TRENDS IN SNOWCOURSE AND STREAMFLOW DATA

IN BRITISH COLUMBIA AND THE YUKON

by

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INTRODUCTION

As concern for environmental problems such as man induced climate change has grown in recent years the need for large spatial scale data analysis has increased. In this paper long term, continuous snowcourse and hydrometric data sequences from British Columbia and the Yukon are examined for patterns and statistical characteristics, in particular, trends in time and space. No attempt is made to relate the possible patterns with natural or man induced climate change.

Detection of change requires a definition of change. For this study change is defined as a spatially consistent statistically significant pattern of trends. Spatially consistent means that all trends in a geographic area are similar.

Environmental data sets such as streamflow and snowcourse data have properties which make statistical analysis difficult. The data may be non-normally distributed, prone to missing record and suffer from external interventions. These interventions may be natural or man induced. Whatever the source, interventions may significantly affect the stochastic manner in which a time series behaves. For these reasons, as proposed by Tukey (1977) and demonstrated by McLeod et al (1983) statistical analysis should be conducted in two major steps, exploratory data analysis and confirmatory data analysis. Exploratory data analysis employs various graphical and numerical techniques to discover patterns and statistical characteristics. Confirmatory data analysis tests in a rigorous statistical examination the presence of the proposed properties in the data.

The underlying mechanisms which produce time series are different. For example, Peck and Schaake (1990) state, "Although precipitation and snow survey records are both measurements of winter precipitation, they cannot be directly related." Streamflow is even more complicated as inputs of mass and energy interact with each other and with drainage basin conditions in a complex fashion. These complex, probably non-linear, interactions may have thresholds, so streamflow may not be as sensitive to climate change as more direct quantities such as temperature and precipitation.

DATA

The snowcourse data for British Columbia is gathered by the Water Management Branch, Ministry of Environment, Province of British Columbia and is available in Snow Survey Bulletin Publications. For this study snow water equivalents on the day of the most frequent maximum were used.

Paper presented at the Western Snow Conference, 1991

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The streamflow data were selected for hydrometric stations with long records, i.e., 30 years, gauging basins which produce natural streamflow or streamflow considered to be little altered by diversion or impoundment. For example, the basin gauged by station (WSOC) 08NL022. Similkameen River at Nighthawk has some extraction for irrigation and impoundment by a small dam at the outlet of Otter Lake. Annual flows at Nighthawk are considered to be unaffected. Several of the records are from basins with large lakes, this natural storage could affect flows and dampen a trend. Possible interventions to basin flows which may affect trends are noted in Table 1.

Table 1. Basins and Associated Hydrometric Stations

	HYDROMETEOROLOGICAL STATION			DRAINAGE BASIN
NUMBER	NAME	RECORD	AREA (km^2)	COMMENTS
08MA001	Chilko R. nr Redstone	1934-88	6,940	- large lake in basin - many low flow months missing 1934-65 - station relocated 1966
08NA002	Columbia R. at Nicholson	1917-88	6,660	- manual gauge - only 4 monthly values missing
08MF005	Fraser R. at Hope	1913-88	217,000	- regulation began 1952
08NN013	Kettle R. nr Ferry	1929-88	5,750	- no missing data
10BE001	Liard R. at Lower Crossing	1948-88	10,400	- from 1952 to 1965 there are many months missing
08MG005	Lillooet R. nr Pemberton	1926-88	2,160	- large glacier field in basin
08NH006	Moyie R. at Eastport	1930-88	1,480	- two moderate-sized lakes
10CD001	Muskwa R. nr Ft. Nelson	1955-88	20,300	- 1955-64 missing many low flow months
08DB001	Nass R. ab Shumal Creek	1947-88	19,200	- 1947-58 missing many low flow months
08JB003	Nautley R. nr Ft. Fraser	1952-88	6,030	- large lakes in basin
08LB064	North Thompson at McLure	1959-88	19,600	- combined 2 stations
08LB022	North Thompson at Barrier	1917-58	17,700	
08KH001	Quesnel R. at Likely	1938-88	5,930	- large lakes in basin missing some low flow months
08NL022	Similkameen R. nr Nighthawk	1929-88	9,190	- extractions for irrig. - impounded at Otter L. - a diverse basin
08EF001	Skeena R. at Usk	1938-88	42,200	- missing several months 1938-57
08NJ013	Slocan R. nr Crescent	1925-88	3,320	- missing several months in early part of record - no missing record 1933 on
08JE001	Stuart R. nr Ft. St. James	1934-88	14,600	- manual gauge - several large lakes
09AC001	Takhini R. nr Whitehorse	1949-88	6,990	- one large and several smaller lakes in basin
09AH001	Yukon R. at Carmacks	1952-88	81,800	- large lakes in upstream portion of basin - flow regime assumed natural

For annual mean flows, some missing data were estimated, primarily for low flow months but also for high flow months when only a few days were missing. Records for two hydrometric stations on the North Thompson have been combined and several months of missing data have been estimated to produce a continuous record for 1917 to 1988.

EXPLORATORY DATA ANALYSIS

The statistical procedures used in this study are contained in a package of computer programs developed by consultants A.I. McLeod and K.W. Hipel for the Water Resources Branch, Inland Waters Directorate. The package produces graphical output together with test statistics. The first procedure in the package produces a time series plot with a robust locally weighted regression smooth (RLWRS) and a Kendall tau statistic with significance level.

The robust locally weighted regression smooth (RLWS) (Cleveland, 1979) provides a visual indication of the presence or absence of trends or smoothed patterns in the data. Smooth is used in this context to describe a filtering action by which high frequency variability is removed from the time series. The local weighting is accomplished by weighting the data within a range or window. This window excludes the effects of data, except those in a small neighbourhood, thus the term local.

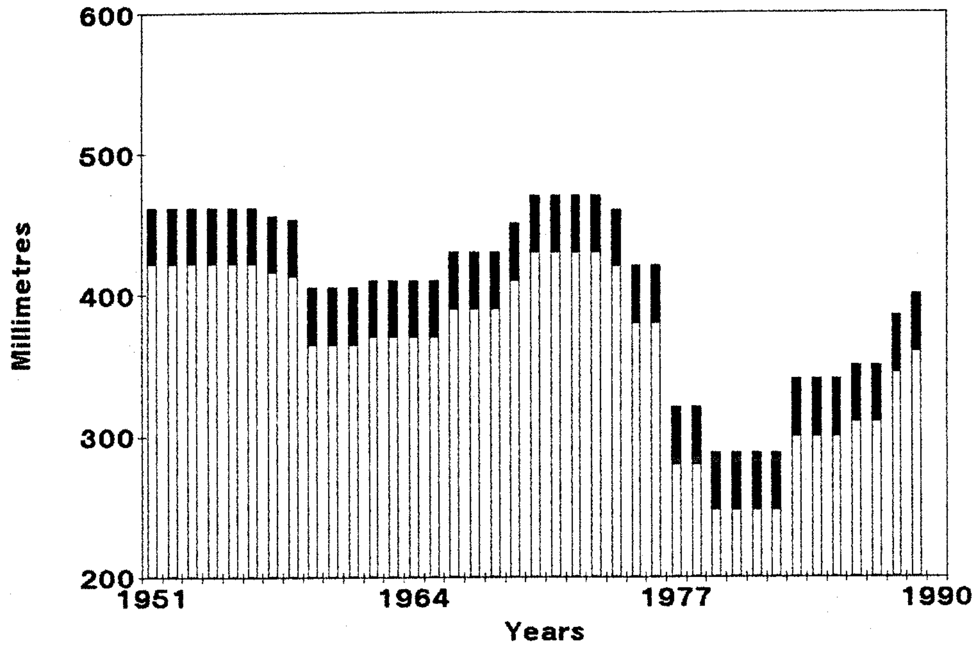
The size of the window can be varied (and this is indicated on the plots). As the window becomes wider, the smooth becomes more like a straight line. The points fitted by RLWS are only slightly affected by extreme values, hence the turn robust.

The Mann-Kendall test statistic (s) or Kendall's tau (τ) are similar, related measures of running sum of sign differences between observations (Mann, 1945; Hirsch et al, 1982). For example, if the sign of the difference between two observations is positive, a plus one is added to the sum, if the difference is negative, a minus one is added. A positive value of the sum indicates a positive or upward trend, a negative value a declining trend. τ or s can be shown to be asymptotically normally distributed so a significance level can be calculated. If the significance level is greater than 0.05 then at the 5% significance level the null hypothesis, i.e., that the data comes from a population for which random variables are independent and identically distributed cannot be rejected, i.e., there is not a significant trend.

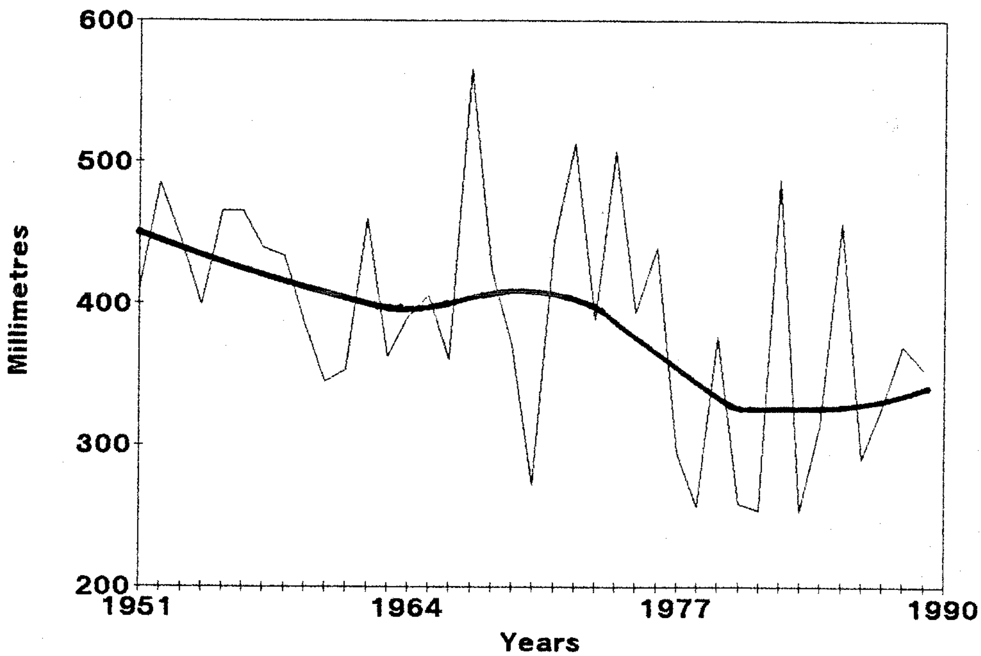
A plot of a time series may "blur" patterns in the data which a smoothed plot may reveal (Tukey, 1977). The Tukey blurred smooth must be used with evenly spaced data with no gaps. At each observation, the "rough" is the observed value minus the smoothed value. The vertical bars on a blurred smooth plot are the median of the absolute values of all the roughs. The smoothed observation is located at the midpoint of the vertical bars.

RESULTS

Figure 1 shows two smooth representations (smooths) for the 1 April snow water equivalent series for the Barkerville snowcourse. The patterns are generally similar, declining from the 1950s, with slight increase in the 1970s, but in the last 10 years, the Tukey blurred smooth shows an increasing tendency while the robust locally weighted smooth shows a horizontal tendency. At the 5 percent significance level, the declining trend is significant by the Mann-Kendall test, i.e., the significance level (0.00697) is much less than 0.05. The negative trend is indicated by a tau of -0.303. The significance of the decline is also apparent in the Tukey blurred smooth as it is much greater than the blur or vertical bar. Variability appears to have increased since 1950s and early 1960s.



Blurred Smooth



Robust Locally Weighted Regression Smooth

FIGURE 1
DATA SMOOTHS - BARKERVILLE SNOWCOURSE
1 APRIL SNOW WATER EQUIVALENT

Table 2. Statistical Results for Snowcourses

	Station	Mann-Kendall tau	Significance level
1A03	Barkerville	- 0.303	0.007
1C01	Brookmere	- 0.212	0.042
4C04	Cassier	0.247	0.081
2A02	Glacier	0.161	0.089
	1 May	- 0.018	0.871
4B01	Kidprice Lake 1 May	0.247	0.033
2E01	Monashee Pass	- 0.118	0.286
4A02	Pine Pass	- 0.007	0.970
	1 May	- 0.111	0.428
2C01	Sinclair Pass	0.053	0.575
1D06	Tenquille Lake	- 0.204	0.078
09AASC3	Log Cabin	0.317	0.001
10AASC1	Watson Lake A	- 0.190	0.185

Results are for 1 April Data Sets unless otherwise noted.

The results for the snowcourse data are summarized in Figure 2 and Table 2. Figure 2 shows a geographical display of robust locally weighted regressing smooths. The geographical distribution appears to indicate most stations in the south have a decreasing tendency while stations in the north have an increasing tendency. Table 2 indicates that at the 5 percent level only 4 stations had statistically significant trends. Several others are close, Cassier (0.081), Glacier (0.089), Tenquelle Lake (0.078).

Figure 3 provides a geographical display of robust locally weighted regression smooths for annual mean flows, the general pattern is similar to that of the snow course data. Table 3 shows that only 5 stations had statistically significant trends. One of these is the North Thompson which is an amalgamation of records from 2 stations. The North Thompson shows a significant increasing trend. This must be examined carefully as records from 2 different stations have been used. The recent record, i.e., since 1950s does show a decreasing tendency, but the low levels of the 1920s, 30s have produced an overall increasing trend.

Table 3. Statistical Results for Hydrometeorologic Stations

	Station	Mann-Kendall tau	Significance level
08MA001	Chilko River	- 0.275	0.0032
08NA002	Columbia River	0.030	0.717
08MF005	Fraser River	0.061	0.442
08ND013	Kettle River	0.137	0.124
10BB001	Liard River	0.166	0.129
08MG005	Lillooet River	- 0.100	0.252
08NH006	Moyie River	- 0.018	0.849
10CD001	Muskwa River	0.307	0.011
08DB001	Nass River	- 0.081	0.496
08JB003	Nautley River	- 0.292	0.015
	North Thompson	0.174	0.031
08KH001	Quesnel River	0.204	0.037
08NL022	Similkameen R.	0.034	0.702
08EF001	Skeena River	0.135	0.165
08NJ013	Slocan River	0.157	0.068
08JB001	Stuart River	0.123	0.190
09AC001	Takhini River	- 0.023	0.843
09AH001	Yukon River	0.066	0.574

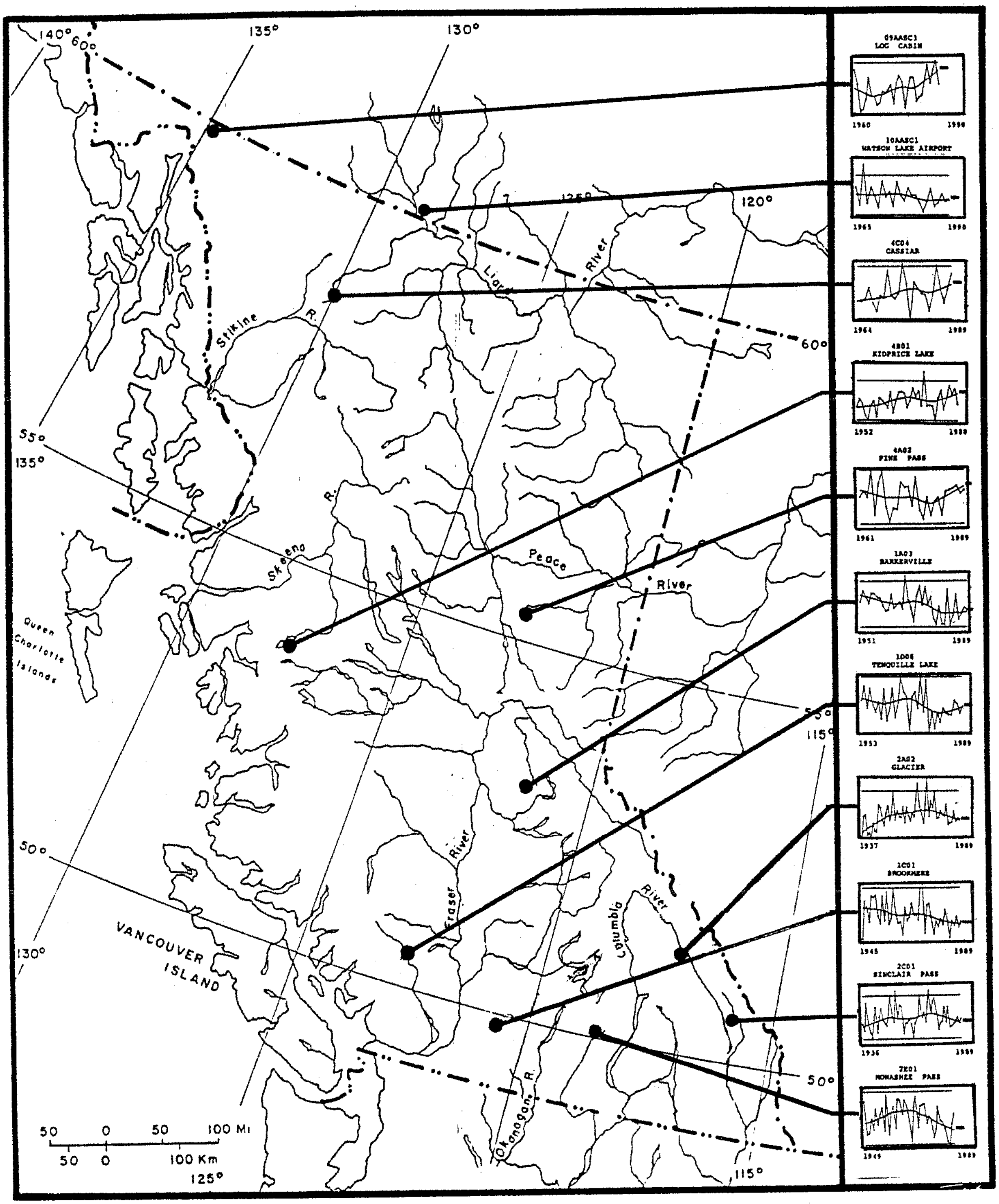


FIGURE 2

Geographic Summary Of Robust Locally Weighted Smooths For Snow Water Equivalent Data

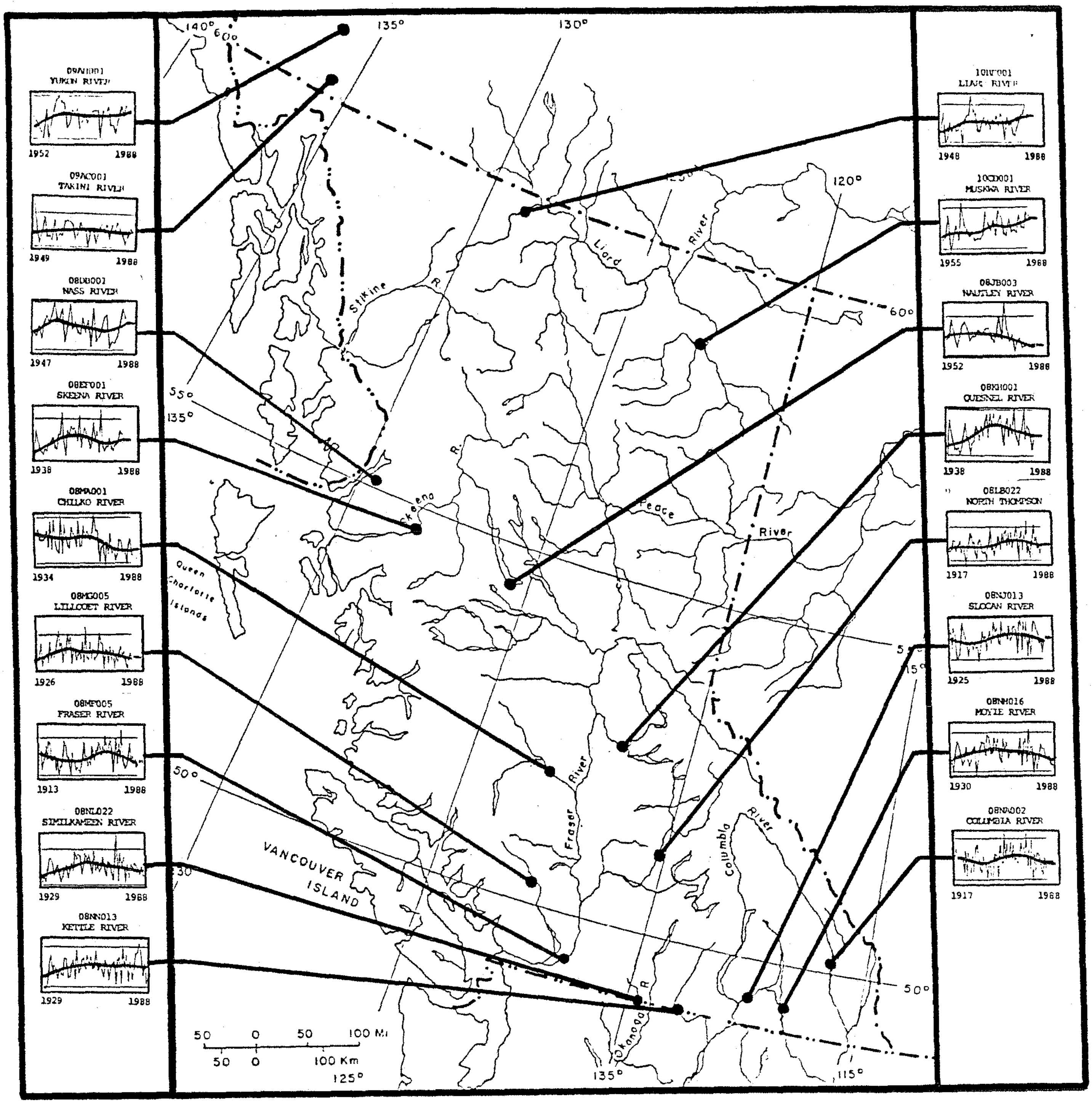


FIGURE 3

Geographic Summary Of Robust Locally Weighted Smooths for Annual Mean Flows

CONCLUSIONS

Based upon the definition of a uniform statistically significant pattern for climate change, exploratory data analysis methods have not established the existence of climate change in the data from snowcourses and hydrometric stations. But there are indications of tendencies in the data which should receive further investigation, particularly with respect to the sensitivity of the tests and the validity of the definition of climate change.

Once again the need for high quality (or at least known quality) continuous, long term data sets is demonstrated.

REFERENCES

Cleveland, W.S. 1979. "Robust Locally Weighted Regression and Smoothing Scatterplots." Journal of the American Statistical Association, Vol. 74, No. 368, pp.829-836.

Hirsch, R.M., J.R. Slack and R.A. Smith. 1982. "Techniques for Trend Assessment for Monthly Water Quality Data." Water Resources Research. Vol. 18, No. 1, pp. 107-121.

Mann, H.B. 1945. "Nonparametric Tests Against Trend." Econometrics. Vol. 13, pp. 245-259.

McLeod, A.I., Hipel, K.W., and Camacho, F. 1983. "Trend Assessment of Water Quality Time Series." Water Resources Bulletin. Vol. 19, No. 4, pp. 537-547.

Peck, E.L. and J.C. Shaake. 1989. "Network Design for Water Supply Forecasting in the West." Water Resources Bulletin, Vol. 26, No. 1, pp. 87-99.

Tukey, J. 1977. Exploratory Data Analysis. Addison-Wesley. Reading, Massachusetts.