LONG-TERM TRENDS IN THE WATER QUALITY OF THE BEAVER RIVER

R. D. Shaw, Ph.D.
Shaw Environmental Consulting

Prepared for

Environmental Quality Monitoring Branch
Environmental Assessment Division
Environmental Protection Services
Alberta Environment

May 1990

W90-05

INTRODUCTION

Federal water quality records for the Beaver River at Beaver Crossing, Alberta, date back to September 1966. Sampling was sporadic, however, from 1966 to 1972 - the number of samples collected per year ranged from 3 in 1969 to 10 in 1967. Since 1973, samples have been collected monthly. This evaluation of long-term trends in water quality of the Beaver River focuses on those data collected at Beaver Crossing from January 1973 to July 1989 (the most recent data listed in NAQUADAT).

METHODS

The following variables were to be tested for long-term trends:

Alkalinity
Specific Conductance
Total Dissolved Solids
Chloride
Sodium
Potassium
Sulphate
Dissolved Oxygen
Colour
Phenolic Compounds
Dissolved Organic Carbon
Chlorophyll-a
Fecal Coliforms
Total Coliforms
Cyanide
$(NO_2^-+NO_3^-)$-N
NH_3-N
TKN
SRP
TDP
PP
TP
Aluminum
Arsenic
Copper
Nickel
Manganese
Iron
Mercury
α-BHC
τ-BHC
2,4-D

A preliminary inspection of the historical data set revealed that long-term trends for four constituents (phenolic compounds, NH_3-N, mercury, and 2,4-D) could not be evaluated statistically with the tests used in this study. For these variables, there were either too many changes in analytical methods and detection limits, too many missing data, and/or too few values above detection. However, visual inspection of these data revealed no obvious long-term changes in these variables.

The other variables were tested for flow-dependency, seasonality, serial correlation, and long-term trends. Even though monthly sampling commenced January 1973, the period of record for many of the variables is much less. Thus, in addition to assessing long-term trends for the entire period of record, a subset of data (1980 to 1989) was also tested. The 1980 to 1989 data set is complete for most variables.

It is well known that concentrations of some variables are related to river discharge (Smith et al. 1982). For flow-dependent variables, the detection of seasonal and long-term trends may be obscured by changes in streamflow. In such cases, a residual analysis technique was used to determine flow-adjusted concentrations. First, for each variable, a best-fit regression of concentration against discharge was calculated. If the slope of the regression was significantly different from 0 (at $\underline{P}<0.05$) and the regression model explained more than 20 % of the variance in the data (i.e., $\underline{r}^2>0.20$), then the variable was considered to be flow-dependent. For flow-dependent variables, the regression model was used to provide expected concentration for every flow, and the flow-adjusted concentration is the actual concentration minus the expected concentration (i.e., residual). For flow-dependent variables, both the actual and flow-adjusted concentrations were tested for long-term trends as outlined below.

Most parametric and non-parametric statistical tests for long-term trends require data that are independently distributed. However, water quality data are often time dependent - either because of seasonality, serial correlation, or both. Seasonality implies that the value of a variable exhibits fluctuations based on the time of the year. Seasonality increases the variance of the data, which decreases the power of many statistical tests for long-term trends. Thus, if seasonality is present, the data should be deseasonalized before testing for trends, or statistical tests that account for seasonality should be used. Seasonal trends in the flow-dependent constituents were assessed graphically by inspection of box and whisker plots of actual and flow-adjusted concentrations on month. Box and whisker plots show the median, minimum and maximum values (whiskers) and the interquartile values (box) and provide an indication of seasonal change in the constituent concentrations. In addition, seasonality was tested statistically with the Kruskal-Wallis test.

Serial correlation arises from the fact that the value of a data point is dependent, to some degree, upon the value of previous data points (after seasonality and trend have been removed). Serial correlation was assessed with the use of a correlogram. If serial correlation was present, then quarterly data rather than monthly data were used to test for long-term trends.

Long-term trends were assessed graphically by inspection of time-series plots and statistically with either the Seasonal Kendall test (if seasonality was significant) or the Kendall test (if seasonality was not significant) (Berryman et al. 1988). The null hypothesis for the Kendall tests is that the constituent concentrations (actual or flow-adjusted) are independent of time. These are non-parametric tests and are not dependent on normally distributed data. In addition, missing values or values reported below the analytical detection limit (i.e., censored data) present no problems for the Kendall tests.

All analyses were carried out on an IBM-AT personal computer with a LOTUS 123 program, which was developed to test for flow-dependency and compute flow-adjusted concentrations (Shaw 1990), and with WQSTAT II, a water quality statistics program to assess seasonality, serial correlation and long-term trends (Loftis et al. 1989).

RESULTS

Of the 28 variables evaluated, seven were considered flow-dependent. Values of true colour and chlorophyll-<u>a</u> increased significantly with flow, whereas total dissolved solids, specific conductance, alkalinity, sodium, and chloride decreased significantly with flow (Table 1).

Seasonality was present in approximately half of the flow-independent variables (Table 2). Seasonality was of course present in the actual concentrations of all flow-dependent variables (i.e., flow is seasonal), although it was reduced or eliminated in the flow-adjusted data sets (Table 2).

For the entire period of record, there were significant long-term decreases in the values of six of 20 flow-independent variables (Table 2) - dissolved oxygen, $(NO_2^- + NO_3^-)$-N, sulphate, potassium, total coliforms, and the pesticide α-BHC. Four of these variables (sulphate, potassium, total coliforms, and α-BHC) have also decreased significantly from 1980 to 1989. Changes in the values of most of the variables have been slight. Investigation of the causes of these changes is beyond the scope of this study. However, the decrease in concentrations of α-BHC appears to be widespread across northern Alberta as it has also been observed in the Peace and North Saskatchewan rivers (Shaw et al. 1990a, 1990b).

The actual concentrations of all flow-dependent variables have changed significantly over their period of record (Table 2) - concentrations of TDS and associated variables (specific conductance, alkalinity, sodium, and chloride) increased while true colour and chlorophyll-a decreased. Interestingly, the decrease in concentrations of TDS and associated variables was only significant when the entire data set (1973-89) was included; these variables did not change significantly from 1980 to 1989. In contrast to the results for actual concentrations, flow-adjusted concentrations have not changed significantly, with the exception of values of true colour (Table 2). These results suggest that changes in discharge may be the cause of the long-term trends for the actual concentrations of all flow-dependent variables, except for true colour.

Discharge, as recorded on the dates that water quality data were available, was also tested for long-term trends with the Seasonal Kendall test. The results of the trend test indicate that discharge has decreased significantly ($\underline{P}<0.10$) from 1973 to 1989 (0.32 cms/yr), but it has not decreased significantly ($\underline{P}>0.1$) since 1980. These results are consistent with the findings for the flow-dependent variables - i.e., for TDS and associated variables, which are negatively correlated with flow, a decrease in flow would cause an increase in concentrations, as was observed. On the other hand, the significant decreases in both actual and flow-adjusted values of true colour suggests that there have been either (1) changes in the processes that deliver constituents that impart colour to the Beaver River, or (2) unrecorded changes in sampling or analytical methods, which would affect the measurement of true colour.

LITERATURE CITED

Berryman D., B. Bobee, D. Cluis, and J. Haemmerli. 1988. Nonparametric tests for trend detection in water quality time series. Water Res. Bull. 24:545-556.

Loftis J.C., R.D. Phillips, R.C. Ward, and C.H. Taylor. 1989. WQSTAT II: A water quality statistics package. Ground Water. 27:866-873.

Shaw R.D. 1990. TREND - An integrated computer procedure for evaluating time-series data. Prep. for Environmental Quality Monitoring Branch, Alberta Environment. 25pp.

Shaw R.D., L.R. Noton, A.M. Anderson, and G.W. Guenther. 1990. Water quality of the Peace River in Alberta. Draft Report. Prep. for Environmental Quality Monitoring Branch, Alberta Environment. 263p.

Shaw R.D., P.A. Mitchell, and A.M. Anderson. 1990. Water quality overview of the North Saskatchewan River in Alberta. in prep.

Smith R.A., R.M. Hirsch, and J.R. Slack. 1982. A study of trends in total phosphorus measurements at NASQAN stations. U.S. Geol. Survey Water Supply Pap. 2190.

Table 1. Relationship between concentration and flow for flow-dependent variables.

Variable(unit)	Regression	r^2
TDS (mg/L)	$TDS = 112.9 + 210.0/(1 + 0.1Q)$	0.43
Conductivity (uS/cm)	$SC = 224.9 + 323.5/(1 + 0.1Q)$	0.30
Alkalinity (mg/L)	$Alk = 87.5 + 196.9/(1 + 0.1Q)$	0.49
Sodium (mg/L)	$Na = 5.46 + 22.2/(1 + 0.1Q)$	0.35
Chloride (mg/L)	$Cl = 1.06 + 5.03/(1+0.1Q)$	0.25
True Colour (RCU)	$TC = 25.1 + 1.16Q - 0.0067Q^2$	0.47
Chlorophyll-a (μg/L)	$\ln(Chl) = -7.17 + 0.775\ln(Q)$	0.43

Table 2. Trends in flow-independent and flow-dependent variables.

Variable	Period of Record	Seasonality (Y/N)	Trend*	
			Period of Record	1980-89
FLOW-INDEPENDENT VARIABLES				
DOC	1978-89	N	-	-
$(NO_2^-NO_3^-)$-N	1976-89	Y	-0.00143 mg/L/yr	-
DO	1974-89	Y	-0.05 mg/L/yr	-
TP	1974-89	N	-	-
TDP	1975-89	Y	-	-
SRP	1981-89	N	n/a	-
PP	1975-89	Y	-	-
Sulphate	1973-89	Y	-0.44 mg/L/yr	-0.60 mg/L/yr
Potassium	1973-89	Y	-0.12 mg/L/yr	-0.23 mg/L/yr
Cyanide	1974-89	N	-	-
Aluminum (extr.)	1981-89	N	n/a	-
Manganese (diss.)	1979-89	Y	-	-
Iron (diss.)	1979-89	Y	-	-
Nickel (total)	1983-89	N	n/a	-
Copper (total)	1983-89	Y	n/a	-
Arsenic (diss.)	1974-89	Y	-	-
Total Coliforms	1974-89	N	-7.4 #/100mL/yr**	-0.9 #/100mL/yr
Fecal Coliforms	1974-89	Y	-	-
α-BHC	1976-89	N	-0.0002 μg/L/yr	-0.00019 μg/L/yr
τ-BHC	1975-89	N	-	-
FLOW-DEPENDENT VARIABLES (ACTUAL CONCENTRATIONS)				
TDS	1973-99	Y	2.37 mg/L/yr	-
Conductivity	1973-89	Y	4.47 uS/cm/yr	-
Alkalinity	1973-89	Y	2.65 mg/L/yr	-
Sodium	1973-89	Y	0.33 mg/L/yr	-
Chloride	1973-89	Y	0.092 mg/L/yr	-
True Colour	1981-89	Y	n/a	-0.71 RCU/yr
Chlorophyll-a	1980-89	Y	n/a	-0.00017 μg/L/yr
FLOW-DEPENDENT VARIABLES (FLOW-ADJUSTED CONCENTRATIONS)				
TDS	1973-99	Y	-	-
Conductivity	1973-89	Y	-	-
Alkalinity	1973-89	Y	-	-
Sodium	1973-89	Y	-	-
Chloride	1973-89	Y	-	-
True Colour	1981-89	N	n/a	-2.98 RCU/yr
Chlorophyll-a	1980-89	N	n/a	-

---

n/a - not applicable since period of record does not precede 1980.

[*] The Seasonal Kendall slope estimate is given for those data with a significant long-term trend (i.e., $P < 0.05$), - denotes no significant trend is present.

[**] Trend may be an artifact of serial correlation.