(3)	113(4)
Aug. 7	37(9)	33(8)	[2]35(8)	11(2)	20(7)	6(3)	[2]22(9)	164(6)
Sep. 11	50(12)	40(10)	51(11)	11(2)	51(17)	------ -5(-1)---------		198(8)
Sep. 24	34(8)	73(18)	------------63(5)------------			----- -18(-4)---------		152(6)
Oct. 18	44(11)	33(8)	-------63(6)-------		9(3)	-------18(4)----------		167(6)
Averages for winter (Dec. and Feb.) investigations-------	38(9)	34(8)	[3]30(7)	[3]36(6)	[3]15(5)	-5(-2)	13(5)	[4]161(6)
Averages for irrigation season (Apr. to Oct.) investigations	[3]42(10)	[3]31(8)	[3]23(5)	[3]16(3)	[3]14(5)	[3]8(4)	[3]4(2)	[4]138(5)
Averages for all investigations-----	[3]41(10)	[3]32(8)	[3]24(5)	[3]19(4)	[3]14(5)	[3]6(3)	[3]7(3)	[4]143(6)

[1]Stream subreaches shown on figures 2 and 3.
[2]Value adjusted for nonsteady-state conditions (see text).
[3]Does not include values for combined subreaches.
[4]Total of average subreach values.

(maximum measured difference was 2.4 ft^3/s), the average of these was assumed to represent the ground-water effluent component of the total flow. This average winter flow, 4.22 ft^3/s for eight measurements, was rounded to 5.0 ft^3/s and subtracted from the flow measured during the irrigation season gain-and-loss investigations before the measured flow was entered in the tabulations.

The origin of the discharge of Bijou Creek at the streamflow-gaging station is similar to that of the slough inflows discussed above. The discharge is predominantly ground-water effluent originating within an approximately 1.5-mi reach upstream from the gage and generally is very uniform at 5 to 10 ft^3/s. Occasionally, however, Bijou Creek transports waste flows from Fort Morgan Canal, releases from Bijou No. 2 Reservoir, and thunderstorm or snowmelt runoff. The gaged discharge of Bijou Creek is readily separable into its surface- and ground-water components as was done for Weldon Valley and Jackson Lake Seep. However, since the measured discharge represents inflow from a major tributary drainage basin, total Bijou Creek discharge, including the ground-water component, was included in the tabulation.

Another principal slough, Day Seep, is not located within an irrigated area and, as a result, intercepts no irrigation waste flows (fig. 3). Flow in this slough is ground-water effluent derived primarily from Riverside Reservoir, which is upgradient and approximately 1 mi to the north. Flow in Day Seep is intercepted by Jackson Lake Inlet Canal from November to April. During the irrigation season, however, when Jackson Lake Inlet Canal does not divert water from the river, Day Seep flow is routed to the river through the main canal wasteway, Jackson Lake Inlet Waste No. 2.

Water-Level Measurements

Starting in December 1977, water levels in 30 wells or observation pipes were measured concurrently with each gain-and-loss investigation to document ground-water levels in the vicinity of the river. Nine of these wells or pipes are located south of the river and within 2 mi on either side of Bijou Creek in an area that would have one of the most significant changes in water levels with construction of the reservoir. The remaining 21 wells or pipes are located on transects through the main-stem measurement sites. Analysis of ground-water gradients determined from water-level measurements in these wells or pipes and their relationship to variations in measured river gains and losses was not attempted due to termination of the project. However, a cursory examination of the measurements obtained indicates that localized perturbations, such as nearby pumping wells and flowing ditches, which are common throughout the study area, effectively mask the more widespread water-table gradients that exist.

Relation of Gains in River Discharge to Aquifer Saturated Thickness

The average gains noted for the individual subreaches show a relation to saturated thickness of the alluvial aquifer in the valley-fill beneath the river. The most upstream subreach--station 06756995 at Masters to Sublette--had the largest gain in all but four of the gain-and-loss investigations and averaged 41 ft^3/s for all investigations. The saturated thickness of the aquifer beneath the river for this subreach is 120 ft or more (Hurr and others, 1972). In contrast, the two most downstream subreaches--station 06758500 near Weldona to Bridge Site and Bridge Site to the site downstream from the Bijou Creek confluence--on the average had the smallest gains recorded (6 and 7 ft^3/s, respectively) and in all but one instance had the only losses in streamflow recorded (table 4). In comparison, the maximum aquifer saturated thickness beneath the river for these two subreaches is 20 ft and averages less than 10 ft (Hurr and others, 1972). In addition, the intermediate subreaches, on the average, had a decrease in gain in the downstream direction, whereas the average aquifer saturated thickness, while showing substantial local variation, also decreases in the downstream direction. The results of the gain-and-loss investigations, then, show a significant relation to the opportunity for the river to gain (or lose) flow as represented by the saturated thickness of the aquifer beneath the river.

Discussions of Results

Although large gains were recorded for each gain-and-loss investigation for the total reach, large variations in total gain as well as large variations for some subreaches from investigation to investigation are apparent in table 4. Gains for the total reach ranged from 82 ft^3/s on April 14, 1977, and September 12, 1978, to 198 ft^3/s on September 11, 1979, whereas the values for the Goodrich to Weldona subreach, for example, ranged from a gain of 67 ft^3/s on February 1, 1977, to a loss of 15 ft^3/s on September 12, 1978. Possible reasons for these variations are: (1) Transient effects within the river system due to changes in stage and evapotranspiration, (2) undetected irrigation waste flowing directly to the river, (3) individual measurement error, and (4) variability in Weldon Valley ditch terminus waste inflow (fig. 3).

Changes in stage affect measured river gains and losses because these changes affect bank-and-channel storage. These relatively short-term effects can combine with relatively longer-term effects due to evapotranspiration. Evaporation from ponded water and transpiration from riparian vegetation within the river bottom can alter water-table gradients adjacent to the river and, as a result, measured river gains and losses.

Undetected irrigation waste inflows, while probably small individually, could have a significant combined effect upon the total reach. As discussed earlier, estimates were made of suspected irrigation waste inflows but there undoubtedly are additional inflows from fields near the river. Detection of these inflows is difficult because they vary not only with time but also with location.

Discharge-measurement error under favorable conditions, such as those usually needed for a gain-and-loss investigation, normally is about 5 percent. In computing gain or loss in a river subreach, it usually is assumed that the error associated with the largest discharge measurement represents the error for the subreach. An indication of the range in discharge-measurement errors associated with the gain-and-loss investigations and their relation to calculated gain or loss may be seen by comparing maximum discharge-measurement errors for the highest and lowest river-flow conditions encountered for the subreach which generally had the largest gains, station 06756995 at Masters to Sublette (table 4). The highest riverflow during a gain-and-loss investigation occurred on September 24, 1979. The gain calculated on this date for the station 06756995 at Masters to Sublette subreach was 34 ft^3/s (table 4). The error associated with the largest discharge measurement (717 ft^3/s) for this subreach was ±36 ft^3/s, which exceeds the calculated gain. By comparison, the lowest river flow during a gain-and-loss investigation occurred on April 10, 1979. The gain calculated on this date for the station 06756995 at Masters to Sublette subreach was 38 ft^3/s, which is well in excess of the error of ±2.4 ft^3/s associated with the largest discharge measurement (47.9 ft^3/s) for the subreach.

The Weldon Valley ditch terminus waste flows into the South Platte River 0.8 mi downstream from station 06758500 near Weldona (fig. 3) and may account for some variation noted in the two most downstream subreaches, station 06758500 near Weldona to Bridge Site and Bridge Site to the site downstream from the Bijou Creek confluence. As discussed in the section "Ungaged Flows near Selected Ditch Headgates," potential for variation in this inflow is great. Because this inflow was not gaged continuously, a change in its flow shortly before a discharge measurement was made would result in an unnoticed wave in the river.

Some general trends are apparent by averaging the results of all gain-and-loss investigations. The most obvious of these is the magnitude of the measured gain in the South Platte River discharge in the 25.8-mi study reach (table 4). For the 25 gain-and-loss investigations conducted during the 1977-79 irrigation years (November 1 through October 31), this gain averaged 143 ft^3/s, or 6 ft^3/s per river mile. Cumulative average gain for all investigations, in cubic feet per second, versus river miles downstream from station 06756995 at Masters is presented in figure 5. As a measure of variation in the data, 90-percent confidence limits based on the standard deviation also are shown for each subreach in figure 5. It should be emphasized that the 90-percent confidence limits do not represent a 90-percent confidence envelope for the cumulative average gain curve because the limits were individually calculated for each subreach.

A seasonal trend is apparent in a graph of average monthly gains for all investigations as presented in figure 6. Considering the large variations in the data and that monthly averages are based on only two to four investigations each, average monthly results are not conclusive. However, in most instances the average monthly variations follow a pattern that reasonably may be expected to occur within an irrigated river-valley system underlain by an extensive aquifer such as the valley-fill alluvium of the South Platte River valley. In general, a higher water table will result in larger gains in riverflow whereas a lower water table will result in smaller gains. Factors that tend to raise the water table, such as recharge from flood irrigation of crops, or those which tend to lower the water table, such as pumping wells or evapotranspiration, will, therefore, affect the volume of gain (or loss) in riverflow.

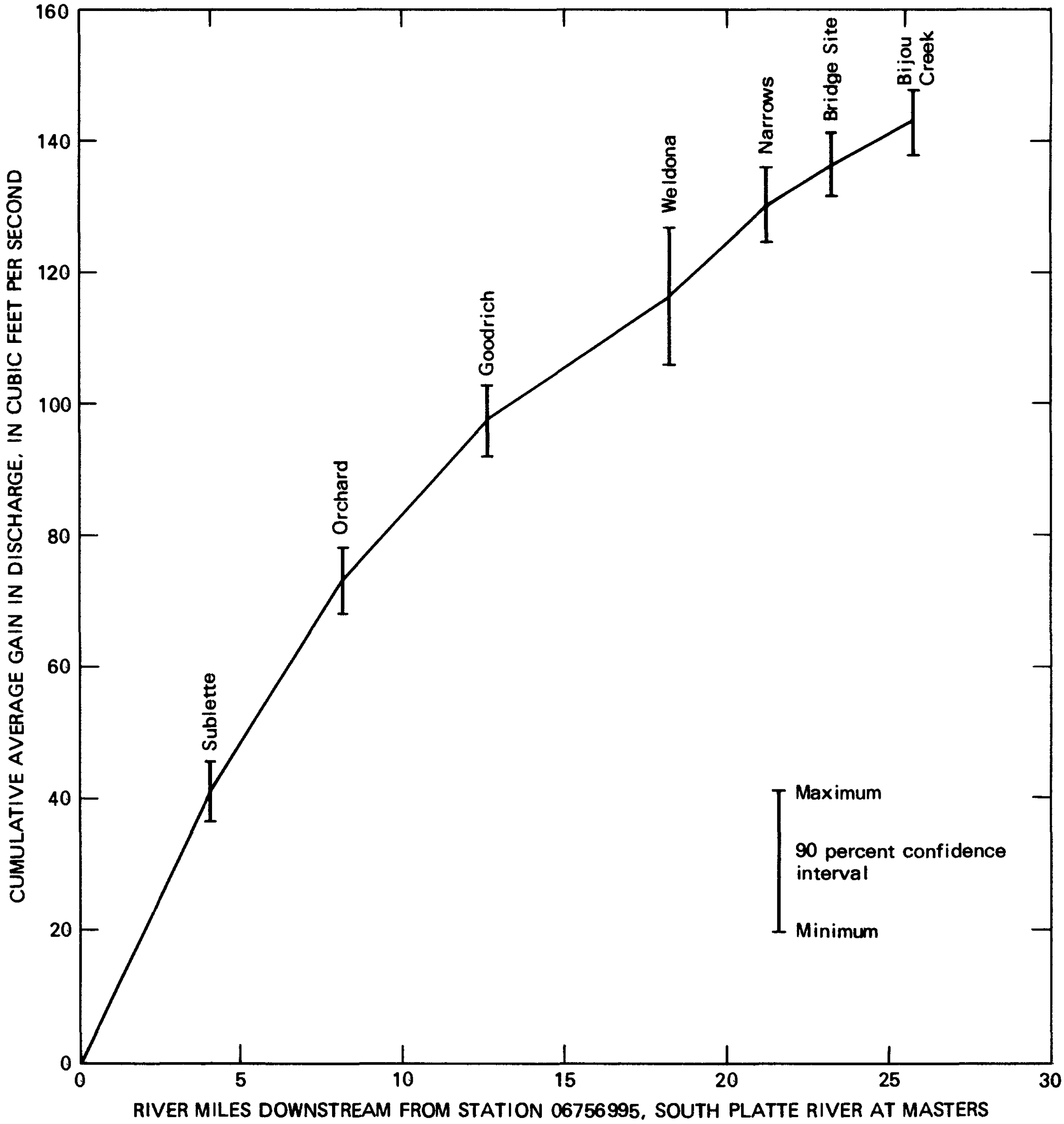

Figure 5.--Cumulative average gain in discharge for all gain-and-loss investigations, South Platte River from station 06756995 at Masters to a site downstream from the Bijou Creek confluence.

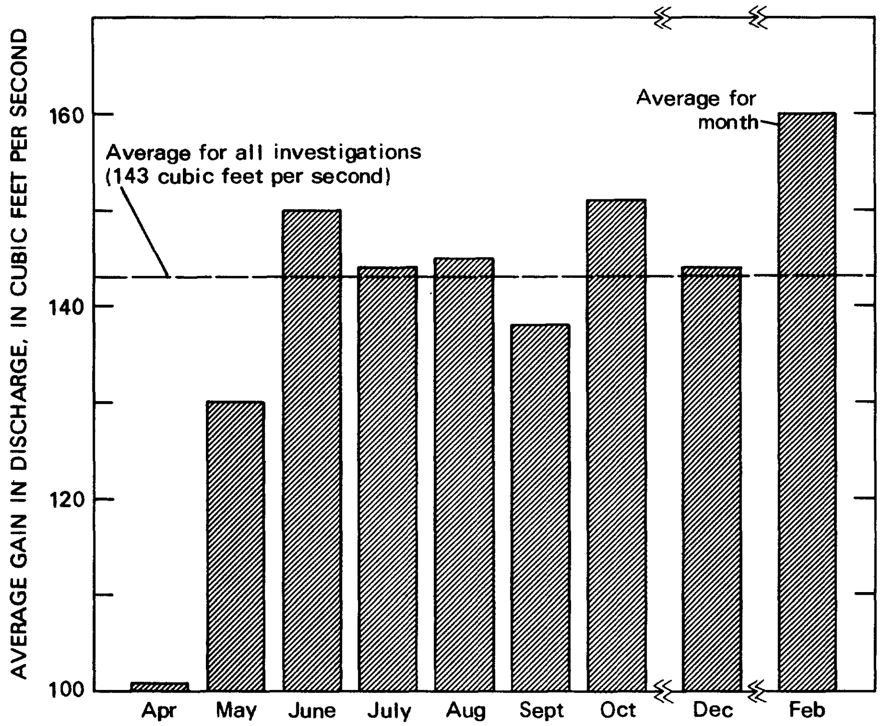

Figure 6.-- Average gain in discharge by month for all gain-and-loss investigations, South Platte River from station 06756995 at Masters to a site downstream from the Bijou Creek confluence.

As shown in figure 6, the average gain is smallest in April just prior to the start of the irrigation season. This small gain is the result of the water table being at its lowest level for the year due to minimal recharge through the winter months. Thereafter, average gains increase through May to a high in June in response to a rise of the water table with the start of ditch diversions and flood irrigation of crops. The gradual decrease in gains from June through September can be attributed to a combination of increasing pumpage from the aquifer together with decreasing surface-water application as supplies diminish through the summer --both of which tend to lower the water table. The increased gain in October probably results primarily from recovery in the near-river water-table elevation as a result of cessation of evapotranspiration by riparian vegetation with freezing temperatures. This effect, in turn, is compounded by cessation of pumping. Thereafter, the decrease in gain in December reflects the gradual decline in water-table elevation after the irrigation season.

The large average gain in February is an anomaly since a continued decline in water-table elevation as a result of minimal recharge should result in decreasing gains through the winter. The large gain noted may be the result of a more short-term effect resulting from ice buildup along the river through the winter. River ice tends to constrict the flow and raise the stage which, in turn, results in an increase in bank storage along the river. With decreasing ice through February, the river stage declines, allowing this bank storage to reenter the river, resulting in the greater gain noted.

UNGAGED FLOWS NEAR SELECTED DITCH HEADGATES

Correlative Discharge Measurements

To document South Platte River discharges near the headgates of three ditch systems that could be affected by the Narrows Reservoir, correlative discharge measurements were made at five sites on the South Platte River and Bijou Creek as well as on intermediate inflows. The purpose of this phase of the study was to develop reliable correlations between discharges at gaged sites and discharges in the vicinity of the ditch headgates. Discharge at Sublette, 4.1 mi downstream from station 06756995 at Masters and 1.1 mi upstream from the Weldon Valley Ditch headgate, was measured concurrently with discharge at station 06756995 at Masters. In addition, South Platte River discharge immediately downstream from the Bijou Creek confluence, 4.5 mi downstream from station 06758500 near Weldona and 1.6 mi upstream from the common diversion dam of the Deuel and Snyder Canal and the Upper Platte and Beaver Canal, was measured concurrently with discharges at stations 06758500 South Platte River near Weldona and 06759100 Bijou Creek near Fort Morgan.

During the first 30 months of the study, discharges at these sites were measured once a week on the average throughout the April 1 to October 31 irrigation season and once a month through the winter (November to March). Adverse ice conditions from late November 1978 to late February 1979 prevented measurements during that period. In addition, high flows due to snowmelt runoff during May, June, and July 1979 precluded weekly measurements. Corrections to measured discharges were made to compensate for nonsteady-state conditions and were calculated in the same manner as for the gain-and-loss investigations.

A graph of the relation between discharge of the South Platte River at Sublette (Q_s) and station 06756995 at Masters (Q_m) is shown in figure 7. Two intermediate inflows--Jackson Lake Inlet Canal waste No. 2 (Day Seep Ditch, fig. 3) and No. 2a--consist of ground-water seepage flows routed to the river during the irrigation season when the canal is not diverting water from the river and, as a result, were not subtracted from the measured Sublette discharge. During the winter, however, when the canal diverts water from the river, these waste flows consist primarily of direct leakage from the canal and were subtracted from the measured Sublette discharge.

A graph of the relation between the discharge of the South Platte River downstream from the Bijou Creek confluence (Q_{dB}) and the discharge at station 06758500 near Weldona (Q_w), assuming no tributary inflow, is shown in figure 8. The discharge of the South Platte River at the site downstream from the Bijou Creek confluence does not include the discharge at station 06759100 Bijou Creek near Fort Morgan (Q_B) or the Weldon Valley ditch terminus waste inflow (Q_{wv}) (see fig. 3). During the irrigation season Weldon Valley ditch terminus waste consists of direct irrigation waste flows that are quite variable and, as a result, have a significant effect on riverflow. Prior to the 1978 irrigation season, a step-backwater survey was done on a reach of this inflow channel approximately 0.5 mi upstream from its mouth from which a theoretical stage-discharge relation was developed. A staff gage was installed at the upstream end of this reach so that the stage of the flow could be used in conjunction with the stage-discharge relation in determining the inflow to be subtracted from riverflow measured downstream from Bijou Creek confluence (Q_{dB}). Discharge measurements made during each gain-and-loss investigation verified the theoretical stage-discharge relation and determined the shift to be applied to the rating. During the winter, flow in the channel consists only of ground-water seepage, and this was not subtracted from riverflow.

Discussion of Results

Regression equations together with correlation coefficients, R, developed from the two sets of discharge data are presented in figures 7 and 8. Because the Weldon Valley ditch terminus waste was determined to have a significant effect on riverflow (average discharge for all irrigation-season measurements was 22.4 ft^3/s with discharges ranging from 4.62 to 47.9 ft^3/s), it was decided to use only those sets of data which included a determination of this discharge in developing the relation for the reach from station 06758500 near Weldona to the site downstream from the Bijou Creek confluence.

As would be expected, there is a significant degree of correlation between discharge at the main-stem stations and that at the ungaged sites. Both relations indicate an average net gain: 44.1 ft^3/s for the reach from station 06756995 at Masters to Sublette and 13.6 ft^3/s for the reach from station 06758500 near Weldona to the site downstream from the Bijou Creek confluence. Of particular interest is the fact that for both sets of data the slopes of the regression lines are virtually 1.00, indicating that the net gain is independent of the magnitude of the main-stem flow. Results for the same subreaches from the 25 gain-and-loss investigations indicate average gains of 41 and 13 ft^3/s, respectively (table 4),

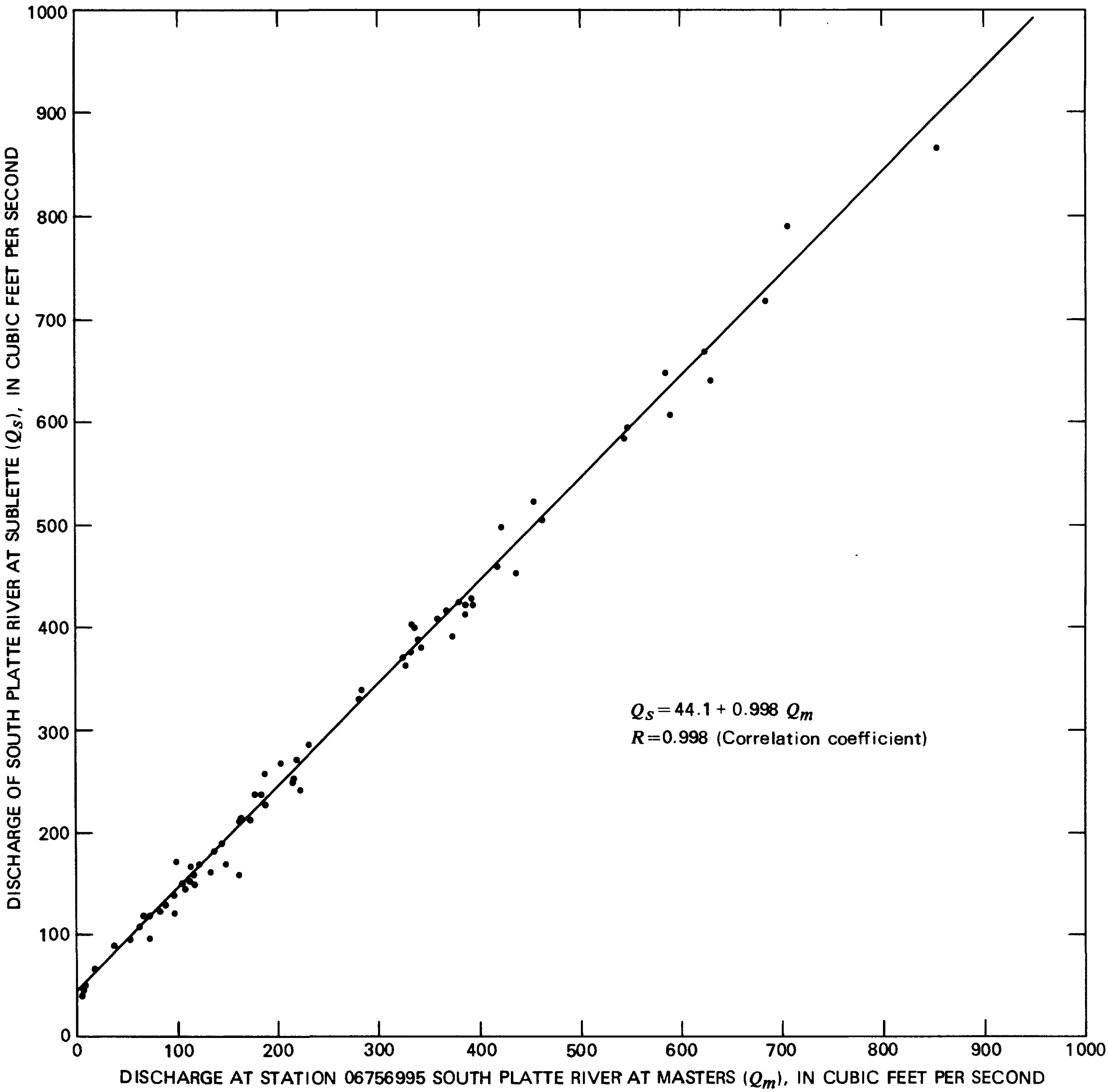

Figure 7.-- Relation between discharge of South Platte River at Sublette and at station 06756995 at Masters.

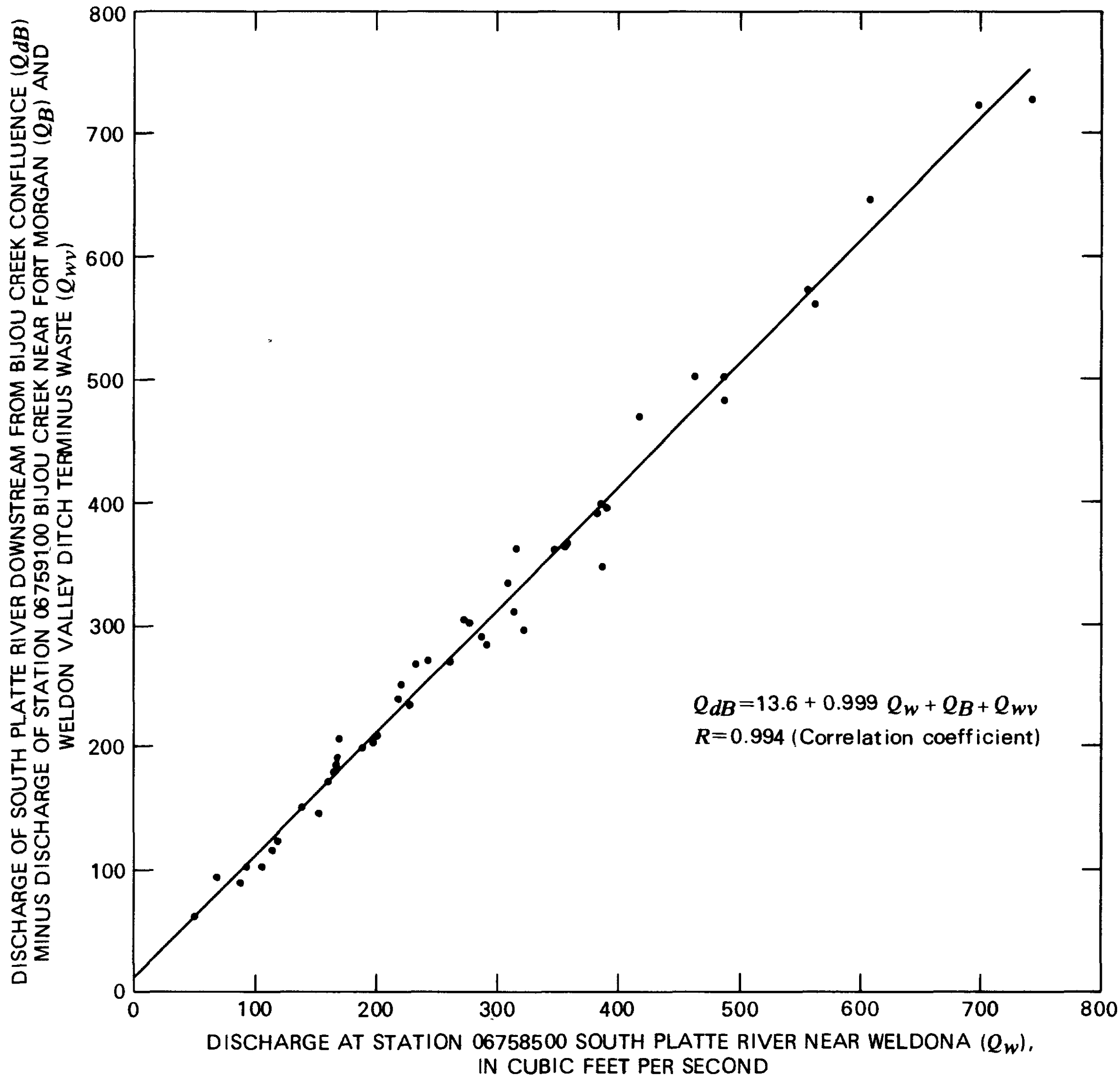

Figure 8.--Relation between discharge of South Platte River downstream from the Bijou Creek confluence and at station 06758500 near Weldona, assuming no tributary inflow.

which agree very well with the regression-equation results. The gains indicated by the regression equations, however, are considered more reliable because they were developed from 73 and 47 data sets, respectively.

Several sets of data were not used in developing the relations because of nonsteady conditions in the South Platte River or in Bijou Creek. Although the remaining sets of data represent reasonably steady conditions, the calculated gains (or losses) show a relatively large degree of variation. This variation most probably is due to a combination of short-term and long-term transient effects and measurement error, as discussed earlier, together with undetected variations in Weldon Valley ditch terminus waste inflows into the reach of the South Platte River from station 06758500 near Weldona to the site downstream from the Bijou Creek confluence.

CONCLUSIONS

Summaries of dissolved-constituent concentration data for the South Platte River streamflow-gaging stations at Masters and near Weldona, 21.3 river miles downstream, indicate increases in the mean concentrations of all constituents except orthophosphate, iron, and manganese. In addition, all major chemical constituents in samples collected at the two South Platte River stations and the Bijou Creek station are significantly correlated with specific conductance at the 95-percent confidence level except for: (1) Oxygen, carbonate, nitrogen, orthophosphate, and fluoride at all three stations; (2) silica at the Masters and Bijou Creek stations; and (3) calcium and potassium at the Bijou Creek station. Total monthly suspended-sediment load in general shows a linear relation to total monthly discharge at station 06758500 South Platte River near Weldona.

The average gain in discharge in the 25.8-mi study reach of the South Platte River in the vicinity of the proposed Narrows Reservoir was 143 ft^3/s for 25 gain-and-loss investigations conducted during 3 years--1977, 1978, and 1979. The gain averaged 138 ft^3/s in 20 investigations conducted during the irrigation season (April 1 to October 31) and 161 ft^3/s in 5 investigations during the winter months of December and February.

Measured gains in river discharge were found to be related to saturated thickness of the alluvial acquifer in the valley-fill beneath the river. The largest average measured gain, 41 ft^3/s, was in the most upstream subreach where saturated thickness averages more than 120 ft, whereas the smallest average measured gains, 6 and 7 ft^3/s, were within the two most downstream subreaches where average saturated thickness is less than 10 ft.

Correlative discharge measurements to relate ungaged discharge near selected ditch headgates to discharge at the two main-stem streamflow-gaging stations indicated a significant degree of correlation between gaged and ungaged discharge. Linear-regression summaries of these measurements indicated an average gain of 44.1 ft^3/s within the 4.1 mi of the most upstream subreach and an average gain of 13.6 ft^3/s within the 4.5 mi of the two most downstream subreaches. These average gains were found to be virtually constant and independent of the magnitude of river discharge.

SELECTED REFERENCES

Bjorklund, L.J., and Brown, R. F., 1957, Geology and ground-water resources of the lower South Platte River valley between Hardin, Colorado, and Paxton, Nebraska, *with a section on* Chemical quality of the ground water, by H.A. Swenson: U.S. Geological Survey Water-Supply Paper 1378, 431 p.

Carpenter, L. G., 1911, Seepage and return waters: Colorado Agricultural Experiment Station Bulletin 180, Part 1, 70 p.

Hurr, R. T., Schneider, P. A., Jr., and Minges, D. R., 1975, Hydrology of the South Platte River valley, northeastern Colorado: U.S. Geological Survey Circular 28, 24 p., 5 maps.

Hurr, R.T., Schneider, P. A., Jr., and others, 1972, Hydrogeologic characteristics of the valley-fill aquifer in the Weldona reach of the South Platte River valley, Colorado: U.S. Geological Survey open-file report, 2 p., 6 maps.

Matthai, H. F., 1968, Magnitude and frequency of floods in the United States, Part 6-B, Missouri River basin below Sioux City, Iowa: U.S. Geological Survey Water-Supply Paper 1680, 491 p.

Parshall, R. L., 1922, Return of seepage water to the lower South Platte River in Colorado: Colorado Agricultural Experiment Station Bulletin 279, 72 p.

U.S. Bureau of Reclamation, 1967, Report on the Narrows Unit, Colorado, South Platte division, Missouri River basin project: U.S. Bureau of Reclamation, 125 p., appendix.

U.S. Geological Survey, 1978, Water resources data for Colorado, Water year 1977, Volume 1. Missouri River basin, Arkansas River basin, Rio Grande basin: U.S. Geological Survey Water-Data Report CO-77-1, 369 p.

_____1979, Water resources data for Colorado, Water year 1978, Volume 1. Missouri River basin, Arkansas River basin, Rio Grande basin: U.S. Geological Survey Water-Data Report CO-78-1, 415 p.

_____1980, Water resources data for Colorado, Water year 1979, Volume 1. Missouri River basin, Arkansas River basin, Rio Grande basin: U.S. Geological Survey Water-Data Report CO-79-1, 499 p.

☆ U.S. Government Printing Office 1984 - 680-387/394 Reg. 8