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ABSTRACT

The lengths of wet and dry periods, the relationship of precipitation with distance, and the variation of precipitation through the years of record, are matters of great interest in agricultural areas such as the Canadian Prairies. Most of the precipitation on the prairies falls in the six months, April to September, inclusive. Within the three provinces, the proportion falls to 60 per cent or lower in the Rocky Mountain area and in the upper Peace River district. The minimum value, and the only one below 50 per cent is 42 at Lake Louise. For the remainder of the area, the summer precipitation is generally 65 to 75 per cent of the annual. At a few stations, such as Hardisty, Red Deer and Three Hills, Alberta; Chaplin, Kindersley and Outlook, Saskatchewan; and Russell, Manitoba, the summer precipitation is about 75 per cent. Summer precipitation, being the most plentiful, the most variable, and the most valuable, is the subject of much of this study.

PRECIPITATION PROBABILITY

The Climatology Division of the Atmospheric Environment Service has prepared an extensive analysis of precipitation probability for eleven stations in the three provinces. Information from this analysis for three significant periods, the seeding period, the period of crop growth, and the harvest period is presented in the publication, "The Climate of the Prairie Provinces". These data show that while there are variations, there are also marked similarities in the precipitation regime across the prairies, such that one could assume that a general picture could be obtained from an analysis of data for the eleven stations; Beaverlodge, Lacombe, Ranfurly, Vauxhall, Indian Head, Prince Albert, Scott, Swift Current, Brandon, Morden and The Pas.

Figure 1 gives another picture of the variation. The chart gives the probability of precipitation less than certain amounts during the 30-day periods beginning 1 January, 1 May, 1 June, 1 July, and 1 September for Indian Head, Saskatchewan. The basic data were obtained from 70 to 80 year records. The curve for 1 January typifies the winter season. Precipitation is light, with a mean of less than 1 in. per month. The chart shows that 2 ins. precipitation is rare. With the coming of spring, precipitation is greater. The figure shows that in one year out of three, May rainfall is less than 1 in. The curve for June is less steep because of the greater tendency for large precipitation amounts. If Q_{25} and Q_{75} are the first and third quarters of the cumulative probability of occurrence, respectively, $Q_{75} - Q_{25} = 1.7$ in. for May and 2.3.in. for June. For comparison, $Q_{75} - Q_{25}$ is less than 1 in. during the winter months. The month of July lacks the frequency of high precipitation found in June, and by September the curve has receded somewhat toward a winter variability.

The quantity $Q_{75} - Q_{25}$ is not a good measure of variability because it fails to take into consideration the normal rainfall. Another measure frequently used is the coefficient of variation which is the ratio of the standard deviation to the mean. A similar measure is the quotient, $(Q_{75} - Q_{25})/Q_{50}$ where Q_{50} is the median value. This quotient, called Q, can be obtained readily from the statistics supplied by the Climatology Division.

The values for the quotient, Q, varied among the eleven stations but the curves have similarities. Figure 2 gives the curves for Q_{25}, Q_{50}, Q_{75}, and the quotient Q for the different observing periods of the year for Ranfurly, Alberta, based on 64 years of record. In general, the values of Q for the period 1 November to 15 March lay between 0.80 and 1.10. During the period 15 May until 15 August, most values lay between 0.70 and 0.90 with an occasional one as high as 1.10. Occasionally, there was an abnormal value, such as 1.63 for Ranfurly for 1 February which seems to arise from a deficiency in the statistics

The curves of Figure 1 are not the smooth curves one would expect from data extending over 100 years or more but have irregularities which arise because, even with 70 years of data, the problem of sampling is not completely solved. The value of Q_{50} for 1 February for Ranfurly seems relatively small, and this results in an extremely high value for Q.

High values similar to the ones for 15 April, 1 October and 15 October are found at a number of other stations. It would seem that these are associated with the annual variation of precipitation. The mean precipitation rises from 0.97 in. in April to 1.51 in. in May. During this period, Q_{75} rises from 1.20 in. for 1 April to 1.72 in. for 15 April to 2.23 in. for 1 May. The rise of Q_{50} between 15 April and 15 May is similar to that for Q_{75}, 0.90 to 1.50. But the rise during the first half of the month, 0.74 to 0.90 is relatively small. This small value of Q_{50} for 15 April results in an abnormal peak in the curve for Q. A lag in the decrease of Q_{75} in October results in a similar variation in the value of Q for that month.

From the foregoing discussion, and the results found at the other stations, it appears that during those periods when the mean precipitation is changing from or to its winter values, a few abnormally wet years will cause an increase in the value of Q_{75} to a greater degree than of Q_{25} and Q_{50}. A confirmation of this hypothesis could be obtained from an analysis of the skewness of the frequency distribution, for the skewness seems a better measure of such a variability than Q_{75} or Q. But the analysis should not be based only on monthly precipitation values. The abnormal situation in the spring at Ranfurly would have been missed if one examined only the data for the months of April and May, and the same situation would occur at some of the other stations.

LENGTHS OF WET AND DRY SPELLS

Another statistic which is a measure of the variability of precipitation, and which also is of interest to the agriculturalist and others, is the length of wet and dry spells. A dry spell can be defined as the period during which no measurable rain fell on any day, and a wet spell the period during which a measurable amount of rain (0.01 in. or more), fell on every day. For practical reasons, one might wish to follow the British definition which makes the rainfall of 1 mm or 0.04 in. as the dividing line, but for this analysis the former definitions were used.

The exact values of the frequency of wet spells and dry spells of various lengths can be obtained by examining the various spells that have occurred during the period of record. A simpler method was used, based upon a conclusion arising from such a counting (Longley, 1953). When a day is dry (wet), the probability that the following day is dry (wet) is constant and does not depend upon the length of the period which has been dry (wet). This results in the equation

$$N(n) = Kp^n.$$

Where N(n) is the number of dry (wet) periods having a length n days or more, K is a constant, and p the probability of a dry (wet) day following a dry (wet) day. The value of p varies from one month or season to the next, and from station to station.

To obtain the values of p, data for 21 stations selected from different river valleys across the prairie provinces were examined for the months April – September, inclusive, 1940 – 1969. At times when the data were missing for the selected station, the records for a neighbouring station were substituted, i.e., Waskada for Pierson, Manitoba. The results should then be considered as giving values for the district rather than for the specified station.

Table 1 gives the monthly values of the probabilities for the 21 stations for both a wet day following a wet day and a dry day following a dry day.

Table 1. Values of the probability of a wet day following a wet day, or a dry day following a dry day for selected stations.

	Wet day following wet day						Dry day following dry day					
	Apr	May	Jun	Jul	Aug	Sept	Apr	May	Jun	Jul	Aug	Sept
Alberta												
Brooks	.36	.39	.52	.37	.38	.41	.85	.79	.76	.80	.79	.83
Calmar	.39	.44	.55	.50	.52	.46	.82	.78	.70	.64	.72	.77
Edson	.39	.50	.58	.58	.53	.44	.79	.76	.66	.60	.64	.72
Fairview	.36	.48	.45	.44	.50	.43	.82	.83	.68	.69	.75	.73
Lac La Biche	.37	.40	.47	.52	.45	.45	.80	.79	.71	.65	.72	.77
Lacombe	.41	.44	.54	.48	.50	.48	.80	.79	.67	.66	.72	.77
Pekisko	.53	.56	.61	.45	.50	.51	.77	.78	.72	.80	.78	.81
Saskatchewan												
Consul	.36	.41	.53	.35	.40	.41	.87	.82	.73	.81	.85	.88
Choiceland	.33	.39	.47	.35	.41	.42	.87	.85	.78	.66	.76	.81
Lintlaw	.43	.41	.51	.43	.47	.47	.80	.77	.70	.67	.71	.76
Regina	.42	.45	.51	.39	.41	.43	.81	.79	.67	.69	.76	.80
Saskatoon	.36	.41	.47	.42	.42	.46	.82	.80	.71	.68	.75	.78
Swift Current	.43	.44	.49	.36	.43	.49	.80	.77	.68	.76	.79	.81
Turtleford	.23	.42	.38	.43	.38	.41	.88	.85	.72	.73	.75	.82
Manitoba												
Brandon	.33	.42	.44	.43	.40	.39	.82	.76	.67	.71	.73	.80
Churchill	.48	.50	.46	.48	.49	.56	.74	.74	.76	.71	.68	.63
Indian Bay	.40	.46	.49	.44	.40	.39	.79	.75	.67	.65	.71	.72
Morden	.37	.43	.46	.40	.39	.39	.81	.76	.71	.71	.76	.78
Neepawa	.40	.44	.43	.38	.35	.40	.82	.78	.70	.68	.74	.80
Pierson	.34	.43	.47	.33	.33	.41	.85	.78	.69	.74	.76	.84
The Pas	.43	.43	.51	.41	.49	.51	.79	.80	.72	.61	.62	.71

The probabilities generally vary in a manner that one would expect having a knowledge of the prairie precipitation. April, which is relatively dry, has high probabilities of a dry day following a dry day (usually 0.80 or higher), and relatively low values for a wet day following a wet day. The maximum value for this latter variable is found for most stations in June, even though for some stations (i.e., Choiceland and Fairview) July has more rain than June. The wet fall in northern Manitoba shows up in the statistics for The Pas and Churchill.

Equation (1) may be used in a number of ways. For instance, one may wish to determine the probability that a dry period last 15 days or longer. Now

$$N(1) = Kp$$

gives the total number of dry periods, and

$$N(15) = Kp^{15}$$

gives the number 15 days or longer.

$$N(15)/N(1) = p^{14}$$

For p = 0.70, the ratio of the two, is 0.0067, or one wet period in 150 lasts 15 days. For p = 0.80, the corresponding values are 0.044, and one in 23. A more meaningful quantity is the length of the period which is equally by 1 wet (dry) period in 10, or in the 10 percentile of lengths. In this problem, if n is the desired length

$$N(n) = Kp^n = \frac{1}{10}Kp.$$

Therefore,

$$n = 1 - \frac{1}{\log p}$$

or

$$\log p = - \frac{1}{n-1}$$

The values obtained from this relationship are given in Table 2. The lengths are given to the tenths of a day for comparison purposes. Obviously, in a practical situation n must be a whole number.

Table 2. Values of the 10-percentile of the lengths of wet periods and dry periods in days at selected stations in the prairie provinces.

	Wet Periods						Dry Periods					
	Apr	May	Jun	Jul	Aug	Sept	Apr	May	Jun	Jul	Aug	Sept
Brooks	3.1	3.4	4.6	3.3	3.4	3.6	15.2	11.0	9.4	11.0	10.5	13.0
Calmar	3.4	3.8	4.9	4.3	4.5	4.0	12.6	10.3	7.4	6.1	8.0	10.0
Edson	3.4	4.3	5.3	5.2	4.6	3.7	11.0	9.5	6.6	5.4	6.0	8.1
Fairview	3.2	4.1	3.8	3.8	4.3	3.7	12.6	13.7	7.0	7.2	8.8	8.4
Lac la Biche	3.2	3.5	3.9	4.4	3.8	3.8	11.5	10.8	7.6	6.3	7.9	9.7
Lacombe	3.6	3.8	4.8	4.2	4.3	4.2	11.3	10.5	6.8	6.6	8.0	9.8
Pekisko	4.8	5.0	5.6	3.8	4.3	4.4	9.8	10.3	8.1	11.3	10.2	12.2
Consul	3.2	3.6	4.1	3.2	3.5	3.5	17.0	12.8	8.3	12.1	15.7	19.2
Choiceland	3.0	3.4	4.0	3.1	3.6	3.6	17.7	14.7	10.6	6.5	9.2	11.9
Lintlaw	3.7	3.6	4.4	3.7	4.0	4.0	11.3	9.6	7.3	6.8	7.6	9.4
Regina	3.6	3.8	4.4	3.4	3.6	3.7	11.9	10.6	6.8	7.2	9.4	11.1
Saskatoon	3.2	3.6	4.0	3.6	3.6	3.9	12.9	10.8	7.6	7.0	9.0	9.9
Swift Current	3.6	3.7	4.2	3.4	3.6	3.7	11.9	10.6	6.8	7.2	9.4	11.1
Turtleford	2.5	3.6	3.4	3.8	3.4	3.6	18.7	14.8	8.0	8.4	9.1	12.7
Brandon	3.1	3.6	3.8	3.7	3.5	3.4	12.9	9.4	6.8	7.6	8.3	11.2
Churchill	4.1	4.2	3.9	4.1	4.2	4.9	8.6	8.6	9.3	7.6	6.9	5.9
Indian Bay	3.4	4.0	4.2	3.8	3.5	3.4	10.8	8.8	6.8	6.3	7.6	8.1
Morden	3.3	3.8	4.0	3.5	3.4	3.4	11.7	9.3	7.6	7.7	9.2	10.4
Neepawa	3.4	3.8	3.7	3.4	3.1	3.5	12.4	10.1	7.4	7.0	8.5	11.4
Pierson	3.1	3.7	4.0	3.0	3.1	3.6	15.0	10.5	7.3	8.4	9.4	13.8
The Pas	3.7	3.7	4.4	3.6	4.2	4.4	11.0	11.3	8.1	5.7	5.9	7.6

The values given for a specific month in Tables 1 and 2 can be plotted on a map and analyzed. The number of values are few and conclusions must be used with caution. Yet the maps do show some features of the climate of the prairies. Figure 3 gives the map of the southern prairies with the probabilities of a wet day following a wet June day. On it, isolines are drawn for p = 0.56, 0.52, and 0.46. Along these lines, the 10-percentile of lengths of wet periods are 5, 4.5, and 4 days, respectively. Figure 4 gives a similar map for dry July periods. On this map, isolines for p = 0.61 to p = 0.80 give the lines along which the 10-percentiles of the lengths of dry periods are 6 to 11 days.

In drawing the maps, Figures 3 and 4, one recognizes that the data are scarce and for that reason the reliability of the lines is slight. On the other hand, the data fall into patterns which seem to fit the information on precipitation amounts and variability, and therefore, can be accepted as giving a first approximation to the true values.

CORRELATIONS OF AMOUNTS OF PRECIPITATION

Another relationship examined was to determine the extent to which rain at one location implies rain at another location. The technique used was to compute correlation coefficients between monthly precipitation totals for the months April to September, using data from the 30 years,1940 – 1969. Correlation coefficients were also used combining all monthly values for the total period, but with normal monthly values subtracted to give the departures of the precipitation from the normal for the month. Twenty-four stations were selected for analysis, 22 in Alberta and 2, Biggar and Leader, in western Saskatchewan. Seven sets of r_{ij}, i and j both going from 1 to 24, were obtained with the use of the University of Alberta computer.

One example of the use of the results is seen in Figure 5. This gives the correlations for June precipitation with Ranfurly. The pattern does not differ from the expected pattern, i.e., that correlations are high with the stations near Ranfurly with the values dropping off rapidly to 0.30 and to slight negative values in the Lethbridge area.

Figure 6 gives the relationship between the correlations for the seasonal precipitation and the distance between the stations by plotting the individual values. The scatter is less here than for any of the plots for the individual months. The diagram shows that the correlation coefficients decrease with increasing distance. According to the graph, the value of the correlation seldom is above 0.40 when the stations are more than 200 miles apart and at times the coefficient drops to a small negative value.

Figure 7 summarizes the data shown in Figure 6 and also for the individual months by showing how the mean values grouped into 50-mile intervals varies with the distance. The 25 values where the distance was over 450 miles are formed into one group. Coefficients for distances over 250 miles are so variable and the values so small that the trends are irregular. For distances from 0 to 250 miles, there is a drop in the mean as the distance increases.

The curve for April shows the best relationship, with September a close second, and that for July the worst. If we take the value of r = 0.40 as indicating a marginal relationship, then correlations are significant in April, August, and September up to a distance of 200 – 225 miles. For June and for the total season, significant correlations are found at 150 miles dropping to 120 miles in May and to only 100 miles in July. This variation is, of course, related to the organization of and sizes of storms that produce precipitation on the prairies. July storms are convective, and although they may give a large amount of precipitation in one locality, the precipitation can be small 100 miles away.

Observations from three stations along the Bow River, Lethbridge, Magrath, and Taber were used in the study. Coefficients between values from these three stations are high, 0.80 and above. But the correlations with stations at a distance are small, and frequently negative. Correlations between Lethbridge or Taber on the one hand and Edson, Calmar, or Sion on the other in the month of June are in the range -0.20 to -0.30, and with Wagner or Lac la Biche -0.35 to -0.40. Although these values are not great, they do suggest that there is a tendency for rain to fall in any one year on one of these two areas and not the other.

The data showed some evidence that west-east combinations tended to show higher correlations than north-south pairings. But the stations were poorly selected to produce any clear evidence of such a relationship.

CLIMATIC TRENDS

The "Climate of the Prairie Provinces" gave the 10-year running mean annual precipitation for five river basins of the prairies and discussed the other curves. The data used to determine the running means were the values given for the river basins in the Monthly Record of Meteorological Observations.

The curve for the Peace River Basin in Alberta illustrates the danger of the method used. Figure 8 gives (curve a) the trend found using the Monthly Record values. Curve (b) shows the trend based on the precipitation at Beaverlodge, Fairview, Fort Vermilion and Fort St. John. For the period from 1933 to 1960, the curves are similar. No reason can be found for the lower values for curve (a) for the initial period, but it may be that the stations not used were, on the average, stations with less precipitation than the chosen four. The divergence after 1960 arose because in the 1950's stations were established at Alberta Forest Service fire-lookout stations. These were stations with greater precipitation than the valley stations. Because of these, the mean value for the basin was greater than it otherwise would have been. In an area, such as the Peace River Basin where the precipitation varies widely from place to place, mean values from observed data may not be representative. The curve of the 10-year running mean for the Churchill River Basin was suspect for this same reason, and no curve was determined for the Rocky Mountain area. For the prairie districts, the number of stations was generally large and precipitation differences sufficiently small so that the means should be representative. There could be an error in the trend for the South Saskatchewan Basin of Alberta because of the shifting of some foothill stations such as Pekisko and Lundbreck from this district to the Rocky Mountain area about 1950. However, with the large number of stations, the shift would not cause much of an error in the trend.

Figure 9 gives the running mean precipitation by seasons for the Assiniboine River Basin of Saskatchewan. This district was chosen because it has the best defined cyclical variation in precipitation. The curves show clearly that winter and spring precipitation varied little during the past 50 years, but that the major cause for the changes in the annual precipitation was the variations found during the summer months. The increase in the 1920's was partially a result of a one-inch increase in the autumn precipitation. Wet autumns were also found in the southern areas of Manitoba. For the area as a whole, the variations noted in the annual trends reflect the trends of summer precipitation.

Figure 10 gives the 10-year running mean precipitation for five more river basins, the Red Deer and North Saskatchewan of Alberta, the North and South Saskatchewan of Saskatchewan, and the Assiniboine of Manitoba. A study of the figure, and a comparison of the cures with those of Figures 8 and 9 confirm statements made in the previous report that the trends in precipitation vary from river basin to river basin. One cannot treat the prairie area of Canada as a unit when considering precipitation. This fact was also seen in the results of the study of inter-station correlations of precipitation.

CONCLUSION

This report gives information about precipitation over the prairie provinces of Canada. It treats the variability of precipitation from year to year and from station to station. The results show clearly that this region is one of extreme variability spatially as well as in time and one should not generalize too much when speaking of the rainfall over these three provinces.

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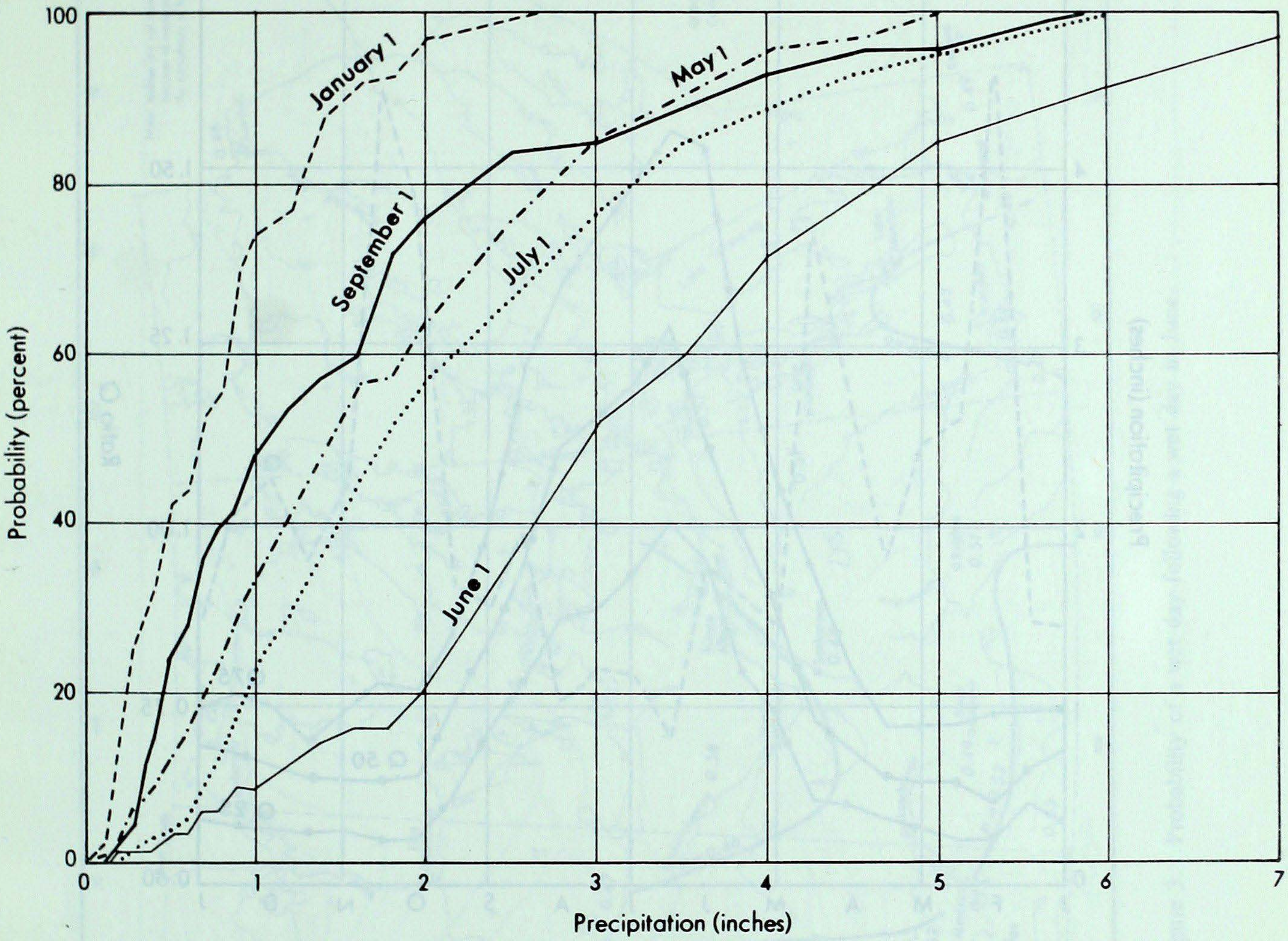

Figure 1. For Indian Head, probability of less than the given amount of precipitation in 30 days starting on a given date.

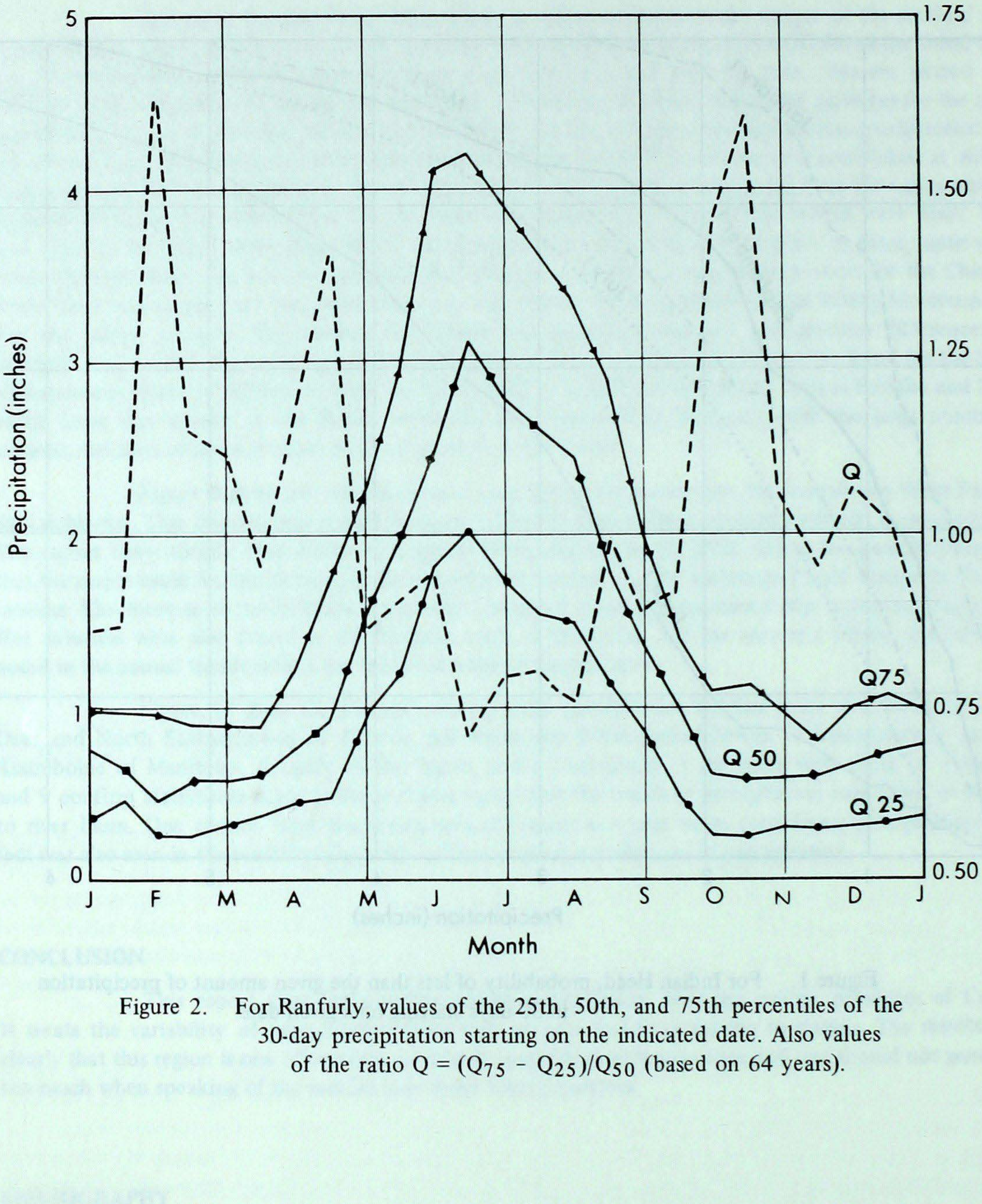

Figure 2. For Ranfurly, values of the 25th, 50th, and 75th percentiles of the 30-day precipitation starting on the indicated date. Also values of the ratio $Q = (Q_{75} - Q_{25})/Q_{50}$ (based on 64 years).

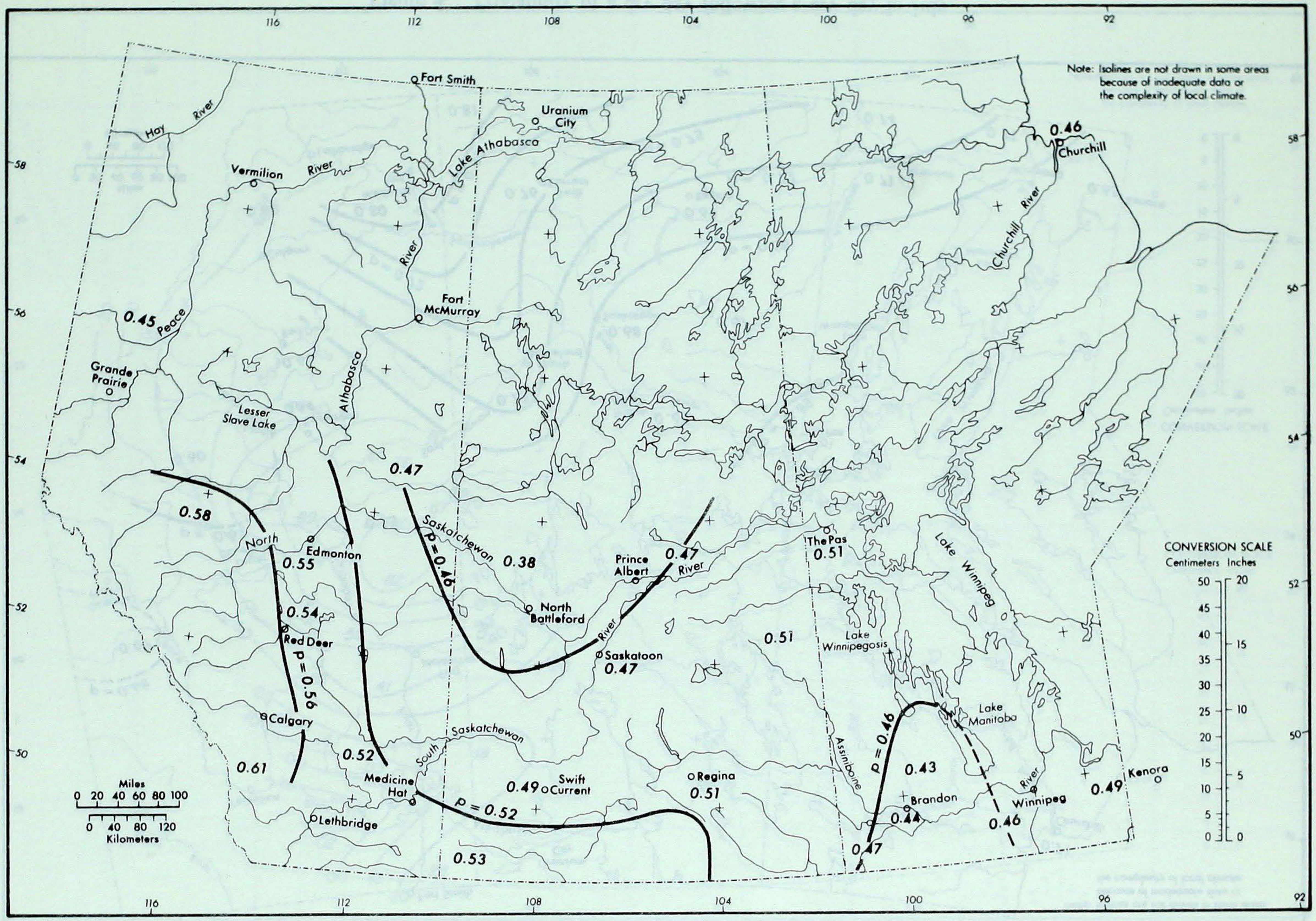

Figure 3. Probability of a wet day following a wet day in June.

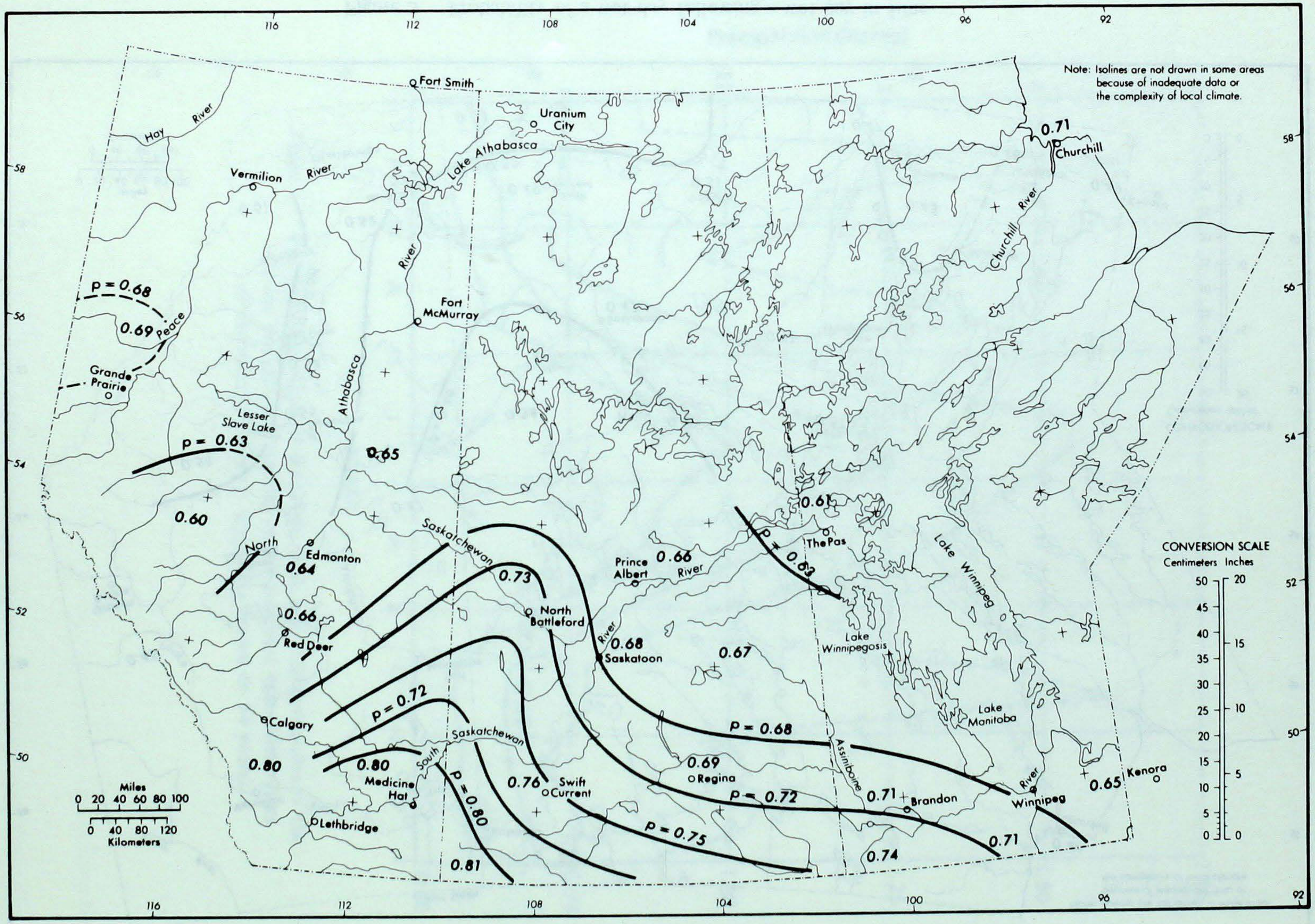

Figure 4. Probability of a dry day following a dry day in July.

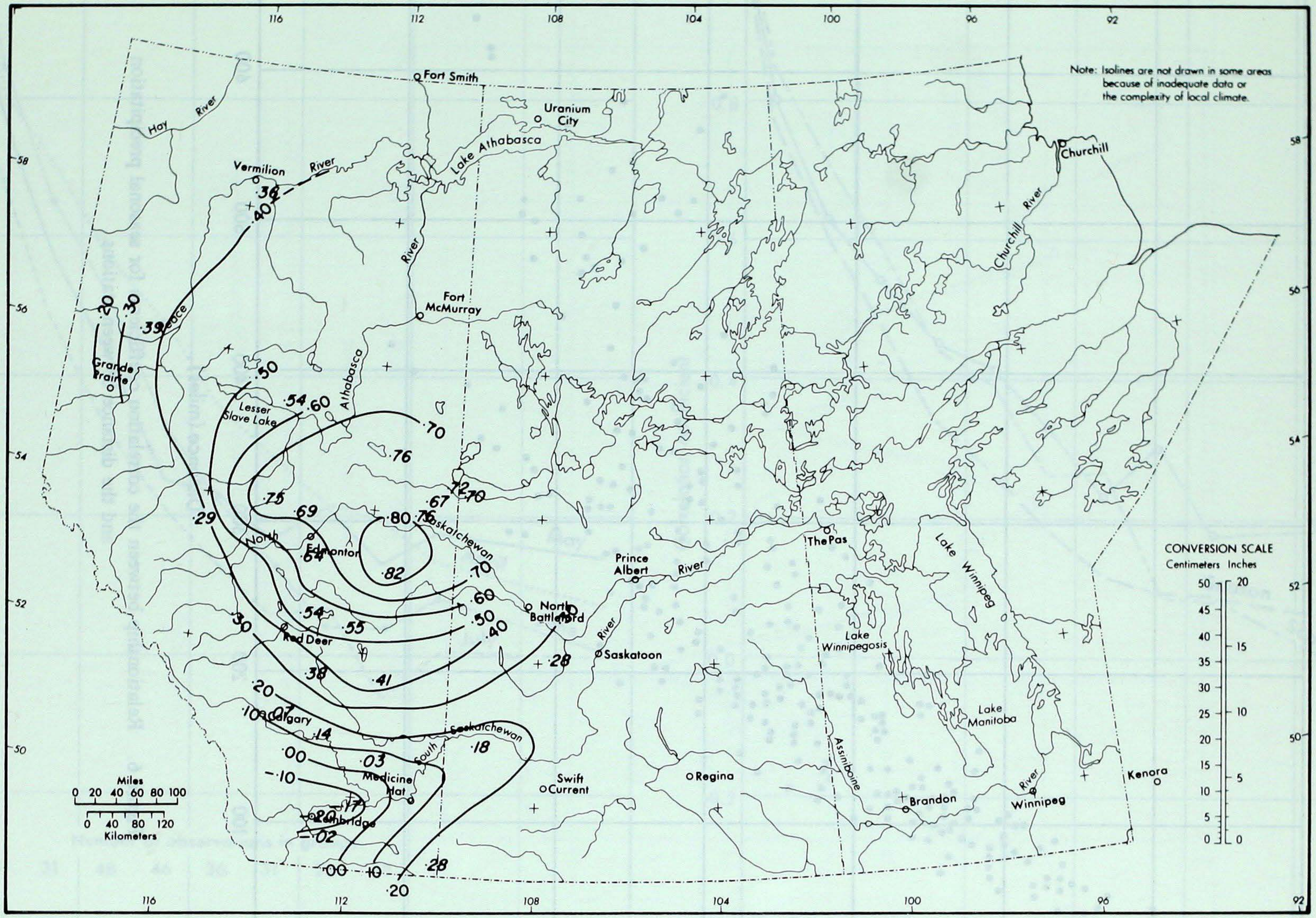

Figure 5. Correlation of monthly precipitation, April – September, with that at Ranfurly.

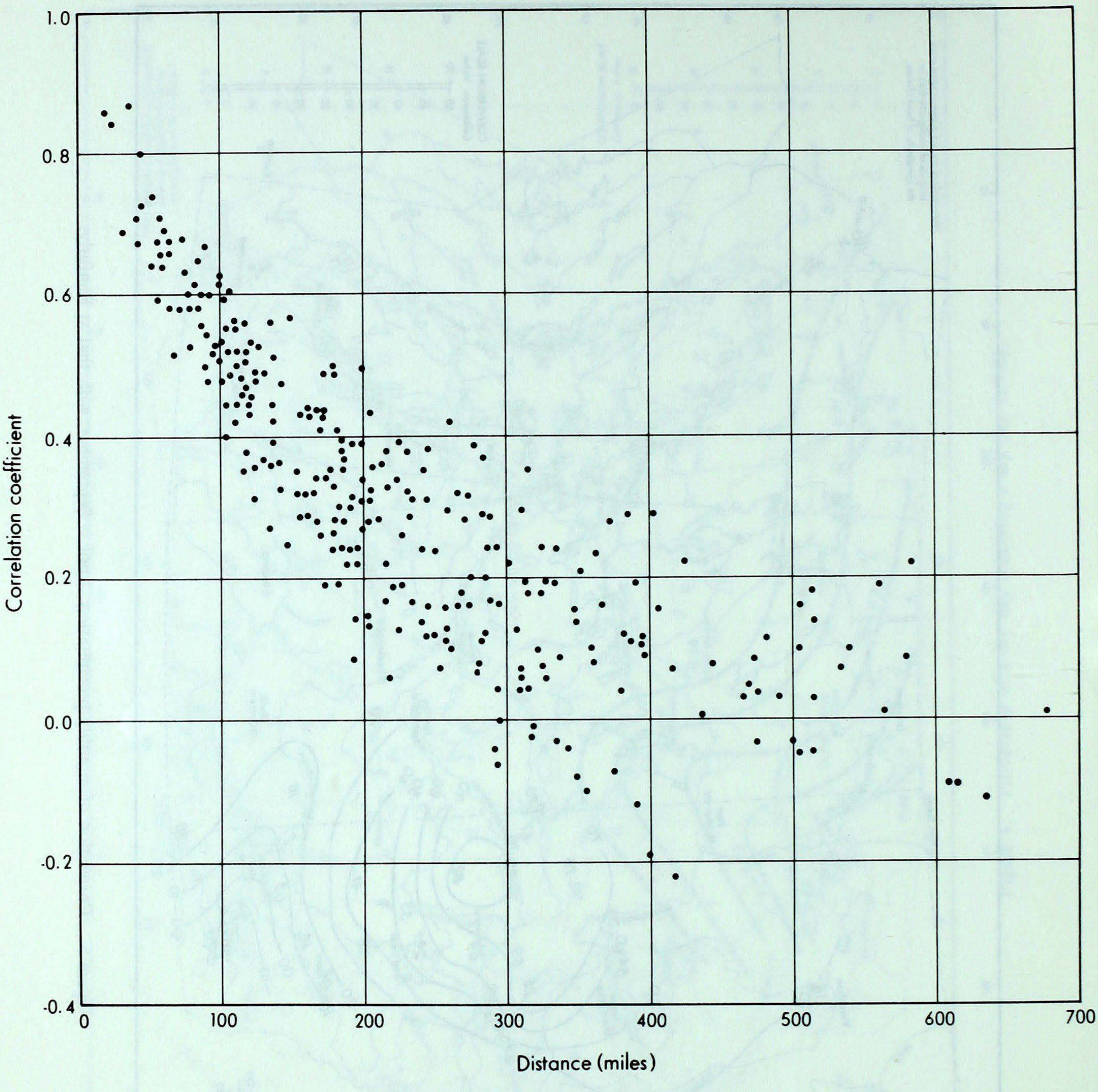

Figure 6. Relationship between the correlation coefficients for seasonal precipitation and the distance between stations.

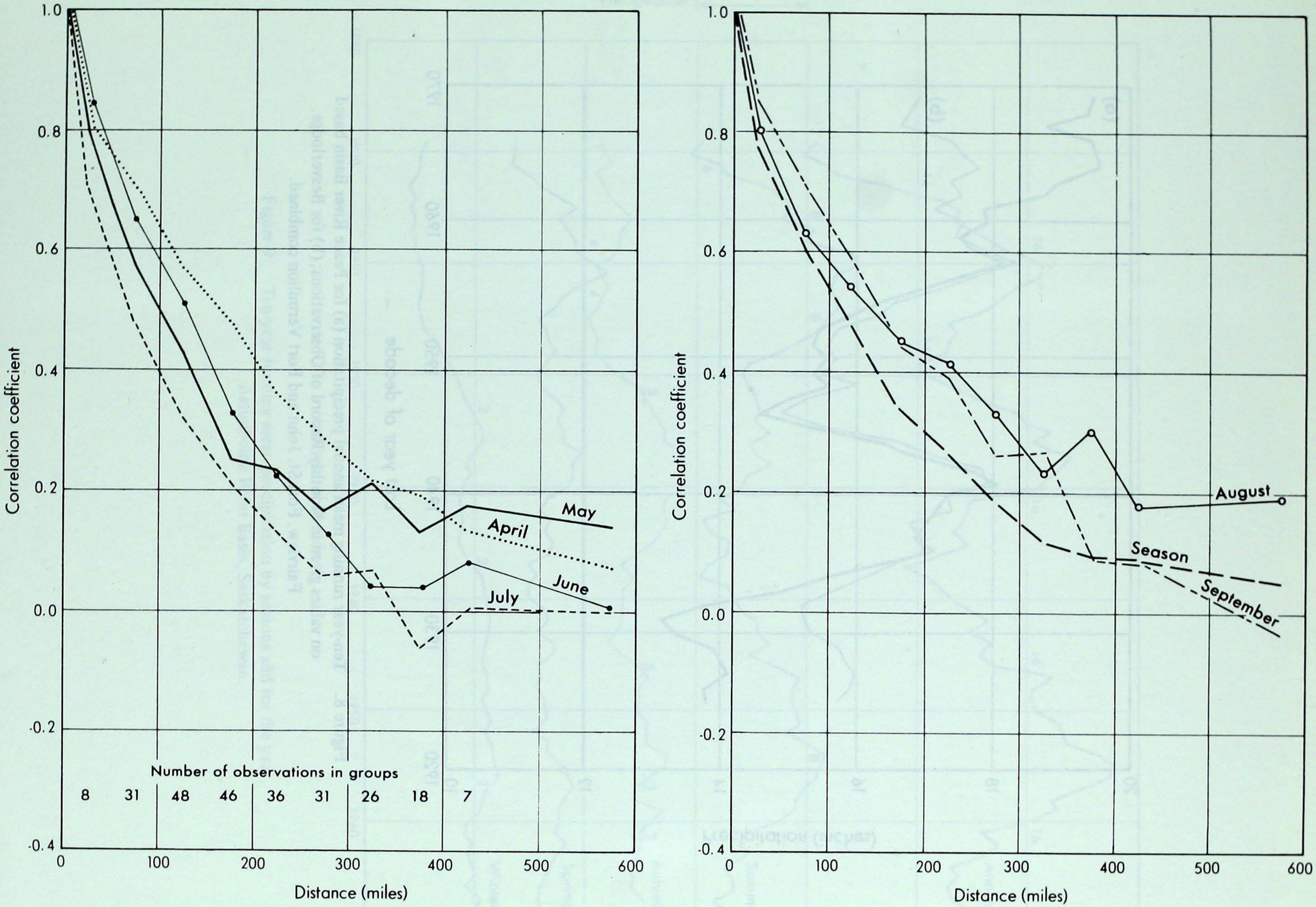

Figure 7. Decrease of correlation coefficients of monthly precipitation with distance.

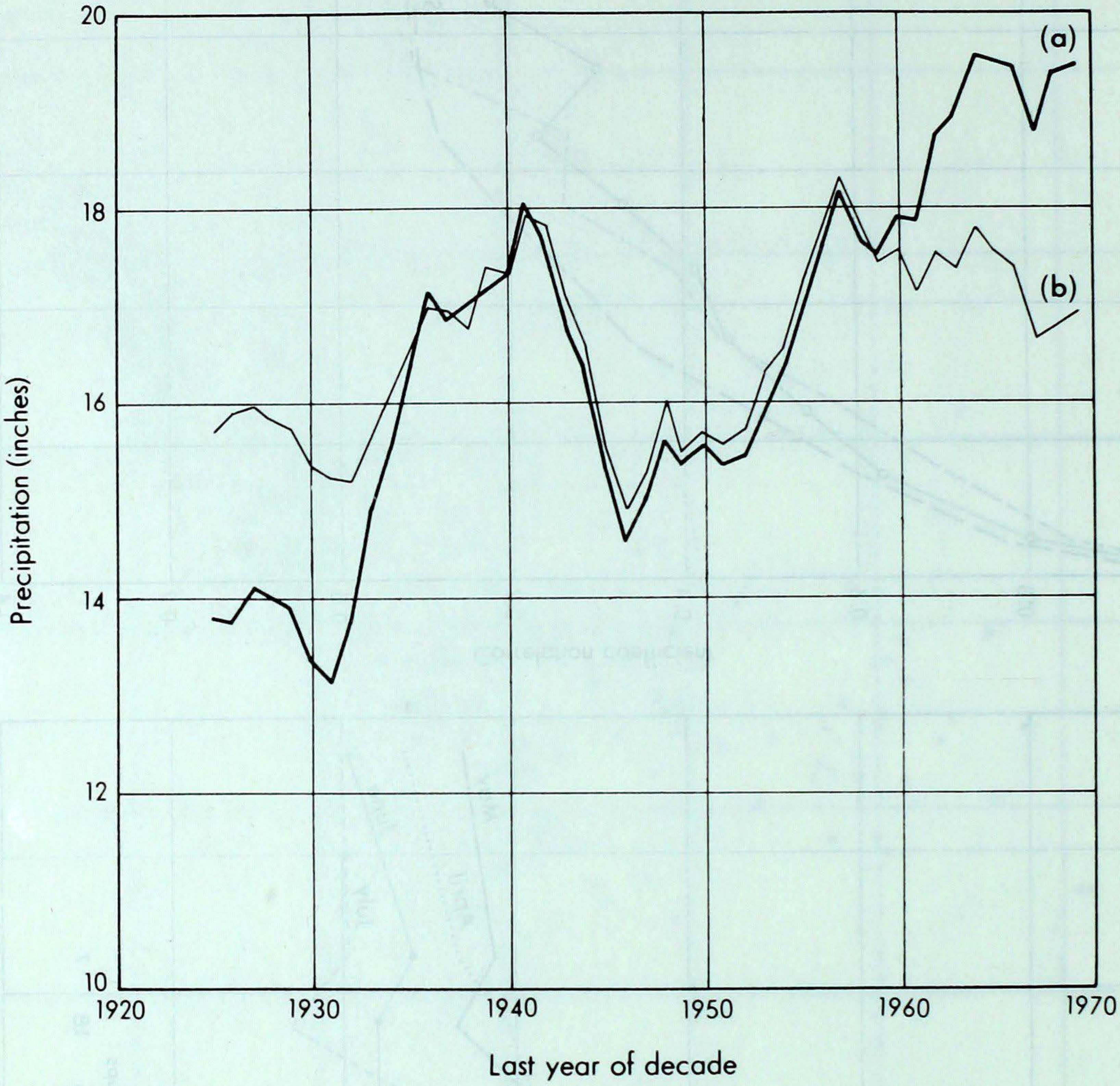

Figure 8. Ten-year running mean annual precipitation (a) for Peace River Basin based on values given in Monthly Record of Observations; (b) for Beaverlodge, Fairview, Fort St. John and Fort Vermilion combined.

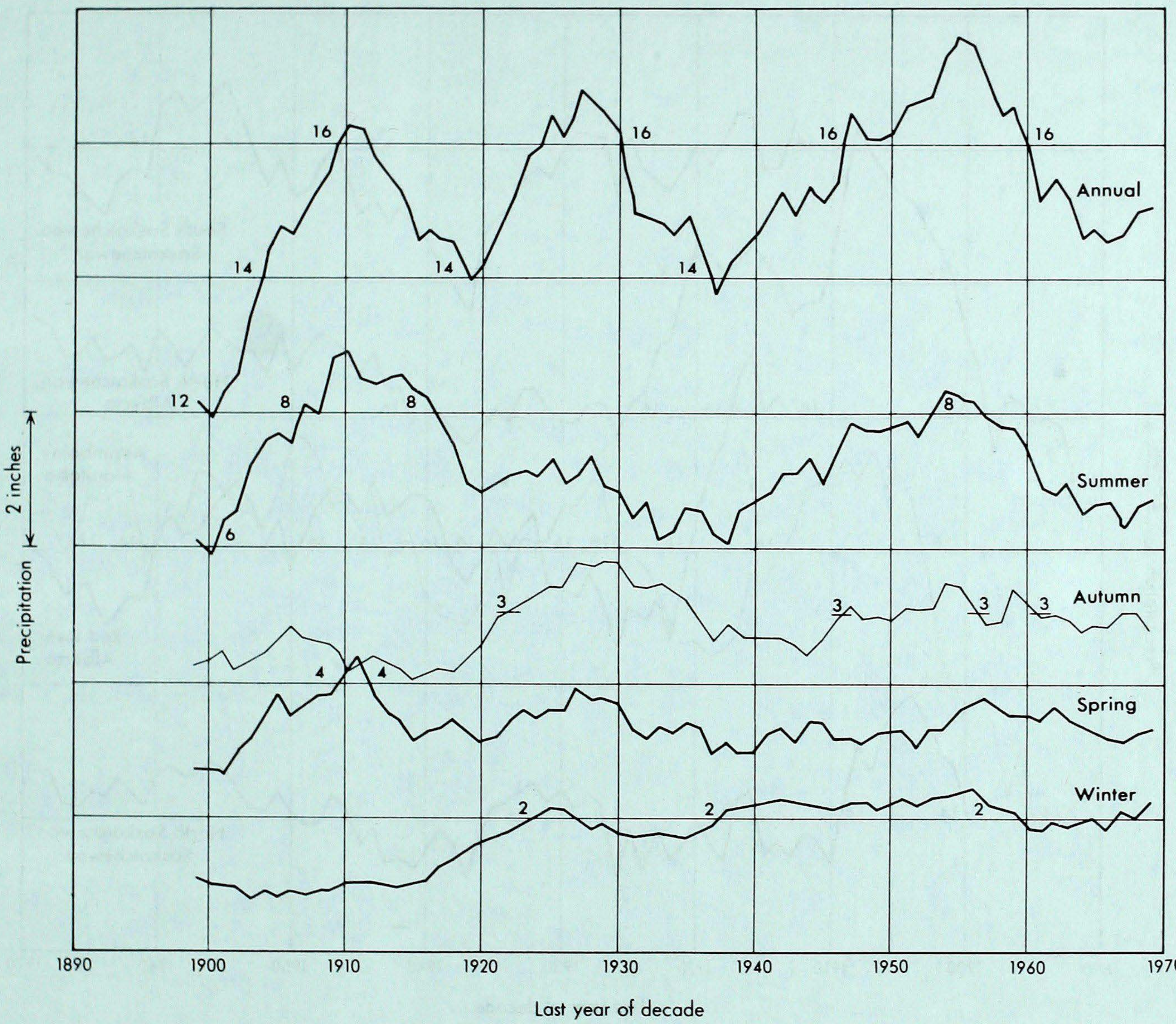

Figure 9. Ten-year running mean precipitation by seasons and for the year, Assiniboine River Basin, Saskatchewan.

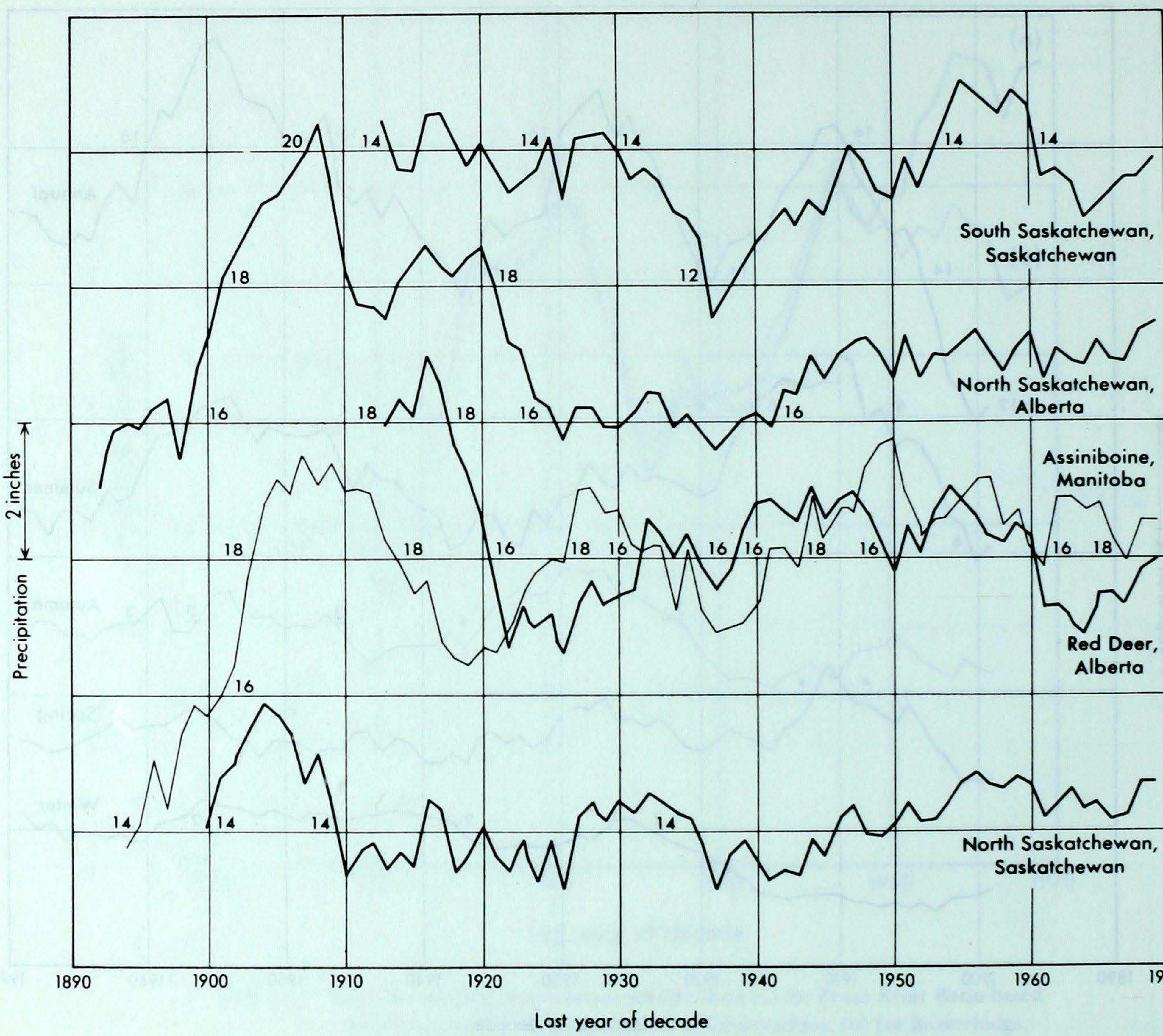

Figure 10. 10-year running mean precipitation for selected river basins.