The Contribution of Snow to Soil Moisture Reserves

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Introduction

In the dryland farming regions of the Prairies, water used by crops is supplied by rain and snowmelt water infiltrating the soil surface. The quantity of water infiltrating the soil surface is dependent on the soil infiltration rate relative to the rainfall intensity or to the snowmelt rate.

Although the average snowfall water equivalent for the Prairie region provides only approximately 1/3 of the long term annual precipitation total (see Tables 1 and 2), snow water represents the primary source of manageable fresh water supplies. According to Gray (1968) approximately 80-85% of the streamflow in the major river systems, whose drainage areas fall within a prairie environment, and the water stored in prairie dugouts and sloughs come from the shallow snowpack. In addition, studies have shown that snow is a major source of water for replenishing prairie soil moisture supplies (Banga, 1981).

In the absence of severe soil cracks, snowmelt infiltration to frozen soils depends primarily on the amount of soil water at the time of melt in the surface soil layer. Willis et al (1961) in their studies on small plots in North Dakota reported that up to 90% of the snowpack water was lost as surface runoff when soils were frozen at high moisture levels. In the absence of significant depths of autumn rain, the relative amounts and distribution of fall soil moisture levels within unsaturated soil profiles is largely established by summer landuse practices (e.g. fallow, crop, pasture, etc.). Studies conducted by Hoekstra (1966), Pelton et al (1968) and Jame (1977) suggest that modification of the fall soil moisture status due to late fall rains, midwinter melt periods and thermally-induced moisture redistribution during freezing may limit spring snowmelt infiltration rates by creating impermeable ice lenses near the soil surface.

This paper examines the contribution of snow meltwater to soil moisture reserves in fallow and stubble fields during the 1980/81 winter season; a winter with below normal precipitation.

Basic Data

Snowmelt infiltration, runoff and evapotranspiration studies were conducted on fallow and wheat fields located at the University of Saskatchewan Kernen Crop Research Farm near Saskatoon (Latitude 52° 09' N, Longitude 106° 31' W) and at the Bad Lake Research Watershed near Bickleigh, Saskatchewan (Latitude 51° 18' N, Longitude 108° W).

The soil at the Kernen Farm is an Orthic Dark Brown soil belonging to the Elstow Association, the soil at the Bad Lake Watershed is an Orthic Brown soil belonging to the Scepter Association. The texture of

Table 1. Precipitation Summary for selected Time Periods for Bad Lake Research Watershed; 1968-81. Data from Bad Lake Climatological Station located near Bickleigh, Saskatchewan.

Year	Rainfall Sept.1 to Mar.31 (mm)	Rainfall Apr.1 to Apr.30 (mm)	Snowfall Water Equivalent Oct.1 to Apr.30 (mm)	Rainfall May 1 to Aug.31 (mm)	Total Precipitation Sept. 1 to Aug. 31 (mm)	Snow/ Total Ratio
1968/69	59.7	26.2	108.2	153.9	348.0	.31
1969/70	65.3	6.1	144.5	220.7	436.6	.33
1970/71	14.2	14.5	107.7	170.7	307.1	.35
1971/72	10.5	2.5	93.5	133.6	240.1	.39
1972/73	21.1	22.1	67.6	89.9	200.7	.34
1973/74	9.1	8.9	167.4	302.8	488.2	.34
1974/75	9.6	27.2	102.6	162.6	302.0	.34
1975/76	22.3	1.8	81.0	203.5	308.6	.26
1976/77	13.2	.3	39.1	232.2	284.7	.14
1977/78	29.2	34.4	112.8	140.8	317.2	.36
1978/79	33.2	28.8	64.0	139.2	265.2	.24
1979/80	16.6	0	70.8	195.0	282.4	.25
1980/81	35.6	5.8	58.0	145.2	244.8	.24
Mean	26.1	13.7	93.6	176.2	309.7	0.30
Standard Deviation	18.4	12.4	35.8	54.6	78.4	0.07

Table 2. Precipitation Summary for selected Time Periods for Saskatoon; 1968-81. Data from Saskatchewan Research Council Climatological Station located at Saskatoon, Saskatchewan.

Year	Rainfall Sept.1 to Mar.31 (mm)	Rainfall Apr.1 to Apr.30 (mm)	Snowfall Water Equivalent Oct.1 to Apr.30 (mm)	Rainfall May 1 to Aug.31 (mm)	Total Precipitation Sept. 1 to Aug. 31 (mm)	Snow/ Total Ratio
1968/69	67.1	9.9	116.6	148.3	341.9	.34
1969/70	96.5	8.4	153.9	227.8	486.6	.32
1970/71	10.6	10.7	136.9	267.0	425.2	.32
1971/72	19.8	3.6	132.3	174.2	329.9	.40
1972/73	16.0	31.8	97.5	176.0	321.3	.30
1973/74	48.5	4.6	185.4	294.4	532.9	.35
1974/75	39.4	15.5	95.3	219.7	369.9	.26
1975/76	32.5	16.0	117.4	190.0	355.9	.33
1976/77	18.5	1.8	62.7	226.8	309.8	.20
1977/78	52.5	15.8	97.0	176.8	342.1	.28
1978/79	83.1	13.2	138.4	159.5	394.2	.35
1979/80	36.6	0.7	112.7	138.3	288.3	.39
1980/81	54.8	14.3	92.4	137.0	298.5	.31
Mean	44.3	11.3	118.4	195.1	369.0	.32
Standard Deviation	26.4	8.2	31.5	49.1	73.5	0.05

the soil at the Kernen Farm sites is primarily silty clay loam as compared to clay at Bad Lake. At both the Kernen Farm and Bad Lake Watershed, a wheat-fallow cropping rotation was followed on the instrumented areas. Measurement sites were located within fields having areas of at least 5 hectares. The slope of the fields was less than 1 percent.

Each infiltration-evaporation site consisted of a pair of pvc access tubes installed vertically in the soil to a depth of 1.6 metres. The tubes, with an inside diameter of 5 cm and set approximately 25 cm apart, accommodated the gamma radiation twin probe density meter. Repeated measurements taken with the instrument have shown that the measurement error of soil water in a 1-m soil profile is ±2.47 mm (Granger and Dyck, 1978).

During the installation of the access tubes, soil samples were taken at 10-cm increments to establish the initial soil moisture conditions, soil bulk density and soil particle size distribution.

Infiltration estimates were obtained from the measurements of changes in total wet density in the soil profile. Increases in soil wet density at various depths were attributed to infiltration or moisture redistribution within the soil profile; decreases in soil wet density were attributed to either evapotranspiration or to deep percolation.

The measurements of precipitation, snowcover depth, snow-water equivalent, air and soil temperatures, humidity and other meteorological variables were observed on a regular basis at all locations.

Variability of Prairie Precipitation

The data provided in Tables 1 and 2, which list the precipitation depths occurring during the different periods of the water year; September 1-August 31, for the 13-year period; 1968-1981 at Bad Lake and Saskatoon illustrate the temporal variability in precipitation on the Prairies. As shown, the mean annual precipitation depths at Bad Lake and Saskatoon were 309.7 mm (Table 1) and 369.0 mm (Table 2) respectively. The yearly precipitation at Bad Lake (Table 1) ranged from a low of 244.8 mm in 1980/81 to a high of 488.2 mm in 1973/74; at Saskatoon (Table 2) the maximum yearly total of 532.9 mm also occurred in 1973/74, whereas the minimum, 288.3 mm occurred in 1979/80. At both locations over 50% of the yearly precipitation occurs as rain that falls during the 4-month growing season; May-August. The average depths for this period at Bad Lake and Saskatoon were 176.2 mm and 195.1 mm respectively.

The relative contribution of snow to the yearly total precipitation at a particular location varies widely from year to year. The data in Table 1 indicate that at Bad Lake during the 13 year period; 1968-81 the ratio of snow water equivalent to total precipitation ranged from 0.14 to 0.39. During this period, the average snow water equivalent was 93.6 mm. The minimum seasonal (Oct. 1 - Apr. 30) snowfall water equivalent of 39.1 mm occurred during 1976/77. At Saskatoon, the range in snow water:total precipitation values was somewhat smaller ranging from 0.20 to 0.40 (see Table 2). The average seasonal snow water equivalent at Saskatoon was 118.4 mm, approximately 25 mm greater than the average for Bad Lake; the minimum value of 62.7 mm occurred during 1976/77.

Fall Moisture Levels

The water transmission characteristics of a non-cracked soil during the spring snowmelt period is governed largely by its frozen moisture content, which is influenced by fall moisture conditions. In the absence of significant depths of fall rains, soil moisture levels in the fall are largely established by agricultural practices, e.g., summer cropping, fallow and pasture. The extent to which the soil moisture reserves are depleted during the summer months influences the amount of soil pore space available for water infiltrating the soil surface during the snowmelt season. Under dryland farming conditions water requirements to grow specific crops vary regionally depending on the climatic conditions. The long term climatic statistics for the Bad Lake area (Table 1) show that on average 176.2 mm of rain occurs during the growing season with 89.9 mm as a minimum and 302.8 mm as a maximum. Staple and Lehane (1954) suggest that from 262-412 mm of water is needed to produce an economical spring wheat crop. For the Bad Lake area, this would imply that, depending on the year, a significant portion of the water required for plant growth must be derived from soil moisture reserves.

Precipitation and soil water data collected during the 1980 growing season on a spring wheat field located in the Bad Lake Research Watershed indicated that 313 mm of water was used by a wheat crop yielding approximately 2350 kg/ha. As shown in Figure 1, this quantity of water was derived from 195 mm of rain and 118 mm from soil moisture reserves during the period; seeding to harvest. A significant but temporary recharge of soil moiture occurred between June 24 and June 27 when 64.6 mm of rain added 30 mm of water to the 0-30 cm surface soil layer. Similarly, following harvest 20 mm of rain between September 16 and 24 increased the soil moisture reserve by 18 mm; however, this gain was more than offset by evapotranspiration during the following 40 day period to November 4. The net withdrawal of water from soil moisture from seeding to November 4 was measured at 115 mm. It should be noted that rainfall during the 1980 growing season was approximately 19 mm above the long-term average (see Table 1).

The average growing season rainfall is 195.1 mm at Saskatoon (see Table 2) which is approximately 19 mm greater than at Bad Lake. This suggests that at Saskatoon the dependence of crops on stored water would generally be less than at Bad Lake.

The above results tend to support the recommendation of the Saskatchewan Advisory Council on Soils and Agronomy (1982) that a root-zone water reserve of 125 mm in the Brown soil zone (includes the Bad Lake area) and a 100-mm water reserve in the Dark Brown soil zone (includes the Saskatoon area) is needed at seeding time to achieve satisfactory yields. Although this recommendation is made specifically for seeding stubble crops, it is equally valid for crops sown on fallow fields and it assumes that normal or near normal rainfall will occur during the growing period.

The influence of the two summer land use practices; fallow and spring wheat, on fall moisture levels at Bad Lake and at the Kernen Farm is shown in Table 3. These data include the average water contents (% Vol)

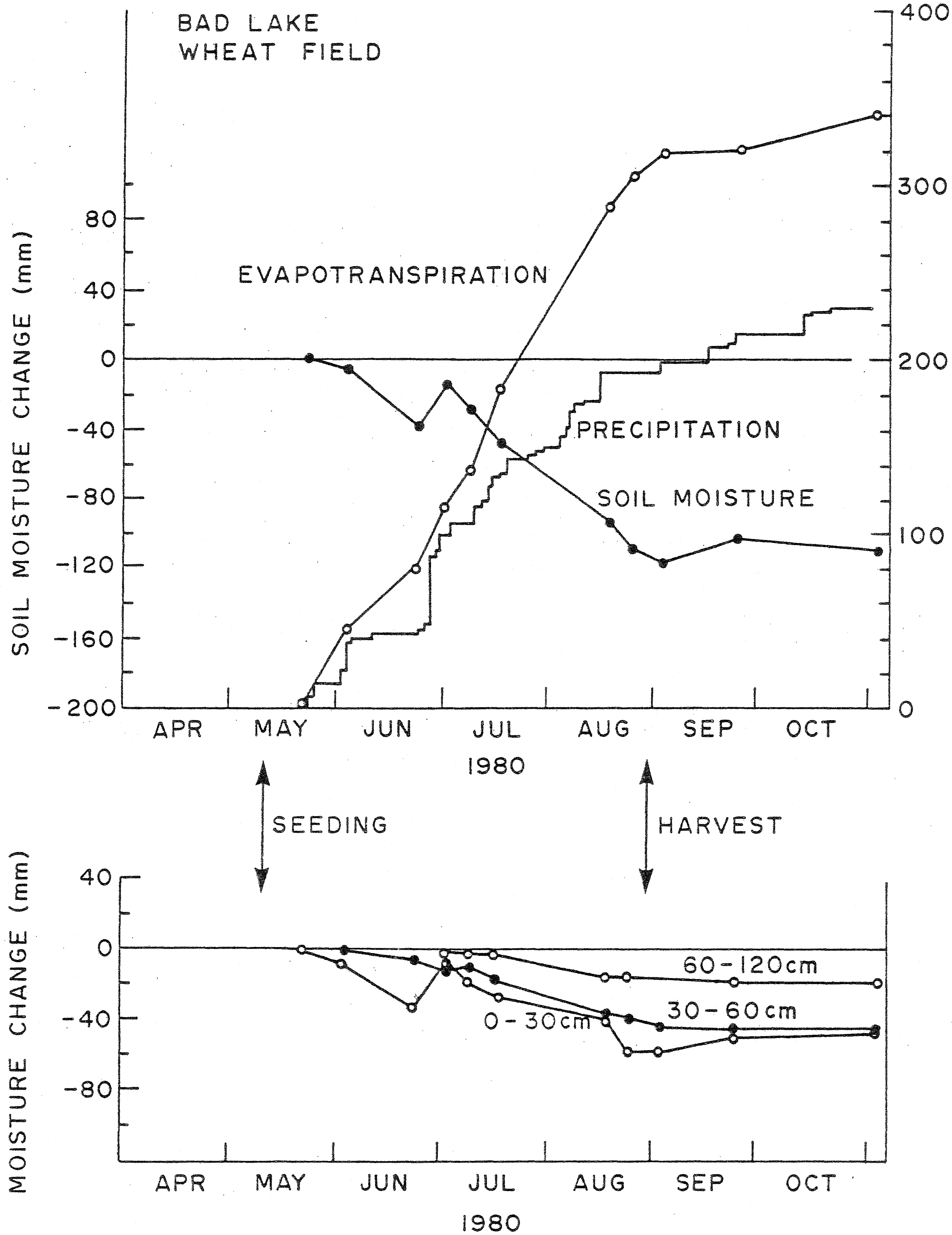

Figure 1. Accumulated precipitation, soil moisture changes and evapotranspiration (Δ Soil moisture + precipitation) amounts at Bad Lake Watershed wheat field. 1980.

Table 3. Fall soil moisture contents and saturation levels (% Vol) at the Bad Lake Watershed (Nov. 4, 1980) and at the Kernen Crop Research Farm (Nov. 5, 1980).

	Bad Lake Watershed				Kernen Crop Research Farm			
	Fallow Site		Stubble Site		Fallow Site		Stubble Site	
Depth cm	Moisture	Saturation	Moisture	Saturation	Moisture	Saturation	Moisture	Saturation
0-10	20.3	67.2	13.5	60.8	29.9	70.0	6.6	66.2
10-20	37.2	56.1	19.9	52.4	38.0	56.1	24.5	57.4
20-30	33.6	48.3	17.7	49.7	39.3	52.4	27.4	52.7
30-40	26.3	46.6	26.7	48.0	40.2	50.0	25.9	51.4
40-50	25.5	44.6	18.0	44.6	37.2	47.6	22.1	52.0
50-60	28.9	45.3	15.8	42.9	37.4	46.3	22.6	51.7
60-70	28.7	43.2	19.8	42.6	38.3	45.6	22.6	50.3
70-80	24.1	41.9	22.5	42.6	39.0	44.9	19.5	49.7
80-90	23.2	40.9	22.7	42.6	36.8	43.9	27.5	49.7
90-100	29.3	39.9	27.8	42.2	34.5	42.9	32.2	48.0
100-110	32.8	39.5	33.0	43.2	29.8	46.3	31.2	46.3
110-120	33.1	37.2	31.1	41.6	27.0	46.6	28.6	46.2
120-130	32.4	37.1	29.9	39.9	27.7	44.3	26.3	45.3
130-140	35.6	37.8	30.2	40.5	27.8	43.2	24.6	48.3
140-150	35.8	38.9	28.8	41.2	24.4	44.6	25.7	50.7
Average	29.8	44.3	23.8	45.0	33.8	48.3	24.5	51.1

in 10-cm increments for the 150 cm soil profiles. As expected, significantly wetter fall soil conditions prevail in fallow fields compared with those in stubble fields. For example, the average soil moisture contents (% Vol) in the 1.5 m profiles at Bad Lake under fallow and stubble were 29.8% and 23.8% respectively. Similarly, the average moisture contents at the Kernen Farm fallow and stubble sites were 33.8% and 24.5% respectively. Note that at both locations the major differences in soil moisture conditions occur in the depth 0-100 cm.

Also listed in Table 3 are the saturation levels for the various depth increments. These values were calculated from measurements of the dry bulk density assuming a soil particle specific gravity of 2.72. The pore space available for infiltrating water is the difference between the fall moisture status and the saturation level. For example, it would require 47.3 mm of water to completely saturate the surface 10 cm of soil at the Bad Lake stubble site.

Winter Soil Moisture Changes

Comparisons between soil moisture profiles taken prior to spring snowmelt with those taken the previous fall provide a measure of net overwinter soil moisture changes. Table 4 summarizes the winter soil moisture changes for stubble and fallow at the Bad Lake Watershed and on the Kernen Farm during the 1980/81 winter season. All sites showed net overwinter moisture gains to a depth of 1.6 m. Increases in net soil moisture ranged from 1.6 mm at the Bad Lake stubble site to 92.6 mm in the Bad Lake fallow site. All sites, with the exception of the Kernen Farm fallow site, show soil moisture increases near the surface; these increases being a result of a mid-winter melt. As shown in Figure 2 the mid-winter thaw at the Bad Lake stubble site saturated the surface to a depth of ~6 cm. The decrease in moisture of 5% in the (0-13 cm depth) layer at the Kernen Farm fallow site was possibly due to evaporation during periods of little or no snowcover. It should be noted that snowfall at Bad Lake and Saskatoon during the winter of 1980/81 was the second lowest depth recorded in 13 years (see Tables 1 and 2).

The soil moisture increases below a depth of 13 cm, under fallow, varying from ~89-93 mm, were much larger than the moisture changes in the same soil depth zone under stubble. Moisture increases in this zone can be attributed to the upward migration of water, either as a liquid or a vapor, to the freezing front. The fact that the amounts may be small, such as those measured in stubble, infers that substantial migration will occur only when there is an adequate supply of soil water. Figure 3 shows that below 1 m the fall soil moisture content in the Bad Lake fallow site was greater than 90% saturation; in stubble it was substantially lower, in the order of ~75% saturation (see Figure 2).

Snowmelt Infiltration

Infiltration estimates were obtained from measurements of changes in total wet density in the 1.6-m soil profiles. Soil density profiles obtained during the melt period were compared with those obtained prior to the melt with the increases in density attributed to meltwater infiltration.

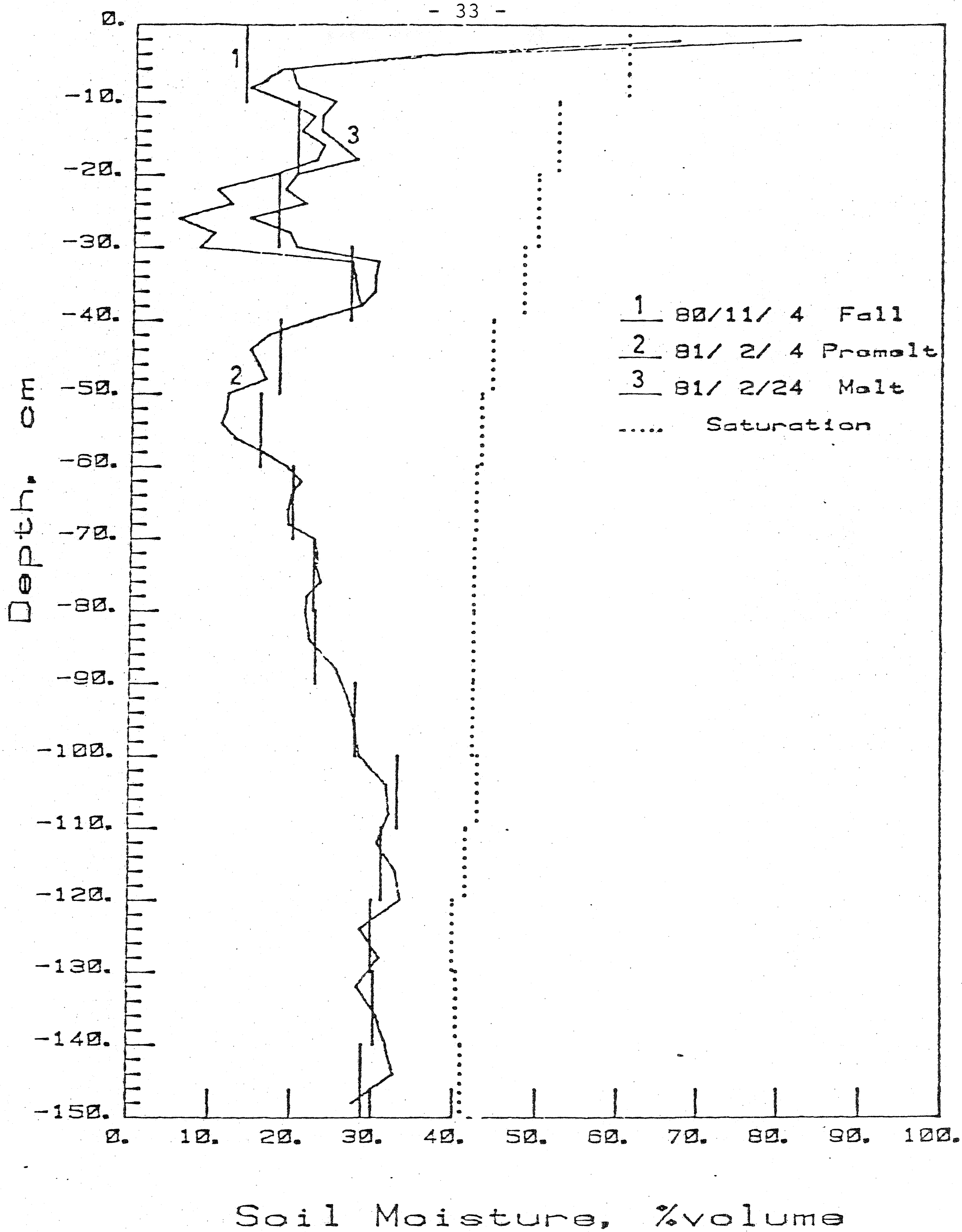

Figure 2. Soil moisture status at various stages of the snow season at Bad Lake Watershed, stubble site.

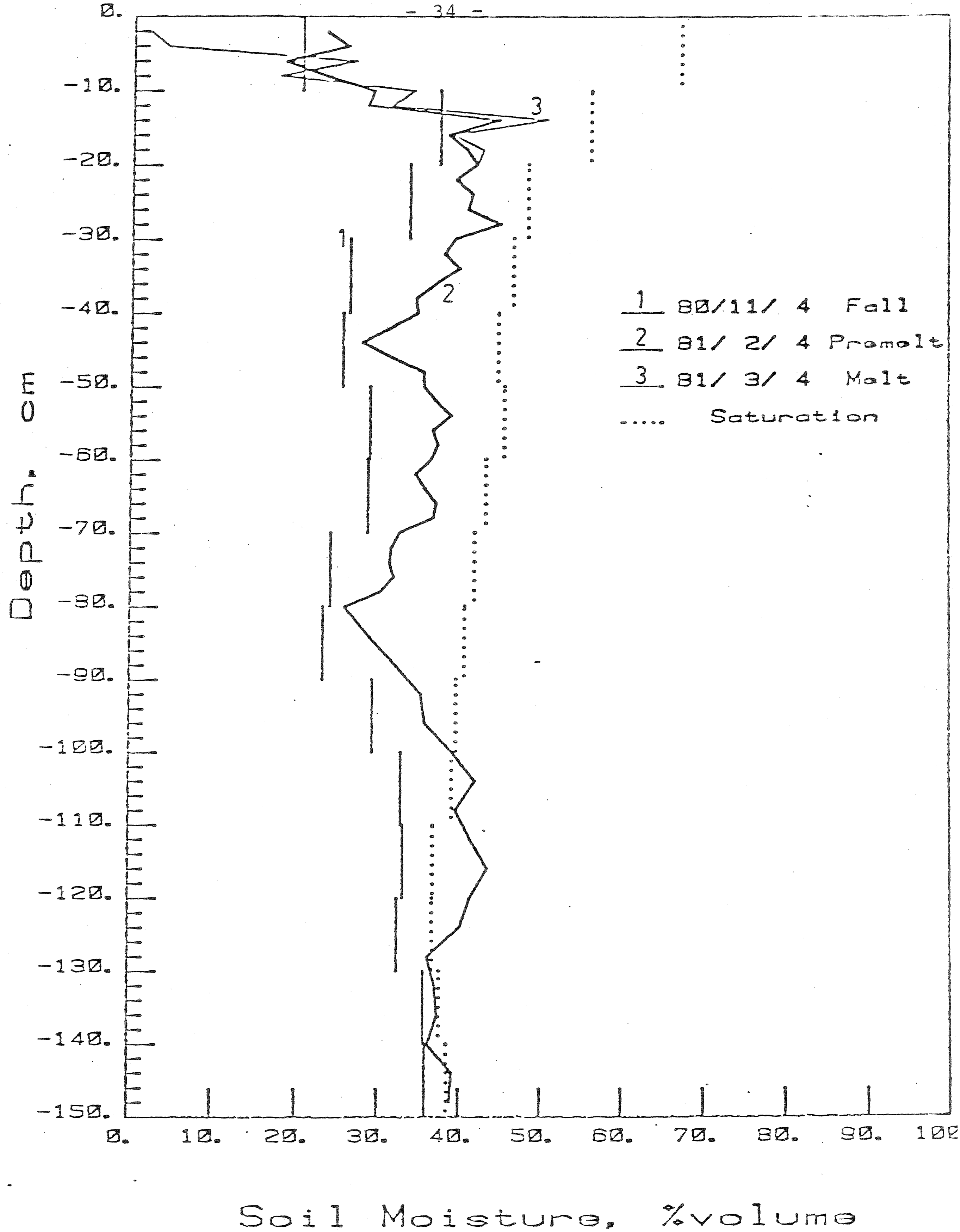

Figure 3. Soil moisture status at various stages of the snow season at Bad Lake Watershed, fallow site.

The results obtained from the snowmelt infiltration measurements for the 1980-81 snowmelt season are summarized in Table 5. The data listed serve to place the infiltration amounts into perspective with respect to changes in soil moisture that occur overwinter. Only at the Bad Lake stubble site did snowmelt infiltration represent the major portion of the net soil moisture change. At this site, 91.5% of the total net change of 18.8 mm occurred as a result of spring snowmelt infiltration. This is in sharp contrast with the results for the Bad Lake fallow site where no infiltration occurred, as there was no snowcover, yet there was an increase of 66.5 mm of water in the 1-m profile. The 66.5 mm soil moisture increase that occurred at this site was due to thermally induced moisture changes occurring during the fall freezing phase. At the Kernen Farm snowmelt infiltration at the stubble and fallow sites accounted for 47.4% and 33.7% respectively of the total moisture changes.

Conclusions

The results obtained at the Bad Lake Research Watershed and at the Kernen Crop Research Farm during the 1980/81 winter season confirm that the contribution of snowmelt infiltration to soil moisture reserves is limited not only by the snowcover present but also by the premelt moisture content of the soil, with initially wetter soils permitting less infiltration. The results also show that thermally-induced moisture movement may constitute a major source of soil moisture increases under favorable climatic and fall soil moisture conditions. The data also suggest that soil moisture measurements in the fall cannot be used directly as indices of premelt spring moisture conditions. The fall data must be adjusted to account for overwinter moisture changes (mid-winter melts and thermally induced moisture migration) taking into account such factors as; the fall soil moisture status, the ambient air temperature regime and the presence and extent of snowcover.

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Table 4. 1980/81 Over Winter Soil Moisture Changes

Location	Soil layer (cm)	Soil Moisture Change % Vol	mm	Total change (mm)
<u>Bad Lake</u>				
Stubble	0-19	+7.3	13.8	
	19-57	-3.2	-12.2	
	57-160	0	0	+1.6
Fallow	0-13	+0.3	0.4	
	13-130	+7.6	88.9	
	130-160	+1.1	3.3	+92.6
<u>Kernen Farm</u>				
Stubble	0-11	+6.3	6.9	
	11-21	-3.7	-3.7	
	21-87	+6.2	40.9	
	87-160	+0.3	2.2	+46.3
Fallow	0-13	-5.0	-6.5	
	13-160	+6.3	92.6	+86.1

Table 5. Summary of snow water equivalent, soil moisture and snowmelt infiltration.

Site	Land use	Winter change to 1 m (mm)	Snow water equivalent (mm)	Infiltration (mm)	Depth of infiltration (cm)	Net change (mm)
<u>Bad Lake</u>						
	stubble	1.6	39.2	17.2	36	18.8
	fallow	66.5	0	0	-	66.5
<u>Kernen Farm</u>						
	stubble	44.5	16.0	40.1	34	84.6
	fallow	48.3	26.1	16.3	20	64.6

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Acknowledgements

The authors gratefully acknowledge the financial assistance given to this study by: Water Resources Support Program, Water Research Incentives Office, IWD/DOE, Ottawa, Ontario, the Hydrometeorological Research Division, Atmospheric Environment Service, Environment Canada, Downsview, Ontario and the National Science and Engineering Research Council.