ASSESSING RAINFALL EROSION RISK IN SOUTHERN SASKATCHEWAN FROM DAILY RAINFALL RECORDS

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ABSTRACT

A mean annual rainfall erosion index (R1daily) calculated from daily rainfall records satisfactorily compared with the mean annual erosion index (R) calculated using the more accepted method with hourly rainfall records. An R1daily contour map of Southern Saskatchewan was constructed from a greater number of weather stations keeping daily rainfall records compared to the R contour map constructed from very few stations that keep hourly rainfall records. It was concluded that the R1daily contour map provided a more reliable assessment of rainfall erosion potential than the R contour map because the former distinguished local areas with high values and interpolation of rainfall risk involved much shorter distances between point measurements.

Since significant erosion requires a combination of rainfall detachment as well as runoff, a runoff model that operated from daily climatic records was used to determine which days with rainfall also produced runoff. The runoff model was run for 62 stations in southern Saskatchewan and only days that produced runoff were included in the annual erosion index total. This effective erosion index (Reff) varied from 3.4 to 83.9% of R1daily and was particularly sensitive to soil texture. Heavy-textured soils were, on average, more than four times as susceptible to water erosion than light-textured soils. It should be noted that the analysis does not include the effects of slope length and steepness, the crop canopy nor soil erodibility.

INTRODUCTION

Water erosion is closely related to rainfall since rainsplash is an important mechanism of soil detachment and rainfall patterns have a strong effect on runoff generation (Morgan 1986). In the Universal Soil Loss Equation (USLE), the erosivity of the rainfall is expressed as an index, R, based on the kinetic energy of the storm (Wischmeier and Smith 1958; Zanchi and Torri 1980). Calculation of R requires a continuous record of rainfall intensity over a period of several decades. Unfortunately, records of this sort are usually not widely available. In Saskatchewan, hourly rainfall values are the most detailed records kept on a routine basis, but are available only for about a dozen major weather stations in the agricultural portion of the province. Wigham and Stolte (1986) used the procedure of Wischmeier and Smith to calculate the R value for a number of stations on the Canadian prairies. They commented on the limited length of the records for most of the stations. Daily rainfall records are available for much longer periods and for many more stations than just at the major weather stations. An estimate of the rainfall erosion index from daily rainfall records would be useful for providing input to erosion models and for assessing erosion risk in areas where detailed hourly records are not available for a sufficiently long period of time.

Soil detachment and transport occurs by rainsplash and by runoff (Edwards and Burney 1987). The relative importance of splash and runoff is still subject to debate (Thompson et al. 1986). Foster et al. (1981) concluded that erosivity indices based on volume and rate of runoff may be better than the R value since the R value over-estimates the soil loss that occurs with negligible runoff, and conversely, under-estimates the erosion when runoff is great relative to rainfall.

The objectives of this study were:

(1) to compare rainfall erosion indices calculated from hourly data using different simplifying assumptions to previously published estimates by the Wischmeier and Smith approach,

(2) to compare the erosion index calculated from hourly data with an index calculated from daily rainfall records, and

(3) to combine the estimated daily erosivity with a daily runoff model to determine an "effective" erosion index for days in which there was runoff produced.

MATERIALS AND METHODS

Calculation of Erosion Indices

In the method of Wischmeier and Smith (1978), the rainfall erosion index R is calculated from the kinetic energy of a storm and the maximum 30 minute rainfall intensity for that storm. The storm is divided into a number of periods of equal intensity and the total kinetic energy is summed over the various periods as shown in Equations [1] to [3] (Foster et al. 1981):

$$e_j = 0.119 + 0.0873 \log_{10}(ij), \qquad i_j \leq 76 \text{ mm h}^{-1} \qquad [1]$$

$$e_j = 0.283, \qquad i_j > 76 \text{ mm h}^{-1} \qquad [2]$$

where e_j = kinetic energy per mm rainfall for time interval j (MJ ha^{-1} mm^{-1})

i_j = rainfall intensity in time interval j (mm h^{-1}).

$$E = \sum_j e_j \cdot p_j \qquad [3]$$

where E = kinetic energy for a rainfall event (MJ ha^{-1})

p_j = rainfall in time period j.

The equation for the rainfall erosion index, R, is

$$R = E \cdot I_{30} \qquad [4]$$

where I_{30} = maximum 30 minute rainfall intensity (mm h^{-1}).

Storms with less than 13 mm rainfall are not included in the calculation of R and storms separated by less than 6 h are considered a single event (Wischmeier and Smith 1978).

For this study, four rainfall erosion indices were calculated by combining the rainfall kinetic energy, as calculated from hourly rainfall values, with different measures of rainfall intensity. Days with less than 5 mm rainfall were not included in the annual rainfall erosion index total. Table I lists the stations and the lengths of rainfall record used in calculating the annual erosion indices as shown in Equations [5] to [8]:

$$R1 = E \cdot I_{30} \qquad [5]$$

$$R2 = E \cdot I_{60} \qquad [6]$$

$$R3 = E \cdot \text{MAXHR} \qquad [7]$$

$$R4 = \text{SUMKE} \cdot \text{SUMI}_{30} \qquad [8]$$

where E = daily kinetic energy calculated with Equation [3] using 24 periods of 1 h

I_{30} = maximum daily 30 minute rainfall intensity (from daily rainfall data)

I_{60} = maximum daily 60 minute rainfall intensity (from daily rainfall data)

MAXHR = maximum hourly rainfall amount (from hourly rainfall data)

SUMKE = storm kinetic energy value calculated by summing daily KE values for consecutive days of rainfall

SUMI_{30} = maximum 30 minute rainfall intensity for a storm taken from consecutive days with rainfall.

In Equations [5] to [8], no attempt was made to separate individual storms that might occur on any given day. Because of this, the calculation is simpler than the detailed calculation according to Wischmeier and Smith (1978), but the four indices may over-estimate the true R values by joining individual storms which are separated by periods of more than 6 hours. The advantage of calculating R3 is that only one set of records (the hourly rainfall data) needs to be accessed. To assess the success of these simplified calculations, the four erosion indices (R1, R2, R3 and R4) were compared to the erosion indices calculated by Wigham and Stolte (1986).

Erosion Index Versus Daily Rainfall

For each of the major climatic stations shown in Table I, daily rainfall was calculated by summing the hourly rainfall for each day. The R1 value (equation 5) was then plotted against daily rainfall using a relationship of the form (Richardson et al. 1983):

$$R1 = a\,\mathrm{Rain}^{b} \qquad [9]$$

where Rain = daily rainfall

a,b = equation coefficients.

Days with less than 5 mm of rainfall were excluded from the comparison because of the large number of points with an extremely low erosion index.

The daily rainfall records from 62 climatic stations in the agricultural region of Saskatchewan with at least 15 years of record were then used as input for equation [9] to calculate R1daily. A contour map of mean annual R1daily for Southern Saskatchewan was constructed from the 62 point measurements.

Combining Erosivity and the Occurrence of Runoff

An effective rainfall erosivity (Reff) was calculated for each of the 62 daily reporting stations by summing the R1daily values for those rainfall days on which runoff was also estimated to have occurred. Thus, Reff, is calculated in exactly the same manner as R1daily except that the Reff annual total includes only those days when runoff was produced. Estimation of days which produced runoff was based on a runoff model similar to the Versatile Soil Moisture Budget (Dyer and Mack 1984). The model, which uses a daily time step, divides the soil into six layers each with a defined available water and saturation capacity based on soil texture (Fig. 1). The model inputs are daily maximum and minimum temperature, rainfall, snowfall and potential evaporation.

Runoff was predicted using a variation of the SCS curve number technique (McCuen 1981):

$$Q = \frac{(P - 0.2s)^2}{(P - 0.8s)} \qquad [10]$$

where Q = runoff (mm)

P = precipitation (mm)

s = soil storage term described by

$$s = \frac{25400}{CN} - 254 * \left(1 - \frac{(W(1) + W(2))}{(Sat(1) + Sat(2))} \right) \qquad [11]$$

where W(1), W(2) = water content of soil layers 1 and 2 (mm)

Sat(1), Sat(2) = saturation capacity of soil layers 1 and 2 (mm)

CN = SCS curve number (50 for light-textured soils, 60 for medium-textured soils and 70 for heavy-textured soils).

Infiltration (precipitation minus runoff) recharges the various layers to field capacity starting from the soil surface downwards. If infiltration exceeds the field capacity of the first layer, the excess moisture is routed to the second soil layer and so on. Excess moisture from the deepest soil layer is lost from soil storage as deep percolation.

Daily evapotranspiration is calculated by multiplying the potential evaporation by the crop water extraction coefficients based on growth stage (Table II). Each soil layer can be dried down to zero available water. The various growth stages were estimated using accumulative growing degree days (Robertson 1968): emergence, 90 growing degree days; jointing for 180 growing degree days; heading, 1050 growing degree days; soft dough, 1600 degree growing days; and ripening at 1890 degree days. All values are in degree Fahrenheit-days.

Accumulation of snow during the winter period is achieved by multiplying the snowfall by 0.9 and 0.7 for stubble and fallow fields, respectively. These coefficients were chosen because they provided the best match between predicted and measured snowpacks for a set of test data (Tabble III). The snowpack is measured in mm of water equivalent. On winter days when there was potential evaporation, the evaporation was subtracted from the snowpack. When the maximum daily temperature was above zero, snowmelt was calculated using the McKay (1964) curves as given by Dyer and Mack (1984). The snowpack was assumed to retain 15% of the snowmelt; the remainder of the snowmelt was added to the daily precipitation total. Snowmelt runoff was not included in the Reff calculation, but rain (in excess of 5 mm) on a thawing snowpack of less than 10 mm water equivalent was included in the Reff.

Infiltration into frozen soil was simulated with the equation given by Gray et al. (1984). Infiltrating water was assumed to freeze in the two top soil layers. The second layer was first filled to saturation before the top soil layer was filled. Once both soil layers were saturated, no further infiltration could occur until the soil thawed out, which was assumed to occur when the snowpack had completely melted and the mean daily temperature was above 0°C. At this time all soil layers were assumed to drain to field capacity.

The performance of the model during the critical early spring period was calibrated using data from a small basin study near Saskatoon (Table III). The most critical criteria was the predicted runoff dates. During the time of the basin study, there were some complex spring runoff patterns and, due to the simplicity of the model, it was not possible to match the dates or volumes precisely. However, the data were useful for calibrating snow coefficients and root water extraction coefficients. It was necessary that the runoff model run on the minimal inputs listed earlier which is the reason for using this particular type of runoff model. Although it is simplistic in nature, it fits well with the daily data being used in this study and was considered to be a reasonable tool for estimating days when runoff was produced.

RESULTS AND DISCUSSION

The arithmetic mean annual value for the four erosion indices is shown in Table I for the major climatic stations used in this study. The mean annual R1 was on average, 1.5 times larger than the mean annual value for R2, indicating the difference in maximum daily 30 and 60 minute rainfall amounts. Calculating the erosion index using the maximum hourly precipitation, R3, resulted in a value halfway between R1 and R2. The difference between R2 and R3 reflects the difference between the maximum hourly precipitation and the maximum 60 minute precipitation for any given day and the fact that for some dates maximum 60 (and 30) minute rainfall amounts were missing. No attempt was made to estimate the missing I_{30} and I_{60}. The largest value for the erosion index were obtained when consecutive rainy days were combined into one storm as was done in the calculation of R4. On average, R4 was approximately 40% larger than the mean annual value for R1. Since R4 joins individual storms that occur within 24 hours of each other into one large storm, it may over-estimate the true value of R as calculated according to the Wischmeier and Smith (1978) procedure.

As expected, the four erosion indices were highly correlated. Since the R1 is relatively simple to calculate and is very similar to the widely accepted R value calculated by the Wischmeier and Smith (1978) procedure, it is used in the remainder of this paper. Table I shows the arithmetic mean values of the various indices, but plotting of the R1 values for the individual stations indicated that the probability distribution tends to be log normal, confirming earlier work by Kachanoski et al. (1984) and Wigham and Stolte (1986). Figure 2 is a comparison of the geometric mean annual R1 (estimated by visual line fit) for all the stations in Table I with the values for the erosion index for those stations estimated from Wigham and Stolte's (1986) map. The mean annual R1 values are consistently about 70% of the R value given by Wigham and Stolte (1986). There are three major reasons for this: Wigham and Stolte (1986) estimated missing I_{30} values, applied a correction factor to convert storm kinetic energy from hourly data to short period data, and, finally, for storms that lasted more than one day, they used the maximum I_{30} for those days (a procedure similar to that used in calculation of R4).

The rainfall erosivity indices calculated in this paper (Table I) and by Wigham and Stolte (1986) are limited by the small number of meteorological stations where hourly rainfall data of sufficient length are available. To overcome this limitation, a relationship was sought between daily rainfall and R1 using Equation [9]. For Saskatchewan, the 'a' coefficients ranged from 0.113 to 0.254 and the 'b' coefficients ranged from 1.545 to 1.933 (Table IV), similar to the results shown by Richardson et al. (1983) for the cool season in the eastern United States. Fortunately, the magnitude of the 'a' and 'b' coefficients appears to be related to the mean annual rainfall (Figs. 3a, 3b) as shown below.

$$a = 0.341 - 0.000702 \times MAR \qquad r^2 = 0.68, n = 12 \qquad [12]$$

$$b = 1.16 + 0.00231 \times MAR \qquad r^2 = 0.74, n = 12 \qquad [13]$$

where MAR = mean annual rainfall (mm).

This relationship was not apparent for the Alberta and Manitoba stations.

An estimate of R1 was calcuated using daily rainfall records as input to Equations [9], [12] and [13] (R1daily). First, the mean annual rainfall was used to obtain estimates of the a and b coefficients using equations [12] and [13]. Second, the a and b coefficents were input into Equation [9] to calculate R1daily. For each of the 62 weather stations in Southern Saskatchewan with at least 15 years of record, the daily rainfall was used to calculate R1daily for all days with greater than 5 mm of rainfall using the procedure described above. The R1daily values were summed for each year and the mean annual values were calculated for each station. For the Saskatchewan stations with both hourly and daily data, the mean annual R1daily provided a good measure of the mean annual R1 (Fig. 4). All 62 stations were used to produce a contour map of R1daily for Southern Saskatchewan. The resulting map has much greater detail concerning areas with locally high R1daily values than there is for the R value contour shown by Wigham and Stolte (1986). Also, there are much shorter distances involved with interpolating between point measurements of R1daily than with point measurements of R.

The arithmetic mean was used for the annual R1daily values since their distribution is approximately normal compared to the log normal distribution of the annual R1 values (Fig. 6). Since the probability distribution is not the same, the annual R1daily values should not be used to estimate extreme annual R1daily because they tend to underestimate the larger values. Examination of the annual R1 values for the Saskatchewan stations suggested that once in five years (80% probability) the annual R1 value will be 1.8 times higher than the mean annual R1 value and once in 10 years (90% probability) the annual R1 value will be 2.5 times the mean annual R1 (Table V). Use of these ratios to estimate extreme values is preferred rather than use of the R1daily distributions because of the underestimation problem given above.

At each of the 62 Saskatchewan stations shown in Figure 5, the runoff model was run for three different soil textures (light, medium and heavy) and with two cropping systems (fallow-crop and continuous crop). An effective erosion index (Reff) was calculated by summing the R1daily values for days that had runoff from rainfall events in excess of 5 mm per day; snowmelt runoff was not included in the calculations. No attempt was made to take into account the amount of runoff, since this would vary with slope position which is taken into account in the LS factor of the USLE. The Reff reacted more strongly to differences in soil texture than to differences in cropping practices (Table VI). The latter is not surprising in view of the similarity of the soil water extraction coefficients for the upper soil layers in cropped and fallowed fields (Table II). Other effects of cropping systems, e.g. the sheltering of the soil surface against raindrop impact, are not taken into account here and are covered by additional factors in the Universal Soil Loss Equation.

Figure 7 shows a contour map of annual Reff for the three soil textures for the fallow year (the calendar year in which no crop was grown). As discussed in the previous paragraph, the difference in effective erosion index between different cropping systems is very small, and for all practical purposes the erosivity contours in Figure 7 also apply to cropped fields.

The much lower value for Reff (Fig. 7) than either R1daily (Fig. 5) or R1 (Table I) is largely due to the fact that many of the rainfall events in June and July do not lead to runoff. Hence, Reff in these months is substantially lower than either R1 or R1daily (Fig. 8). The absence of significant runoff during the growing season is a well documented fact on the Canadian prairies where streams show maximum flows in early spring during or following snowmelt.

CONCLUSIONS

The relationship between daily rainfall and the daily rainfall factor is exponential with two coefficients that can be estimated from mean annual rainfall. The relationship between these coefficients and mean annual rainfall is not apparent for climate stations in Alberta and Manitoba.

Estimation of erosion index from daily data (R1daily), has provided a means for constructing a map of rainfall erosivity in Southern Saskatchewan using records from a wide network of weather stations that have recorded daily rainfall for many decades. This denser network of coverage helps isolate local areas with high rainfall erosion potential and shortens the distance over which rainfall erosion potential must be estimated from point measurements. This suggests that the R1daily contour map is more reliable than the R contour map (Wigham and Stolte, 1986) because the latter is based on a limited number of point measurements.

The coupling of the rainfall erosion index (R1daily) with the occurrence of runoff provides a perhaps more realistic assessment of rainfall erosion hazard since it is the combination of rainfall and runoff that causes water erosion damage. The runoff model used in this analysis was more sensitive to soil texture than to cropping practices since protection of the soil surface against water impact was not included in the calculations. The resulting index, Reff, showed large differences in erosion risk due to soil texture. The combination of climatic data and soils data has provided an alternative assessment of the R factor for Southern Saskatchewan. This can now be applied along with local topographic, soil erodibility, and crop cover data to provide a detailed appraisal of water erosion risk using the USLE for specific areas of the province.

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FIGURE CAPTIONS

Figure 1. Schematic of the soil profile used in the runoff model.

Figure 2. Comparison of mean annual erosion index for Saskatchewan stations as calculated in this paper (R1) and by Wigham and Stolte (1986). Units are MJ ha^{-1} mm h^{-1}.

Figure 3. a) Relationship between 'a' coefficient and mean annual rainfall
b) Relationship between 'b' coefficient and mean annual rainfall.

Figure 4. Comparison of mean (geometric) annual erosion index (R1) and mean (arithmetic) annual erosion index as calculated from daily rainfall (R1daily). Units are MJ ha^{-1} mm h^{-1}.

Figure 5. Contour map of mean (arithmetic) annual erosion index (R1daily), (MJ ha^{-1} mm h^{-1}) as calculated from daily rainfall for Southern Saskatchewan. Data is from 62 stations with a minimum of 15 years of daily records.

Figure 6. Probability distribution of annual R1 values (log normal) versus probability distribution of R1daily values (normal) for the Saskatoon climate data. The R1daily index underestimates the extreme events compared to the R1 index.

Figure 7. Contour maps of Reff (MJ ha^{-1} mm h^{-1}) for Southern Saskatchewan for a) light-textured soils, b) medium-textured soils and c) heavy-textured soils for the calendar year that there was no crop grown.

Figure 8. Comparison of monthly R1daily to the mean crop-fallow Reff for the Regina station.

Table I. Mean annual erosion indices calculated from hourly rainfall data

Weather Station	Period of Record	Erosion Indices (MJ ha^{-1} mm h^{-1})			
		R1	R2	R3	R4
Bad Lake	1972-1982	256	172	195	283
Broadview	1965-1982	399	255	223	462
Estevan	1964-1982	828	538	489	906
Hudson Bay	1966-1982	503	396	363	565
Kindersley	1966-1982	207	127	176	316
Nipawin	1973-1982	464	287	372	720
Outlook	1963-1982	256	162	193	406
Regina	1960-1982	551	386	335	610
Saskatoon	1960-1982	334	233	245	432
Swift Current	1961-1982	405	258	254	500
Wynyard	1964-1982	637	422	373	764
Yorkton	1970-1982	783	497	443	869
Glenlea	1967-1982	1158	734	683	1311
Gimli	1972-1982	946	606	617	1220
Morden	1977-1982	671	420	659	1248
Winnipeg	1960-1982	1114	695	634	1242
Beaverlodge	1960-1982	367	234	243	469
Calgary	1960-1982	239	158	226	405
Edson	1970-1982	217	144	406	829
Lacombe	1963-1982	514	344	344	696
Lethbridge	1960-1982	219	151	297	474
Peace River	1965-1982	109	72	169	288
Slave Lake	1972-1982	142	100	217	400

Table II. Root extraction used in the runoff model

Soil layer	Growth stage				
	P-E[†]	E-J	J-H	H-S	S-R
1	0.36	0.36	0.36	0.36	0.36
2	0.12	0.17	0.22	0.27	0.27
3	0.10	0.11	0.13	0.18	0.18
4	0.09	0.11	0.11	0.14	0.14
5	0.01	0.02	0.07	0.08	0.06
6	0.00	0.01	0.02	0.03	0.02

[†] Growth stages are P-E Planting to Emergence (includes bare soil), E-J Emergence to Jointing, J-H Jointing to Heading, H-S Heading to Soft Dough, S-R Soft Dough to Ripening

Table III. Comparison of measured and predicted runoff for the Floral Basin

	Measured[†]			Predicted[‡]		
		Runoff			Runoff	
Year	Snowpack mm	Date	Amount mm	Snowpack mm	Date	Amount mm
1962	75	April 5-17	4	48	April 4-8	12
1963	14	March 21-24	6	37	March 23-26	9
1964	70	April 2-10	8	40	April 2	9
1965	74	April 5-16	30	61	April 5-16	30
1970	ND[§]	April 5-9	42	82	April 8-12	52
1971	ND	April 8-18	27	72	April 8-10	23
1972	ND	March 15-April 14	22	88	April 1-10	57

[†] Data from Saskatchewan Research Council, Drainage Basin Study, Report Nos. 2, 3, 4, 5 and 8

[‡] Data from Saskatoon meteorological station (13 km west)

[§] ND - no data

Table IV. Coefficients from the exponential relationship between erosion index (R1) and daily rainfall

	Coefficients for Equation 9			
Weather station	From regression of R1 versus Rain		Predicted with Equations 12 and 13	
	'a'	'b'	'a'	'b'
Bad Lake	0.204	1.627	no daily rainfall data available	
Broadview	0.187	1.717	0.137	1.837
Estevan	0.124	1.933	0.111	1.923
Hudson Bay	0.140	1.823	0.102	1.953
Kindersley	0.186	1.545	0.181	1.688
Nipawin	0.113	1.786	0.086	2.005
Outlook	0.254	1.554	0.169	1.730
Regina	0.148	1.843	0.145	1.810
Saskatoon	0.178	1.691	0.162	1.753
Swift Current	0.161	1.716	0.167	1.737
Wynyard	0.148	1.796	0.128	1.864
Yorkton	0.120	1.918	0.104	1.946

Table V. Ratios of the (1in 10 year index/mean index) and the (1 in 5 year index/mean index).

Weather Station	(1 in 10 year index/mean index)	(1 in 5 year index/mean index)
Bad Lake	2.35	1.72
Broadview	1.65	1.40
Estevan	3.49	2.25
Hudson Bay	2.43	1.82
Kindersley	2.77	1.95
Nipawin	2.06	1.62
Outlook	2.10	1.62
Regina	2.01	1.57
Saskatoon	2.85	1.97
Swift Current	2.27	1.66
Wynyard	3.39	2.23
Yorkton	3.03	2.03
Average	2.53	1.82

Table VI. Assessment of effective rainfall erosion index (Reff) from the runoff model for selected weather stations

Texture	Cropping System	Ratio (Reff/R1daily)			
		Swift Current	Regina	Saskatoon	Prince Albert
Light	Crop/Fallow	0.13	0.23	0.16	0.16
Light	Continuous Crop	0.13	0.23	0.16	0.16
Medium	Crop/Fallow	0.33	0.45	0.41	0.36
Medium	Continuous Crop	0.33	0.45	0.40	0.35
Heavy	Crop/Fallow	0.69	0.75	0.70	0.70
Heavy	Continuous Crop	0.69	0.73	0.69	0.68

Soil Layer	Depth (cm)	Available Water (mm) Texture Light	 Medium	 Heavy	Saturated Water Content (mm of water above PWP)
1	6	5.0	7.5	10	24
2	9	7.5	11.25	15	36
3	15	12.5	18.75	25	60
4	30	25	37.5	50	120
5	30	25	37.5	50	120
6	30	25	37.5	50	120

Figure 1.

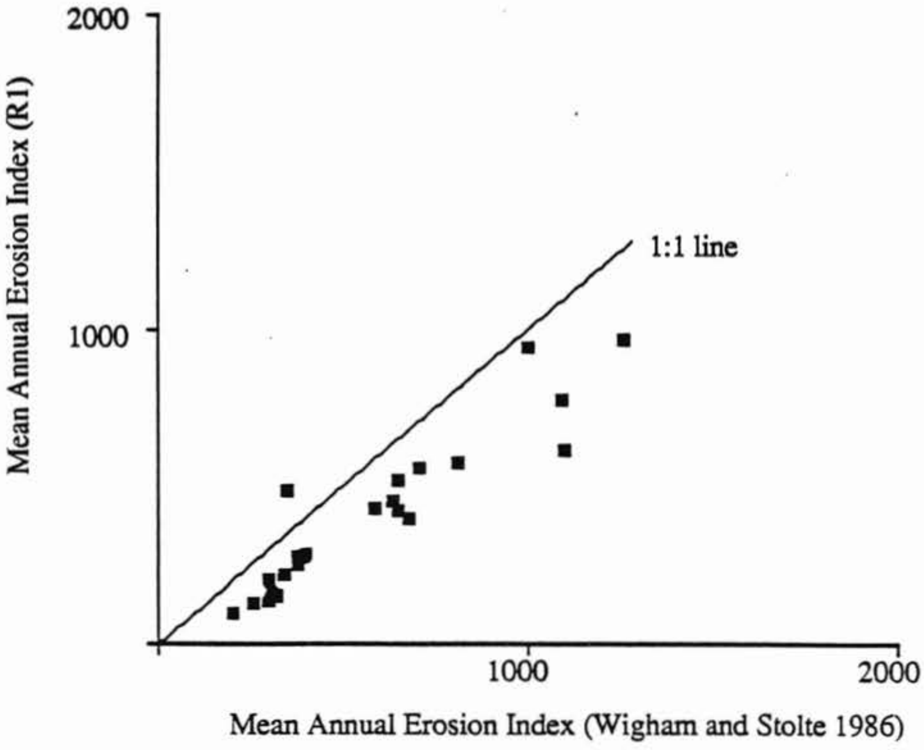


Figure 2.

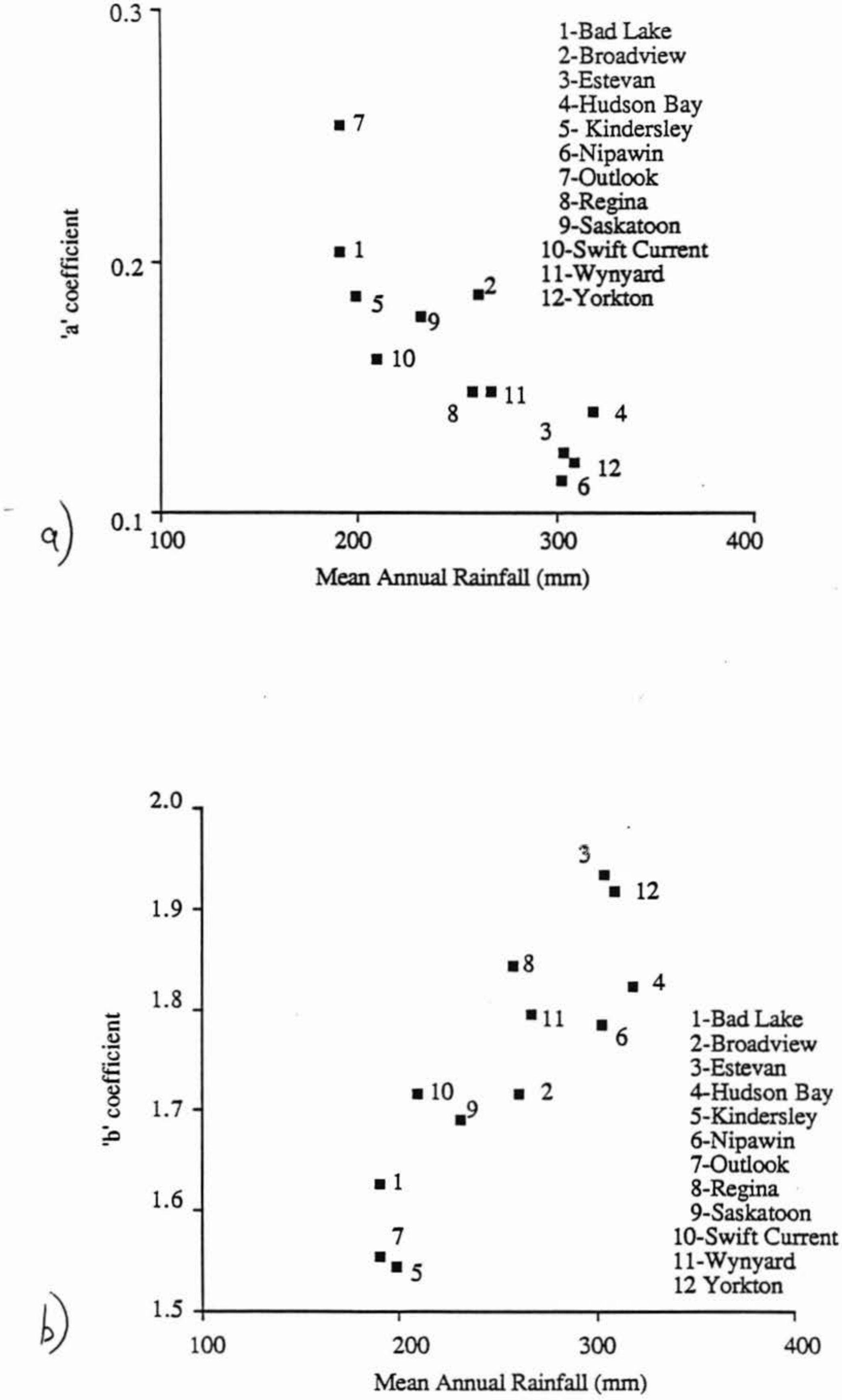
a)
'a' coefficient
0.3
0.2
0.1
100
200
300
400
Mean Annual Rainfall (mm)
1-Bad Lake
2-Broadview
3-Estevan
4-Hudson Bay
5- Kindersley
6-Nipawin
7-Outlook
8-Regina
9-Saskatoon
10-Swift Current
11-Wynyard
12-Yorkton
7
1
5
2
9
10
8
11
4
3
12
6
b)
'b' coefficient
2.0
1.9
1.8
1.7
1.6
1.5
100
200
300
400
Mean Annual Rainfall (mm)
3
12
8
4
11
6
10
9
2
1
7
5
1-Bad Lake
2-Broadview
3-Estevan
4-Hudson Bay
5-Kindersley
6-Nipawin
7-Outlook
8-Regina
9-Saskatoon
10-Swift Current
11-Wynyard
12 Yorkton

Figure 3.

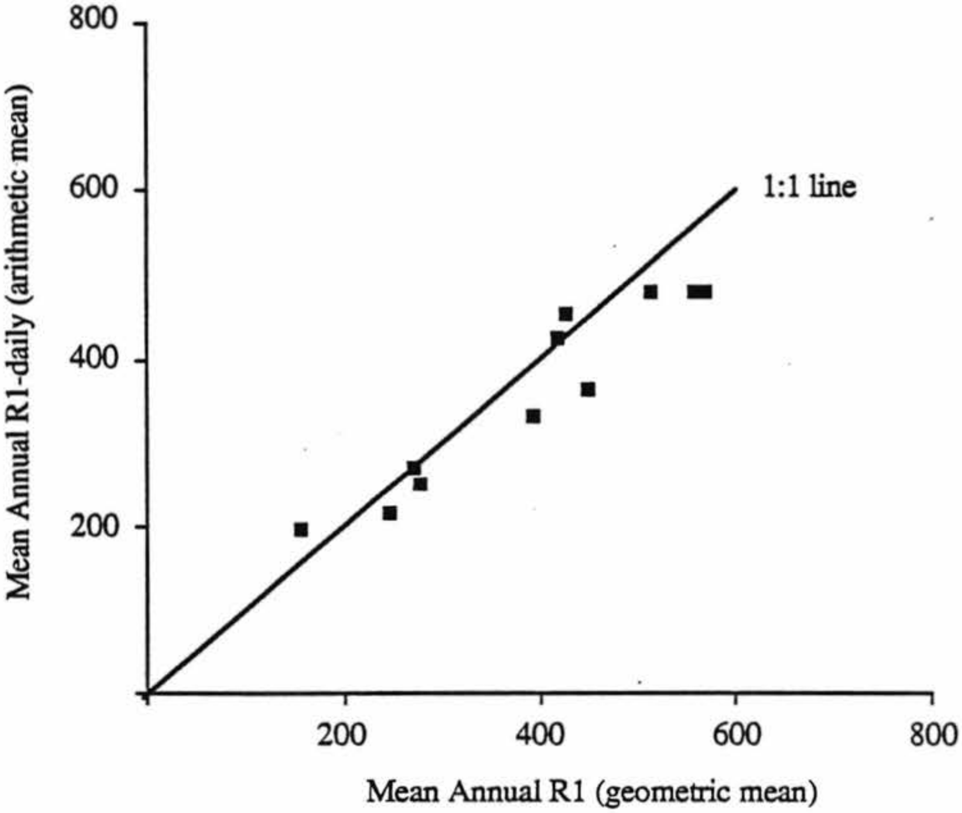

800
600
400
200
200
400
600
800
1:1 line
Mean Annual R1-daily (arithmetic mean)
Mean Annual R1 (geometric mean)

Figure 4.

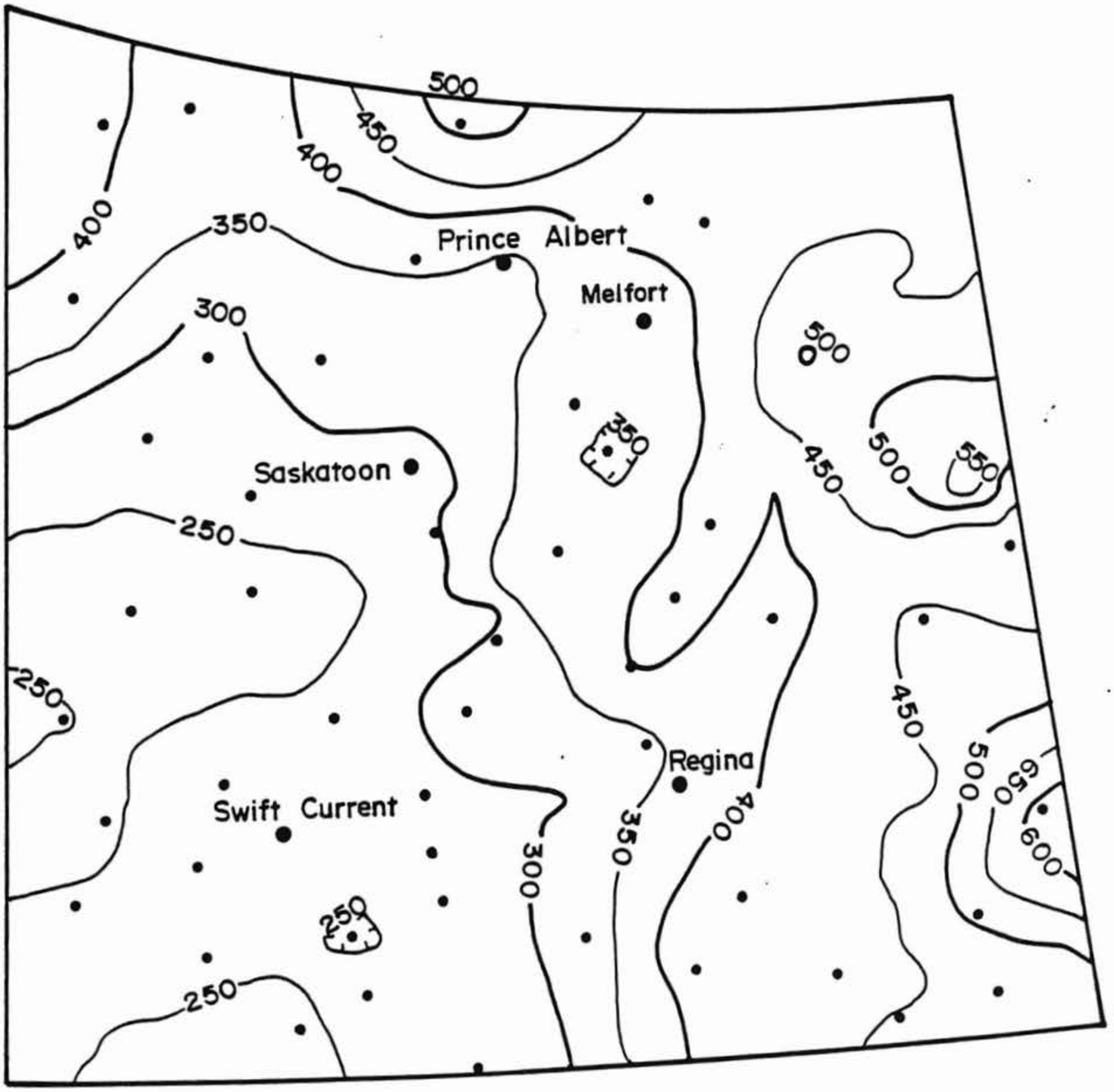
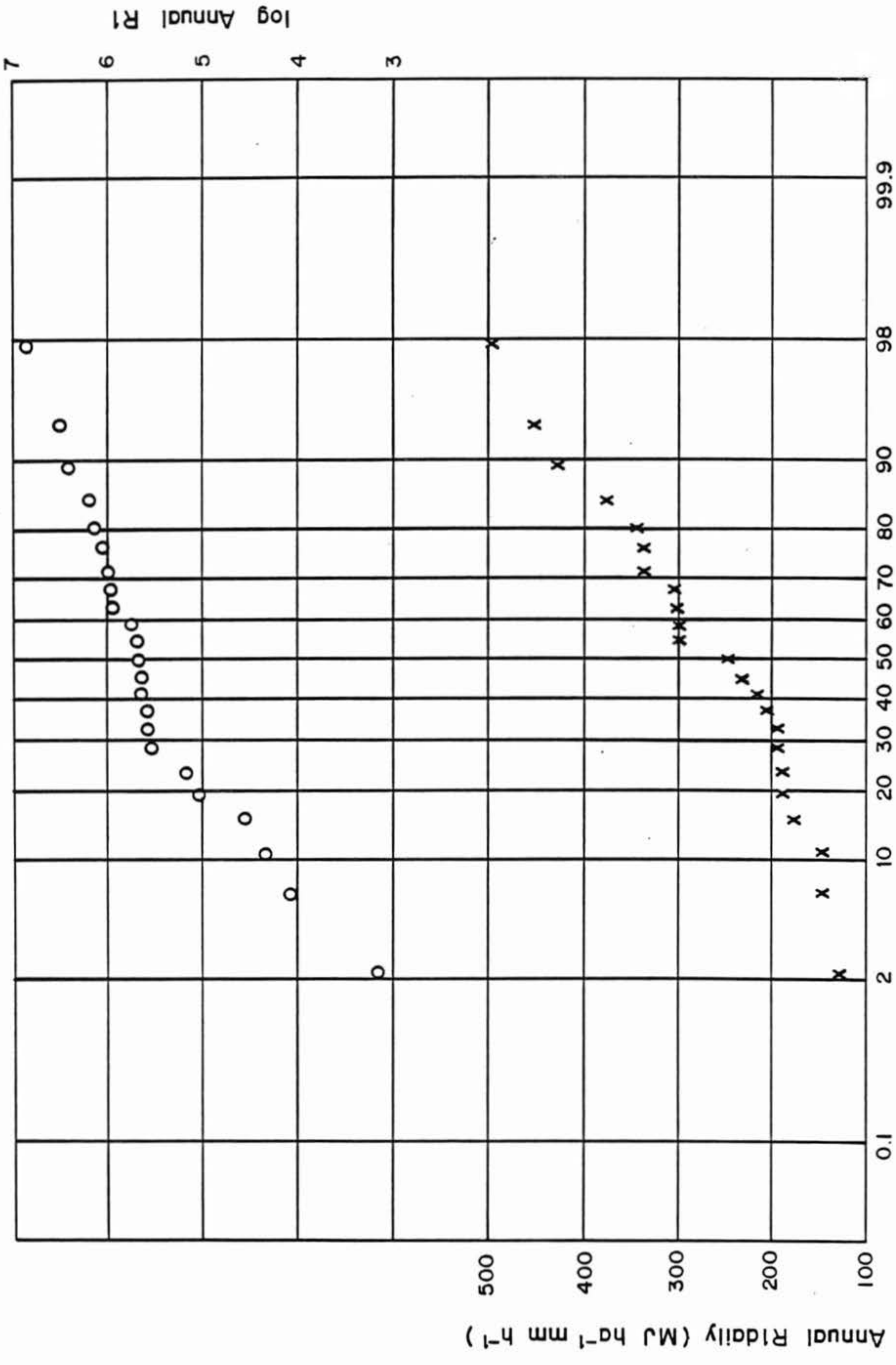

500
450
400
400
350
Prince Albert
Melfort
300
500
350
450
500
550
Saskatoon
250
250
Regina
Swift Current
450
500
650
600
300
350
400
250
250

Figure 5.


log Annual R1
7
6
5
4
3
0.1
2
10
20
30
40
50
60
70
80
90
98
99.9
Probability (%)
500
400
300
200
100
Annual R1daily (MJ ha⁻¹ mm h⁻¹)

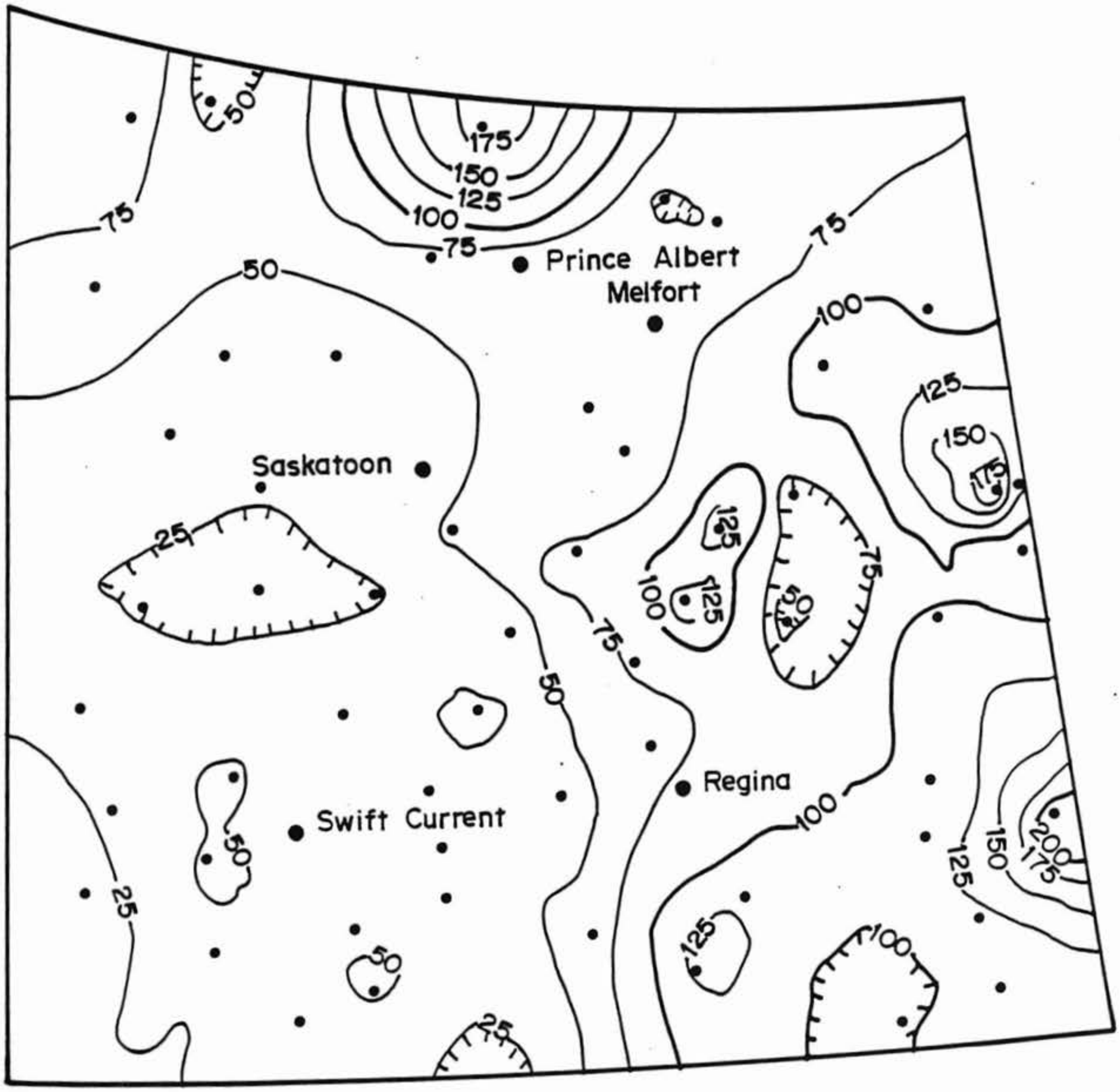
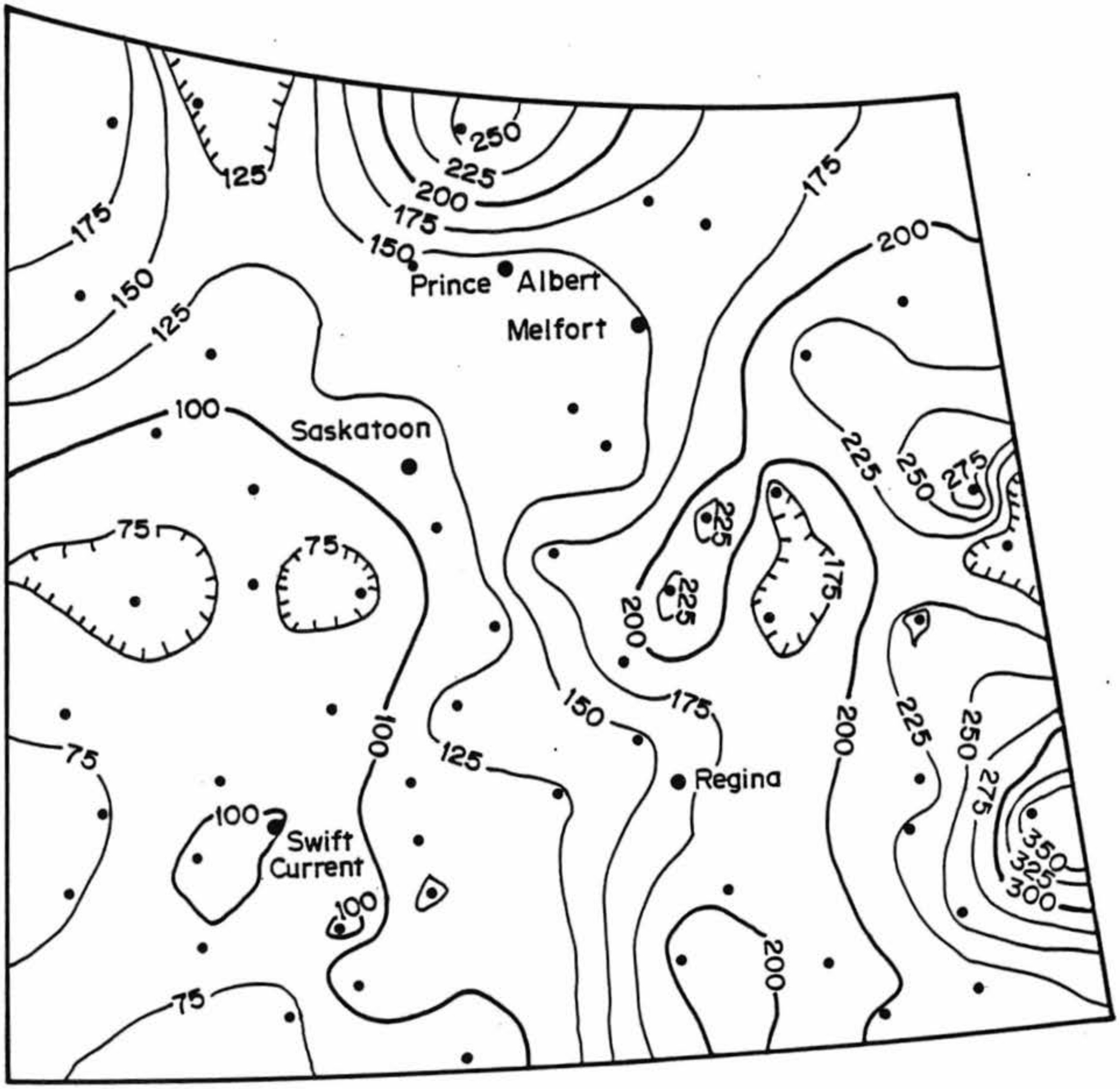

50
175
150
125
100
75
75
Prince Albert
Melfort
75
50
100
125
150
175
Saskatoon
25
125
100
125
50
75
75
50
Regina
100
Swift Current
50
25
150
200
175
125
125
50
100
25

Figure 7a.



125
250
225
200
175
150
175
175
200
150
125
Prince Albert
Melfort
100
Saskatoon
225
250
275
75
75
225
225
200
175
150
175
200
225
250
100
125
75
Regina
275
350
325
300
100
Swift Current
100
200
75

Figure 7b.

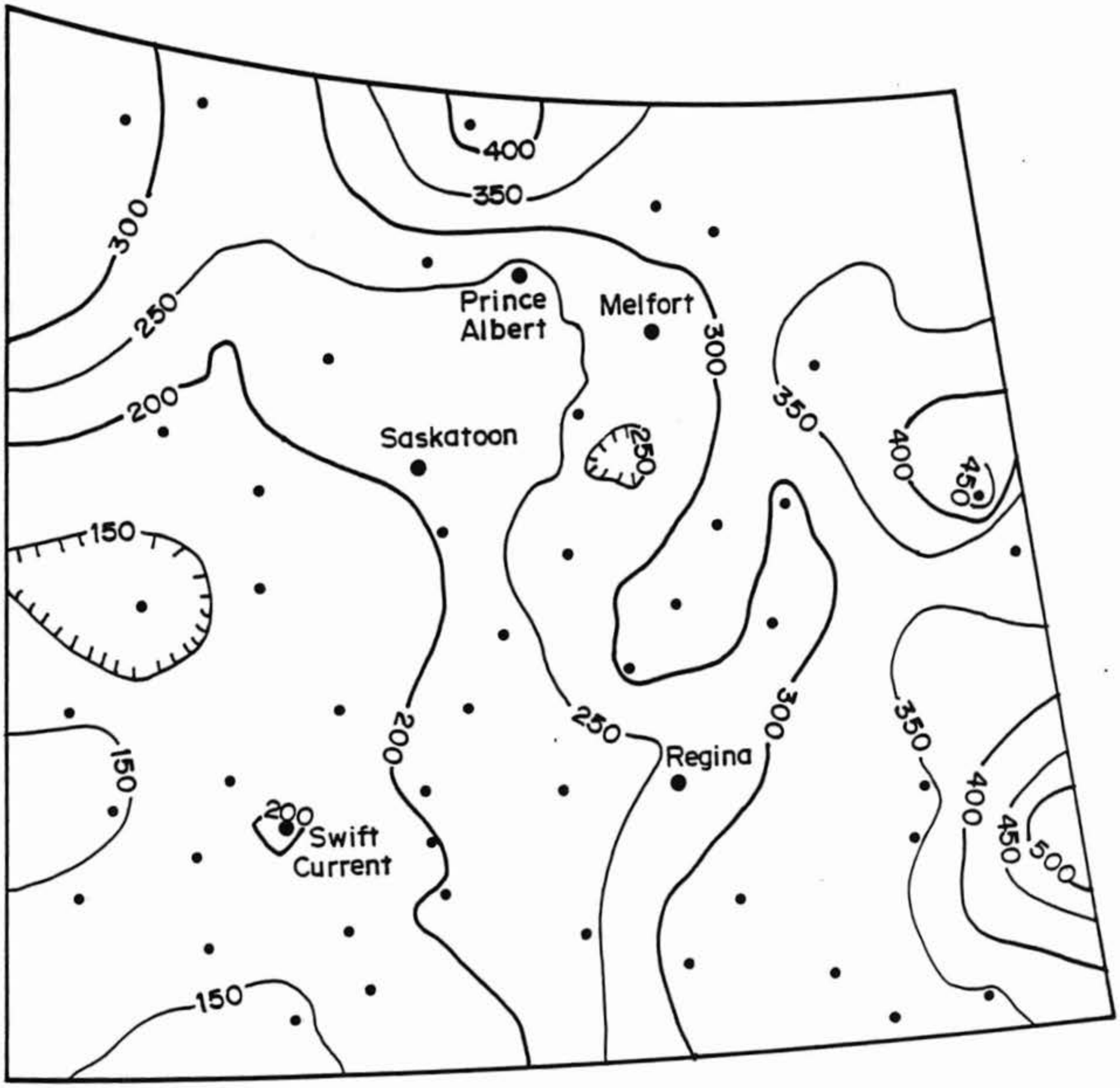

400
350
300
250
200
150
Prince Albert
Melfort
Saskatoon
300
350
400
450
250
150
200
Swift Current
250
300
Regina
350
400
450
500
150

Figure 7c.

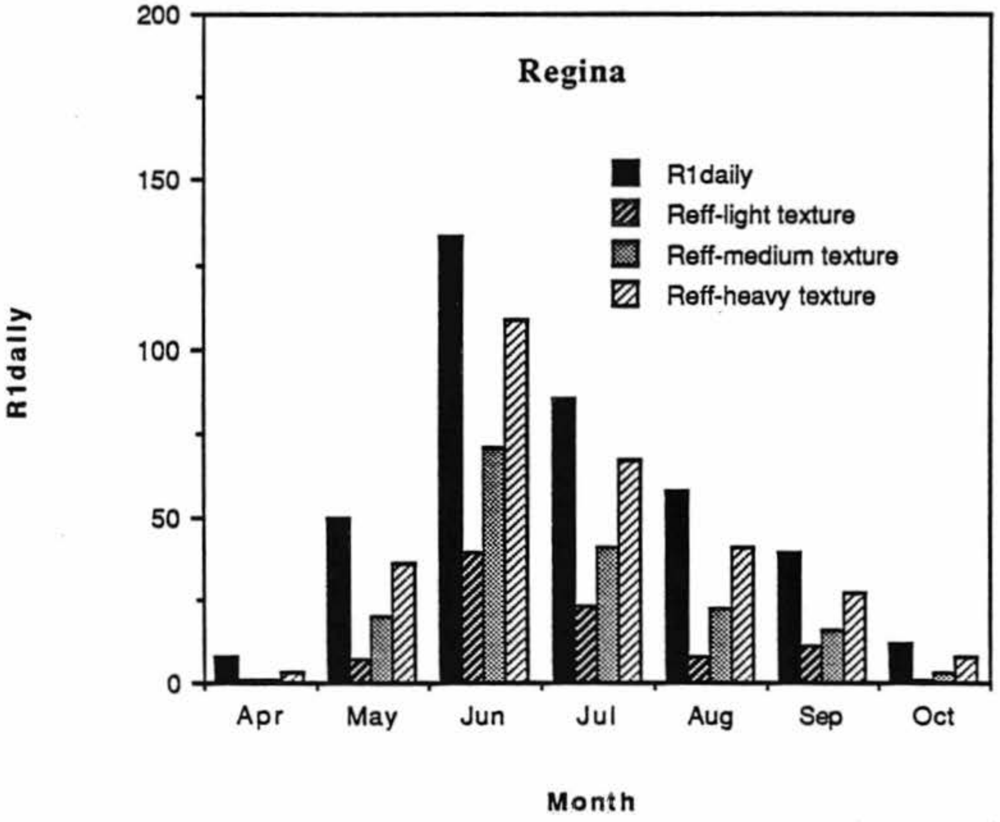

Regina
R1daily
Reff-light texture
Reff-medium texture
Reff-heavy texture
200
150
100
50
0
R1daily
Apr
May
Jun
Jul
Aug
Sep
Oct
Month

Figure 8.