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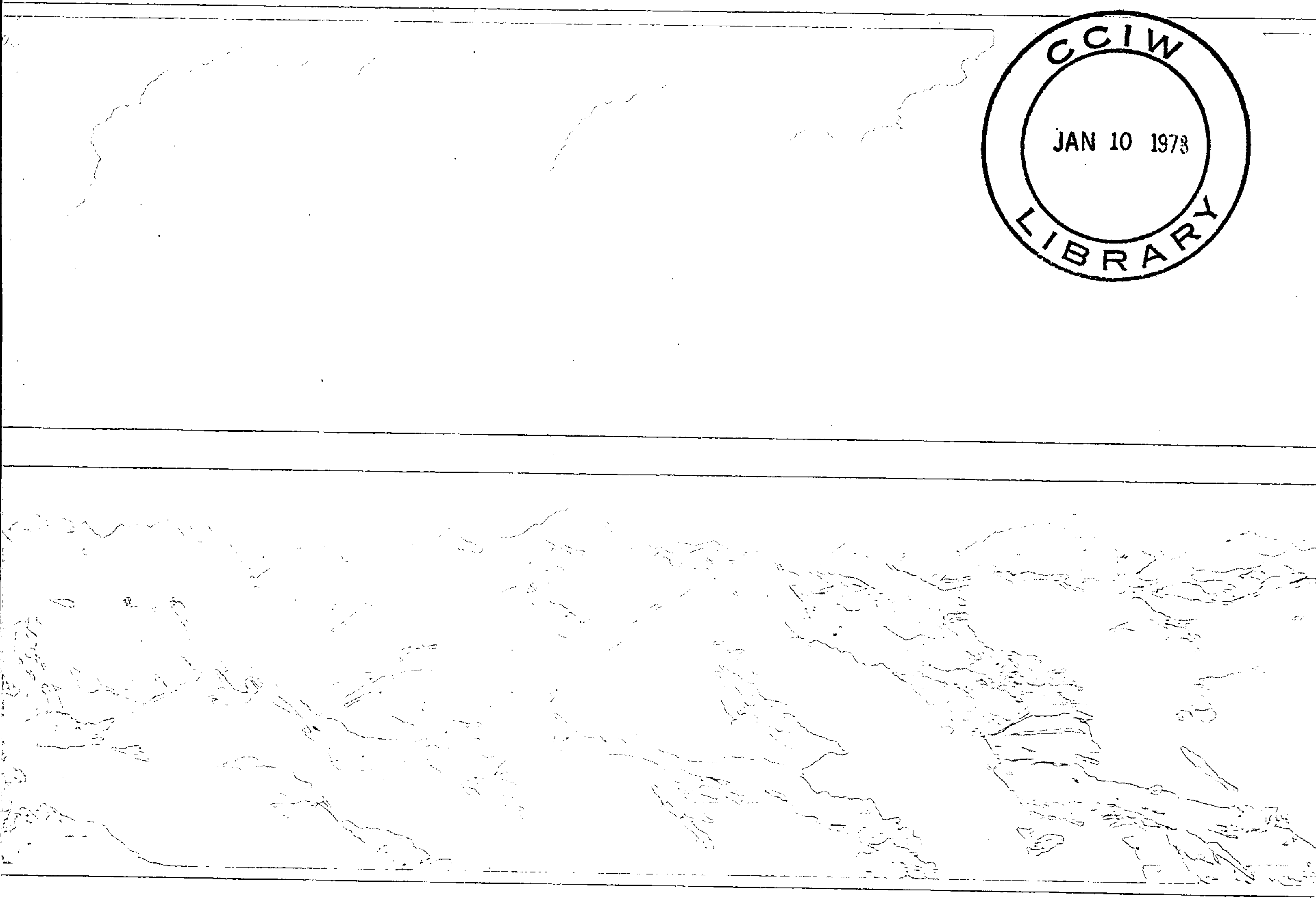
Streamflow Regionalization in British Columbia, No. 3

Statistics of Mean Annual Flow

R.M. Leith



REPORT SERIES NO. 50
(Résumé en français)

INLAND WATERS DIRECTORATE,
PACIFIC AND YUKON REGION,
WATER RESOURCES BRANCH,
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ABSTRACT

Trends and serial correlations have been examined for series of annual flows and annual precipitations for 17 streamflow and 9 precipitation stations in British Columbia. This was undertaken to determine if there were statistically distinct trends in mean annual values which could bias regional analysis.

No province-wide statistically distinct trends were found, although mean flows and precipitations were lower in the 1920's, 1930's, and 1940's than in the 1950's and 1960's.

The maximum deviations of 5, 10, 15 year mean flows from 40 and 50 year mean flows were studied also to provide an indication of the extent to which short term means can differ from long term means.

RÉSUMÉ

Dans la présente étude, il s'agissait d'analyser les corrélations sérielles et tendancielles de séries d'écoulements annuels et de précipitations annuelles pour 17 stations d'observation de l'écoulement et 9 stations pluviométriques situées en Colombie-Britannique. L'étude devait déterminer s'il existait, dans les valeurs annuelles moyennes, des tendances statistiquement distinctes et susceptibles d'influencer une analyse effectuée à l'échelle régionale.

Aucune tendance statistiquement distincte à l'échelle de la province n'a pu être décelée, bien que les écoulements moyens et les précipitations des années 20, 30 et 40 aient été plus faibles que dans les années 50 et 60.

En outre, les écarts maximaux entre les écoulements moyens de périodes de 5, 10 et 15 ans et ceux de périodes de 40 et 50 ans ont servi à déterminer dans quelle mesure les moyennes à court terme peuvent être différentes des moyennes à long terme.

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1. INTRODUCTION

The object of this study was the examination of trends and serial correlations for mean annual flows of selected streams in British Columbia. To seek an explanation of the trends in mean annual flows, mean annual precipitations were also studied. Information from this study will be input into regional studies in British Columbia.

As an extension of this study the maximum deviations of 5, 10, and 15 year mean flows from 40 and 50 year mean flows were examined. This provides an indication of how well a short term mean represents the long term mean.

Streamflow gauging stations selected for the study had records of 40 or more years of natural flow. In northern and central British Columbia the 40 year criterion was reduced to 30 years. In order that records from various stations could be compared, continuous data with a common end point of 1969 were employed.

For the study of maximum deviations 1974 data were used where available. A comparison of long term averages is provided in Section 3 (Results).

2. PROCEDURE

2.1 Station Selection

At first stations gauging natural flow from drainage areas of less than 500 square miles were selected. This was done so that regionality of the trends could be examined. However, as few stations were available, the study was extended to include stations gauging larger drainage areas and near natural flow.

Near natural flow refers to pondages or other mild artificial changes to flow which are assumed to have a negligible effect on annual flow. An example is Station 08NK005 Elk River at Phillips Bridge, which has been affected by pondage from the Elko Power Plant since 1924.

The stations used in the study are listed in Table 1 and the locations are indicated in Figure 1.

TABLE 1. Hydrometric and Meteorologic Stations Used in Study

Hydrometric Stations

Station	Drainage Area (sq.mi.)	Notes	
08LD001 Adams River	1190	Flow from large lake	1974†
08NH032 Boundary Creek	97		
08NG002 Bull River	578	Regulated	1974†
08GA010 Capilano River	66.6		1974†
08KH003 Cariboo River	1310	Flow from large lakes	
08MH016 Chilliwack River	131	Flow from large lake	1974†
08MH001 Chilliwack River	484	Flow from large lake	1974†
08NA002 Columbia River	2570		
08NK005 Elk River	1710	Pondage	
08MF005 Fraser River	83800		1974†
08NH004 Goat River	430	Pondage	1974†

TABLE 1. (continued)

Station	Drainage Area (sq.mi.)	Notes
08NN013 Kettle River	2200	1974†
08NG005 Kootenay River	5200	
08MG005 Lillooet River	835	Glacier fed stream
08NH006 Moyie River	570	
08KH001 Quesnel River	2330	Flow from large lakes
08NJ013 Slocan River	1270	

† Continuous data up to and including 1974.

Meteorologic Stations

Station	Period of Record Used in Study
Agassiz	1905 to 1969
Barkerville	1900 to 1969
Creston	1930 to 1969
Deer Park	1930 to 1969
Fernie	1919 to 1958
Kaslo	1920 to 1969
Newgate	1920 to 1959
Pemberton Meadows	1913 to 1961
Vernon Coldstream Ranch	1910 to 1969

2.2 Missing Records

Continuous records were required for the examination of trends so gaps in records were filled by correlation. The quantities correlated were residuals of monthly flows after periodic and sequential components had been removed.

The periodic component was removed by subtracting the monthly mean and dividing the remainder by the standard deviation of monthly flows. This provides a series of normal variates.

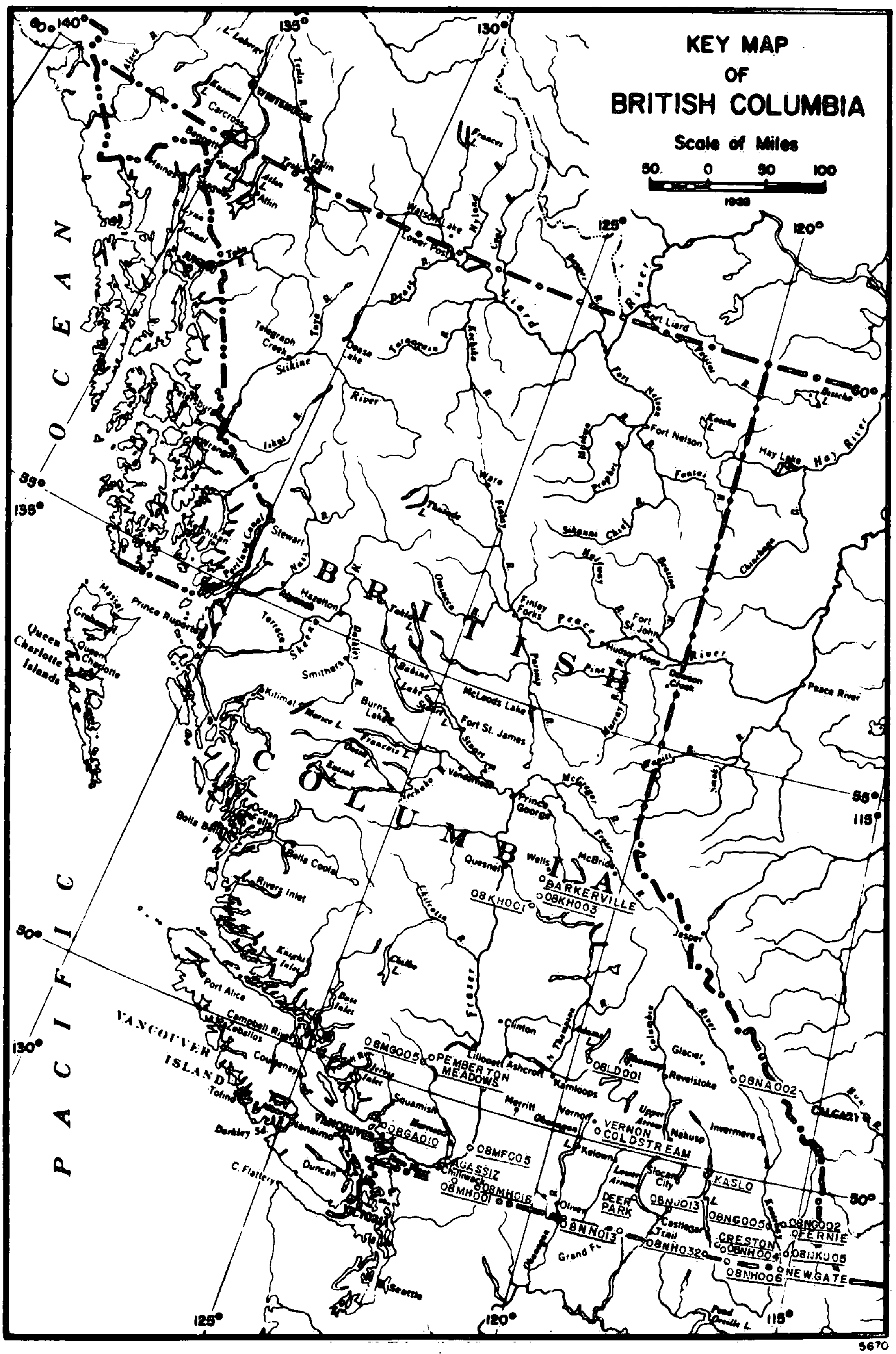


Figure 1. Locations of Hydrometric and Meteorologic Stations

The sequential component was removed by assuming a simple Markov model, so that the flow in any given month is related only to the flow in the previous month. With this assumption only the lag one serial correlation coefficient was found for the series of normal variates.

In this manner the sequence of monthly flows for a station was reduced to a sequence of residuals with the periodic and sequential components removed. These residuals were the quantities regressed, using the sequence of the station with missing record as the dependent variable.

Missing records were filled from the regression equations and the reconstitution of serial dependence and periodic component. The process of filling in record was accepted if the information content of the mean for the annual flows was greater after the record was filled.

2.3 Sampling or Grouping the Data

2.3.1 Sampling by Specific Time Spans

Sampling by specific time spans was employed to investigate trends in annual flow records. The records were divided into fixed spans with the long term span ending in 1969; for example, 40 years of record divided into four 10-year spans, 1930-1939, 1940-1949, 1950-1959, 1960-1969. These common time spans allowed trends for different stations to be compared.

2.3.2 Other Sampling Methods

In the examination of maximum deviations of short term means from long term means other sampling methods were used. These methods and comparisons of the results from these methods are discussed in Appendix 3.

2.4. Statistical Components

2.4.1 Statistical Tests

A statistical test was employed to provide a criterion as to whether a short term mean were statistically distinct from a long term mean. The development of this criterion is in Appendix 2. The criterion states that:

$$|RAFL - 1| \leq \frac{t\alpha,\nu \times s}{\sqrt{Ne} \times \mu}$$

RAFL is the ratio of the short term mean to the long term mean.

$t\alpha,\nu$ is the t statistic for α level of significance and ν degrees of freedom.

$\nu = Ne - 1$.

$Ne = N \times \frac{(1 - R(1))}{(1 + R(1))}$ is the effective length of record.

N is the number of years of record.

R(1) is the first serial correlation coefficient.

s is the standard deviation of the sample of size N.

μ is the long term mean.

A cumulative sum test was applied to records from two stations to discover if significant deviations had taken place in annual flows. This technique is based on random walk theory. Each year that the flow is below median a minus step is recorded; each year the flow is above median a positive step is recorded and the running sum is kept. The sum is then examined to see if it is significant. The details of the test are in Reference 2. Median is defined as the middle or interpolated middle value.

2.4.2 Effective Length of Record

If a quantity is serially correlated the number of observations N, which appear in formulas such as $\bar{x} = \frac{1}{N} \sum_{i=1}^{N} x_i$, must be adjusted. In this report the adjusted number of observations Ne is called the effective length of record (Reference 4, Page 186).

2.4.3 Information Content of the Mean

As in this study information content is not used in an absolute sense but only as an indicator of the effectiveness of record extension, Fisher's definition has been adopted. By this definition the information content of the mean is given by Ne/sample variance where Ne is the effective length of record (Reference 4, Page 212).

An example of the use of the information content of the mean is provided in Section 3.3 for the Chilliwack River at Vedder Crossing.

3. RESULTS

Results for selected stations are discussed in this section. Tables of statistics for the remaining stations are in Appendix 3. Station 08NG005 Kootenay River at Wardner is typical for stations in southeastern British Columbia but 08KH001 Quesnel River at Likely and 08MH001 Chilliwack River at Vedder Crossing cannot be considered typical because they record flows from lakes.

It is to be noted that first, for stations with discontinuous records there are no trend analyses; second, the long term averages used in this study are not necessarily those published in _Historical Streamflow Summary, British Columbia to 1973_ (see Table 2 and Reference 3).

TABLE 2. Mean Annual Flow Comparison in cfs for Selected Stations

Station	Used in Study to 1969	Published including 1973	Long Term including 1974
Boundary Creek	192	195	198
Cariboo River including synthetic data	3280	3280	3284
Columbia River	3803	3850	3858
Elk River	2720	2740	2767
Fraser River	96200	96100	96400
Kootenay River	7215	7240	-
Lillooet River	4523	4500	(1974 incomplete)
Moyie River	712	711	721
Quesnel River	4494	4460	4475
Slocan River	3090	3080	3097

Note: Largest difference for any station is 3%.
1974 data were used for maximum deviation study.

3.1 Kootenay River at Wardner

Trends in the 10- and 25-year averages for Kootenay River at Wardner, Figure 2, are similar to those for other streams in southeastern British Columbia, that is, low in the 1920's, 1930's, 1940's and high in the 1950's and 1960's. Care must be taken with interpretation of these trends as only those periods indicated in Table 3 are statistically distinct.

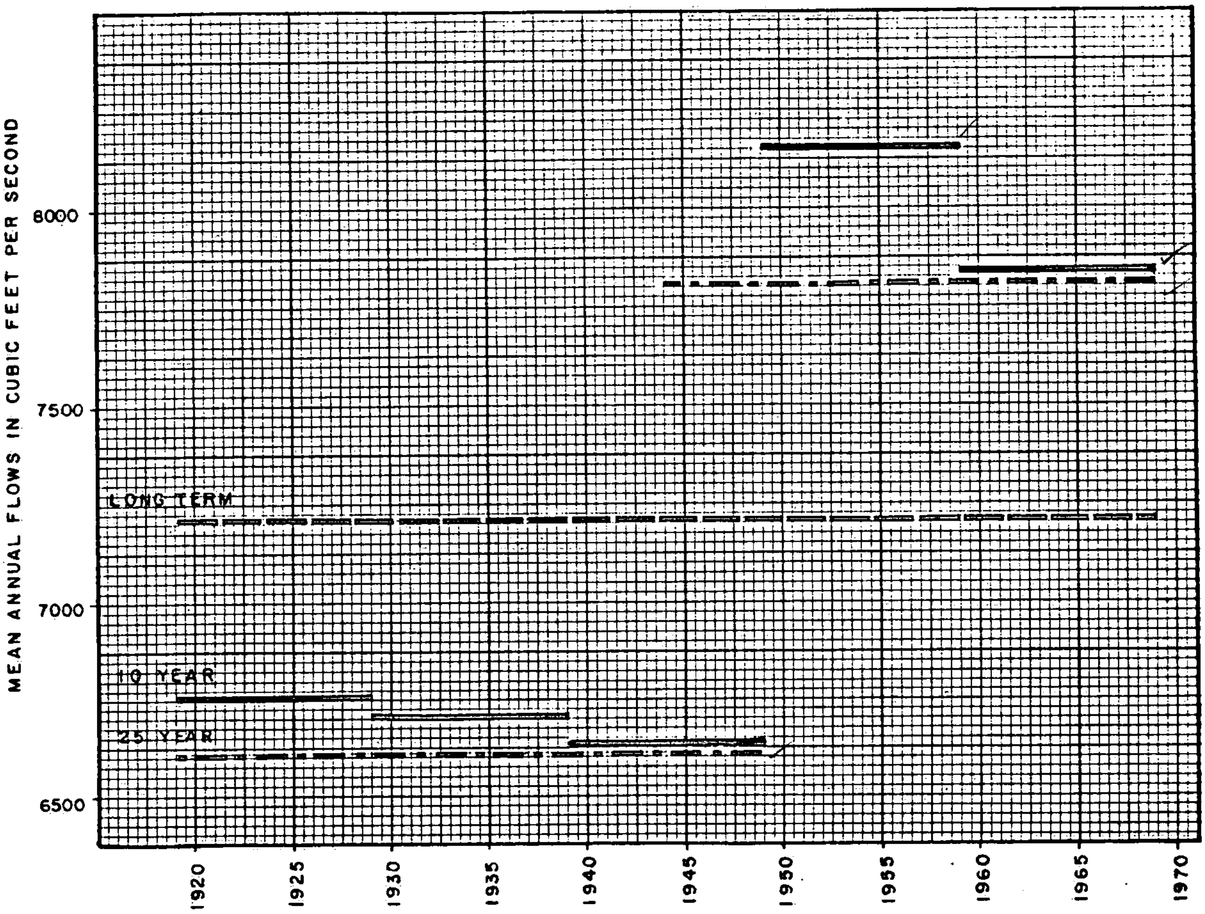


Figure 2. Trends in Mean Annual Flows for Kootenay River at Wardner

TABLE 3. Statistical Significance of Deviations
08NG005 Kootenay River at Wardner

Period	Mean	CV	RAFL	|RAFL-1|	Criterion
1920-1929	6765	0.203	0.9382	0.0618	0.1283
1930-1939	6709	0.193	0.9305	0.0695	0.1204
1940-1949	6629	0.221	0.9194	0.0806	0.1362
1950-1959	8141	0.160	1.1291	0.1291*	0.1211
1960-1969	7808	0.080	1.0829	0.0829*	0.0582
1920-1944	6617	0.198	0.9177	0.0823*	0.0704
1945-1969	7804	0.147	1.0823	0.0823*	0.0616
1920-1969	7210	0.188	-	-	-

* Statistically distinct

In calculating criterion values for statistical similarity of long and short term means, the formula developed in Appendix 2 was used with N the number of observations.

First Serial Correlation Coefficient 0.114

Effective Length of 10 years of Record $10 \times \frac{(1.000 - 0.114)}{(1.000 + 0.114)} = 7.95$

Similarity Criterion 1920-1929 $\frac{1.895 \times 1370}{\sqrt{7.95} \times 7210} = 0.1283$

Precipitation records in southeastern British Columbia were analyzed to see if they explained the patterns and deviations in annual streamflow. Precipitation trends appeared to be similar, low in the 1920's, 1930's, 1940's, high in the 1950's and 1960's (Figure 3 and Table 4). Since Kaslo has a high first serial correlation coefficient, 0.314, records at Newgate from 1920 to 1959 and Creston from 1930 to 1969 were studied also. Their serial correlation coefficients are lower, 0.079 and 0.215 respectively.

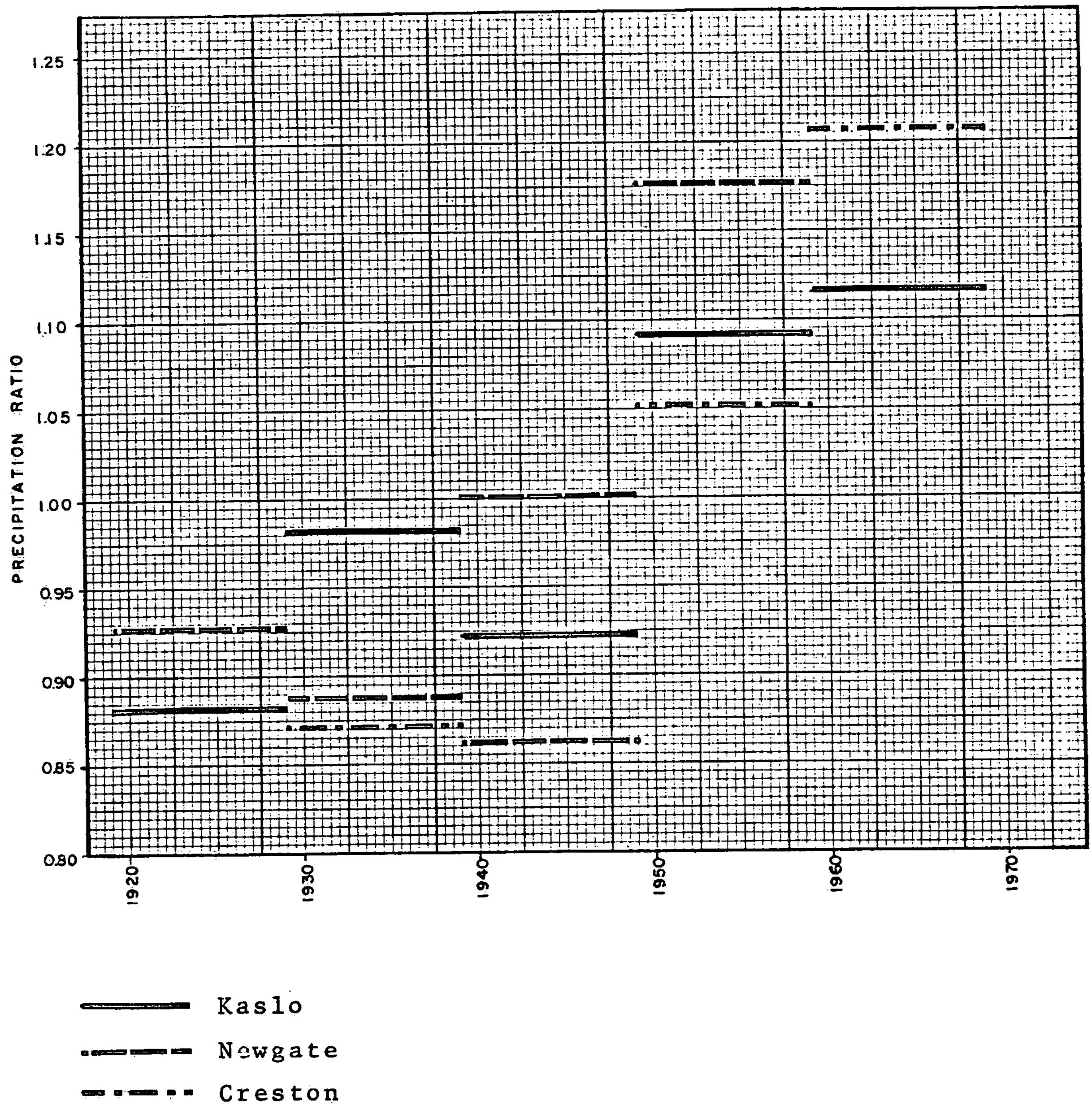


Figure 3. Ratios of short term mean annual precipitation to long term mean annual precipitation for Kaslo, Newgate and Creston

TABLE 4. Statistical Significance of Deviations
Kaslo Precipitation

Period	Mean	CV	RAPRE	|RAPRE-1|	Criterion
1920-1929	26.07	0.137	0.8847	0.1153	0.1155
1930-1939	28.94	0.190	0.9820	0.0180	0.1778
1940-1949	27.14	0.195	0.9211	0.0789	0.1716
1950-1959	32.24	0.152	1.0940	0.0940	0.1579
1960-1969	32.95	0.090	1.1183	0.1183*	0.0956
1920-1944	26.64	0.184	0.9041	0.0959*	0.0816
1945-1969	32.29	0.115	1.0959	0.0959*	0.0617
1920-1969	29.47	0.175	-	-	-

* Statistically distinct

First Serial Correlation Coefficient 0.314

Effective Length of 10 Years of Record becomes 10 x 0.522 = 5

25 Years of Record becomes 25 x 0.522 = 13

Table 5 shows the results of applying the cumulative sum technique to the records of annual flow at the Columbia River at Nicholson and the Kootenay River at Wardner. The number of steps for a significant change is 9 at a 10% significance level and 10 for a 5% level. Thus for the Columbia there is a 95% chance that there were significant changes in annual flows from 1920 to 1945 and from 1945 to 1969. When mean annual flows are considered neither period is statistically distinct, although values are close to the criterion.

For the Kootenay both 25-year and mean annual flows are distinct from long term, but the cumulative sum technique shows no significant change in annual flows, although values are close to critical, i.e. 8 steps instead of 9 or 10.

TABLE 5. Cumulative Sum Results
08NG005 Kootenay River at Wardner and
08NA002 Columbia River at Nicholson

Columbia River				Kootenay River			
Year	Steps*	Year	Steps*	Year	Steps*	Year	Steps*
1920	1	1946	-9	1920	1	1946	-7
1921	2	1947	-8	1921	2	1947	-6
1922	1	1948	-7	1922	1	1948	-5
1923	0	1949	-8	1923	0	1949	-6
1924	-1	1950	-7	1924	-1	1950	-5
1925	0	1951	-6	1925	0	1951	-4
1926	-1	1952	-7	1926	-1	1952	-5
1927	0	1953	-8	1927	0	1953	-6
1928	-1	1954	-7	1928	1	1954	-5
1929	-2	1955	-8	1929	0	1955	-4
1930	-1	1956	-7	1930	-1	1956	-3
1931	-2	1957	-6	1931	-2	1957	-4
1932	-3	1958	-5	1932	-3	1958	-5
1933	-2	1959	-4	1933	-2	1959	-4
1934	-1	1960	-3	1934	-1	1960	-5
1935	-2	1961	-2	1935	-2	1961	-4
1936	-3	1962	-3	1936	-3	1962	-5
1937	-4	1963	-4	1937	-4	1963	-6
1938	-3	1964	-5	1938	-3	1964	-5
1939	-4	1965	-4	1939	-4	1965	-4
1940	-5	1966	-3	1940	-5	1966	-3
1941	-6	1967	-2	1941	-6	1967	-2
1942	-7	1968	-1	1942	-5	1968	-1
1943	-8	1969	0	1943	-6	1969	0
1944	-9			1944	-7		
1945	-10			1945	-8		

*Cumulative steps from median flow (1920-1969)

Columbia River median flow 3860 cfs.
Kootenay River median flow 7395 cfs.

3.2 Quesnel River at Likely

In the central interior flows for the Quesnel River at Likely and Cariboo River below Kangaroo Creek were highly correlated, and had high first serial correlation coefficients. The 1947 record for Quesnel River has been filled in from Cariboo River, and the Cariboo record was extended from the Quesnel record. The results of trend analysis are shown in Figure 4 and Table 6.

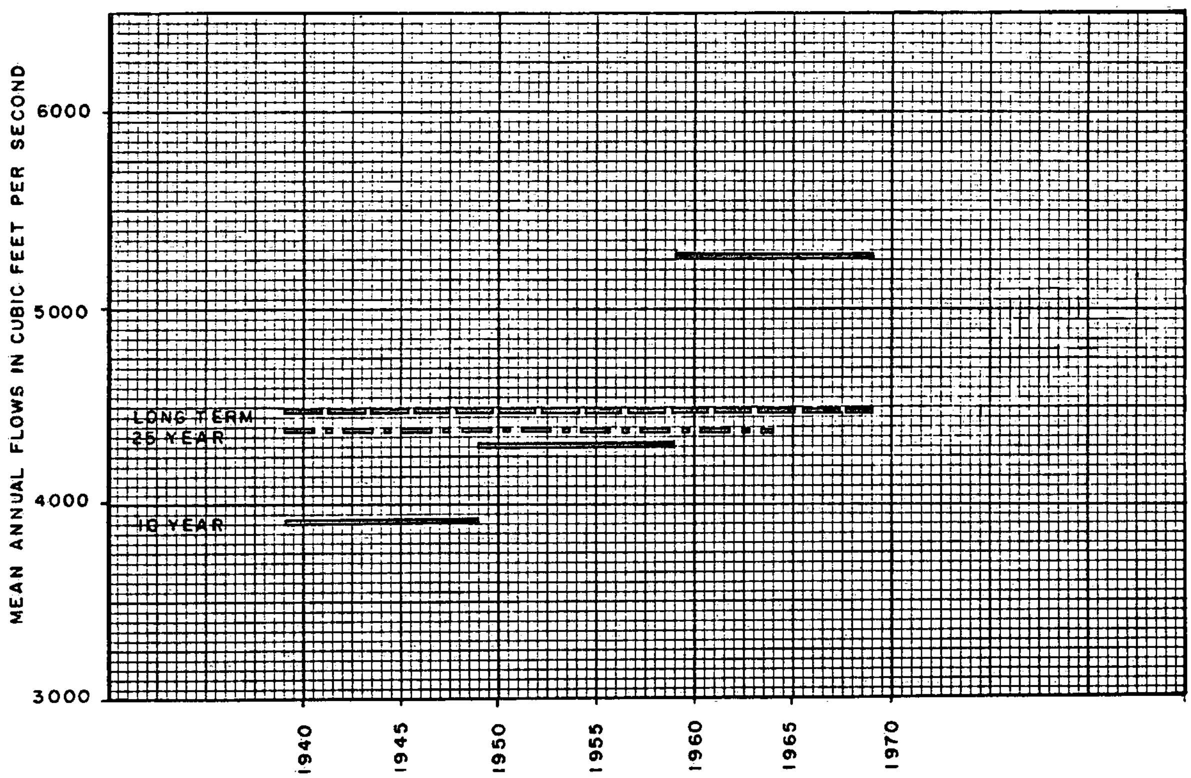


Figure 4. Trends in Mean Annual Flows for Quesnel River at Likely

TABLE 6. Statistical Significance of Deviations
08KH001 Quesnel River at Likely

Period	Mean	CV	RAFL	|RAFL-1|	Criterion
1940-1949	3917	0.159	0.8715	0.1285	0.2509
1950-1959	4307	0.144	0.9583	0.0417	0.2494
1960-1969	5259	0.094	1.1701	0.1701	0.1988
1940-1964	4355	0.183	0.9690	0.0310	0.1410
1940-1969	4494	0.178	-	-	-

First Serial Correlation Coefficient 0.592

Effective Length of 10 Years of Record becomes 2.6
25 Years of Record becomes 6.4

The trends are not in agreement with precipitation at Barkerville, but the 1940-1949 precipitation at Barkerville was high owing to three high years: 1946, 1947, and 1948. Precipitation for December 1948 was estimated.

TABLE 7. Statistical Significance of Deviations
Barkerville Precipitation

Period	Mean	CV	RAPRE	|RAPRE-1|	Criterion
1900-1909	36.11	0.146	0.8651	0.1349	0.1545
1910-1919	38.59	0.146	0.9246	0.0754	0.1641
1920-1929	40.29	0.108	0.9653	0.0347	0.1268
1930-1939	41.78	0.144	1.0010	0.0010	0.1752
1940-1949	50.99	0.265	1.2217	0.2217	0.3940
1950-1959	41.93	0.099	1.0046	0.0046	0.1204
1960-1969	42.48	0.126	1.0177	0.0177	0.1533
1900-1924	38.08	0.140	0.9124	0.0876*	0.0779
1925-1949	45.03	0.235	1.0787	0.0787	0.1544
1900-1969	41.74	0.191	-	-	-

* Statistically distinct

First Serial Correlation Coefficient 0.456

Effective Length of 10 Years of Record becomes 3.7
25 Years of Record becomes 9.3

3.3 Chilliwack River at Vedder Crossing

The trends for Chilliwack at Vedder Crossing flow and Agassiz precipitation are similar, low in the 1920's, 1930's, 1940's and high in the 1950's and 1960's (Tables 8 and 9). However, none of the deviations are statistically distinct. The record for Chilliwack River at Vedder Crossing has been filled in by normal variate correlation with Chilliwack River at Outlet of Chilliwack Lake. The effectiveness of this procedure can be seen in the increase in information content of the mean after the record extension.

TABLE 8. Statistical Significance of Deviations
08MH001 Chilliwack River at Vedder Crossing

Period	Mean	CV	RAFL	|RAFL-1|	Criterion
1920-1929	2258	0.171	0.9578	0.0422	0.1351
1930-1939	2279	0.179	0.9667	0.0333	0.1427
1940-1949	2182	0.208	0.9255	0.0745	0.1588
1950-1959	2649	0.245	1.1236	0.1236	0.2271
1960-1969	2420	0.135	1.0265	0.0265	0.1143
1920-1944	2187	0.184	0.9277	0.0723	0.1408
1945-1969	2528	0.189	1.0723	0.0723	0.1672
1920-1969	2358	0.199	-	-	-

First Serial Correlation Coefficient 0.253

Effective Length of Record $50 \times \frac{(1 - 0.253)}{(1 + 0.253)} = 50 \times 0.596 = 29.8$

Information Content of Mean

After Record Extension: $\frac{29.8}{(0.199 \times 2357)^2} = 0.000135$

Before Record Extension: $\frac{21.6}{471^2} = 0.000097$

TABLE 9. Statistical Significance of Deviations
Agassiz Precipitation

Period	Mean	CV	RAPRE	|RAPRE-1|	Criterion
1890-1899	65.84	0.150	1.0303	0.0303	0.1418
1900-1909	58.60	0.119	0.9170	0.0830	0.1001
1910-1919	68.97	0.158	1.0792	0.0792	0.1564
1920-1929	60.31	0.296	0.9437	0.0563	0.2563
1930-1939	63.23	0.247	0.9894	0.0106	0.2242
1940-1949	59.23	0.132	0.9269	0.0731	0.1122
1950-1959	67.96	0.210	1.0635	0.0635	0.2049
1960-1969	67.11	0.102	1.0501	0.0501	0.0983
1890-1914	63.12	0.156	0.9876	0.0124	0.0747
1915-1939	63.66	0.244	0.9962	0.0038	0.1179
1940-1964	63.92	0.172	1.0003	0.0003	0.0834
1890-1969	63.91	0.189	-	-	-

First Serial Correlation Coefficient 0.299

Effective Length of 10 Years of Record becomes 5.4

25 Years of Record becomes 13.5

4. CONCLUSIONS AND RECOMMENDATIONS

No statistically significant province-wide trends were observed. This lack of significant trends was attributable to sparse data and a high noise floor. Only a few of the short term fixed time span sample averages were statistically distinct from the long term averages. In the southeastern part of the province where data are most plentiful, mean annual flows were in most cases below long term average in the 1920's, 1930's and 1940's and above average in the 1950's and 1960's. The mean precipitation for that area exhibited a similar pattern.

Agassiz mean annual precipitation showed a pattern similar to that of stations in southeastern British Columbia except that there were no statistically distinct periods. If the records are compatible the 1910's should have been a high flow decade.

The first serial correlation coefficients for annual flows and annual precipitations were surprisingly high. High correlation coefficients would be expected for streams such as Quesnel River, which drain large lake systems. These high serial correlation coefficients decrease the information content of records.

In light of these results stations are required in northern and central British Columbia in order to trace long term hydrologic changes. These stations should be located in watersheds draining approximately 300 to 600 square miles without major lakes or storage areas. This precaution will reduce the chances of sampling isolated phenomena or having small changes in the basin result in a large effect on basin response.

Whether regional studies should have a common base period does not appear to have a clear answer, as no province-wide trends could be found. Certainly most of the records are taken in the 1950's, 1960's and 1970's, so this will tend to bias the results if these were indeed periods of higher than average flow. If a common time base period were accepted then results would be applicable only to that period.

REFERENCES

1. International Symposium on Uncertainties in Hydrologic and Water Resource Systems, Vol. 1, pages 245-252. Effect of Length of Records of Monthly Flows on the First Serial Correlation Coefficient.

   University of Arizona, Tucson, Arizona, 1972.

2. McGilchrist, C.A. and K.D. Woodyer
   Note on a Distribution-free CUSUM Technique.

   Technometrics, Vol. 17, No. 3, page 321, 1975.

3. Water Survey of Canada
   Historical Streamflow Summary British Columbia to 1973.

   Inland Waters Directorate, Water Resources Branch, Ottawa, 1974.

4. Yevjevich, V.
   Probability and Statistics in Hydrology.

   Water Resources Publications, Fort Collins, Colorado, 1972.

APPENDIX 1. Statistical Terms and Techniques

1. Extension of Records

Since continuous records were required for the examination of trends, attempts were made to fill by correlation the gaps in monthly records. To remove the periodic component each monthly flow for a given station was reduced to a normal random variate (NRV) by subtracting from the monthly flow the mean monthly flow and dividing the remainder by the standard deviation (Reference 1).

For example for the Jth October in a station's record

$$NRV = \frac{FLOW(J) - MEAN\ FLOW\ IN\ OCTOBER}{STANDARD\ DEVIATION\ OF\ FLOW\ IN\ OCTOBER}$$

To remove the sequential component a simple Markov model was assumed, that, is the flow in any given month is related only to the flow in the previous month so only the lag one serial correlation R(1) need be considered. The residual or quantity remaining after the periodic sequential components have been removed is:

$$RES(K) = NRV(K) - R(1) \times NRV(K - 1)$$

where K = 2, up to the total number of months in the station's record.

Simple linear regression equations were developed for sequences or residuals using the sequence from the station with missing record as the dependent variable.

Missing records were filled by reversing this procedure. The filling in of records was judged to be a success if the information content of the series of annual flows was greater after the extension than before the extension.

APPENDIX 1. (continued)

Extension of Record by Correlation of Normal Variate Monthly Flows - Summary of Statistics

Stations	R(1)	R.C. Intercept	& Slope	R^2	S.E.E.
Bull River near Wardner	0.607				
with		-0.000397	0.934	0.791	0.356
Kootenay River at Wardner	0.653				
Cariboo River below Kangaroo Creek	0.477				
with		0.0225	0.845	0.586	0.539
Quesnel River at Likely	0.606				
Kootenay River at Wardner	0.653				
with		-0.000397	0.956	0.920	0.210
Kootenay River at Newgate	0.650				
Columbia River at Nicholson	0.640				
with		0.00114	0.648	0.410	0.579
Kootenay River at Newgate	0.650				
Quesnel River at Likely	0.687				
with		-0.00317	0.457	0.239	0.616
Columbia River at Nicholson	0.638				
Adams River near Squilax	0.551				
with		0.00138	0.455	0.219	0.725
Columbia River at Nicholson	0.512				
Chilliwack River at Vedder Crossing	0.425				
with		0.000734	0.918	0.858	0.335
Chilliwack River at Outlet of Chilliwack Lake	0.409				

R(1) - First Serial Correlation Coefficient
R.C. - Linear Regression Coefficients; intercept and slope
R^2 - Coefficient of Linear Regression; sum squared regression/ sum squared total
S.E.E. - Standard Error of Estimate; square root of sum squared residual divided by its degrees of freedom

APPENDIX 1. (continued)

2. Serial Correlation

In a series of flows such as monthly flows or annual flows serial correlation measures the amount by which one flow depends on a previous flow.

For lag I, the serial correlation coefficient is given by:

$$R(I) = \frac{\sum_{J=1}^{N} (FLOW(J + I) - MEAN\ FLOW)(FLOW(J) - MEAN\ FLOW)}{N \times VARIANCE\ OF\ FLOW}$$

3. Information Content of the Mean

$I = \frac{N}{\sigma^2}$ where N is the number of observations and σ^2 is the variance of the observations; but if the observations are serially correlated, the effective number Ne should be used instead of N (Reference 4, page 188).

4. Effective Number of Observations, Ne

can be approximated by $Ne \simeq N \times \frac{(1 - R(1))}{(1 + R(1))}$

where R(1) is the first serial correlation coefficient.

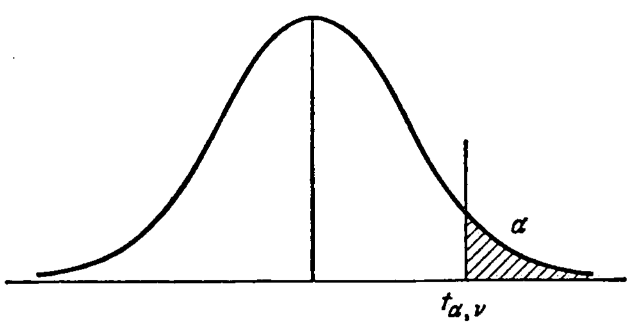
APPENDIX 2. Development of Criterion for Statistical Similarity

By the Central Limit Theorem, if a random variable x has a distribution with mean μ and standard deviation s for which the first two moments exist, then $t = (\bar{x} - \mu) \times \frac{\sqrt{N}}{s}$ has a distribution which approaches standard normal distribution as N, the sample size, becomes infinite. A standard normal distribution is a normal distribution with mean = 0 and standard deviation = 1.

The following statistical criterion is developed under the assumption that:

1. Flow is a random variable with a distribution for which the first two moments exist.
2. The long term average flow and standard deviation of the sequence of annual flows approximate μ and s.

The t statistic has two parameters, α and ν. ν, the degrees of freedom equals N - 1, where N is the number of observations. α provides a region or an estimate of precision, that is $\int_{t_{\alpha,\nu}}^{\infty} f(t)\,dt = \alpha$ where f(t) is the t distribution.



APPENDIX 2. (continued)

1) $\alpha = 0.05$ is used to take into consideration both tails of the distribution.

2) s is the standard deviation of the short sample. This is done to allow for the variability of a particular sample.

$$\left|\frac{\bar{x} - \mu}{s}\right| \times \sqrt{Ne} \leq t_{\nu, 0.05}, \quad \nu = Ne - 1$$

$$\left|\frac{\frac{\bar{x}}{\mu} - 1}{\frac{s}{\mu}}\right| \times \sqrt{Ne} \leq t_{\nu, 0.05}$$

$$\left|\frac{\bar{x}}{\mu} - 1\right| \leq \frac{t_{\nu, 0.05}}{\sqrt{Ne}} \times \frac{s}{\mu}$$

$$|RAFL - 1| \leq \frac{t_{\nu, 0.05}}{\sqrt{Ne}} \times \frac{s}{\mu}$$

If $|RAFL - 1|$ is greater than $\frac{t_{\nu, 0.05}}{\sqrt{Ne}} \times \frac{s}{\mu}$ then there is a 90% chance that $\bar{x}$ is statistically significant from μ.

APPENDIX 3. Trends and Deviations for Mean Annual Flows and Mean Annual Precipitations

As was stated in Section 2.3.2, other sampling methods were employed in the study of maximum deviations of short term means from long term means. These methods were:

Moving Average Sampling

One of these sampling methods was moving average, for example, for 10-year samples the averages over the spans 1930-1939, 1931-1940, 1932-1941, etc. were considered. The largest deviations from the long term average both positive and negative were noted.

Random Sampling

Flow sequences were selected randomly with replacement from the long term record. For example, for a 10-year sequence from 40 years of record 10 random numbers from 1 to 40 were generated from a uniform distribution and the flows corresponding to these numbers were averaged. This procedure was repeated thirty times for each sequence length. The term "with replacement" refers to the fact that repeats of the numbers between 1 and 40 were possible.

Extreme Sampling

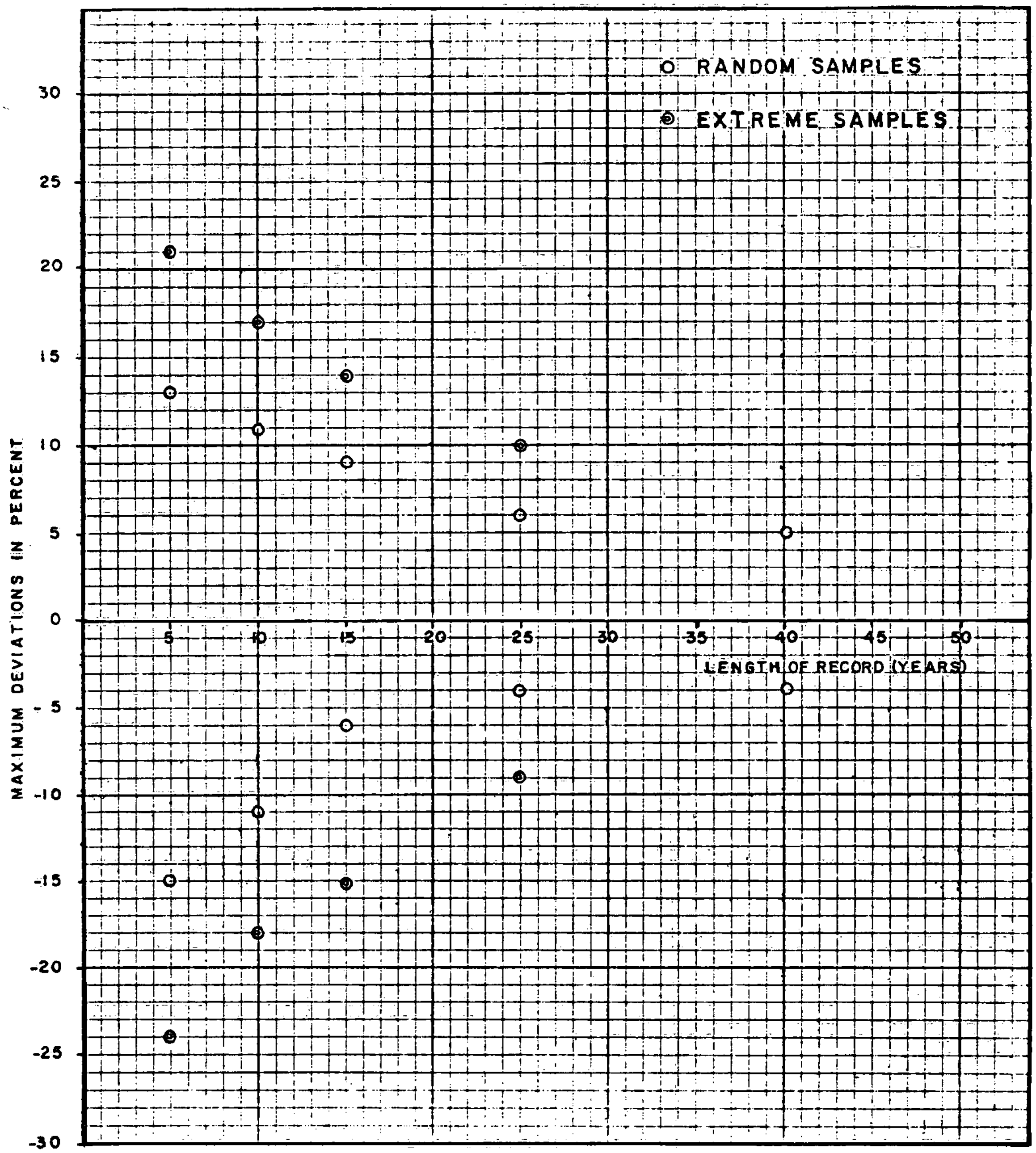
To gain an indication of the maximum possible deviations for the recorded sequences of flows extreme values were averaged. For example, the 10 highest flows were averaged and the difference between that average and the long term average was taken as an estimate of maximum positive deviation for 10 years of record.

APPENDIX 3. (continued)

08LD001 Adams River near Squilax

Coefficient of Variation 0.136

Long Term Mean Flow 2490 cfs.



Maximum Deviation as a Function of Sample Length for Adams River near Squilax

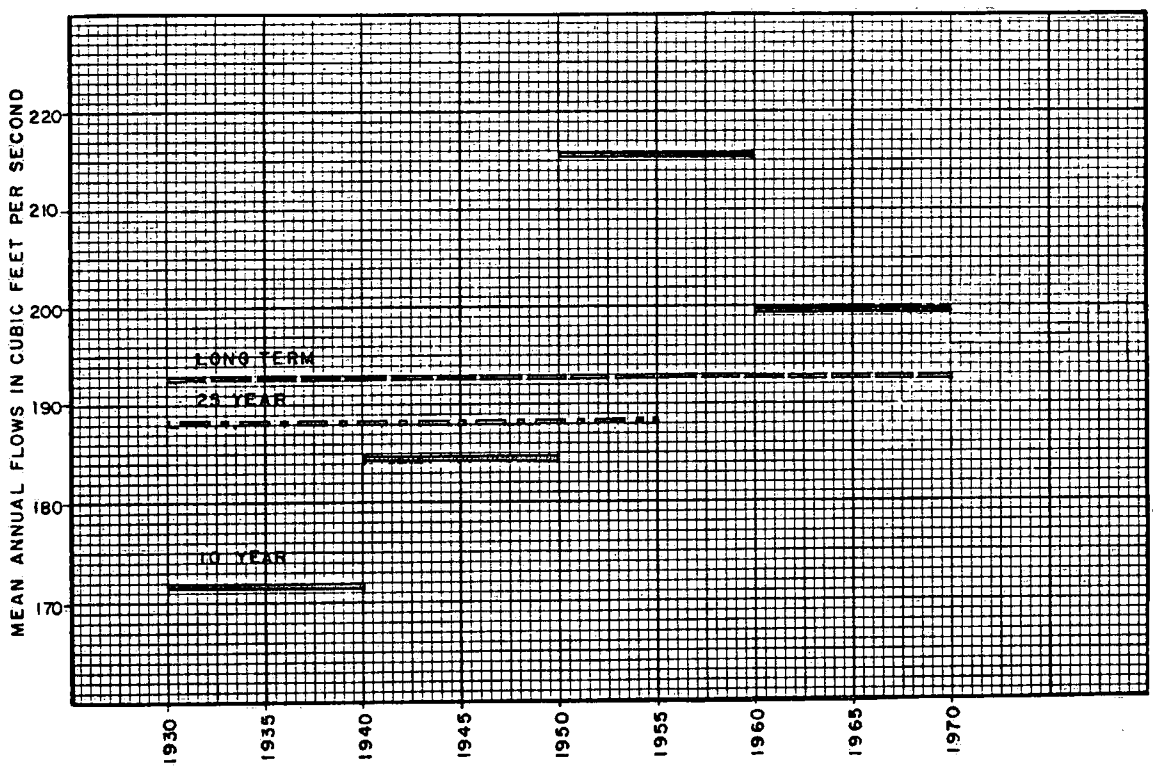
APPENDIX 3. (continued)

Statistical Significance of Deviations

08NH032 Boundary Creek near Porthill

Period	Mean	CV	RAFL	|RAFL-1|	Criterion
1931-1940	172	0.289	0.8964	0.1036	0.1940
1941-1950	185	0.271	0.9651	0.0349	0.1956
1951-1960	216	0.164	1.1260	0.1260	0.1382
1961-1970	199	0.150	1.0354	0.0354	0.1165
1931-1955	188	0.262	0.9798	0.0202	0.1092
1931-1970	193	0.227	-	-	-

First Serial Correlation Coefficient 0.201



Trends in Mean Annual Flows for Boundary Creek near Porthill

APPENDIX 3. (continued)

Statistical Significance of Deviations
08NG002 Bull River near Wardner

Period	Mean	CV	RAFL	|RAFL-1|	Criterion
1930-1939	1029	0.256	0.8947	0.1053	0.1664
1940-1949	1027	0.226	0.8930	0.1070	0.1466
1950-1959	1295	0.180	1.1263	0.1263	0.1472
1960-1969	1249	0.092	1.0860	0.0860*	0.0725
1930-1954	1088	0.241	0.9464	0.0536	0.0938
1930-1969	1150	0.212	-	-	-

* Statistically distinct

First Serial Coefficient 0.166

Statistical Significance of Deviations
08MH005 Fraser River at Hope

Period	Mean	CV	RAFL	|RAFL-1|	Criterion
1920-1929	93900	0.147	0.9758	0.0242	0.2267
1930-1939	94100	0.142	0.9774	0.0226	0.2195
1940-1949	88000	0.126	0.9141	0.0859	0.1821
1950-1959	97900	0.102	1.0168	0.0168	0.1640
1960-1969	107400	0.077	1.1159	0.1159	0.1358
1920-1944	91900	0.138	0.9547	0.0453	0.0839
1945-1969	100600	0.114	1.0453	0.0453	0.0759
1920-1969	96200	0.133	-	-	-

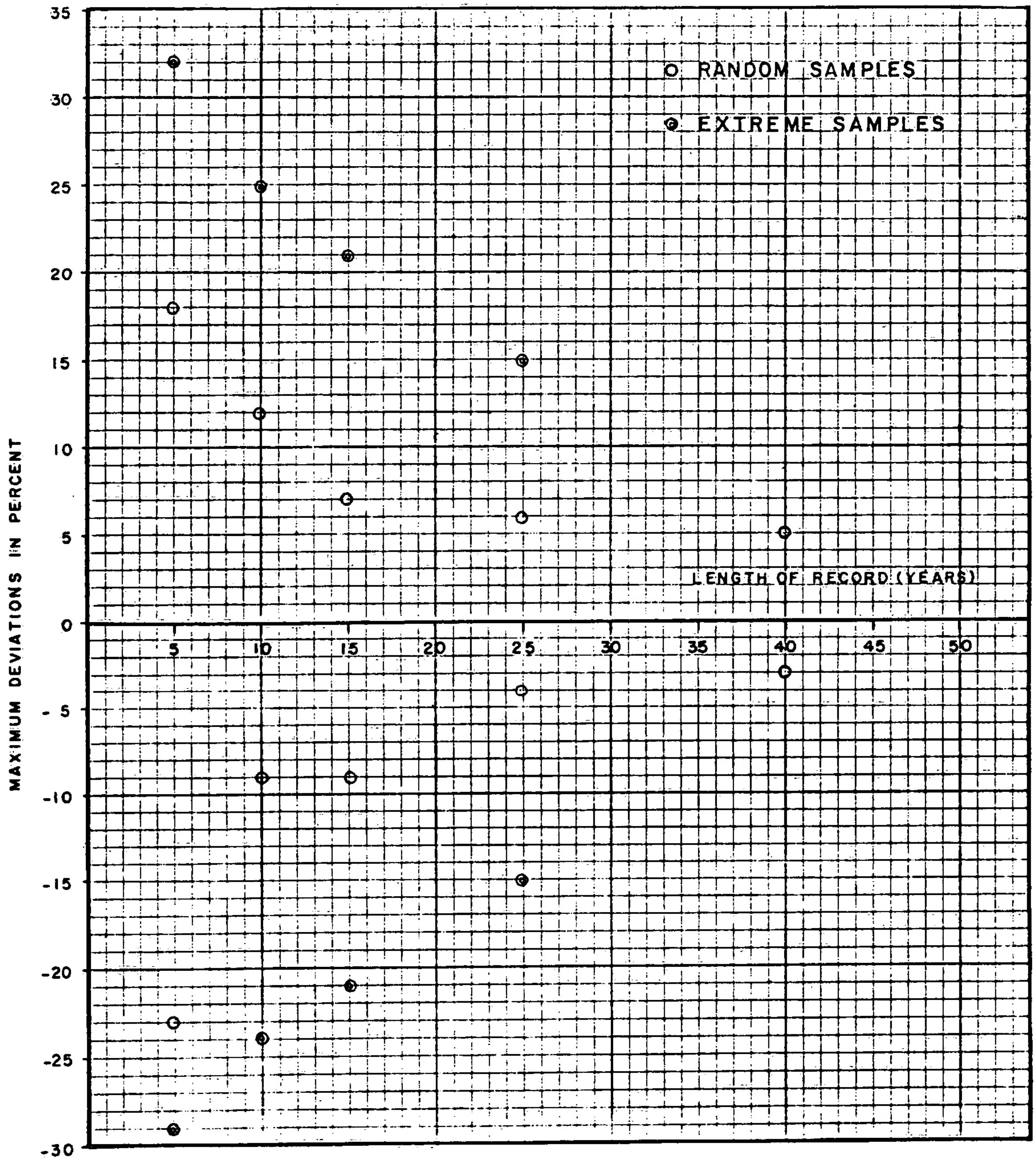
First Serial Correlation Coefficient 0.491

APPENDIX 3. (continued)

08GA010 Capilano River above Intake

Coefficient of Variation 0.175

Long Term Mean Flow 712 cfs.



Maximum Deviation as a Function of Sample Length for Capilano River above Intake

APPENDIX 3. (continued)

Statistical Significance of Deviations
08KH003 Cariboo River below Kangaroo Creek

Period	Mean	CV	RAFL	|RAFL-1|	Criterion
1940-1949	3013	0.132	0.9192	0.0808	0.1969
1950-1959	3139	0.095	0.9576	0.0424	0.1476
1960-1969	3682	0.080	1.1232	0.1232	0.1458
1940-1964	3186	0.128	0.9719	0.0281	0.0828
1940-1969	3278	0.133	-	-	-

First Serial Correlation Coefficient 0.511

For the period 1940-1969:

Information Content of the Mean before extension(24 yrs) 0.000035

Information Content of the Mean after extension (30 yrs) 0.000050

Statistical Significance of Deviations
08NA002 Columbia River at Nicholson

Period	Mean	CV	RAFL	|RAFL-1|	Criterion
1920-1929	3670	0.121	0.9650	0.0350	0.0845
1930-1939	3745	0.132	0.9847	0.0153	0.0941
1940-1949	3347	0.163	0.8801	0.1199*	0.1039
1950-1959	4172	0.121	1.0970	0.0970*	0.0961
1960-1969	4081	0.081	1.0731	0.0731*	0.0629
1920-1944	3610	0.134	0.9493	0.0507	0.0521
1945-1969	3996	0.134	1.0507	0.0507	0.0577
1920-1969	3803	0.142	-	-	-

* Statistically distinct

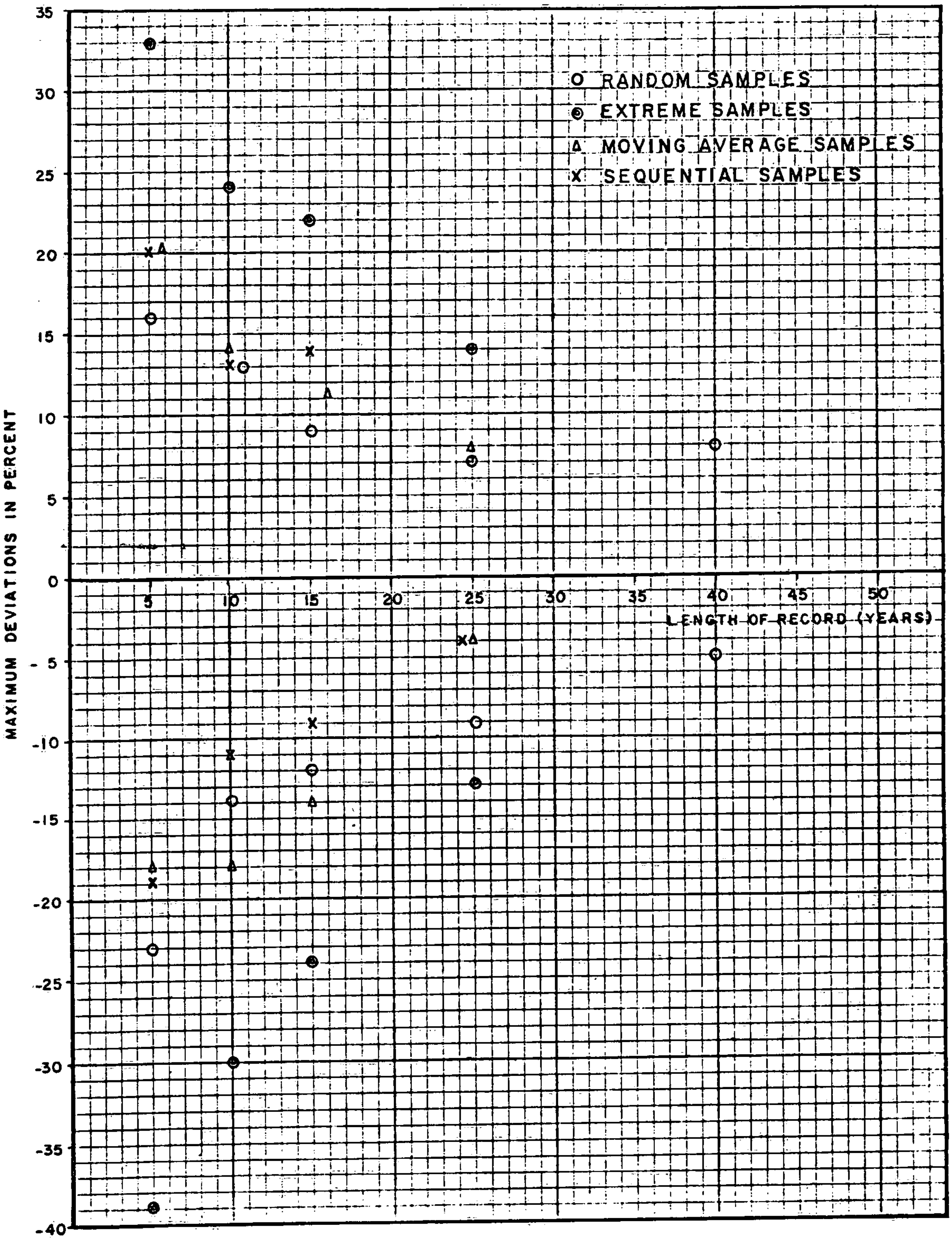
First Serial Correlation Coefficient 0.163

APPENDIX 3. (continued)

08NK005 Elk River at Phillips Bridge

Coefficient of Variation 0.225

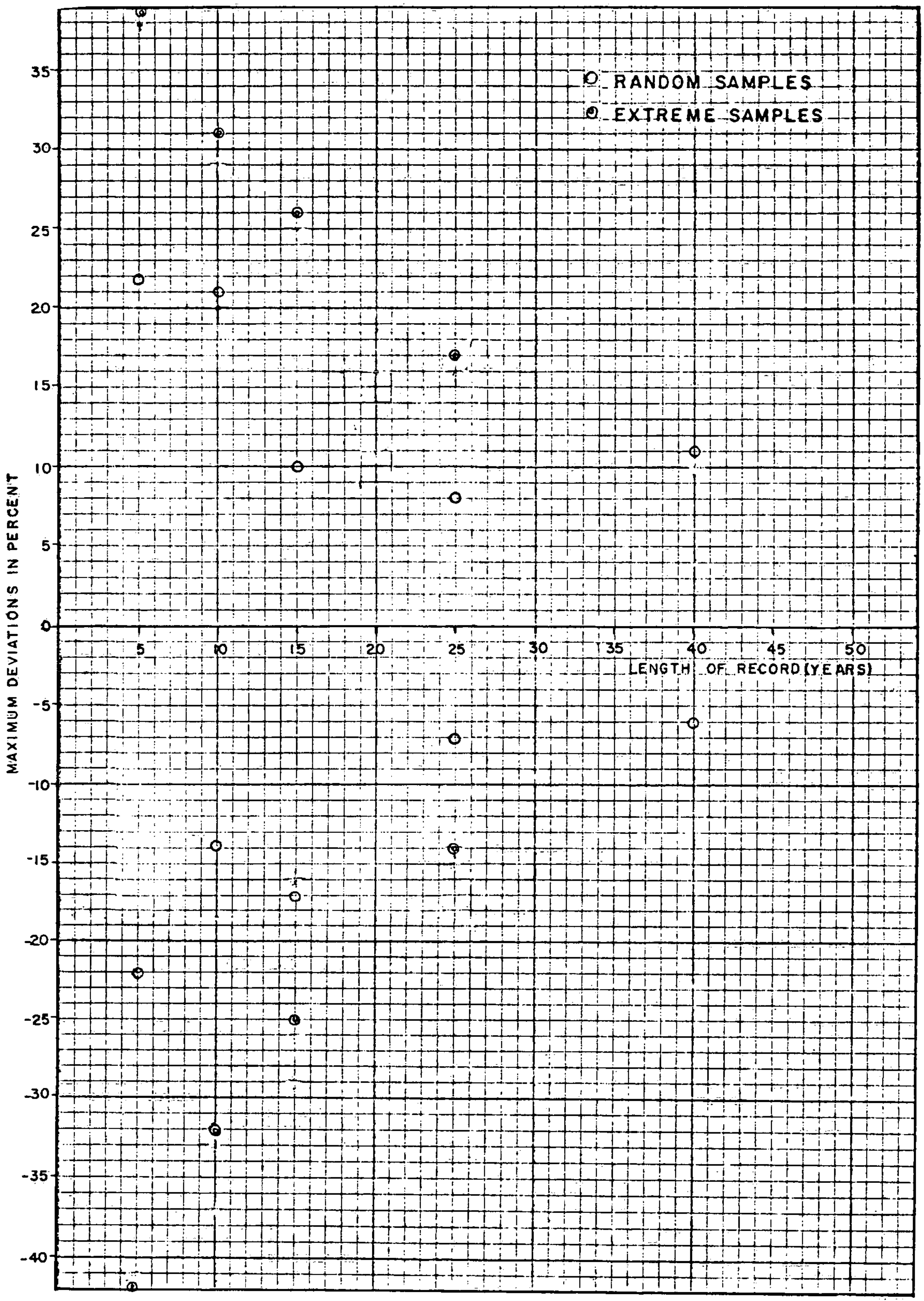
Long Term Mean Flow 2767 cfs. Regulated Flow



Maximum Deviation as a Function of Sample Length for Elk River at Phillips Bridge

APPENDIX 3. (continued)

08NH004 Goat River near Erickson
Coefficient of Variation 0.245
Long Term Mean Flow 946 cfs. Regulated flow



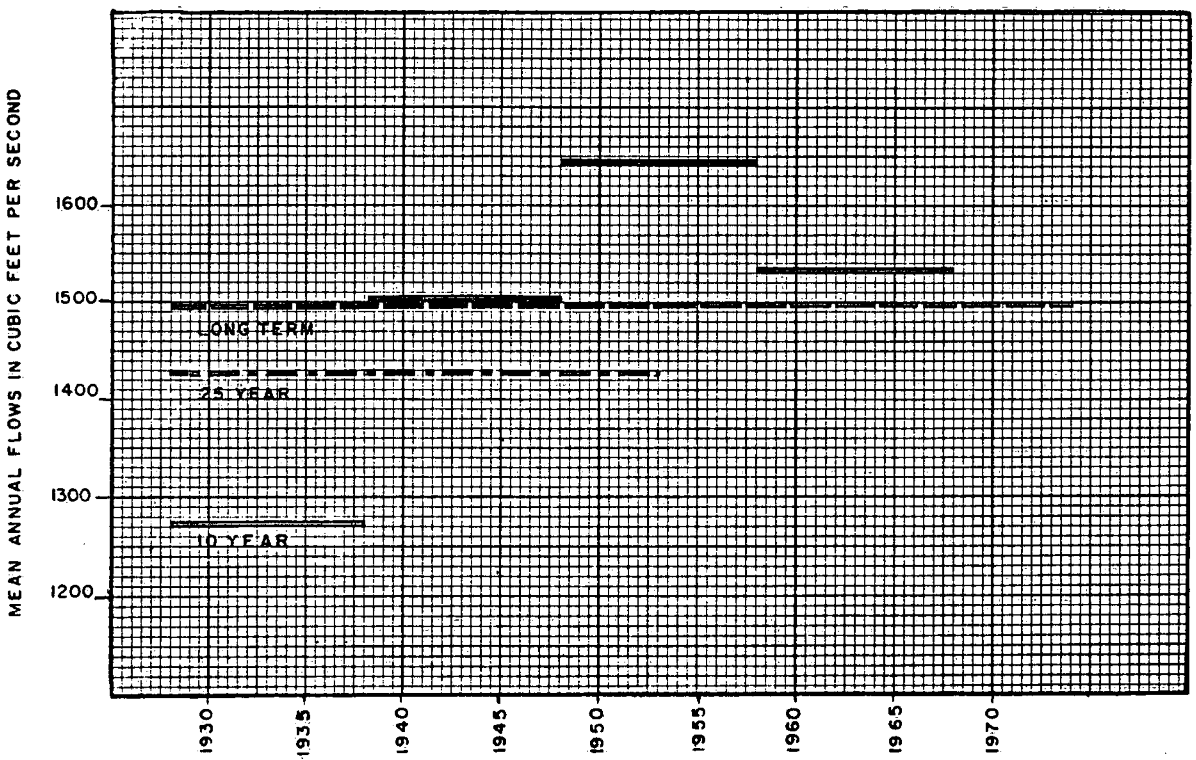
Maximum Deviation as a Function of Sample Length for Goat River near Erickson

APPENDIX 3. (continued)

Statistical Significance of Deviations
08NN013 Kettle River near Ferry

Period	Mean	CV	RAFL	|RAFL-1|	Criterion
1929-1938	1275	0.335	0.8562	0.1438	0.2334
1939-1948	1505	0.257	1.0107	0.0107	0.2114
1949-1958	1646	0.137	1.1054	0.1054	0.1232
1959-1968	1531	0.199	1.0282	0.0282	0.1665
1929-1953	1429	0.272	0.9597	0.0403	0.1174
1929-1968	1489	0.240	-	-	-

First Serial Correlation Coefficient 0.004



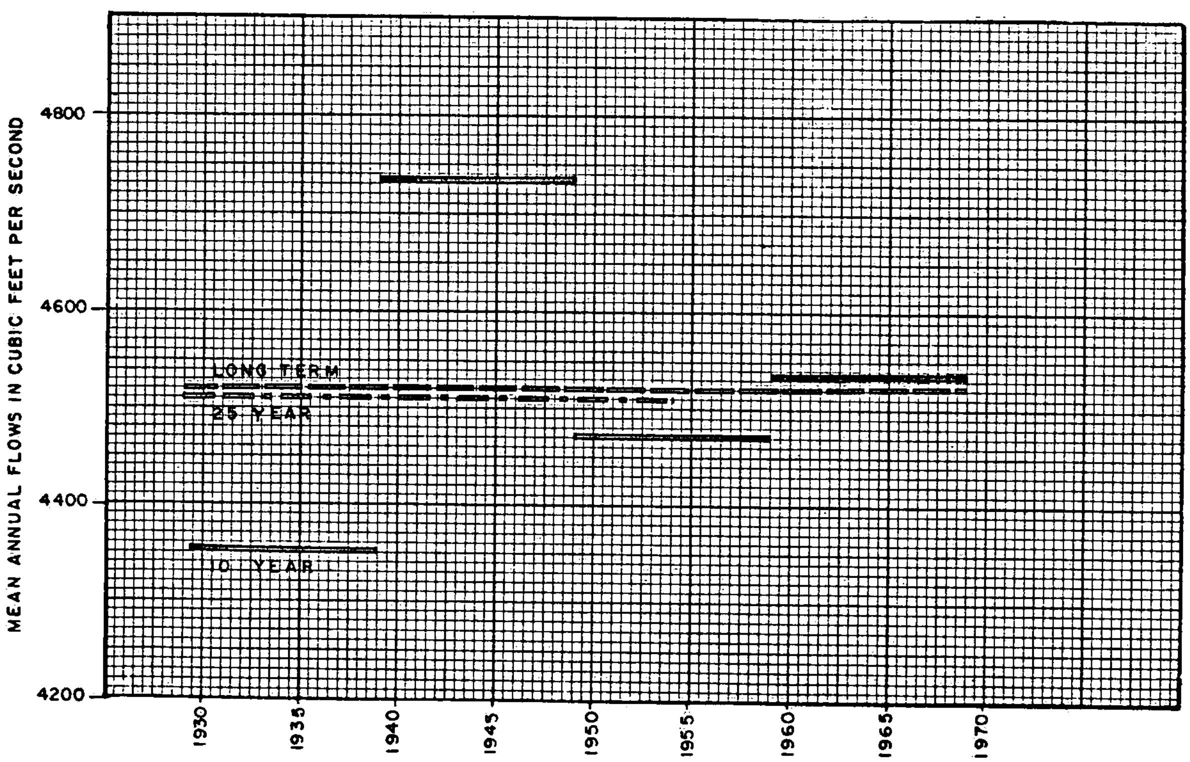
Trends in Mean Annual Flows for Kettle River near Ferry

APPENDIX 3. (Continued)

Statistical Significance of Deviations
08MG005 Lillooet River near Pemberton

Period	Mean	CV	RAFL	|RAFL-1|	Criterion
1930-1939	4351	0.086	0.9620	0.0380	0.0519
1940-1949	4736	0.116	1.0471	0.0471	0.0762
1950-1959	4471	0.119	0.9885	0.0115	0.0738
1960-1969	4535	0.105	1.0027	0.0027	0.0660
1930-1954	4512	0.102	0.9975	0.0025	0.0373
1930-1969	4523	0.108	-	-	-

First Serial Correlation Coefficient 0.065



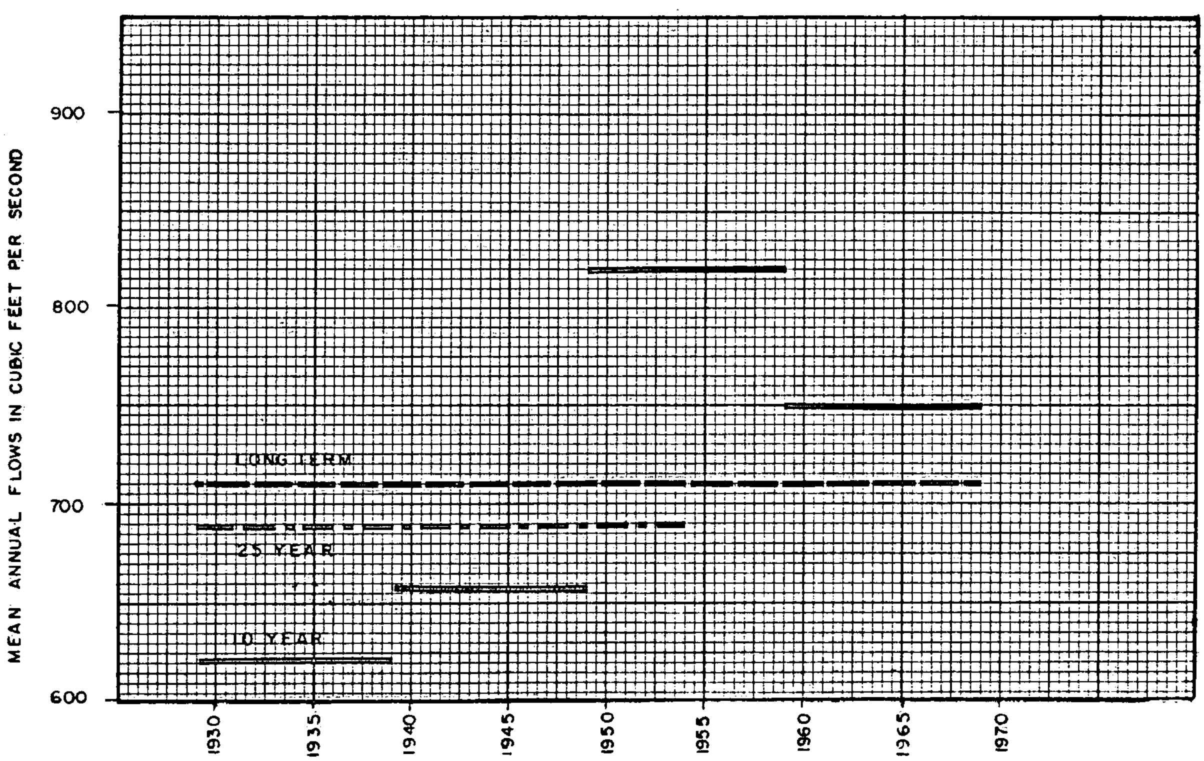
Trends in Mean Annual Flows for Lillooet River near Pemberton

APPENDIX 3. (continued)

Statistical Significance of Deviations
08NH006 Moyie River at Eastport

Period	Mean	CV	RAFL	|RAFL-1|	Criterion
1930-1939	621	0.312	0.8715	0.1285	0.2155
1940-1949	658	0.332	0.9246	0.0754	0.2429
1950-1959	820	0.239	1.1517	0.1517	0.2179
1960-1969	750	0.145	1.0538	0.0538	0.1209
1930-1954	687	0.317	0.9653	0.0347	0.1332
1945-1969	780	0.200	1.0948	0.0948	0.1097
1930-1969	712	0.272	-	-	-

First Serial Correlation Coefficient 0.214



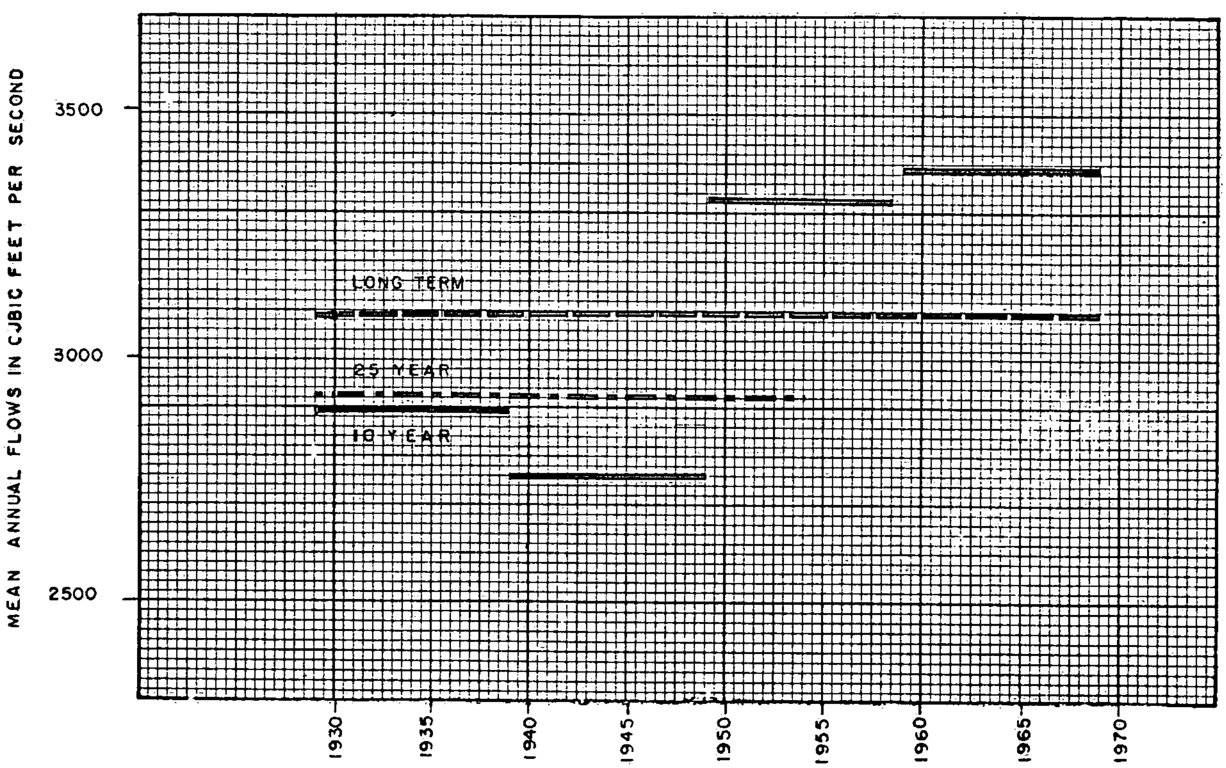
Trends in Mean Annual Flows for Moyie River at Eastport

APPENDIX 3. (continued)

Statistical Significance of Deviations
08NJ013 Slocan River near Crescent Valley

Period	Mean	CV	RAFL	|RAFL-1|	Criterion
1930-1939	2899	0.197	0.9367	0.0633	0.2063
1940-1949	2761	0.155	0.8921	0.1079	0.1546
1950-1959	3328	0.132	1.0753	0.0753	0.1587
1960-1969	3390	0.081	1.0953	0.0953	0.0992
1930-1954	2922	0.175	0.9442	0.0558	0.0899
1930-1969	3094	0.163	-	-	-

First Serial Correlation Coefficient 0.386



Trends in Mean Annual Flows for Slocan River near Crescent Valley

APPENDIX 3. (continued)

Statistical Significance of Deviations
Creston Precipitation

Period	Mean	CV	RAPRE	|RAPRE-1|	Criterion
1930-1939	17.56	0.200	0.8748	0.1252	0.1387
1940-1949	17.38	0.212	0.8661	0.1339	0.1455
1950-1959	21.13	0.200	1.0528	0.0528	0.1669
1960-1969	24.21	0.159	1.2063	0.2063*	0.1520
1930-1954	18.12	0.212	0.9029	0.0971*	0.0834
1930-1969	20.07	0.232	-	-	-

* Statistically distinct
First Serial Correlation Coefficient 0.215

Statistical Significance of Deviations
Deer Park Precipitation

Period	Mean	CV	RAPRE	|RAPRE-1|	Criterion
1930-1939	16.09	0.150	0.8832	0.1168*	0.0892
1940-1949	16.88	0.203	0.9264	0.0736	0.1267
1950-1959	19.60	0.162	1.0757	0.0757	0.1174
1960-1969	20.31	0.119	1.1148	0.1148*	0.0894
1930-1954	16.88	0.184	0.9264	0.0736*	0.0663
1930-1969	18.22	0.182	-	-	-

* Statistically distinct
First Serial Correlation Coefficient 0.117

APPENDIX 3. (continued)

Statistical Significance of Deviations
Fernie Precipitations

Period	Mean	CV	RAPRE	|RAPRE-1|	Criterion
1914-1923	37.55	0.123	0.9373	0.0627	0.0921
1924-1933	41.06	0.231	1.0248	0.0248	0.1892
1934-1943	38.10	0.096	0.9509	0.0491	0.0729
1944-1953	42.08	0.214	1.0505	0.0505	0.1797
1914-1938	39.05	0.177	0.9747	0.0253	0.0872
1914-1959	40.06	0.178	-	-	-

First Serial Correlation Coefficient 0.223

Statistical Significance of Deviations
Newgate Precipitation

Period	Mean	CV	RAPRE	|RAPRE-1|	Criterion
1920-1929	13.51	0.274	0.9297	0.0703	0.1621
1930-1939	12.91	0.179	0.8880	0.1120*	0.1012
1940-1949	14.62	0.188	1.0060	0.0060	0.1204
1950-1959	17.10	0.277	1.1763	0.1763	0.2075
1920-1944	13.35	0.234	0.9188	0.0812*	0.0802
1920-1959	14.53	0.257	-	-	-

* Statistically distinct

First Serial Correlation Coefficient 0.079

APPENDIX 3. (continued)

Statistical Significance of Deviations
Pemberton Meadows Precipitation

Period	Mean	CV	RAPRE	|RAPRE-1|	Criterion
1913-1922	37.51	0.217	1.0144	0.0144	0.1828
1923-1932	32.54	0.150	0.8798	0.1212*	0.1096
1933-1942	37.49	0.175	1.0137	0.0137	0.1473
1943-1952	40.22	0.150	1.0875	0.0875	0.1355
1913-1937	35.60	0.189	0.9626	0.0374	0.0835
1913-1961	36.98	0.183	-	-	-

* Statistically distinct
First Serial Correlation Coefficient 0.259

Statistical Significance of Deviations
Vernon Coldstream Precipitation

Period	Mean	CV	RAPRE	|RAPRE-1|	Criterion
1910-1919	14.97	0.103	0.9867	0.0133	0.0591
1920-1929	14.73	0.210	0.9711	0.0289	0.1186
1930-1939	14.93	0.180	0.9842	0.0158	0.1030
1940-1949	15.49	0.161	1.0210	0.0210	0.0956
1950-1959	15.64	0.180	1.0309	0.0309	0.1080
1960-1969	15.26	0.132	1.0060	0.0060	0.0772
1910-1934	14.81	0.164	0.9763	0.0237	0.0550
1935-1959	15.49	0.166	1.0213	0.0213	0.0582
1910-1969	15.17	0.159	-	-	-

First Serial Correlation Coefficient 0.004