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CALIBRATION PERIOD.

(Contribution for presentation at the Nineteenth
Pacific Northwest Regional Meeting of the American
Geophysical Union, The University of British Columbia,
16-17 October 1972.)

Northern Forest Research Centre
Environment Canada
Edmonton

WATER QUALITY OF AN EXPERIMENTAL WATERSHED
DURING THE CALIBRATION PERIOD

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Paper presented at the 19th Annual Meeting of the Pacific Northwest Region, American Geophysical Union, University of British Columbia, Vancouver, 16-17 October 1972.

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INTRODUCTION

The possible adverse effects of commercial timber harvest on the physical and chemical quality of streams arising in mountainous areas have led to genuine concern in the management of forest watersheds (Eschner and Larmoyeux, 1963; Krygier and Hall, 1971; Pierce et al., 1970). Effect of forest cutting on the quantity and quality of drainage waters has been reported, among others, by Likens et al. (1970). The study objectives of most experimental watersheds accordingly place high priority on the determination of any changes in the stream environment due to forest removal.

Marmot Basin was selected in August 1962 for studying the hydrology of sub-alpine spruce-fir (Picea-Abies) forests. The overall objectives of the studies at this watershed have been given in detail by Jeffrey (1965). An extensive water quality sampling program was started in May 1963 to determine the quality of the watershed streams before and after the application of treatment. This investigation was designed to assess the current water quality levels and also to obtain a measure of correlation among the three sub-basins on important parameters during the calibration period.

MATERIALS AND METHODS

A. Description of the catchment area

The Marmot Creek Research Basin (Fig. 1) is located in the Kananaskis Range of the Eastern Rocky Mountains, which are headwaters for the Saskatchewan River, in the uplands of southwestern Alberta.

Geographic situation of the watershed is as follows (Canadian National Committee, 1967):

Longitude 115° 09' 05" W

Latitude 50° 56' 57" N

Surface 9.76 km²

Altitude 1585 - 2805 m

Annual precipitation is 900-1270 mm. Snow constitutes about three-quarters of the annual precipitation. Principally the soils consist of Gray Luvisols at lower elevations, Humo-ferric Podzols and Dystric Brunisols at mid-slope locations and Regosols at higher elevations. Average slope is 39%. Details about geology, soils, and vegetation are given by Stevenson (1967), Beke (1969), and Kirby and Ogilvie (1969), respectively.

The watershed has three sub-basins: Twin, Middle, and Cabin. Of these, Middle has been selected as a control. Treatment is expected to be applied on Cabin in 1974. Twin would be treated later on.

B. Field methods

All samples for the sub-basin comparisons were collected at the permanent gauging sites. Samples were also obtained from the main gauging site for Marmot Creek.

A cirque station was also chosen on the Middle Creek to provide a comparison of water quality changes occurring on a mountain stream as it traverses from the alpine and above-timber line part of the watershed to well-vegetated portions along its lower reaches.

Streamflow measurements were obtained from permanent V-notch weir and H-flumes. Water temperature reading at the time of sampling was obtained with a mercury thermometer. Streamflow measurements were read concurrently from the automatic recording gauges established at each sampling site.

C. Laboratory methods

Samples were analyzed immediately after opening the container in the laboratory. Total dissolved solids were estimated gravimetrically by evaporating an aliquot of the filtered sample at 110°C. All the other analyses were carried out by the methods in use at the Water Quality Division laboratory, Inland Waters Branch, Department of the Environment, Calgary, Alberta (Traversy 1971) and are mentioned below.

pH was determined electrometrically (APHA). Color was determined by a visual comparison with a Hellige Aqua Tester. Turbidity was measured with a Hach Turbidimeter (APHA). Specific conductance was measured with a platinum-electrode type conductivity cell. For such analyses as Calcium, total hardness, sulphate, etc. samples, if not free from turbidity, were filtered through a 0.45- μ membrane filter. Total hardness and calcium were determined by complexometric method with EDTA (APHA). Alkalinity values were subtracted from total hardness values to obtain non-carbonate hardness. Alkalinity was determined by potentiometric titration of the dissolved carbonate and bicarbonate with standard sulphuric acid (Thomas and Lynch, 1960). Magnesium was calculated by difference from the calcium and total hardness titrations (Rainwater and Thatcher, 1960). Sodium and potassium were determined by flame emission photometry with an AutoAnalyzer (APHA). Sulphate was determined by barium chloride titrimetric method, in an alcoholic solution, using

Thorin as an indicator (ASTM). Calcium, magnesium, sodium, potassium, chloride, sulphate, fluoride, nitrate, silica, and carbonate equivalent of bicarbonate were added to obtain "sum of constituents".

D. Statistical analysis

Mean and its standard error were used for summarizing stream discharge and total dissolved solids data collected during each month. Considered this way, each mean represents the mid-monthly value and the standard error its variation during the month. Simple correlations were obtained among the mean monthly discharge and mean total dissolved solids for the low-flow and high-flow periods. Maximum, minimum and the average values of physical and chemical water quality characteristics were determined for each sub-basin creek. Correlations among the sub-basins on selected water quality parameters were calculated for calibration purposes.

Correlations of specific conductance with the main cations and anions of the natural waters of Marmot Creek were also computed. The degree of correlation, and the regression coefficients and constants needed for the prediction equations were obtained using the method of least squares. Standard errors of estimate are provided to indicate the goodness of fit obtained in each case. Wilcoxin's signed ranks test was used to test differences in total dissolved solids among the sub-basin creeks.

RESULTS AND DISCUSSION

Mean monthly discharge of the Main and sub-basin creeks is given in Table 1. May, June and July are the months with high streamflow. Most of the flow during this period is derived from snow-melt

and from precipitation when soil storage is at the maximum. Streamflow during the remaining months is low and derived largely from base flow and ground water reservoir.

Mean total dissolved solids corresponding to the discharge readings of Table 1 are given in Table 2. The concentration of total dissolved solids varies throughout the year.

The relationship between discharge and total dissolved solids is more pronounced in Twin and Middle creeks than Cabin Creek. Such correlations on the basis of mean values are listed in Table 3 for the high-flow and low-flow periods. Inverse correlations between discharge and solute concentration have also been reported by Johnson and Needham (1966). Such dilution effects have similarly been observed by Keller (1967), Pinder and Jones (1969), and Johnson et al. (1969). The correlation coefficients were higher for the April-July period than for the August-March period.

Cabin Creek correlations on the basis of mean monthly data were low by comparison. However, these correlations were positive as compared to the negative correlations for the other two streams. Cabin Creek, therefore, responds differently for the two time periods in this respect. Soil and vegetation conditions on each catchment are likely to account for some of this variation (Keller, 1970). The time of contact of water with soils and rocks and the ready availability of constituents are among other determining factors.

When correlations on the basis of entire year data are considered, the overall relationships are negative for all the four creeks. In Cabin Creek this is caused by a sharp drop in the mean discharge

value of 118.4 (l/sec) in July to 18.1 (l/sec) in August. Thus, inverse relationship between mean discharge and mean total dissolved solids holds good for all streams on a yearly basis.

The maximum and minimum observed values of the physical and chemical characteristics based on extensive sampling throughout the calibration period are given in Table 4. Although differing slightly in the extreme values, there is considerable similarity among the three on the basis of averages for the sampled physical characteristics.

Cabin Creek appears to be slightly warmer than Middle Creek, which in turn is slightly warmer than Twin Creek. Stream temperature is an important physical characteristic of mountain watersheds, having considerable influence on fishery resource and related aquatic life. Indiscriminate cutting of vast tracts of forest land, including complete removal of the shelter strips along stream banks, has inherent harmful effects on this valuable resource and associated habitat. Determination of water temperature changes induced by logging is, thus, an important part of the forest watershed research.

Correlation of the three sub-basin creeks on the basis of 115 water temperature measurements is given in Table 5. All the sub-basin creeks show highly significant correlations among each other (r ranging from 0.95 to 0.96). The sub-basins are, therefore, already well calibrated for determining any real changes that may occur in stream temperatures as a result of intended treatments.

Mean specific conductance of Marmot Creek based on 204 samples is given in Table 6. The main cations and anions and their correlation with specific conductance are as shown in the table.

Calcium and magnesium are the main cations (mean concentration 58.55 mg/l). Bicarbonate is the main anion (mean concentration 182.57 mg/l). The main constituents of the natural waters of Marmot Basin, therefore, are calcium and magnesium bicarbonates. Alkali metals are present in very small quantities and heavy metals are almost absent.

The regression equations listed in Table 6 can be used to provide reasonably accurate predictions of the prominent ions, found in the natural waters of Marmot Creek, from a relatively simple measurement like specific conductance. The correlation coefficients and the standard errors of estimate are provided in each case.

Cabin Creek, on the whole, shows more mineral content than the other two sub-basin creeks. Past history of the sub-basin, particularly a fire in 1936 which burnt the mature spruce-fir forest to be replaced by lodgepole pine (Pinus contorta var. latifolia) over considerable area, may have exercised some modifying influence in this respect.

Wilcoxin's signed ranks test applied to the total dissolved solids showed highly significant differences among the three sub-basin creeks. There are also variations among the same sub-basin in most of the water quality characteristics due to elevation differences. Thus, for example, the mineral content at cirque station was found lower than at the main gauging site for Middle Creek. The elevation differences cause temperature variations which influence the rate of physical and chemical weathering differently in different parts of the catchment.

The differential rates of physical and chemical weathering are also generated by the general aspect of a given sub-basin. Twin is the most and Cabin the least sheltered of the three sub-basins in

this respect. Cabin is more exposed to the direct action of the sun than the other two and therefore receives more radiation intensity. This is evident from stream temperature variations noticed in the three sub-basins.

The high mineral content of Cabin Creek, as shown by high conductivity values, may further be the result of relatively slow percolation. On the average, the specific conductance values for Cabin Creek are 39% higher than Twin Creek and 27% higher than Middle Creek. The water held in solution longer in the substratum is likely to be concentrated more in mineral content than when delivered quickly into streams. Evaporation and transpiration rates are further modifying influences affecting the concentration of solutes. These hypotheses, however, need to be tested in future studies on this watershed.

ACKNOWLEDGEMENTS

The authors would like to thank Mr. Z. Fisera and Mr. T. Thompson for their help in the collection of samples. Analytical work was done by the Water Quality Division, Environment Canada, Alberta. Assistance of Mr. W. Chow in statistical analysis and computer programming is also gratefully acknowledged.

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FIGURE 1
MARMOT CREEK BASIN

Twp. 23, Rge. 9, W5 Mer.

HYDROMETRIC
INSTALLATIONS

Date: February 1966

M.C.B. 6

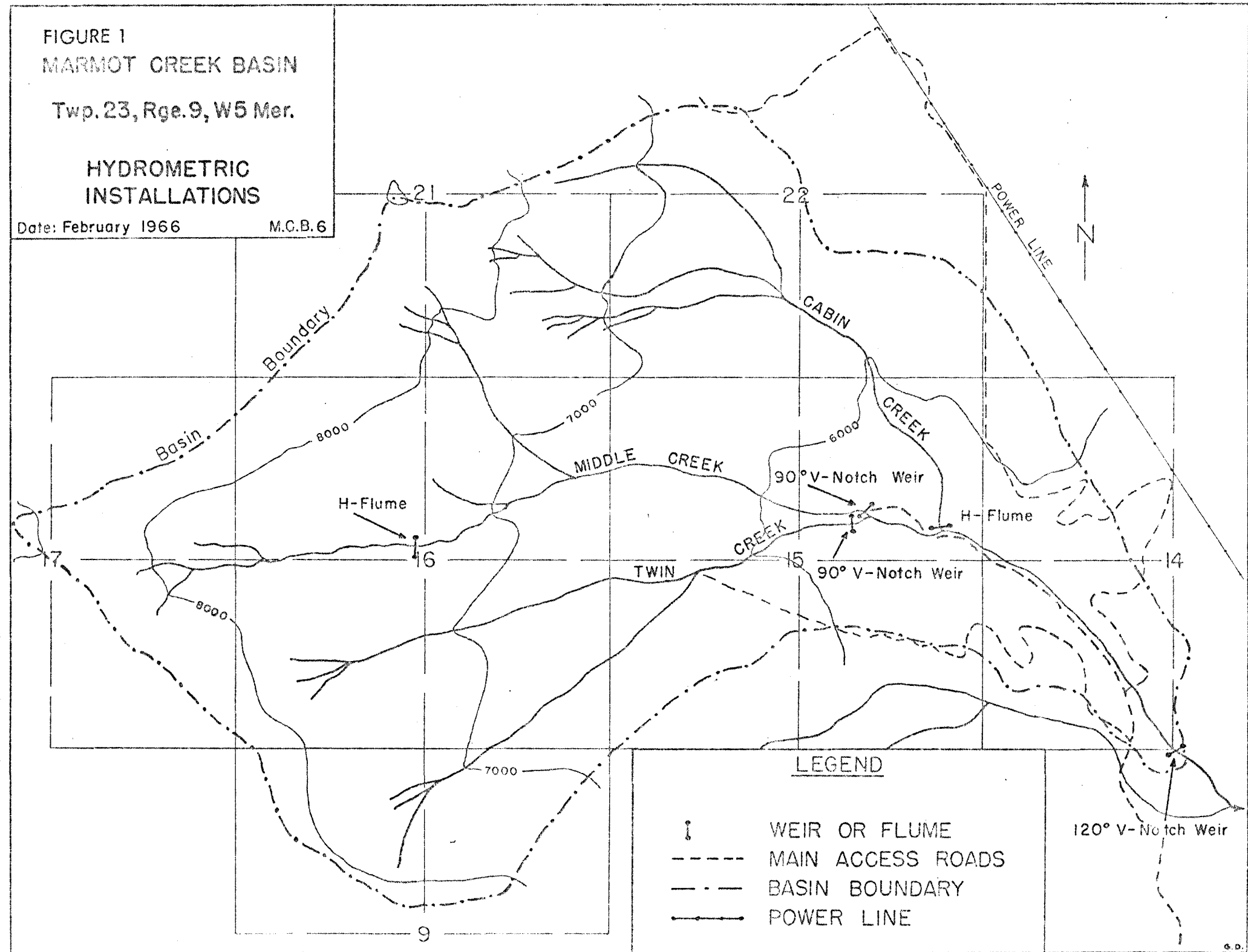


Table 1. Discharge (l/sec) at the time of sampling

Month	Year	Twin			Middle			Cabin			Main		
		Total samples	Mean	Standard error	Total samples	Mean	Standard error	Total samples	Mean	Standard error	Total samples	Mean	Standard error
April	1969	4	12.7	3.4	4	25.8	9.3	4	16.4	4.8	4	80.7	13.7
May	1969	6	132.2	43.0	6	175.0	47.9	7	94.0	18.7	4	443.9	111.8
June	1969	33	258.0	12.5	33	196.8	10.8	33	103.6	10.8	8	591.8	46.1
July	1969	26	162.5	18.1	27	179.8	22.1	26	118.4	13.9	4	603.8	120.4
August	1969	24	30.9	1.1	26	27.2	1.4	15	18.1	1.1	4	90.6	9.1
September	1969	4	18.7	0.8	4	14.7	0.6	4	9.1	0.6	2	48.1	0.0
October	1969	3	15.3	0.8	3	12.2	1.1	3	7.6	0.3	3	37.8	2.8
November	1969	2	9.1	0.3	2	7.9	0.8	2	6.2	0.8	2	25.6	1.6
December	1969	2	7.1	0.0	2	5.7	0.8	2	4.8	0.0	2	19.0	0.0
January	1970	2	4.5	0.3	2	3.4	0.0	2	3.4	0.0	2	14.4	0.6
February	1970	2	4.0	0.6	2	2.8	0.8	2	3.4	0.0	2	12.0	1.1
March	1970	2	2.8	0.3	2	2.3	0.3	2	3.4	0.0	2	11.8	0.7

Table 2. Total dissolved solids (mg/l) in the three sub-basin streams and main stem of
Marmot Creek Watershed

Month	Year	Twin			Middle			Cabin			Main		
		Total samples	Mean	Standard error	Total samples	Mean	Standard error	Total samples	Mean	Standard error	Total samples	Mean	Standard error
April	1969	4	175.8	7.2	4	174.0	5.8	4	174.5	6.4	4	203.0	4.4
May	1969	7	126.1	10.6	7	129.0	10.6	7	181.6	5.3	4	166.5	20.6
June	1969	33	96.1	1.9	33	119.5	2.1	33	201.0	2.3	8	123.8	9.4
July	1969	26	131.2	3.1	27	145.6	3.1	26	219.4	2.3	4	175.0	7.7
August	1969	24	167.3	1.0	26	177.8	1.7	15	227.0	3.6	4	212.8	3.3
September	1969	4	171.5	2.7	4	205.8	6.0	4	224.0	6.5	2	222.0	6.0
October	1969	3	179.7	5.7	3	220.3	0.7	3	200.3	18.7	3	235.3	0.7
November	1969	2	181.0	5.0	2	228.0	2.0	2	203.0	4.0	2	224.5	11.5
December	1969	2	192.5	2.5	2	226.5	1.5	2	216.5	15.5	2	229.5	8.5
January	1970	2	196.5	3.5	2	219.0	1.0	2	236.5	19.5	2	229.0	9.0
February	1970	2	199.0	1.0	2	221.0	4.0	2	186.0	7.0	2	179.0	41.0
March	1970	2	202.0	3.0	2	221.5	1.5	2	208.0	19.0	2	133.5	1.5

Table 3. Correlation (r) between mean monthly discharge (l/sec) and the mean total dissolved solids (mg/l) in the three sub-basins; Total dissolved solids = a + b (Discharge)

Sub-basin	April to July, 1969			August, 1969 to March, 1970		
	r	a	b	r	a	b
Twin	-0.98	177.360	-0.319	-0.93	200.752	-1.263
Middle	-0.92	1.200	0.032	-0.89	231.563	-1.741
Cabin	0.80	164.720	0.354	0.35	204.512	1.164
Main	-0.76	210.856	-0.102	0.30	195.406	0.395

Table 4. Minimum, maximum, and average water quality values

Characteristic	Total samples	Middle			Twin			Cabin		
		Min.	Max.	Av.	Min.	Max.	Av.	Min.	Max.	Av.
Water temperature (°C)	115	0.0	10.0	3.7	0.0	9.4	2.7	0.0	12.8	4.3
pH	116	7.2	8.6	8.1	7.1	8.6	8.1	7.7	8.6	8.1
Turbidity (Jackson units)	116	0.0	8.8	0.5	0.0	9.0	0.4	0.0	50.0	0.6
Specific conductance (μmho /cm)	116	156	372	296	136	339	270	245	439	375
Total hardness (mg/l)	116	80.5	206.0	158	67.2	201.0	144	130.0	240.0	198
Non-carbonate hardness (mg/l)	114	5.9	46.0	25.8	0.0	34.0	8.3	2.0	24.0	13.5
Color (Hazen units)	114	0	30	7	0	30	6	0	30	6
Discharge (l/sec)	183	0.3	600.3	74.1	3.1	693.7	72.6	2.3	424.7	36.0

Table 5. Correlation among sub-basins on water temperature data
during calibration period (n = 115)

Control	Twin			Cabin			Middle		
	Correlation coefficient (r)	Constant (a)	Regression coefficient (b)	Correlation coefficient (r)	Constant (a)	Regression coefficient (b)	Correlation coefficient (r)	Constant (a)	Regression coefficient (b)
Middle	0.95	-0.244	1.055	0.96	10.504	0.711			
Twin				0.95	11.674	0.636	0.95	3.458	0.864
Cabin	0.95	-12.744	1.421				0.96	-10.931	1.307

Table 6. Water quality characteristics (y) and their correlation with specific conductance (x), $y = a + bx$

Quality characteristic	Total samples	Mean	Correlation coefficient (r)	a	b	Standard error of estimate
Specific conductance ($\mu\text{mho/cm}$)	204	316.66				
vs. Calcium (mg/l)	204	45.03	0.83	2.461	0.134	5.52
Magnesium (mg/l)	204	13.52	0.56	0.984	0.040	3.54
Calcium and magnesium (mg/l)	204	58.55	0.86	3.441	0.174	6.37
Bicarbonate (mg/l)	201	182.57	0.88	19.110	0.517	16.83
Carbonate and bicarbonate (mg/l)	201	182.89	0.88	19.02	0.519	16.73
Sulphate (mg/l)	204	17.06	0.88	-3.524	0.065	2.15
Sodium (mg/l)	204	1.35	0.78	-0.825	0.007	0.33
Sodium and potassium (mg/l)	204	1.86	0.77	-0.456	0.007	0.37
Sum of constituents (mg/l)	202	172.57	0.91	12.961	0.505	14.09