SNOWMELT RUNOFF FROM AGRICULTURAL LAND IN THE PEACE RIVER REGION

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Snow represents a significant source of manageable water for crop production on the Canadian prairies. Unfortunately the proportion of snowmelt water that runs off is often high. Runoff not only reduces the amount of water available for crop growth but can also cause soil erosion. A clear understanding of the effects that different cropping practices have on the amount of runoff is essential before effective moisture enhancement and erosion control practices can be recommended. For this purpose, research plots were established in the Peace River region of Alberta to determine the runoff and sediment loss for four different cropping practices common to the region. Two years of data pertaining to the timing and rates of snowmelt are presented and discussed.

INTRODUCTION

Soil moisture deficiency limits agricultural production on both farmland and rangeland and is the major constraint to increased production on over two-thirds of Canadian agricultural land (Oosterveld and Nicholaichuk 1983).

Snow represents a significant source of manageable water for crop production on dryland agricultural fields. The quantity of water available from snow depends primarily on the depth of the local snowcover, weather conditions fostering snowmelt and soil properties affecting infiltration (Steppuhn 1981). In order for snow to be utilized by crops, meltwater must infiltrate and be stored in the root zone.

Greb (1975), upon examination of eight studies, concluded that recharge of soil water by melted snow was considered highly significant to the overall moisture status of cereal grains, oilseeds and forages. Staple et al. (1960) evaluated 20 years of data and related the change in over-winter soil water between harvest and seeding (C) to the winter snowfall (S) and post-harvest rainfall (R) for cropped and fallowed fields in southwestern Saskatchewan. For stubble, C was equally affected by S and R, but for the wetter fallow fields (approximately three times wetter) the effect of S on C was negligible. Granger et al. (1984) found that soils which differed in texture and land use, but had similar moisture regimes at the time of melt, had similar amounts of snowmelt infiltration and that the greater the snowwater equivalent, the larger were the losses to evaporation and runoff during the melt period.

Willis et al. (1969) in a study in North Dakota determined that the quantity of snowmelt runoff increased with increased stubble height for the same soil water status, but soil water status had more influence on the quantity of runoff than did stubble height. They also found that in general snowmelt began first on plots with tall stubble, and that the duration of snowmelt increased with decreasing stubble height. The average duration of melt was 6 days.

The proportion of snowmelt water that runs off is often high. Willis and Haas (1969) found that if snow was held where it fell and if the soil was dry in the fall before freezing, spring runoff amounted to approximately 50% of the snowpack, but if the soil was wet before freezing, approximately 80% of the snowpack ran off. Runoff was 57, 67, and 69% of the snowpack for 0-, 25-, and 50-cm stubble heights, respectively, and 47, 68 and 78% with dry, normal and wet soils, respectively, in the fall. Bauder et al. (1975) reported that 80% or more of the winter precipitation in eastern North Dakota became runoff.

Snowmelt runoff is the major contributor to the total annual runoff on the prairies. Nicholaichuk (1967), in a study of two watersheds in southern Saskatchewan, found that 85% of the total runoff originated from snow. If a greater proportion of snowmelt water infiltrated, increased crop yields could be expected. A better understanding of the effects that different cropping practices have on the amount of runoff is essential before moisture enhancement through runoff reduction is possible. Most studies have concentrated on cereal grains and fallow rotations. Canola, grasses and forages are also common on the prairies but relatively little is known about their effect on snowmelt runoff.

A study designed to gain such knowledge was initiated in the Peace River region of Alberta (considered to be a high erosion risk area) in 1981. The objective of the study was to determine the runoff and sediment loss from agricultural land under management practices characteristic of the area, with particular emphasis on the snowmelt period.

METHODOLOGY

In May 1981 four research plots were established near La Glace, Alberta in the Peace River region, approximately 500 km northwest of Edmonton. The plots, each 5 m by 75 m, were located on a 5% slope with a westerly aspect. Plots used in the United States to develop a data base on erosion were 22.6 m long and 1.8 m wide (Hudson 1981). A greater plot length was deemed necessary in this study to characterize the rather long slopes of the Peace River region. Unfortunately, simple slopes greater than 100 m in length are infrequent; therefore, a compromise length of 75 m was chosen. A greater width (5 m) was used to give a greater plot area, thereby minimizing boundary effects. Plots were directed downslope to minimize cross-slope flow.

Individual plots were bordered by boards buried in the ground, pegged in place and caulked. Plots were located adjacent to each other, separated by a 2-m-wide grassed access strip. A meteorological station, consisting of a continuously recording raingauge and a Stevenson screen containing a thermograph, was also set up at the site. The field was in fallow the year prior to plot establishment. In 1981 one plot was seeded to fescue and the remaining three plots were managed in a canola-barley-fallow rotation, a common rotation for the study area. All plots were cultivated and seeded upslope. Seeding was usually completed in late May and the crop was harvested in mid-September. After harvest, the stubble was left standing over winter in both the canola and barley plots.

A snow survey was conducted each spring before snowmelt. A number of locations at the site were sampled to determine mean snowdepth and water equivalent of the snowpack. During melt, runoff rates were determined at 0.5-h or 1-h intervals by measuring the time required to fill a container of known volume. These measurements were subsequently used to establish the daily discharge hydrographs.

Soil moisture was measured within each plot using a Campbell Pacific Nuclear Depthprobe (Model 503) at a single access tube, located approximately one-third of the way up the slope. Measurements were taken at 10-cm intervals from a depth of 25–95 cm. Soil moisture contents were then converted to equivalent depths of water in the soil. Changes in soil water status between late winter and post-melt measurements were assumed to be attributable to meltwater infiltration.

RESULTS AND DISCUSSION

Results for 2 yrs. of snowmelt runoff, 1982 and 1983, are reported here. Monthly precipitation at Grande Prairie Airport (approximately 50 km southeast of the study site) was below normal for all months September to April, inclusive for the three years 1981, 1982 and 1983, except for January 1982 and April 1983 (Fig. 1). Because of the two exceptions, it is difficult to assess whether the runoff measured in the two study years would be below the long-term average for the area.

Texture of the uppermost 15 cm of the soil, as determined by the hydrometer method (McKeague 1978), was silty clay. Detailed soil physical characteristics of the site are reported in Chanasyk and Woytowich (1983).

Comparing 1981 and 1982, soil moisture levels were similar for fallow in both years, but 5% lower for fescue and 15% higher for both canola and barley in 1982 (Table I). The soil moisture increase as a result of snowmelt was greatest for barley both years; second highest in the 1982 spring and lowest in 1983 for canola; and lowest for fallow in 1982 and second lowest for spring 1983 (Table I). The large increases in soil moisture for barley reflect a low fall soil moisture status and the effective trapping of snow by barley stubble. The 1982 gain for canola was high, reflecting low fall soil moisture levels while the gain in 1983 was low as a result of high fall soil moisture levels. The fallow plot had relatively high fall moisture levels for both years and consequently low soil moisture increases resulted from reduced snowmelt water infiltration.

Runoff occurred on 7 days in both 1982 and 1983 but melt was discontinuous in 1983 as air temperatures dropped below 0°C for 5 days after 2 days of runoff. During the 1982 springmelt, snowmelt water from upslope ran onto the canola plot, making use of that data for comparative purposes highly questionable. The data are, however, included for the reader's benefit.

Summaries of daily peak flow rates,

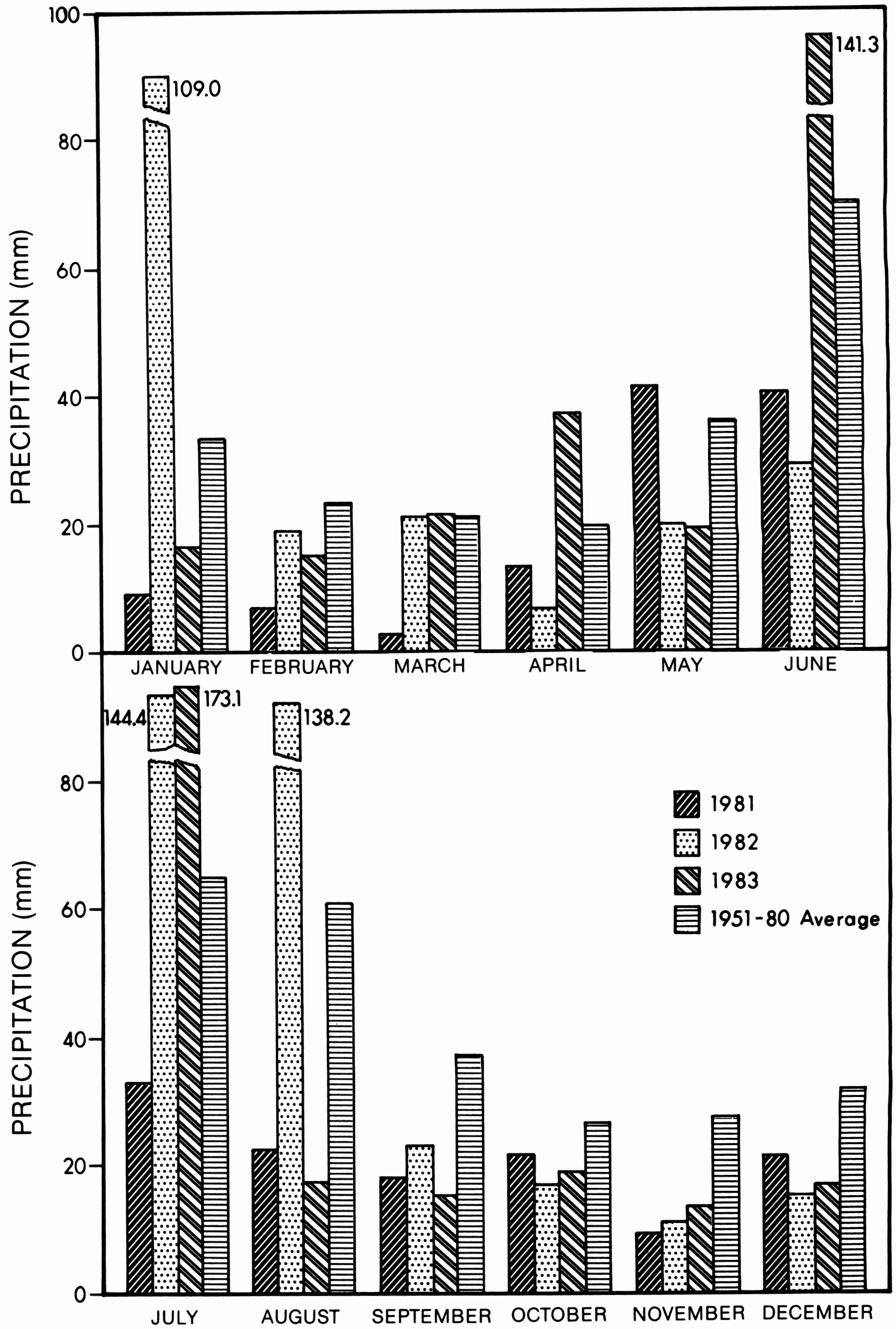

Figure 1. Monthly precipitation at Grande Prairie.

TABLE 1. SOIL MOISTURE STATUS

Crop	Soil Moisture Status†		Moisture Gain‡	
	Fall 1981	Fall 1982	1981–1982	1982–1983
Fallow	324	320	50	30
Fescue	324	307	70	44
Barley	239	274	122	74
Canola	291	336	92	16

†Soil moisture content (mm water per 100 cm soil).
‡Overwinter soil moisture gain (mm).

TABLE II. DAILY PEAK FLOW RATES ($m^3/(ha \cdot h)$) AND TIME OF PEAK FLOW

Crop	April 1982						
	23	24	25	26	27	28	29
Canola†	30.8	72.0	108.0	124.0	72.0	16.0	0
Fescue	8.0	11.7	21.6	43.2	27.0	25.4	5.5
Fallow	17.3	18.8	19.7	27.0	39.3	24.0	22.8
Barley	11.0	16.0	19.7	30.8	48.0	18.8	2.5
Canola†	1600	1545	1500	1500	1400	1130	
Fescue	1415	1345	1445	1445	1500	1130	1100
Fallow	1415	1345	1330	1500	1500	1130	1200
Barley	1430	1345	1400	1500	1500	1130	1100

	April 1983						
	6	7	12	13	14	15	16
Barley	2.5	11.7	9.8	28.8	25.4	11.7	3.1
Fescue	14.4	14.9	7.2	28.8	28.8	13.5	0
Canola	9.8	16.6	7.2	28.8	30.8	14.4	1.3
Fallow	0.4	7.7	1.0	20.5	33.2	28.8	8.6
Barley	1630	1200	1600	1500	1345	1200	1045
Fescue	1530	1030	1630	1430	1400	1200	
Canola	1600	1030	1700	1500	1400	1230	1045
Fallow	1815	1630	1630	1600	1430	1315	1230

†Should not be used for comparative purposes due to run on.

TABLE III. TOTAL DAILY RUNOFF (m^3)

Crop	April 1982						
	23	24	25	26	27	28	29
Canola†	8.2	21.7	34.6	30.2	9.5	1.8	0.0
Fescue	1.5	2.4	5.5	8.7	5.2	4.0	0.5
Fallow	4.0	3.7	5.5	7.0	7.1	4.8	2.3
Barley	2.5	3.1	4.8	7.6	8.9	3.3	0.3

Crop	April 1983						
	6	7	12	13	14	15	16
Barley	0.5	3.2	1.3	5.0	4.9	1.9	0.2
Fescue	2.5	3.0	0.9	4.3	5.4	1.5	0.0
Canola	1.4	3.8	0.9	4.5	5.6	2.4	0.1
Fallow	0.0	2.2	0.1	2.9	6.3	5.4	1.9

†Should not be used for comparative purposes due to run on

times of peak flow and daily total runoff volumes from each plot are given in Tables II and III, respectively. Hydrographs of the 1982 and 1983 melt from each plot are given in Figs. 2, 3a, and 3b. The peak flow rate measured from each plot occurred on the fourth or fifth day of runoff during both 1982 and 1983. Initially daily peak flow rates occurred between 1400 and 1800 h, but as melt progressed peak flows occurred earlier in the day (as early as 1000 to 1300 h on the last day of runoff). This was probably due to the reduced insulation and albedo of the soil resulting from a discontinuous snow cover on the last days of melt.

Daily runoff hydrographs were generally single-peaked. Complex hydrographs were measured on all plots on 27 Apr., 1982. If temperatures were above 10°C, multi-peaked hydrographs were the result of passing clouds; if the temperature was less than 5°C, net radiation appeared to be the important factor (personal observations).

In 1982 the fallow plot yielded 23% more runoff than the fescue plot while the barley plot yielded 9% more than the fescue plot. During the 1983 melt the fallow plot yielded 7% more runoff than the fescue plot while yields were 6% more and 3% less than fescue for the canola and barley plots, respectively. Trends in cumulative runoff were similar for the vegetated plots (particulary in 1983), but differed for fallow (Fig. 4).

Daily data for the time of runoff initiation and runoff duration are given in Table IV. Runoff generally began first from the fallow plot followed by barley, canola and fescue. The snowpack was in direct contact with the soil surface on the fallow plot while the barley and canola plots had a large portion of the snowpack in contact with the soil surface. In contrast, the fescue plot was covered by a thick vegetative mat so the snowpack was not in direct contact with the soil surface. Meltwater penetrating this mat froze upon contact with the insulated soil surface. Also, meltwater runoff was impeded by the vegetative cover. The differences in timing of runoff initiation between barley and canola plots were not great and probably can be attributed to differences in stubble density, basal area and height.

On a given day, runoff usually stopped first on the fescue plot, followed closely by barley, fallow and canola. In terms of cover and insulation effects, it is difficult to explain why runoff from the canola plot persisted longer than runoff from the fallow plot. Since the data for canola in 1982 could not be used for comparative purposes, results can only be compared for 1 year. The 1983 results might reflect snow drifting patterns, frost conditions or other parameters not measured.

Distinct trends in daily runoff duration for the different plots were not observable (Table IV). In 1982 the fallow plot had the longest total duration followed by fescue and barley in decreasing order. During the 1983 melt, barley had the greatest total runoff duration followed by fallow and canola with fescue having the shortest total duration.

On the average, runoff was initiated 1 to 2 h earlier in 1982 than in 1983. These differences resulted in total runoff durations being approximately two times greater in 1982 than in 1983 for the same crop. For a given year differences in the times of runoff initiation and termination between plots can be attributable primarily to cover and insulation effects; however, the year-to-year variations depend, in part, on the timing of the melt. The 1982 melt period occurred in late April; the 1983 melt in early April. Total solar insolation for the 1982 melt was approximately 23.2 $kJ \cdot cm^{-2}$ as compared to 20.4 $kJ \cdot cm^{-2}$ in 1983. Sunlight totalled 104 hrs in 1982 as compared to 97 hrs in 1983 (horizontal surface with clear sky using a program from Robertson and Russelo (1968)). Additionally, solar altitude was greater in 1982 than during the 1983 melt so the overall effect was greater net radiation in 1982.

The uniform slope at the site and the close proximity of the plots to each other resulted in a relatively uniform snowpack overlying the plots. In 1982 the measured water equivalent of the snowpack was 1280 $m^2 \cdot ha^{-1}$, between 58 and 71% of which ran off (Table V). In 1983 the snowwater equivalent was 1387 $m^3 \cdot ha^{-1}$ of which 35–38% ran off. Values for the proportion of the snowpack appearing as runoff ranged from 0.35 to 0.71 for the two study years. These values agree with those reported by Gray and Male (1981).

Peak flow rates in 1983 were 60–85% of those observed for plots under the same crops in 1982 while total runoff was 55–63% of that measured from each plot in 1982.

Water balance estimates for the 1982 and 1983 springmelt periods are given in

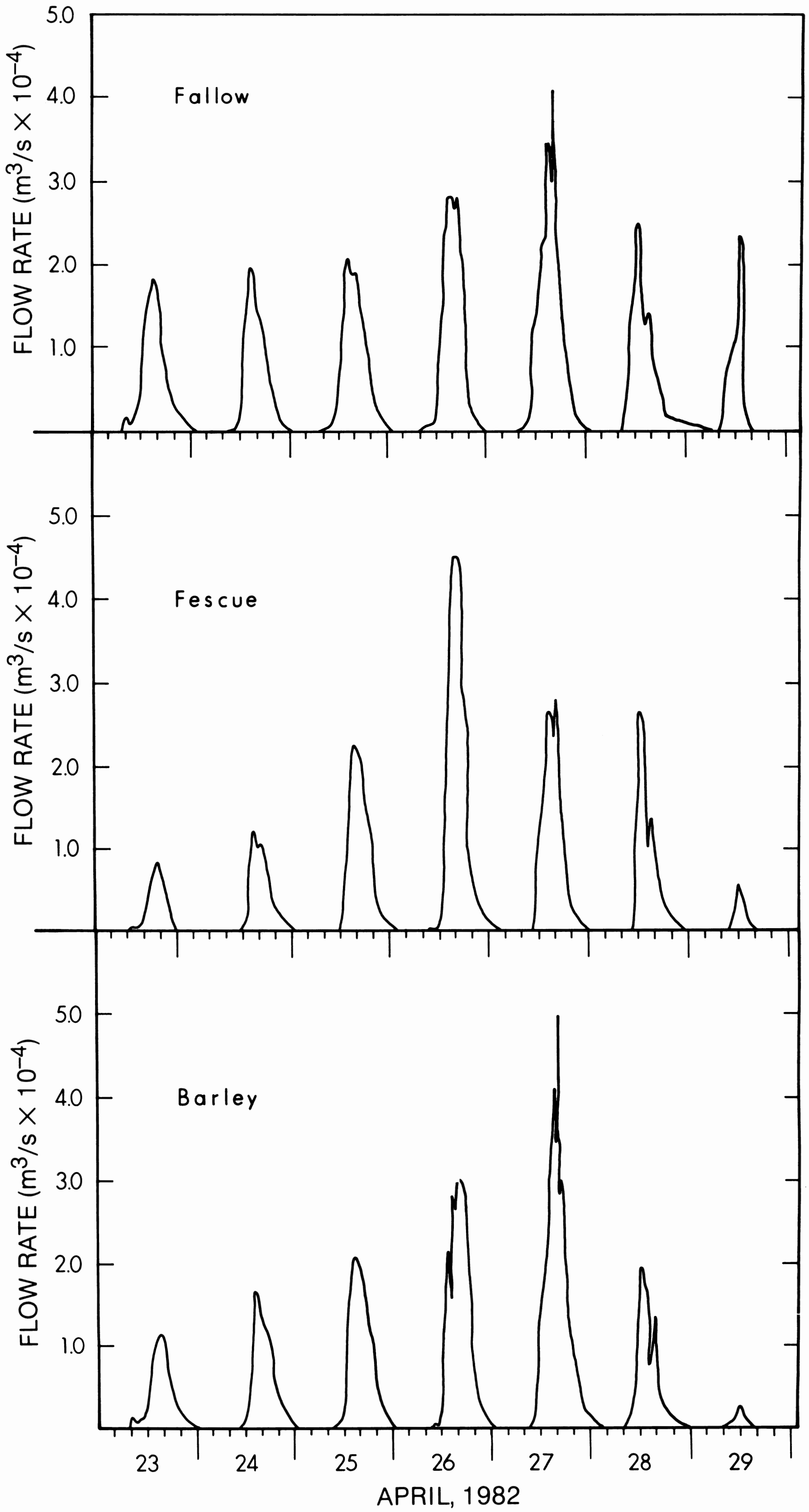

Figure 2. Springmelt hydrographs: 1982

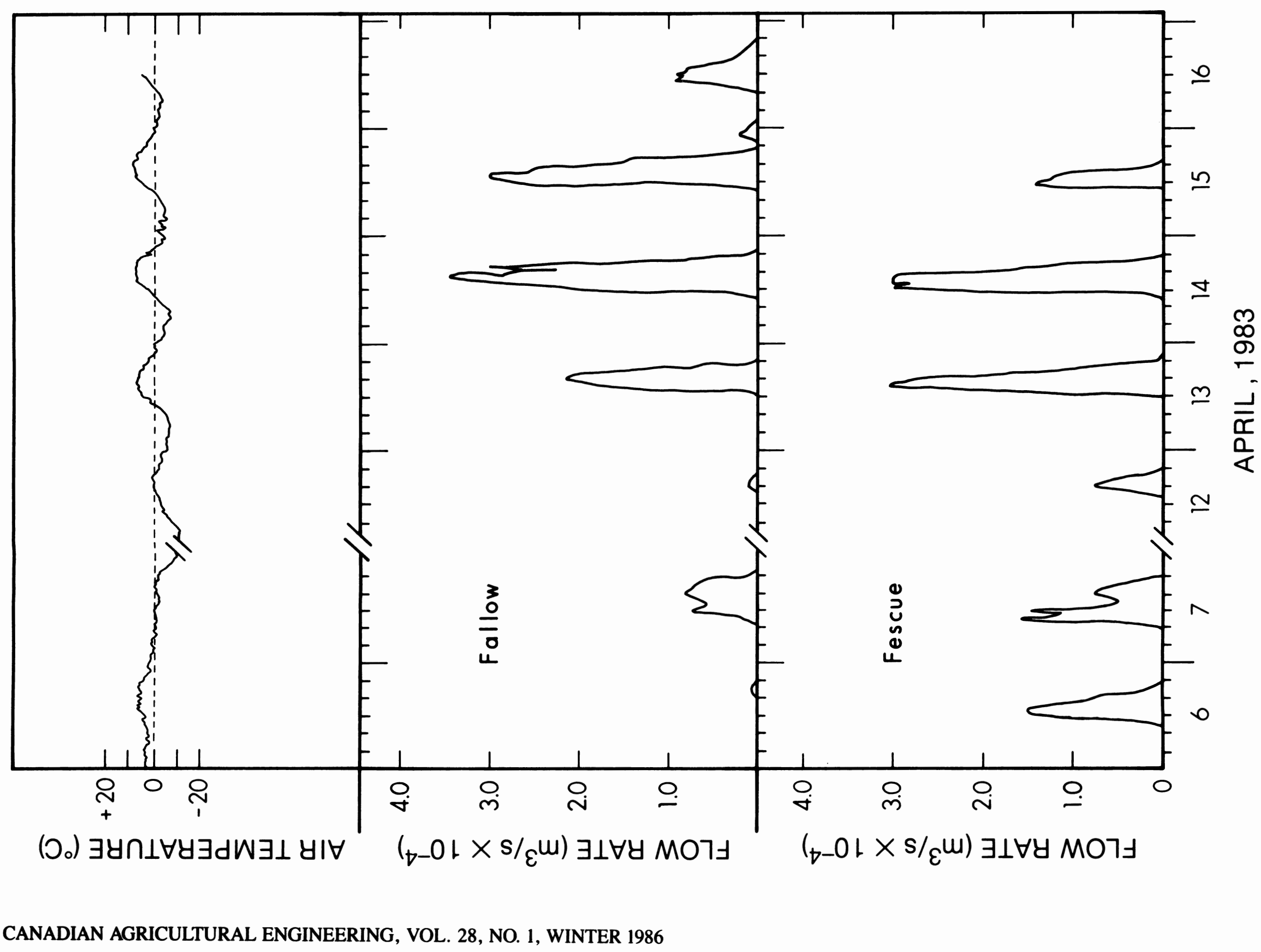

Figure 3a. Springmelt hydrographs: 1983.

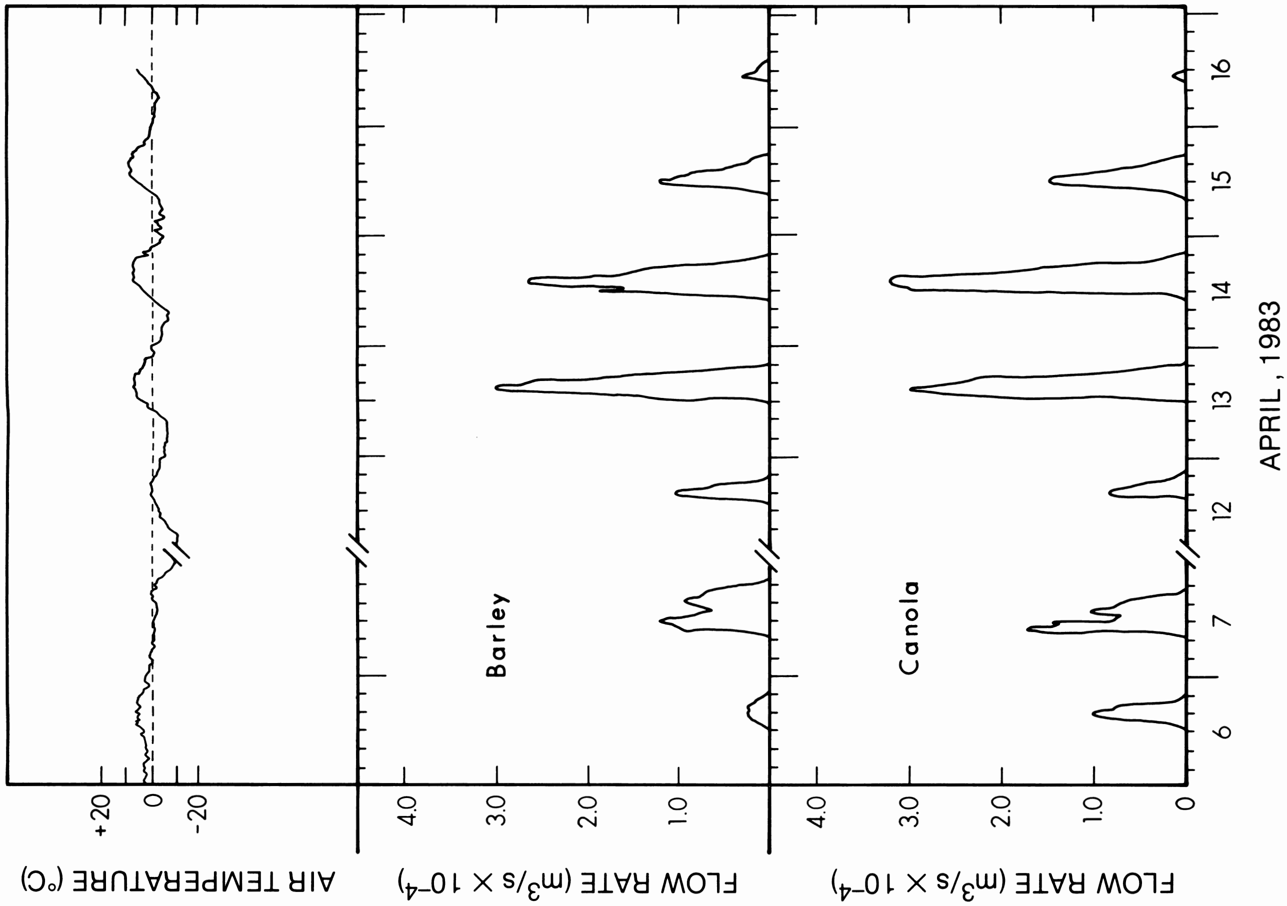

Figure 3b. Springmelt hydrographs: 1983.

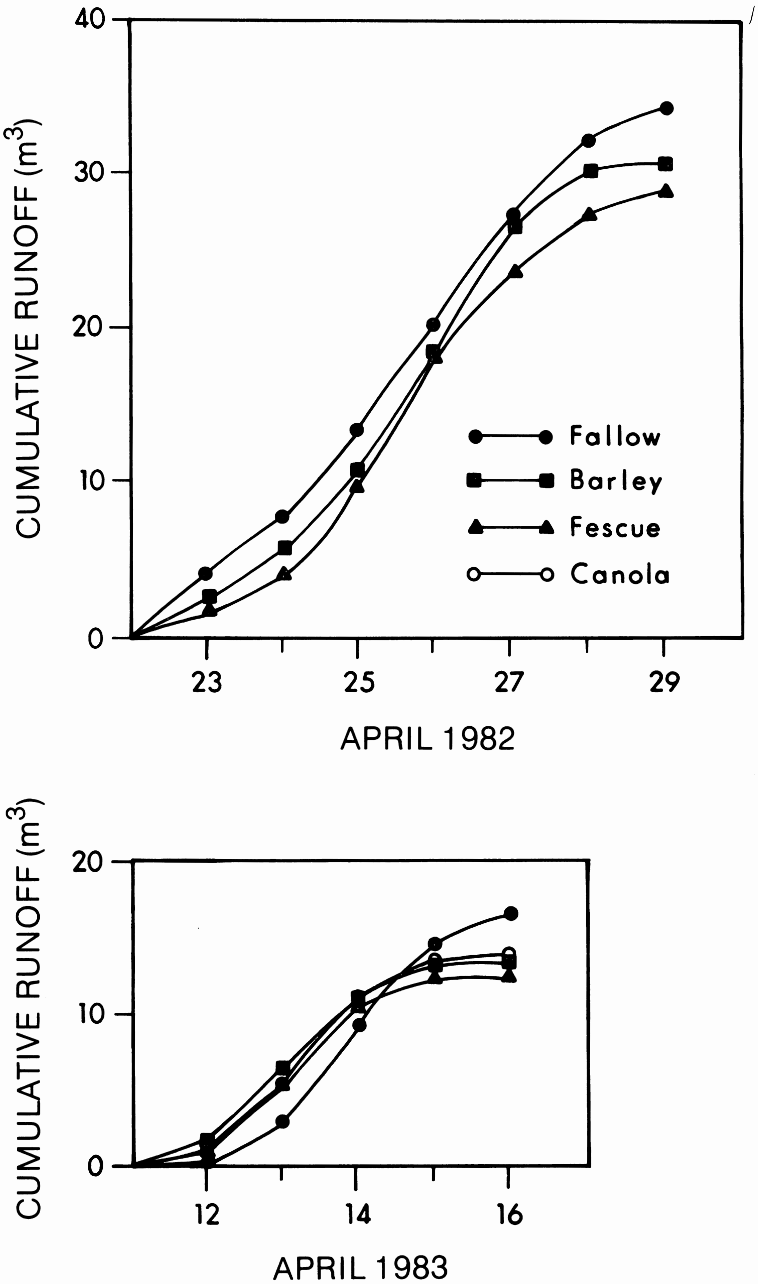

Figure 4. Trends in cumulative runoff.

Table V. In 1982 the actual change in soil moisture was greater than could be accounted for by the snowmelt water. This was likely a result of some infiltration between the time of the mid-winter soil moisture measurement and the spring snow survey. In 1983, when the snowwater equivalent was 8% higher than in 1982, the measured change in soil moisture was less than that which could be accounted for by snow meltwater. The 1983 springmelt period was characterized by continuous winds (typically 15–35 $km \cdot h^{-1}$) while conditions were relatively calm during the 1982 melt. Therefore, substantial sublimation of the snowpack occurred in 1983, accounting for much of the differences in total runoff volumes between 1982 and 1983 as well as some of the discrepancy in the 1983 spring water balance estimates. Use of only one moisture measurement to represent the moisture status of the entire plot likely contributed to some of the discrepancy.

The validity of extrapolation of results as those reported here is always difficult to assess. Attempts were made to select a site representative of a large area; but differences in the timing of the melt within the region were observed. These differences may or may not have translated into runoff volume differences.

Problems relating to extrapolation of data from plots to larger fields were believed to be minimal because of the large plot size used. The plots were not replicated and thus no statistical significance was attached to the results. However, the relative ranking of plots with respect to runoff is believed to be valid. Replication is time-consuming and expensive and was not believed to be warranted until preliminary data were obtained.

The short length of study is also recognized. A much longer study period is required before the true representativeness of the results reported here can be determined.

TABLE IV. DAILY TIME OF RUNOFF INITIATION AND DAILY TOTAL RUNOFF DURATION (h)

Crop	April 1982						
	23	24	25	26	27	28	29
Fescue	0700	1000	1000	0800	0800	0830	0830
Fallow	0630	0830	0700	0700	0700	0800	0700
Barley	0630	930	0830	0830	0800	0700	0700
Fescue	16.0	14.5	15.5	19.0	16.0	15.5	9.0
Fallow	18.5	15.0	19.0	16.5	18.0	21.0	8.0
Barley	16.5	14.0	15.0	15.5	19.0	17.0	7.0

Crop	April 1983						
	6	7	12	13	14	15	16
Barley	1230	0830	1330	1200	1000	0900	1000
Fescue	1200	0800	1400	1200	1030	1030	0
Canola	1300	0900	1500	1200	1030	0900	0900
Fallow	1730	0900	1530	1230	1000	1000	0800
Barley	7.5	12.5	6.0	8.0	10.0	8.5	4.5
Fescue	8.0	12.0	6.0	8.0	9.0	6.0	0
Canola	7.0	12.0	5.0	8.5	9.5	9.0	3.5
Fallow	1.5	12.0	3.0	7.5	10.5	9.0	12.0

TABLE V. SPRING WATER BALANCE ESTIMATES

	1982	1983
Snow survey (12 loc'ns sampled)		
Mean depth (cm)	55.4	35.9
Mean density (%)	23.0	37.0
Mean water equivalent† (m^3)	48.0	49.8
Measured runoff (m^3)		
Fescue	27.9	17.6
Fallow	34.3	18.8
Barley	30.5	18.7
Canola	106.1‡	18.7
Change in soil moisture (m^3/plot)		
Fescue	25.9	15.0
Fallow	18.8	10.5
Barley	45.8	26.3
Canola	34.5	5.6
Melt water not running off (m^3)		
Fescue	20.1	32.2
Fallow	13.7	31.0
Barley	17.5	32.8
Canola		31.1
Percent of snowpack running off		
Fescue	58	35
Fallow	71	38
Barley	64	38
Canola	—	38

‡Should not be used for comparative purposes due to run on.
†Estimated covering each plot.

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