WATER RESOURCES INVESTIGATIONS
79-29

Red Cedar River Basin, Wisconsin: Low-flow Characteristics

PREPARED BY
UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
IN COOPERATION WITH
WISCONSIN DEPARTMENT OF NATURAL RESOURCES

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ABSTRACT

The purposes of the report are to determine the low-flow characteristics in the Red Cedar River basin, where surplus water may be diverted, and to present methods to determine low-flow characteristics at additional sites. The low-flow characteristics were determined by various methods at 71 sites in the basin. For the three gaging stations in the basin frequency analysis was used to determine the low-flow characteristics. At 17 partial-record sites correlation analyses were used to estimate the low-flow characteristics.

Where only a single base-flow measurement was available the following equations were developed to estimate low-flow characteristics at 41 sites:

$$Q_{7,2} = 0.812A^{1.06}Bf^{1.14}$$

$$Q_{7,10} = 0.425A^{1.12}Bf^{1.26}$$

where: $Q_{7,2}$ and $Q_{7,10}$ are the annual minimum 7-day mean flow below which the flow will fall on the average of once in 2 years and once in 10 years,

A is drainage area, in square miles, and

Bf is base-flow index.

The relationships were determined from multiple-regression analyses that related low-flow characteristics at gaging stations, low-flow partial-record stations, and sewage-treatment-plant sites to the drainage area and base-flow index values. The standard errors of estimate were determined to be 25 percent for the $Q_{7,2}$ equation and 34 percent for the $Q_{7,10}$ equation.

For the main stem of the Red Cedar River where only one discharge measurement was available the low-flow characteristics were determined from a drainage area-discharge relationship.

Low-flow characteristics were determined at an additional 30 sites in the Red Cedar River basin by various methods. The method used for these sites depended upon the type and amount of data available at each site.

INTRODUCTION

The Red Cedar River basin (fig. 1) is an area where surplus water has been used extensively for irrigation. Since the drought of 1976, the use of this water has increased dramatically. A method is needed to provide uniform and accurate evaluation of the low-flow resource in this basin.

The purposes of this report are to determine the low-flow characteristics in the Red Cedar River basin where surplus water may be diverted and to present a method to determine low-flow characteristics at additional sites. The study was part of the low-flow project in cooperation with the Wisconsin Department of Natural Resources (DNR).

The report includes: estimates of the annual minimum 7-day mean flow below which the flow will fall on the average of once in 2 years ($Q_{7,2}$) and once in 10 years ($Q_{7,10}$) at 71 sites; two equations that can be used to estimate low-flow characteristics where only one base-flow discharge measurement is available; and relationships for estimating low-flow characteristics on the main stem of the Red Cedar River between Mikana and Colfax.

For the convenience of readers who may want to use metric units, the data may be converted by using the following factors:

Multiply	By	To obtain
mile (mi)	1.609	kilometer (km)
foot (ft)	.3048	meter (m)
square mile (mi^2)	2.59	square kilometer (km^2)
cubic foot per second (ft^3/s)	.02832	cubic meter per second (m^3/s)
foot per mile (ft/mi)	.1894	meter per kilometer (m/km)
inch (in.)	2.54	centimeter (cm)
cubic foot per second per square mile {$(ft^3/s)/mi^2$}	.01094	cubic meter per second per square kilometer {$(m^3/s)/km^2$}

LOW-FLOW CHARACTERISTICS

Table 1 presents low-flow characteristics for 71 sites in the Red Cedar River basin. Information included for most sites is: station number, station name, measured discharge, drainage area, estimated $Q_{7,2}$ and

$Q_{7,10}$, and basis of estimate. The location of each site is shown on plate 1.

The low-flow characteristics in table 1 are determined by four methods of analysis, depending upon the type of data available. The four basic types of data available are: (1) continuous record of daily streamflow (gaging stations), (2) 10 to 14 base-flow discharge measurements (low-flow partial-record stations), (3) 4 to 7 base-flow discharge measurements (sewage-treatment-plant sites), and (4) a single discharge measurement made during August 23-26, 1977, or March 21, 1978, for this study (miscellaneous sites).

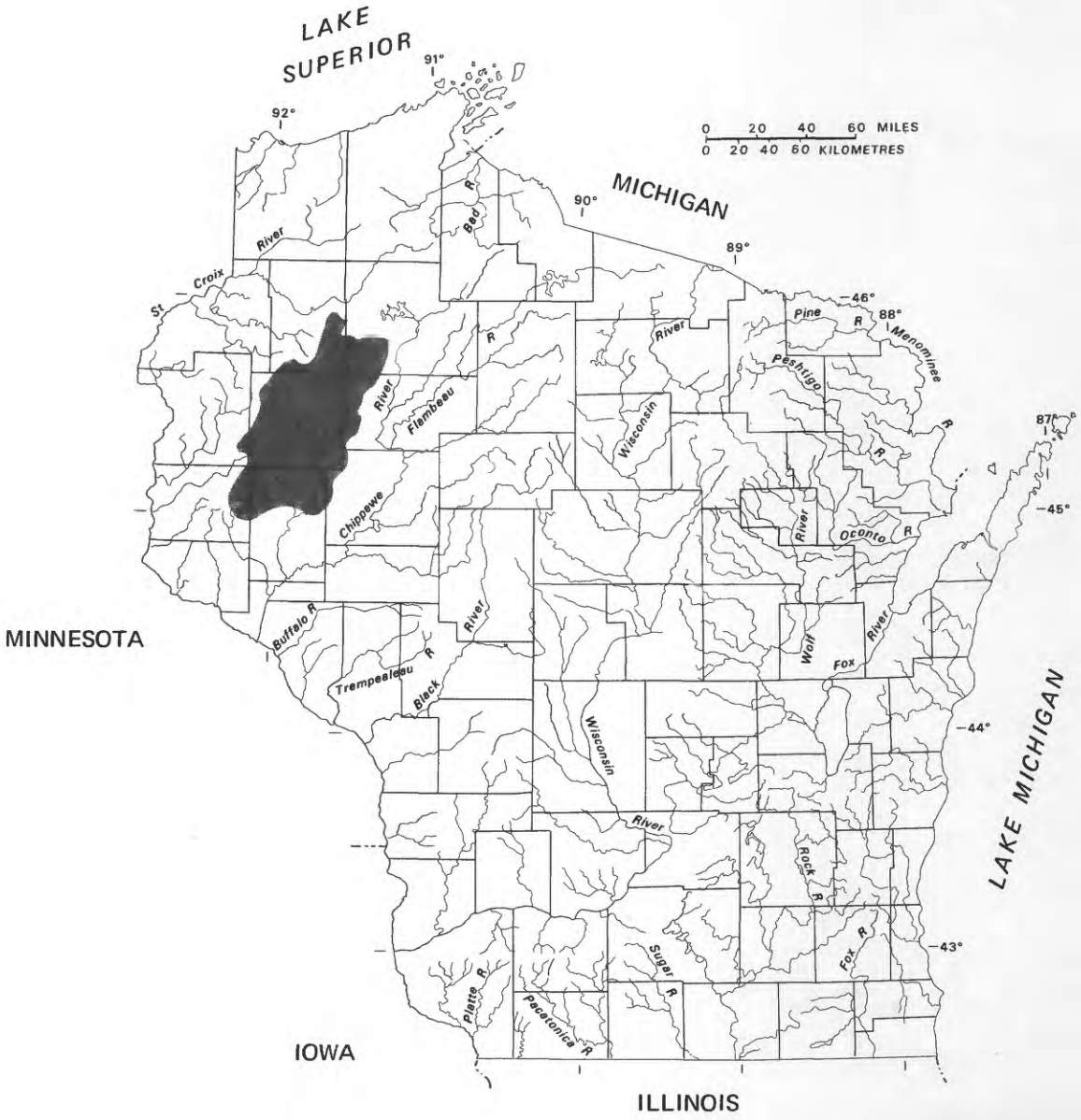

Figure 1. Location of the Red Cedar River basin in Wisconsin

Table 1.--Low-flow characteristics for sites in the Red Cedar River basin

Station number	Station name	Discharge measured Aug. 23-26, 1977 (ft^3/s) Qm	Drainage area (mi^2) A	River miles upstream from Red Cedar River at Menomonie gaging station	Low-flow characteristics $Q_{7,2}$ (ft^3/s)	Low-flow characteristics $Q_{7,10}$ (ft^3/s)	Basis of estimate[1]
05367102	Red Cedar River at County Trunk D	5.47	69.5	89.7	3.2	1.5	c
05367150	Sucker Creek at County Trunk FF	.50	8.49		.26	.11	d
05367202	Red Cedar River at outlet of Red Cedar Lake	42.1	148	82.7	35	21	d
05367210	Red Cedar River at country road	[2]84.6	155	79.7	38	23	e
05367301	Brill River at County Trunk D	20.7	83.6		16	9.0	d
05367310	Brill River at County Trunk V	26.9	94.3		20	11	c
05367320	Brill River at country road	29.8	105		24	14	d
05367340	Red Cedar River at country road	[2]128	264	76.6	77	52	e
05367350	Red Cedar River at State Highway 48	[2]137	271	73.3	80	54	e
05367370	Red Cedar River tributary at State Highway 48 near Rice Lake	0	22.7		0	0	d
05367401	Bear Creek at outlet of Bear Lake	7.57	36.8		5.6	3.0	c
05367402	Little Bear Creek at country road	3.24	15.2		2.2	1.1	d
05367404	Bear Creek at U.S. Highway 53	14.6	64.9		11	6.0	d
05367405	Red Cedar River at Northern Railroad	124	378	69.9	110	73	e
053674095	Spring Creek at country road	.07	12.4		.03	.01	d
05367411	Spring Creek at County Trunk C	0	25.9		0	0	d
05367412	Spring Creek at County Trunk M	2.72	31.6		1.8	.84	d
05367415	Meadow Creek at U.S. Highway 53	10.0	36.4		7.6	4.1	d
05367417	Red Cedar River at country road	147	426	64.7	120	80	e
05367420	Barker Creek at country road	1.34	16.7		.78	.35	d
05367425	Red Cedar River at U.S. Highway 8	138	450	60.3	125	85	a
05367427	Cranberry Creek at U.S. Highway 8	1.36	4.52		1.2	.50	c
05367430	Yellow River at State Highway 48	9.19	55.6		8.4	5.6	b
05367433	Hickey Creek at State Highway 48	2.93	8.11		2.1	1.1	d
05367434	Engle Creek at country road	.55	7.48		.33	.14	d
05367436	Yellow River at country road	30.3	91.4		25	15	d
05367438	Vermillion River at country road	4.82	7.85		3.7	2.0	d

Table 1.--Low-flow characteristics for sites in the Red Cedar River basin--Continued

Station number	Station name	Discharge measured Aug. 23-26, 1977 (ft^3/s) Qm	Drainage area (mi^2) A	River miles upstream from Red Cedar River at Menomonie gaging station	Low-flow characteristics $Q_{7,2}$ (ft^3/s)	Low-flow characteristics $Q_{7,10}$ (ft^3/s)	Basis of estimate[1]
05367440	Vermillion River at country road	4.48	17.7		4.2	2.2	b
05367443	Vermillion River at County Trunk T	8.48	39.0		6.4	3.4	d
05367444	Yellow River at Barron	42.2	146		29	14	c
05367445	Ovaderer Creek at Barron	2.23	11.4		1.5	.75	d
05367447	Fourmile Creek at country road	2.94	16.0		2.0	1.0	d
05367448	Yellow River at County Trunk O	49.2	192		40	24	d
05367450	Red Cedar River at County Trunk OO	195	657	54.7	165	115	e
05367452	Brown Creek at country road	1.38	10.0		.83	.39	d
05367454	Red Cedar River at County Trunk D	187	674	51	170	120	e
05367456	Pokegama Creek at country road	.02	6.63		.01	0	d
05367457	Silver Creek at country road	.15	3.68		.075	.029	d
05367458	Pokegama Creek at country road	2.67	15.5		1.8	.91	d
05367459	Rock Creek at country road	.82	19.3		.45	.19	d
05367460	Pokegama Creek at U.S. Highway 8	8.15	40.3		8.0	3.9	b
05367461	German Creek at U.S. Highway 8	.32	7.72		.17	.067	d
05367462	Moose Ear Creek at U.S. Highway 8	1.17	15.6		.70	.31	d
05367463	Moose Ear Creek at County Trunk D	6.05	38.2		4.10	2.1	d
053674633	Chetek River at County Trunk SS	47.2			28	11	c
05367464	Tenmile Creek at country road	10.8	18.5		8.7	5.0	d
05367465	Beaver Creek at country road	0	29.0		0	0	d
05367468	Chetek River at country road	39.8	200		32	18	d
05367469	Red Cedar River at County Trunk A and I	280	901	44.1	230	175	e
05367474	Upper Pine Creek at County Trunk U	4.21	8.85		3.8	2.9	c
05367480	East Branch Upper Pine Creek at County Trunk O	1.35	3.85		.82	.47	b
05367481	East Branch Upper Pine Creek at County Trunk U	3.55	9.60		2.5	1.3	d
05367483	Upper Pine Creek at country road	12.5	36.7		9.7	5.5	d
05367487	Sand Creek at County Trunk I	7.74	20.2		5.7	3.2	d
053674879	Lower Pine Creek at State Highway 25	.95	19.2		.54	.23	d
05367488	Lower Pine Creek tributary at Ridgeland	.88	7.94		.41	.18	c

Table 1.--Low-flow characteristics for sites in the Red Cedar River basin--Continued

Station number	Station name	Discharge measured Aug. 23-26, 1977 (ft^3/s) Qm	Drainage area (mi^2) A	River miles upstream from Red Cedar River at Menomonie gaging station	Low-flow characteristics $Q_{7,2}$ (ft^3/s)	Low-flow characteristics $Q_{7,10}$ (ft^3/s)	Basis of estimate[1]
05367490	Lower Pine Creek at County Trunk V	11.5	50.4		10	4.3	b
05367491	Red Cedar River at State Highway 64	350	1,033	34.6	300	210	e
05367492	Hay Creek at country road	2.82	15.2		1.9	.96	c
05367495	Popple Creek at County Trunk S	2.01	8.06		1.3	.65	d
05367497	Trout Creek at County Trunk M	8.15	30.4		6.0	3.2	d
05367500	Red Cedar River near Colfax	436	1,111	26.3	350	225	a
05367640	Hay River at country road	0	2.46		0	0	d
05367642	Hay River at country road	7.41	15.1		5.7	3.2	d
05367772	Turtle Creek at U.S. Highway 8	1.96	3.08		1.1	.42	c
05367834	Hay River at State Highway 64	66.5	148		57	36	d
05367970	Beaver Creek at State Highway 170	5.06	17.7		2.9	1.8	b
05367975	Tiffany Creek at State Highway 79	19.1	73.3		13	8.2	c
05367995	South Fork Hay River at mouth	62.4	184		54	33	d
05368000	Hay River at country road	141	426		130	86	a
05369000	Red Cedar River at Menomonie	643	1,760	0	590	420	a

[1]The method used to estimate the low-flow characteristics is indicated by:

a = frequency analysis at gaging station,
b = correlation analysis using 10 to 14 discharge measurements at low-flow partial-record stations,
c = correlation analysis using 4 to 7 discharge measurements at sewage-treatment plant sites,
d = regression equations using Bf values, and
e = graphical drainage area-discharge relationship.

[2]Discharge measured on March 21, 1978.

GAGING STATIONS

The low-flow characteristics at the four gaging stations were determined by a frequency analysis of the recorded 7-day annual minimum flows. A log-Pearson Type III probability distribution was used to compute the frequency curves (Riggs, 1972).

LOW-FLOW PARTIAL-RECORD STATIONS

The basin has six low-flow partial-record stations. Low-flow characteristics for these sites were determined from a relation line established by correlating 10 to 14 base-flow discharge measurements at these stations to the concurrent discharges at gaging stations in the area (Gebert, 1971). The $Q_{7,2}$ and $Q_{7,10}$ at the continuous-record gaging stations then were transferred through the relation line to estimate $Q_{7,2}$ and $Q_{7,10}$ for the partial-record stations.

SEWAGE-TREATMENT-PLANT SITES

For the 11 sewage-treatment-plant sites in the basin, 4 to 7 base-flow discharge measurements were available at each site. The same technique used for low-flow partial-record stations was used, except that fewer measurements were available to define the relation line (Gebert and Holmstrom, 1974). The estimated low-flow characteristics for these sites generally were not as well defined as those at partial-record sites.

MISCELLANEOUS SITES

The data collected at the three types of sites discussed above provide considerable information on the low-flow characteristics in the Red Cedar River basin. They do not, however, provide adequate coverage to estimate the low-flow characteristics at the required sites for this study. Therefore, estimates had to be based on additional data.

It has been shown that a base-flow index (Gebert, 1978), based on one base-flow discharge measurement, can be used in a regression analysis to provide equations for estimating low-flow characteristics.

The base-flow index is:

$$Bf = \frac{Q_m \, Q_{90}}{A \, Q_r}$$

where: Q_m = discharge measured during base-flow conditions at the miscellaneous site,

Q_{90} = 90 percent flow-duration discharge at nearby gaging station,

A = drainage area at the miscellaneous site, and

Q_r = discharge recorded at nearby gaging station on the same day the discharge was measured at the miscellaneous site.

To compute Bf values for an intervening drainage area between sites with discharge measurement the following procedure would be used. The upstream discharge would be subtracted from the downstream discharge to determine Q_m. The same procedure would be applied to their respective drainage areas to determine A. Base-flow discharge measurements were made at 63 miscellaneous sites in the basin to determine the base-flow index (Bf) at each of those sites.

For this study an average value of Q_{90}/Q_r was obtained for use at all the miscellaneous sites. This value was obtained by averaging individual values calculated at four nearby gaging stations. The four gaging stations are: 053325 Namekagon River near Trego, Wis. (not shown on map); 053415 Apple River near Somerset, Wis. (not shown on map); 053680 Hay River at Wheeler, Wis.; and 053690 Red Cedar River at Menomonie, Wis. (not shown on map).

Multiple-regression analyses were used to determine the relationship between low-flow characteristics (dependent variables) and the drainage area and base-flow index (independent variables). Data from 18 sites were included in the analyses which include all the gaging stations, low-flow partial-record stations, and sewage-treatment-plant sites in the Red Cedar River basin.

The equations and their corresponding standard errors of estimate (SE) are:

	Equation	SE
(1)	$Q_{7,2} = 0.812A^{1.06}Bf^{1.14}$	25 percent
(2)	$Q_{7,10} = 0.425A^{1.12}Bf^{1.26}$	34 percent

The standard errors of estimate reflect the accuracy or ability of the equations to fit the observed data. Values estimated by the regression equation are within the range of one SE at 67 percent of the sites and within twice this range at 95 percent of the sites.

To test the validity of equations (1) and (2) with streamflow data for other periods, the following comparisons were done using data collected at nine low-flow partial-record stations located within or near the Red Cedar River basin. Streamflow measurements were selected for: a low base-flow period, August 5, 1964; a medium base-flow period, September 27, 1966; and a high base-flow period, October 30, 1962. Values of Bf were obtained as outlined on page 7 for the nine low-flow partial-record stations. These values were substituted into equations (1) and (2) to determine estimates of $Q_{7,2}$ and $Q_{7,10}$. When compared to $Q_{7,2}$ and $Q_{7,10}$ values listed in table 1, the following SE's were determined for the estimated low-flow characteristics.

Regression equation	SE from regression analysis	SE using streamflow data from other periods to determine Bf		
		Low base flow	Medium base flow	High base flow
1	25	22	21	35
2	34	33	39	66

As illustrated, equations (1) and (2) produce satisfactory results for low and medium base-flow conditions. However, unsatisfactory results were obtained for high base-flow conditions.

Equations (1) and (2) were used to estimate low-flow characteristics at 41 sites (table 1). These were not used on the main stem of the Red Cedar River downstream from Mikana.

Equations (1) and (2) also can be used to estimate low-flow characteristics at ungaged sites in the Red Cedar River basin. To use the equations Bf can be determined by the following methods:

1. A base-flow discharge measurement can be obtained, during low to medium base-flow conditions (flow duration greater than 60 percent), at the site to determine a Bf value. The Bf values can then be calculated using the procedure outlined on page 7. The recorded streamflow and 90 percent flow duration for the indicated gaging stations can be obtained from the U.S. Geological Survey district office in Madison.

2. For sites that are located in an area where a high degree of uniformity exists among Bf values shown on plate 1 and the site is close to a measured site, the Bf value from the subbasin could be used.

Low-flow characteristics for nine miscellaneous sites downstream from Mikana were determined from a plot of drainage area versus discharge. Discharge measurements made during the August 23-26, 1977, and March 21, 1978, periods were plotted against their respective drainage areas to establish a relation line. The $Q_{7,2}$ and $Q_{7,10}$ discharge for the three gaging stations on the Red Cedar River also were plotted. To establish $Q_{7,2}$ and $Q_{7,10}$ relation lines, lines parallel to the August 23-26 relation were drawn through the $Q_{7,2}$ and $Q_{7,10}$ values at the gaging stations. The low-flow characteristics at the nine miscellaneous sites on the Red Cedar River below Rice Lake were determined from this relationship.

To estimate low-flow characteristics at ungaged sites on the main stem of the Red Cedar River a relationship between discharge and stream length was established (fig. 2). The relationship was based on data from the

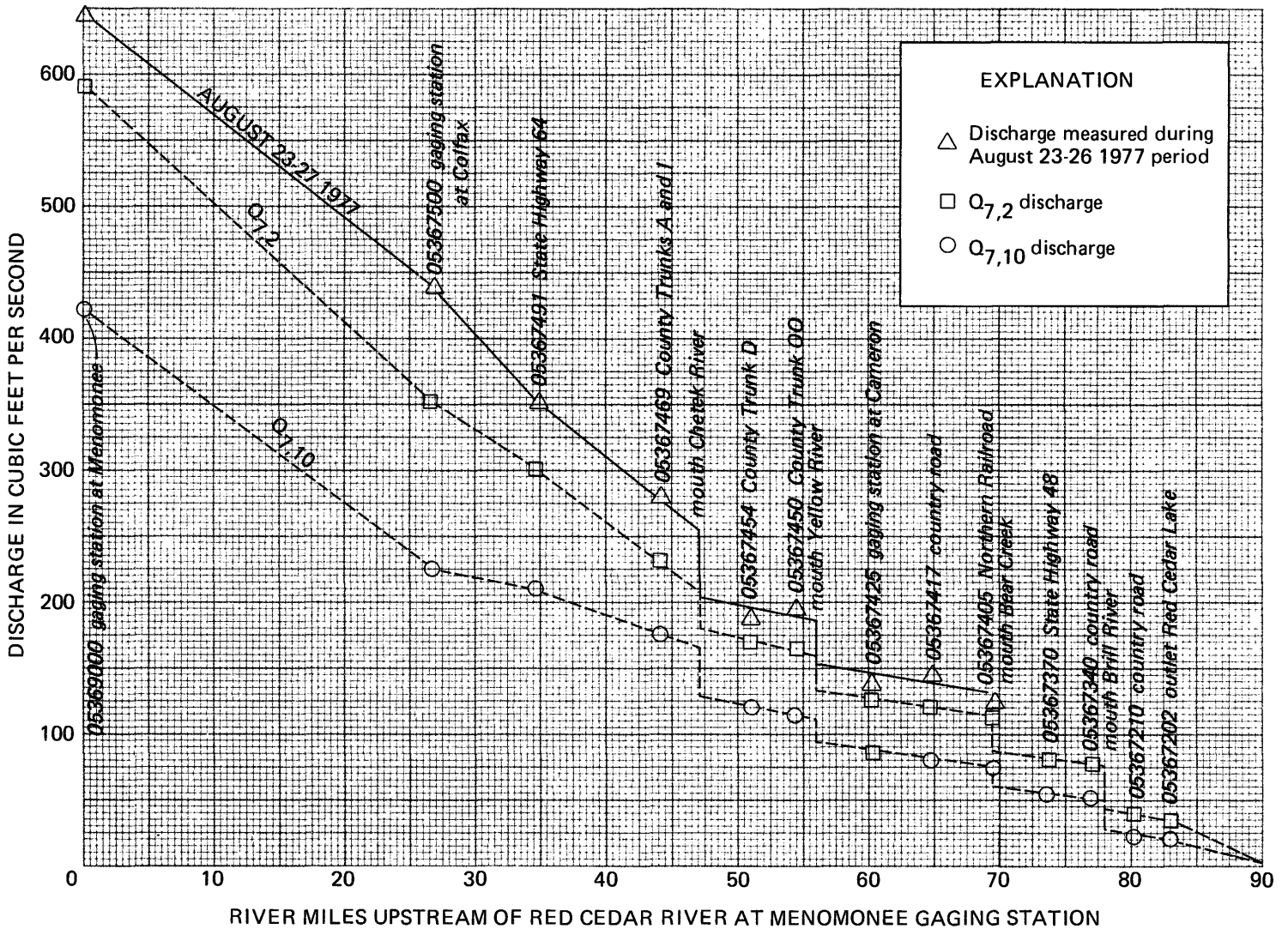

Figure 2. River mile—discharge relationship for estimating $Q_{7,2}$ and $Q_{7,10}$ discharge on main stem of the Red Cedar River.

drainage area versus discharge analysis. Figure 2 provides a better method for estimating low-flow characteristics at ungaged sites since increases in discharge due to tributary flow can be shown and the user does not have to measure drainage area.

A losing and a subsequent gaining reach of the Red Cedar River was found during the analysis of the August 24, 1977, streamflow data. The reach extends from Mikana (05367210) to near Rice Lake (05367350). Measurements on March 21, 1978, made during higher flow conditions, did not show a loss in the reach. The following losses and gains were measured on August 24, 1977, and March 21, 1978.

Station name and number	Drainage area (mi^2)	Measured discharge Aug. 27, 1977 (ft^3/s)	Loss (-) or gain (+) (ft^3/s)	Measured discharge Mar. 31, 1978 (ft^3/s)	Loss (-) or gain (+) (ft^3/s)
Red Cedar River at Mikana (05367202)	148	42.1		77.0	
Red Cedar River at Mikana (05367210)	155	26.1	-16.0	84.6	+ 7.6
Tributary inflow from Brill River (05367320)	105	29.8		39.3	
Red Cedar River near Campia (05367340)	264	49.8	- 6.1	128	+ 4.1
Red Cedar River near Rice Lake (05367370)	271	93.3	+43.5	137	+ 9

The reason for the large loss and gain during the August discharge measurements is not apparent. Additional streamflow measurements with the same or lower streamflow conditions would be required to confirm the observed losses and gains. If they were confirmed, additional geohydrologic information would have to be obtained to understand the cause and extent of this untypical stream behavior.

SUMMARY

Low-flow characteristics are provided for 71 sites to provide information for assessment of the water resource for irrigation permits. Equations (1)

and (2) were used to estimate the $Q_{7,2}$ and $Q_{7,10}$ discharge at sites where only base-flow discharge measurement was available and not on the main stem of the Red Cedar River downstream from Rice Lake.

To use the equations for sites that are not included in this report would require a base-flow discharge measurement. The discharge measurement then could be used to determine a base-flow index value. For sites on the Red Cedar River downstream from Mikana, low-flow characteristics can be determined on the basis of river miles with figure 2.

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