STREAMFLOW FOR IRRIGATION IN THE UPPER PRYOR CREEK BASIN, MONTANA, BASE PERIOD WATER YEARS 1937-86

By Dave R. Johnson

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CONVERSION FACTORS AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
acre	0.4047	hectare
acre-foot (acre-ft)	1,233	cubic meter
acre-foot per acre (acre-ft/acre)	0.3048	cubic meter per square meter
cubic foot per second (ft^3/s)	0.028317	cubic meter per second
inch (in.)	25.4	millimeter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.59	square kilometer

Temperature can be converted to degrees Fahrenheit (°F) by the equation:

$$°F = 9/5\ (°C) + 32$$

Water-quality units that are abbreviated in this report:

μg/L micrograms per liter
μS/cm microsiemens per centimeter at 25 degrees Celsius
mg/L milligrams per liter

Water-year definition:

A water year is the 12-month period October 1 through September 30. It is designated by the calendar year in which it ends.

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ABSTRACT

Streamflow and its use for irrigation were studied in the upper Pryor Creek basin. This report describes the data and methods of analysis used to determine the streamflow availability, water needs for irrigation, adequacy of streamflow quantity for irrigation, and streamflow quality.

Two methods were used to estimate mean monthly streamflow. The concurrent-measurement method was used to estimate mean monthly flow at 13 ungaged sites where irrigation use was assumed to be negligible. This method is based on the correlation of measured flow at ungaged sites with the flow at a gaged site. The gain-loss-measurement method was used to estimate the mean monthly natural flow at two ungaged sites along Pryor Creek where irrigation use is substantial. This method is based on two sets of gain-loss streamflow measurements, which describe a nearly linear increase of flow in a 10-mile reach of Pryor Creek.

To evaluate water needs for irrigation in the study area, monthly and seasonal water requirements and losses were determined. The consumptive-use requirement was calculated using factors for alfalfa. The conveyance and on-farm losses and the diversion requirement were calculated using factors based on the overall irrigation efficiency in Big Horn County. The resulting data for the Pryor Unit indicate that the irrigation-season diversion requirement is about 15,300 acre-feet.

The streamflow quantity available in the Pryor Unit during the irrigation season is about 50 percent of the diversion requirement. However, the available streamflow would be adequate to almost meet the consumptive-use requirement of the Pryor Unit if conveyance losses were eliminated and on-farm irrigation efficiency were increased.

Water samples for chemical analysis were collected at 8 streamflow sites on August 16, 1989, and 11 sites on July 24, 1990. The dissolved-solids concentration in water from Pryor Creek increased downstream from 346 to 543 milligrams per liter for the August samples and from 331 to 517 milligrams per liter for the July samples. Dissolved-solids concentrations in 17 of the 19 water samples collected for chemical analysis were less than 1,000 milligrams per liter. These results indicate that, with few exceptions, the water generally is suitable for irrigation with respect to dissolved-solids concentration.

INTRODUCTION

Streams in the upper Pryor Creek basin drain about 225 mi^2 of mountains and foothills in the Crow Indian Reservation in south-central Montana (fig. 1). The annual precipitation at Pryor is about 16 in., with more than half occurring during the irrigation season (May-September). Pryor Creek is an important, although limited, source of water for irrigating croplands. In Pryor Creek valley, the limited streamflow and large irrigation-ditch conveyance losses caused by porous soil have restricted irrigation and irrigation development.

Tribal officials need detailed knowledge of streamflow to evaluate its adequacy for irrigation in the upper Pryor Creek basin. Accordingly, the Crow Tribe requested the U.S. Bureau of Indian Affairs to enter into a cooperative program with the U.S. Geological Survey to study the adequacy of streamflow for irrigation in the basin.

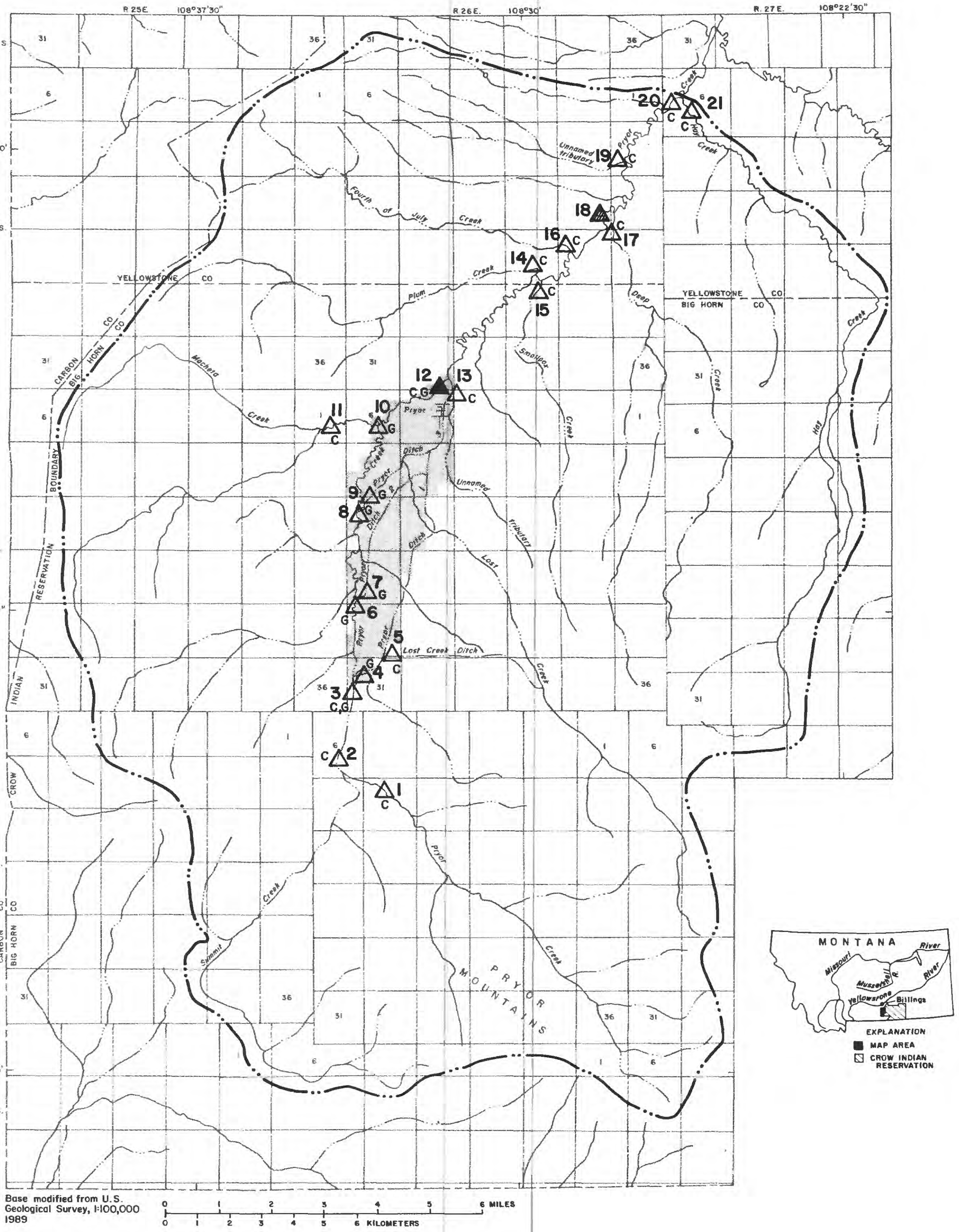

Figure 1.--Location of study area, ungaged study sites, and one streamflow-gaging station used for estimation and correlation.

EXPLANATION FOR FIGURE 1

PRYOR UNIT

BASIN BOUNDARY (STUDY AREA)

12▲ STREAMFLOW-GAGING STATION AND SITE NUMBER (STATION 06216000)--Used for estimation and correlation

18▲ STREAMFLOW-MEASUREMENT SITE AND NUMBER--Not used for estimation or correlation

2△ UNGAGED STREAMFLOW-ESTIMATION SITE AND NUMBER

LETTERS INDICATE METHOD OF STREAMFLOW ESTIMATION

- C Concurrent-measurement method
- G Gain-loss-measurement method
- C,G Both concurrent-measurement and gain-loss-measurement methods

Purpose and Scope

This report describes the results of the study. Specifically, the report describes the data and methods of analysis used to determine the streamflow, water needs for irrigation, adequacy of streamflow quantity for irrigation, and streamflow quality.

Long-term (water years 1937-86) mean monthly streamflows were estimated using two methods. The first method (concurrent measurement) was based on the assumption that the streamflow record at the gaged site, Pryor Creek at Pryor (site 12, station 06216000), is representative of tributary streamflow. This method is a curve-fitting technique that correlates measured flow at an ungaged site with concurrent daily flow at the gaged site. The log-linear relations thus developed were used to estimate the long-term mean monthly flow at 13 ungaged sites upstream from, within, and downstream from the Pryor Unit (fig. 1). The second method (gain-loss measurement) was based on streamflow measurements at five sites along Pryor Creek. In this method, estimated mean monthly natural flow of Pryor Creek upstream from Macheta Creek was used to estimate available mean monthly natural flow at two sites on Pryor Creek.

Water needs for irrigation of crops in the study area were calculated from consumptive-use, irrigated-acreage, and county irrigation-efficiency data. The water requirements were calculated for monthly and irrigation-season time periods using normal seasonal consumptive-use data for alfalfa.

Nineteen water samples were collected from Pryor Creek, selected tributaries, and irrigation ditches for chemical analysis. Dissolved-solids concentrations determined from these analyses were used to indicate the suitability of the water for irrigation.

Acknowledgments

Appreciation is expressed to Lawrence A. Merritt, Bruce M. Bochy, Timothy J. Morgan, and James L. Fisher of the U.S. Geological Survey Field Headquarters in Billings. They determined stream and irrigation-ditch flows, collected water samples for chemical analysis, and noted which fields were being irrigated.

METHODS OF ESTIMATING STREAMFLOW

Long-term mean monthly streamflows were estimated using two methods: concurrent measurements and gain-loss measurements. The first method correlates measured flow at an ungaged site with flow at a gaged site. The second method uses natural flow of the mainstem to estimate flow at other sites on the mainstem.

Concurrent-Measurement Method

Estimates of long-term mean monthly streamflow are needed at selected sites to determine if the quantity of streamflow in the Pryor Creek basin is generally sufficient for irrigation. In any stream, the quantity of flow is a function of the natural (unaffected by human use) flow and the degree of use. For streams with no significant use, the flow at any point is the natural flow. The concurrent-measurement method, which is based on the correlation of streamflow measurements at ungaged sites with concurrent streamflow at a gaged site, is applicable only to sites where irrigation use is negligible.

For this study, the concurrent-measurement method was based on streamflow measurements at 13 ungaged sites and 1 gaged site (fig. 1). Only measurements made from April through September 1989 were included in the analysis; thus, four measurements were available for site 2 and nine measurements were available for each of the other 13 sites (table 1). Data for Pryor Ditches 1, 2, and 3 (sites 4, 7, and 9) were not included in this analysis, because they represent withdrawals rather than available streamflow.

Table 1.--*Instantaneous streamflow and specific conductance at measurement sites*

[Estimation method: C, concurrent measurement; G, gain-loss measurement. ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; --, no data or not applicable]

Site No. (fig. 1)	Site name	Esti-mation method	Date	Stream-flow (ft^3/s)	Spe-cific conduct-ance (µS/cm)	Date	Stream-flow (ft^3/s)	Spe-cific conduct-ance (µS/cm)
1	Pryor Creek upstream from Summit Creek, near Pryor	C	04-20-89	5.7	345	07-20-89	3.1	319
			05-11-89	7.6	330	08-16-89	3.1	402
			05-25-89	6.6	365	09-12-89	3.0	335
			06-01-89	5.8	329	10-24-89	2.7	391
			06-16-89	4.9	349	03-29-90	3.5	379
			07-07-89	3.9	330	07-24-90	5.9	389
2	Pryor Creek downstream from Summit Creek, near Pryor	C	05-25-89	.3	378	10-24-89	.2	390
			08-30-89	.02	340	03-29-90	0	--
			09-07-89	.2	278	07-24-90	.6	--
			09-26-89	.1	367			
3	Pryor Creek upstream from Pryor Ditch 1, near Pryor	C,G	04-20-89	0	--	07-20-89	0	--
			05-11-89	0	--	08-16-89	0	--
			05-25-89	0	--	09-12-89	0	--
			06-01-89	0	--	10-24-89	0	--
			06-16-89	0	--	03-29-90	0	--
			07-07-89	0	--	07-24-90	0	--
4	Pryor Ditch 1 near Pryor	G	04-20-89	0	--	07-20-89	0	--
			05-11-89	0	--	08-16-89	0	--
			05-25-89	0	--	09-12-89	0	--
			06-01-89	0	--	10-24-89	0	--
			06-16-89	0	--	03-29-90	0	--
			07-07-89	0	--	07-24-90	0	--
5	Lost Creek Ditch near Pryor	C	04-20-89	.9	--	07-20-89	.6	--
			05-11-89	.8	--	08-16-89	.5	380
			05-25-89	.6	348	09-12-89	.5	--
			06-01-89	.5	--	03-29-90	.4	--
			06-16-89	.6	--	07-24-90	1.0	338
			07-07-89	.6	--			
6	Pryor Creek upstream from Pryor Ditch 2, near Pryor	G	10-24-89	[1]5.3	[2]490	07-24-90	[1]13.8	[2]448
			03-29-90	[1]6.9	[2]455			
7	Pryor Ditch 2 near Pryor	G	04-20-89	.02	--	07-20-89	8.3	--
			05-11-89	.3	--	08-16-89	7.4	494
			05-25-89	.3	--	09-12-89	7.6	--
			06-01-89	.4	--	10-24-89	.2	--
			06-16-89	6.4	--	03-29-90	.1	--
			07-07-89	6.7	--	07-24-90	8.4	434
8	Pryor Creek upstream from Pryor Ditch 3, near Pryor	G	10-24-89	15.5	490	07-24-90	12.5	442
			03-29-90	[3]13.2	--			
9	Pryor Ditch 3 near Pryor	G	04-20-89	0	--	07-20-89	5.8	--
			05-11-89	0	--	08-16-89	1.2	498
			05-25-89	0	--	09-12-89	.4	--
			06-01-89	0	--	10-24-89	3.5	--
			06-16-89	2.9	--	03-29-90	1.2	--
			07-07-89	5.5	--	07-24-90	3.3	434
10	Pryor Creek upstream from Macheta Creek, near Pryor	G	10-24-89	[4]15.3	[5]850	07-24-90	[4]10.6	[5]495
			03-29-90	[4]18.7	[5]522			
11	Macheta Creek near Pryor	C	04-20-89	1.3	--	07-20-89	.1	920
			05-11-89	1.5	879	08-16-89	0	--
			05-25-89	1.2	885	09-12-89	.01	850
			06-01-89	1.2	--	10-24-89	.2	850
			06-16-89	.5	329	03-29-90	1.4	918
			07-07-89	.03	475	07-24-90	.1	790

Table 1.--*Instantaneous streamflow and specific conductance at measurement sites*--Continued

Site No. (fig. 1)	Site name	Esti-mation method	Date	Stream-flow (ft^3/s)	Spe-cific conduct-ance (µS/cm)	Date	Stream-flow (ft^3/s)	Spe-cific conduct-ance (µS/cm)
12	Pryor Creek at Pryor (station 06216000)	C,G	04-20-89	27.0	--	07-20-89	7.2	--
			05-11-89	27.5	462	08-16-89	8.5	528
			05-25-89	26.0	478	09-12-89	16.1	495
			06-01-89	26.1	--	10-24-89	17.1	518
			06-16-89	13.4	511	03-29-90	23.5	538
			07-07-89	6.6	266	07-24-90	10.1	498
13	Unnamed tributary at Pryor	C	04-20-89	0	--	07-20-89	0	--
			05-11-89	0	--	08-16-89	0	--
			05-25-89	0	--	09-12-89	0	--
			06-01-89	0	--	10-24-89	0	--
			06-16-89	0	--	03-29-90	0	--
			07-07-89	0	--	07-24-90	0	--
14	Plum Creek near Pryor	C	04-20-89	.02	--	07-20-89	0	--
			05-11-89	.1	978	08-16-89	0	--
			05-25-89	.04	1,080	09-12-89	0	--
			06-01-89	.01	1,080	10-24-89	0	--
			06-16-89	0	--	03-29-90	.02	--
			07-07-89	0	--	07-24-90	0	--
15	Smallpox Creek near Pryor	C	04-20-89	1.0	--	07-20-89	.1	890
			05-11-89	.9	730	08-16-89	.1	995
			05-25-89	.8	775	09-12-89	.1	905
			06-01-89	.8	724	10-24-89	.1	760
			06-16-89	.5	779	03-29-90	.6	--
			07-07-89	.1	765	07-24-90	.1	903
16	Fourth of July Creek near Pryor	C	04-20-89	.4	--	07-20-89	0	--
			05-11-89	.4	1,740	08-16-89	0	--
			05-25-89	.3	1,780	09-12-89	0	--
			06-01-89	.3	1,780	10-24-89	0	--
			06-16-89	.1	--	03-29-90	.8	1,540
			07-07-89	0	--	07-24-90	.3	775
17	Deep Creek near Pryor	C	04-20-89	1.5	--	07-20-89	.1	1,280
			05-11-89	2.3	900	08-16-89	.1	1,400
			05-25-89	1.9	1,100	09-12-89	.1	--
			06-01-89	1.6	945	10-24-89	.1	--
			06-16-89	.6	1,100	03-29-90	2.0	900
			07-07-89	.2	1,190	07-24-90	.1	1,220
18	Pryor Creek downstream from Deep Creek, near Pryor	--	10-24-89	29.9	525	07-24-90	9.5	--
			03-29-90	20.1	622			
19	Unnamed tributary downstream from Deep Creek, near Pryor	C	04-20-89	.2	--	07-20-89	0	--
			05-11-89	.01	1,550	08-16-89	0	--
			05-25-89	0	--	09-12-89	0	--
			06-01-89	0	--	10-24-89	0	--
			06-16-89	0	--	03-29-90	0	--
			07-07-89	0	--	07-24-90	0	--
20	Pryor Creek upstream from Hay Creek, near Pryor	C	04-20-89	34.0	--	07-20-89	6.6	640
			05-11-89	33.8	548	08-16-89	8.6	642
			05-25-89	31.0	592	09-12-89	20.6	542
			06-01-89	32.5	543	10-24-89	19.1	--
			06-16-89	20.0	604	03-29-90	28.9	654
			07-07-89	5.1	618	07-24-90	10.3	622
21	Hay Creek near Pryor	C	04-20-89	5.0	--	07-20-89	.3	865
			05-11-89	7.0	710	08-16-89	.01	--
			05-25-89	4.8	795	09-12-89	0	--
			06-01-89	4.8	720	10-24-89	1.4	--
			06-16-89	2.9	772	03-29-90	5.6	845
			07-07-89	.5	835	07-24-90	.9	899

[1] Streamflow computed by adding measured flow in Pryor Ditch 2 to measured flow in Pryor Creek just downstream from Pryor Ditch 2.
[2] Specific conductance measured just downstream from Pryor Ditch 2.
[3] Streamflow computed by adding measured flow in Pryor Ditch 3 to measured flow in Pryor Creek just downstream from Pryor Ditch 3.
[4] Streamflow computed by subtracting tributary inflow (site 11) from measured flow in Pryor Creek just downstream from tributary.
[5] Specific conductance measured just downstream from Macheta Creek.

In the concurrent-measurement method analysis, long-term (water years 1937-86) mean monthly streamflow estimates for the gaged site, Pryor Creek at Pryor (site 12), were developed using a mixed-station record-extension procedure described by Alley and Burns (1983). This mixed-station procedure necessitates selecting the best base stations from all those available in a region to fill in each month of missing record. The same set of base stations used in the Musselshell River basin study for the Plains Region (Parrett and Johnson, 1989) was used to extend the record of site 12. The curve-fitting technique and record-extension procedure are described in detail by Parrett and Johnson (1989) and Parrett and others (1989).

Next, measured streamflows at each ungaged site were paired with concurrent flows for gaged site 12, and a line was drawn through the logarithms of the data set using the MOVE.1 (Maintenance of Variance Extension, Type 1) curve-fitting technique (Parrett and Johnson, 1989; Parrett and others, 1989). Because zero flows are commmon in the Pryor Creek basin, 1 ft^3/s was added to all streamflows before the data were converted to logarithms. An example of a typical MOVE.1 line fit to streamflow data at an ungaged site in the study area is shown in figure 2. To estimate the long-term mean monthly streamflow at an ungaged site using the concurrent-measurement method, the long-term mean monthly streamflow at the gaged site plus 1 ft^3/s (value of 20 ft^3/s) is located on the x-axis and projected upward to the MOVE.1 line; the estimated value then is read on the y-axis (value of 2 ft^3/s) as shown in figure 2. Finally, 1 ft^3/s is subtracted from the value read from the y-axis to arrive at the correct estimated long-term mean monthly streamflow for the ungaged site (2 - 1 = 1 ft^3/s).

Estimates of long-term mean monthly, mean annual, and mean irrigation-season available streamflow for the 13 ungaged sites and 1 gaged site are given (table 2). Because of the overall streamflow characteristics, the reliability of concurrent-

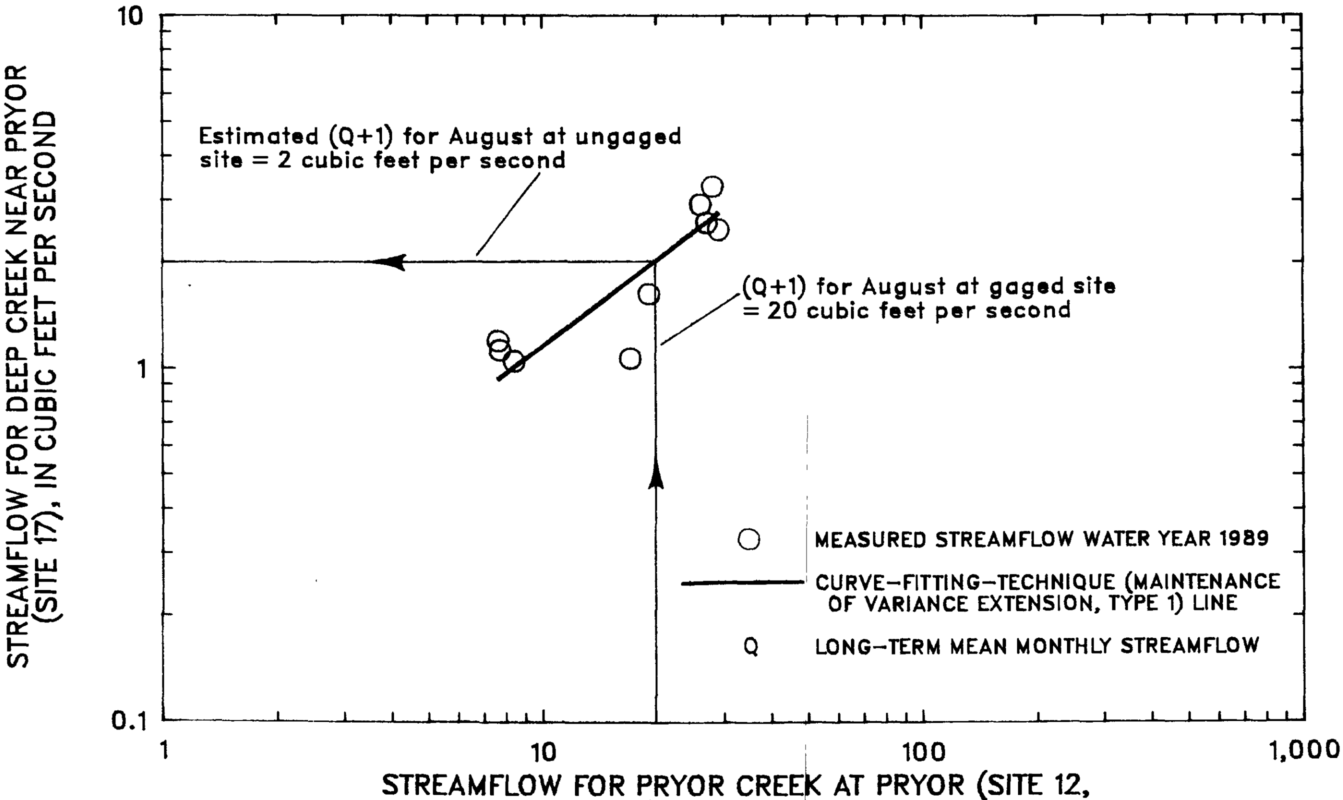

Figure 2.--Line for the curve-fitting technique and an example of estimation of the long-term mean monthly streamflow for an ungaged site.

measurement estimates for this study area is considered to be comparable to that for the Plains Region in the Mussellshell River basin study (Parrett and Johnson, 1989). Standard errors in the Plains Region of that study, in log units, ranged from 0.39 to 0.68. The large standard errors were attributed to the large natural variability of streamflow and the considerable effect of irrigation on streamflow in the Plains Region.

Table 2.--*Estimated long-term mean monthly, mean annual, and mean irrigation-season streamflow*

[--, no data]

Site No. (fig. 1)	Site name	Cubic feet per second Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
1	Pryor Creek upstream from Summit Creek, near Pryor	7	7	7	6	6	7	7
2	Pryor Creek downstream from Summit Creek, near Pryor	.5	.5	.5	.4	.4	.6	.5
3	Pryor Creek upstream from Pryor Ditch 1, near Pryor	0	0	0	0	0	0	0
5	Lost Creek Ditch near Pryor[1]	--	--	--	--	--	--	--
11	Macheta Creek near Pryor	1	1	1	1	1	2	2
12	Pryor Creek at Pryor (station 06216000)	30	31	33	28	26	35	33
13	Unnamed tributary at Pryor	0	0	0	0	0	0	0
14	Plum Creek near Pryor	0	0	.1	0	0	.1	.1
15	Smallpox Creek near Pryor	.9	1	1	.9	.8	1	1
16	Fourth of July Creek near Pryor	.4	.4	.4	.3	.3	.4	.4
17	Deep Creek near Pryor	2	2	2	2	2	2	2
19	Unnamed tributary downstream from Deep Creek, near Pryor	.1	.1	.1	.1	.1	.1	.1
20	Pryor Creek upstream from Hay Creek, near Pryor	39	41	44	35	33	47	44
21	Hay Creek near Pryor	6	7	7	5	5	8	7

Site No. (fig. 1)	Site name	Cubic feet per second May	June	July	Aug.	Sept.	Mean annual	Mean irrigation season (May-Sept.)
1	Pryor Creek upstream from Summit Creek, near Pryor	9	8	6	5	6	7	7
2	Pryor Creek downstream from Summit Creek, near Pryor	.8	.7	.4	.2	.4	.5	.5
3	Pryor Creek upstream from Pryor Ditch 1, near Pryor	0	0	0	0	0	0	0
5	Lost Creek Ditch near Pryor[1]	.9	.9	.7	.7	.7	--	.8
11	Macheta Creek near Pryor	2	2	1	.7	1	1	1
12	Pryor Creek at Pryor (station 06216000)	50	46	24	19	25	32	33
13	Unnamed tributary at Pryor	0	0	0	0	0	0	0
14	Plum Creek near Pryor	.1	.1	0	0	0	0	0
15	Smallpox Creek near Pryor	1	1	.8	.6	.8	.9	.8
16	Fourth of July Creek near Pryor	.6	.5	.3	.2	.3	.4	.4
17	Deep Creek near Pryor	3	3	2	1	1	2	2
19	Unnamed tributary downstream from Deep Creek, near Pryor	.1	.1	.1	0	.1	.1	.1
20	Pryor Creek upstream from Hay Creek, near Pryor	72	64	30	22	31	42	44
21	Hay Creek near Pryor	14	12	4	3	5	7	8

[1] No estimates made outside the irrigation season because flow may be discontinued.

Gain-Loss-Measurement Method

Because of the large observed flow variability of Pryor Creek upstream from the gaged site, three sets of gain-loss measurements (fig. 3) were made along 33 mi of Pryor Creek to document the ground-water/surface-water interaction and to estimate long-term mean monthly flow of Pryor Creek upstream from Pryor Ditches 2 and 3 (at sites 6 and 8). The October measurements were made after the 1989 irrigation season, the March measurements were made before the 1990 irrigation season, at or near base flow, and the July measurements were made during the 1990 irrigation season. The July 24th measurements are presented for comparative purposes only, because gaged records showed a streamflow increase greater than 25 percent on that day.

As shown in figure 3, the flow of Pryor Creek is interrupted (near sites 2 and 3) and variable. The gain-loss measurements indicate that Pryor Creek loses flow in the reach farthest upstream, is dry upstream from Pryor Ditch 1 (site 3), and gains substantial flow between site 3 and site 10 (upstream from Macheta Creek). The October and March measurements indicate that Pryor Creek gains flow between Macheta Creek and Deep Creek, but loses flow downstream from Deep Creek (site 18) to upstream from Hay Creek near Pryor (site 20). The loss in streamflow might be

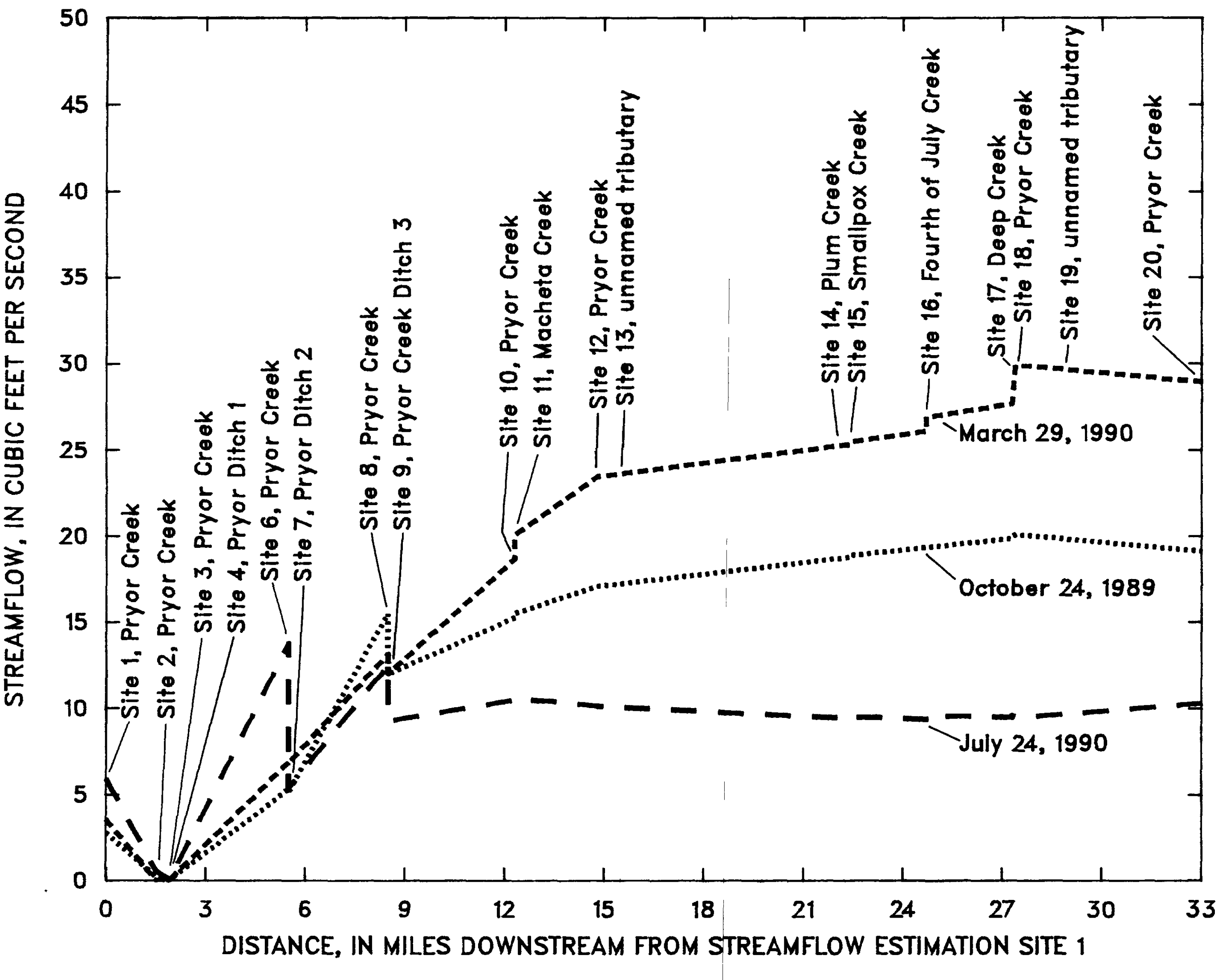

Figure 3.--Results of gain-loss measurements of flow at selected sites along Pryor Creek, October 24, 1989; March 29, 1990; and July 24, 1990.

the result of an unaccounted diversion in this reach. A sudden decrease of streamflow (fig. 3) represents water withdrawal; for example, Pryor Creek downstream from site 8 at times loses flow to Pryor Ditch 3 (site 9). A sudden increase represents tributary inflow; for example, Pryor Creek downstream from site 10 gains flow from Macheta Creek (site 11).

Because of variable streamflows and substantial withdrawals for irrigation between sites 3 and 10, a multi-step, gain-loss-measurement method for estimating the long-term mean monthly streamflow was developed for this reach of Pryor Creek. In this instance, the effect of irrigation withdrawals was minimized by adding, sequentially, measured flows of Pryor Ditches 1, 2, and 3 (sites 4, 7, and 9) to the measured streamflows at sites 6, 8, and 10). Streamflow at site 12, although outside the reach between sites 3 and 10, also was used in the natural-flow determination. All these flows, hereinafter referred to as natural streamflows, represent those that likely would have occurred without any human use of the water.

Computed natural streamflows for the October 1989 and March 1990 measurements are presented in figure 4. As shown, natural streamflow increases nearly linearly between sites 3 and 10 for both sets of measurements. The linear relation can be used to determine the long-term mean monthly natural streamflow at any point on Pryor Creek within that reach if the long-term mean monthly natural flows are known for sites 3 and 10. On the basis of available measurements, long-term mean monthly natural streamflow at site 3 for all months during the irrigation season is zero (table 3).

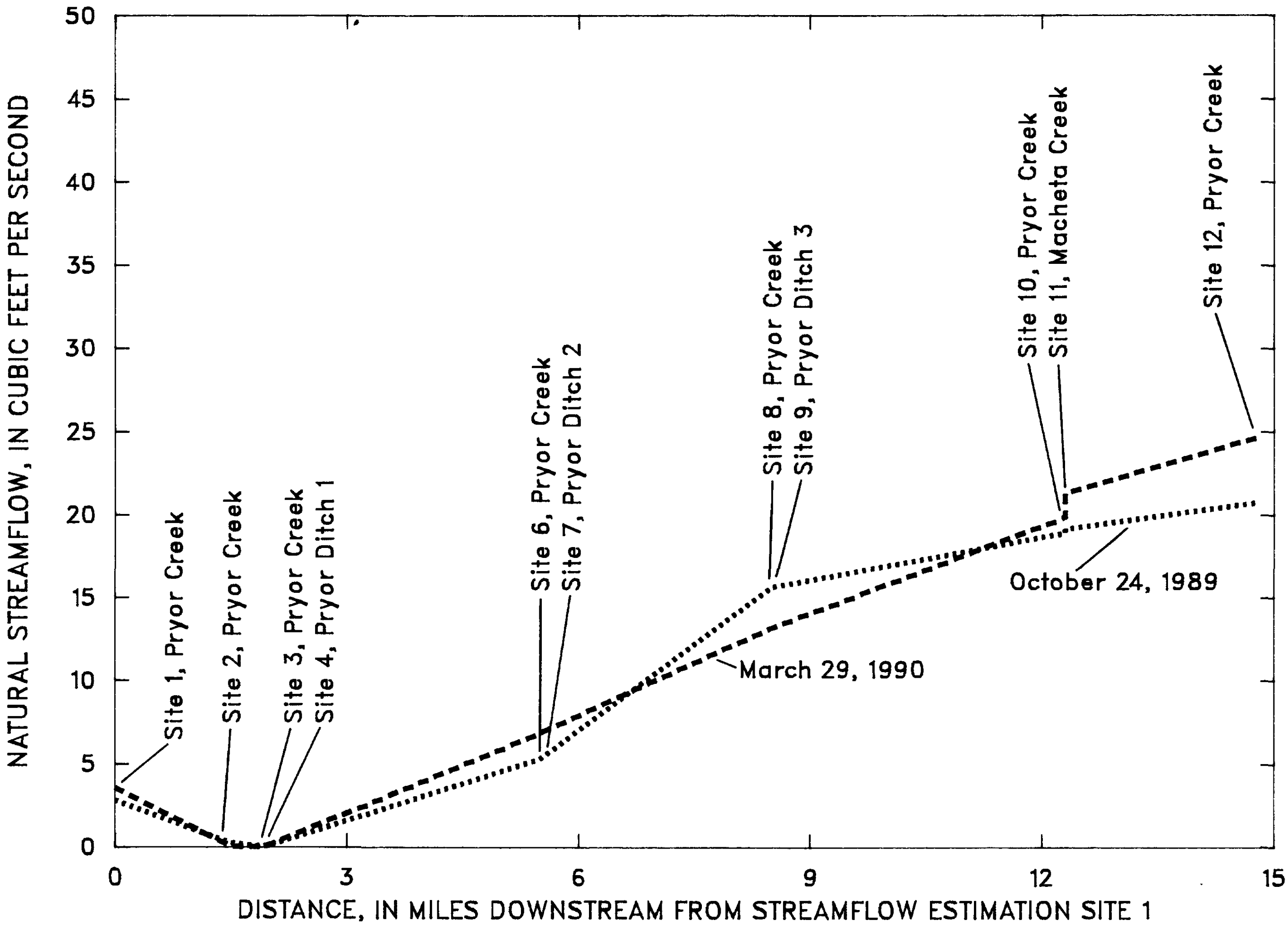

Figure 4.--Computed natural flow of Pryor Creek, October 24, 1989, and March 29, 1990.

Table 3.--*Estimated long-term mean monthly natural flow of Pryor Creek for the irrigation season*

Site No. (fig. 1)	Site name	Cubic feet per second				
		May	June	July	Aug.	Sept.
3	Pryor Creek upstream from Pryor Ditch 1, near Pryor	0	0	0	0	0
6	Pryor Creek upstream from Pryor Ditch 2, near Pryor	16	19	13	10	10
8	Pryor Creek upstream from Pryor Ditch 3, near Pryor	29	34	24	19	18
10	Pryor Creek upstream from Macheta Creek, near Pryor	45	54	38	29	28
12	Pryor Creek at Pryor (station 06216000)	50	59	42	33	32

The first step in estimating natural streamflow using the gain-loss-measurement method was to determine the long-term mean monthly natural streamflow at the gaging station (site 12), which was assumed to equal the long-term mean monthly flow for site 12 plus that for sites 4, 7, and 9. The long-term mean monthly flow for sites 4, 7, and 9 was based on estimates of monthly mean flow for the 1989 irrigation season. Because Pryor Ditch 1 at site 4 was dry during all visits in 1989, the long-term mean monthly flow for site 4 was estimated to be zero for all months. For sites 7 and 9, monthly mean flow was based on nine measurements from April through September 1989. Each measurement was assumed to equal the daily mean flow, which was assumed to be constant for one-half the elapsed time since the last measurement plus one-half the elapsed time until the next measurement. The daily values thus determined were summed and then divided by the number of days of the month to yield estimates of monthly mean flow for 1989. Between measurements at both sites, flows were assumed to be fairly constant because headgate settings were observed to not vary greatly.

Long-term mean monthly flows for the ditches (sites 7 and 9) were computed by multiplying the 1989 monthly mean flow of the ditches by the long-term mean monthly flow at site 12, then dividing the product by the 1989 monthly mean flow at site 12. The combined estimated mean monthly flow for sites 7 and 9 was assumed to never be greater than the combined average ditch capacity of 18 ft^3/s. The average ditch capacities, which were determined from channel washlines and brush growth, were 10 ft^3/s at site 7 and 8 ft^3/s at site 9. Estimates of the 1989 and long-term mean monthly combined flow for sites 4, 7, and 9 are given in table 4. The long-term mean monthly natural flow for site 12, estimated by summing data from tables 2 and 4, is given in table 3.

The second step in estimating natural streamflow was to determine the natural flow for the Pryor Creek site upstream from Macheta Creek (site 10). The long-term mean monthly natural flow at this site was computed by subtracting the mean monthly flow for Macheta Creek (site 11) and the estimated monthly flow gain of Pryor Creek between sites 10 and 12 from the long-term mean monthly natural flow at site 12.

Table 4.--*Estimated 1989 and long-term mean monthly combined flow of Pryor Ditches 1, 2, and 3 (sites 4, 7, and 9) for the irrigation season*

Period	Cubic feet per second				
	May	June	July	Aug.	Sept.
1989	0.01	5	13	9	4
Long-term mean (water years 1937-86)	0	13	18	14	7

The streamflow gain between Macheta Creek and site 12--believed to be mostly irrigation return flow--was estimated by linearly varying, on a monthly basis, the gain determined from the October 1989 and March 1990 gain-loss measurements (1.6 and 3.4 ft^3/s, respectively). For April through September, the estimates of streamflow gain varied linearly from 2.1 to 3.1 ft^3/s. The computed long-term mean monthly natural streamflow for site 10 is presented in table 3.

The third, and final, step in estimating natural streamflow was to calculate the natural flow for Pryor Creek at sites 6 and 8 using the presumed linear gain in flow between sites 3 and 10. Natural flow for Pryor Creek at sites 6 and 8, and for any point between sites 3 and 10, can be estimated from figure 5. For example, the mean June natural flow for site 8 is read from the y-axis of the graph as 34 ft^3/s. The long-term mean monthly natural flow for sites 6 and 8 is listed in table 3.

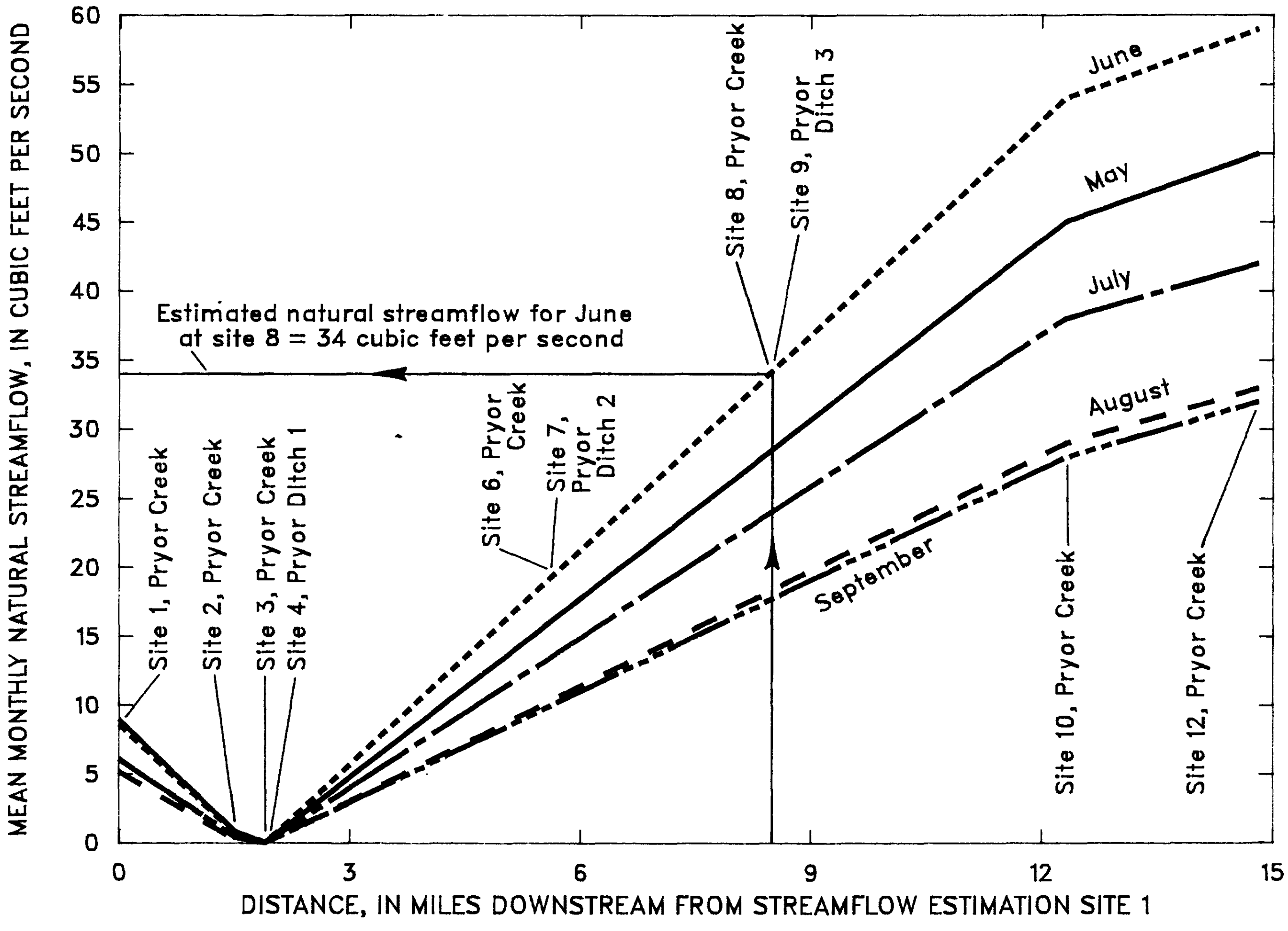

Figure 5.--Lines for estimating mean monthly natural flow of Pryor Creek, May through September.

The estimates of mean monthly natural streamflow can be used to estimate the effects of diversions on downstream flow. For example, the mean September natural flow at site 6 is 10 ft^3/s (table 3). If 10 ft^3/s is withdrawn into Pryor Ditch 2 (site 7), the estimated flow of Pryor Creek upstream from Pryor Ditch 3 (site 8) is the estimated natural flow minus the quantity withdrawn (18 ft^3/s - 10 ft^3/s = 8 ft^3/s). The quantity withdrawn (10 ft^3/s) would also be subtracted from the mean

September natural flow for sites 10 and 12 if actual streamflow at these sites needed to be estimated.

The streamflow available for monthly use in the Pryor Unit is the long-term mean monthly natural flow of Pryor Creek upstream from Pryor Ditch 1 (site 3) plus the long-term mean monthly natural flow gain between Pryor Ditches 1 and 3 plus the small quantity of flow diverted from Lost Creek into Pryor Ditch 1 by way of Lost Creek Ditch (site 5). Because of the assumed linear increase in natural flow between sites 3 and 10, the streamflow available for use in the Pryor Unit can be expressed simply as the long-term mean monthly natural flow at site 8 plus the mean monthly flow at site 5, which is the water diverted from Lost Creek to Pryor Ditch 1. Thus, for example, the water available to the Pryor Unit in May is 29 ft^3/s (site 8, table 3) plus 0.9 ft^3/s (site 5, table 2) or 30 ft^3/s (rounded). Similarly, the water available in June, July, August, and September is 35, 25, 20, and 19 ft^3/s, respectively.

In general, the gain-loss-measurement method is considered to be more reliable than the concurrent-measurement method for estimating mean monthly streamflow at sites 6 and 8. The gain-loss-measurement method is more reliable because the effect of streamflow withdrawals for irrigation was minimized. However, the reliability of this method cannot be measured precisely without more data on irrigation water use and streamflow over a period of several years.

WATER NEEDS FOR IRRIGATION

In the upper Pryor Creek basin, irrigation is by far the largest use of water and most irrigation occurs in the Pryor Unit. To evaluate water needs for irrigation, water requirements and losses were determined first for 1 acre and then for the total acreage under irrigation facilities in the Pryor Unit.

Water requirements and losses (table 5) were determined using monthly and seasonal factors. The factors for consumptive use are based on alfalfa, which has the largest consumptive-use requirement of irrigated crops grown in the area. The consumptive-use requirement of pasture grass and spring grain, the other crops irrigated in the area, is about 90 percent that of alfalfa.

Table 5.--*Estimated normal monthly and total water requirements and losses for the irrigation season in the Pryor Unit*

Variable	May	June	July	Aug.	Sept.	Irrigation season (May-Sept.)
			Acre-feet per acre			
Consumptive-use requirement[1]	0.34	0.50	0.66	0.54	0.28	2.32
Net irrigation requirement[1]	.02	.35	.58	.47	.02	1.44
Conveyance loss[2]	.06	.84	1.38	1.12	.05	3.45
On-farm loss[2]	.03	.48	.80	.65	.03	1.99
Diversion requirement[2]	.11	1.67	2.76	2.24	.10	6.88
			Acre-feet per 2,220 acres in Pryor Unit			
Consumptive use	750	1,100	1,500	1,200	620	5,200
Net irrigation requirement	40	780	1,300	1,000	40	3,200
Conveyance loss	100	1,900	3,100	2,500	100	7,700
On-farm loss	70	1,100	1,800	1,400	70	4,400
Diversion requirement[3]	200	3,800	6,200	4,900	200	15,300

[1]From U.S. Soil Conservation Service (1988); precipitation data based on period 1941-70 (John Dalton, U.S. Soil Conservation Service, Bozeman, Mont., oral commun., 1991).
[2]From U.S. Soil Conservation Service (1978).
[3]Determined by addition of values for net irrigation requirement, conveyance loss, and on-farm loss (values may not total exactly because of rounding).

The normal seasonal consumptive-use requirement for alfalfa (based on median climatic conditions) is about 2.32 acre-ft of water per acre (table 5). Of this quantity, about 0.88 acre-ft/acre is supplied from precipitation and soil moisture stored between irrigation seasons. The difference between the water requirement of a crop and the precipitation plus stored soil moisture, which is about 1.44 acre-ft/acre, is the quantity of water needed for irrigation (net irrigation requirement).

The diversion requirement is the sum of the net irrigation requirement, the conveyance (delivery-system) losses, and the on-farm (water-application) losses. About 79 percent of the diversion requirement is attributed to conveyance and on-farm losses (table 5). Thus, to supply the irrigation requirement, a diversion requirement needs to be about five times greater than the net irrigation requirement (U.S. Soil Conservation Service, 1978). An example of the use of table 5 to estimate water requirements and losses for 1,000 acres in July follows: the consumptive-use requirement is 660 acre-ft (1,000 acres multiplied by 0.66 acre-ft/acre), the net irrigation requirement is 580 acre-ft, the conveyance loss is 1,380 acre-ft, the on-farm loss is 800 acre-ft, and the diversion requirement is 2,760 acre-ft.

The factors for conveyance loss, on-farm loss, and diversion requirement are based on the overall irrigation efficiency in Big Horn County (U.S. Soil Conservation Service, 1978) and are considered to be representative of the Pryor Unit. Because the small irrigated fields between Macheta Creek and Hay Creek and elsewhere in the study area generally have short conveyance systems, the factors for conveyance and on-farm losses, and thus the diversion requirement calculated using these factors, might 'be too large. In addition, where the water table is high enough to cause subirrigation, the quantity of water available to crops is increased and thus the net irrigation requirement is decreased. A decrease in the net irrigation requirement, in turn, decreases the conveyance and on-farm losses and the diversion requirement.

Onsite surveys during the 1989 irrigation season were used to estimate irrigated acreage for the Pryor Unit and the area adjacent to Pryor Creek between Macheta Creek and Hay Creek. Acreage that might not have been irrigated in 1989 but that appeared capable of being irrigated with existing facilities (acreage under irrigation facilities) also was estimated. For the Pryor Unit, a map furnished by the U.S. Bureau of Indian Affairs that had delineated acreages under irrigation facilities was used to denote fields that received irrigation in 1989. For the area adjacent to Pryor Creek between Macheta Creek and Hay Creek, fields that received irrigation in 1989 were sketched onto U.S. Geological Survey 7.5-minute series topographic maps using local landmarks as guides. Also denoted on these topographic maps were fields under irrigation facilities, as evidenced by nearby irrigation equipment or facilities. The acreages were determined by manual planimetering.

The acreage observed being irrigated at least once during 1989 was about 400 acres in the Pryor Unit and about 250 acres adjacent to Pryor Creek between Macheta Creek and Hay Creek. The estimated acreage under irrigation facilities during the 1989 irrigation season was about 2,220 acres for the Pryor Unit and about 350 acres adjacent to Pryor Creek between Macheta Creek and Hay Creek.

This method of estimating irrigated acreage is considered to provide the most accurate estimate of total acres under irrigation facilities (Parrett and Johnson, 1988, p. 645-647). The total acreage irrigated in 1989 could have been larger because some fields might have received irrigation between, but not during, visits. On the basis of observations of irrigation practices and the random timing of visits, however, few irrigated fields are believed to have been missed.

The estimated normal monthly and irrigation-season water requirements and losses for the 2,220 acres of the Pryor Unit are presented in table 5. Because water used for irrigation commonly is reported as a volume and not as a streamflow rate, data in table 5 are reported in acre-feet. According to these data, the irrigation-season diversion requirement for the Pryor Unit is about 15,300 acre-ft. About 73 percent of this total is during July (6,200 acre-ft) and August (4,900 acre-ft).

ADEQUACY OF STREAMFLOW QUANTITY FOR IRRIGATION

The adequacy of streamflow available for irrigation can be determined by comparing the diversion requirement with the available streamflow. An assumption made here is that the Pryor Unit conveyance system is capable of delivering the monthly diversion requirement.

According to the data in table 6, about 7,700 acre-ft (50 percent) of the estimated irrigation-season diversion requirement for the Pryor Unit (15,300 acre-ft) is available from Pryor Creek and Lost Creek Ditch flows. Only during May and September does the available streamflow exceed the diversion requirement. For the water-short periods of June, July, and August, when the diversion requirement is largest (total of 14,900 acre-ft), the estimated available streamflow is only about 4,800 acre-ft. The result is a deficit of 10,100 acre-ft, of which 8,400 acre-ft occurs during July and August.

Table 6.--*Normal monthly and total water excess or deficit for the irrigation season in the Pryor Unit*

	Acre-feet					
	May	June	July	Aug.	Sept.	Irrigation season (May-Sept.)
Diversion requirement (table 5)	200	3,800	6,200	4,900	200	15,300
Available streamflow[1]	1,800	2,100	1,500	1,200	1,100	7,700
Water excess (+) or deficit (-)	+1,600	-1,700	-4,700	-3,700	+900	-7,600

[1]Estimated mean monthly natural flow for Pryor Creek upstream from Pryor Ditch 3 (site 8) plus flow for Lost Creek Ditch (site 5).

If the diversion requirements for July and August are to be satisfied, a water supply capable of delivering additional daily mean flows of about [2]76 ft^3/s during July and 60 ft^3/s during August would be needed. These large quantities of flow cannot be supplied from surface-water sources in the study area. Also, these large quantities probably could not be supplied from nearby ground-water sources (M.R. Cannon, U.S. Geological Survey, oral commun., 1991).

The current available streamflow would be adequate to almost meet the estimated consumptive-use requirements of the Pryor Unit during July and August if conveyance losses were eliminated and the on-farm irrigation efficiency were increased, such as by sprinkler irrigation. For example, the consumptive use for July and August is about 2,700 acre-ft (table 5) and the available streamflow is about 2,700 acre-ft (table 6). Improved irrigation efficiency would mean that fewer new water sources would need to be located and developed.

STREAMFLOW QUALITY

Water samples for chemical analysis were collected from Pryor Creek, selected tributaries, and irrigation ditches using standard U.S. Geological Survey methods as described by Knapton (1985). Samples were collected at 8 sites on August 16, 1989, and 11 sites on July 24, 1990 (table 7). The samples obtained from two of the irrigation ditches (sites 7 and 9) are presumed to be representative of Pryor Creek at sites 6 and 8, because the sampling locations were just downstream from the diversion structures. Macheta Creek (site 11), Fourth of July Creek (site 16),

[2]An example computation:

$$\text{Daily mean flow} = (\text{monthly water excess or deficit/days in month})/1.9835$$
$$= (4{,}700/31)/1.9835$$
$$= 76\ \text{ft}^3/\text{s}.$$

Table 7.--*Water-quality data for selected streamflow sites*

[Analyses by Montana Bureau of Mines and Geology laboratory. Abbreviations: ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 °C; °C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter. Symbols: <, less than; --, no data]

Site No. (fig. 1)	Site name	Date	Streamflow, instantaneous (ft^3/s)	Specific conductance (µS/cm)	pH, laboratory (standard units)	Temperature, air (°C)	Temperature, water (°C)	Hardness, total (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Sodium-adsorption ratio
1	Pryor Creek upstream from Summit Creek, near Pryor	8/16/89	3.1	402	8.4	15.0	8.5	219	52	22	2.0	0.05
		7/24/90	5.9	389	8.3	16.5	9.5	217	51	22	.6	.01
5	Lost Creek Ditch near Pryor	8/16/89	.5	380	8.4	15.5	14.0	200	47	20	.7	.02
		7/24/90	1.0	338	8.1	24.5	17.0	192	45	19	.5	.02
7	Pryor Ditch 2 near Pryor	8/16/89	7.4	494	8.4	21.5	13.0	253	58	26	3.4	.09
		7/24/90	8.4	434	8.4	31.0	15.0	246	56	26	2.4	.06
9	Pryor Ditch 3 near Pryor	8/16/89	1.2	498	8.0	19.5	12.5	249	56	27	3.7	.10
		7/24/90	3.3	434	8.3	31.0	15.0	266	59	29	3.7	.09
11	Macheta Creek near Pryor	7/24/90	.1	790	8.8	27.0	24.5	274	49	37	79	2
12	Pryor Creek at Pryor (station 06216000)	8/16/89	8.5	528	8.3	21.5	16.5	284	59	34	7.2	.18
		7/24/90	10.1	498	8.0	27.5	17.5	275	57	32	6.1	.16
15	Smallpox Creek near Pryor	8/16/89	.1	995	8.5	24.5	15.5	326	59	43	98	2
		7/24/90	.1	903	8.4	29.0	24.5	345	59	48	79	2
16	Fourth of July Creek near Pryor	7/24/90	.3	775	8.2	20.5	17.0	346	68	43	38	.89
17	Deep Creek near Pryor	8/16/89	.1	1,400	8.6	26.5	20.0	342	51	52	176	4
		7/24/90	.1	1,220	8.3	23.5	16.0	372	60	54	139	3
20	Pryor Creek upstream from Hay Creek, near Pryor	8/16/89	8.6	642	8.4	22.0	22.0	283	50	39	31	.79
		7/24/90	10.3	622	8.1	21.0	18.0	288	52	39	29	.75
21	Hay Creek near Pryor	7/24/90	.9	899	8.3	16.5	17.0	361	81	38	65	1

Site No. (fig. 1)	Potassium, dissolved (mg/L as K)	Alkalinity, laboratory (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Solids, sum of constituents, dissolved (mg/L)	Solids, dissolved (tons per day)	Boron, dissolved (µg/L as B)	Cadmium, dissolved (µg/L as Cd)	Chromium, dissolved (µg/L as Cr)	Iron, dissolved (µg/L as Fe)	Lead, dissolved (µg/L as Pb)	Manganese, dissolved (µg/L as Mn)
1	0.22	205	11	0.8	0.9	7.1	346	2.9	<20	<2	<2	0.010	<40	0.001
	.47	196	9	.6	.6	8.0	331	--	<40	<5	<5	.004	--	.005
5	.11	184	8	2.1	.5	4.5	307	.4	<20	<2	<2	.002	<40	.002
	.94	171	5	.1	.4	6.0	294	--	<40	5	<5	--	--	.042
7	.52	235	28	1.3	.6	8.2	414	8.3	<20	<2	<2	<.002	--	.004
	.86	215	24	1.0	.5	9.2	377	--	<40	<5	<5	.008	--	.003
9	.60	236	28	1.5	.7	8.2	413	1.3	<20	<2	<2	.005	<40	.005
	1.1	226	26	1.1	.5	9.4	406	--	<40	<5	<5	.004	--	.002
11	3.1	196	187	9.1	.5	7.8	639	--	198	<5	<5	.006	--	.045
12	1.1	246	50	2.9	.3	9.5	466	11	<40	<5	<5	<.002	<40	.013
	1.4	244	30	1.5	.4	10	437	--	<40	<5	<5	.004	--	.008
15	2.4	359	153	17	1.4	12	827	.2	90	<2	6	.020	<40	.023
	2.4	332	133	11	.6	12	750	--	144	<5	<5	.014	--	.006
16	2.4	246	130	27	.5	11	621	--	<40	<5	<5	.007	--	.031
17	1.6	333	371	21	.9	3.8	1,080	.1	109	<2	<2	<.002	<40	.004
	2.4	363	279	16	.6	6.7	1,000	--	204	<5	<5	.009	--	.026
20	1.2	235	89	11	.6	36	543	13	<20	<2	<2	<.002	<40	.015
	1.7	237	89	10	.4	5.7	517	--	40	<5	<5	.008	--	.027
21	2.2	314	164	9.3	.5	9.6	753	--	144	<5	<5	.005	--	.1

and Hay Creek (site 21) were not sampled on August 16, 1989, because the flow was 0.01 ft^3/s or less. All samples were sent to the Montana Bureau of Mines and Geology laboratory for chemical analysis using methods described by Fishman and Friedman (1989). Specific conductance and temperature were measured onsite.

Dissolved-solids concentration in Pryor Creek increased downstream (table 7). On August 16, 1989, the dissolved-solids concentration was 346 mg/L at site 1, 466 mg/L at site 12, and 543 mg/L at site 20. Similarly, on July 24, 1990, the concentration was 331 mg/L at site 1, 437 mg/L at site 12, and 517 mg/L at site 20. These data indicate increases of 57 and 56 percent, respectively, for the two time periods from site 1 to site 20, a distance of about 33 stream miles.

The water samples were collected during the middle to latter part of the irrigation season when irrigation water demand was large, irrigation return flow was present, and mainstem and tributary streamflows were small. Because ground water contributes most of the dissolved constituents to natural streams (Hem, 1985), the dissolved-solids concentrations (table 7) might be larger than those that would have occurred earlier in the irrigation season when streamflows were larger and return flows were minimal.

The dissolved-solids concentrations in table 7 are considered to be representative of conditions when streamflow is low; however, they might not represent extreme conditions. For example, dissolved-solids concentrations in Pryor Creek could be greatly increased temporarily by a thunderstorm that produces runoff into a normally dry tributary channel and flushes downstream the dissolved constituents that have been concentrated in pools or precipitated as salt deposits by evaporation.

Although dissolved-solids concentration is a useful guide for irrigation management, it needs to be determined by laboratory analysis. Specific conductance, which is highly correlated with dissolved-solids concentration and can be determined onsite at the time of sampling, is a good surrogate for dissolved-solids concentration. Considerably more analyses of specific conductance (table 1) are available than analyses of dissolved-solids concentration (table 7). During water year 1989, the specific conductance for Pryor Creek varied from 319 to 402 µS/cm at site 1, 266 to 528 µS/cm at site 12, and 542 to 642 µS/cm at site 20. The specific conductance of 266 µS/cm at site 12 on July 7, 1989, was the smallest determined for Pryor Creek during the study. This value appears to be anomalous because it corresponds to the smallest flow for site 12 during water years 1989-90.

Irrigation water having dissolved-solids concentrations of less than 1,000 mg/L generally has little or no detrimental effect on plant growth. However, without careful management, concentrations in the range of 1,000 to 2,000 mg/L could be detrimental to plant growth and soil conditioning (U.S. Environmental Protection Agency, 1986).

Of the water sampled from Pryor Creek, tributaries, and irrigation ditches, all samples but two had dissolved-solids concentrations less than 1,000 mg/L (table 7), indicating that the water is suitable for irrigation. Deep Creek water might not be suitable for irrigation, however, because two samples had dissolved-solids concentrations that equaled or exceeded 1,000 mg/L.

SUMMARY

Two methods were used to estimate mean monthly streamflow that is available for irrigation in the upper Pryor Creek basin. The concurrent-measurement method, which was based on the correlation of flow at ungaged sites with the concurrent flow at a nearby gaged site, was used to estimate flow at 13 ungaged sites, most of which were tributaries to Pryor Creek. The gain-loss measurement method, which was based on two sets of measurements, was used to estimate the mean monthly natural flow at two ungaged sites along Pryor Creek. In the latter method, the nearly linear increase of flow, as described by the two sets of measurements, was used along Pryor Creek from site 3 to site 10. The streamflow available for irrigation in the Pryor Unit is the long-term mean monthly natural flow of Pryor Creek upstream from Pryor Ditch 3 near Pryor (site 8) plus the long-term mean monthly flow of Lost Creek Ditch near Pryor (site 5). The mean monthly streamflow available to the Pryor Unit during the irrigation season ranges from 19 ft^3/s in September to 35 ft^3/s in June.

To evaluate water needs for irrigation in the study area, monthly and seasonal water requirements and losses were calculated for the total acreage for irrigation facilities in the Pryor Unit. The consumptive-use requirement was calculated using monthly and seasonal factors for alfalfa, which has the largest consumptive-use requirement of crops grown in the area. The conveyance and on-farm losses and the diversion requirement were calculated using monthly and seasonal factors that are based on the overall irrigation efficiency in Big Horn County. When these factors are used to estimate the losses and diversion requirement for small irrigated fields elsewhere in the study area that are supplied from short conveyance systems, the results might be too large. The resulting data for the Pryor Unit indicate that the estimated monthly diversion requirement is largest in July (about 6,200 acre-ft) and the estimated irrigation-season diversion requirement is about 15,300 acre-ft.

The streamflow quantity available to offset the diversion requirement is about 7,700 acre-ft during the irrigation season, which leaves a deficit of 7,600 acre-ft. The current available streamflow would be adequate to almost meet the consumptive-use requirement of the Pryor Unit if conveyance losses were eliminated and the on-farm irrigation efficiency were increased, such as by sprinkler irrigation.

Water samples for chemical analysis were collected at 8 streamflow sites on August 16, 1989, and 11 sites on July 24, 1990. The dissolved-solids concentration in water from Pryor Creek increased downstream from 346 to 543 mg/L for the August samples and from 331 to 517 mg/L for the July samples. Dissolved-solids concentrations in 17 of the 19 water samples collected for chemical analysis were less than 1,000 mg/L, indicating that the water generally is suitable for irrigation with respect to dissolved-solids concentration.

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