ENVIRONMENT CANADA

ATMOSPHERIC ENVIRONMENT SERVICE

EVAPORATION FROM ST. MARY AND WATERTON RESERVOIRS 1981

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SCIENTIFIC SERVICES REPORTS

28. Evaporation from Val Marie reservoir - 1977. April 1978 - H.F. Cork

29. Wyoming-shielded storage gauge, Regina, 1977 and 1978. May 1978 - H.F. Cork.

30. Computation of evaporation from a water surface without on-site data using a combination of energy budget and Dalton's Law Methods. September 1978 - H.F. Cork.

31. Evaporation from a salt solution. November 1978 - H.F. Cork.

32. Evaporation from a salt solution. November 1978 - D.J. Bauer

√33. Evaporation from St. Mary and Waterton reservoirs, 1978. August 1979 - H.F. Cork.

34. Temperature and evaporation on Lake Diefenbaker, 1978. September 1979 - R.F. Hopkinson.

35. Wyoming-shielded storage gauge. October 1979 - J. Dublin.

CSS-R80-01. Evaporation from Tobin Lake, 1979. March 1980 - J. Dublin.

CSS-R80-02. Temperature and evaporation on Lake Diefenbaker, 1979. May 1980 - R.F. Hopkinson

CSS-R81-01. Temperature and evaporation on Lake Diefenbaker, 1980. April 1981 - R.F. Hopkinson.

CSS-R81-02. Evaporation from Tobin Lake, 1980. July 1981 - R.F. Hopkinson.

CSS-R81-03. A comparison of various storage snow gauges on the Canadian prairies. October 1981 - J. Dublin.

√ CSS-R81-04. Evaporation from St. Mary and Waterton reservoirs. November 1981 - R.F. Hopkinson.

CSS-R82-01. A comparison of various snow gauges on the Canadian prairies for the winter 1981 - 1982. July 1982 - K.H. Jones.

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Titles of older reports are listed in Reports #15 and 31. Some are in short supply. Hydrometeorological work carried on in the Prairie Hydrometeorological Centre is now performed by Scientific Services Regina. The numbering of reports, commencing in 1980, reflects this change. For example, CSS-R80-01 is Central Region Scientific Services Regina Report Number one for 1980.

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ABSTRACT

The on-site data for 1981 are presented in addition to the comparative data for the previous three years. The corresponding evaporation figures using the Meyer equation, an energy budget, and Cork's combination equation are recorded. The results for 1981 are discussed and recommendations for improved on-site data collection are advanced.

LIST OF SYMBOLS

E_M — Evaporation calculated using the Meyer equation (mm/month or mm/day as indicated)

$u_{7.6}$ — Monthly mean wind speed at 7.6 m above the surface of the ground or water (km/hour)

e_w — Saturation vapour pressure corresponding to the monthly mean water temperature (mb)

e_a — Monthly mean vapour pressure of the air at 7.6 m above the water or ground (mb)

E_{EN} — Evaporation calculated using an energy budget (mm/day or mm/month as indicated)

$K\downarrow$ — Incoming short-wave radiation (ly/day)

a — Short-wave albedo

L — Latent heat of condensation/vaporization (cal/cm3)

T_a — Monthly mean air temperature (^oC)

C* — Effect of cloud on incoming long-wave radiation

T_w — Monthly mean surface water temperature (^oC)

D — Vertical transport factor for Dalton-type evaporation equation, a function of wind speed

γ — Theoretical coefficient for Bowen's Ratio ≃ 0.00061 P where P is the mean station pressure in millibars

ST — Heat storage in a water body in evaporation units (mm/day)

E_C — Evaporation calculation from a weighted combination of the energy budget and a Dalton-type (Meyer) equation (mm/day or mm/month as indicated)

m — Weighting factor determined so that $((1-m)\ E_{EN} + m\ E_M)$ is insensitive to water temperature

u_z — Monthly mean wind speed at z m above the ground or water surface (km/hour)

z — Height of an observation above the ground or a water surface (m)

E_L — Shallow lake evaporation computed from class A pan data (mm)

EVAPORATION FROM ST. MARY AND WATERTON RESERVOIRS, 1981

1. INTRODUCTION

This report presents the evaporation calculated for the St. Mary and Waterton reservoirs in 1981 based upon on-site measurement of the required meteorological parameters and surface water temperature. Cork (1979) prepared the report for 1978 and Hopkinson (1981) discussed the evaporation for 1979 and 1980.

Figure 1 indicates the location of the reservoirs in south-western Alberta. Figures 2 and 3 provide more detailed maps of the individual reservoirs and indicate the location of the instrumentation.

2. CALCULATION OF EVAPORATION

The Meyer Equation

A form of Dalton's law developed by Meyer (1915, 1942) was used to calculate evaporation from the two reservoirs. On the basis of the Weyburn reservoir water budget study of McKay (1962), the Meyer equation evaporation is presented as the standard in this report. McKay found that provided water temperature was measured, the Meyer equation provided acceptable estimates of monthly and seasonal evaporation. In metric form for these reservoirs the equation with a Meyer coefficient of 10 becomes

$$E_M = 10 \times 0.778 \; (1 + 0.0621 \; u_{7.6})(e_w - e_a) \qquad (1)$$

The Energy Budget and Combination Equation

Cork (1978) noted that errors in the surface water temperature caused errors of opposing sign in the evaporation calculated from a Dalton's law equation like Meyer's and an energy budget. Thus, a suitably weighted combination of the two could be made nearly insensitive to water temperature. The equations for the energy budget, the Meyer method and the weighted combination follow:

$$E_{EN} = \frac{K\downarrow (1 - a)}{0.1L} + \frac{1.06}{0.1L} \left\{ \frac{Ta + 273.15}{100} \right\}^6 C^* - \frac{11.36}{0.1L} \left\{ \frac{Tw + 273.15}{100} \right\}^4 - D\gamma\ (Tw - Ta) + ST\ \text{(mm/day)} \quad (2)$$

$$E_M = D(e_w - e_a) \quad \text{(mm/day)} \quad (3)$$

$$E_C = (1 - m)\ E_{EN} + mE_M\ \text{(mm/day)} \quad (4)$$

It should be noted that the energy budget contains a number of simplifications necessitated by a lack of explicit data. Thus, while the need to measure surface water temperature is apparently obviated, uncertainties in other terms may lead to significant errors.

3. DATA ACQUISITION

Wind Data

At each reservoir a cup counter (totalizing) anemometer was mounted on a 3 m mast near the shore line. The anemometer counters were read at weekly intervals and the values recorded. The total wind distance for a month was divided by the number of hours to determine the mean wind speed. The average wind speed at 3 m was adjusted to a height of 7.6 m by using the equation (Buckler, 1969)

$$u_{7.6} = u_z \left\{ \frac{7.6}{z} \right\}^{0.25} \quad (5)$$

where z is the height (m) above ground of the observed wind and u represents the mean wind speed at 7.6 m and z (m) as indicated. For comparison purposes, the monthly average wind speeds from Lethbridge airport were abstracted and adjusted from the 10 m observation height

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to 7.6 m using equation 5. The adjustment to 7.6 m is a requirement for the Meyer equation. The data adjusted to 7.6 m are recorded in Table 1.

The correlation between the Lethbridge and St. Mary monthly mean wind speeds inclusive of 1981 data was poorer than the 1978 to 1980 period alone as measured by simple linear regression analysis. The percentage of the variance explained by the resultant regression equation including 1981 data was 52% whereas for 1978 to 1980 it was 66%. A similar comparison of the Lethbridge and Waterton data yielded figures at 66% and 67% respectively - essentially unchanged.

Comparison of the data for the two reservoir sites indicated a better correlation with addition of 1981 data with 85% of the variance explained as opposed to the 1978 to 1980 figure of 76%. The use of equation A1 from the previous report (Hopkinson, 1981) to predict the mean wind speed at the St. Mary reservoir resulted in an underestimate in every month and ranged from 1 to 6 km/hour. Similarly for Waterton reservoir, equation A4 of the previous report (Hopkinson, 1981) yielded values 1 to 3 km/hour less than observed values in 1981. An examination of the frequency distribution of onshore and offshore wind failed to explain the shift in relationship. If the wind speed was estimated from equations A1 and A4, from the previous report, the calculated evaporation for 1981 for the months May to October would have been respectively 10% and 6% less than that using the measured on-site winds at the St. Mary and Waterton reservoirs.

Vapour Pressure Data

The monthly mean atmospheric vapour pressures for Lethbridge were abstracted from the Canadian Weather Review which is published monthly

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by the Atmospheric Environment Service. At each reservoir, a Stevenson screen was installed with a hygrothermograph. Two vapour pressure values were calculated daily corresponding to the minimum temperature/maximum relative humidity and the maximum temperature/ minimum relative humidity. The monthly mean vapour pressure was the arithmetic mean of the daily values. For input to the Meyer equation, the vapour pressures were then multiplied by 0.944 to approximate the vapour pressure at 7.6 m. The height adjusted vapour pressures for 1981 and the previous years were recorded in Table 1.

As discussed in the previous report, the method used to calculate vapour pressure at the reservoirs introduces a systematic bias. A detailed evaluation of the errors of this methodology and of the limitations of the instrumentation is in progress at the Regina Airport.

Air Temperature Data

At each reservoir, in addition to the hygrothermograph already mentioned, the Stevenson screen was equipped with maximum and minimum thermometers. The recorded air temperature from the hygrothermograph was corrected on the basis of periodic (usually weekly) observations from maximum and minimum thermometers. Air temperature data for Lethbridge were available from the Lethbridge Monthly Summary. The monthly mean air temperature data were recorded in Table 1. The air temperature data were not needed for the Meyer equation calculations; however, they were a requirement for the energy budget of Cork's (1978) combination equation.

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		WIND SPEED YQL	WIND SPEED STM	WIND SPEED WTR	VAPOUR PRESSURE YQL	VAPOUR PRESSURE STM	VAPOUR PRESSURE WTR	AIR TEMPERATURE YQL	AIR TEMPERATURE STM	AIR TEMPERATURE WTR	WATER TEMPERATURE YQL	WATER TEMPERATURE STM	WATER TEMPERATURE WTR
1978	MAY	18.8	21.9	21.9	6.9	6.3	6.1	10.3	8.1	7.2	8.6	8.9	7.4
	JUN	16.2	20.4	19.4	8.7	8.5	8.1	16.0	14.6	13.1	16.4	14.7	14.4
	JUL	12.6	15.8	14.2	11.6	11.0	10.5	18.1	16.7	15.4	20.0	18.3	16.3
	AUG	15.0	17.7	16.0	10.1	9.1	9.3	16.7	14.8	14.6	19.8	18.3	17.3
	SEP	16.7	21.4	18.6	8.7	7.9	7.8	13.1	12.1	11.8	16.4	14.4	13.4
	OCT	18.7	21.9	20.0	5.5	5.3	5.5	8.6	7.6	7.6	11.4	(9.0)	(8.0)
1979	MAY	16.9	16.5	17.6	6.2	5.5	6.0	9.7	8.6	8.6	7.7	8.5	(7.0)
	JUN	18.8	18.7	18.2	8.0	8.2	7.7	15.7	14.9	14.1	15.7	15.0	(12.7)
	JUL	16.3	18.2	17.2	10.1	9.9	9.2	18.7	17.4	16.8	20.1	18.9	(17.5)
	AUG	12.1	13.8	14.1	11.1	9.5	9.5	18.4	16.6	16.9	20.6	19.8	(17.4)
	SEP	16.0	18.0	16.3	8.1	7.7	7.6	15.3	14.6	14.6	17.3	17.2	(15.7)
	OCT	17.1	19.6	17.6	6.1	6.0	5.8	8.9	8.0	7.9	11.8	(11.0)	(9.6)
1980	MAY	16.3	17.5	16.7	6.9	6.8	6.4	12.7	11.2	11.2	11.1	12.2	(11.0)
	JUN	17.0	17.2	16.3	9.6	8.8	8.0	15.2	13.5	13.0	17.8	16.3	(13.4)
	JUL	17.5	20.0	18.9	9.8	9.6	8.8	18.1	16.9	16.7	20.4	19.1	(16.9)
	AUG	15.8	17.2	16.7	8.8	8.6	8.4	14.8	13.4	13.4	18.9	17.9	(16.4)
	SEP	20.1	21.6	19.0	7.6	7.3	6.9	12.7	11.4	11.5	16.1	14.1	(12.7)
	OCT	18.2	21.4	17.9	5.9	6.0	5.8	8.8	7.5	7.5	11.4	(9.6)	(8.9)
1981	MAY	14.5	20.2	17.6	7.7	7.8	7.0	11.6	10.4	9.4	9.8	10.3	(10.0)
	JUN	19.1	27.2	22.9	8.2	8.2	6.9	13.8	12.3	11.3	16.1	14.0	(11.7)
	JUL	12.0	17.4	15.7	11.0	10.8	9.4	17.5	16.4	15.9	19.4	18.3	(16.6)
	AUG	8.0	11.9	12.2	11.7	11.3	9.3	19.3	19.0	17.9	20.9	21.3	(19.3)
	SEP	13.7	18.5	16.6	7.0	7.8	6.7	13.9	13.4	13.0	16.8	16.9	(15.7)
	OCT	15.8	24.5	20.1	5.4	5.7	5.1	6.3	6.1	6.0	10.3	(9.6)	(9.2)
MEAN		16.0	19.1	17.6	8.4	8.1	7.6	13.9	12.7	12.3	15.6	14.7	13.3

TABLE 1 Monthly mean wind speed (km/hour), vapour pressure (mb), air temperature (^{o}C) at Lethbridge (YQL), St. Mary reservoir (STM), and Waterton reservoir (WTR). The vapour pressures have been rounded to the nearest tenth of a millibar. The water temperature for Lethbridge is for a fictitious reservoir and is based on the PPWB (1952) water temperature equations. Bracketed values indicate that estimation was required based on partial data.

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Surface Water Temperature Data

The water temperature at the St. Mary reservoir was measured using a Bristol water temperature recorder. The recorder was in continuous operation from April 15 to October 19. The monthly mean water temperature was the average of the daily mean values.

Since May of 1979, water temperature at the Waterton reservoir was estimated on the basis of the bucket water temperature measured at approximately weekly intervals and the continuous water temperature record at the St. Mary reservoir.

None of the estimation methods based upon air temperature as investigated in previous reports has proved sufficiently accurate to eliminate the need to measure surface water temperatures at these reservoirs. The water temperatures tabulated for the Waterton reservoir should be treated with caution for the years 1979 to 1981. An improvement in the water temperature measurements at Waterton in 1982 will be a priority.

4. RESULTS

The evaporation for the years 1978 to 1981 inclusive is presented in Table 2. The standard is the evaporation calculated from the Meyer equation and is listed under the columns labelled E_M. The table does not include the evaporation for April 1981 calculated using the Meyer equation. These values are 68 mm and 80 mm respectively for the St. Mary and Waterton reservoirs. The relative meteorological data indicated that April of 1981 was warmer, drier, and sunnier than normal, all of which contributed to evaporation estimates which are probably twice that expected in an average April.

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		LETHBRIDGE				ST. MARY			WATERTON		
		E_{EN}	E_M	E_C	E_L	E_{EN}	E_M	E_C	E_{EN}	E_M	E_C
1978	MAY	79	70	74	123	28	95	63	36	79	59
	JUN	156	163	159	175	153	142	148	133	141	137
	JUL	186	214	197	166	153	158	155	161	120	143
	AUG	180	182	181	151	142	199	165	155	166	160
	SEP	169	178	172	98	120	151	134	132	124	128
	OCT	92	126	109	107	114	116	115	129	93	110
	TOTAL	862	933	892	820	710	861	780	746	723	737
1979	MAY	73	74	73	133	47	90	70	68	66	67
	JUN	158	153	156	187	148	147	147	68	114	142
	JUL	160	166	163	194	174	201	185	185	176	181
	AUG	160	199	176	160	156	201	174	194	154	176
	SEP	115	156	133	133	153	193	170	175	158	167
	OCT	99	137	118	80	85	126	105	105	102	103
	TOTAL	765	885	819	887	763	958	851	895	770	836
1980	MAY	101	100	101	158	57	122	89	75	109	92
	JUN	113	169	137	153	102	155	125	135	114	125
	JUL	177	234	199	208	166	223	188	197	180	189
	AUG	123	205	156	134	107	195	143	129	165	145
	SEP	105	184	139	120	108	157	130	132	130	131
	OCT	99	127	113	96	100	109	105	112	93	102
	TOTAL	718	1019	845	869	640	961	780	780	791	784
1981	MAY	68	66	67	137	39	84	62	27	87	58
	JUN	114	169	138	181	111	160	133	132	127	129
	JUL	162	160	162	172	150	168	157	167	149	160
	AUG	212	154	188	150	192	194	193	202	183	194
	SEP	144	172	157	118	126	188	152	138	173	154
	OCT	71	112	93	67	67	125	96	75	117	97
	TOTAL	771	833	805	825	685	919	793	741	836	792

TABLE 2 Monthly and total evaporation (mm) for a fictitious reservoir at Lethbridge and for the St. Mary and Waterton reservoirs. The columns labelled E_M were computed using the Meyer equation. E_{EN} and E_C are the energy budget and Cork's combination estimates respectively. E_L under Lethbridge is the shallow lake evaporation computed from class A pan data.

At the reservoir sites for the period May to October inclusive, the total evaporation ranked third for the St. Mary reservoir and first for the Waterton reservoir. The computed shallow lake evaporation figures from class A pan data for Lethbridge CDA have been included for comparison.

5. DISCUSSION

The analysis of the data which were used as input to the Meyer equation indicated some inadequacies in the data acquisition system for this project. The most serious problem is the lack of a continuous water temperature record at the Waterton reservoir. Although it is well established that there is a difference in the surface water temperature regimes of the two reservoirs and consequently, in the evaporation, the sensitivity of the Meyer equation to small errors in the surface water temperature casts doubt on the reliability of the evaporation estimates for the Waterton reservoir.

The evaporation totals for the St. Mary reservoir consistently exceeded the normal shallow lake evaporation determined from the Atlas of Climatic Maps (1970) as well as the computed shallow lake evaporation from Lethbridge class A pan observations for the years corresponding to this study. The latter difference is about 9%, of which 5% may be attributable to the method used to compute the atmospheric vapour pressure.

A discrepancy of nearly 5% remains and could be explained by either a systematic error in the wind adjustment or an inappropriate choice of the Meyer coefficient. Better on-site wind measurements at a standard height of 10 m would allow the first conjecture to be evaluated. An accurate water budget would be required to test the Meyer coefficient. Alternately, the difference could be due to the lack of data in the

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months of April and November which have been ignored in this study. Pan evaporation can be significant in April whereas ice cover on the reservoir for much of this month and cold water temperature would imply little real evaporation from the reservoir.

The energy budget estimates of evaporation are not well related to the values from the Meyer equation. For the St. Mary reservoir, even if one uses a Meyer coefficient of 9, the total Meyer equation evaporation is consistently higher than the comparable energy budget totals.

The reason for the apparent failure of the energy to agree with Meyer evaporation can be ascribed to erroneous assumptions, data inadequacies, and poor parameterization of some of the terms. In particular, energy advection is ignored. The energy storage term is crudely estimated at best and even if it is correct in an average year, it fails to reflect the variability evident in surface water temperatures in Table 1. The combination of neglecting energy advection and improperly estimating energy storage could easily account for much of the difference in the monthly and season energy budget values from the Meyer ones. Since these terms are impossible to estimate accurately without appreciably more on-site water temperature data (inflow, outflow, and depth soundings) in addition to accurate streamflow data, refinements in other parts of the energy budget are unlikely to yield much overall improvement. The sensible heat term is small compared to the radiation terms. The radiation terms, although large, can be determined with fair accuracy with the exception of the downward long wave radiation. Modest improvements in the latter could be expected if the cloud factor were determined from actual cloud conditions instead of relying on climatological values. The only other improvement would involve tuning the

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energy storage term so that the energy budget would yield values comparable to the Meyer evaporation.

The total shallow lake evaporation computer from class A pan data for Lethbridge yields values which fall between the calculated Meyer evaporation figures for the two reservoirs. On a monthly basis, the usual lag effect due to heat storage is evident in the reservoir evaporation when compared to the pan-derived values. For this reason, an on-site evaporation pan station is not seriously proposed as an alternative to the current on-site data gathering. It should be noted that the pan-derived shallow lake evaporation figures in Table 2 do not agree with those published in the Monthly Record of Meteorological Observations in Western Canada. The latter are incorrect because of an error in the computer program which was used to adjust for the heat advection through the walls of the pan. The values in Table 2 reflect the proper correction.

The estimation of on-site wind data at the St. Mary and Waterton reservoirs based upon regressions on Lethbridge data for the previous years would have resulted in a reduction in the calculated evaporation of 10% and 6% respectively. The on-site wind data are gathered from towers of a non-standard height. Hence there is a suspicion that there may be a systematic bias in the on-site winds because of the height adjustment. The additional data of 1981 confirmed the need for on-site wind measurements at a standard height (10 m).

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6. RECOMMENDATIONS

The recommendations of the previous report are repeated below as follows:

(a) establish a Ryan water temperature recorder on the Waterton reservoir using an anchor and buoy mounting similar to that used at Sage Creek on Lake Diefenbaker.

(b) test a hygrothermograph locally in Regina to determine its level of accuracy for the determination of mean vapour pressure and air temperature.

(c) install a 45B anemometer mounted at 10 m near the current Casella totalizing anemometer at the St. Mary reservoir.

(d) compute evaporation based on measured water temperatures and other on-site data using the Meyer equation.

7. ACKNOWLEDGEMENTS

Mr. E.E. Hohm and the staff of Environment Alberta, Headworks Branch, Waterton-St. Mary Irrigation Project installed and serviced the equipment, took the necessary observations and forwarded the data to Scientific Services Regina.

Mr. R. Smith processed the data, made the necessary calculations, and prepared the diagrams.

The instruments were supplied by the Atmospheric Environment Service, Environment Canada.

The cooperation of Mr. K.J. Johnstone of the Hydrometeorology Division of the Canadian Climate Centre in supplying the correct pan-derived shallow lake evaporation for Lethbridge CDA is gratefully acknowledged as is the help of AES Western Region in providing pan data tabulations for selected months in 1981.

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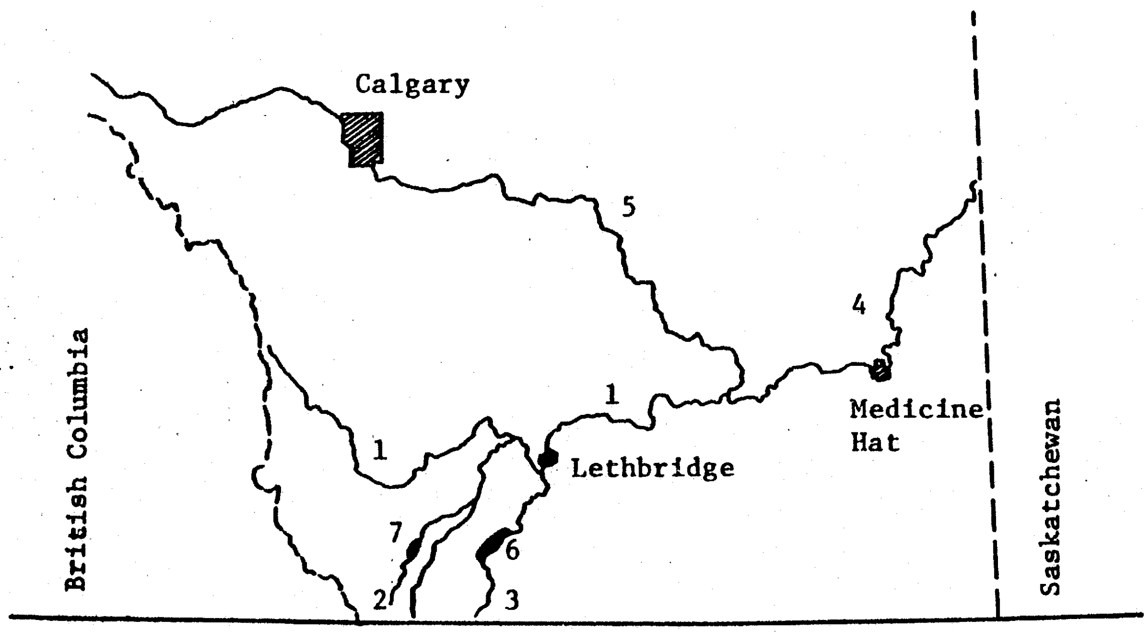

Fig. 1 Map of southern Alberta showing location of St. Mary Reservoir and Waterton Reservoir.
1-Oldman river 2-Waterton river 3-St. Mary river
4-South Saskatchewan river 5-Bow river
6-St. Mary Reservoir 7-Waterton Reservoir

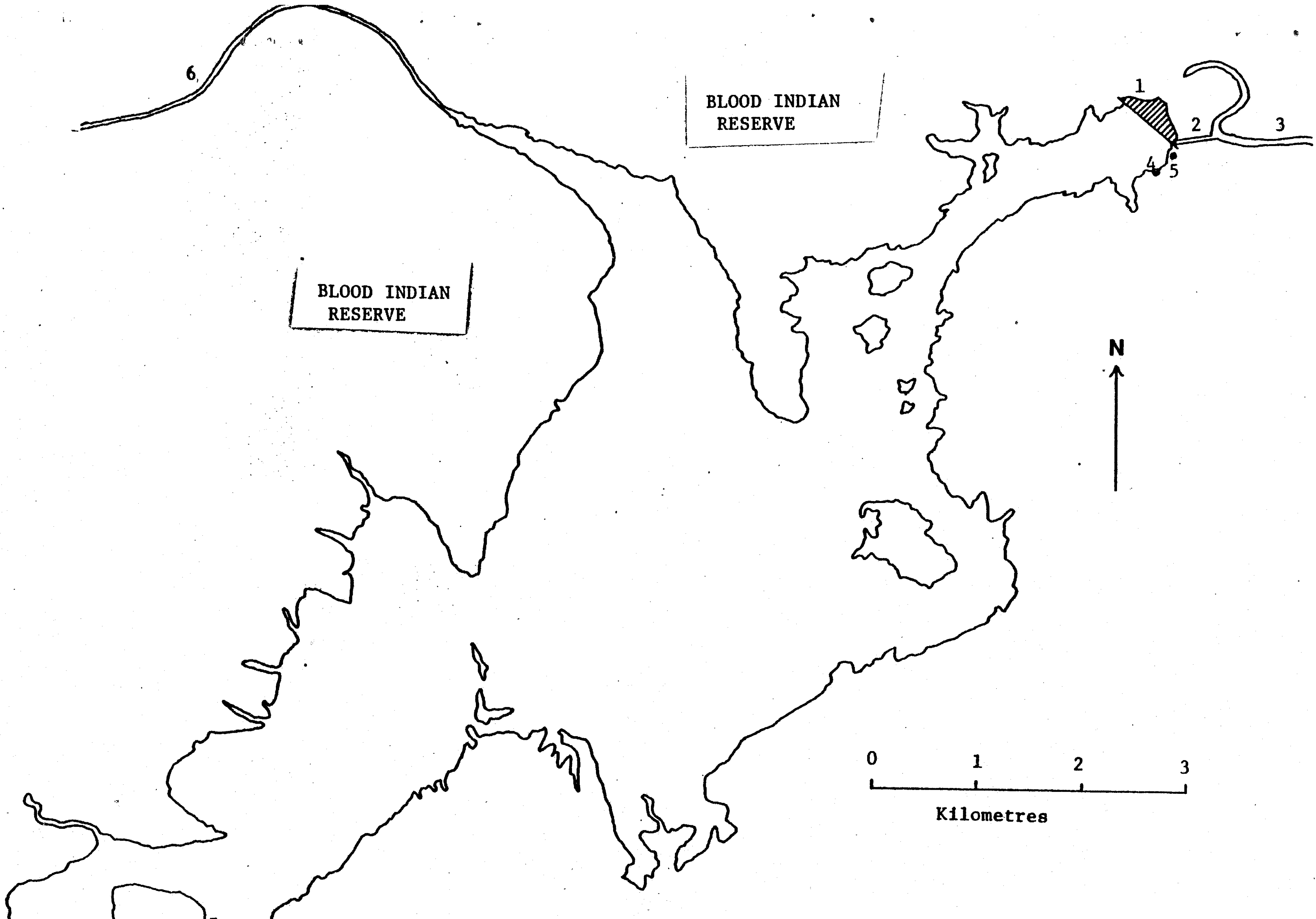

Fig. 2 St. Mary Reservoir. 1 St. Mary Dam 2 Spillway
3 St. Mary River 4 Bristol Recorder 5 Anemometer
and Thermometer Screen 6 Canal from Waterton Reservoir.

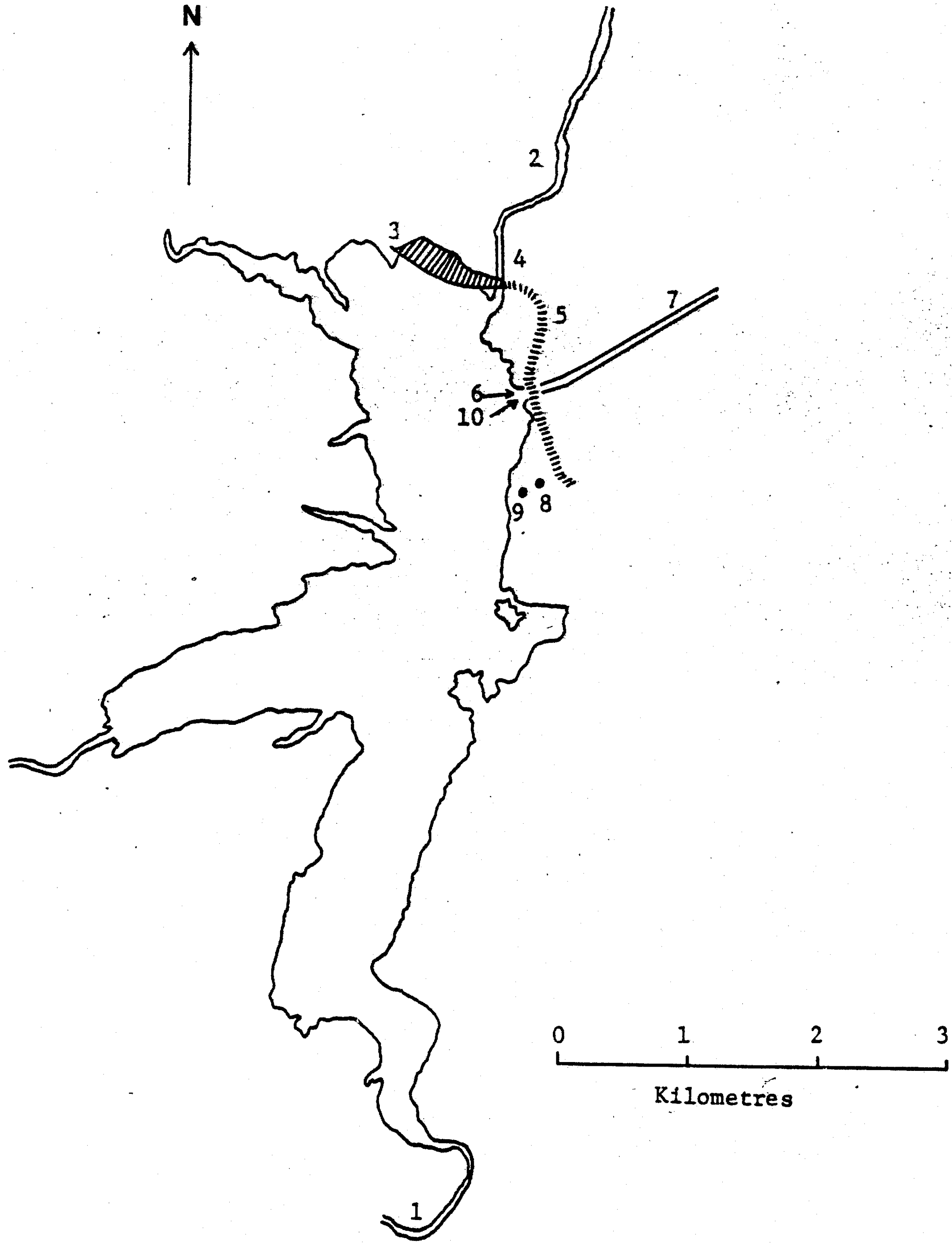

Fig. 3 Waterton Reservoir 1 and 2 Waterton river.
3 Waterton dam. 4 Spillway. 5 Dike. 6 Sluice gate.
7 Canal to St. Mary Reservoir. 8 Thermometer screen.
9 Anemometer. 10 Bristol water temperature recorder.