NATURAL FLOW AND WATER CONSUMPTION IN THE MILK RIVER BASIN, MONTANA AND ALBERTA, CANADA

By R. E. Thompson, Jr.

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CONVERSION FACTORS

The following factors can be used to convert inch-pound units in this report to the International System (SI) of metric units.[1]

Multiply inch-pound unit	By	To obtain metric unit
acre	0.4047	hectare (ha)
acre-foot (acre-ft)	1.233	cubic decameter (dam^3)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
foot (ft)	0.3048	meter (m)
inch (in.)	25.40	millimeter (mm)
	2.540	centimeter (cm)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)

Temperature can be converted to degrees Celsius (°C) or degrees Fahrenheit (°F) by the equations:

$$°C = 5/9\ (°F - 32)$$
$$°F = 9/5\ (°C) + 32$$

[1]Any disparities between inch-pound units and the equivalent SI values in the text of the report are due to rounding.

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ABSTRACT

United States-Canada interaction concerning water appropriation in the Milk and St. Mary River basins was a significant factor leading to the Boundary Waters Treaty of 1909 and the International Joint Commission Order of 1921. Prior to partial diversion of St. Mary River streamflow into the Milk River basin, irrigation-season monthly mean natural flow of the Milk River reentering the United States ranged from 5 ft^3/s (cubic feet per second) or 0.14 m^3/s (cubic meter per second) to 766 ft^3/s (21.7 m^3/s) during 1910-16. After diversion began in 1917, irrigation-season streamflow increased in the North Milk River entering Canada from 700 to 1,400 percent and in the Milk River reentering the United States from 140 to 460 percent. In a median-flow year, the mainstem Milk River entering Canada contributes about 50 percent, the North Milk River entering Canada contributes about 25 percent, and ungaged inflow contributes 25 percent of the natural flow reentering the United States. The North Fork Milk River upstream from St. Mary Canal outlet supplies the greatest percentage during summer and fall.

Water consumption consists principally of irrigated agriculture, municipal use, and evapotranspiration. Irrigated agriculture covers about 4,400 acres (1,800 hectares) in the Canada part of the study area and about 5,000 acres (2,000 hectares) in the United States part. Mean daily water consumption by irrigation ranges from 10 ft^3/s (0.28 m^3/s) to 26 ft^3/s (0.74 m^3/s) in the Canada part and from 6 ft^3/s (0.17 m^3/s) to 41 ft^3/s (1.16 m^3/s) in the United States part. Two Canada municipalities consume about 320 acre-feet (390 cubic decameters), and one United States municipality consumes about 20 acre-feet (25 cubic decameters) yearly. Evaporation from the water surface comprises 80 to 90 percent of the flow reduction in the Milk River attributed to total evapotranspiration.

The current procedure for computing natural flow of the Milk River where it reenters the United States was refined into an interim procedure, which includes allowances for man-induced consumption and a method for apportioning computed natural flow between the United States and Canada. The refined procedure is considered interim because further study of flow routing, tributary inflow, and man-induced consumption is needed before a more accurate procedure for computing natural flow can be developed.

INTRODUCTION

Historical Apportionment of Natural Flow

The Boundary Waters Treaty of 1909 is the legal basis for apportionment of the Milk and St. Mary Rivers between the United States and Canada. Prior to ratification of the treaty, emphasis was on the doctrine of prior appropriation--that the first to appropriate was the first in right. This type of appropriation resulted in much discussion about water rights between and within both countries.

Irrigation appropriations were first attempted in the United States when the potential for arid-land reclamation was recognized during the 1870's (Dreisziger, 1975). However, low natural streamflow in the Milk River downstream from reentry into the United States prevented large-scale increases in irrigated agriculture. After an 1891 study by the United States concluded that diverting flow from the St. Mary River to the Milk River was feasible, irrigation-project proposals proliferated during the 1890's. The possibility that the diversion might seriously reduce flow in the Canadian part of the St. Mary River basin led to the start of "Spite Ditch" in 1903 (Dreisziger, 1975). The purpose of this unfinished canal near the municipality of Milk River, Alberta, was to redivert the streamflow diverted from the St. Mary River by the United States.

Following additional feasibility studies in both countries, a draft treaty concerning apportionment of the Milk and St. Mary Rivers was presented to Great Britain by the United States in 1907. The treaty was signed by the Secretary of State of the United States and the British Ambassador to Washington, D.C. on January 11, 1909.

Article III of the treaty establishes a joint commission, to be known as the International Joint Commission. The commission is composed of representatives from the United States and Canada to oversee treaty implementation.

Article VI states that for the purposes of irrigation and power: (1) the waters of the Milk and St. Mary Rivers and their tributaries are to be treated as one stream and apportioned equally between the United States and Canada; (2) from April 1 to October 31 (irrigation season) of each year, the United States is entitled to a prior appropriation of 500 ft^3/s (14.2 m^3/s) of the Milk River, or so much of such amount as constitutes three-fourths of its natural flow; (3) during the irrigation season, Canada is entitled to an equivalent appropriation of the St. Mary River natural flow; and (4) the Milk River channel in Canada may be used by the United States for conveyance of waters diverted from the St. Mary River.

In 1921, the International Joint Commission modified the wording in Article VI such that: (1) during the irrigation season when the Milk River natural flow, where it reenters the United States, is 666 ft^3/s (18.9 m^3/s) or less, the United States is entitled to three-fourths and Canada to one-fourth; (2) natural flow in excess of 666 ft^3/s (18.9 m^3/s) during the irrigation season and all natural flow during the nonirrigation season is to be divided equally; and (3) the accredited officers representing each country are to ascertain and keep a daily record of the natural flow.

Although approximate estimates of Milk River natural flow have been computed for many years, the water has not been formally apportioned. Historically, the insignificant use of the water in both countries upstream from reentry into the United States has made an accurate determination and apportionment of natural flow unnecessary. However, because of increasing irrigation demand, recent prolonged low-flow periods, and possible Canadian reservoir construction, an improved procedure for computing natural flow of the Milk River where it reenters the United States is needed so that apportionment between the United States and Canada can be accomplished pursuant to the Boundary Waters Treaty and the International Joint Commission Order.

Purpose and Scope

The purpose of this report, which was prepared in cooperation with Environment Canada, is threefold: To describe the differences between natural and nonnatural Milk River streamflow, to delineate and quantify the types and effects of water consumption on streamflow, and to refine the current computation procedure into one which computes and apportions natural flow.

Differences between natural and nonnatural flow are explained through statistical analyses of daily and monthly streamflow data at selected locations in the study area. Gaged flows are compared to show the significant increases in Milk River streamflow that have occurred since partial diversion of St. Mary River streamflow into the Milk River basin began in 1917.

Estimates of water consumed by irrigated agriculture, municipal and domestic use, evapotranspiration, and reservoirs were made through a combination of direct measurement and informed approximation. Surface areas of flood- and sprinkler-irrigated agriculture were determined through telephone surveys, analysis of video-taped overflights, and limited onsite observations. Mean daily water consumption by irrigated agriculture was estimated using crop requirement and plant use factors, and surface area of irrigated agriculture.

Pumping records from municipalities in the study area were used to make estimates of municipal use. Streamflow measurements along tributaries and the mainstem Milk River were made to estimate tributary inflow and gains or losses along the mainstem. Measurements of average humidity, average maximum and minimum temperatures, and average sunshine duration were used with location latitude, altitude, and long-term mean annual precipitation to estimate evapotranspiration.

The current procedure for computing natural flow of the Milk River was refined into an interim one that computes and apportions natural flow by using some of the previously mentioned effects. Deficiencies in the current procedure, complications introduced by the interim procedure, and hydrologic processes needing additional study were identified.

Location, Physiography, and Drainage

The study area encompasses the Milk River drainage from the headwaters in northwestern Montana downstream to the point of reentry into the United States. The area includes parts of northern Montana and southern Alberta (fig. 1).

The study area is on the eastern slope of the Rocky Mountains. Land-surface features range from foothills in the western part to prairies in the central and eastern parts. The Sweet Grass Hills, three areas of Tertiary igneous intrusive rock, are prominent in the south-central part.

Two streams, both originating in northwestern Montana, form the Milk River. The North Fork Milk River flows northeastward and becomes the North Milk River in Canada. The South Fork Milk River combines with other drainages to become the Milk River, which flows northeastward into southern Alberta. The combined drainage area of the rivers upstream from entry into Canada is about 460 mi^2 (1,200 km^2). West of the municipality of Milk River, Alberta, the two rivers join and flow eastward, roughly paralleling the international boundary for about 130 mi (210 km) before

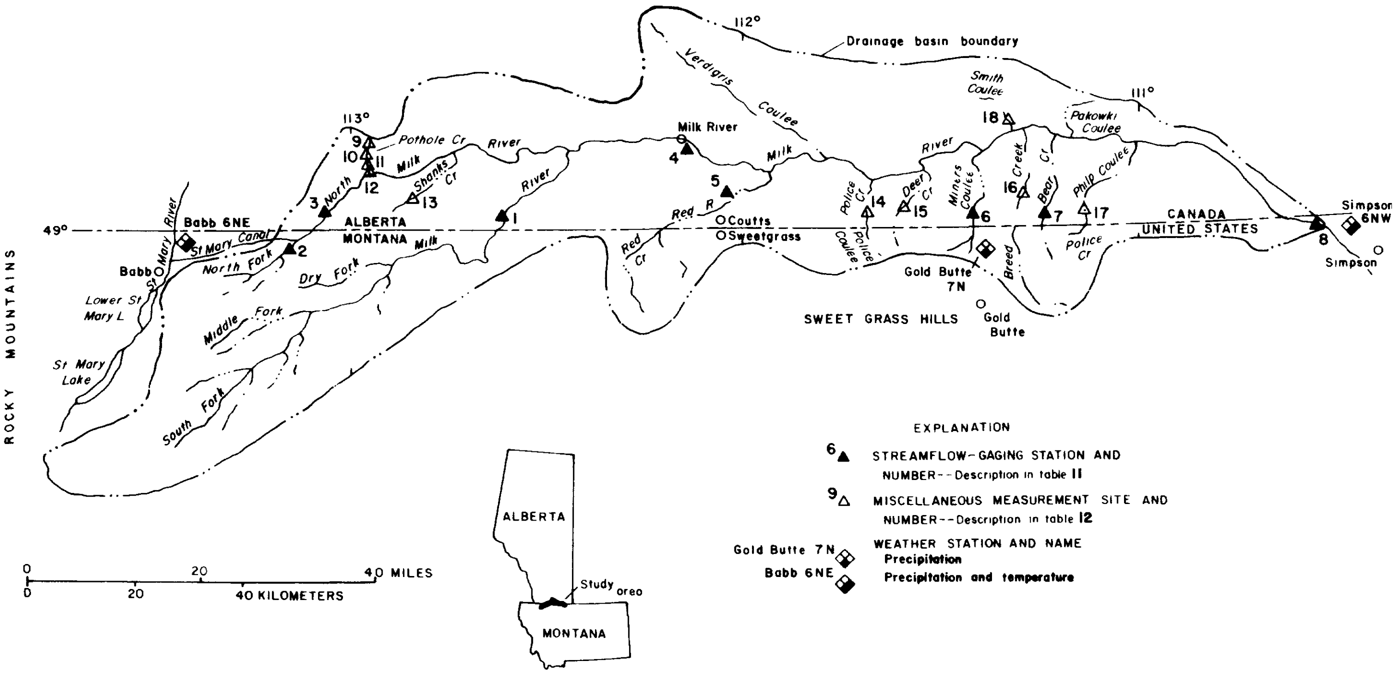

Figure 1.—Location of study area, data-collection sites, and selected geographic features.

reentering Montana. The drainage area upstream from reentry into the United States is about 2,600 mi^2 (6,700 km^2).

Many creeks and coulees intersect the Milk River channel in the study area. Although none downstream from entry into Canada are perennial, Red Creek (Red River in Canada), Police Coulee (Police Creek in Canada), Deer Creek, Miners Coulee, Breed Creek, Bear Creek, and Police Creek (Philp Coulee in Canada) have intermittent flow that can be used for irrigation. These small streams originate in north-central Montana, drain northward into Alberta, and are collectively known as the southern tributaries. From the northern edge of the study area, Verdigris and Pakowki Coulees, which are former glacial melt-water channels (McLean and Beckstead, 1981) that have no surface flow, meander southward to join the Milk River channel. Unnamed tributaries can contribute substantial smaller flow during intense precipitation.

Glacial activity has greatly affected the physiography and drainage patterns of the area. The North Fork Milk River and much of the upper mainstem Milk River valleys are former courses of preglacial drainage channels that were altered by glaciers (Williams and Dyer, 1930). Valley walls are composed of glacial till underlain by sandstone. Downstream from the municipality of Milk River, Alberta, the valley has a badlands appearance with eroded walls, terraces, meanders, and sparse vegetation.

Altitude of the study area ranges from about 8,900 ft (2,700 m) in the headwaters to about 2,700 ft (820 m) at the downstream end. Milk River, Alberta, the approximate midpoint of the study area, is at an altitude of about 3,400 ft (1,000 m). A longitudinal profile of the Milk River is depicted in figure 2.

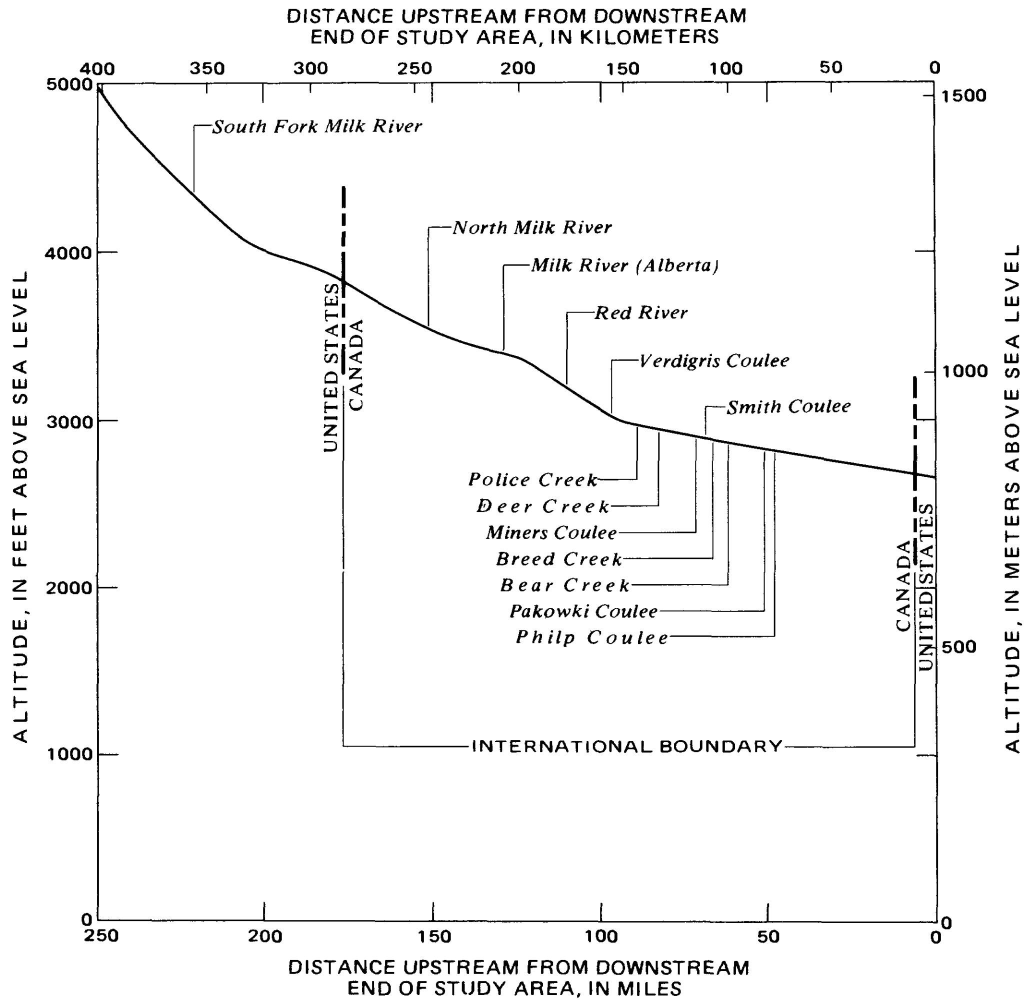

Figure 2.—Longitudinal profile of the Milk River in the middle and downstream parts of the study area.

Climate

The study area has a cool, arid climate that is affected by the Rocky Mountain rain shadow. Annual precipitation across the area decreases from west to east. Mean annual precipitation is about 19 in. (480 mm) close to Babb near the western edge of the study area, 13 in. (330 mm) close to Goldbutte in the central part, and 10 in. (250 mm) close to Simpson near the eastern edge. Mean monthly precipitation at these three locations is depicted in figure 3. Mean annual temperature throughout the area is about 40°F (4°C); mean monthly temperatures near Babb and Simpson are depicted in figure 4.

STREAMFLOW

Streamflow at gaging stations in the study area was determined by procedures described by Carter and Davidian (1968) and Buchanan and Somers (1968 and 1969). Although stage records generally are reliable, unstable stage-discharge relation-

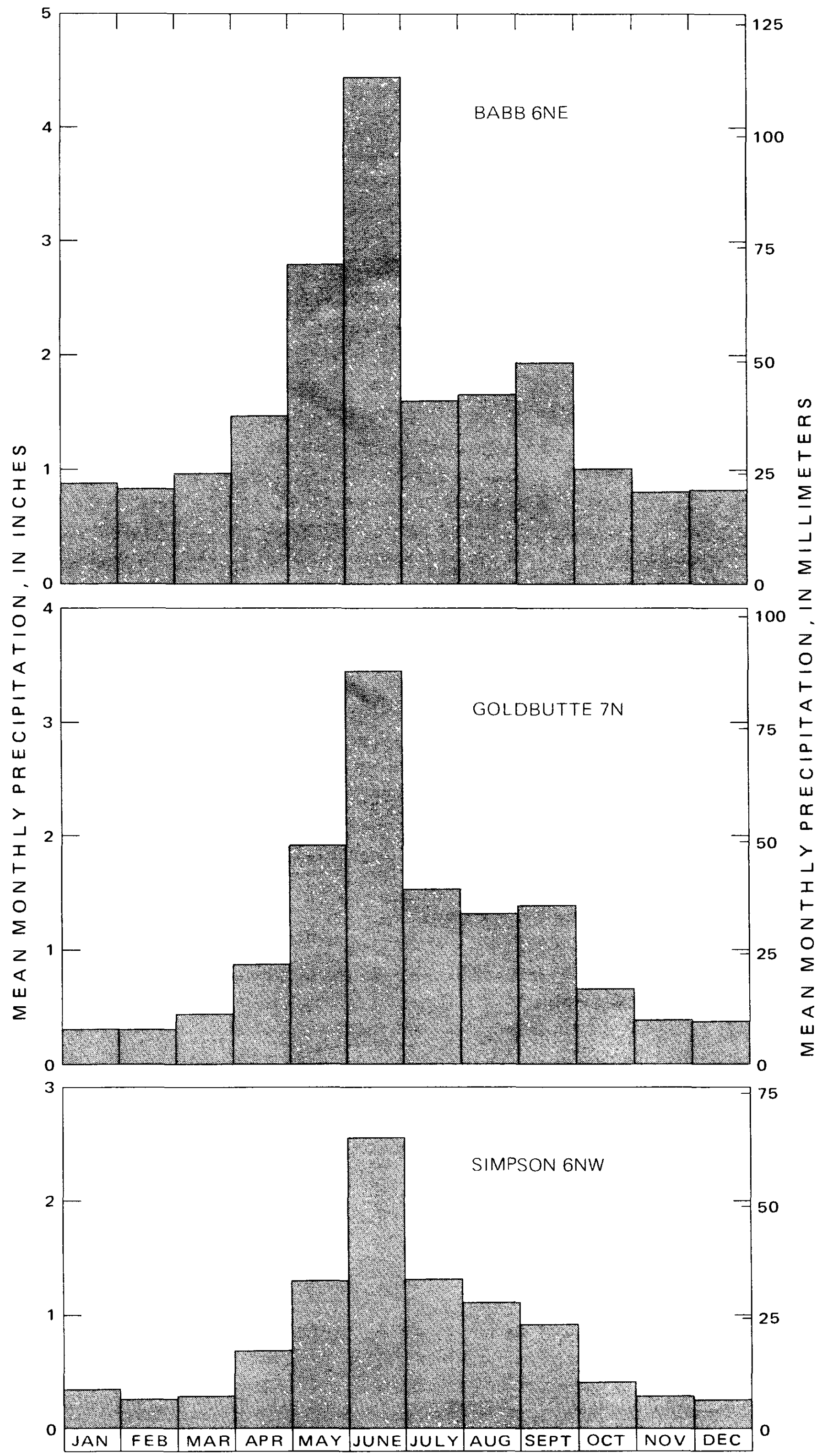

Figure 3.—Mean monthly precipitation at weather stations Babb 6NE, Goldbutte 7N, and Simpson 6NW, Montana, 1941-70. (Data from U.S. Department of Commerce, 1973.)

ships and poor measurement conditions can cause inaccurate computations of daily discharge. This problem is commonplace where the Milk River reenters the United States as a result of sand-channel conditions.

Because the U.S. Geological Survey (Department of the Interior) and the Water Survey of Canada (Environment Canada) have different methods for numbering gaging stations, an arbitrary system was used for this study. The system consists of

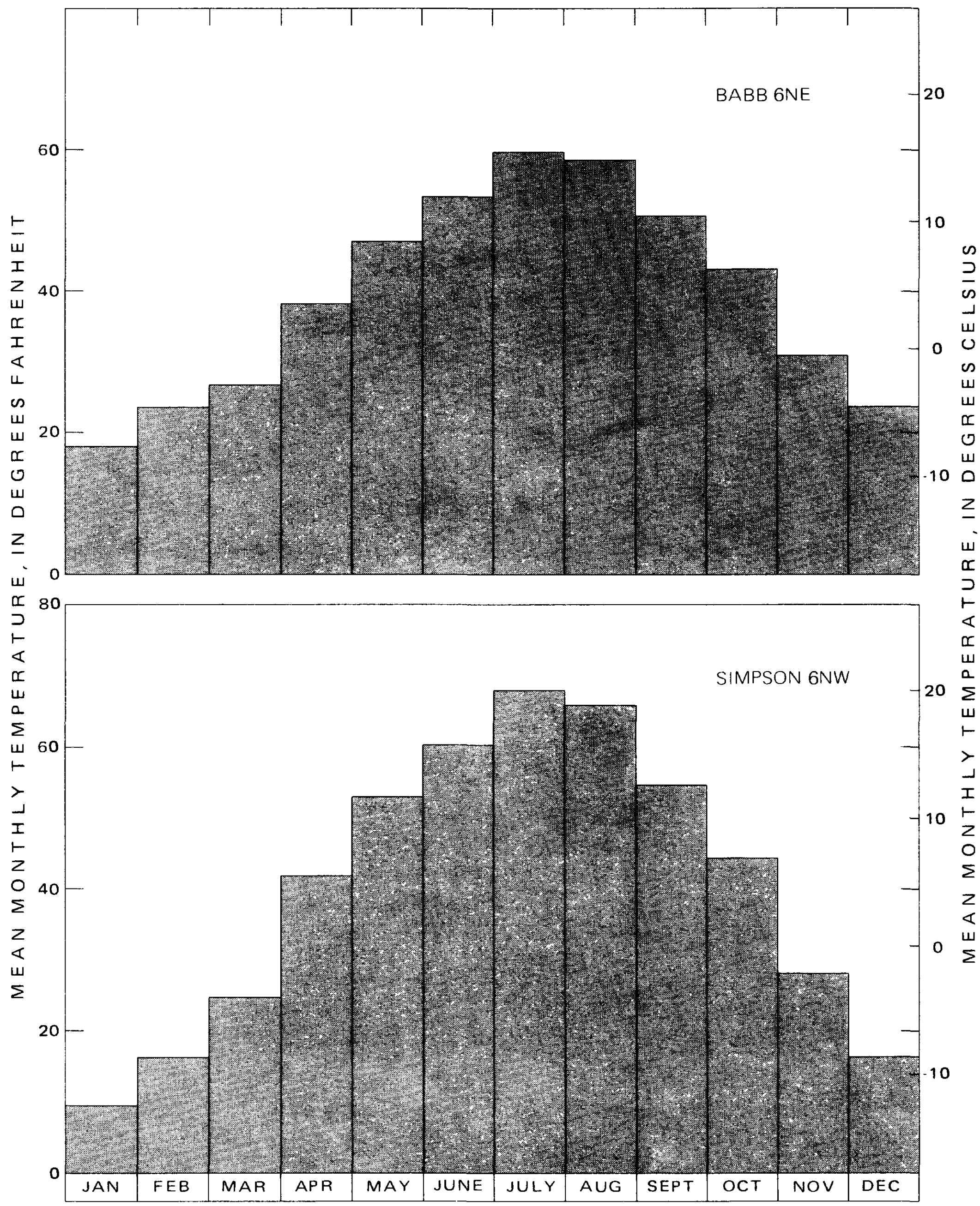

Figure 4.—Mean monthly temperatures at weather stations Babb 6NE and Simpson 6NW, Montana, 1941-70. (Data from U.S. Department of Commerce, 1973.)

assigning to the station farthest upstream the number 1 and then assigning succeeding downstream stations incremental numbers. Station names, descriptions, and respective U.S. Geological Survey and Water Survey of Canada numbers for stations used in this study are given in table 11.

Natural Streamflow

Diversion of St. Mary River streamflow into the Milk River basin through the St. Mary Canal began in July 1917. Prior to that diversion into the basin, water utilization upstream from the point of reentry into the United States was inconsequential (Dreisziger, 1975; Jones and Burley, 1920), and Milk River streamflow was unregulated and in a natural state.

Monthly statistics for streamflow at three gaging stations in the study area during May through October 1910-16 are listed in table 1. The values for stations 1 and 3 are the respective streamflows entering Canada for the Milk and North Milk Rivers at the western crossing of the international boundary. Station 8 values are for Milk River streamflow reentering the United States at the eastern crossing of the international boundary which is the downstream end of the study area.

Monthly statistics for differences between streamflow entering Canada and streamflow reentering the United States during May through October 1910-16 are given in table 2. The differences are equal to the combined monthly flows entering Canada subtracted from the monthly flows reentering the United States. Positive differences for the mean, maximum, and minimum are net gains in streamflow between crossings of the boundary, whereas negative differences for the minimum are net losses.

Net gains mean that accretions, such as tributary inflow and ground-water discharge, were greater than depletions, such as evaporation from the water surface and transpiration by riparian vegetation from the alluvium. Net losses mean that depletions were greater than accretions. For example, during 3 weeks from late July to mid-August 1914, streamflow ceased downstream from Milk River, Alberta (station 4) to reentry into the United States, while streamflow entering Canada was about 14 ft^3/s (0.40 m^3/s), thereby resulting in a minimum difference of -14 ft^3/s (0.40 m^3/s).

Postdiversion Streamflow

After partial diversion of St. Mary River streamflow into the Milk River basin began in 1917, irrigation-season streamflow in the North Milk River entering Canada and in the Milk River reentering the United States increased significantly. Monthly streamflow statistics for March through October 1931-82 are given in table 3 for the same three stations identified in table 1. The mean monthly streamflow for May through September 1931-82, compared to the same months for 1910-16, increased from 700 to 1,400 percent in the North Milk River entering Canada and from 140 to 460 percent in the Milk River reentering the United States.

Mean monthly streamflows in the mainstem Milk River entering Canada for May and June 1931-82 were about equal to those during 1910-16, whereas those for July through October 1931-82 were less than those for 1910-16. The decrease during 1931-82 may be the result of irrigation withdrawals not present during 1910-16, or 1931-82 may have been a period of less runoff.

Table 1.--*Monthly streamflow statistics for the mainstem Milk River entering Canada (station 1), the North Milk River entering Canada (station 3), and the Milk River reentering the United States (station 8), 1910-16*

Station No. (fig. 1)	Statistic	Streamflow, in indicated units					
		May	June	July	Aug	Sept	Oct
		Cubic feet per second					
1	Mean	199	176	88	45	61	59
	Standard deviation	82	113	60	27	46	17
	Maximum	311	358	174	87	128	80
	Minimum	114	63	17	11	17	32
3	Mean	51	61	45	39	44	41
	Standard deviation	19	42	31	27	27	19
	Maximum	82	120	102	83	78	73
	Minimum	26	18	15	15	15	21
8	Mean	309	332	225	106	149	137
	Standard deviation	125	251	227	97	152	72
	Maximum	477	766	678	262	422	212
	Minimum	158	103	26	5	23	42
		Cubic meters per second					
1	Mean	5.64	4.98	2.49	1.27	1.73	1.67
	Standard deviation	2.32	3.20	1.70	.76	1.30	.48
	Maximum	8.81	10.1	4.93	2.46	3.62	2.27
	Minimum	3.23	1.78	.48	.31	.48	.91
3	Mean	1.44	1.73	1.27	1.10	1.25	1.16
	Standard deviation	.54	1.19	.88	.76	.76	.54
	Maximum	2.32	3.40	2.89	2.35	2.21	2.07
	Minimum	.74	.51	.42	.42	.42	.59
8	Mean	8.75	9.40	6.37	3.00	4.22	3.88
	Standard deviation	3.54	7.11	6.43	2.75	4.30	2.04
	Maximum	13.5	21.7	19.2	7.42	12.0	6.00
	Minimum	4.47	2.92	.74	.14	.65	1.19

Monthly streamflow statistics for the North Fork Milk River above St. Mary Canal outlet (station 2) during May through October 1931-82 are listed in table 4. Differences in monthly mean streamflow between this station and the North Milk River entering Canada are primarily attributable to additions from the St. Mary Canal.

Table 2.--*Monthly statistics for differences between streamflow entering Canada (stations 1 and 3), and streamflow reentering the United States (station 8), 1910-16*

Statistic	Differences in streamflow, in indicated units					
	May	June	July	Aug	Sept	Oct
	Cubic feet per second					
Mean	59	95	92	22	44	37
Standard deviation	34	102	157	46	94	45
Maximum	107	294	432	92	229	100
Minimum	12	11	-17	-28	-16	-18
	Cubic meters per second					
Mean	1.67	2.69	2.61	0.62	1.25	1.05
Standard deviation	.96	2.89	4.45	1.30	2.66	1.27
Maximum	3.03	8.33	12.2	2.61	6.49	2.83
Minimum	.34	.31	-.48	-.79	-.45	-.51

Tributary Inflow

Tributary inflow downstream from the entry into Canada is sporadic, both in timing and quantity. Chinook winds can cause intermittent snowmelt runoff anytime during the winter. Steady snowmelt runoff generally begins no later than March and continues until May or June. Rainstorms that coincide with snowmelt can prolong its effects; however, sustained tributary inflow from creeks and coulees usually ceases prior to the end of July. After snowmelt has ended, general rainstorms may cause tributary inflow lasting several days, whereas localized cloudbursts may cause only flash flows.

Miners Coulee (station 6) and Bear Creek (station 7) near the international boundary exemplify the irregularity of tributary inflow. These streams flow from the Sweet Grass Hills, have respective drainage areas of 42.1 mi^2 (109 km^2) and 33.7 mi^2 (87.3 km^2), and are affected by irrigation withdrawals upstream from the gaging stations. The duration of recorded streamflow in Miners Coulee and Bear Creek during March through October 1967-82 is shown in figure 5. The extreme fluctuations in streamflow duration are most noticeable for Miners Coulee in 1978, when flow occurred during most of the season, and in 1973 and 1977, when the channel had no flow the entire season. Flow intensity and duration in Miners Coulee and Bear Creek during August, September, and October 1967-82 were such that the monthly means and standard deviations either approached zero or were zero as indicated in table 5.

During April 1983 a gaging station was established on the Red River in Canada (station 5) in an attempt to determine inflow from prairie-type tributaries. The

Table 3.--*Monthly streamflow statistics for the mainstem Milk River entering Canada (station 1), the North Milk River entering Canada (station 3), and the Milk River reentering the United States (station 8), 1931-82*

Station No. (fig. 1)	Statistic	Mar	Apr	May	June	July	Aug	Sept	Oct
		Streamflow, in indicated units							
		Cubic feet per second							
1	Mean	98	236	232	191	59	21	21	24
	Standard deviation	125	145	158	186	62	25	32	21
	Maximum	717	615	679	877	348	142	168	133
	Minimum	10	42	13	3	0	0	0	0
3	Mean	52	171	435	536	597	578	351	60
	Standard deviation	58	145	196	167	115	135	211	87
	Maximum	402	560	682	745	727	721	690	524
	Minimum	12	24	43	44	191	16	9	6
8	Mean	381	590	741	797	659	593	429	126
	Standard deviation	355	326	290	288	134	132	207	113
	Maximum	1,520	1,690	1,750	2,220	1,050	810	740	551
	Minimum	16	80	317	200	262	77	24	13
		Cubic meters per second							
1	Mean	2.78	6.68	6.57	5.41	1.67	0.59	0.59	0.68
	Standard deviation	3.54	4.11	4.47	5.27	1.76	.71	.91	.59
	Maximum	20.3	17.4	19.2	24.8	9.86	4.02	4.76	3.77
	Minimum	.28	1.19	.37	.08	0	0	0	0
3	Mean	1.47	4.84	12.3	15.2	16.9	16.4	9.94	1.70
	Standard deviation	1.64	4.11	5.55	4.73	3.26	3.82	5.98	2.46
	Maximum	11.4	15.9	19.3	21.1	20.6	20.4	19.5	14.8
	Minimum	.34	.68	1.22	1.25	5.41	.45	.25	.17
8	Mean	10.8	16.7	21.0	22.6	18.7	16.8	12.1	3.57
	Standard deviation	10.1	9.23	8.21	8.16	3.79	3.74	5.86	3.20
	Maximum	43.0	47.9	49.6	62.9	29.7	22.9	21.0	15.6
	Minimum	.45	2.27	8.98	5.66	7.42	2.18	.68	.37

Table 4.--*Monthly streamflow statistics for the North Fork Milk River above St. Mary Canal outlet (station 2), 1931-82*

Station No. (fig. 1)	Statistic	Streamflow, in indicated units					
		May	June	July	Aug	Sept	Oct
		Cubic feet per second					
2	Mean	37	31	20	17	17	17
	Standard deviation	27	27	16	11	10	8
	Maximum	164	139	88	66	61	38
	Minimum	7	7	4	3	4	7
		Cubic meters per second					
2	Mean	1.05	0.88	0.57	0.48	0.48	0.48
	Standard deviation	.76	.76	.45	.31	.28	.23
	Maximum	4.64	3.94	2.49	1.87	1.73	1.08
	Minimum	.20	.20	.11	.08	.11	.20

Red River gaging station monitors streamflow from a drainage area of 226 mi^2 (585 km^2), with no known irrigation or other regulation upstream from the gaging station. From April 13 through October 31, 1983, the recorded instantaneous peak streamflow was about 0.85 ft^3/s (0.024 m^3/s), with days of no flow common.

During 1983, streamflow measurements were made at 10 miscellaneous sites in an attempt to determine tributary inflow from the ungaged parts of the study area. Drainage areas upstream from the miscellaneous sites ranged from 0.85 mi^2 (2.2 km^2) to 74.6 mi^2 (193 km^2). The miscellaneous site locations, drainage areas, dates of measurement, and measured discharges are listed in table 13. As with the recorded flows at the Red River gaging station, the flows measured at the miscellaneous sites tended to be small or zero.

Hydrographic comparison of the measured flows at miscellaneous sites versus the recorded flows at the gaging stations indicated that none of the miscellaneous sites were reliable predictors of tributary inflow during 1983. Regulation upstream from some of the sites by irrigators significantly affected streamflow at those sites. Additionally, hydrographic comparison of flows at the 10 miscellaneous sites and at stations 1 through 7 with flows downstream at station 8 indicated that all the upstream locations were bypassed by a rainstorm during early July. In 1 day alone this rainstorm caused about 300 ft^3/s (8.5 m^3/s) of tributary inflow reentering the United States.

G. H. Morton (Water Survey of Canada, written commun., 1985) studied the effects of tributary inflow on natural flow reentering the United States during median- and low-flow years. Some of his conclusions were: (1) that in a representative median-flow year, the mainstem Milk River entering Canada contributes

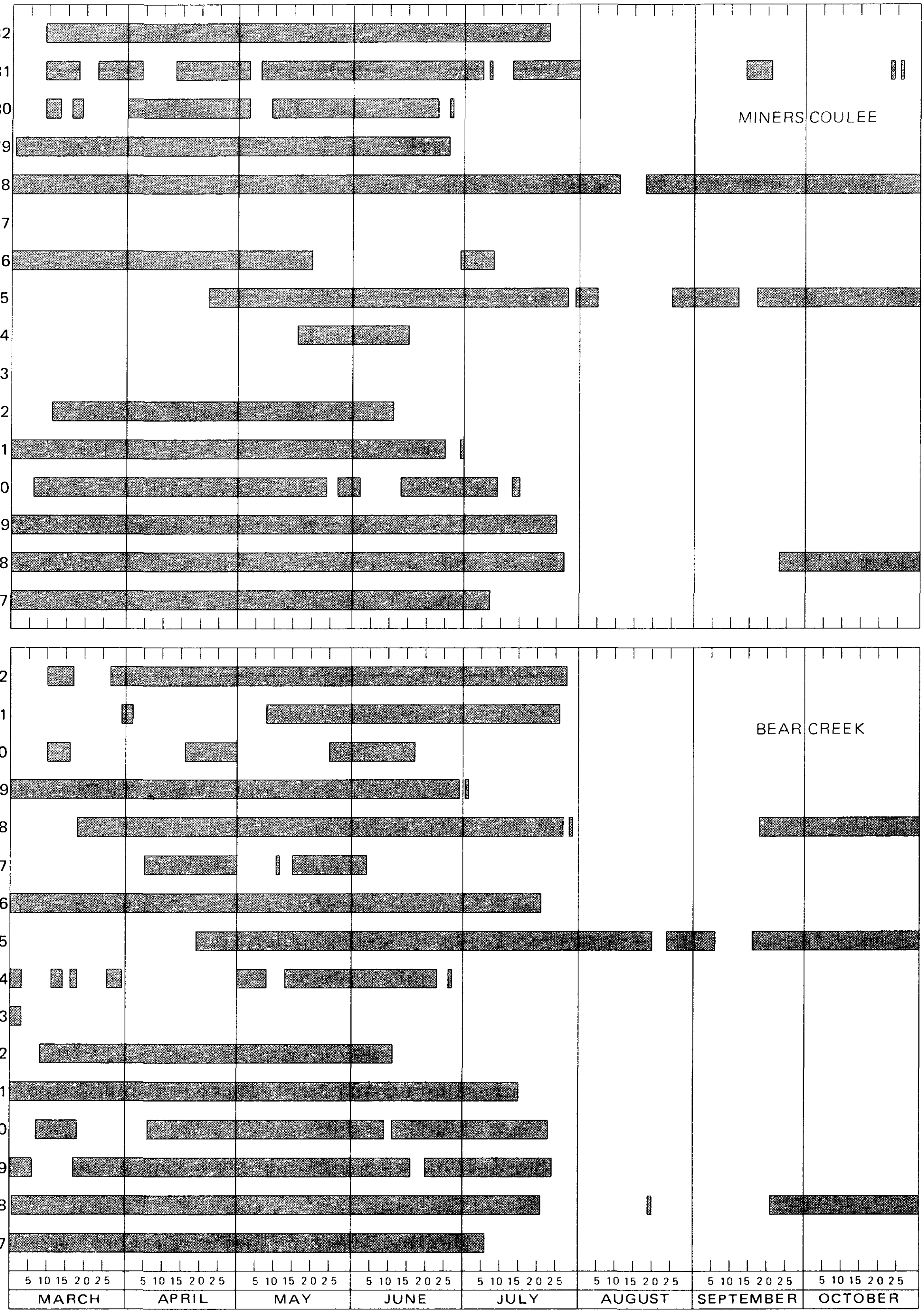

Figure 5.—Duration of recorded streamflow in Miners Coulee (station 6) and Bear Creek (station 7) near international boundary, 1967-82.

Table 5.--*Monthly streamflow statistics for Miners Coulee (station 6) and Bear Creek (station 7) near international boundary, 1967-82*

Station No. (fig. 1)	Statistic	Streamflow, in indicated units							
		Mar	Apr	May	June	July	Aug	Sept	Oct
		Cubic feet per second							
6	Mean	5	5	8	5	1	0	1	0
	Standard deviation	7	6	14	7	2	1	2	1
	Maximum	20	18	48	21	5	4	7	5
	Minimum	0	0	0	0	0	0	0	0
7	Mean	6	6	13	7	1	0	0	0
	Standard deviation	9	6	19	10	1	0	0	1
	Maximum	34	19	70	32	4	0	2	4
	Minimum	0	0	0	0	0	0	0	0
		Cubic meters per second							
6	Mean	0.14	0.14	0.23	0.14	0.03	0	0.03	0
	Standard deviation	.20	.17	.40	.20	.06	.03	.06	.03
	Maximum	.57	.51	1.36	.59	.14	.11	.20	.14
	Minimum	0	0	0	0	0	0	0	0
7	Mean	.17	.17	.37	.20	.03	0	0	0
	Standard deviation	.25	.17	.54	.28	.03	0	0	.03
	Maximum	.96	.54	1.98	.91	.11	0	.06	.11
	Minimum	0	0	0	0	0	0	0	0

about 50 percent, the North Milk River entering Canada contributes about 25 percent and ungaged inflow contributes about 25 percent of the natural flow; (2) although the Milk River entering Canada is the major contributor during the spring, the North Fork Milk River upstream from the St. Mary Canal supplies the greatest percentage during the summer and fall; (3) for both median- and low-flow years the Canadian prairie areas supply more ungaged inflow than the southern tributaries, which contribute about 2.5 percent; and (4) during low-flow years small stock-water and irrigation reservoirs are used to store a large percentage of the tributary flow downstream from entry into Canada.

Ground-Water Interaction

A detailed quantitative analysis of ground-water interaction with streamflow along the entire river reach was outside the scope of the study; however, an investigation at selected locations (Gary Grove, Environment Canada, written commun., 1985), measurements of streamflow and specific conductance, and inspections of riverbank geology have indicated no major interaction between the regional aquifer and streamflow. Net movement of flow into or out of valley alluvium probably varies with season of the year. During spring and summer when runoff occurs and when the St. Mary Canal is adding flow, some streamflow likely moves into the alluvium. After added flow through the canal is stopped, usually in late summer or early fall, water is discharged from the alluvium.

During 1981 and 1982, measurements were made along the river between crossings of the international boundary in an attempt to determine the extent of ground-water interaction with streamflow. Two procedures were followed in making streamflow measurements. In the first procedure a single discharge measurement was made at each site, and in the second two simultaneous measurements were made at each site.

Measured streamflow versus distance upstream from the downstream end of the study area using single measurements is depicted in figure 6. No consistent pattern regarding change in streamflow magnitude is evident for individual reaches of the river.

Measured streamflow versus distance upstream from the downstream end of the study area using two simultaneous measurements is depicted in figure 7. Simultaneous measurements that closely agree were usually made at sites having good measuring conditions such as firm bottoms and trapezoidal-shaped cross sections, whereas those with the larger differences were usually made at sites having irregular bottoms, turbulent flows, and sand-dune regimes.

Daily mean flows at Milk River, Alberta, during July 1-October 31, 1981 and 1982, are depicted in figure 8. This illustration indicates that the measurement trip of July 14-16, 1981, was conducted during a period of steady flow.

The measurements during the July 14-16, 1981 trip (fig. 6) showed little net change in streamflow between the upstream and downstream ends of the study area. The trip of September 28-30, 1981 (fig. 7), was conducted just as the effect of St. Mary Canal shutoff became evident at Milk River, Alberta; the measurements also showed little net change in streamflow. The trip of October 13-15, 1981 (fig. 7), was conducted about 2 weeks after the effect of canal shutoff became evident; the measurements showed a gradual increase in streamflow from about 60 ft^3/s (1.7 m^3/s) to 90 ft^3/s (2.5 m^3/s). The increase was attributed to alluvium discharge because no measurable rainfall occurred during the trip and none of the tributaries downstream from entry into Canada contained surface flow. The trip of October 25-26, 1982 (fig. 7), was conducted more than 2 months after the effect of canal shutoff became evident, neither rainfall nor tributary inflow occurred, and the measurements showed a gradual increase from about 33 ft^3/s (0.93 m^3/s) to 38 ft^3/s (1.08 m^3/s). Specific-conductance measurements made concurrently with the streamflow measurements during the October 25-26, 1982, trip indicated a gradual increase from 570 microsiemens (microsiemens per centimeter at 25°C) at the upstream site to 766 microsiemens at the downstream site, signifying that the streamflow increase was attributable to discharge from alluvium.

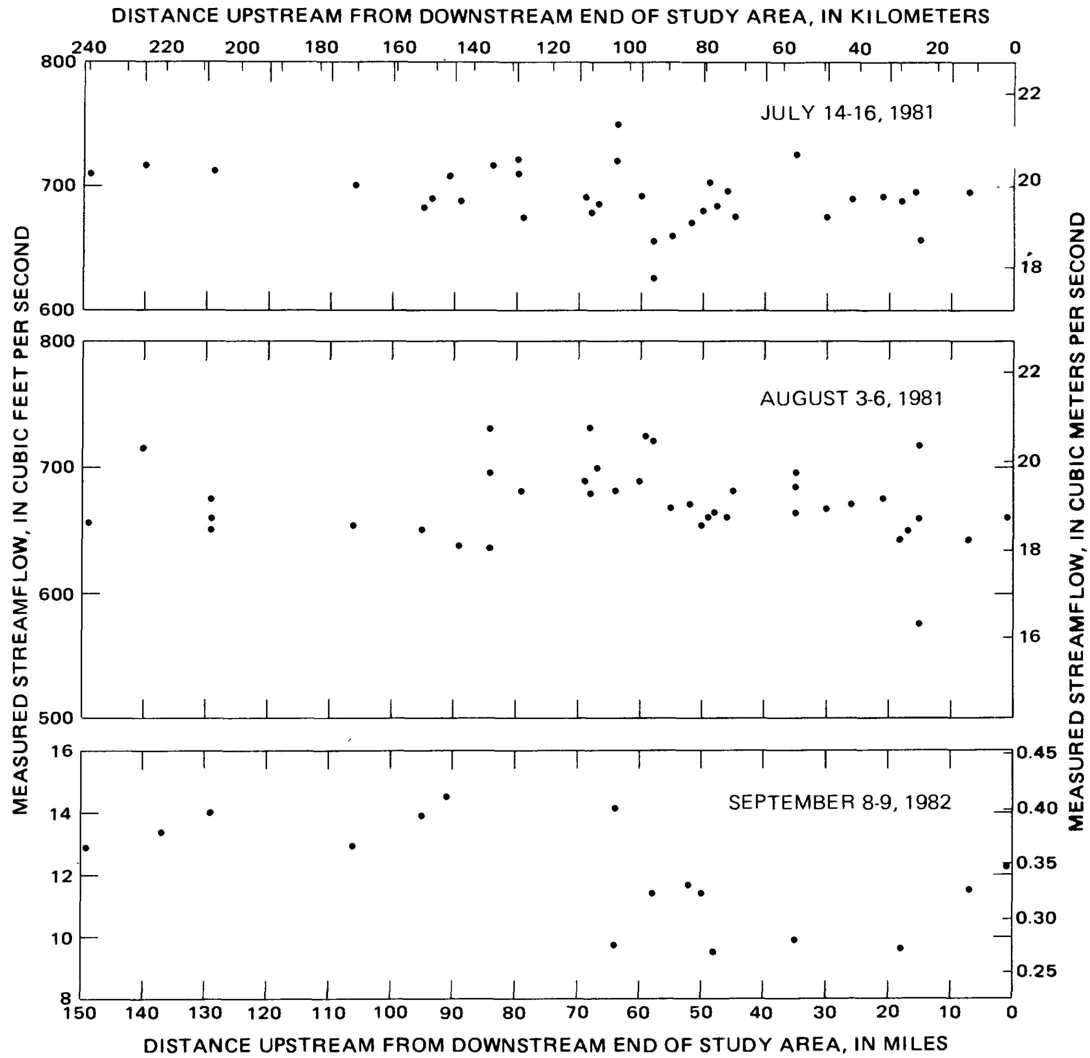

Figure 6.—Single measurements of flow of the Milk River versus distance from downstream end of the study area, July 14-16 and August 3-6, 1981, and September 8-9, 1982.

WATER CONSUMPTION

Irrigated Agriculture

Irrigated agriculture is widespread in the study area, is usually close to a surface supply, and is the largest man-induced consumption of water. Its extensiveness and proximity to surface water are due to the arid climate and the lack of ground-water development for irrigation purposes.

The crops that are irrigated are relatively few. Alfalfa, native grasses, and other types of hay predominate. Limited acreages of grains such as barley, oats, and wheat are irrigated to provide supplements to hay as livestock feed. In some years, scattered parcels of textile crops such as flax also are irrigated.

Irrigation within the study area can be divided into two types--flood and sprinkler. Flood irrigation generally occurs only during the runoff period and is

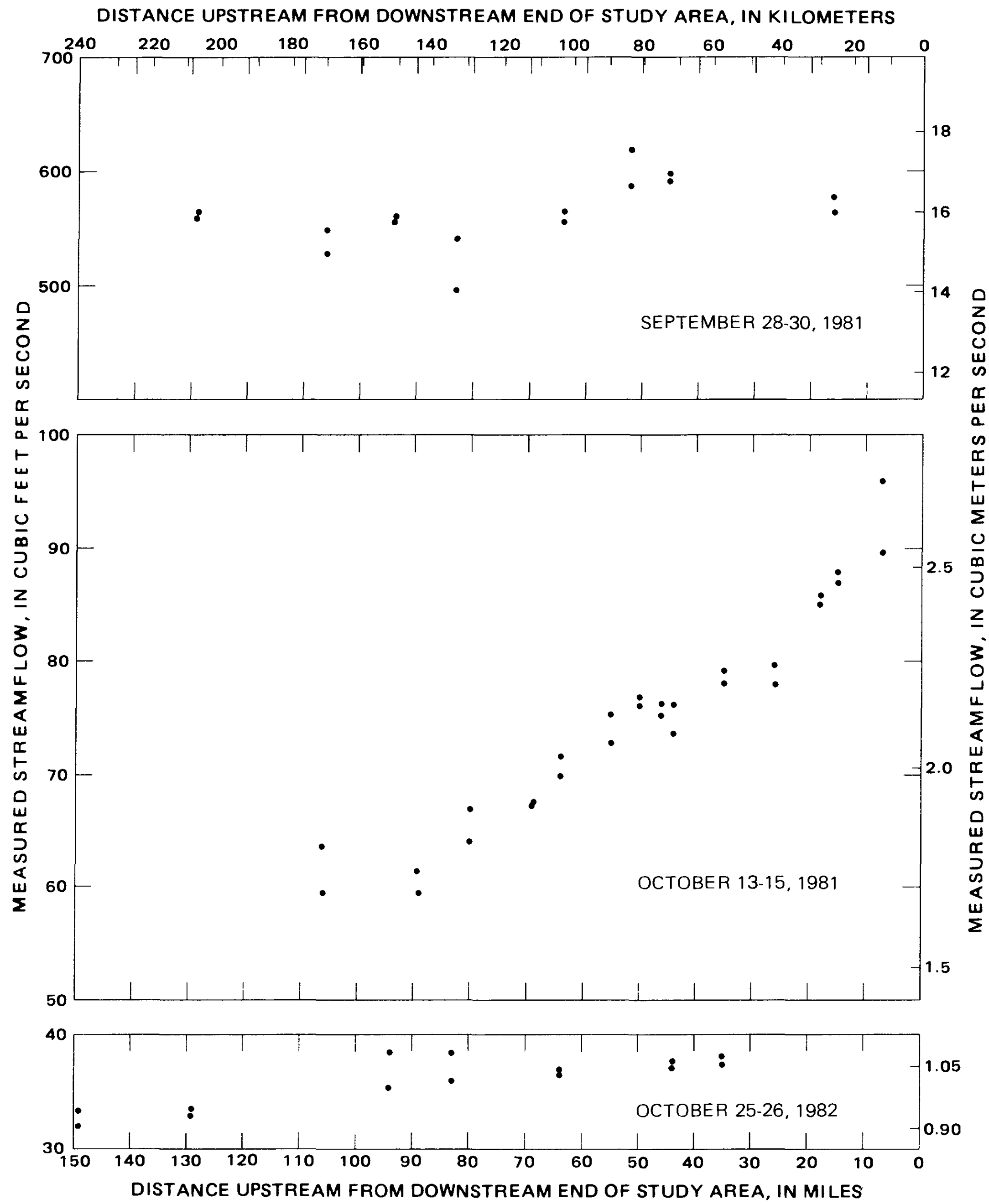

Figure 7.—Simultaneous measurements of flow of the Milk River versus distance from the downstream end of the study area, September 28-30 and October 13-15, 1981, and October 25-26, 1982.

accomplished through small-ditch spreader systems that originate as diversions along creeks, as interceptors at the mouths of coulees, or as small reservoirs with overflow systems. The technique used in flood irrigation is to saturate the crop root zone by spreading water after the ground has thawed until the high-volume part of runoff ceases, usually from about mid-May to mid-June each year. Mean annual water consumption for flood-irrigated crops in the study area is about 8 in. (200 mm) (A. H. Ferguson, Montana State University, oral commun., 1982). Excess water

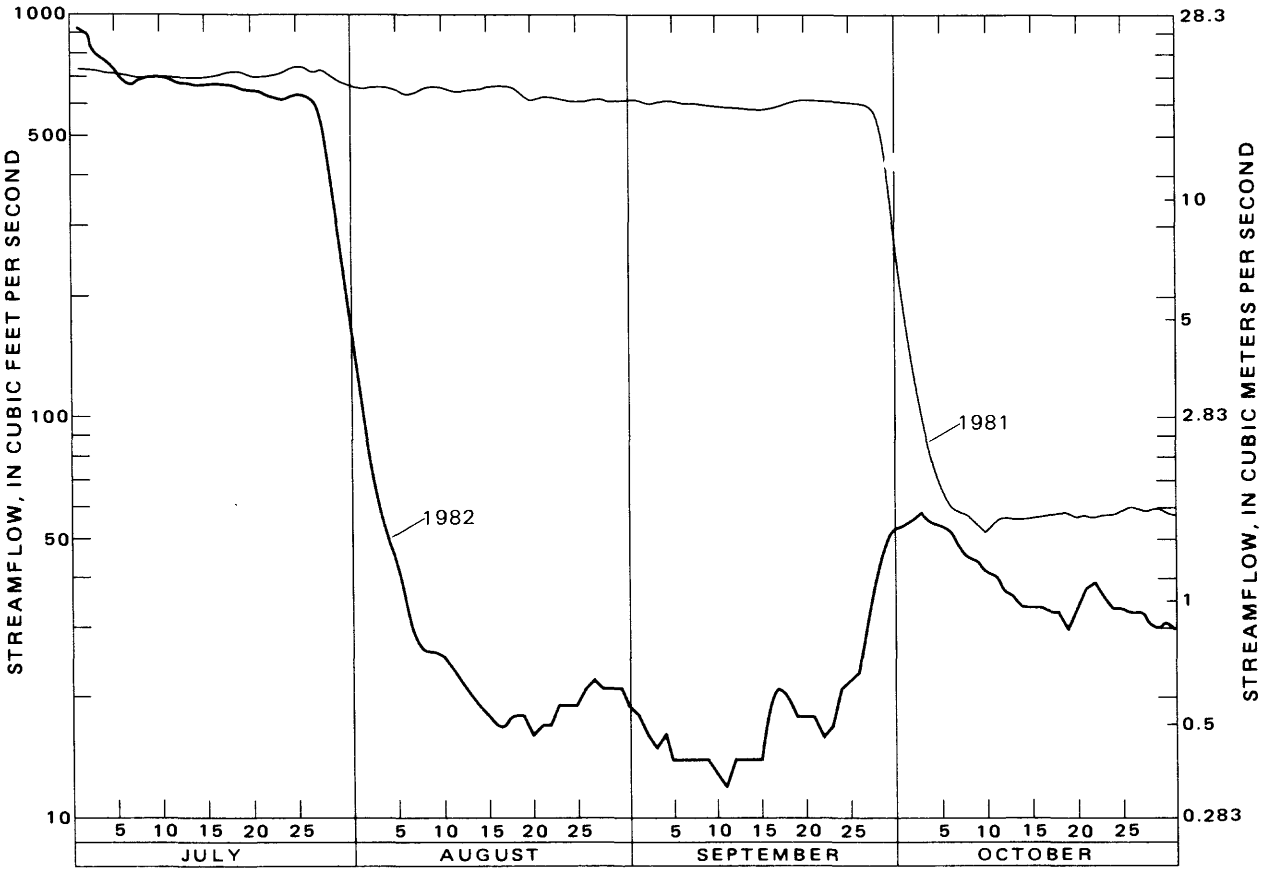

Figure 8.—Hydrographs of daily mean flow of the Milk River at Milk River, Alberta (station 4), July 1-October 31, 1981 and 1982.

that percolates past the root zone probably recharges the water table and eventually becomes surface flow downgradient.

Sprinkler irrigation generally is practiced on an as-needed basis, is accomplished by pumping from flowing streams, and is restricted to the mainstem drainage and tributaries having dependable summer flow. Sprinkler irrigation begins about mid-May and usually ceases by mid-September each year. Mean monthly net irrigation requirements for sprinkler irrigated crops in the study area are contained in table 6.

In a telephone survey of licensed irrigators, Alberta Environment (1980) found that about 1,500 acres (610 ha) were flood irrigated and 2,900 acres (1,200 ha) were sprinkler irrigated during 1979 in the Canada part of the study area. The mean daily water consumption by month and irrigation type, given in table 7, is based on the assumptions that no significant change in irrigated acreage has occurred in the Canada part of the study area since 1979 and that 1979 was an average irrigation year.

The mean daily water consumption for flood irrigation during May 16 to June 15 was derived by: (1) multiplying the mean annual water consumption of 8 in. (200 mm) by the area flood irrigated, 1,500 acres (610 ha); and (2) then converting the product volume of 1,000 acre-ft (1,200 dam^3) into discharge values averaged for

31 days. A similar process, using the mean monthly net irrigation requirements in table 6 and the sprinkler-irrigated area from the telephone survey, gave the sprinkler mean daily consumption.

Table 6.--*Mean monthly net irrigation requirements for sprinkler-irrigated crops in the study area*

Period	Irrigation requirements	
	Inches	Millimeters
May 16-31	1.2	30
June	2.5	64
July	4.7	120
August	3.7	94
September 1-15	1.2	30

From U.S. Soil Conservation Service (1974).

Table 7.--*Mean daily water consumption and irrigation type in the Canada part of the study area*

Period	Mean daily consumption					
	Cubic feet per second			Cubic meters per second		
	Flood	Sprinkler	Total	Flood	Sprinkler	Total
May 16-31	16	9	25	0.45	0.25	0.71
June 1-15	16	10	26	.45	.28	.74
June 16-30	0	10	10	0	.28	.28
July	0	18	18	0	.51	.51
August	0	15	15	0	.42	.42
September 1-15	0	10	10	0	.28	.28

Irrigation in the United States part of the study area can be segregated into two geographic areas. One area includes the headwaters of the North Fork Milk and Milk Rivers upstream from entry into Canada. The other area includes the southern tributaries upstream from entry into Canada.

The extent of irrigated agriculture in the United States part of the study area was determined in 1982. Review of maps delineating irrigation (Montana Water Resources Board, 1969) provided previously mapped locations. Wendell Martinelle (U.S. Soil Conservation Service, oral commun., 1982) and Charles Gephart and Mike Linsenbigler (U.S. Soil Conservation Service, written commun., 1982) provided names and telephone numbers of local irrigators. During July 1982, the United States part of the study area was video taped from an airplane using black and white cameras. The video tapes were analyzed with a Linear Measuring Set (LMS) system manufactured by Measuronics Corporation,[1] of Great Falls, Montana. Tentative irrigated surface area was measured using a light pencil attached to the LMS in combination with a television monitor and scaled map overlays. A telephone survey of the irrigators and onsite checks of about 20 percent of the irrigated plots indicated that the surface area from the tape analysis was less than the actual area being irrigated. The discrepancy was due to lack of contrast on the tape between irrigated and nonirrigated land and to incomplete land coverage while taping. The above described process resulted in values of about 1,900 acres (770 ha) under flood irrigation and 800 acres (320 ha) under sprinkler irrigation in the headwaters area, and about 1,300 acres (530 ha) under flood irrigation and 950 acres (380 ha) under sprinkler irrigation in the southern tributaries area during 1982.

Even though some irrigators in the United States part of the study area irrigate relatively constant parcels of land, others may vary their areas yearly. The variation is mostly associated with the volume and duration of runoff. When runoff is substantially diminished during droughts, less land is irrigated because of water shortages. Most irrigators surveyed felt that 1982 was an average year regarding total area irrigated.

The mean daily water consumption by area and irrigation type in the United States part of the study area, given in table 8, is based on the assumption that the 1982 irrigated areas were representative. The mean daily water consumption was derived by the same process described in the discussion of table 7.

Municipal and Domestic Use

For the purposes of this report, municipal use is defined as those volumes of water consumed by the incorporated communities of Milk River and Coutts, Alberta, and Sweetgrass, Montana. These communities pump their water from the Milk River through two infiltration galleries in the river bed, with Sweetgrass purchasing its water from the Coutts system.

Mean yearly withdrawals by Milk River, Alberta, from 1964 through 1979 were about 230 acre-ft (280 dam^3) (Alberta Environment, 1980). Mean yearly withdrawals by Coutts from 1973 through 1979 were about 110 acre-ft (140 dam^3), of which 17 percent was purchased by Sweetgrass (Alberta Environment, 1980). The mean monthly municipal withdrawals by country are depicted in figure 9. Municipal use has an insignificant effect on natural flow except during periods of low flow.

[1]The use of the brand name in this report is for identification purposes only and does not imply endorsement by the U.S. Geological Survey.

Table 8.--*Mean daily water consumption, area, and irrigation type in the United States part of the study area*

Period	Mean daily consumption						
	Headwaters			Southern tributaries			
	Flood	Sprinkler	Subtotal	Flood	Sprinkler	Subtotal	Total
	Cubic feet per second						
May 16-31	21	3	24	14	3	17	41
June 1-15	21	3	24	14	3	17	41
June 16-30	0	3	3	0	3	3	6
July	0	5	5	0	6	6	12
August	0	4	4	0	5	5	9
September 1-15	0	3	3	0	3	3	6
	Cubic meters per second						
May 16-31	0.59	0.08	0.68	0.40	0.08	0.48	1.16
June 1-15	.59	.08	.68	.40	.08	.48	1.16
June 16-30	0	.08	.08	0	.08	.08	.17
July	0	.17	.17	0	.17	.17	.34
August	0	.11	.11	0	.14	.14	.25
September 1-15	0	.08	.08	0	.08	.08	.17

Domestic use is that water consumed by unincorporated communities and the many farms in the study area. Ground-water wells drilled into the aquifer of the Upper Cretaceous Milk River Sandstone of Alberta (Eagle Sandstone equivalent in Montana) and improved artesian springs provide much of the water consumed through domestic use. Surface impoundments by small dams and dugouts into the water table, resulting in small-capacity reservoirs, are the other sources of supply for domestic use. Human consumption of water is mainly restricted to the ground-water source, whereas livestock consumption is spread among the reservoirs, flowing wells, and flowing streams.

Most of the water consumed by domestic use affects only the regional aquifer water table. Because there appears to be little interaction between the regional aquifer and streamflow in the Milk River, most domestic use probably has a negligible effect on surface flow. Human consumption of water from alluvium and livestock consumption of water from flowing streams are also assumed to be minor.

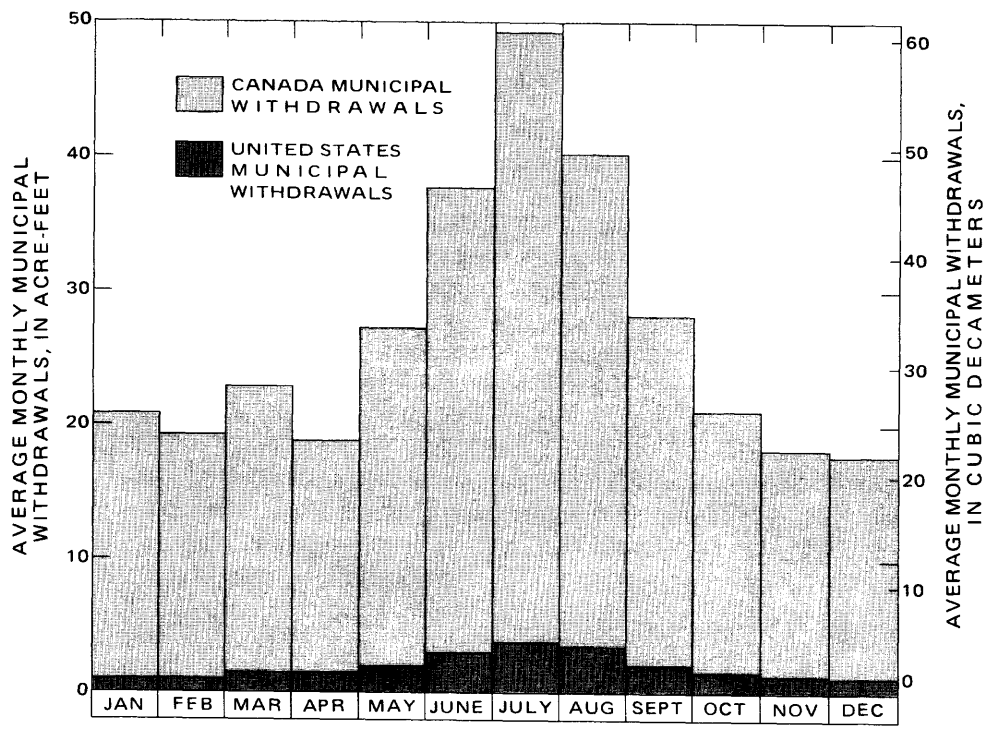

Figure 9.—Mean monthly municipal withdrawals from the Milk River in the study area, by country.

Evapotranspiration

Evaporation from the water surface and transpiration by vegetation from water in the alluvium are collectively known as evapotranspiration. Evapotranspiration cannot be measured directly; however, its effects can be estimated indirectly, either as a residual in a water budget or as a computed value derived from observations of other hydrologic phenomena.

F. I. Morton (1978, 1979) presented models for estimating lake evaporation and transpiration from routine climatological observations. These models are based on the concept that a complementary relationship exists between the evapotranspiration from an area and the potential evaporation at some point in the area. Minor modifications to the lake model allow computation of evaporation from a river surface.

The climatological observations needed in Morton's models are average humidity (dew point temperature, or vapor pressure), the average of maximum and minimum temperatures, and the average sunshine duration for periods of 5 days to 1 month. Additional fixed inputs required are latitude, altitude, and long-term mean annual precipitation.

Morton's methodology is theoretically usable on a worldwide basis and requires that a correction made to obtain agreement between model and water-budget estimates in one river basin must be applicable to all others. F. I. Morton (1983), in applying his methodology to 143 river basins in North America, Africa, Ireland, New Zealand, and Australia, provided estimates of evapotranspiration that closely agreed with water-budget estimates for those basins.

At three test sites downstream from Milk River, Alberta, F. I. Morton (Environment Canada, written commun., 1982) computed evapotranspiration totals during May, June, July, and August 1982 that agreed closely with the total evaporation observed at Medicine Hat Airport, which is about 70 mi (110 km) from the sites. The test sites were chosen individually as representative of phreatophyte, riparian, and prairie environments based on the expectation that evapotranspiration from cottonwoods, willows, and other woody shrubs in the phreatophyte zone would be considerably greater than that from sagebrush and grasses in the riparian and prairie zones. The computed results indicated otherwise, in that the estimated evapotranspiration totals were roughly equal at all three sites.

During early spring 1983 the data-gathering instrumentation was relocated to three new sites, again representative of phreatophyte, riparian, and prairie environments but upstream from the original sites. Computed evapotranspiration totals at the new sites for May 31-July 26, 1983, were once again roughly equal.

After further data collection and analysis, F. I. Morton (written commun., 1985) found that: (1) evapotranspiration was slightly greater for phreatophytes than for riparian and prairie vegetation, (2) riparian and prairie evapotranspiration had an insignificant effect in decreasing streamflow, (3) phreatophyte evapotranspiration probably reduces ground-water yield to the river rather than using streamflow directly, and (4) evaporation from the water surface of the river comprises 80 to 90 percent of the flow reduction due to total evapotranspiration.

Reservoir Effects

Most of the reservoirs currently in the study area are ponds formed by low dams across coulees and dugouts bulldozed into the water table. These small reservoirs are used primarily for livestock watering and limited irrigation and probably have a negligible effect on Milk River streamflow, except during years of low flow as mentioned previously.

Preliminary feasibility analyses (Prairie Farm Rehabilitation Administration, 1978 and 1980) have been completed for several large reservoirs in Canada ranging in storage capacity from 23,000 acre-ft (28,400 dam^3) to 200,000 acre-ft (247,000 dam^3). The primary purpose of such reservoir(s) would be to retain spring runoff for irrigation use later in the year. Storage of water during runoff would diminish streamflow, in contrast to later releases, which would augment streamflow. Increased surface area resulting from storage would increase evaporation from the water surface.

COMPUTATION AND APPORTIONMENT OF NATURAL FLOW

Current Procedure

The current procedure for computing Milk River natural flow where it reenters the United States is a water-budget approach that has evolved over time (U.S. Geological Survey, 1979). It has the following deficiencies: no allowance for man-induced consumption is included; the computation method may have inherent error that is greater than the natural flow being computed; and a method for apportioning the computed natural flow between the United States and Canada is lacking.

Warner (1968) reported a total time of travel, from the confluence of the St. Mary Canal with the North Fork Milk River to reentry into the United States, of about 5 days when measured streamflow in river subreaches ranged from 675 ft^3/s (19.1 m^3/s) to 750 ft^3/s (21.2 m^3/s). This 5-day lag, between when streamflow enters Canada and when its effects are apparent at reentry, has been incorporated into the current procedure on a constant basis. For example, flow entering Canada at the western end of the study area on May 27 is lagged 5 calendar days and used in natural-flow computations for June 1 at reentry.

Computed effects of evaporation on natural flow and total flow are based on estimates of surface area of the river versus amount of streamflow, factors converting pan evaporation to streamflow evaporation, and the 5-day lag. The estimates of surface area versus streamflow were developed by the Canadian Reclamation Service about 1923 from a survey of the river channel completed during 1915. Included in the surface area estimates is a variable allowance for movement of surface flow into the alluvium. The estimated surface area versus streamflow relationship is shown in figure 10.

The factor used to convert pan to streamflow evaporation is 0.756. This factor is derived by multiplying a factor of 0.70 that converts pan to reservoir

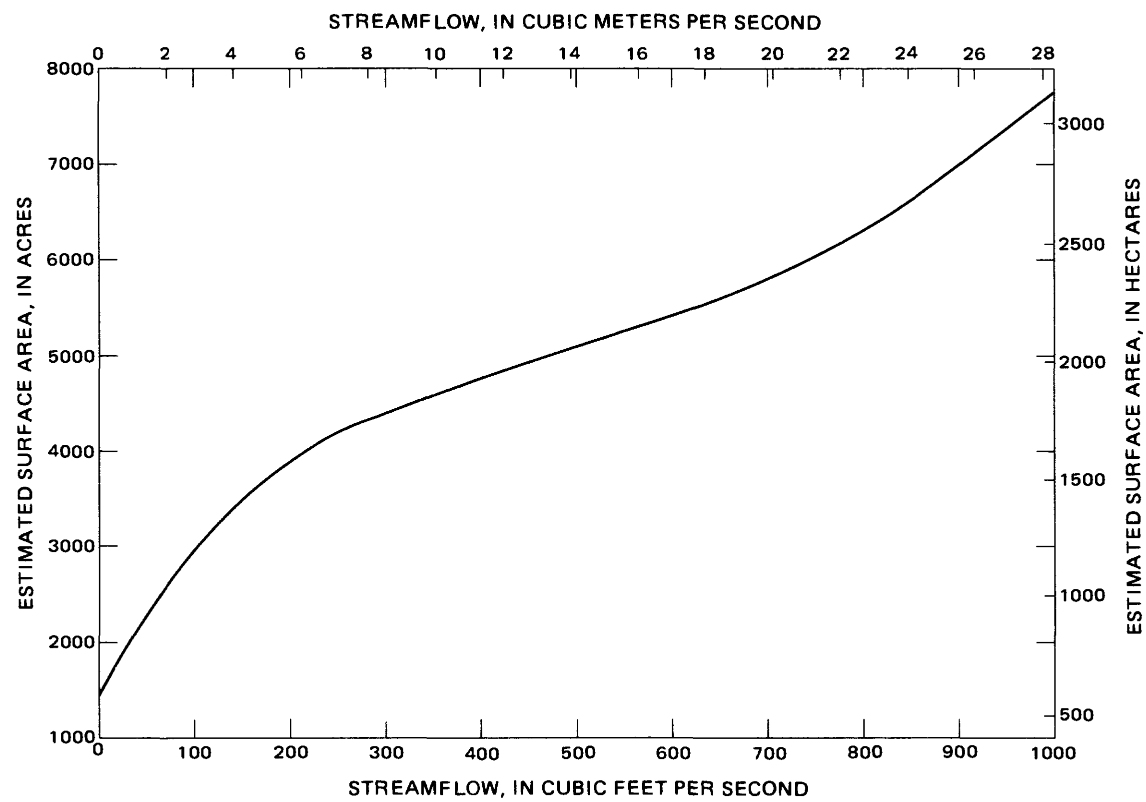

Figure 10.—Estimated surface area of the Milk River versus streamflow.

evaporation and a factor of 1.08 that converts reservoir to streamflow evaporation. Streamflow consumed by evaporation can then be estimated using the following equation:

$$Q_E = SA \times E \times C_1 \times C_2 \tag{1}$$

where

- Q_E is the streamflow consumed by evaporation, in cubic feet per second;
- SA is the surface area of the river, in acres;
- E is the depth of pan evaporation, in feet;
- C_1 is the inch-pound conversion constant, $\dfrac{1\ \text{ft}^3/\text{s}}{1.9835\ \dfrac{\text{acre-ft}}{\text{day}}} = 0.504$; and
- C_2 is the pan-to-streamflow evaporation conversion constant 0.756.

Substituting the values of the constants C_1 and C_2 gives:

$$Q_E = 0.381\ SA \times E \tag{2}$$

For example in inch-pound units, assume that pan evaporation is 1 in. and streamflow is 200 ft^3/s. From figure 10, the estimated surface area corresponding to a streamflow of 200 ft^3/s is about 4,000 acres. Substituting in equation 2:

$$Q_E = 0.381 \times 4{,}000 \times \frac{1}{12}$$
$$Q_E = 127\ \text{ft}^3/\text{s}\ (3.60\ \text{m}^3/\text{s})$$

Using equation 2 and substituting the varying surface-area estimates from figure 10 results in the relationship shown in figure 11.

The 5-day lag is applied to pan evaporation measured near the western and eastern edges of the study area. Thus, pan evaporation measured near the western edge on May 27 is averaged with pan evaporation measured near the eastern edge on June 1; the resulting mean evaporation is then used to compute the effect on June 1 flow reentering the United States.

Milk River natural flow computations using inch-pound units and the current procedure are shown in table 9. Columns 1 and 2 show the constant 5-day lag incorporated into the procedure. Column 2, the computation date, is 5 days after the date in column 1. All values on the same row in the succeeding columns are referenced to the dates in either column 1 or 2.

The values in columns 3 through 9 either are the gaged flows at stations 1, 2, 3, and 8 or are arithmetic manipulations of those flows. Column 3 is the flow of the North Fork Milk River upstream from the St. Mary Canal outlet on the date in column 1. Column 4 is the flow of the North Milk River entering Canada on the date in column 1. Column 5 is the flow of the mainstem Milk River entering Canada on the date in column 1. Column 6 is the flow of the Milk River reentering the United States on the date in column 2. Column 7 is the total flow entering Canada at the western crossings of the international boundary on the date in column 1, and is the sum of columns 4 and 5. Column 8 is the total non-canal flow entering Canada at the western crossing of the boundary on the date in column 1, and is the sum of columns 3 and 5. Column 9 is the average lagged flow in the Milk River channel

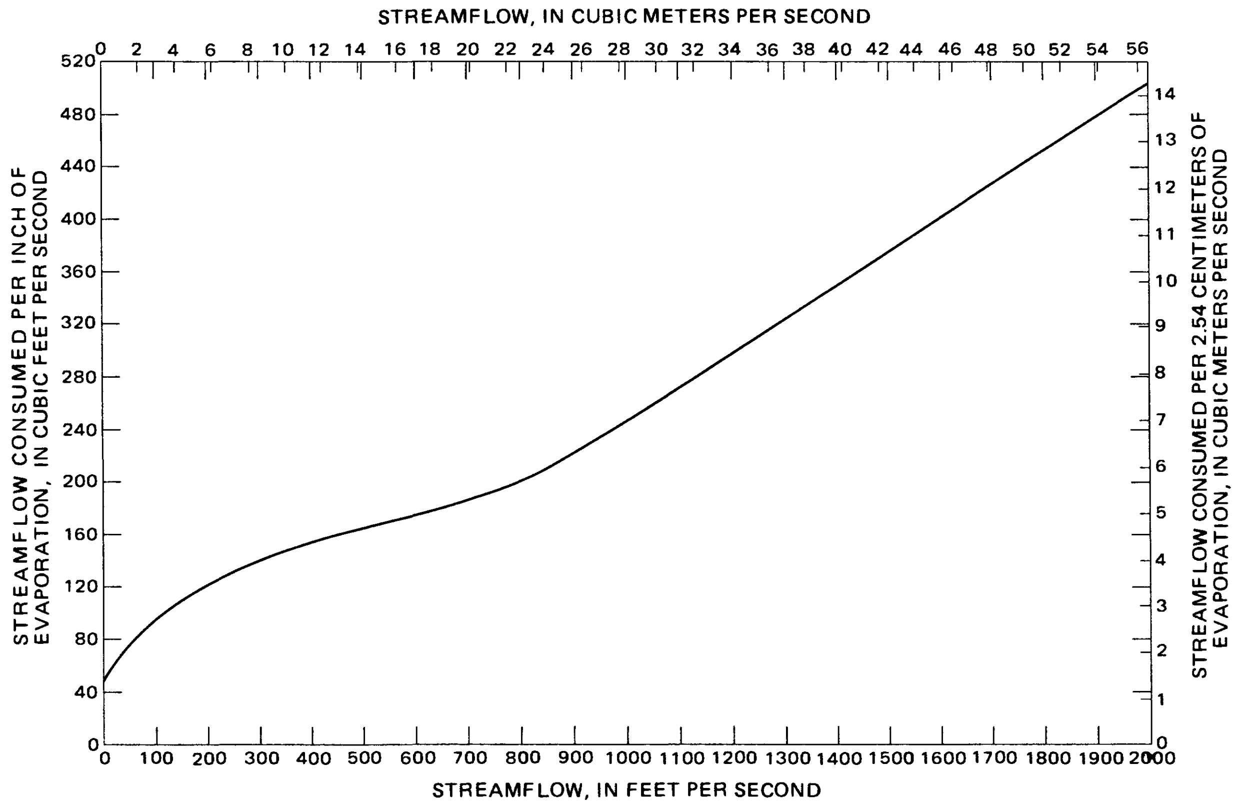

Figure 11.—Streamflow consumed per depth of pan evaporation versus streamflow in the Milk River.

for the date in column 2, and is the mean of the flow in column 6 on the date in column 2 and the flow in column 7 on the date in column 1.

Columns 10 through 14 are estimates of the evaporation effects as discussed previously. Column 10 is the mean of the pan evaporation at the western edge of the study area on the date in column 1 and the pan evaporation at the eastern edge on the date in column 2. Column 11 is the amount of average actual flow (column 9) that would be consumed per 1 inch (2.54 cm) of evaporation from the relation in figure 11. Column 12 is the amount of natural flow (column 8) that would have been consumed per 1 inch (2.54 cm) of evaporation from the relation in figure 11. Column 13 is the flow that would be consumed per 1 inch (2.54 cm) of evaporation due to the addition of St. Mary Canal flow, and is the result of subtracting column 12 from column 11. Column 14 is the actual amount of flow consumed by evaporation due to the addition of St. Mary Canal flow and is the product of columns 10 and 13.

Columns 15 and 16 are for computations of the natural flow reentering the United States. Column 15 is the apparent gain or loss in the Milk River between entering Canada and reentering the United States, is the result of subtracting column 7 from column 6, and can be either positive or negative in value. Column 16 is the computed natural flow reentering the United States, is the sum of columns 8, 14, and 15, and can only be zero or greater.

By using the unadjusted flows at stations 1, 2, 3, and 8 to compute natural flow, the current procedure makes no allowance for man-induced consumption taking

Table 9.--*Example natural-flow computation in inch-pound units using the current procedure, June 1-10, 1977*

[ft^3/s, cubic foot per second; in., inch]

Date		Actual flow, in cubic feet per second per day						
1	2	3	4	5	6	7	8	9
Western crossing[1] with 5-day lag	Eastern crossing[2]	North Fork Milk River above canal (station 2)	North Milk River near international boundary[1] (station 3)	Milk River at western crossing[1] (station 1)	Milk River at eastern crossing[2] (station 8)	Total flow, western crossing[1] (4+5)	Natural flow, western crossing[1] (3+5)	Mean of eastern and western crossing $\frac{1}{2}$(6+7)
May 27	June 1	13	629	18	729	647	31	688
28	2	13	629	16	718	645	29	682
29	3	13	637	14	703	651	27	677
30	4	13	630	12	670	642	25	656
31	5	13	635	11	657	646	24	652
June 1	6	12	634	11	648	645	23	646
2	7	12	634	9	641	643	21	642
3	8	12	633	7	647	640	19	644
4	9	12	642	7	650	649	19	650
5	10	12	645	6	651	651	18	651

Evaporation					Natural flow, in cubic feet per second per day	
10	11	12	13	14	15	16
Mean pan evaporation (in.)	From figure 11 and actual flow, (ft^3/s per 1 in.) (9)	From figure 11 and natural flow, (ft^3/s per 1 in.) (8)	Increment in evaporation (ft^3/s per 1 in.) (11-12)	Increment in evaporation (ft^3/s) (10x13)	Gain or loss(-) (6-7)	Eastern crossing[2] (8+14+15)
0.30	183	64	119	36	82	149
.36	182	62	120	43	73	145
.28	182	61	121	34	52	113
.45	179	60	119	54	28	107
.35	178	59	119	42	11	77
.47	178	59	119	56	3	82
.45	177	58	119	54	-2	73
.27	177	56	121	33	7	59
.38	178	56	122	46	1	66
.31	178	56	122	38	0	56

[1]Entering Canada
[2]Reentering the United States

place upstream from the stations. Using flows at station 8, which is subject to poor measurement conditions and an unstable stage-discharge relationship, may also introduce error that is greater than the natural flow being computed. The current procedure (table 9) also lacks a method for apportioning natural flow.

Interim Procedure

Information gathered in this study can be used to institute refinements in the current procedure. Allowances can be made for man-induced consumption, and an apportionment method also can be included.

Surveys in the study area indicated that irrigated agriculture is extensive and a significant consumer of streamflow. Its effects can be estimated using the information in tables 7 and 8.

An interim format for computing and apportioning Milk River natural flow is given in table 10. Although several headings have been relabeled, columns 1 through 14 are essentially unchanged and use the same data sources as table 9.

Column 15 is the estimated United States use of natural flow on the date in column 1. It is the total mean daily water consumption by irrigated agriculture from table 8.

Column 16 is the estimated Canada use of natural flow on the date in column 1 and is the total mean daily water consumption by irrigated agriculture from table 7. Column 17 is any Canada interbasin transfer that adds to the flow in the river.

Columns 18, 19, and 20 are for the computation of natural flow and indicate respective shares of natural flow on the date in column 2. Column 18 is the computed natural flow at reentry into the United States derived by subtracting column 7 from column 6 and adding columns 8, 14, 15, 16 and subtracting column 17. Column 19 is the United States share of computed natural flow in column 18 and is based on the entitlements specified in the International Joint Commission Order of 1921. Column 20 is the Canada share of computed natural flow.

Columns 21 through 23 are used to apportion the shares in columns 19 and 20. Column 21 is an estimate of the net depletions to natural flow in Canada and the result of subtracting column 17 from column 16. Column 22 is an estimate of the excess natural flow reentering the United States, is the result of subtracting column 21 from column 20, and can be either positive or negative in value. Column 23 is a summation of the values in column 22.

HYDROLOGIC PROCESSES NEEDING ADDITIONAL STUDY

Although the interim procedure discussed above is a refinement of the current natural-flow computation process, it is not the best obtainable method for computing and apportioning natural flow. It fails to address some of the problems inherent in the current process and introduces additional complications. Further study of flow routing, tributary inflow, and man-induced consumption is needed before a more accurate procedure for determining natural flow of the Milk River can be developed.

Table 10.--*Interim computation and apportionment procedure for natural flow of the Milk River*

Date		Actual flows							Evaporation				
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Western crossing	Eastern crossing	North Fork Milk River above canal	North Milk River near international boundary	Milk River at western crossing	Milk River at eastern crossing	Total flow, western crossing (4+5)	Noncanal flow, western crossing (3+5)	Mean of eastern and western crossing $\frac{1}{2}(6+7)$	Mean pan evaporation	From figure 11, and actual flow (9)	From figure 11, and natural flow (8)	Increment in evaporation (11-12)	Increment in evaporation (10x13)
5-day lag													
	1												
	2												
	3												
	4												
	5												

United States consumption	Canada consumption	Canada contribution	Natural flow			Apportionment		
15	16	17	18	19	20	21	22	23
Irrigation	Irrigation	Interbasin transfer	Eastern crossing (6-7+8+14 +15+16-17)	United States share	Canada share	Canada net depletions (16-17)	Excess flow to United States (20-21)	Cumulative excess flows (Σ 22)

Flow Routing

The interim procedure retains the constant 5-day lag in routing flows from the date of entry into Canada to the date of reentry into the United States. Although this approach may be appropriate in situations where steady-state flows are uninterrupted, it does not recognize the variable lag attendant to the nonsteady flows occurring in the study area.

Analyses of the daily mean flows at study area stations (results not presented herein) indicated that variable lags are more appropriate than a constant 5-day lag for routing upstream flows downstream to reentry into the United States. Although the results are not indisputable evidence that the 5-day lag is invalid, they do imply a need for further study of flow routing. To better understand the variability of the lag, hydrologic modeling through a computer-based analysis may be warranted.

Tributary Inflow

In the current and interim procedures discussed above, estimates of tributary inflow are made indirectly by subtracting flow entering Canada from flow reentering the United States. The result of this subtraction process includes phenomena other than inflow, such as evaporation, irrigation withdrawals, ground-water interaction, and so forth.

During runoff and periods of high-volume precipitation, inflow may be a significant portion of the natural flow. A valid method for determining tributary inflow may be required if a more accurate procedure for computing natural flow becomes necessary.

Man-Induced Consumption

The interim procedure makes allowances for man-induced consumption. Those allowances are based on the assumptions that consumption can be either measured or accurately estimated and that consumption comes solely from natural flow.

The effects of irrigated agriculture currently can be estimated only from surveys that may or may not reflect conditions at any given time. Because irrigation is the single greatest man-induced consumer of streamflow, it needs to be monitored closely, particularly during periods of low natural flows when its effects are most significant.

The assumptions that irrigation comes solely from natural flow and that the irrigated area is unchanging may be erroneous. For example, even if agricultural uses could be accurately determined during periods of low natural flow there may be insufficient natural flow available for irrigation withdrawals. By adding an average irrigation usage that is greater than natural flow to recorded flows to compute natural flow, as described in the interim procedure, the computed natural flow would be inflated. A restriction in the interim computation procedure may be needed to preclude such inflated natural flows.

SUMMARY

Interaction between the United States and Canada concerning the Milk River has been substantial since the late part of the 19th century. This interaction has been concerned primarily with the appropriation of streamflow and was a significant factor in the Boundary Waters Treaty of 1909 and the International Joint Commission Order of 1921, which modified the treaty.

After partial diversion of St. Mary River streamflow into the Milk River basin began in 1917, irrigation-season streamflow in the North Milk River entering Canada and in the Milk River reentering the United States increased significantly. Mean monthly streamflow for May through September 1931-82, compared to the same period for 1910-16, increased from 700 to 1,400 percent in the North Milk River entering Canada and from 140 to 460 percent in the Milk River reentering the United States. Mean monthly streamflows in the mainstem Milk River entering Canada for May and June 1931-82 were about equal to those during 1910-16, whereas those for July through October 1931-82 were significantly less than those for 1910-16. The changed flow regime for July through October 1931-82 may have been the result of irrigation withdrawals not present during 1910-16 or may have been due to a period of less runoff.

Tributary inflow is sporadic, both in timing and quantity. Although chinook winds can cause intermittent snowmelt anytime during the winter, steady snowmelt runoff generally begins no later than March and continues until May or June. Sustained tributary inflow downstream from entry into Canada usually ceases prior to the end of July. In a representative median-flow year, the mainstem Milk River entering Canada contributes about 50 percent and ungaged inflow contributes about 25 percent of the natural flow reentering the United States. Although the Milk River entering Canada is the major contributor of natural flow during the spring, the North Fork Milk River above St. Mary Canal supplies the greatest percentage during the summer and fall. For both median- and low-flow years the Canadian prairie areas supply more ungaged inflow than the southern tributaries, which contribute about 2.5 percent of the natural flow. During low-flow years small stock-water and irrigation reservoirs are used to store a large percentage of the tributary flow downstream from entry into Canada.

Ground-water interaction between the regional aquifer and streamflow in the Milk River is negligible. During spring and summer when runoff exists and when the St. Mary Canal is adding flow, some streamflow likely moves into the alluvium. After added flow through the canal is stopped, usually in late summer or early fall, water is discharged from the alluvium.

Irrigated agriculture is the largest man-induced consumption of water in the study area. Alfalfa, native grasses, and other types of hay are the predominant irrigated crops. During 1979 about 1,500 acres (610 ha) were flood irrigated and 2,900 acres (1,200 ha) were sprinkler irrigated in the Canada part of the study area. During 1982 about 3,200 acres (1,300 ha) were flood irrigated and 1,800 acres (730 ha) were sprinkler irrigated in the United States part of the study area. Assuming that these values are representative of the average irrigated surface area, mean daily water consumption by irrigation ranges from 10 ft^3/s (0.28 m^3/s) to 26 ft^3/s (0.74 m^3/s) in the Canada part of the study area, and from 6 ft^3/s (0.17 m^3/s) to 41 ft^3/s (1.16 m^3/s) in the United States part.

Mean yearly consumption by Canada municipalities is about 320 acre-ft (390 dam^3). Mean yearly consumption by the United States municipality is about 20 acre-ft (25 dam^3). Because most of the domestic use affects only the regional aquifer system, domestic use probably has little effect on streamflow.

Evapotranspiration is slightly greater for phreatophytes than for riparian and prairie vegetation. Riparian and prairie evapotranspiration has an insignificant effect in decreasing streamflow. Phreatophyte evapotranspiration probably reduces ground-water yield to the river, which is negligible, rather than using streamflow directly. Evaporation from the water surface of the river comprises 80 to 90 percent of the flow reduction attributed to total evapotranspiration.

Existing reservoirs probably have a negligible effect on Milk River streamflow, except during years of low flow. Any additional large reservoir(s) in Canada would diminish streamflow through storage and increased evaporation, and would augment streamflow through releases.

The current procedure for computing Milk River natural flow where it reenters the United States is a water-budget approach that has evolved over time. It has the following deficiencies: no allowance for man-induced consumption is included, the computation method may have inherent error that is greater than the natural flow being computed, and a method for apportioning the computed natural flow between the United States and Canada is lacking.

The interim procedure discussed herein is a refinement of the current procedure in that it includes estimates of man-induced consumption, accounts for Canada interbasin transfer, and contains a method for apportioning the computed natural flow between the United States and Canada. However, it retains the computational error inherent in the current procedure. Further study of flow routing, tributary inflow, and man-induced consumption is needed before a more accurate procedure for determining natural flow of the Milk River can be developed.

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Table 11.--*Station descriptions*

Station No. (fig. 1)	Station name and location	Formal station number: U.S. Geological Survey	Formal station number: Water Survey of Canada
1	Milk River at western crossing of international boundary, lat 49°00'27", long 112°32'42", in NE1/4 sec. 1, T. 1, R. 20 W., Fourth Meridian, in Alberta, on left bank 0.8 mi (1.3 km) north of international boundary, 22 mi (35 km) upstream from North Milk River, and 23 mi (37 km) southwest of Milk River, Alberta.	06133000	11AA025
2	North Fork Milk River above St. Mary Canal, near Browning, Mont., lat 48°58'15", long 113°03'19", in NE1/4 NW1/4 NE1/4 sec. 16, T. 37 N., R. 11 W., Glacier County, Mont., on left bank, 1.7 mi (2.7 km) upstream from outlet of canal, 1.9 mi (3.1 km) south of international boundary, and 29 mi (47 km) north of Browning, Mont.	06133500	11AA032
3	North Milk River near international boundary, lat 49°01'19", long 112°58'16", in SW1/4 NE1/4 sec. 11, T. 1, R. 23 W., Fourth Meridian, in Alberta, on right bank 0.4 mi (0.6 km) upstream from highway bridge, 1.6 mi (2.6 km) north of international boundary, 2.8 mi (4.5 km) east of Whiskey Gap, Alberta, and 11 mi (18 km) southeast of Kimball, Alberta.	06134000	11AA001
4	Milk River at Milk River, Alberta, lat 49°08'37", long 112°04'44", in NE1/4 sec. 21, T. 2, R. 16 W., Fourth Meridian, in Alberta, on right bank, at Milk River, Alberta.	06134500	11AA005
5	Red River near Coutts, Alberta, lat 49°02'39", long 111°59'43", in SE1/4 sec. 19, T. 1, R. 15 W., Fourth Meridian, in Alberta, on left bank, about 3.5 mi (5.6 km) north of Coutts, Alberta.	---	11AA037
6	Miners Coulee near international boundary, lat 49°01'05", long 111°24'10", in SW1/4 sec. 10, T. 1, R. 11 W., Fourth Meridian, in Alberta, on left bank, about 30 mi (48 km) east of Coutts, Alberta, and 2 mi (3 km) north of international boundary.	---	11AA029

Table 11.--*Station descriptions*--Continued

Station No. (fig. 1)	Station name and location	Formal station number: U.S. Geological Survey	Formal station number: Water Survey of Canada
7	Bear Creek near international boundary, lat 49° 01'30", long 111°12'48", in NE1/4 sec. 12, T. 1, R. 10 W., Fourth Meridian, in Alberta, on right bank, about 43 mi (69 km) east of Coutts, Alberta, and 2 mi (3 km) north of international boundary.	---	11AA028
8	Milk River at eastern crossing of international boundary, lat 48°59'05", long 110°28'15", in NE1/4 NW1/4 sec. 7, T. 37 N., R. 10 E., Hill County, Mont., on right bank 1.1 mi (1.8 km) south of international boundary, 6.5 mi (10.5 km) upstream from Lost River, 12.5 mi (20.1 km) northwest of Simpson, Mont., and 29.5 mi (47.5 km) north of Rudyard, Mont.	06135000	11AA031

Table 12.--*Streamflow measurements at miscellaneous sites*

[mi^2, square mile; km^2, square kilometer; ft^3/s, cubic feet per second; m^3/s, cubic meters per second]

Stream	Location	Drainage area (mi^2)	Drainage area (km^2)	Date	Discharge (ft^3/s)	Discharge (m^3/s)
Pothole Creek (site 9)	Lat 49°17'02", long 112°51'06", in SE1/4 sec. 14, T. 4, R. 22 W., Fourth Meridian, in Alberta	4.7	12.2	04-12-83	0.04	[1] 0.001
				04-19-83	[1] .02	.0006
				05-04-83	.97	.027
				05-17-83	.04	[1] .001
				05-31-83	.04	[1] .001
				06-08-83	3.7	.105
				06-15-83	0	0
				06-28-83	0	0
				07-12-83	0	0
				07-25-83	0	0
				08-16-83	0	0
				08-31-83	0	0
				09-12-83	0	0
				09-29-83	0	0
				10-18-83	0	0
				10-31-83	0	0
Pothole Creek (site 10)	Lat 49°16'40", long 112°51'07", in NE1/4 sec. 11, T. 4, R. 22 W., Fourth Meridian, in Alberta	49.6	128	04-12-83	.91	.026
				04-19-83	.88	.025
				05-04-83	3.4	.096
				05-17-83	1.1	.031
				05-31-83	.42	.012
				06-08-83	2.2	.062
				06-08-83	3.7	.105
				06-15-83	[1] .2	.006
				06-28-83	1.6	.045
				07-12-83	.21	.006
				07-25-83	.25	.007
				08-16-83	[1] .5	.01
				08-31-83	[1] .5	.01
				09-12-83	.04	.001
				09-29-83	.49	.014
				10-18-83	[1] .3	.008
				10-31-83	.18	.005

Table 12.--*Streamflow measurements at miscellaneous sites*--Continued

Stream	Location	Drainage area (mi²)	Drainage area (km²)	Date	Discharge (ft^3/s)	Discharge (m^3/s)
Pothole Creek (site 11)	Lat 49°15'29", long 112°51'06", in NW1/4 sec. 1, T. 3, R. 22 W., Fourth Meridian in Alberta	5.3	13.7	04-12-83	.11	.003
				04-19-83	0	0
				05-04-83	.48	.014
				05-17-83	.11	.003
				05-31-83	0	0
				06-08-83	0	0
				06-15-83	0	0
				06-28-83	3.2	.091
				07-12-83	.04	[1] .001
				07-25-83	3.3	.093
				08-16-83	0	0
				08-31-83	0	0
				09-12-83	0	0
				09-29-83	0	0
				10-18-83	0	0
				10-31-83	0	0
Pothole Creek (site 12)	Lat 49°14'39", long 112°50'06", in NE1/4 sec. 25, T. 3, R. 22 W., Fourth Meridian, in Alberta	.85	2.2	04-19-83	.84	.024
				05-04-83	1.7	.048
				06-08-83	.18	[1] .005
				06-15-83	[1] 1	.03
				06-28-83	5.4	.153
				07-25-83	2.2	.062
				08-16-83	[1] 3.5	.099
				08-31-83	[1] 1.3	.037
				09-12-83	0	0
				09-29-83	0	0
				10-18-83	.65	.018
				10-31-83	0	0
Shanks Creek (site 13)	Lat 49°02'37", long 112°47'25", in SE1/4 sec. 19, T. 1, R. 21 W., Fourth Meridian, in Alberta	27.9	72.3	04-12-83	.88	.025
				04-19-83	.83	.024
				05-04-83	2.7	.076
				05-17-83	.71	.020
				05-31-83	.42	.012
				06-08-83	.32	.009
				06-15-83	[1] .4	.01
				06-28-83	.66	.019
				07-12-83	.42	.012
				07-25-83	.39	.011
				08-16-83	[1] .5	.01
				08-31-83	[1] .5	.01
				09-12-83	.49	.014
				09-29-83	.49	.014
				10-18-83	.56	.016
				10-31-83	.60	.017

Table 12.--*Streamflow measurements at miscellaneous sites*--Continued

Stream	Location	Drainage area		Date	Discharge	
		(mi^2)	(km^2)		(ft^3/s)	(m^3/s)
Police Creek (site 14)	Lat 49°00'23", long 111°39'49", in NW1/4 sec. 3, T. 1, R. 13 W., Fourth Meridian, in Alberta	17.3	44.8	04-13-83	.46	.013
				04-21-83	.36	.010
				05-05-83	.71	.020
				05-18-83	6.7	.190
				05-19-83	4.9	.139
				05-20-83	4.2	.119
				05-24-83	5.8	.164
				05-30-83	1.3	.037
				06-04-83	.53	.015
				06-07-83	.18	[1] .005
				06-28-83	.41	.012
				07-13-83	.46	.013
				07-26-83	.25	.007
				09-01-83	[1] .15	.004
				09-14-83	.35	[1] .01
				09-28-83	.07	[1] .002
				10-19-83	[1] .2	.006
				11-01-83	.04	[1] .001
Deer Creek (site 15)	Lat 49°01'42", long 111° 32'21", in NW1/4 sec. 10, T. 1, R. 12 W., Fourth Meridian, in Alberta	6.8	17.6	03-03-83	.28	.008
				03-14-83	1.0	.028
				03-29-83	.39	.011
				04-13-83	.39	.011
				04-21-83	.78	.022
				05-05-83	2.0	.057
				05-18-83	11.1	.314
				05-19-83	10.3	.292
				05-20-83	8.4	.238
				05-24-83	8.8	.249
				05-30-83	1.6	.045
				06-07-83	1.0	.028
				06-14-83	1.2	.034
				06-28-83	.59	.017
				07-13-83	.28	.008
				07-26-83	.28	.008
				09-01-83	0	0
				09-14-83	0	0
				09-28-83	0	0
				10-19-83	[1] .35	.01
				11-01-83	0	0

Table 12.--*Streamflow measurements at miscellaneous sites*--Continued

Stream	Location	Drainage area (mi^2)	Drainage area (km^2)	Date	Discharge (ft^3/s)	Discharge (m^3/s)
Breed Creek (site 16)	Lat 49°01'39", long 111°17'15", in NW1/4 sec. 9, T. 1, R. 10 W., Fourth Meridian, in Alberta	74.6	193	03-03-83	1.4	.040
				03-14-83	3.3	.093
				03-29-83	.56	.016
				04-13-83	.49	.014
				04-21-83	.58	.016
				05-05-83	.69	.020
				05-18-83	17.1	.484
				05-19-83	34.5	.977
				05-20-83	31.6	.895
				05-24-83	28.3	.801
				05-30-83	5.3	.150
				06-07-83	3.7	.105
				06-14-83	.76	.022
				06-28-83	.04	.001
				07-13-83	1.8	.051
				07-26-83	.56	.016
				09-01-83	0	0
				09-14-83	0	0
				09-28-83	0	0
				10-19-83	0	0
				11-01-83	0	0
Philp Coulee (site 17)	Lat 49°01'38", long 111° 04'44", in SW1/4 sec. 13, T. 1, R. 9 W., Fourth Meridian, in Alberta	20.1	52.1	03-03-83	0	0
				03-14-83	.07	.002
				03-29-83	.04	[1] .001
				04-13-83	0	0
				04-21-83	0	0
				05-05-83	[1] .1	.003
				05-18-83	5.8	.164
				05-19-83	4.6	.130
				05-20-83	3.6	.102
				05-24-83	.67	.019
				05-30-83	.04	[1] .001
				06-07-83	0	0
				06-14-83	0	0
				06-27-83	0	0
				07-13-83	0	0
				07-26-83	0	0
				09-01-83	0	0
				09-14-83	0	0
				09-28-83	0	0
				11-01-83	0	0

Table 12.--*Streamflow measurements at miscellaneous sites*--Continued

Stream	Location	Drainage area (mi²)	Drainage area (km²)	Date	Discharge (ft³/s)	Discharge (m³/s)
		(mi^2)	(km^2)		(ft^3/s)	(m^3/s)
Smith Coulee (site 18)	Lat 49°08'50", long 111°18'25", in SE1/4 sec. 29, T. 2, R. 10 W., Fourth Meridian, in Alberta	16.5	42.7	04-13-83	0	0
				04-20-83	0	0
				05-05-83	0	0
				05-10-83	.04	[1] .001
				05-17-83	0	0
				05-24-83	0	0
				05-30-83	0	0
				06-07-83	0	0
				06-14-83	0	0
				07-14-83	0	0
				07-25-83	0	0
				09-14-83	0	0
				09-28-83	0	0
				09-19-83	0	0
				11-01-83	0	0

[1]Flow estimated in indicated units