VOLUMETRIC FORECASTS OF THE SNOW-MELT FLOODS

OF

THE LAKE ST. JOHN WATERSHED

by

A. N. ANDREW

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Abstract

A method of computing the accumulated winter precipitation on the basis of precipitation station data is presented. The relation between the April 1st precipitation accumulation and the spring flood volume is significant at the 1% level while the relation between the data from late March snow surveys and the spring flood volume is not significant at the 5% level. The water available to influence spring floods, as measured by the precipitation station method, and a measure of ground water storage capacity are used in a multiple regression analysis to prepare equations for use in estimating the spring flood volume. Individual equations are presented for the April 1st, March 1st and February 1st forecasts. The important statistics of each equation are summarized below.

Forecast Date	Equation	Multiple Correlation Coefficient R.	Standard Error of Estimate $S_{1.23--n}$
April 1st	$X'_1 = 1.03 + 0.696X_{2p} + 0.072X_3$	0.841	0.77
March 1st	$X'_1 = 1.81 + 0.750X_{2pm} + 0.083X_3$	0.850	0.75
Feb. 1st	$X'_1 = 2.30 + 1.053X_{2pf} + 0.046X_{3f}$	0.777	0.90

Note: X'_1 = the water yield of the spring flood in inches.

X_{2p}, X_{2pm}, X_{2pf} = the accumulated precipitation available on the specified date.

X_3, X_{3f} = measures of the available ground water storage capacity based on winter runoff.

The method of computing the fiducial limits of error probable in an individual forecast is outlined with an example.

General Introduction

The Lake St. John Watershed is an area of some 30,000 square miles of untamed wilderness lying at the head of the Saguenay River in Northern Quebec. The area is rich in developed and undeveloped hydro-electric power. Development of the Saguenay River power sites was commenced in 1922, at Isle Maligne (see Figure 1) with a plant which now has an installed capacity of 540,000 horsepower. The construction of the second development, Shipshaw, was begun in 1926 but was not completed until 1943. The installed capacity at this site, in two power houses, is 1,500,000 h.p. During the last three years two more plants have been built on the lower Peribonka River, each with a capacity of 270,000 h.p. The total installed capacity of the system is now in excess of 2,500,000 h.p.

This capacity, under normal water conditions, is sufficient to enable the Aluminum Company of Canada to fully utilize its aluminum ingot smelting capacity in the Saguenay District, and, at the same time provide power for other industries. A substantial percentage of the aluminum ingot produced is exported to the United States to satisfy the needs of American industry.

To insure a sufficient dependable flow in the Saguenay and Peribonka Rivers, a system of storage reservoirs has been constructed. In addition to Lake St. John itself, which has a usable storage in excess of 140 billion cubic feet, there are two reservoirs on the Upper Peribonka River, Passe Dangereuse with a capacity of 180.0 b.c.f. and Lake Manouan which stores another 80.0 b.c.f. The total storage capacity is slightly greater than 400.0 b.c.f.

This power system, which depends solely on hydro developments, is capable of producing a firm load of approximately 1,850,000 h.p. during six years out of seven. This indicates the need for accurate forecasts of the hydrological phenomena of the watershed.

Presently, a series of investigations are being carried out with the hope of learning all that existing records can reveal concerning snow melt floods of the spring season.

This paper will be confined to the discussion of methods derived for the purpose of forecasting the spring flood volume. The equations apply to the watershed as a whole rather than to the individual reservoir drainages. This will be sufficient to illustrate the basic considerations and methods used in preparing each of the estimates.

The Data Available

The 30,000 square mile area of the Lake St. John Watershed is largely uninhabited forest. The main settlements are immediately around the lake itself with only a few rough logging roads penetrating beyond 20 miles from it. It is natural that widespread precipitation and stream flow records are not available.

The total watershed run-off, as measured in inflow to Lake St. John, has been recorded since 1913. Similar data from the upper reservoir areas have been collected since their construction in the early part of the last decade.

Watershed precipitation data are based upon a weighted mean of the records from five stations, Chibougamau, Depot Les Loutres, Isle Maligne, Passe Dangereuse and Lake Manouan. These stations are fairly widely distributed throughout the watershed area, (see Figure 1). Their records are available only since 1941. It will be shown later that these provide a reasonably accurate measure of the watershed precipitation.

Snow surveys were begun in the spring of 1944 and have been carried out on an annual basis ever since, usually in the latter half of March. This system of snow courses has been expanded from only those areas accessible by ground transport to include a wide network of stations accessible only by air. The present snow survey would seem to cover all areas of the watershed about equally.

Calculation of the Basic Data

The spring flood volume or water yield, will refer to that volume of run-off beginning with the first rise of run-off from snow-melt and ending June 15th. The flood period is arbitrarily ended as of June 15th whether or not the snow-melt flood has been completed. The particular advantage in this method lies in the fact that the so-called spring precipitation will fluctuate between narrower limits than if the flood period were not limited by such a method. Further it does not introduce the human guess work involved in estimating the end of the flood. It assumes that the volume of the snow-melt that has run-off by June 15th will be a function of the total snow volume and the date that the flood begins, both of which can be measured at the beginning of the flood period. The flood volumes were corrected for the recession from winter flows as follows:-

(See Figure 2) The recession curve of winter flows is extended forward (curve A-B) from the date of the first increase in run-off from snow-melt until June 15th. The area under the curve A-B is then the volume of run-off which would have occurred without the spring break-up, and is subtracted from the total spring flood volume. The remainder is the water yield from the snow and spring rains.

These and other data for the period 1942 to 1954 inclusive are shown in Table I.

A method of measuring the water accumulated, as of April 1st, was derived, based on the precipitation data of the five stations previously mentioned. This method involves accumulating the precipitation forward from about November 1st until April 1st or any desired date and subtracting from this total that volume which apparently has run-off from it prior to April 1st or the particular date in question.

Figure 3 shows an over-simplified case to illustrate the method. In this example the run-off is on a ground water recession from October 20th to October 31st. On October 31st a heavy rain caused the run-off increases as shown. The curve C-F is the hydrograph which would have appeared had this rain not occurred. All the run-off in excess of line C-F must be due to the rains of October 31st or later, and would be the volume subtracted from a precipitation accumulation begun on October 30th.

It may be seen that to include all the excess above the recession would involve extending C-F and D-G to zero. (Curve D-G being the recession curve resumed after the surface run-off from the storm has passed). Curves D-G and C-F are parallel. If C-F and D-G be extended to zero the figure CFGD would be a parallelogram lying between lines AB and CD. Figure ABDC is a parallelogram standing on a base common to Figure CFGD and is bounded by the same parallel lines, AB and CD. By geometry Figure ABDC is equal in area to Figure CFGD. Therefore the excess above the recession C-F can be computed as the total of the daily volumes from the beginning of the surface run-off hydrograph until this hydrograph drops back to the same level as it was at its beginning.

By this method the volume of precipitation which has run-off during the winter was computed for each year. The individual data are shown in Table I. If these volumes are subtracted from the accumulated precipitation the remainder must be the volume available to influence the spring flood. The accumulations remaining as of April 1st, March 1st, and February 1st are all shown in Table I.

The snow survey data from all stations were averaged to obtain a value of snow water equivalent. These data are included in Table I for the years 1944 to 1954.

Selection of the Most Reliable Measure of Precipitation

With two possible methods of measuring the precipitation available for April 1st forecasts it became a simple matter to select the one most closely related to the water yield. This was done by computing the correlative coefficient between each of the two measures of precipitation and the resultant water yield. This coefficient was found to be 0.595 between the snow survey data and the water yield, and 0.845 when the precipitation station data were used with the water yield. The former is not statistically significant at the 5% level while the latter is significant at the 1% level. This clearly indicates that the accumulated precipitation must be used as the basic measure of water available to influence the spring flood volume.

Using standard statistical methods (Reference 1) simple regression equations were derived between each precipitation measure and the spring flood volume (Figure 4). The standard error of estimate of the points about the regression line from the snow survey data was 1.26 inches and only 0.83 inches from the precipitation data. This gives a quantitative measure of the difference in reliability of the two methods.

It is not felt that these findings would apply equally well to all regions. There are two or three conditions in the Lake St. John Watershed to which this result might be attributed, and which may or may not be the case in other areas. The first of these is that the watershed is essentially uniform in topographic relief, as opposed to mountainous areas. The average elevations rise gradually away from Lake St. John. The land is quite broken and hilly but the fluctuations of elevation do not normally exceed 1,000 feet. Therefore the precipitation records, which are all from the valleys, can be expected to be reasonably representative. Secondly, the severity of the winters undoubtedly reduces evaporation from the snow pack to a minimum and thus nearly eliminates what may be in other areas a large variable. A third reason, which is perhaps of more importance than the others, is that frequently late fall rains will freeze before they have completely run-off. This water is not included in the snow survey but will be accounted for by the precipitation station method.

Ground Water Measurements

Parameters other than the accumulated precipitation are known to influence the volume of spring floods. Among the few that can be measured before or on April 1st is the condition of the soil and its capacity to take in moisture.

Mr. Carrol F. Merriam (Reference 2) has illustrated that the ground water storage acts as a huge reservoir, and that the discharge of this reservoir fluctuates according to a ground water index. This index was based upon ground water well observations. Thus it would seem that if the run-off were solely from ground water then a measure of the run-off would vary as some function of the ground water storage capacity, and thus indicate the volume which will be necessary to make up the ground water deficit.

The run-off into the Lake St. John during the winter months is largely from the ground water storage. An average winter run-off based on December, January and February flows was used as a criterion of the ground water storage capacity available. The relationship of this parameter to the resultant yield was assumed linear. (It is improbable that this is exactly the case.)

An equation including this measure of ground water storage was derived by standard statistical methods and is:- (See Figure 5)

$$X'_1 = 1.03 + 0.696X_{2p} + 0.072X_3 \qquad (1)$$

Where X'_1 = the volume of water yield in inches.

X_{2p} = the precipitation remaining on April 1st.

X_3 = the average winter run-off in cubic feet per second.

The standard error of estimate of this equation was computed to be 0.77 inches. This is an improvement of nearly 8 percent over the simple relation between the precipitation and the flood volume. Figure 5 illustrates graphically this improvement in the results.

The Spring Break-up Date

The flood period was defined as ended on June 15th whether this was so or not. Logically then it would seem that the date upon which the break-up occurred would offer some indication of the volume to be expected before June 15th.

Break-up date as used here is defined as that day upon which the run-off from the Lake St. John watershed equals or exceeds 45,000 c.f.s. and does not drop below this value until the flood has passed. The date will be measured in days from March 26th as zero. The maximum limits of variation have been 0 to 40 with a forty-year average of 26.

This measurement of break-up date was then included in an expression together with those parameters used in equation 1. The resulting equation which was derived by standard statistical procedures was: (refer to Figure 6)

$$X'_1 = -0.12 + 0.720X_{2p} + 0.093X_3 + 0.0173X_4 \qquad (2)$$

where X'_1, X_{2p}, and X_3 are as above and

X_4 = break-up date as defined above.

The standard error of the points about the regression line is 0.79 inches. The addition of the break-up parameter has not added to the forecast accuracy. The partial correlation coefficient of X_4 is significant only at about the 30% level, X_4 will therefore be discarded. The results of this equation are illustrated in Figure 6.

It is interesting to note that the break-up date has not significantly influenced the flood volume. This would not be so surprising if the flood period were not arbitrarily ended. This leads to the hypothesis that late break-ups must be accompanied by more rapid snow-melt and that this in turn means greater flood peaks. To prove or disprove this theory an equation was derived by standard statistical procedures to relate the independent variables of flood volume and break-up date to the three-day average flood peak. The resulting equation, based on the 40 years of available records, is:

$$F'_p = 27.3X_1 + 3.80X_4 - 147.0 \qquad (3)$$

where F'_p = the three day average flood peak in 1,000's c.f.s.

X_1 = the volume of water yield measured in inches (as used elsewhere in this paper).

X_4 = The break-up date in days measured from March 26th as zero.

The results are illustrated by Figure 7. The data are shown in Table II.

The maximum range of the break-up date is 40 days. This equation shows that a spring flood having a 10.0 inch volume and a zero break-up date will most probably have a three day average peak of 126,000 c.f.s. A flood with the same volume but breaking up on May 5th would be most likely to have a three day average peak of 278,000 c.f.s. This would seem to illustrate that the later break-up dates are accompanied by more rapid melting as was hypothesized. This subject, although not specifically concerned with volume forecasting, is of interest in planning reservoir operations.

Application of the Results to March and February Forecasts

Up to this point reference to April 1st forecasts only has been made. It has been illustrated that the best forecast on April 1st can be made on the basis of equation (1) when (refer to Figure 8).

$$X'_1 = 1.03 + 0.696X_{2p} + 0.072X_3 \qquad (1)$$

and where X'_1 = the water yield forecast in inches

X_{2p} = the precipitation available as of April 1st.

X_3 = the average winter run-off in 1,000's c.f.s. (Ave. Dec., Jan. and Feb.)

The standard error of estimate of the observed data about the regression line was 0.77. The multiple correlation coefficient of 0.841 is significant at the 1% level.

(a) March 1st Forecasts

It may be seen that if the accumulated precipitation of March 1st was used in place of the April 1st figure, the only possible loss in accuracy would be due to the difference in the standard deviations of the spring precipitation as measured from March 1st to June 15th and from April 1st to June 15th. Therefore, by standard statistical procedures an equation was derived using the March 1st accumulated precipitation instead of that for April 1st. The resulting equation was:

$$X'_1 = 1.81 + 0.750X_{2pm} + 0.083X_3 \qquad (4)$$

where X'_1 and X_3 are as above and

X_{2pm} = the precipitation available as of March 1st.

The results of this equation are shown in Figure 9. The standard error of estimate of the sample points about the regression line was computed at 0.75, indicating that this equation gives a slightly more accurate result than the April 1st forecast. The multiple correlation coefficient of 0.850 is significant at the 1% level.

A check of the standard deviations of the spring precipitation as measured from March 1st and April 1st was calculated to determine which was the larger. (see Table III).

The result was that the standard deviation of the spring precipitation from April 1st to June 15th was 1.15 inches, while that measured from March 1st only 1.12 inches. This partially explains the greater accuracy of the March 1st equation, but leaves in doubt the general reliability of the data from the sample years.

Further tests were made to determine whether or not there was anything basically wrong with the data from the years which were used. A check of the standard deviation of spring precipitation measured from March 1st to June 1st was calculated by using an average from six stations in the region (see Table IV). Twenty-eight years of data were available. The standard deviation of this sample from their mean was found to be 1.16 inches. This compares reasonably well with similar statistics from the 13-year sample. It does not seem that there is any significant error in the data used.

The results obtained from March 1st forecasts should be approximately as shown here. Over a long period it would be expected that April 1st forecasts will be a little more accurate than has been found in the sample years.

(b) <u>February 1st Forecasts</u>

A forecast equation using February 1st accumulated precipitation was also prepared. The value of winter run-off was based on only the December and January run-off period. The resulting equation was found to be:

$$X'_1 = 2.30 + 1.053X_{2pf} + 0.046X_{3f} \quad (5)$$

where X'_1 = the forecast value of water yield in inches.

X_{2pf} = the precipitation available as of February 1st.

X_{3f} = the average December and January run-off in 1,000's c.f.s.

The results are illustrated in Figure 10.

The standard error of estimate of the points about the regression line was 0.90. The multiple correlation coefficient of 0.777 is significant at exactly the 1% level.

Sample Forecast

Equations have been established by which the water yield from the winter precipitation can be estimated at various dates prior to the outset of the spring flood.

Figure 11 shows a sample of the calculations necessary to compute an individual estimate and the probability of any particular limit of error being experienced. The selected example is the April 1st forecast for 1954.

The data and the solution of the equation for the basic estimate are straight forward. The limit of error estimate introduces the equation for determining the standard error of the individual estimate. The derivation of this equation is fully describes in Snedecor's book (Reference 3). The equation is:-

$$s_E^2 = s_{1.2p3}^2 \left\{1 + \frac{1}{N} + c_{22}x_{2p}^2 + c_{33}x_3^2 + 2c_{23}x_2x_3\right\} \qquad (6)$$

The values of c_{22}, c_{33} and c_{23} are the so-called Gauss multipliers. The values of 'x' are the deviations of the particular samples from their respective normals.

It may be seen that the standard error of estimate of an individual point is thereby enlarged for small samples and when the individual samples of X_{2p} and X_3 deviate greatly from their means.

Finally, the fiducial limits at any level of probability may be computed by multiplying the computed values of s_E by the appropriate value of 't' selected from standard tables (Reference 4). In the example the probability level of 0.10 was selected and the value of 't' corresponding to 10 degrees of freedom was found to be 1.81.

The final forecast then for 1954 would have been 8.7 inches with only one chance in ten of the errors exceeding 1.56 inches. Other limits can be computed by selecting other values of 't' as desired.

REFERENCES

(1) "An Outline of Statistical Methods", Arkin and Culton,
(2) "Evaluation of two Elements Affecting the Characteristics of The Recession Curve", by Carroll F. Merriam - Trans. A.G.U. Vol. 32, No.4.
(3) "Statistical Methods" by George W. Snedecor.
(4) Table 3.8 Tables of 't' - Footnote (3).

Table I

DATA - LAKE ST. JOHN SPRING FLOODS

	PRECIPITATION - INCHES									
YEAR	Total Accumulated to April 1st	Excess Winter Run-off	Remaining Precipitation			Snow Survey Water Equivalent (in.) X_{2S}	Average Dec., Jan. and Feb. Run-off (1000's c.f.s.) X_3	Average Dec., Jan. Run-off (1000's c.f.s.) X_{3f}	Break-up Date (days) X_4	Water Yield (inches X_1
			April 1st X_{2p}	March 1st X_{2pm}	Feb. 1st X_{2pf}					
1942	16.6	4.1	12.5	10.0	6.5	-	25.0	30.0	26	11.6
1943	15.5	3.0	12.5	10.0	7.2	-	18.0	18.0	38	11.6
1944	10.2	2.1	8.1	5.8	4.5	8.0	14.0	17.0	39	7.3
1945	14.7	1.4	13.3	11.0	7.6	8.5	17.0	20.0	5	11.3
1946	11.0	1.6	9.4	7.7	5.5	8.7	19.0	20.0	29	10.3
1947	14.8	1.3	13.5	11.6	8.2	11.5	21.0	22.0	40	12.5
1948	10.6	-	10.6	8.6	5.4	8.2	16.0	18.0	33	8.0
1949	13.7	1.8	11.9	9.6	7.8	9.7	19.0	21.0	19	10.7
1950	11.7	1.5	10.2	8.6	7.2	6.1	21.0	22.0	30	9.7
1951	14.7	3.8	10.9	8.6	6.6	9.6	29.0	35.0	12	10.1
1952	14.3	4.2	10.1	8.3	6.2	9.5	27.0	32.0	26	9.7
1953	14.6	3.0	11.6	8.7	6.4	9.5	30.0	35.0	3	11.0
1954	11.1	2.6	8.5	6.6	5.1	6.6	24.0	27.0	26	9.3
Average			11.0	8.8	6.5	8.7	21.0	24.0	25.0	10.2

Table II

THE SPRING FLOOD PEAK DISCHARGE* AND

RELATED DATA

Year	Water Yield (inches) X_1	Break-up Date (days) X_4	Flood Peak (1000's cfs) F_p	Year	Water Yield (inches) X_1	Break-up Date (days) X_4	Flood Peak (1000's c.f.s) F_p
1914	6.5	39	170.0	1935	8.0	20	150.0
1915	9.1	24	210.0	1936	13.1	0	220.0
1916	9.8	24	220.0	1937	11.9	29	280.0
1917	9.4	27	200.0	1938	9.3	24	150.0
1918	10.2	27	220.0	1939	8.6	35	230.0
1919	10.5	20	210.0	1940	11.0	34	250.0
1920	10.7	20	240.0	1941	7.0	20	170.0
1921	9.2	17	270.0	1942	11.6	26	290.0
1922	8.8	14	180.0	1943	11.6	38	360.0
1923	8.1	33	210.0	1944	7.3	39	240.0
1924	10.7	33	270.0	1945	11.3	5	160.0
1925	9.2	31	170.0	1946	10.3	29	250.0
1926	7.6	39	180.0	1947	12.5	40	370.0
1927	8.4	26	160.0	1948	8.0	33	240.0
1928	14.5	36	380.0	1949	10.7	19	200.0
1929	11.0	34	250.0	1950	9.7	30	200.0
1930	10.0	35	210.0	1951	10.1	12	160.0
1931	7.5	25	130.0	1952	9.7	26	220.0
1932	7.0	25	140.0	1953	11.0	3	160.0
1933	10.8	21	220.0				
1934	9.0	29	220.0				
				Average	9.8	26	219.0

* three day average peak

TABLE III
(1)
SPRING PRECIPITATION - YEARS 1942 - 1954

April 1st to June 15th (2)				March 1st to June 15th (3)			
Year	Precip.	Year	Precip.	Year	Precip.	Year	Precip
1942	4.5	1949	6.0	1942	7.1	1949	8.3
1943	6.6	1950	4.6	1943	9.1	1950	6.2
1944	6.3	1951	4.4	1944	8.5	1951	6.7
1945	7.3	1952	5.0	1945	9.6	1952	6.8
1946	6.7	1953	4.1	1946	8.4	1953	7.0
1947	7.3	1954	6.2	1947	9.2	1954	8.1
1948	4.8			1948	6.8		
		Aver.	5.7			Aver.	7.8

(1) Based on the weighted mean of these five stations, Chibougamau, Depot Les Loutres, Isle Maligne, Passe Dangereuse, and Lake Manouan.

(2) The spring precipitation includes April and May precipitation plus that from June which would be expected to influence the run-off prior to June 15th.

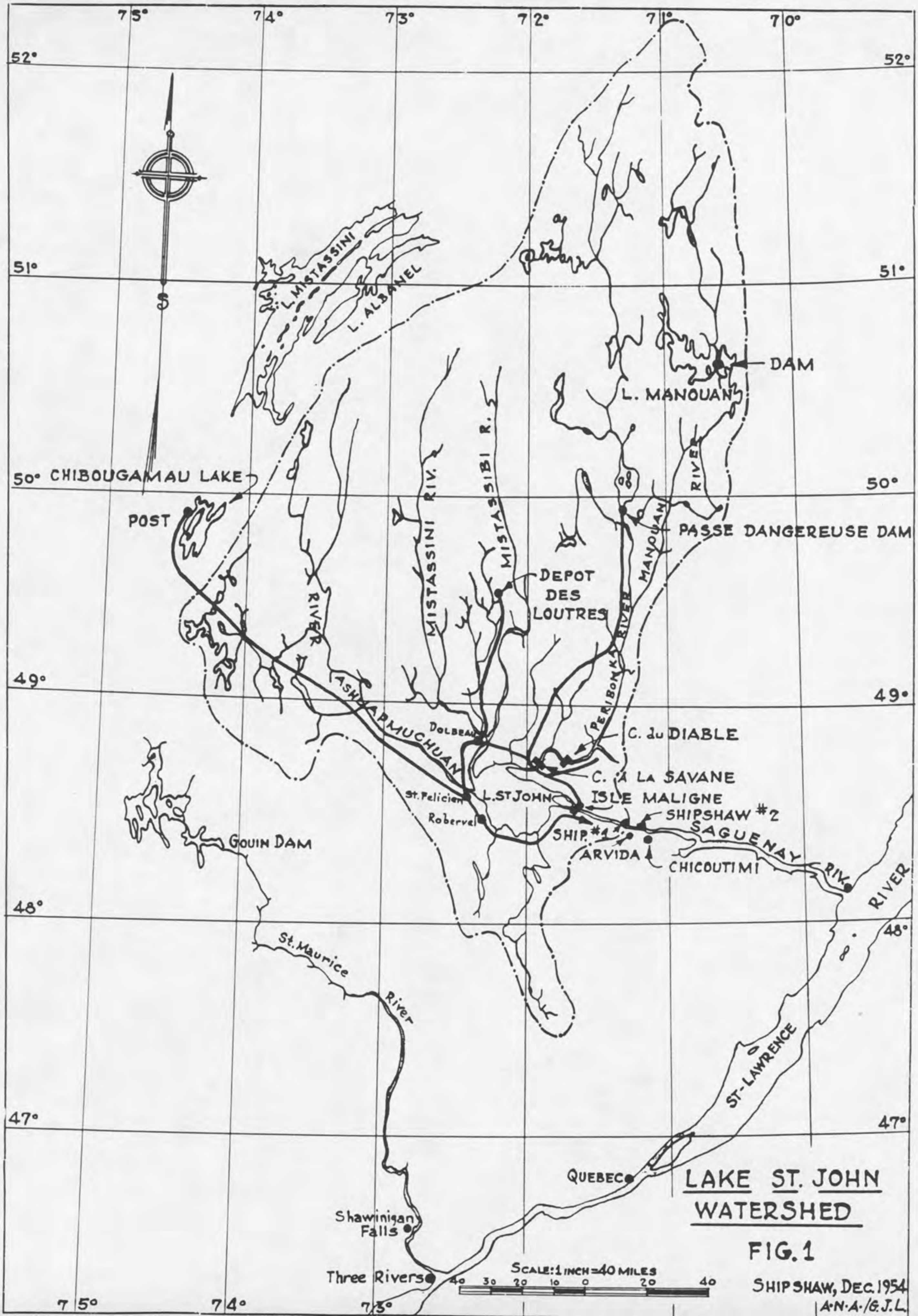
(3) Includes item 2, plus March precipitation.

TABLE IV

SPRING PRECIPITATION* - YEARS 1925 - 1952

Year	Precip.	Year	Precip.	Year	Precip.	Year	Precip.
1925	7.1	1932	7.2	1939	6.8	1946	8.5
1926	6.5	1933	7.8	1940	6.9	1947	10.5
1927	5.8	1934	7.1	1941	7.6	1948	7.7
1928	8.2	1935	7.6	1942	7.3	1949	7.2
1929	6.9	1936	10.8	1943	7.0	1950	7.1
1930	8.0	1937	5.9	1944	7.0	1951	6.9
1931	7.3	1938	7.8	1945	9.4	1952	6.1
						Aver.	7.50

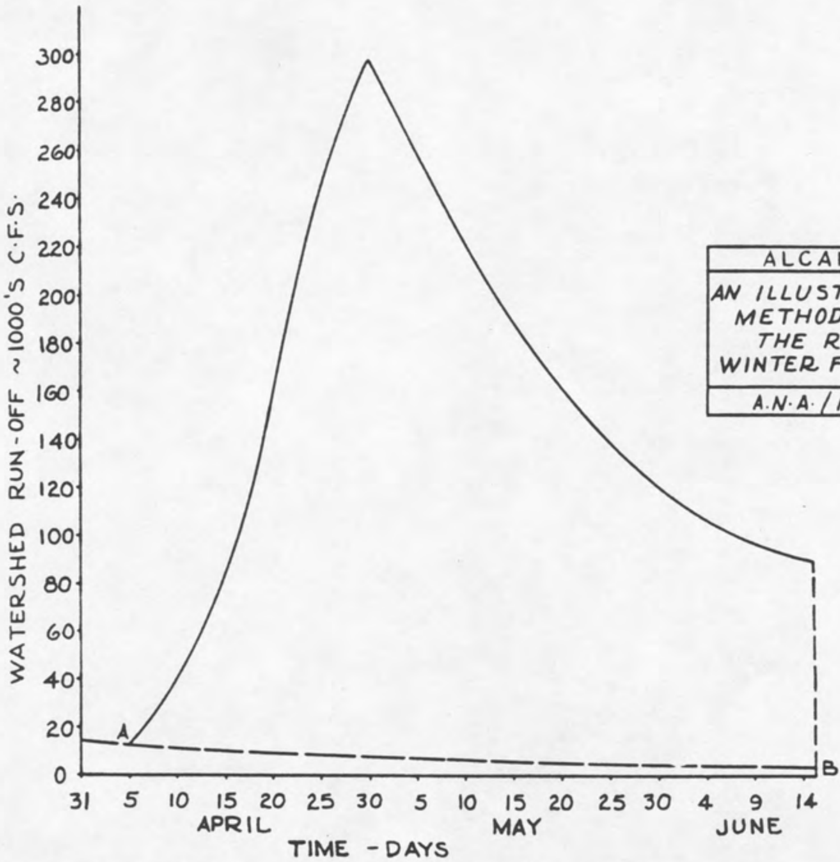
* March, April and May - based on an arithmetic average of the data from La Tuque, Onatchiway, Kenogami, Roberval, Isle Maligne and Chute-aux-Galets.



LAKE ST. JOHN WATERSHED

FIG. 1

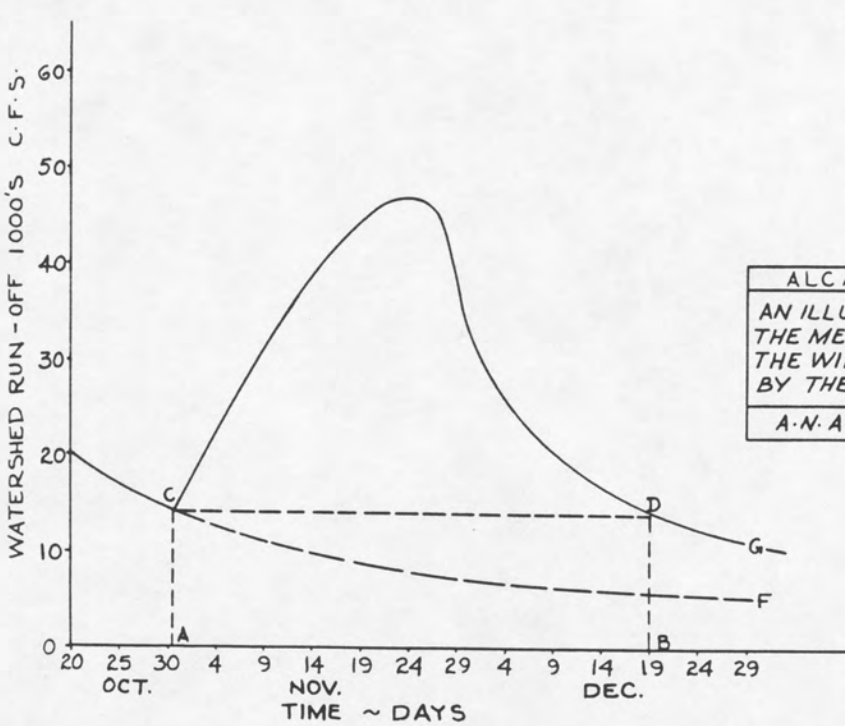
SHIPSHAW, DEC. 1954
A.N.A./G.J.L.



ALCAN SHIPSHAW, QUE.

AN ILLUSTRATIVE EXAMPLE OF THE METHOD USED TO SUBTRACT THE RECESSION OF THE WINTER FLOW FROM THE SPRING FLOOD

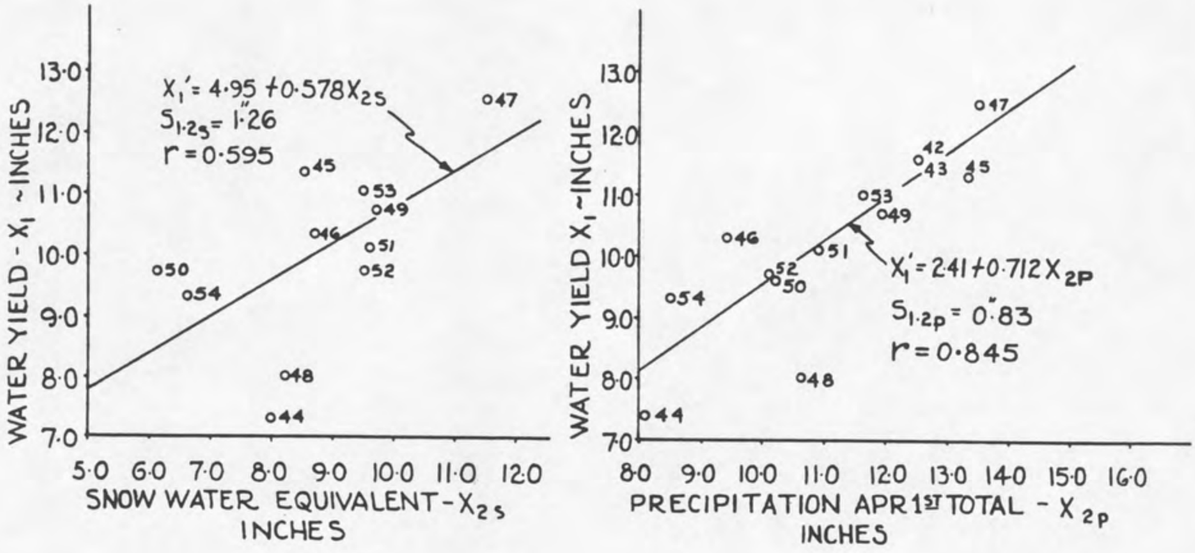
A.N.A./P.R.L. FIG. 2



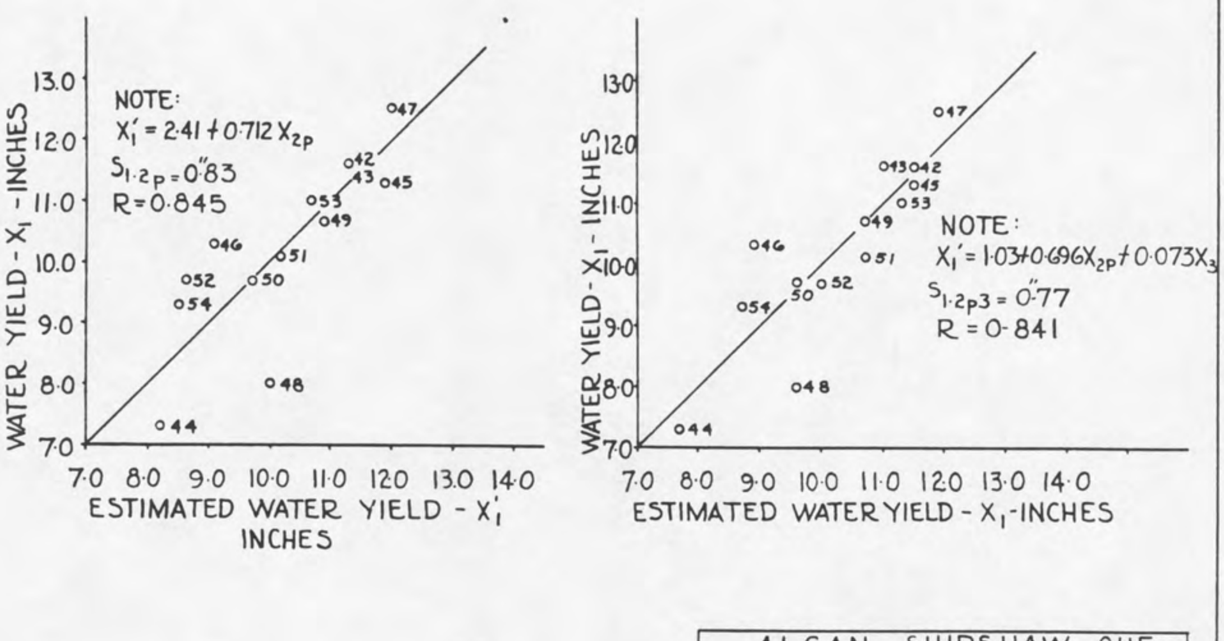
ALCAN SHIPSHAW, QUE.

AN ILLUSTRATIVE EXAMPLE OF THE METHOD USED TO DETERMINE THE WINTER RUN-OFF CAUSED BY THE WINTER PRECIPITATION

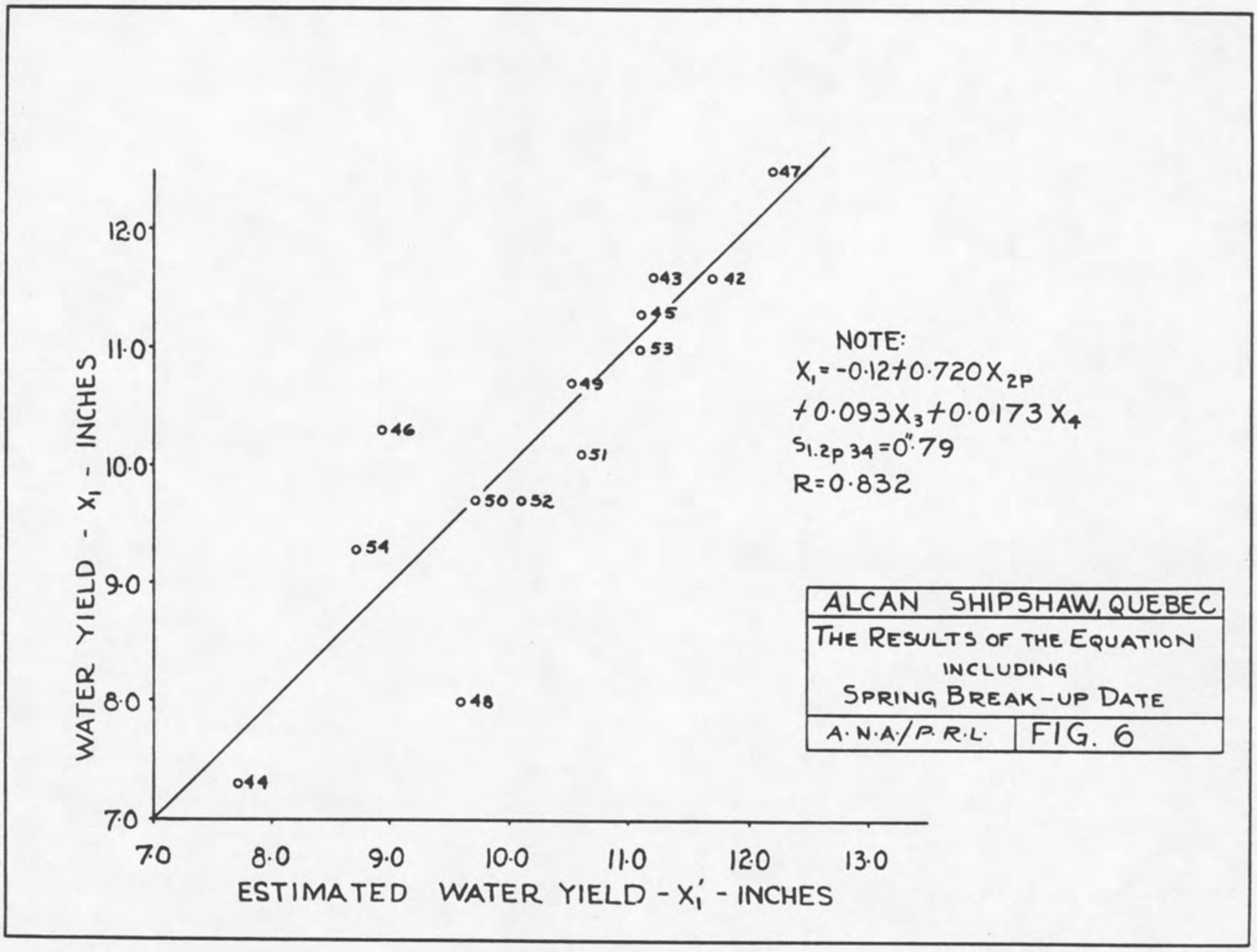
A.N.A./P.R.L. FIG. 3

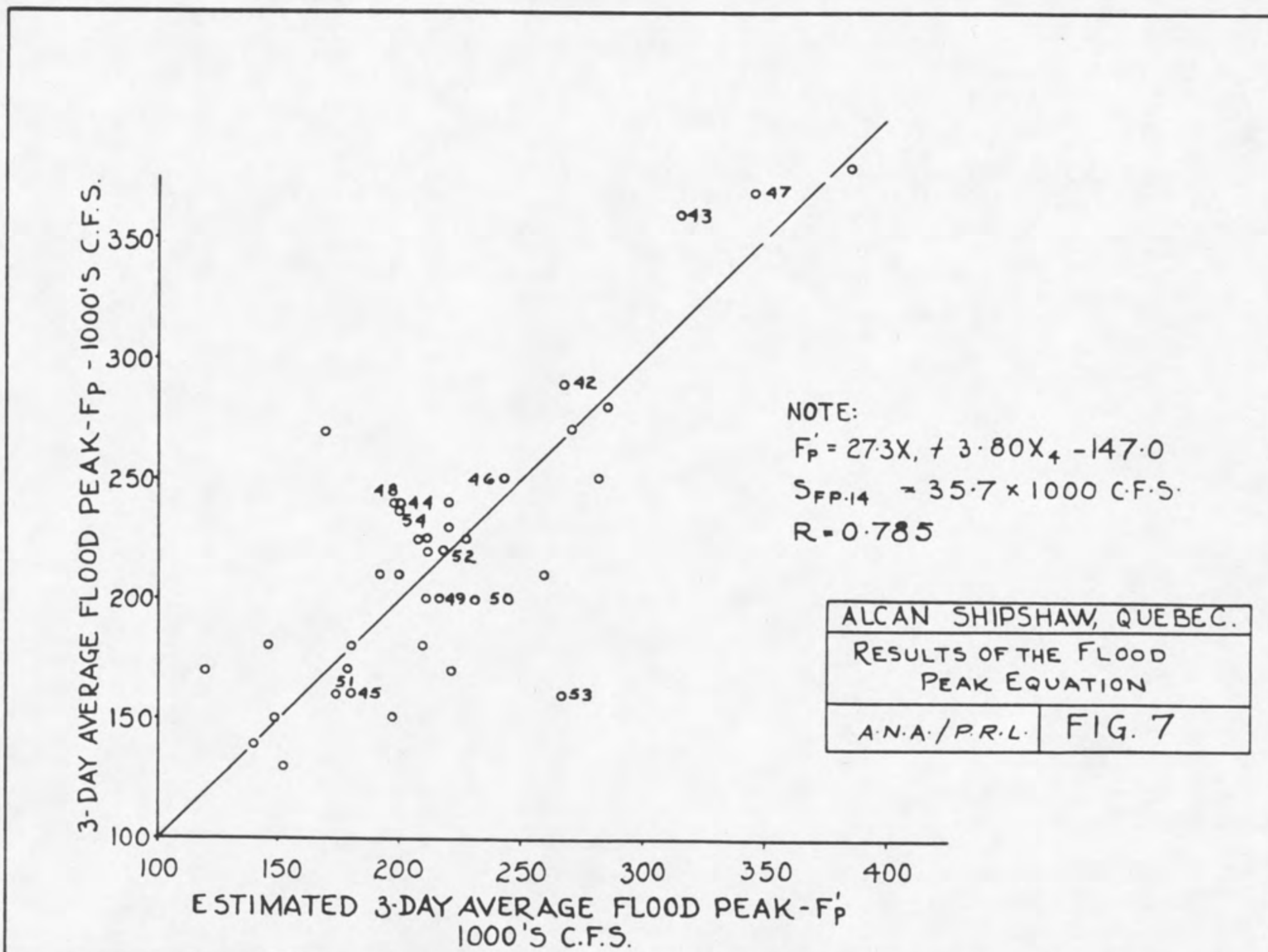


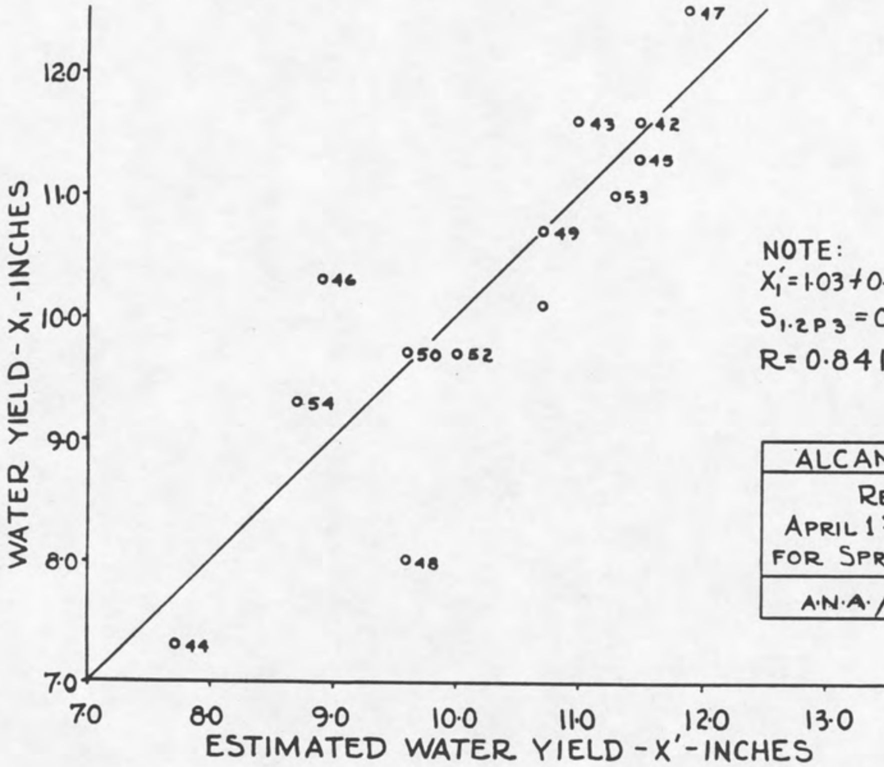
ALCAN SHIPSHAW, QUE.	
COMPARISON OF THE CORRELATION OF SNOW WATER EQUIVALENT TO "WATER YIELD" AND ACCUMULATED PRECIPITATION APR 1ST TO "WATER YIELD"	
A.N.A. / P.R.L.	FIG. 4



ALCAN SHIPSHAW, QUE.	
COMPARISON OF THE RESULTS OF THE EQUATIONS $X_1' = 2.41 + 0.712 X_{2P}$ & $X_1' = 1.03 + 0.696 X_{2P} + 0.072 X_3$	
A.N.A./P.R.L.	FIG. 5

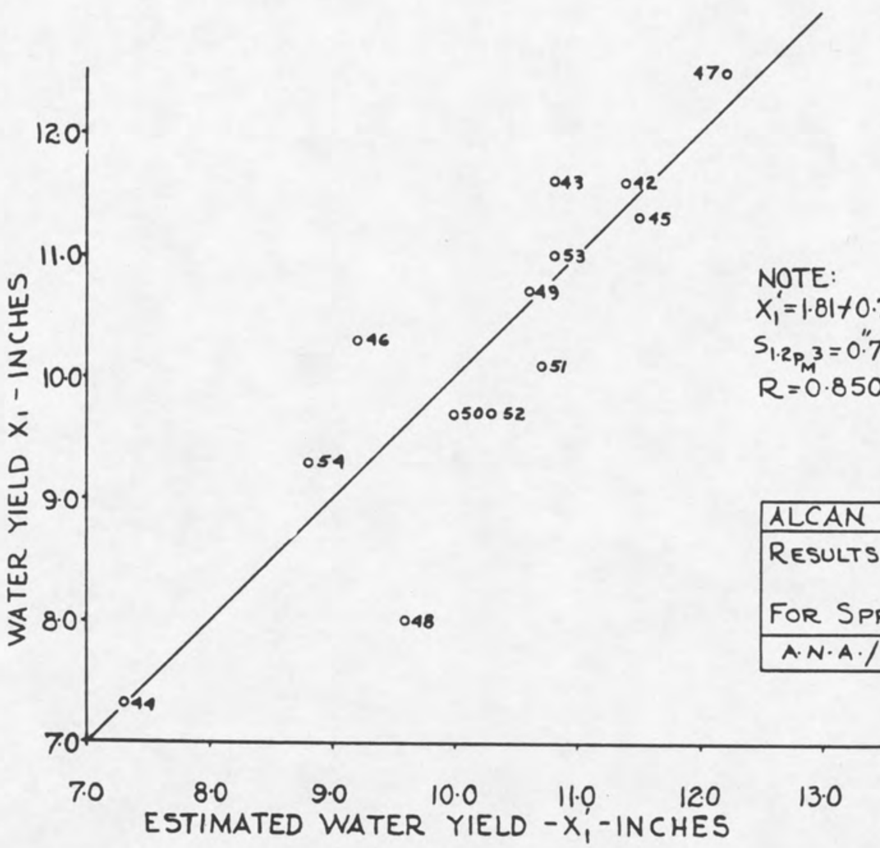

WATER YIELD - X_1 - INCHES
ESTIMATED WATER YIELD - X_1' - INCHES
7.0
8.0
9.0
10.0
11.0
12.0
13.0
047
043
042
045
053
049
046
051
050
052
054
048
044
NOTE:
$X_1 = -0.12 + 0.720 X_{2P} + 0.093 X_3 + 0.0173 X_4$
$S_{1.2P34} = 0''79$
$R = 0.832$
ALCAN SHIPSHAW, QUEBEC
THE RESULTS OF THE EQUATION INCLUDING SPRING BREAK-UP DATE
A.N.A./P.R.L.
FIG. 6


3-DAY AVERAGE FLOOD PEAK - F_P - 1000'S C.F.S.
ESTIMATED 3-DAY AVERAGE FLOOD PEAK - F_P'
1000'S C.F.S.
100
150
200
250
300
350
400
47
43
42
46
48
44
54
52
49
50
51
45
53
NOTE:
$F_P' = 27.3 X_1 + 3.80 X_4 - 147.0$
$S_{FP.14} = 35.7 \times 1000$ C.F.S.
$R = 0.785$
ALCAN SHIPSHAW, QUEBEC.
RESULTS OF THE FLOOD PEAK EQUATION
A.N.A./P.R.L.
FIG. 7



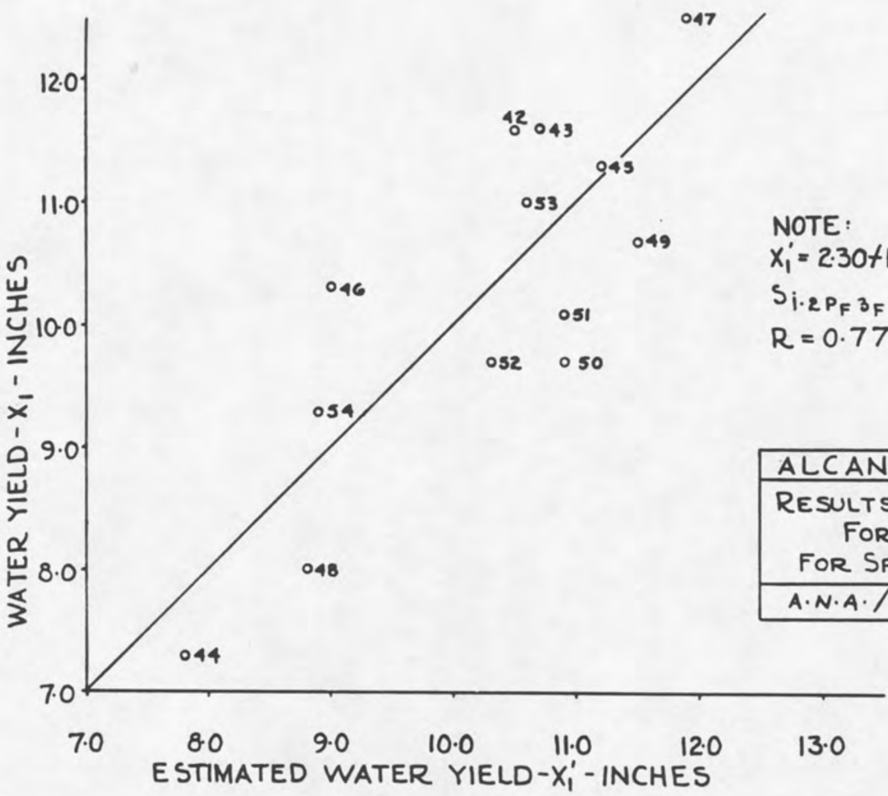
NOTE:
$X_1' = 1.03 + 0.696X_{2P} + 0.072X_3$
$S_{1.2P3} = 0''.77$
R= 0.841

ALCAN SHIPSHAW, QUE.	
RESULTS OF THE APRIL 1ST FORECAST EQUATION FOR SPRING FLOOD VOLUME	
A.N.A./P.R.L.	FIG. 8



NOTE:
$X_1' = 1.81 + 0.75X_{2P_M} + 0.083X_3$
$S_{1.2P_M3} = 0''.75$
R = 0.850

ALCAN SHIPSHAW QUE.	
RESULTS OF THE MARCH 1ST FORECAST EQUATION FOR SPRING WATER YIELD	
A.N.A./P.R.L.	FIG. 9



NOTE:
$X_1' = 2.30 + 1.053 X_{2P_F} + 0.046 X_{3F}$
$S_{1 \cdot 2P_F 3_F} = 0.90$
$R = 0.777$

ALCAN SHIPSHAW, QUE.	
RESULTS OF THE FEBRUARY 1ST FORECAST EQUATION FOR SPRING WATER YIELD	
A.N.A./P.R.L.	FIG. 10

DATA:

$X_{2p} = 8.5$ INCHES

$X_3 = 24.0 \times 1000$ C.F.S.

$\bar{X}_{2p} = 11.0$ INCHES

$\bar{X}_3 = 21.0 \times 1000$ C.F.S.

$S_{1 \cdot 2p3} = 0''.77$

N = 13

EQUATION

$X_1' = 1.03 + 0.696 X_{2p} + 0.072 X_3$

FOR 1954:

$X_1' = 1.03 + (0.696 \times 8.5) + (0.072 \times 24.0)$
$= 8.7$ INCHES

THE LIMITS OF ERROR *

$$S_E = \sqrt{S_{1 \cdot 2p3}^2 (1 + 1/N + C_{22} X_{2p}^2 + C_{33} X_3^2 + 2C_{23} X_{2p} X_3)}$$

$$= \sqrt{0.77^2 (1 + 1/13 + (0.028 \times 2.5^2) + 0.0032 \times 3.0^2) - (2 \times 0.0054 \times 3.0 \times 2.5)}$$

$= 0''.86$

WITH FIDUCIAL LIMITS AT THE 0.10 PROBABILITY LEVEL THE FORECAST WOULD BE:

$X_1' = 8''.7 \pm t^{**}_{.10} S_E$
$= 8''.7 \pm 1.81 \times 0.86$
$= 8''.7 \pm 1.56$

* REFER: STATISTICAL METHODS
By: GEORGE W. SNEDECOR

** TABLE - 3.8 - VALUES OF "t" ~ SNEDECOR

ALCAN SHIPSHAW, QUE.	
SAMPLE CALCULATION OF A FLOOD FORECAST - DATA APR. 1ST 1954	
A.N.A./P.R.L.	FIG. 11